NIRM
Silver Jubilee Commemorative Volume

राष्ट्रीय शिला यांत्रिकी संस्थान

National Institute of Rock Mechanics

(Ministry of Mines, Government of India)

Kolar Gold Fields, Karnataka

April, 2014

SILVER JUBILEE YEAR 2013-14

Foreword

I am happy to note that the National Institute of Rock Mechanics (NIRM), one of the three premier autonomous research Institutes under the Ministry of Mines, has completed 25 years of its existence, and is celebrating its Silver Jubilee. During the last 25 years, the Institute has made significant contributions in the service to the Nation, particularly for the development of the mining industry and the hydel sector. The Institute has a number of scientific and technical achievements. Its credibility is reflected in the number of projects coming to it from all over the country and abroad, its good financial standing, and its multitudinous clientele list. I congratulate the Scientists, Scientific & Technical Staff, Supporting Staff and Administrative Officers, both past and present, for making this possible.

On the occasion of its Silver Jubilee, NIRM is bringing out a Commemorative Volume. I understand that this volume contains all the historical details since inception, the people behind its development, and the events that charted its course. I am sure this volume would be a source of inspiration for the future generation of Scientists at the Institute.

Dr Anup K Pujari
Secretary to the Govt
Ministry of Mines

Preface

The National Institute of Rock Mechanics (NIRM) was registered under the Karnataka Societies Act on 23rd July, 1988, as an autonomous research Institute under the Ministry of Steel & Mines, Govt of India, and has just completed 25 years of its existence.

The Silver Jubilee is an occasion to rejoice for any organization, so is it for NIRM, particularly because it has been a fulfilling 25 years for the Institute, during which it has grown from strength to strength in the service to the Nation. It has earned a good name, recognition and credibility based on the work of the Scientists and the staff. We have a number of scientific and technical achievements. The credibility is reflected in the number of projects coming to it from all over the country and abroad, its good financial standing, its multitudinous clientele list and the support coming forth from our Administrative Ministry, and the industry.

We are extremely thankful to all those who made this possible before us. On this occasion, i would like to congratulate Scientists, Scientific & Technical Staff, Supporting Staff and Administrative Officers. Excellent, dedicated people, committed to the growth of the Institute. We have the best work force, and the best work ethos. All of us can really feel proud that we are part of NIRM at the time of its Silver Jubilee.

On this occasion, we are bringing out a Commemorative Volume, detailing a historical account on the formation of the Institute, listing out the founding fathers and all others who contributed directly or indirectly for the growth of the Institute. We have also included the technical achievements and R&D developments made by the Institute. The Volume also contains the status of research in the specialized areas of work by the Institute, and the contributions made by the Scientists in these areas during the last 25 years.

I am sure this volume would be a good source of reference on the history of NIRM. It also inspires us to resolve to take the Institute forward, towards the next Jubilee.

V Venkateswarlu
Director

Founder Chairman Sri BK Rao, and the first Director Dr NM Raju

The first generation Scientists with the first Chairman and the first Director

ESTABLISHMENT OF AN INSTITUTE OF ROCK MECHANICS AND GROUND CONTROL IN KOLAR GOLD FIELDS

Stability of underground excavations is a major problem facing the mining industry. Especially with the mine workings reaching greater depths in the country, the available planning and designing methods are inadequate. In view of this, a need was felt for trained and competent rock mechanics engineers to tackle problems of rock mechanics and ground control in mines.

There was no institute to look after the problems of hard rock mining and other civil engineering projects. Consequently, many project authorities in India were taking the help of foreign consultants to solve their rock mechanics problems. In view of above, there was an urgent need for establishing a rock mechanics research centre, exclusively to tackle the problems of stability of underground excavations in mines, particularly at deeper levels, and in civil engineering projects.

BGML R&D Unit

The Kolar Gold Fields was unique in that it had one of the deepest underground mines in the world. The mining activities at the Kolar Gold Fields (KGF) had a history of over a century. The holding company, the Bharat Gold Mines Limited (BGML), had a Research & Development Unit, which had gained over the years unique expertise in solving hard rock deep mining problems pertaining to rock mechanics and ground control.

The Research & Development Unit of BGML at KGF was functioning since pre-independence. It had three cells, namely the Rock Mechanics Cell, Seismic & Micro-seismic Monitoring Cell and Material Testing Laboratory. The pioneering work by the Unit in the field of rock mechanics in non-coal mines was recognized internationally.

The Rock Mechanics Cell had carried out investigations on the rock mass movement, in-situ stress conditions, and the rock characteristics due to rock bursts, including laboratory investigations into the physico-mechanical and elastic properties of rock. Advanced rock mechanics instruments, including the hydro-frac tool, were used to study the strata movement and stress build up for the assessment of stope stability. The scientific personnel have acquired experience in this field for more than 20 years. Daily monitoring of the movements in the stope drives and other excavated areas was continued and the results analysed. Based on the rock mechanics studies carried out in the Kolar gold mines, new mining system were designed and adopted which resulted in better ground stability and also a decrease in the frequency and intensity of rock bursts in KGF mines.

The Seismic and Micro-seismic Cell was established in 1978 with the collaboration of Bhabha Atomic Research Centre for evaluation and prediction of ground stability in mine excavations prone to rock burst. Seismological analysis of the stress regime of mine excavations was carried out to delineate high in-situ stress. Seismic and micro-seismic techniques were adopted to monitor the seismic activity and to predict rock bursts. As a complement to the rock burst research programme, tests on rock specimens for their physico-mechanical properties were carried out in the Materials Testing Laboratory.

The contribution of Sri R Krishnamurthy, the Manager (Mine Planning & Technical Services), BGML till 1986, and later Consultant (Rock Mechanics) for BGML, was vital in creating the facilities for strata monitoring at BGML and in establishing in collaboration with BARC. Truly, he can be named as the father of rock mechanics research in India.

The expertise developed by the Research & Development Unit of Bharat Gold Mines Limited was also utilised to carry out studies on ground control for other mining organisations including the mines of Hindustan Zinc Limited and Hutti Gold Mines Limited, on a limited scale. The rock mechanics investigations were acknowledged as to be of very high standard in the opinion of UNDP/ILO experts who visited the R&D Unit. In view of this, Dr Yung Sam Kim, UNDP Consultant on Rock Mechanics, in his final report to BGML in December 1986, suggested that an "International Rock Mechanics & Mining Research Centre – IRMMC" can be established at KGF keeping the R&D Unit of BGML as the nucleus.

Proposal for a Research Institute

The mining activity in KGF mines was on the downward trend and the Government of India have, vide their letter dated 17th December, 1987, directed that the mines of Kolar Gold Fields be closed in a period of 7 years.

The Ministry of Mines, under the Chairmanship of Sri BK Rao, Secretary (Mines), called for a meeting with respect of establishment of a Rock Mechanics Institute at KGF on 29th April 1987, and another meeting on 8th May 1987. The Expert Group constituted by the Secretary, Department of Mines, Ministry of Steel & Mines in 1987 proposed that this Institute of Rock Mechanics and Ground Control be formed at Kolar Gold Fields with the Research & Development Unit of M/s Bharat Gold Mines Limited, as its nucleus. Sri R Krishnamurthy facilitated BGML in the preparation of S&T Scheme (of BGML) for this. Sri BK Rao held a meeting with the Polish Delegation, along with Sri IM Aga and Sri R Krishnamurthy of BGML, on 11th Feb 1988 to firm up the proposal. Prof A Kidybinski of International Bureau of Strata Mechanics, Dr E Puszczewicz, Dy Director General of Polish Coal Industry & R&D Division and Dr A Goszcz, Central Mining Institute of Poland, recommended in writing for the establishment of a research institute at KGF.

The justification for a separate research institute on rock mechanics stems from the fact that many metalliferous mines including Mosaboni mines of Hindustan Copper Limited, Mochia & Balaria mines of Hindustan Zinc Limited, Hutti & Chitradurga mines of Hutti Gold Mines Limited and mines of Manganese Ore (India) Limited were reaching deeper levels and were exposed to large areas of wall rocks resulting in severe ground control problems. This has called for a scientific approach based on sound rock mechanics principles to design the workings. The coal mines, and the civil engineering projects too, with increasing tunnelling activity and need for construction of large underground caverns, require the expertise of rock mechanics engineers to tackle their problems related to site characterization, support design, numerical modelling and blasting.

In view of above, it was strongly felt that a Research Centre for Rock Mechanics and Ground Control should be established to evolve new mining methods to promote productivity, safety and conservation in coal and non-coal mines and to solve the rock mechanics related problems being faced by the mining and civil engineering sectors in the country.

Formation of NIRM

The Government of India, vide their letter No.14/22/87-Met.V dated 27th January, 1988, conveyed the sanction of the President for establishment of the Institute of Rock Mechanics and Ground Control at Kolar Gold Fields under Science & Technology (Plan) at a total expenditure not exceeding Rs. 200 lakhs including a foreign component of Rs.40 lakhs.

The Hon'ble Union Minister of State for Mines, Smt Ramdulari Sinha, announced the approval of the Government of India for the establishment of the Institute of Rock Mechanics and Ground Control at Kolar Gold Fields while inaugurating the fifth plenary scientific session of the working group on "Rock Bursts" of the International Bureau of Strata Mechanics at the Regional Research Laboratory, Hyderabad on 3rd February, 1988.

The Memorandum of Association was framed by a societal Body of technical people (the General Body and the Governing Body of the Institute), with the name “Kolar Institute of Rock Mechanics and Ground Control” and registered on 23rd July 1988, under Karnataka Societies Registration Act, 1960 & Karnataka Societies Registration Rules 1961, as an autonomous research institute under the administrative control of Ministry of Mines, Government of India. The Rules and Regulations of the Institute were also adopted.

Subsequently the name of the Institute was changed to “National Institute of Rock Mechanics” by a resolution of the General Body.

Initial Years in the Development of NIRM

Sri PAK Shettigar, Managing Director, BGML, was given the responsibility of acting Director for the Institute, and Sri VN Murthy, Secretary, BGML, was to act as Secretary of the Institute. Sri R Krishnamurthy, who was earlier the head of the erstwhile R&D Unit, and Sri Shrikant B Shingarputale, Manager (Mine Planning & Technical Services), BGML, took care of the activities of the Institute and did all the background work required for the formation of the Institute and for transfer of manpower and assets from BGML to NIRM.

Subsequently, Dr NM Raju took charge as the Director of the Institute in June, 1989. Technical Framework and the Organizational Structure of the Institute were drafted and adopted. Similarly, the Terms & Conditions of Service of Employees were also made and approved by the Governing Body. A total manpower strength of 88 was sanctioned for the Institute (which was later reduced to 82), including 14 Administrative staff. This paved the way for transfer of the employees of the R&D Unit of BGML to the Institute. Eight Scientists and 25 scientific, technical and supporting staff were formally absorbed into NIRM with effect from 1.1.1990. During 1990-91, 17 more Scientists were appointed. The Administrative Officer of the Institute was the *de facto* Secretary of the Institute (Society).

The infrastructure available with the BGML R&D Unit became the property of the new Institute. This included the land, office buildings and residential buildings within and around the Institute, the rock and material testing equipment, and the rock mechanics and micro-seismic monitoring facilities.

The technical manpower of the Institute was organized into ten disciplines, namely,

1. Numerical Modelling and Mine Design.
2. Rock Mechanics Instrumentation
3. Geotechnical Studies
4. Ground Control
5. Slope Stability
6. Rock Blasting
7. Seismology
8. Electronics Instrumentation
9. Materials Testing and Rock Fracture Mechanics
10. Technical Services

Each discipline was headed by an experienced and qualified senior Scientist, and supported by meritorious young Scientists,

Augmenting the already available rock and materials testing equipment in the earlier R&D Unit, additional state-of-the-art equipment was procured to enable the Scientists to carry out the investigations and the research in different areas of rock mechanics. Modern computing hardware and software were provided for the data analysis and presentation of the results. Some of these facilities were :

- 150-t Servo controlled MTS
- SBEL and Hoek triaxial cells

- Acoustic emission monitoring system
- Hydro-fracturing & stress measuring equipment
- USBM borehole deformation gauges
- CSIRO hollow-inclusion cells
- Seismic and micro-seismic monitoring network
- S-6blast vibration monitors
- Velocity of detonation probes
- Blast design and analysis software
- Software for stress analysis around excavations in rock
  - B-Mines – 2d & 3d finite element program
  - UDEC distinct element code
  - FLAC finite difference program
  - BESOL 2d & 3d hybrid models

Since experienced Scientists were available, the Institute started taking up sponsored projects right away. Several S&T schemes and in-house projects were also taken up in due course.

OBJECTIVES OF NIRM & THE ORGANIZATIONAL STRUCTURE

The mandate of NIRM is to provide enabling technology to mining, civil engineering sectors and construction industries to achieve improved production, productivity and quality, with enhanced safety and economy. The major areas of research include rock mechanics, rock engineering and geotechnical engineering.

Based on the expertise developed over the years, the objectives and areas of work have been redefined time and again to meet continuously changing needs of the industry. In the year 2005, NIRM charted its Roadmap, and also formulated its Vision and Mission in its Vision 2020 document.

Objectives of NIRM

- To assist the mining, civil and construction engineering projects including hydro-electric projects/railway tunnels/underground storage caverns in solving ground control problems for the safety and stability of the structures in rock;
- To optimize the design of mine workings for improved safety, conservation & productivity;
- To mitigate the environmental impacts in rock excavation engineering, and to undertake EIA and EMP of mega projects;
- To develop excellence in rock engineering and provide consultancy services to mining, civil and construction engineering projects in the design of rock excavation; and
- To organize training courses in rock mechanics/engineering and develop facilities for research leading to doctorate degree.

Vision

NIRM has a vision to provide scientific and technological expertise with the state-of-the art techniques to mining, civil and infrastructure industries in the field of rock mechanics; to serve as a valuable resource in rock mechanics, to be identified as benchmark and statutory body for all types of investigations in rock mechanics; and to be a national pride by remaining as a Centre of Excellence of global standards.

Mission

The Mission of NIRM is to continue to support the mining and construction industries in safety and resource optimization by way of providing consultancy in the fields of scientific design of mine workings, design of rock excavations and support systems, optimized site characterization and evaluation and testing of rock and material samples for understanding rock mass and material behavior relevant to design requirement.

With this in view, the following Mission Objectives have been identified :

- To develop innovative methods of mining under adverse geomining conditions for unlocking precious mineral wealth in synergy with the national mineral policy.
- To develop accredited testing and calibration facilities of international standards for various laboratory scale as well as in-situ tests.
- To identify, based on national and global needs, areas of specialization which needs to be developed at the institute with the available or upgraded resources.
- To get empanelled with various statutory bodies in India, and establish linkages with international organizations through collaborative projects in relevant fields.
- To conduct short-term and long-term training courses on modern investigation techniques for executives from the industry
- To develop human resources by supporting cutting-edge research for post-graduate and doctoral programmes in collaboration with reputed Institutions.

Organizational Structure

According to the Rules and Regulations of the Institute, the Secretary, Department of Mines / Ministry of Mines, is the Chairman of both the General Body and the Governing Body. The General Body would appoint the members of the Governing Body. The General Body will have a Chairman, conventionally up to 12 ex-officio members (senior officers of MoM, and Director-level officers from the industry), and maximum 3 non-official members (experts in the area of rock mechanics); many of the members are common to the Governing Body as well. The Members would have a term of three years.

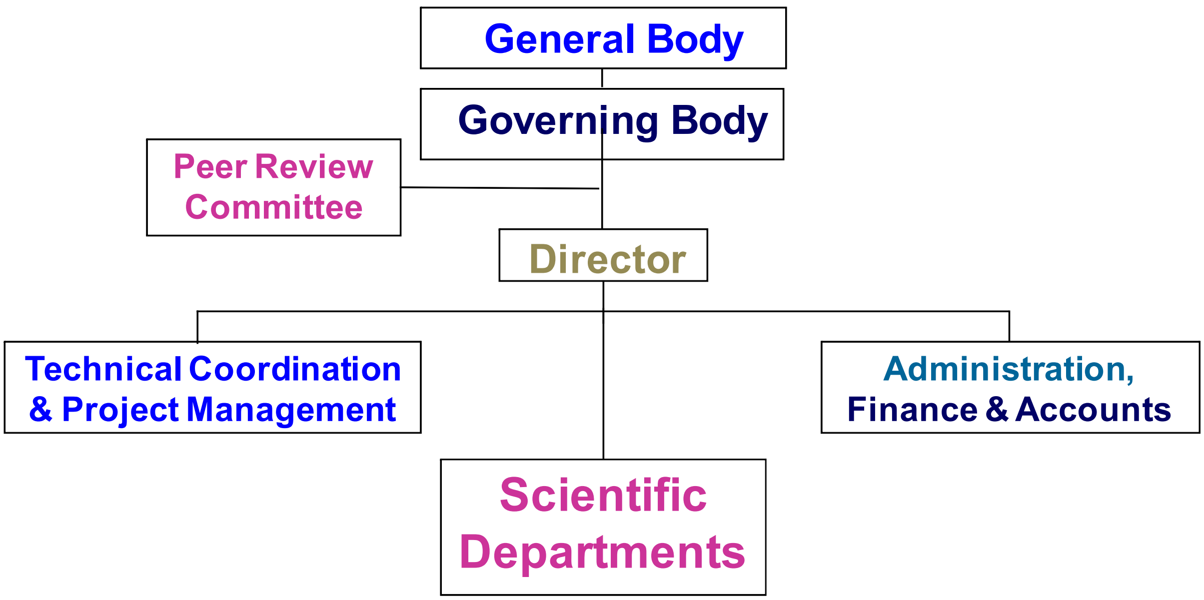
Director, NIRM, is vested with executive and administrative powers of the Society. Director is responsible for the proper administration of the affairs and funds of the Society under the direction and guidance of the GB.

To help the Director in the day-to-day affairs of the Institute, there is an Administration Department, with an Administrative Officer and a Finance & Accounts Officer. During 1999 to 2010, a functional post of Controller of Administration (CoA) was operated to look after the administrative affairs of the Institute. A senior Scientist was given the additional assignment. The posts of Purchase & Stores Officer and Registrar were created in 2009 and 2010, respectively.

For technical support to the Director in managing the project works of the different departments, and for liaison with the funding agencies, a Technical Services Department was formed by the Director, with a senior Scientist as its Head. Later, in 2008, this department was renamed as Technical Coordination & Project Management Department (TCPMD).

Earlier, the Director, NIRM, was reviewing the research activities of the Institute periodically and was reporting to the Governing Body. In the year 2000, a research advisory committee for the Institute, named as the Peer Review Committee (PRC), was constituted by the GB for this purpose. This Committee has a Chairman and minimum seven Members, all experts from academic / research institutes and the industry, with a term of three years.

Accordingly, the present overall organizational structure of Institute is :



Department is the technical and administrative unit at NIRM. The departments are identified with specific areas of work, and a group of Scientists and staff are assigned to each to execute the research in the subject area. Each department has one senior Scientist as Head of the Department (HoD) for administrative purposes, and the HoDs report directly to the Director.

When the Institute was formed, a Sub-Committee recommended the Technical Framework for the Institute with the areas of research as : Geomechanics & Ground Control, Numerical Modelling & Mine Design, Seismic / Micro-seismic Lab & Instrumentation, Rock Blasting and Testing Services. The Director organized them into ten disciplines, as : 1) Numerical Modelling and Mine Design, 2) Rock Mechanics Instrumentation, 3) Geotechnical Studies, 4) Ground Control, 5) Slope Stability, 6) Rock Blasting, 7) Seismology, 8) Electronics Instrumentation, 9) Materials Testing and Rock Fracture Mechanics, 10) Technical Services. Later, Ground control and Slope Stability were clubbed together, and Rock Mechanics Instrumentation was also brought under the same department.

The department of Engineering Geophysics was carved out of Seismology in 1996. In 1997, the Granite Mining Cell was formed. In 2002, a department of Environmental Geotechnology was started, and Mine Design was separated out. A separate department of Engineering Geology was started in 2008. Thus, during the last 25 years, the original disciplines morphed into departments and divisions, and inter-disciplinary work culture was encouraged. While attrition was taken in stride, many of the young Scientists were rotated from one department to the other to broaden their areas of work. The scientific departments were re-named and redesigned depending on the areas of work, expertise developed at the Institute and as per the needs of the industry.

Areas of Expertise

The areas of research at the Institute are the areas in which the Scientists have gained expertise by virtue of the qualifications and experience, as also from the exposure to the field conditions and the problems face by the industry. Over the last 25 years, the Institute has developed expertise in the following areas of rock mechanics :

1. Engineering Geology

Engineering geological investigations of the project sites for locating different engineering structures including the hydro-electric project sites during pre-construction, construction and post-construction stages. Engineering geological and geotechnical investigations include surface and sub-surface geological mapping on 1:100 to 1:10,000 Scale. During construction stage detailed mapping on 1:100 to 1:500 Scale is undertaken for identifying different geological/structural features and their impact on the geo-mechanical properties of the rock masses in different geological setting. The rock mass classifications depending upon the rock mass characteristics are attempted to understand the rock mass behaviour, failure modes etc and to work out suitable support system.

2. Engineering Geophysics

The Institute is actively engaged in carrying out Ground Penetrating Radar (GPR) mapping of subsurface using reflection, sounding and cross-hole tomographic techniques. In addition, we also carry out seismic refraction survey for strata evaluation for analysing foundation and excavation problems. These investigations supplement various rock mechanics investigations for site characterisation and foundation engineering. Some of these facilities have been established under technical collaboration with the Norwegian Geotechnical Institute, Oslo, Norway. The activities of this group include:

- Site characterisation of major subsurface structures
- Seismic refraction survey for stratigraphic mapping
- Mapping of bedrock topography and soil stratigraphy
- Location of hidden cavities, tunnels, and fractures planes
- Mapping old water-logged workings & barriers in coal mines
- Foundation evaluation of bridge pillars
- Cross-hole tomography with seismic & GPR techniques

3. Engineering Seismology

NIRM has proven capability in the design, fabrication, installation and monitoring of micro-seismic networks for evaluating ground stability in underground and opencast excavations, and rock slopes. The micro-seismic technique has been proven to locate areas of potential ground failure. The Institute has vast experience of monitoring rockburst in deep mines of Kolar Gold Fields. We have developed a PC based micro-seismic monitoring system, which has been extensively used in various mines.

4. Geotechnical Engineering

Geotechnical investigations are integral part of any underground excavation project. All the major hydro-electric projects require in-situ geotechnical investigations to be carried out prior to the design. With increasing size of the engineering structures and prevailing complexity of rock structures, in-situ geotechnical investigations are particularly gaining importance. NIRM meets the requirements of the civil, mining and construction industries in these areas.

The Institute has been involved in conducting in-situ tests for excavations in most of the major hydro-electric projects in India with various government agencies, international consultants and private companies. Over the last two decades, we have earned the customers' satisfaction with our reliable and prompt services. Major areas of our service in this field are:

- In-situ stress measurement by hydro-fracture method
- In-situ deformability measurement by plate loading method
- In-situ shear testing
- In-situ permeability or rock mass transmissivity measurement
- Rock mass characterisation
- Scanning and investigation through boreholes

5. Rock Fracture Mechanics

NIRM is equipped with modern laboratory facilities for determining the engineering properties of rocks as per international standards, and to carry out basic research on rock fracture mechanics. The Institute is engaged in some of the frontier areas of research like thermo-mechanical behaviour of rocks, and has developed expertise in the application of acoustic emission and ultrasonic imaging techniques. The facilities available are:

- Preparation of rock samples as per international standards
- 150 ton MTS stiff compression testing machine
- 300 ton compression testing machine
- High temperature and pressure triaxial cell
- Shear Testing machine
- Acoustic emission monitoring system
- Equipment for determining joint properties
- Thin section study using polarised microscope

6. Rock & Materials' Testing

The Institute has been involved in conducting laboratory tests for rock samples from most of the major hydro-electric projects/mining industries in India. Major areas of our testing service in this field are:

Rock Testing for determining the physico-mechanical properties

- uniaxial compressive strength
- triaxial compressive strength
- tensile strength
- elastic constants
- cohesion
- friction angle
- joint properties
- fracture toughness
- density
- porosity
- P-wave velocity
- permeability
- abrasivity & drillability of rocks
- impact test
- reflectivity (gloss)
- hardness and petrography

Materials' Testing: NIRM offers services in the areas of

- wire rope testing,
- proof load testing,
- hydraulic prop testing
- non-destructive testing using ultrasonic examination, both in the field and the laboratory.

7. Underground & Surface Mine Design

The Institute provides expert services to assist the non-coal and coal mining sector in scientific design of mines. The areas of work include optimising the design of excavations for maximising ore recovery, stability evaluation of stopes, shafts and other critical structures in the underground.

- Coal mine pillar design
- Design of mining methods for increased safety and productivity
- Feasibility study for new mines and expansion schemes
- Technical audit of mining operations

8. Numerical Modelling

Numerical modelling is one of the major tools for design of excavations in rock. The Institute has experienced civil and mining engineers with expertise in providing solutions to varied problems related to excavations in rock. Anticipated rock mass behaviour around an excavation can be reliably predicted using the latest FEM and BEM numerical modelling codes (software based on discrete and continuum element methods) available at the Institute. We undertake the stress analysis and support design for tunnels, caverns and large underground multiple excavations.

With experience gained over the years in the analysis and design of underground excavations using numerical modelling, the group offer solutions in the following areas:

- Analysis and design of caverns and tunnels
- Rock liner interaction analysis for pressure shafts
- Design of supports (rock bolts and SFRS)
- Coupled thermo-hydro-mechanical analysis of the rock mass
- Dynamic analysis including seismic and liquefaction behaviour
- Stability analysis of earth dams and slopes

9. Rock Blasting & Excavation Engineering

NIRM provides innovative solutions to challenging problems in blasting for various mining and civil engineering and construction projects. The Institute has the latest micro-processor based instruments like seismographs, laser profiler, velocity of detonation measuring systems and high resolution video camera for blast monitoring. We have developed various techniques to optimise blast design parameters for surface and underground excavations. Several controlled blasting operations have been successfully devised and experimented by this group.

- Optimisation of blast design parameters
- Monitoring & control of ground vibration and air overpressure
- Control of fly-rock
- Controlled blasting
- Development of blasting techniques and instrumentation

10. Ground Control and Mining Technology

One of the major thrust areas of the Institute is to improve safety and productivity from underground coal mines in the country. The Institute is involved in the design of proper roof supports in addition to studies on ground stability assessment through strata and support monitoring and development of equipment for mechanised roof bolting systems. The areas of research include:

- Design of rock reinforcement systems
- Study of parting behaviour in multiple seam extraction
- Subsidence prediction and control
- Strata mechanics in stopes & longwall panels
- Stability evaluation of critical underground structures

11. Slope Engineering

With increasing depth of surface excavations, the problem of stability of slopes is becoming a major concern for the engineers, in hydro-electric projects, open-cast mining and quarrying. NIRM has been involved in the design of safe and economic slope angles in various open pit mines, abutment stripping in hydro-electric projects and slope stabilisation for landslide mitigation. The Institute has also been involved in monitoring of the stability of slopes, subsidence studies, monitoring of ground water and permeability studies. Expertise is available in the following areas:

- Stability analysis of the benches, and design of slope parameters
- Design of ultimate pit limits, inter-ramps, and safety berms
- Design of barrier between water bodies and the open pit
- Design of spoil dumps
- Optimisation of slope design parameters using numerical modelling
- Monitoring of slopes
- Landslide hazard assessment and mitigation/reclamation

12. Instrumentation & Automation

The Institute carries out monitoring of the behaviour of excavations in rock using various types of strata monitoring instruments. Stress build-up in rock, strata deformations, rock movements, induced loads, groundwater pressure and various other parameters are monitored using strategically placed instruments. The monitoring data is systematically analyzed to understand the stability of the excavations.

NIRM also develops electronic automation systems for use in mines. The Institute is active in the following areas:

- Development of data loggers (remote, wireless & continuous)
- Development of intelligent systems (on-line, real-time & expert)
- Development of sensors/transducers
- Optical fiber applications to mining industry

13. Environmental Geotechnology

NIRM has developed expertise for solving the environmental problems in the following areas of excavation industries.

- Assessment of air quality, water/effluent quality, noise monitoring to know whether pollution level exceeds standard and technique for environmental remediation measures. Facilities are also available for the analysis of physico-chemical properties of dump materials.
- Facilities for meteorological measurements required in air pollution survey.
- Innovative methods for reclamation of mined areas.
- Design of dumps for the protection of environment.

- Environmental auditing in excavation industries.
- Disposal of fly ash in mined out areas.
- EIA and EMP for mega construction projects.

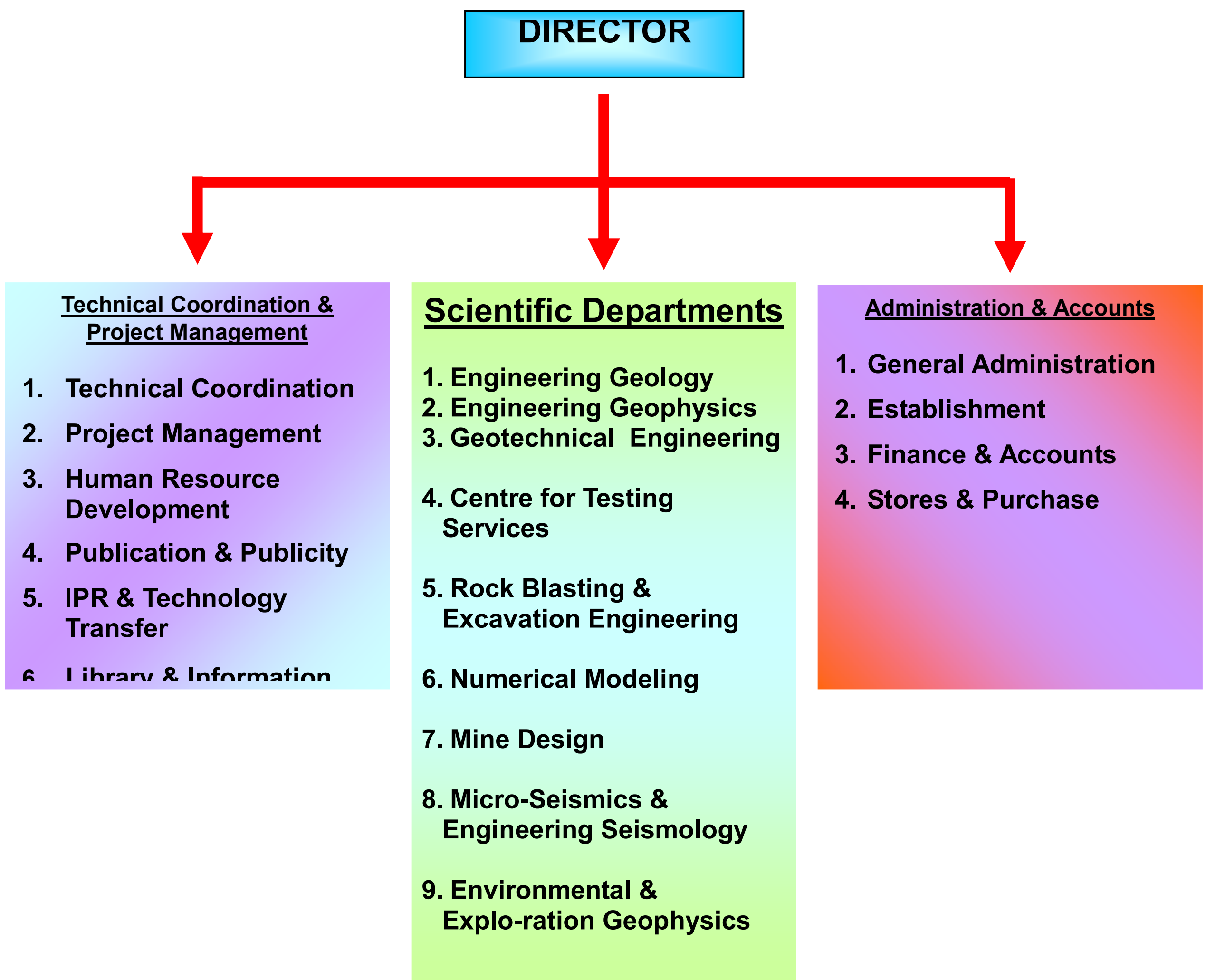
14. Dimensional Stone Technology

NIRM assists the granite/marble industry for scientific exploitation of precious reserves. The Institute provides following technical services towards economic exploitation of granites:

- Improving recovery in granite mining operations
- Geotechnical studies for characterising deposits
- Rock testing to determine the various properties required for quality and marketing potential assessment
- Design of blasting techniques to minimise damages
- Planning for economic exploitation and selection of equipment
- Planning for waste disposal and protection of environment
- Techno-economic evaluation of new quarries

Scientific Departments

The present structure of the different departments at NIRM is :



The different departments and their nature of work are :

Sl. No.	Scientific Department	Nature of Work
1	**Engineering Geology**	Structural mapping; rock mass characterization
2	**Engineering Geophysics**	Geophysical survey for delineation of hidden structures and planes of weakness
3	**Geotechnical Engineering**	Measurement of in-situ stress, rock mass properties, etc.
4	**Rock Fracture Mechanics**	Laboratory testing for physico-mechanical properties of rocks; basic studies on rocks
	Material Testing & Non-Destructive Testing	Rope testing, testing of mining machinery & NDT
5	**Rock Blasting & Excavation Engineering**	Blast design and vibration monitoring
		Machine Excavation
6	**Numerical Modelling**	Evaluation of the stability of mine openings, tunnels and large caverns in mines, hydro-electric projects and infrastructure facilities, through numerical modelling
7	**Mine Design**	Design of new mining methods in metal and coal mines; pillar design; subsidence studies
		Stability of pit slopes in mines, and embankments
8	**Micro-seismics & Engineering Seismology**	Micro-seismic analysis and seismo-tectonic evaluation of structural features; Micro-seismic instrumentation and monitoring; development of instruments for automation in mines
9	**Environmental & Exploration Geophysics**	Development of geophysical techniques for probing ahead of tunnels and other excavations; identifying shallow and deep geological anomalies; environmental and safety hazards

Each department has qualified and experience Scientists and scientific staff, and is headed by a senior Scientist.

SIGNIFICANT R&D ACHIEVEMENTS

NIRM has been developed with a vision to make it a Centre of Excellence for scientific design of mine workings, design of rock excavations and support systems, site characterization practices, and advanced research in rock mechanics and ground control. The Institute has undertaken several S&T projects funded by Central Govt Ministries and Departments. A large number of projects were sponsored by the industry (mining, civil engineering, hydel and infrastructure development) for problem solving and trouble shooting, making use of the expertise developed by the Scientists.

From 1990 to 2013, the Institute had executed nearly 800 projects (765 sponsored projects, and 35 long term S&T Projects) covering most of the rock mechanics topics.

So far, the Scientists have published about 620 research papers in various renowned Journals / periodicals / conference / seminar / symposium etc (nearly 200 papers in International for a, and the remaining in National fora).

The table below indicates the performance of the Institute in terms of projects executed and research papers published since inception.

Performance of the Institute in terms of technical output

Year	Number of Projects Completed	Number of Research Papers Published
1990-1991	04	12
1991-1992	07	11
1992-1993	21	29
1993-1994	20	14
1994-1995	28	22
1995-1996	17	18
1996-1997	29	19
1997-1998	35	11
1998-1999	30	26
1999-2000	46	48
2000-2001	59	34
2001-2002	47	24
2002-2003	53	26
2003-2004	36	26
2004-2005	46	46
2005-2006	37	27
2006-2007	35	13
2007-2008	24	28
2008-2009	26	31
2009-2010	45	25

Year	Number of Projects Completed	Number of Research Papers Published
2010-2011	37	51
2011-2012	29	26
2012-2013	46	28
2013-2014	43	25
Total	**800**	**620**

Note : The total staff strength of NIRM hovered around 65 during the last 22 years.

Equipped with state-of-the-art facilities, the Institute offers research and industry sponsored projects for all types of mining (metal mines, coal mines, opencast mines), tunneling (underground metros, water-carrying tunnels, access tunnels), civil engineering (dams, hydro power projects), and infrastructure (underground storage caverns, civil facilities) sectors. The Institute projects were funded by various Govt bodies, including the Ministry of Mines, the Ministry of Coal and the Ministry of Science & Technology. The Institute has a wide ranging clientele in mining, hydro power projects and allied sectors, who sponsor the projects.

Some of the significant contributions of the Institute are given below.

R&D Innovations

1. **Development of Science :** The Institute is working in the area of applied sciences and engineering. With regard to advancement of science in rock mechanics, the Institute has made the following contributions :
   - (a) Based on acoustic emission studies, the fracturing process leading to failure of rocks has been identified.
   - (b) Post-failure criteria for failure of coal pillars in mines has been developed.
   - (c) For the benefit of research on reservoir rocks for nuclear repository, the thermal cracking of granites, charnockites, etc. under simulated conditions has been studied
   - (d) Actively involved in the development of National Standards for various subsurface investigations as a member of the Bureau of Indian Standards.

2. **Development of Technology :** NIRM has developed some new data acquisition and processing techniques in the areas of mining and geophysics. Some of the developments are :
   - (a) Multipoint borehole extensometers were installed from the surface to a depth of over 300 m to monitor the caving process in the goaf over a retreating longwall.
   - (b) Developed new techniques in geophysical data processing using spectral signatures. Unique FDAT tools identified hidden flaws in both 2-D and 3-D sections
   - (c) Algorithm for 3-D altitude correction for processing geophysical data on inclined and curved plane has been developed leading to isometric presentation of geophysical sections.
   - (d) A method for assessment of caveability of overlying roof rocks has been developed in collaboration with ISM and CIMFR.
   - (e) A PC-based Strata Monitoring System was developed to continuously monitor the roof to floor convergence in coal mines.
   - (f) Micro-controller Based Monitoring System was designed for on-line monitoring of the performance of longwall powered supports.

3. **Development of products :** The Institute has developed some tailor-made and innovative investigation practices, which include :

(a) Mobile drilling equipment for roof bolting purposes in coal mines.
(b) Small diameter drill rods and bits for use in mechanized workings.
(c) Guided probing tool / sheath for GPR for up-dip / down-dip and directional probing.
(d) Single-anchor wire-type extensometer (SAWE) for fast installation and for strata monitoring.

4. Patents : The Institute has two patents to its credit.

(a) Developed ROOF STABILITY TESTER under Coal S&T project. For rapid evaluation of coal mine roof condition under green region.
(b) Developed IMPROVISED HAULAGE MOTOR OUTPUT MONITORING TOOL for optimizing productivity in coal mines. The technology developed for “Microprocessor based solid state controller for improving Hauler’s efficiency in coal mine” has been transferred for commercialization through NRDC.

Service to the Industry

The institute is actively involved in consultancy services to mining, hydroelectric and infrastructure sectors. Key area of NIRM services have been trouble-shooting work wherein several critical problems faced by the industry were investigated using innovative technique and cost-effective solutions are provided. A very wide range of projects were carried out.

Significant Contributions : Sector-wise :

1) Metal Mines

- Guidelines were developed for optimisation of blast design parameters at Malanjkhand Copper Project, Rampura Agucha of HZL and Wadi Limestone Mine of ACC, with improved fragmentation, reduced explosive consumption/specific drilling, and reduced environmental impacts due to blasting.
- NIRM designed the optimum shape of shaft and nature of support for deepening of Mallappa shaft, Hutti Gold Mines Ltd
- The ground stability at Rajpura-Dariba mine, Hiustan Zinc Ltd, NIRM was evaluated and feasibility of depillaring of rib pillars and crown pillars at Zawarmala mine (HZL) was studied.
- NIRM has carried out investigations related to the stability of rock and soil slopes at Goan iron ore mines, limestone mines and iron ore mines in the country.
- Strong Motion Accelerograph has been setup to monitor rockbursts, and to analyze the characteristic features of a rockbursts, such as source radius, seismic moment, stress drop and corner frequency.

2) Coal Mines

- For the purpose of support design at Tandsi mine, WCL, and at Adriyala Block, SCCL, NIRM carried out multi-stage triaxial compression tests using Hoek triaxial cell as per international guidelines.
- As part of an S&T project, NIRM designed non-conventional pillar dimensions for working steeply dipping coal seams in Singareni coalfields, AP. This is first of its kind, and the experimental panel was extracted successfully without any ground control problems. Based on the recommendations from these studies, other panels with similar conditions are also being extracted in the same way.
- NIRM helped in introduction of the first continuous miner in SCCL mines for fast extraction of coal seams.
- Seismic and microseismic investigations have been carried out first time in the country to assess the stability of underground mine workings at Rajendra mine, South Eastern Coalfields Ltd.

3) Hydro-power Sector

- In the Himalayan terrain, for the difficult ground conditions encountered during tunneling for the Tapovan-Vishnugad hydro-electric project (Uttarakhand), the Scientists of NIRM have been carrying out engineering geological mapping on daily basis, and rendering timely advice for rock mass stabilization based on the rock mass conditions encountered and thus ensuring safety and stability of the underground structures.
- NIRM carried out in-situ stress and deformability measurements for dam foundations, large caverns, and hydro-electric project sites at the Teesta Stage-2 & 4, Nathpa & Jhakri, Karcham Wangtoo, Baglihar, Baspa, and Chamera, Dhauliganga, Subansiri Upper & Middle, Pykara and Srisailam within the country, Tala in Bhutan, and Kulekhani in Nepal. These test results were used for the safae and economic design of the dam and underground power houses and other major structures.
- At the hydro-electric project of Nathpa Jhakri Power Corporation (Himahal Pradesh), NIRM carried out micro-seismic monitoring of the slopes to study their behaviour.
- Design of excavations in rock using numerical modelling was carried out at Tala hydro-electric project in Bhutan, Chilime hydro-electric project in Nepal, Sardar Sarovar project, Gujarat, and NJPC / SJVNL in HP.
- The Institute carried out comprehensive monitoring of large underground caverns in several hydro-electric projects, including Srisailam, Nathpa Jhakri, Sardar Sarovar and Pykara projects in the country, and Tala hydro-electric project in Bhutan.
- At Tala hydro-electric project in Bhutan, nano-seismic / microseismic (or acoustic emission) real time monitoring was successfully undertaken in the underground power house cavern where incidents of rock bolt failures have been occurring from 2003 onwards due to time dependent deformations under high stresses. This is a historical step for using nano-seismics/micro-seismics in monitoring underground excavations in hydro power sector.

4) Nuclear Power Sector

- For identifying a suitable site as repository for nuclear wastes, NIRM determined the physico-mechanical properties of the rocks at elevated temperatures, which is an important input for the design.

5) Underground Storage Caverns

- For an underground LPG storage cavern project at Visakhapatnam, AP, NIRM carried out detailed testing of rock samples and rock joints as per the requirements of international clients.
- For another underground oil storage cavern at Visakhapatnam, NIRM is carrying out construction stage detailed engineering geological studies as per the international standards for ensuring safety and stability of the structure.
- In-situ stress measurements were carried out for the underground gas storage caverns at Mangalore for deciding the proper orientation of the caverns and their safe design.

6) Railways / Metro

- NIRM specialised in shallow level prospecting and imaging using the latest geophysical investigation tools like Ground Penetrating Radar (GPR), Seismic Refraction Techniques and Electrical Resistivity Imaging. GPR investigations were carried out at a number of projects including for the Katra-Quazigund Rail Link Project (J&K) and Allain Duhan hydro-electric project (HP).

7) Others (Oil Pipelines, etc.)

- In order to assess the rock mass quality vis-à-vis the tunneling medium (for the design of TBM), seismic refraction survey was carried out for 12 km length for Sleemanabad Carrier Canal Project near Katni in Madhya Pradesh. GPR and Resistivity Survey for Assessing the Stability of HMRB Oil Pipeline of IOCL in Raniganj Coalfields.

- To assess the stability of underground workings following an incidence of coal fire close to the Haldia-Maurigram-Raniganj-Barauni pipeline of M/s IOCL, GPR and Electrical Resistivity Imaging were done to map the subsurface up to a depth of 20 m. Survey was done within 5-10m distance from the pipeline for a length of 3 km in the strategic area.
- NIRM carried out controlled blasts in some projects where blasting was considered impossible; examples include Mangalore Refineries & Petrochemicals Ltd and Chambala Fertilisers & Chemicals Ltd (very close to chemical/crude oil storage tanks), Srisailam project (to excavate the rock under the high tension transmission lines), Kandla-Bhatinda pipeline project (at a distance of 5 m to the existing gas pipeline).
- The seismic Broad Band Station has been established at KGF under the control of NIRM.

<u>Significant Contributions : Subject-wise</u> :

1) **Design of mining methods and optimization of pillars**, for maximising the recovery of extraction and for improved safety - comprehensive studies were undertaken in:
    - Khetri mines, HCL
    - Rajpura-Dariba mines, HZL
    - Zawarmala mine, HZL
    - Mochia mine, HZL
    - different reefs of Hutti gold mine, HGML, at different depths
    - Ingaldhal copper mine, HGML
    - Saladipura phosphorite mine, PPCL
    - Sargipalli lead-zinc mine, HZL
    - Balaghat, Chikla, Kandri and Gumgaon mines, MOIL
    - Boula chromite mine, FACOR
    - Bangur chromite mine, OMC

2) **Comprehensive package to hydro-electric projects covering** a) Geotechnical Investigations, b) Numerical Modelling using 2D & 3D models, c) blast design for smooth blast, d) design of support systems, and strata & support performance monitoring, were carried out at:
    - Sardar Sarovar Project, Gujarat
    - Srisailam Hydro-electric Project, Andhra Pradesh
    - Pykara Hydro-electric Project, Tamil Nadu
    - Satluj Jala Vidyut Nigam Ltd, Himachal Pradesh
    - Lakhwar Hydro-electric Project, Himachal Pradesh
    - Karcham Wangtoo Hydro-electric Project, Himachal Pradesh
    - Baspa Hydro-electric Project, Himachal Pradesh
    - Baglihar Hydro-electric Project, J&K
    - Uri Hydro-electric Project, J&K
    - Dul-hasti Hydro-electric Porject, J&K
    - Dhauli Ganga Hydro-electric Project, UP
    - Tala Hydro-electric Project, Bhutan
    - Pancheswar Hydro-electric Project, Nepal
    - Teesta Hydro-electric Project, Sikkim
    - Allain Duhan Hydroelectric Project, Himachal Pradesh
    - Kol Dam Hydroelectric Project, Himachal Pradesh

3) **Design of optimum drilling & blasting patterns** for safety of the nearby structures, optimisation of blast design Blast vibration and air over-pressure studies were carried out in a number of opencast mines, construction projects, tunnels and large caverns.

During the early nineties when the mining industry was looking into means of reducing the production costs, NIRM took the lead in conducting extensive research on optimisation of blast design parameters for surface mines through an S&T project and implemented the findings successfully in the mines of Hindustan Copper Limited (HCL), Hindustan Zinc Limited (HZL), Iron ore mines and in many limestone quarries. NIRM was the first in India to conduct the evaluation of explosives in real time through discrete Velocity of Detonation (VoD) measurements which was further investigated through an S&T project titled "Evaluation of explosives performance through in-the hole detonation velocity measurement". The research document was on the list of Blasting Library, ISEE, USA.

The Scientists have done innovative work in terms of evolving an integrated muffling procedure in order to control flyrock within safe distances. This was successfully applied in various projects of irrigation canal and other excavations in proximity to villages, operating power projects, near HT lines, bridges and in urban environment. NIRM has the distinction of initiating and conducting full scale hard rock blasting in the city of Bangalore for BMRCL. NIRM has been instrumental in deploying high frequency uniaxial/triaxial geophones in India for near field rock mass damage studies in underground caverns and tunnels. Mitigation of adverse impacts due to blasting in terms of ground vibration and air over pressure levels have been done in various surface and underground projects and a compilation of these studies categorized in terms of limestone quarries, coal mining, construction blasting etc was carried out as ready reckoner. Design of blasts for control of high wall has been carried out in major power projects and to cite about 45,000 sqm of pre-split was successfully carried out at a nuclear power project site in the western part of India.

Controlled blasting for Bangalore Metro : About 500 blasts were successfully conducted to excavate about 35,000cum of hard rock under the technical guidance of NIRM within the city of Bangalore. Controlled blast designs and the guidance on sequencing of benching operations facilitated to avoid the excavation of a launching shaft for the TBM at Sir M V Station area. A muffling method to restrict the flying fragments was evolved comprising sand bags, followed by an over lapping layer of 1.5"x1.5", 14 SWG link mesh, over which rubber mats and implemented successfully

Optimisation of blast design for an Iron Ore Project : The optimised blast designs have ensured the desired fragmentation even with the increased blasthole diameter (102 mm to 165 mm). Fragmentation assessment through image processing showed that the passing percentages at 0.8 m sieve size with the modified blast design was 90.7% comparable with that of the baseline passing percentage of 94.6. Considering the burden stiffness due to shallow bench height, it is recommended to increase the bench height to greater than 12 m.

Controlled blasting for twin tunnels under an operating railway line : The twin tunnels were successfully excavated under the railway line by the suggested blast designs. While blasting under the railway zone, the monitored ground vibration on the track was safe and were lower than the vibration levels due to passage of the train itself. The levels measured before and after blasting on the track in the railway zone showed insignificant ground settlement. The convergence measurements using tape extensometers in the tunnel below the railway line showed no convergence in the tunnel.

Tunneling in the abutment wall of an existing dam at Bhutan : Based on the literature review and NIRM experience on blasting close to dams, the permissible peak particle velocity set for Tala dam is 100mm/s. Considering the left abutment of the dam as integral part of the dam up to a distance of 20m, it is suggested to excavate the adit in two parts i.e. heading with controlled blasting using jack hammer holes and benching with mechanical means. The suggested blast design for heading portion yielded satisfactory results. Beyond 20m, full face blasting was adopted with wedge and burn cut patterns and resulted in desired pull.

Tunneling in the abutment wall of an existing dam at Bhutan : Based on the literature review and NIRM experience on blasting close to dams, the permissible peak particle velocity set for Tala dam is 100mm/s. Considering the left abutment of the dam as integral part of the dam up to a distance of 20m, it is suggested to excavate the adit in two parts i.e. heading with controlled blasting using jack hammer holes and benching with mechanical means. The suggested blast design for heading portion yielded satisfactory results. Beyond 20m, full face blasting was adopted with wedge and burn cut patterns and resulted in desired pull.

Wall rock control at a nuclear power project : Blast designs for different bench heights were suggested, field tested, fine-tuned and optimized and about 15 lakhs cubic meter of hard rock was excavated. Suitable controlled blast design was suggested to achieve stable wall for vertical and inclined faces and about 45000m2 of wall rock was pre- split adopting the suggested blast design.

Blasting feasibility study for a limestone mine : From the analysis of the ground vibration data for the studies carried out by NIRM at different limestone mines all over Idia and also the available data of other researchers with NIRM it was concluded that both 3.5 MMTPA capacity Cement Plant and 1320 MW Thermal Power Plant can co-exist from the blast vibration point of view for the proposed blast design parameters of GCL. It was also recommended that during the actual mining operations ground vibration studies are to be carried out for deriving the site predictor equation

Ground Vibration Study at a dam complex in Bhutan : For the blasting carried out at the dam complex of Mongdechhu Hydroelectric Project, a peak particle velocity of 2mm/s was recommended safe for structures of historical importance (Dzong and Taa Dzong) based on the DGMS standard and the recorded frequency range. Based on the IS code and USBM guidelines, the permissible air overpressure recommended was 133dB. For the blasts carried out at dam complex, the ground vibration attenuates to less than 2mm/s at distance 160m and beyond and 133dB at a distance 350m for air overpressure.

4) **Engineering geological investigations** were carried out during various stages of the project developments, i.e., feasibility report (FR), detailed project report (DPR), construction and post construction stages.
   - Engineering geological and geotechnical investigations were carried out for the preparation of Detailed Project Report (DPR) for Malshej Ghat PSS (700 MW), Maharashtra and Bunakha HEP (180 MW), Bhutan. Construction stage geological and geotechnical investigations were carried out for Tapovan - Vishnugad HEP (520MW), Uttarakhand. The upper dam axis of Malshej Ghat PSS project proposed by Irrigation Department, Maharashtra was changed by NIRM after detail investigations and accordingly the location of its appurtenant structures have also been changed from left abutment to right abutment. The upper dam length is now reduced to 2450m from 2595m thus substantial reduction in excavation and concrete of dam thereby reduction in cost and schedule of the project. The capacity of upper dam reservoir is also increased by changing the dam axis. The installed capacity is increased to 700 MW from 600 MW. This project was investigated in record time. NIRM has contributed in the finalization of new dam axis of Bunakha HEP and by doing this the length of dam crest is reduced to 430m from 500m and reduction in the excavation in the right bank for the construction of flip bucket. By reducing the dam length, excavation and concreting for dam will be reduced thereby reduction in cost and time schedule of the project. Bunakha HEP report was submitted in time and it was appreciated by THDC India Ltd. Reservoir rim area of Malshej Ghat PSS and Bunakha HEP were investigated in detailed regarding reservoir rim stability and reservoir competency.
   - Construction stage engineering geological investigations of Rajasthan Atomic Power Project Units 7 & 8 (2 x 700 MW) at Rawatbhata in Chittorgarh District of Rajasthan were carried out. Based on the detailed investigations, recommendations of the re-

medial measures for the foundations and vertical walls were given as the excavation progresses. First pour of concrete (FPC) for 7th reactor of 700 MW capacity was achieved in July 2011 after the submission of NIRM report. A major pour measuring 5757 cubic meters of concrete for the nuclear building raft foundation (RB-7, Pour No.2), which is the largest pour at a nuclear project in India, was successfully completed at the presence of NIRM Scientists. It was continuously for 110 hours. The reactor is scheduled to be completed in June 2016. The 8th reactor, which is also of 700MW capacity, is expected to be completed by December 2016. This work was done by NIRM well in time and during this period NIRM submitted four reports. The work done by NIRM was highly appreciated by Atomic Energy Regulatory Board (AERB), Nuclear Power Corporation of India Ltd and Hindustan Construction Company Ltd.

- The Indian strategic crude oil reserve programme involves construction of the storage units of 5.33 million metric tones (MMT) of imported crude oil at Visakhapatnam (1.33 MMT), Mangalore (1.50 MMT) and Padur (2.50 MMT) in unlined rock cavern. Construction stage engineering geological investigations were carried out for Visakhapatnam project and are being carried out for Mangalore and Padur projects. After detailed investigations recommendations were given/are being given for temporary and / or permanent rock support system as per design. Works pertains to permission for the bench excavations, hydrogeology i.e. water curtain management, review the ground water level through the monitoring borehole and sustain the water seepage in cavern and accesses tunnel for the Mangalore and Padur projects is also being carried out. The work done by NIRM at Visakhapatnam project site was appreciated by Geoconsult Asia Singapore Pte. Ltd., GC was Design Consultant for this project.
- Construction stage engineering geological investigations of surge pool and pump house areas of Mahatma Gandhi Kalwakurthi lift irrigation scheme-II and Scheme-III at Mahaboobnagar District of Andhra Pradesh were carried out. Suitable measures for stabilization of all the sides of surge pool and pump house and rock ledge based on geotechnical assessment of rock mass were recommended. These reports are well appreciated by Andhra Pradesh Power Generation Corporation Ltd. (APGENCO), Andhra Pradesh Irrigation and CAD Department, Gammon India Limited and Navayuga Engineering Company Ltd. Preliminary geotechnical investigation of Pranahitha - Chevella Sujala Sravanthi Project Package – 8 at Karimnagar District of Andhra Pradesh were also carried out. On the basis of review of reports, field investigations, and exploratory drilling data, rock mass of the surge pool and pump house area has been classified, geotechnical assessment was done and recommendations about the sustainability of rock mass with the underground surge pool and pump house are given. Earlier open surge pool and pump house was recommended for this package.
- Construction stage engineering geological / geotechnical investigations of twin tunnels on the Hungund – Hospet Section of NH-13, near Hospet, Karnataka were carried out. The tunnels are of 14.5 m finished diameters were constructed under a live railway line. Recommendation of permanent support based on rock mass classification system and rock support categories as per design were given for twin tunnels and cut slopes. The work was carried out under severe limitations owing to the proximity to a very congested highway on both ends of the Twin Tubes. The tunnels were excavated mainly through poor rock mass and very low cover, especially on the north portals, which is probably one of the lowest in India for this diameter of tunnels.

5) **Optimum design of rock slopes** under wide range of ground conditions was made in a large number of open cast mines including iron ore, limestone, chromite, copper and lead-zinc mines.

6) **Basic research in the field of Rock Fracture Mechanics** was carried out in the following aspects :
    - Laboratory method of determining the in-situ stress of rock mass using Kaiser Effect (acoustic emission method).
    - Characterizing the rocks for nuclear waste disposal and underground storage of petroleum products.
    - Thermo mechanical behavior of rocks.
    - Development of new theory for the post failure of rocks and coals.
    - Acoustic emission signal analysis for understanding the deformation mechanism of rocks and for the determination of Critical cracking temperature.
    - Dual role of micro cracks i.e. toughening and degradation.
    - Characterization of micro and macro cracks in rocks by Acoustic emission and Ultrasonic C-scan imaging.
    - Measurement of deformation using strain gages under uniaxial and triaxial stress conditions at elevated temperatures (up to 200^0C).
    - Data bank on intact rock properties and rock joints.
    - Non-destructive testing and evaluation of process zone development during rock fracture
    - Characterization of Dimensional Stone Granite of Southern India.
    - Burst proneness index of rocks
    - Studies on negative Poisson's ratio
    - Measurement of strain under triaxial stress conditions in pores rocks
    - Post failure deformation mechanism of coal – a new mechanism
    - Prediction of rock mass properties using the laboratory strength data.
    - Multistage Triaxial Compression testing as per ISRM suggested method and determination of Young's modulus by loading and unloading.
    - Direct Shear testing on contact planes of sedimentary rocks.

7) In the area of **ground control and mine design**, following are some of the major projects undertaken –
    - Designed method for extraction of steeply inclined coal seams at Bhupalpally Area, SCCL, by developing rectangular pillars and rhombus-shaped pillars.
    - Designed partial extraction methods for mining under surface structures, at Sarni mine (Pathakhera Area, WCL), GDK-8A Incline (RG-II Area, SCCL) and in the SMG mines of Srirampur Area (SCCL), because of which the life of the mines could be extended and the otherwise unextractable coal could be recovered.
    - Designed support system for difficult roof conditions, like at Tandsi, for the devolatilized coal seams of Kanhan area, Durgapur-Rayatwari colliery, Nandgaon incline in Chandrapur Area and the shale roof of Chincholi mine in Ballarpur Area (all in WCL)
    - Developed subsidence prediction models for estimating the degree of subsidence over single seam workings in the mines of SCCL.
    - Installed deep hole extensometers from the surface (up to 300 m depth) at GDK-10 incline, and monitored the caving behavior of roof over the goaf in the longwall panel below.
    - Introduced rock bolting at Hutti Gold Mine to prevent the slabbing type of roof falls in the development workings.
    - Introduced cable bolting at Balaghat mine, MOIL, for the weak hangwall formations, thus dispensing with the square set supports in the stopes, and increasing the productivity of the mines.
    - For the first time in India, roof bolting was introduced in a working longwall face in 17 Special seam Jankowice longwall workings at Chasnalla colliery, IISCo.

- In a challenging task, designed rock bolting for support of a thin parting in longwall gate roads below already worked out longwall goafs at JK-5 Incline, Yellandu Area, SCCL.
- Designed, implemented and monitored the support systems for a number of projects
- In coal mines, studies were conducted for design of methods of work for extraction under surface structures, and prediction of surface subsidence
- For longwall panels in coal mines, strata control investigations and assessment of the cavability of roof strata were undertaken
- Strata monitoring in underground coal mines was carried out for a number of depillaring panels

Specific Achievements in Recent Years :

1) Tapovan – Vishnugad Hydro-Electric Project, Uttarakhand

In the Himalayan terrain, for the difficult ground conditions encountered during tunneling for the Tapovan-Vishnugad hydro-electric project (Uttarakhand), the Scientists of NIRM have carried out geotechnical mapping on daily basis, and gave advice on the required support system. When a shear zone was encountered in the Intake Adit – III from Chainage 201 to 224 m, the "extremely poor" rock conditions were tackled with adequate support system, and the drivage advanced successfully.

2) Determination of In-situ Stress by Hydrofracturing Method at the Proposed Underground LPG Cavern at Mangalore, Karnataka, RITES

HPCL's Mangalore LPG Import facilities presently handle approximately 1.5 million metric tonnes per annum of LPG. With a view to leverage its existing facilities and receive LPG in very large size gas carriers, HPCL proposes to set up an LPG underground storage in a mined rock cavern with a capacity of 120 000 m^3. Among others, the design of the cavern is mainly dictated by in-situ stress direction and magnitude. The long axis of the cavern must be parallel to sub-parallel to the direction of maximum compression. High horizontal stress has bearing on dimensions of the main galleries and design of the support. The NIRM Scientists carried out in-situ stress measurement by Hydrofrac method inside a NX size borehole.

3) Seismic Refraction Survey for Sleemanabad Carrier Canal Project near Katni in Madhya Pradesh

In order to assess the rock mass quality vis-à-vis the tunneling medium *(for the design of TBM),* seismic refraction survey was carried out for 12km length. It was proposed to derive 8m diameter tunnel along the lift irrigation canal of Bargi Diversion Project near Jabalpur in MP. Survey results revealed that at least 35% stretch has tunneling medium in the hard marble (V_P>3500m/s), 15 % in the compact overburden and remaining 50% in the weathered or fractured marble (V_P<1500m/s).

4) GPR and Resistivity Survey for Assessing the Stability of HMRB Oil Pipeline of IOCL in Raniganj Coalfields

In order to assess the stability of following incidence of coal fire close to the Haldia-Maurigram-Raniganj-Barauni pipeline of M/s IOCL, GPR and Electrical Resistivity Imaging were done to map the subsurface up to a depth of 20 m. Survey was done within 5-10m distance from the pipeline for a length of 3 km in the strategic area. The survey results showed that there was immediate threat to the pipeline as no progressive disturbance in the subsurface strata was noticed anywhere in the strategic area. IOCL authorities were advised to pack one or two cavity pockets appearing close to the pipelines within 5m depth.

5) Instrumentation, Monitoring and Data analysis at Powerhouse Complex, Tala Hydroelectric Project, Bhutan

NIRM has done complete instrumentation of the underground caverns of Tala Project Bhutan since 2000. Most of the instruments are working and is available for monitoring during the operational period also. The continuation of the monitoring of the existing instruments during the operational period is being carried by THPA on regular basis. The stability of the machine hall cavern was assessed based on the convergence observations of the side walls, the load on the rock bolts and the stress distribution along the length of the instrumented bolts and piezometric observations in the side walls.

6) Support Design for Tunnel at Nettempadu Lift Irrigation Scheme, stage –II, Andhra Pradesh

Delta Construction Systems is executing Nettampadu Lift Irrigation Scheme – II for Govt of A.P. NIRM has done support design for Tunnels, Pump house and Surge Pool using numerical modeling. At tunnel area, after advancing 10 m from the portal, the problem of rock spitting/rock ejection resulted in instability of the face. This has affected the safety and the progress of the face. It was reported by the project authorities that the face used to eject with great sounds soon after the blasting of the face, not allowing even for mucking or any other activities.

7) Measurement of Ground Vibration and Air Overpressure Produced from Quarry Blasting Beyond 500m from Yeleru Reservoir, Yeleswaram, East Godavari, Andhra Pradesh, Department of Mines and Geology, Govt. of Andhra Pradesh, Hyderabad

The Department of Mines and Geology, Andhra Pradesh had granted certain leases for quarrying for road metals in survey No. 54 of Yeleswaram village since 1982. Subsequently, the Yeleru Reservoir was constructed and the Project authorities were apprehensive about the adverse impacts of blasting on the reservoir structure. Though a study was conducted by CWPRS earlier, the quarry leases were cancelled due to apprehensions with regard to safety of the Yeleswaram dam. The affected quarry lease holders represented stating that banning of quarrying will result in depriving of livelihood to labours.

Based on our recommendations, Government of Andhra Pradesh issued orders for continuing the quarrying operations beyond 500m from the dam. The client has communicated that the findings and recommendations are excellent and fulfilled the objectives of this study to their satisfaction.

8) Ground Vibration and Air Overpressure Study Conducted During Test Blasts at an Alternate Site for Bangalore Metro Rail Corporation Ltd

This project deals with the blasting measurement carried out by NIRM for BMRCL at an alternate site in order to estimate the probable ground vibration and air overpressure levels that may be encountered at various distances during the actual blasting operations in the proposed station areas.

Three blasts were monitored using ten seismographs placed at different distances ranging from 5m to 60m. The study revealed that the vibration levels can be restricted to the permissible limit of 10mm/s during the actual blasting operations beyond 20m distance. The report also dealt with the desirables that need to be incorporated in the tender document with regard to controlled blasting. This paves the way for blasting operations even in critical urban areas.

9) Assessment and Expert Opinion on Rock Strata Classification at Pattuvam and adjoining villages for Contract Package-3 of JBIC Assisted Kerala Water Supply Project, Kerala

The Kerala Water Authority has approached NIRM to assist in strata classification into soil and hard rock along the pipe line distribution trench being excavated in the Kannur district, Kerala. It was also requested to suggest a simple and robust procedure to differentiate soil from hard rock at the site.

Massive, compact and hard laterite formation is observed in the exposed area. Field and laboratory Investigations were carried out to assess the ground strata at six places. P-wave velocity, uniaxial compressive strength and rippability were used for strata classification. The laboratory UCS ranged from 13 to 54 MPa and the estimated in-situ UCS varied from 20 to 80 MPa. The material density ranged from 2.1 to 2.4 g/cc indicating compactness and massiveness of the strata. The tensile strength values varied from 1.44 to 3.14 MPa. The average P-wave velocities varied from 1695 to 2195 m/s. From the analysis of data, the strata conditions were considered as 'Hard rock' as their UCS exceeds 12.5 MPa. Rippability charts indicated that the strata conditions require a minimum of 250 KW Tractor with a single shank ripper for optimum excavation.

10) Underground Coal Mining

As part of an S&T project, NIRM designed non-conventional pillar dimensions for working steeply dipping coal seams in Singareni coalfields, AP. This is first of its kind, and the experimental panel was extracted successfully without any ground control problems. Based on the recommendations from these studies, other panels with similar conditions are also being extracted in the same way. NIRM helped in introduction of the first continuous miner in SCCL mines for fast extraction of coal seams, and carried out strata monitoring during the operations.

11) Establishment of Broad Band Seismic Station

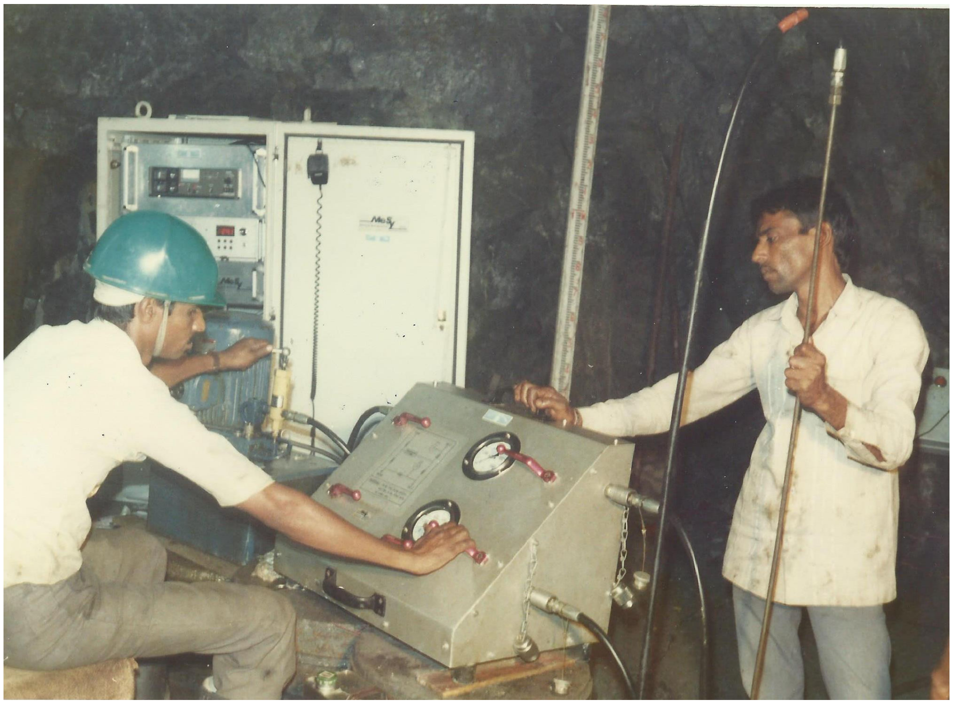
A Broad Band Station was established at KGF and the data retrieved from the system is regularly analysed, archived and sent to the IMD, National Seismological Data Center, New Delhi. Solar panel has been connected at the KGF Observatory to power the VSAT. VSAT has been installed at the KGF Observatory for transmitting data from KGF to NGRI, Hyderabad. The Strong Motion Accelerograph at the Observatory has been recording a number of rockbursts. The data recorded have been used and obtained source parameters of rockbursts, such as source radius, seismic moment, stress drop and corner frequency. These parameters are useful to characterize the rockbursts.

NIRM Success Stories

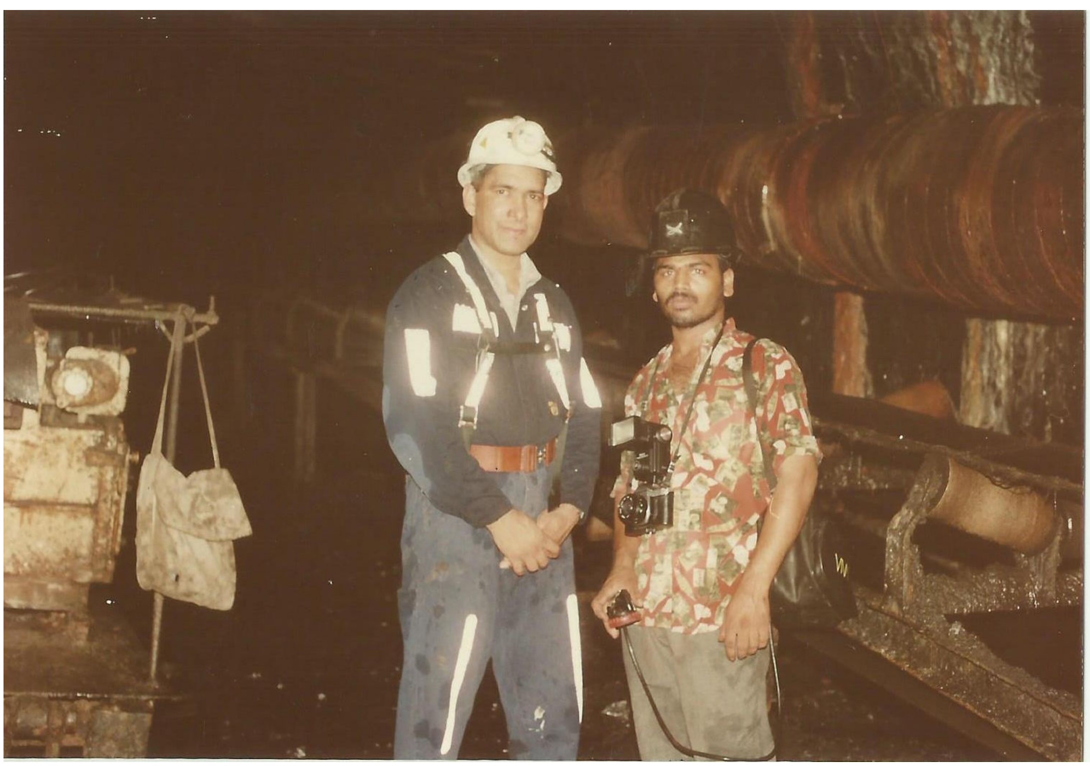
Establishment of underground micro-seismic monitoring station in 1992

Inauguration of Granite Mining Cell in 1997

NIRM Scientists in Action



Hydro-fracture test in progress



Strata monitoring in coal mines

Monitoring of ground vibration at a village produced from a stone quarry, Karnataka

Vibration monitoring near a stone quarry adjacent to a village, Mandya, Karnataka

Awards & Patents

All the previous Directors of the Institute are National Mineral Awardees. The NIRM Scientists, Dr S Jayanthu and Dr HS Venkatesh, have also received the National Mineral Award.

The Institute received the patent rights from the Indian National Patent office for one of its innovations, namely the “Roof Stability Tester”. The instrument was developed under an S&T project, by Mr C Sivakumar, Scientist-IV (Principal Investigator), Dr PC Jha, YV Sivaram, Dr V Venkateswarlu and Dr NM Raju (Co-Investigators).

The Institute also received patent rights for an improvised haulage motor output monitoring tool for optimizing productivity in coal mines, developed by Dr T Srinivasulu and Prof RN Gupta.. The technology developed for “Microprocessor based solid state controller for improving Hauler’s efficiency in coal mine” has been transferred for commercialization through NRDC.

The Institute has received an ISO 9001:2008 certification from RINA, a certification authority of IQ NET.

Financial Performance

NIRM was established in 1988 with a capital grant of Rs. 200 lakhs. It started getting projects from the industry from 1990 when its external cash flow (ECF) was ₹3.86 lakhs. Over the years, NIRM has gradually increased its income from projects and other sources. The quantum of scientific problems addressed by the Institute is reflected in our exponential growth of external cash flow (ECF) through sponsored R&D and industrial projects. This phenomenal growth reflects the faith shown in our work by the sponsoring agencies and industry, both government and private sectors. The external cash flow has tremendously increased, and during 2013-14, it is ₹1200 lakhs. About 30% of this can be taken as the net income to the Institute. Using the amounts excess of income over expenditure, the Institute was able to build-up a Corpus.

As an autonomous research institute under the Ministry of Mines, NIRM is required to get financial support from the Ministry. Such a support, to meet about 80% of the expenditure towards salaries and wages, was extended by the MoM to NIRM from 1988 to 1994-95. From 1995-96 to 2007-08, the support from the Ministry remained at about Rs. 100 lakhs per year, which was 30 to 50% of the total recurring budget of the Institute. The balance amount during this period was being met from the income generated from the scientific projects.

However, from the financial year 2008-09, the expenditure towards salaries and wages went up to Rs. 400 lakhs in 2008-09 and to Rs. 500 lakhs in 2009-10. On the other hand, there was almost no non-plan grant from the Ministry to NIRM during this period. Due to this, the Institute had incurred a net loss of Rs. 140 lakhs in 2008-09 and Rs. 308 lakhs in 2009-10. Even during the years 2010-11 and 2011-12, the shortfall between income generated from projects and the expenditure remained around Rs. 300 lakhs. With this, the Institute had depleted the Corpus.

The following table summarises the financial position of the Institute during the last 25 years.

Recurring Grants-in-aid as a % of recurring expenditure

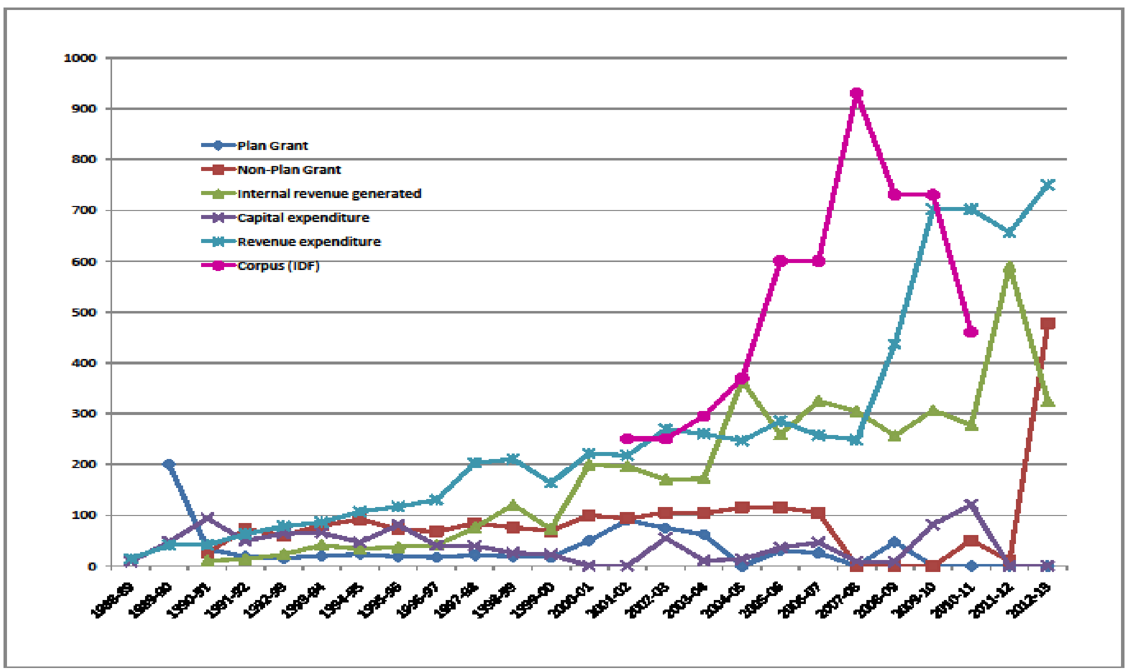
(₹ in Lakhs)

Year	Govt. Grant		Revenue Earned from Projects (IEBR)	Expenditure (including depreciation)
	Capital	Recurring		
Initial Grant for establishment of NIRM	**200**	-	-	-
1990-1991	33.70	26.30	10.83	41.60
1991-1992	18.00	72.00	13.18	63.10
1992-1993	15.00	60.00	22.62	78.72
1993-1994	20.00	80.00	40.59	85.83
1994-1995	23.00	92.00	33.00	107.08
1995-1996	18.00	72.00	37.40	116.79
1996-1997	17.00	68.00	40.89	130.26
1997-1998	21.00	84.00	75.22	202.64
1998-1999	19.00	76.00	120.43	210.40
1999-2000	17.20	68.80	72.69	163.55
2000-2001	50.00	100.20	199.40	221.40
2001-2002	90.00	93.60	196.45	217.66
2002-2003	75.00	105.00	169.73	269.37
2003-2004	62.00	104.00	172.53	259.69
2004-2005	0	115.00	364.60	246.43

2005-2006	30.00	115.00	257.99	284.84
2006-2007	26.00	105.00	324.50	257.22
2007-2008	0	0	304.46	248.05
2008-2009	47.00	0	255.99	436.66
2009-2010	0	0	306.21	701.94
2010-2011	0	50.00	276.98	701.61
2011-2012	0	10	589.64	656.37
2012-2013	0	477	324.6	749.89
2013-2014	1	232	400	800

There was all round scientific and financial improvement of the Institute since inception and efforts were made to minimise the expenditure and maximise the internal resources generation so that the dependence upon government budgetary support could be kept at a minimum. The above tables show the consistent growth of the Institute in every respect. In addition, the concept of generating corpus fund for the Institute was envisaged and the Governing Body in its 40th meeting held on 15th January 2001 approved the creation of corpus fund to a tune of ₹1200 lakhs from its surplus fund so that the Institute may become self-financing and do not depend on any support from the Government. The corpus fund was generated to the tune of ₹930 lakhs, which had been achieved by providing excellent services to the mining and construction industries. Out of this, ₹200 lakhs was used for the infrastructure development of the Institute and ₹270 lakhs to meet the revenue expenditure. Currently, a sum of ₹460 lakhs is available under IDF.

The figure below illustrates the financial trends over the years.



Human Resource Development & Technology Transfer

Continuous training and development, and keeping abreast of the research in other parts of the world, are important for a Scientist. To this end, the library at NIRM was developed, with an annual budget of Rs. 5 lakhs in the first few years. Notable in its formation and development are Mr G Ravi, Scientist, who took keen interest in planning and systematizing the library procedures, and Mr GS Govinda Setty, Librarian, who worked hard to improve his qualifications for this purpose. The library now has the latest books and journals related to rock mechanics and related fields. At present the library has nearly 5,000 books and other documents, and is subscribing to 25 journals (15 foreign and 10 Indian).

'Friday Lecture' series was initiated at NIRM to promote healthy discussions, and to appraise the Scientists of different departments on the work being carried out in other areas.

With facilities and opportunities offered by the Institute, several Scientists pursued higher degrees. The list of PhDs obtained by the Scientists while in service at NIRM is :

Sl. No.	Name	Year	Institute/University
1	C Srinivasan	1992	NIT-Karnataka (Mangalore University)
2	PC Jha	1992	Indian School of Mines, Dhanbad
3	GR Adhikari	1997	Karnataka REC, Mangalore University
4	GM Nagaraja Rao	1997	India Institute of Science, Bangalore
5	S Sengupta	1998	Indian Institute of Technology, Delhi
6	T Srinivasulu	2005	Kyushu University, Japan
7	Surendra Roy	2011	Indian Institute of Technology, Mumbai
8	HS Venkatesh	2003	NIT-Karnataka (Mangalore University)
9	DS Subrahmanyam	2005	Bangalore University
10	Rabi Bhusan	2012	Allahabad University
11	LG Singh	2012	Kurukshetra University, Haryana
12	Devendra Singh Rawat	2012	HNB Garhwal University, Uttarakhand
13	Ritesh D Lokhande	2013	Indian School of Mines, Dhanbad
14	VR Balasubramaniam	2013	Indian Institute of Technology, Mumbai
15	G Doraswamy Raju	2013	Mc Gill University, Canada
16	RK Sinha	2014	Indian School of Mines, Dhanbad

The Institute organized several courses to educate the practice engineers on the basics of rock mechanics, and seminars for dissemination sharing of the latest developments in the area.

Training Programmes Conducted by NIRM

NIRM conducted Workshops and training programs in different areas of rock mechanics and rock engineering for the benefit of practicing civil and mining engineers, geologists and geophysicists. They included :

Event	Date	Place
Workshop on Safety Measures for Rockburst Control	19 March, 1990	NIRM, KGF
Short Course on Rock Mechanics Applications in Mining	12-23 November, 1990	NIRM, KGF
Workshop on Numerical Methods in Rock Excavation Design	29-30 November, 1991	Bangalore, KGF
Workshop on Rock Mechanics Applications in Hydro-electric Projects with Special Reference to Srisailam Project	5-7 July, 1994	SLBHES, Srisailam
Indo-Norwegian Workshop on Recent Trends in Rock Mechanics	7-9 April, 1997	NIRM, KGF
Workshop on Application of Rock Mechanics in Surface and Underground Excavations, for the Executives of NTPC	22-26 August, 2005	Power Management Institute, Noida, UP

Following are some of the short-term training courses organized by NIRM in recent years.

Course	Dates	Place	Participation
Application of Geophysical Investigations to Engineering Projects.	from 11 to 16, July 2011	Banihal, J&K	18 participants, nine each from IRCON and Northern Railway
Drilling and Blasting.	during 8th to 10th August 2011	Jorethang Project Site, Sikkim	29 officials of SEW Infrastructure Ltd
Application of Numerical Modeling to Tunnels, Caverns and Slopes	from 1 to 6 August 2011	NIRM, Bangalore	10 participants from DGPCL, Bhutan, CMPDIL, Ranchi & BMRCL
Dimensional Stone Technology.	from 23 to 25 November 2011	NIRM, KGF	18 officers from different quarries, the Department of Mines & Geology (AP), PRP Exports (TN), POABS Group (Kerala), Mysore Mineral Ltd, (Karnataka), Pallava Granites, Hamsa granites and Anand Granite (AP).
Instrumentation for Tunnels, Caverns and Slopes.	from 12 to 17 December 2011	NIRM, Bangalore	12 participants from DGPCL (Bhutan), DHPC (Bhutan), BMRCL (Bangalore), CEA (New Delhi) and AAR VEE Associates (Hyderabad).
Training Programme on "Rock Mechanics".	from 5th April 2010 to 1st May 2010; and for 75 days till end of March, 2011	Rishikesh, Uttarakhand Bangalore & KGF;	20 engineers and geologists from THDC India Ltd.
Application of Numerical Modelling Techniques.	from 1 to 8 April 2009	Bangalore	10 engineers from THDC India Ltd.
Application of Rock Mechanics Principles to Tunnelling.	from 12 to 18 August 2009	Bangalore	for the executives of Druk Green Power Corporation Ltd., Bhutan
Application of Rock Mechanics in Tunnelling and Under-	from 7 to 10 November 2009	Chuzachen, Sikkim	35 engineers of SEW Infrastructure Ltd.

ground Works.			
Blasting in Surface Mines with Special Reference to Limestone Mines	April, 2009	Chilamkur, Andhra Pradesh	26 officers of the India Cements Limited from all its seven units

Seminars / Symposia Organized by NIRM

The Institute supported several Seminars and Symposium organized by other Institutes. In addition, three of the major events organized by the Institute were :

1. The 6th National Symposium on Rock Mechanics, Bangalore, 15-17 October, 1992.

2. ROCKSITE-99, International Conference on Rock Engineering Techniques for Site Characterization, Bangalore, 6-8 December, 1999.

3. ICUST-2011, International Conference on 'Underground Space Technology, Bangalore, 17-19 January, 2011.

NIRM - Marching Ahead towards the Golden Jubilee

The Institute's research work is of utmost importance to the nation, particularly to the mining, civil and hydroelectric power, nuclear power sectors, railways, rail-metro projects, highways, oil sector. The Institute is also recognized as a Scientific & Industrial Research Organization by the Dept. of Scientific & Industrial Research, Ministry of S&T, Govt. of India. This kind of research work is specialized in nature and needs to be continued in future. Some grey areas in these sectors are to be identified and solved by developing indigenous technology instead of importing technology from abroad.

The high quality services provided by NIRM have found wide acceptance with the industry. With modern equipment and a coherent team of experienced and dedicated Scientists, NIRM combines research activities and consulting services to provide solutions for a wide range of rock engineering problems.

During last twenty-five years, NIRM has carved out a niche in the national arena in the field of rock mechanics and rock engineering by providing solutions to the civil and mining engineering sectors. This is reflected in our exponential growth of external cash flow (ECF) through sponsored R&D and industrial projects.

The Institute has made big strides towards attaining self-sufficiency, which is a key element of our vision. This phenomenal growth reflects the faith shown in our work by the sponsoring industry. Having been encouraged by this response from industry, we have now decided to adopt International Standards in all our works. We have defined our quality policy and objectives to meet the International Standards, and we have obtained the ISO 9001 : 2008 certification.

During the next few years, NIRM proposes to further develop its infrastructure facilities, augment skilled manpower in core areas, and encourage skill development through training. We shall try for collaborative research work with other institutes. We shall strive for the all round development of the Institute, with quality improvement in the overall research output, and to realize the vision of the Institute for a quantum growth as laid out in its Vision document.

Keeping the Roadmap in the sights, and Vision as our target, the Institute has a resolve to achieve still greater heights.

Major Thrust Areas

During the next fifteen years, NIRM proposes to pursue the following major thrust areas:

1) Development of innovative mining methods for optimum exploitation of complex and difficult coal and mineral reserves, and for improvement in production, productivity and quality.

2) Development of innovative excavation and rock fragmentation techniques, through introduction of modern methods of tunnel excavation and controlled blasting.

3) Development of underground space technology for oil and gas storage, and nuclear waste storage.

4) Development of a package for optimum exploitation of mineral deposits, both surface and underground, using improved techniques such as numerical modelling.

5) Development of Information Technology for mining, the use of Virtual Reality Simulation, Expert Systems and Artificial Intelligence, and development of remote monitoring techniques.

Linkages with other National / International Organizations

To maintain the 'best practices in the world', NIRM has R&D collaboration with other advanced research laboratories within the country and abroad. For this the Institute has established linkages and partnership with the following laboratories / organizations :

Name of the Institution	Linkage Envisaged
NATIONAL	
Central Mining & Fuel Research Institute (CIMFR), Dhanbad	Joint research programmes; recently one collaborative project on longwall technology was completed, tow more projects are in proposal stage
Directorate General of Mines Safety, Dhanbad	Research & Development in strata control and method of work
Indian School of Mines, Dhanbad	Post graduate and doctoral students research projects
Indian Institute of Science (IISc), Bangalore	Post graduate and doctoral students research projects
Indian Space Research Laboratories (ISRO)	Academic exchange programmes and training programmes
National Remote Sensing Agency (NRSA), Hyderabad	Academic exchange programmes; joint research projects
Geological Survey of India (GSI)	Collaboration & information sharing; already one project for development of early warning system for landslides is in the pipeline.
National Geotechnical Facility (NGF)	Joint research programme
Industry – mining, civil engineering & infrastructure development	HCL, HZL, MOIL, HGML, UCIL, CIL, SCCL, NHPC, NTPC, THDC, NPCIL, etc. for research and field experimentation
INTERNATIONAL	
Commonwealth Scientific & Industrial Research Organization (CSIRO), Australia	Joint research and exchange programmes
Norwegian Geotechnical Institute (NGI), Norway	Joint research and exchange programmes
National Institute for Occupational Safety and Health (NIOSH), USA	Joint research and exchange programmes

Centres of Advanced Research

It is proposed to establish six Centres of Advanced Research to carry out R&D in the following specialized frontier areas:

Sl. No.	Centres of Advance Research	Areas of Research / Departments
1	Centre for Site Characterization (CSC)	Engineering Geology
		Engineering Geophysics (Electrical & Georadar)

Sl. No.	Centres of Advance Research	Areas of Research / Departments
		Engineering Geophysics (Seismic)
		Geotechnical Engineering
		Engineering Seismology & Micro-Seismics
2	Centre for Testing Services (CTS)	Rock & Material Testing
		Rock Testing
		Rock Fracture Mechanics
		Soil Testing
		Materials Testing
		Non-Destructive Testing
3	Centre for Sustainable Mining (CSM)	Ground Control in Mining
		Method of Work
		Support Design, Pillar Design
		Subsidence Prediction
		Slope Stability Studies
4	Centre for Excavation Engineering (CEE)	Rock Blasting
		Excavation Methods
		Tunnelling Technology
		Tunnel Boring Machines
		Large Underground Caverns
5	Centre for Design & Monitoring (CDM)	Numerical Modelling
		Empirical Design Methodologies
		Instrumentation & Strata Monitoring
6	Centre for Advanced Rock Mechanics Training (CARMT)	Human Resources Development

These Centres will be multi-disciplinary in nature, and will serve as a focal point for industry-driven research. The major objectives of these Centres would be:

- to conduct applied research supporting the technical advances of the mining, civil and construction industry,
- to establish unique partnership between industry and the Institute,
- to perform research of direct benefit to the industry, and
- to transfer the technology directly to the user industries.

Of the above, the Centre for Testing Services has already started functioning within the available resources. The Ministry of Mines have approved the proposal for a one-time grant to upgrade the existing facilities, to augment the existing facilities, and for development of the new Centres of Advanced Research.

Acknowledgement

The Institute is immensely grateful to all those who made it possible for it to reach the Silver Jubilee, and for the wonderful legacy.

The Scientists and Staff of NIRM are thankful to all the Chairmen and Members of the previous and present Governing Bodies, General Bodies, Peer Review and various other Committees, for the guidance provided all through these years.

The achievements made by the Scientists could not have been possible but for the help and support by the various funding organizations, the user industries and the sponsoring clients. We are deeply indebted to them all.

It would be our endeavour to come up to the expectations of all the above and be worthy of them, by achieving greater research output in the coming years.

ORGANIZATIONS ASSOCIATED WITH NIRM

Central Government Ministries / Departments

Ministry of Mines
Central Water Commission
Department of Atomic Energy
Department of Steel
Directorate General of Mines Safety
Ministry of Coal
Ministry of Earth Sciences
Ministry of Environment & Forests
Ministry of Science & Technology
Ministry of Water Resources
Ministry of Railways

State Government Departments & Public Sector Organizations

Airport Authority of India, Chennai (AAI)
Andhra Pradesh Electricity Board
Andhra Pradesh Heavy Machinery and Engineering Limited
Andhra Pradesh Irrigation Department (CAD)
Atomic Minerals Directorate (AMD)
Department of Mines and Geology, Andhra Pradesh
Himachal Pradesh Electricity Board
Kerala State Electricity Board
Krishna Bhagya Jala Nigam Limited
Tamil Nadu Electricity Board
Tamil Nadu Minerals Limited

Metal Mining & Non-Coal Mining Sector

Hindustan Copper Limited
Hindustan Zinc Limited
Hutti Gold Mines Company Limited
Indian Metals and Ferro Alloys Limited
Kudremukh Iron Ore Company Limited
Manganese Ore India Limited
Mysore Minerals Ltd
National Aluminium Company Limited (NALCO)
National Mineral Development Corporation
Uranium Corporation India Limited
Associated Cement Companies Limited
Bharat Gold Mines Limited
Ferro Alloy Corporation Limited, Orissa
Madras Cements Limited

Malabar Cements
Orissa Mining Corporation

Coal Mining Sector

Coal India Limited
Bharat Coking Coal Limited
Central Mine Planning & Design Institute Limited
Eastern Coalfields Limited
South Eastern Coalfields Limited
Western Coalfields Limited
The Singareni Collieries Company Limited

Hydro-power Projects

Allain Dughan Hydroelectric Project, HP
Baglihar Hydro-electric Project, J&K
Baspa Hydro-electric Project, Himachal Pradesh
Chamera Stage-II Hydro-electric Project, HP
Dhauli Ganga Hydro-electric Project, UP
Dibang Multipurpose Project, Arunachal Pradesh
Dul-hasti Hydro-electric Project, J&K
Energy Infratech
Ganvi & Kashang HE Projects, Himachal Pradesh
Ghatghar Pumped Storage Project, Koyna
Gokak Small Hydel Project, Karnataka
Himachal Pradesh State Electricity Board
Indira Sagar Project, MP
Jaiprakash Associates
Jindal Power Limited
Karcham Wangtoo Hydro-electric Project
Koldam HE Project, Himachal Pradesh
Koteswar HE Project, UP
Kulekhani Stage-III HE Project, Nepal
Lakhwar Hydro-electric Project, UP
Larji Hydroelectric Project, Himachal Pradesh
LNJ Bhilwara
Luhri Hydel Project, SJVNL
Malana HE Project, Himachal Pradesh
Mandagere Hydel Scheme, Karnataka
Mangdechhu HE Project, Bhutan
Maniyar Hydel Project, Kerala
Naitwar-Mori Hydroelectric Project, Uttarkhand
Nathpa-Jhakri Hydro-electric Project, Himachal Pradesh
Neria Hydel Scheme, Karnataka
NHPC Ltd
North Eastern Electric Power Corporation Limited (NEEPCO)

NSRS Dam, Srisailam. Govt of Andhra Pradesh
NTPC Ltd
Pala Maneri HE Project, Uttarakhand
Pallivasal Hydro-electric Project, Kerala
Pancheswar Hydro-electric Project, Nepal
Parbarti HE Project, Himachal Pradesh
Pykara Hydro-electric Project, Tamil Nadu
Rampur Hydel Project, SJVNL
Sardar Sarovar Narmad Nigam Ltd, Gujarat
Satluj Jala Vidyut Nigam Ltd, Himachal Pradesh
Sawra Kuddu HE Project, Pabbar Valley Power Corp, HP
Siang Lower Project, NHPC, Arunachal Pradesh
Srisailam Hydro-electric Project, Andhra Pradesh
Tapovan & Loharinag Pala HE Project, THDC
Teesta Hydro-electric Project, Sikkim
Tehri Hydro Development Corporation Ltd
Thottiyar Hydro-electric Project, Kerala
Tungabhadra Dam, Karnataka
Universal Carborundum Ltd
Upper Subansiri HE Project, Arunachal Pradesh
Uri Hydro-electric Project, J&K
Uttarakhand Jal Vidyut Nigam Ltd
Vishnu Prayag Hydro-electric Project, UP
WAPCOS

Infrastructure Development Projects

Engineers India Ltd
Gammon India Ltd
GMR Infrastructure Ltd
Hindustan Construction Company Limited
Indian Strategic Petroleum Reserves Ltd
Karam Chand Thapar Co Ltd
Larsen & Toubro
Mangalore Refineries & Petroleum Ltd
Navayauga Engineering Company
Nuclear Power Corporation of India Ltd
Oil & Natural Gas Commission
POABS Rock Products Pvt. Ltd
RITES
South Asia LPG Co Pvt Ltd
SEW Infrastructure Ltd.
South Korean Engineering Co – KCT JV
Soma Enterprises Ltd
TT-AFCONS JV

International Agencies

China Coal No-5 Construction Limited **(CC5C)**
Commonwealth Scienitific & Industrial Research Organization, Australia
Coyne et Bellier, France
Druk Green Power Corporation, Bhutan
GEOSTOCK, France
L&T Hochtief Joint Venture (Project Seabird)
Mangdechhu HE Project, Bhutan
Nippon Koei, Japan
Norwegian Geotechnical Institute (NGI)
Punatsangchhu HE Project, Bhutan
Rock Mechanics Technology (RMT), UK – now Golder Associates
Shaft Sinkers Mauritius Limited, South Africa
Skanska Civil Engineering AB, Sweden
Tala Hydro-electric Project, THPA, Bhutan

RESEARCH PAPERS PUBLISHED

1990

1. Adhikari G.R, Venkatesh H.S and Raju N.M., (1990) Large scale blasts in underground metalliferous mines – vibration studies, Int. Seminar on Productivity and Mine Mechanisation, Bangalore.
2. Jha P.C., (1990) Seismological approach to the long range rockburst prediction – A case study, Proc. National Symp. Recent Advances in Seismology and their Application, Bangalore/Grouribidanur/KGF.
3. Nagarjan K.S and Shrikant B. Shringarputale, (1990) In-situ stress measurements at Chigargunta mine using hydrofracture technique, IGS Bombay Chapter Workshop on Geotechnical Engg.
4. Nair G. J. and Srinivasan C., (1990) Case study of microseismic date before and after major rockburst in Kolar Gold Fields – Implications to prediction and control", Proc National Symp Recent Advances in Seismology and their Applications, Bangalore/Gouribidanur/KGF (SS3 – 2).
5. Nair G. J, Gupta J.D and Raju N.M., (1990) Subsurface rockburst monitoring system for Kolar Gold Mines, Karnataka, Proc National Symp Recent Advances in Seismology and their Applications, Bangalore/Gouribidanur/KGF (SS3-1).
6. Raju N.M., (1990) Application of rock mechanics for optimization of mine design and conservation of minerals, Proc National Seminar on Recent Developments in Exploration, Exploitation & Conservation of Minerals in India, Bangalore (109 – 113).
7. Raju N.M., (1990) Stoping method and optimisation of mining layout to minimise rockbursts, Proc National Workshop on Safety measures for Rockburst control, 19th March, KGF.
8. Raju N.M., (1990) Strategies for support design in rockburst prone area, Proc National Workshop on Safety Measures for Rockburst Control, 19th March, KGF.
9. Shrikand B. Sringarputale, (1990) Ground stability monitoring systems, Proc. National Workshop on Safety Measures for Rockburst Control, 19th March, KGF.
10. Srinivasan C. and Shrikant B. Shringarputale, (1990) Mine induced seismicity in the Kolar Gold Fields, Gerlands Beitrage zur Geophysik, Leipzig, Volume 99, pp. 10 –20.
11. Srinivasan C., Nair G.J. and Shiva Kumar C., (1990) Microseismic activity in the Glen oreshoot region, Proc. National Symp Recent Advances in Seismology and their Applications, Bangalore/Grouribidanur/KGF (SS – 4).
12. Srinivasan C., Shrikant B. Shringarputale and Raju N.M., (1990) The study of energy released by seismic events in the deeper level workings of Kolar Gold Fields, Proc. National Symp. Recent Advances in Seismology and their Applications, Bangalore/Grouribidanur/KGF (SS – 3).

1991

1. Adhikari G.R., (1991) Experience with sequential blasting machine in limestone quarries, MGMI Paper Session, Ammasandra (September 1, 1991).
2. Adhikari G.R., (1991) Selection and evaluation of hole diameter for bench blasting, The Indian Mining & Engineering Journal, October, 1991 (71-74).
3. Babu Rao Y.V.S. and Dasgupta B., (1991) Discontinum analysis of excavations using distinct element method, Proc. Workshop Numerical Methods in Rock Excavation Design, KGF.

4. Babu Rao Y.V.S, Rao K.R.M, Ramana J.V. and Chandramouli V., (1991) Health monitoring of longwall face equipment using graphical techniques", sent for the Int. Conf. Mine Mechanization, MGMI, Calcutta (held in Jan., 1991).

5. Raju N.M. and Venkateswarlu V., (1991) Ground reinforcement and support techniques in India, Proc. Workshop on Tunnels, Mine Roadways & Caverns, Ooty, 6 – (23-30).

6. Raju N.M., Dasgupta B. and Srikant A., (1991) Geotechnical investigations and design aspects for underground space development, Proc. Indo-US Workshop on Underground Space, New Delhi.

7. Raju N.M., Jha P.C., Shrikant B. Shringarputale, Srinivasan C. and Sivakumar C., (1991) Rockburst research at KGF – Contribution of NIRM, J. Mines, Metals & Fuels – Annual Issue.

8. Ravi G. and Aglawe J.P., (1991) Selection of hardware and software for numerical modeling of mining problems, Proc. Workshop on Numerical Method in Rock Excavation Design, Kolar Gold Fields.

9. Sivakumar C., Raju N.M., Varadaraj S. and Srinivasulu T., (1991) Electronics and computers for monitoring and control of mine roof strata, Proc. Seminar Electronics and Role of ECIL in Mining Sector, Hyderabad.

10. Srikant A., (1991) Calibration of numerical model in rock excavation design, Proc. Workshop on Numerical Methods in Rock Excavation Design, Kolar Gold Fields.

11. Srinivasan C., Nair G.J. and Raju N.M., (1991) Microseismic procursor analysis for seismic events in Kolar Gold Fields, Proc. Acoustic Emission/Microseismic Activity in Geological Materials and Structures, Penn State Univ, USA.

1992

1. Adhikar G.R., (1992) The role of instrumentation in blasting studies, 6th Natl. Symp. on Rock Mechanics Organised by NIRM, Bangalore, October 15-17, 1992.

2. Chaturvedula V.K. and Raju N.M., (1992) The reintroduction of continuous miners to Indian Coal Mines – some relevant issues, on Rock Mechanics Organised by NIRM, Bangalore, October 15-17, 1992.

3. Chaturvedula V.K. and Raju N.M., (1992) Roof bolting in Australian mines and its applicability to Indian conditions, Intl. Symp. on Roof Support Technology – present and future trends, Calcutta, May 708, 1992.

4. Dasgupta S., (1992) Analysis of large caverns using numerical methods, 6th Natl. Symp. on Rock Mechanics Organised by NIRM, Bangalore, October 15-17, 1992.

5. Dasgupta S., Reddy K.N. and Nayak S.R., (1992) Discontinum analysis of rock slopes, Asian regional symp. on Rock Slopes, New Delhi, Dec. 7-11, 1992.

6. Jha P.C. and Raju N.M., (1992) Application of seismology in mines safety (Invited paper), National Symposium on seismology, Organised by Hindi Science Literature council, BARC, Bombay, Feb 11, 1992.

7. Nagaraja Rao G.M., Shivakumar K., Rao M.V.M.S. and Raju N.M., (1992) Rock testing facilities and recent experimental results, 6th Natl. Symp. on Rock Mechanics organised by NIRM, Banglore, Oct. 15-17, 1992.

8. Raju N.M. and Baburao Y.V.S., (1992) Application of cable bolting in effective strata control in thick seam mining. 6th Natl. Symp. on Rock Mechanics organised by NIRM, Banglore, Oct. 15-17, 1992.

9. Raju N.M. and Reddy K.N., (1992) Monitoring of rock slopes, A state of art paper, Asian regional symp. on rock slopes, New Delhi, Dec. 7-11, 1992.

10. Rao M.V.M.S., (1992) Acoustic emission activity and failure precursors in some of the rocks of Koar Gold Mines, 6th Natl. Symp. on Rock Mechanics Organised by NIRM, Bangalore, Oct. 15-17, 1992.

11. Rao M.V.M.S., (1992) Stability monitoring of underground mines using acoustic emission techniques (Invited paper), Natl. workshop on Acoustic Emission, NAWACE-92, Hyderabad, Sept. 1992.

12. Ravi G., Chaturvedula V.K. and Dasgupta S., (1992) Numerical modelling in mine design – a solution or a tools, 6th Natl. Symp. on Rock Mechanics organised by NIRM, Banglore, Oct. 15-17, 1992.

13. Sengupta S., and Chavan A.S., (1992) In-situ stress measurements for design of underground structures, Regional workshop on Rock Mechanics (southern region), Organised by CBIP & ISRM, Cochin, Sept. 16-19, 1992.

14. Shivakumar K. and Nagaraja Rao G.M., (1992) Physico-mechanical properties of rock materials, Regional workshop on Rock Mechanics (southern region), organised by CBIP & ISRM, Cochin, Sept. 16-19, 1992.

15. Shrikant S.B., Sethumadhavan N. and Raju N.M., (1992) Assessment of rockmass response to deep hole drilling and blasting at J-North section, Nudydroog Mine, 6th Natl. Symp. on Rock Mechanics organised by NIRM, Banglore, Oct. 15-17, 1992.

16. Srikant A., (1992) New approaches for the design of large spans in open stopes, 6th Natl. Symp. on Rock Mechanics organised by NIRM, Banglore, Oct. 15-17, 1992.

17. Srikant A., (1992) Numerical modelling for improving recovery from in-situ reserves in underground mines, MGMI paper session, Chavara, Aug. 1992.

18. Srikant A., Venkateswarlu V., Baburao Y.V.S., and Raju N.M., (1992) Rock bolting and cable bolting in hard rock mines, Intl. Symp. on Roof Support Technology – present and future trends, Calcutta, May 7-8, 1992.

19. Venkateswarlu V. and Raju N.M., (1992) Status of longwall gateroad supports and future trends, Intl. Symp. on roof support Technology – present and future trends, Calcutta, May 7-8, 1992.

20. Venkateswarlu V., (1992) Rock Mass improvement, workshop on Rock Mechanics, Cochin Nov. 19, 1992.

21. Venkateswarlu V., Baburao Y.V.S. and Raju N.M., (1992) Design and application of rock reinforcement systems in India, 6th Natl. Symp. on Rock Mechanics organised by NIRM, Banglore, Oct. 15-17, 1992.

1993

1. Adhikari G. R., (1993) Powder factor for blasting in opencast mines, The Indian Mining Engineering Journal, Sept 1993, 33 -39.

2. Jha P.C., Srinivasan C. and Raju N.M., (1993) Area rockbursts in Kolar Gold Fields, The possible attributes, Proc. 3rd Int. Symp. on Rockburst and Seismicity in Mines, Queen's Univ., Ontario, Canada, Aug 16 – 18, 1993, 199-204.

3. Rajan Babu A. and Adhikari G.R., (1993) Tunnel blast design at Maniyar Hydel Project for greater pull and smooth profile, Proc. Natl. Symp. on Drilling and Blasting Kudremukh, Oct 1993, 294-298.

4. Raju N.M., Venkateswarlu V. and Sripad Naik, (1993) Development of roof supports and field trials, Minetech, Vol.14, No.2, 75 – 79.

5. Rao M.V.M.S., (1993) A Status report on the application of acoustic emission and micro-seismic techniques for rock mechanics research in India, Tech. report to AEWG (India), Dec 1993, 29 p.

6. Venkatesh H.S., Adhikari, G.R. and Theresraj A.I., (1993) Reducing production cost through improved blast design, Proc. Natl. Symp. on Drilling and Blasting, Kudremukh, act 1993; 369- 377.

7. Venkateswarlu V. and Raju N.M., (1993) Design of roof supports in coal mines based on geomechnaical classification, Minetech, Vol.14, No.2, 16- 19.

1994

1. Adhikari G.R. and Rajan Babu A., (1994) Controlled blasting in tunnels – Some issues, Journal of the Institution of Engineers (India), Vol. 75, Nov 1994, 56-59.

2. Adhikari G.R., (1994) Opencast blasting trends and techniques in the Indian Mining industry, Journal of Mines Metals & Metals, Nov-Dec 1994, 333-339 and 324.

3. Adhikari G.R., (1994) State-of-the-art in blasthole stemming, Minetech, Vol.15, No.2, Mar-Apr 1994, 56-59.

4. Adhikari G.R., Rajan Babu A., Venkatesh H.S. and Theresraj A.I., (1994) Blast damage assessment for underground structures, Natl. Symp. on Emerging Mining and Ground Control Technologies, BHU, Varanasi, Feb 1994.

5. Adhikari G.R., Yaji R.K. and Raju N.M., (1994) Selection of explosives for surface mines, Minetech, Sep - Dec 1994, 18-24.

6. Chaturvedula V.K. and Bhattacharyya A.K., (1994) Design of yield pillars for improved stability of colliery road ways, Australian Coal Journal.

7. Chaturvedula V.K. and Sripad Naik, (1994) Estimation and evaluation of tunnel wall support - A deformation Measurement approach, Proc. Tunnelling India 94, Natl. Workshop on Tunnelling organised by CHIP, Pune, Feb. 23- 25, 1994, 167- 173.

8. Jha P.C. and Chouhan R.K.S., (1994) Long-range rockburst prediction", A seismological Approach, Int. J. of Rock Mechanics and Min. Sc. Abs., Vol.31, No.1, 71-77.

9. Jha P.C. and Raju N.M., (1994) Fractal patterns of mining-induced seismic events, EGU Annual Symposium, Hamburg, Germany.

10. Jha P.C., Sivakumar C. and Raju N.M., (1994) Blasting induced seismo-acoustic anomalies as a measure of ground stability, Proc. NAWACE-94, IISC, Bangalore.

11. Nagaraja Rao, G.M., Shivakumar, K., Udayakumar S. and Raju N.M., (1994) Thermo- mechanical and microstructural characteristics and behaviour of granites and charnockite, Meeting on Repository Siting and Characterisation Programme, BARC, Bombay, Apr 18-19, 1994.

12. Nagaraja Rao, G.M., Murthy, C.R.L. and Raju, N.M., (1994) Acoustic emission study of thermally treated granite, National Workshop on Acoustic Emission (NAWACE-94), Indian Institute of Science, Bangalore, act 3-12, 1994.

13. Narendar Reddy K, Dasgupta B, Venkateswarlu V. and Nayak S, (1994) Design of soil slopes in an iron ore open pit mine, Proc. Indian Geotech. Conf - IGC-94, Warangal, 415-418.

14. Rao M.V.M.S., (1994) Application of NDT for evaluating the progressive damage in rock under stress, J. Non-dest. Eval. , Vol.13.

15. Reddy K.N. and Venkateswarlu V., (1994) Design methodology for jointed rock slopes – A case study, Proc. Natl. Symp. Emerging Mining and Ground Control Technologies, BHU, Varanasi, Feb 18- 19, 1994, 297 –316.

16. Srinivasulu T., Nagaraja Murthy C., Sivakumar C. and Sastry B.S.R., (1994) Development of low power micro-computer based instruments for underground excavations, Proc. National Symposium on Instrumentation, Karnataka University, Dharwad, No.8-11, 1994.

17. Venkatesh H.S. and Adhikari G.R., (1994) Improvement in fragmentation for an underground gold mine, Explosives Engineering (U.K.), Sep 1994,34-37.

1995

1. Adhikari G.R., (1995) Blasting problems and solutions for surface excavation projects NIRM experience, Journal of Mines, Metals & Fuels, Aug 1995, pp. 212-216 & 239.

2. Adhikari G.R., Venkatesh H.S., Rajan Babu A. and Theresraj A.I., (1995) Air overpressure produced by blasts in surface mines, Minetech, Vol. 16, No. 3&4, May-Aug. 1995, 9-13.

3. Chaturvedula V.K., and Bhattacharya A.K., (1995) Design of yield pillars for improved stability of colliery roadways. Proc. of the Australasian Institute of Mining and Metallurgy. No.2, 1995, pp. 41-46.

4. Chaturvedula V.K., and Naik S., (1995) Subsidence control in multiple seam mining - Some new idea, Proc. First National Conference on Ground Control in Mining, Calcutta. January 12-13, 1995, 307-314.

5. Jha P.C., and Kong F.S., (1995) GPR for mining applications, Norwegian Geotechnical Institute, Norway, Dec 1995.

6. Jha P.C., Sivakumar C., and Raju N.M., (1995) Geomechanics of crown pillar mining, 11th Intl. Conf. on Ground Control in Mining, West Virginia, Aug.1-3, 1995.

7. Narendar Reddy K., Dasgupta B., Venkateswarlu V., and Nayak S., (1995) Role of different methods in the design of slopes. Proc 5th National Seminar Surface Mining, Kharagpur, pp. 4l-49.

8. Sengupta S., Chavan A.S., Joseph D. and Raju N.M., (1995) Performance of in-situ stress monitoring and analysis technique in jointed volcanic rocks of N-W Himalaya with back analysis by numerical modelling, Proc. Int. Symp. on Design and Construction of Underground Structures, New Delhi, Feb 23-25, 1995, 583-592.

9. Sengupta S., Chavan A.S., Joseph D., Raju N.M., (1995) Influence of topography on in-situ stress under a river valley - A case study, Proc. 35th U.S. Symp. on Rock Mechanics, Lake Tahoe, Reno, U.S.A. Jun 4-7, 1995.

10. Sengupta S., Chavan A.S., Joseph, D., Raju, N.M., (1995) Experience with hydraulic fracture stress measuring technique in jointed volcanic rocks of N-W Himalaya, India. Proc. 2nd Int. Conf. on Mechanics of Jointed and Faulted Rock, Tech Inst, Vienna, Austria, Apr 10-14, 1995, 431-436.

11. Shivakumar K., Rao M.V.M.S., Srinivasan C., and Kusunose, (1995) Multifractal analysis of the spatial distribution of. area rockbursts at Kolar Gold Mines”, Int. Journal of Rock. Mech. Min. Sci. U.K.

12. Shivakumar K. and Nagaraja Rao G.M., (1995) Deformability and strength of granite under the influence of stress, temperature, rate of loading and water environment, National Symposium on Management of Radioactive and Toxic Wastes (SMART-95), BARC, Bombay, Mar 20-21,1995.

13. Shridhar Chavan A., Raju N.M. and Srivastava S.B., (1995) Prediction of area instability from mining induced seismicity, Proc. 35th U.S. Symp. on Rock Mechanics, Lake Tahoe, Reno, U.S.A. Jun 4-7, 1995, 533-538.

14. Sitaram N., Narendar K.R., and Venkateswarlu V., (1995) Slope failure in phyllitic clay -A case study”. Proc Indian Geotech Conf, IGC-95, Bangalore, pp. 271-274.

15. Srinivasan C., (1995) Seismic monitoring of rockbursts and underground blastings for assessing the stability of deep mine workings at Kolar Gold Fields, Proc. 17th Annual Seismic Research Symposium on Monitoring at CTBT, Sept 1995, Arizona.

16. Srinivasan C., (1995) Seismological investigation in and around KGF for evaluating the seismic hazard and associated risk following inundation of the mines, Department of Science and Technology, Bhubaneswar, Orissa.

17. Srinivasan C., (1995) Water induced seismicity activity in Kolar Gold Fileds, KGF Mining and Metallurgical Soc!eity, Kolar Gold Fields.

18. Srinivasulu T., (1995) Development of microprocessor based instruments for underground mines, Proc. National Symposium on Instrumentation, Osmaniya University, Hyderabad, pp. 25-28 Sept. 1995.

19. Srinivasulu T., Sudhakar K., and Sivaram Y.V., (1995) A Micro-computer based intelligent remote extensometer for monitoring strata behaviour, Proc. 3rd International Symposium on Mine Mechanisation and Automation, Colorado School of Mines, Golden, Colorado, Jun 12-14, 1995.

20. Venkatesh H.S., Adhikari G.R., and Raju N.M., (1995) Application of high resolution video camera for blast evaluation, Expo '95 Coni Brisbane, Australia, Sept. 1995, pp. 269- 271.

21. Venkateswarlu V., Reddy P.V. and Raju N.M., (1995) Cable bolting as pre-reinforcement for improved productivity in underground mines. Proc Seminar Tech Upgradation in Underground Mining to Meet New Challenges, Nagpur, pp. 50-67.

1996

1. Raju N.M., and Venkateswarlu V., (1996) Rock Mass improvement and support systems. Proc. Int. Coni Recent Advances in Tunneling Tech. (RATT-96), New Delhi.

2. Sengupta S., Joseph D., and Raju N.M., (1996) Topography induced high in-situ stress under a river valley in Himalayas - A case study, Journal of Rock Mechanics and Tunneling Technology, Jan 1996.

3. Shivakumar K., (1996) Role of fractals in rock mechanics, National Workshop on Application of fractals in Earth Sciences, NGRI, Hyderabad.

4. Sivakumar C., Jha P.C., Raju N.M., and Sivaram Y.V., (1996) Development of instrument for in-situ classification of rockmass, Intl. conf. on Instrumentation, IISc, Bangalore, Aug 8-10, 1996.

5. Srinivasan C. and Sagaya Benady, (1996) Spectral analysis of micro seismic signals for prediction of rockbursts, 6th International Conference on AE/MS Activity, Penn, Penn State University, USA, June 1996.

6. Srinivasan C., (1996) Blasting induced seismic events in Kolar Gold Fields, Proc. 18h Annual Seismic Research Symposium, Maryland, USA, Sept. 1996.

7. Srinivasan C., (1996) Prediction of rockbursts and fluid induced events. No.3 and 4 presented at Earth Science Division of Phillips Laboratory, U.S. Air Force, Boston during Sept 1996.

8. Srinivasan C., (1996) Seismic Investigations of Rockbursts. 18h Annual Seismic Research Symposium, Maryland, USA, Sept 1996.

9. Srinivasan C., (1996) Source location of rockbursts in mining environment. Workshop held during I8th Annual Seismic Research Symposium, Maryland, USA, Sept. 1996.

10. Srinivasan C., Rao M.V.M.S., Shivakumar K., and Kusunose K., (1996) Stability Evaluation of Deep Underground Caverns - Field and Laboratory Investigations using micro seismic

and acoustic emission monitoring techniques Interim Report 3 (Oct 94 - Oct 96) Project No. India-Japan S&T collaboration project/93-96.

11. Srinivasulu T., and Sudhakar K., (1996) Development of Microprocessor based Instrument for Microseismic data acquisition and analysis, 96 International Conference on Mining Science and Technology Xuzhou, China. 16-18 Oct. 1996.

12. Srinivasulu T., and Sudhakar K., (1996) Development of Microprocessor based energy calculator for evaluating coal mine roof stability, International Conference on Instrumentation, IISc, Bangalore 8-10 Aug.1996.

13. Srinivasulu T., Sudhakar K., and Venkateswarlu V., (1996) Strata Behaviour in GDK-I0 Inc. Blasting Gallery Panel, SCCL, National Conference on Ground Control in Mining, Calcutta 5th Oct. 1996.

1997

1. Chaturvedula V.K. and Ramalingeswarudu S.V.S.S. (1997) Powered support performance and strata behaviour in a short longwall panel. J. Mines, Metals & Fuels, vol. 45, pp. 274-285.

2. Jayanthu S. et al., (1997) Common complaints during drilling and associated environmental challenges. Proc. National Sem. Engg. Technology in Surface Mining & Environmental Challenges, Mangalore, pp. 158- 161.

3. Jha P.C., Balasubramaniam, V.R. and Raju N.M., (1997) Application of GPR in detecting old water-logged mine workings, 12th International Conference on Applied Geologic Remote Sensing, Colarado, USA, April 1997.

4. Nagaraja Rao G.M., Murthy, C.R.L. and Raju N.M., (1997) Characterization of micro and macro cracks in rocks by Acoustic emission Presented at symposium on Acoustic Emission: Standards and Technology Update, ASTM STP 1353 , January 22-23 , Florida, U .S.A.

5. Raju N.M. and Venkateswarlu V., (1997) Application of rock reinforcement systems for safety in mines. Proc. 27th Int Conf Safety in Mines Res Instts, New Delhi, 1997.

6. Sengupta S., Joseph D., Nagacaj C. and Kac A., (1997) Influence of a fault and a dyke on stress distribution at two project sites in India", Proceedings of the International Symposium on Rock Stress, σ_2, Kumamoto, Japan, 7-10 October, 1997, pp 397 -402. A.A.Balkema, Rotterdam: Eds. K. Sugawara and Y. Obaca.

7. Sivakumar C., Jha P.C., Chandra D., Sivaram Y.V. and Raju N.M, (1997) Application of micro seismic technique for evaluating stability of underground workings, Tunnelling Asia conference, New Delhi, June 20-24, 1997.

8. Sivakumar C. and Srinivasulu T., (1997) Application of Microseismic techniques in evaluating underground working stability - A case study, Tunneling ASIA '97, 2nd International Symposium by International tunneling association.

9. Srinivasan C. and Rao M.V.M.S., (1997) Microseismic monitoring and evaluation of the structural stability of deep underground mines- A candid appraisal - Proc. National seminar on Non-Destructive evaluation for life extension, 11-13 Dec.1997, Hotel Krishna Oberoi, Hyderabad.

10. Srinivasan C., Arora S.K. and Yaji R.K., (1997) Use of mining and seismological parameters as probable premonitors of Rockburst - International Journal of Rock Mechanics, Vol.34, No. 6.pp. 1001-1008.

11. Srinivasan C., Jha P.C. and Raju M.N., (1997) Evaluation of rock stress in the mines of Kolar Gold Fields - A seismological approach, Proc. Int. Symposium on Rock stress Kumamoto/Japan/ pp. 457-462.

12. Srinivasulu T., Sivakumar C., et.al, (1997) Novel Instrumentation System for Monitoring and Evaluating Strata Deformation in Blasting Gallery Workings, International Mining Technology, mining equipment and technology towards 21st century, 7-9 Oct. 1997 China.

13. Srinivasulu T., Sudhakar K., and Venkateswarlu V., (1997) Development and application of low powered micro-computer based continuous strata monitoring system. Proc. 27th Int Conf Safety in Mines Res Instts, New Delhi, 1997.

14. Srinivasulu T., Sudhakar K. and Venkateswarlu V., (1997) Strata Behaviour Monitoring and Stability Evaluation of Large Underground Power House Caverns-A Case study", 2nd International Conference on R&D, Vadodara, 21-24 Oct.1997.

1998

1. Jayanthu S., (1998) Advanced instrumentation for study of strata behaviour during extraction of pillars in thick coal seams. Workshop on Advances in Mining Engineering, Golden Valley Instt of Engg, Kolar Gold Fields, 3-4 July 1998.

2. Jayanthu S., (1998) Trend of convergence during extraction of pillars in thick coal seam - A novel methodology for its interpretation. Workshop on Advances in Mining Engineering, Golden Valley Instt of Engg, Kolar Gold Fields, 3-4 July 1998.

3. Jayanthu S., et al., (1998) A critical study of strata behaviour during extraction of pillars in a thick coal seam. Proc 17th Int Conf on Ground Control in Mining, West Virginia University, USA, 4-6 Aug 1998.

4. Jayanthu S., Patnayak S., Reddy C.D., Venkateswarlu V. and Raju N.M., (1998) Strata control by cable bolting in thick seam containing clay bands. Proc. National Sem. "Indian Mining Industry : Problems & Prospects", Chandrapur.

5. Jayanthu S., Venkateswarlu V. and Raju N.M., (1998) Effectiveness of cable bolting in development galleries of a thick coal seam". National Seminar on Outlook for Fossil Fuels and Non-metallic Mining and Mineral based Industries (FOSMIN-1998.), Chennai, 20-21 Aug 1998.

6. Patnayak S. and Sastry B.S., (1998) A technique for locating critical circular slip surface in homogenous ground. Int Seminar OPENCAST' 1998. Calcutta, July. 1998. pp. 127- 141.

7. Rajan Babu A., Balachander R. and Adhikari G.R., (1998) Improved blast designs for railway tunnel at Nandyal, National Seminar on Global Mining in 2000 and beyond in Indian Context, Kanyakumari, 10-11, Apr. 1998. Pp. I-24 to I-31.

8. Sengupta S., (1998) In-situ stress determination-an appraisal of its significance in water resources and mining projects, Proc. Golden Jubilee Conference IGC-1998. New Delhi 7-10 Dec 1998.

9. Sengupta S., Joseph D., Nagaraj C. and Kar A, (1998) Stress perturbation near two fault zones in Himalayas-field measurements and numerical simulation", Proceedings of the Third International Conference on Mechanics of Jointed and Faulted Rock-MJFR-3, Vienna, Austria, 6-9 April, 1998, pp 83-88. A. A. Balkema, Rotterdam: Ed. Hans- Peter Rossmanith.

10. Srinivas A., Chaturvedula V.K., Naik S., and Raju G.D., (1998) Performance improvement of the longwall gate road support system: A case study. Proc. National Sem. "Indian Mining Industry : Problems & Prospects", Chandrapur.

11. Srinivasan C., Sivakumar C., Varadaraj S., Vijayakumar A., Sagaya Benady and Willy Y.A., (1998) A Regional Seismic Network for Monitoring Instability of Water Inundated Deep Underground Mining Excavations at Kolar Gold Fields - Proc. 11th Symposium on Earthquake Engineering, Roorkee, 17-19, Dec 1998.

12. Srinivasan C., Rao M.V.M.S., Sagaya Benady and Vijayakumar A., (1998) Fluid Induced Seismicity in Champion Reef Mine (1998.) – "Second Meeting of Asian Seismological

Commission and Symposium on Earthquake Hazard Assessment and Earths Interior Related Topics", NGRI, Hyderabad, 1-3, Dec 1998.

13. Srinivasulu T. and Srinivasu Maka, (1998) Role of microprocessor based instrumentation systems for effective strata behaviour monitoring and evaluation", Proc. of National Seminar on Outlook for Fossil Fuels, Non-Metallic Mining and Mineral Based Industries, Anna University, Chennai, 20-21, Aug 1998.
14. Srinivasulu T., Sudhakar K. and Srinivasu Maka, (1998) Development of micro - processor based strata logger for underground mining application, Proce. of National Symposium on Instrumentation (NSI-23), BITS, Mesra, Ranchi, 7 -10, Oct 1998.
15. Subrahmanyam.D.S., (1998) Geological and Mining aspects of commercial granites in India, FOSMIN National seminar, Anna University, Chennai, 20-21 Aug 1998. pp. 19-20.
16. Venkatesh H.S., Adhikari G.R. and Theresraj A.I., (1998) In-the-hole detonation velocity measurement - a case study". National Seminar on outlook for Fossil fuels & Non-Metallic Mining and Mineral Based Industries (FOSMIN -1998.), Chennai, Aug 20-21 pp. 93-99.
17. Venugopal Rao R. and Kameswara Rao N.S.V., (1998) Time Domain Analysis of Flexible foundations using Lanczos Vectors", Journal of Geotechnical and Geoenvironmental Engineering of American Society of Civil Engineers, Vol. 124, No.9, Sep 1998. pp 830-839.

1999

1. Adhikari G.R., (1999) Studies on Flyrock at limestone quarries, Rock Mechanics and Rock Engineering, Vol. 32, No.41, 1999, 291-301.
2. Adhikari G.R., (1999) Burden calculations for partially changed blast design conditions, International Journal of Rock Mechanics and Mining Sciences, Vol. 36, No.2, 1999, pp. 253-253.
3. Adhikari G.R., (1999) Performance evaluation on important criterion for explosives selection, The Journal of Explosives Engineering, Jul-Aug, 1999, pp. 40-45.
4. Adhikari G.R., (1999) Selection of blasthole diameter for a given bench height at surface mines, International Journal of Rock Mechanics and Mining Sciences, Vol. 36, No.6, 1999, pp. 843-857.
5. Adhikari G.R., (1999) Burden calculation for partially changed blast design conditions, International Journal of Rock Mechanics and Mining Sciences., Feb 1999, pp. 253-256.
6. Adhikari G.R., and Ghose A.K., (1999) Various approaches to blast design for surface mines, Journal of Mines, Metals & Fuels, Jan-Feb, 1999, pp. 24-30.
7. Adhikari G.R., Rajan Babu A. and Balachander R. (1999) Blast designs for the excavation of a power house cavern at Srisailam. The Indian Mining & Engineering Journal, Jun 1999, pp. 31-36.
8. Adhikari G.R., Rajan Babu A., Balachander R. and Gupta R.N., (1999) Application of rock mass quality for blasting in large underground chambers. Tunneling and Underground Space Technology, Vol.14, No.3, pp. 367-375.
9. Adhikari G.R., Theresraj A.I. and Balachander R., (1999) Controlled blasting for site grading at MRPL, Journal of Mines, Metals & Fuels, Jan-Feb, 1999, pp. 45-52.
10. Adhikari G.R., Theresraj A.I., Balachander R. and Gupta R.N., (1999) Determination of controlled blast design parameters for construction of a small hydel project near the existing dam, Proceedings of the International Conference on Rock Engineering Techniques for Site Characterisation, Hocksite-99, Bangalore, Dec 6-8, 1999, pp. 587-593.

11. Jayanthu S., (1999) Application of rock mechanics for improvement of productivity in thick coal seams - An appraisal. Proc Platinum Jubilee Symp. on Improvement of Productivity in Mining (PJSPIM '99), Varanasi, 29-30 Jan 1999.
12. Jayanthu S., Srinivas A., Damodara Reddy C. and Gupta R.N. (1999) Caveability of roof rocks during extraction of pillars in a thick coal seam Indian Mining & Engineering Journal - Special Issue on Mining Research in India -Jun 1999, pp. 19- 22.
13. Jayanthu S., Srinivas A., Damodara Reddy C. and Gupta R.N. (1999) Rock mass characterization for understanding caveability and suppol1 requirements in longwall and pillar extraction practices. Proceedings of the International Conference on Rock Engineering Techniques for Site Characterisation, Rocksite'99, Bangalore, Dec, 6-8, 1999, pp. 421-426.
14. Jha P.C., Balasubramaniam V.R. and Sivaram Y.V. (1999) Site Characterisation for location of oil storage tanks - a case study" Proceedings of the International Conference on Rock Engineering Techniques for Site Characterisation, Rocksite'99, Bangalore, Dec 6-8, 1999, pp. 255-262
15. Nagaraj C. and Venkateswarlu V., (1999) Evaluation of the performance of large underground caverns - Some case studies. Proceedings of the Workshop on Rock Mechanics & Tunnelling Techniques, CBIP. Shimla, Apr 14-17, pp. 226- 234.
16. Nagaraja Rao G.M. and Murthy C.R.L. (1999) Acoustic Emission Monitoring and Ultrasonic C-scan Imaging of Microcrack Damage Due to Thermal Exposure, Proceedings of the International Conference on Rock Engineering Techniques for Site Characterisation, Rocksite'99, Bangalore, Dec 6-8, 1999.
17. Patnayak S., (1999) Design of waste embankments - A review. Journal of Mines, Metals & Fuels, vol 47, no.11 , Nov 1999, pp. 317-321
18. Patnayak S., (1999) Slope stability investigations for a iron ore mine under different pore water pressure conditions. Journal of Mines, Metals & Fuels, vol. 47. no.11 , Nov 1999, pp. 370-374
19. Rajan Babu A. and Subrahmanyam D.S., (1999) Geological, geotechnical and geophysical investigations for characterising dimensional stones, Proceedings of the International Conference on Rock Engineering Techniques for Site Characterisation, Rocksite'99, Bangalore, Dec, 6-8, 1999.
20. Reddy M.N., Venugopala Rao R. and Sripad Naik (1999) Application of rock mechanics for optimum extraction of ore reserves at Khetri copper mine, HCL". Proceedings of the Workshop on Rock Mechanics & Tunnelling Techniques, CBIP, Shimla, Apr 14-17, pp. 192- 201
21. Sengupta S., (1999) Measurement of In-situ stress around Lakhwar Hydro-electric power project and assessment of impact of stress at Power House location, Workshop on Rock Mechanics & Tunnelling Techniques, CBIP, Shimla, Apr 14-17.
22. Sengupta S., Abir Kar, Nagaraj C. and Joseph D., (1999) Recommendations for support at pressure tunnel of Dul-Hasti Hydro-electric power project, Jammu & Kashmir, Proceedings of the International Conference on Rock Engineering Techniques for Site Characterisation, Rocksite'99, Bangalore, Dec 6-8, 1999, pp. 129-133.
23. Sivakumar C., Srinivasan C., Arora S.K. and Benady S., (1999) Application of microseismic technique for ground stability assessment", Proceedings of the International Conference on Rock Engineering Techniques for Site Characterisation, Rocksite'99, Bangalore, Dec, 6-8, 1999, pp. 263-269.
24. Srinivasan C., Arora S.K. and Benady S. (1999) Precursory monitoring of impending rockbursts in Kolar gold mines from microseismic emissions at deeper levels, International Journal of Rock Mechanics and Mining Sciences Vol.36, No.7, pp. 941-948.

25. Srinivasulu T., Sudhakar K., Sivakumar C. and Gupta R.N., (1999) Development of low cost deformation logger for underground mining applications, Proce.of National Seminar on Practices & Prospects of Mining Industry in Central India, RKN, Nagpur, 2^{nd} Jan 1999.

26. Srinivasulu Tadisetty and Gupta R.N., (1999) Development and application of Micro-controller based rate of convergence monitoring system - A Case Study, 9th International Symposium on Rock Mechanics, Paris, Aug 25-28, 1999.

27. Srinivasulu Tadisetty and Gupta R.N., (1999) Development of automated data acquisition system for calibrating transducers, International Conference on Standard Laboratories, Colorado, USA, Jul 11-15, 1999.

28. Srinivasulu Tadisetty and Gupta R.N., (1999) Small Expert system for effective longwall operations, International Conference on Management of Mining Machinery, Calcutta, Jul 8-10, 1999

29. Srinivasulu Tadisetty and Gupta R.N., (1999) The information Superhighway - Impact on Rock Mechanics Instrumentation, International Conference on Mining-Challenges of the 21st Century, New Delhi Nov 25-27, 1999

30. Srinivasulu Tadisetty and Gupta, R.N., (1999) PC based on-line Condition Monitoring System for Evaluating longwall Powered Supports Performance, National Symposium on Mining Machinery, Indian School of Mines, Dhanbad, Nov 26-27, 1999

31. Srinivasulu Tadisetty, Gupta R.N. and Maka S., (1999) Development of Low Cost Deformation Logger for Mining Applications, National Seminar on Practices and Prospects of Mining Industry in Central India, Nagpur, Jan 2,1999

32. Sripad and Venugopala Rao R., (1999) Subsidence predictions using discontinuum models for longwall excavations at Singareni Collieries", Symposium on Productivity improvements in Mining industry, 1999, BHU, Varanasi, 29-30, Jan 1999.

33. Venkatesh H.S. and Narasimha Rao G.V., (1999) Economical approach for safe blasting in mines - A case study, Proceedings of the International Conference on Rock Engineering Techniques for Site Characterisation, Rocksite '99, Bangalore, Dec 6-8, 1999, pp 595 - 599.

34. Venkatesh H.S., Bhatawdekar R.M., Adhikari G.R., and Theresraj A.I., (1999) Assessment and mitigation of ground vibrations and flyrock at a limestone quarry, 25^{th} Annual Conf. on Explosives and Blasting Technique, ISSE, Nashville, Tennessee, USA, Feb 1999.

35. Venkateswarlu V. and Raju N.M., (1999) Development of roof bolting equipment for coal mines in India. Proceedings of the National Seminar on Mining Machinery - Present Status & Future Developments, Indian School of Mines, Dhanbad, Nov 26-27, 1999, pp. 110- 113.

36. Venkateswarlu V., Nagaraj C., Doraswamy Raju G. and Damodara Reddy C., (1999) Rock mechanics instrumentation for ground stability evaluation - Some case studies, Proceedings of the International Conference on Rock Engineering Techniques for Site Characterisation, Rocksite'99, Bangalore, Dec, 6-8, 1999, pp. 65-73

37. Venkateswarlu V., Reddy C.D., Bhaskar Rao B., and Sudhakar Rao N., (1999) Innovative technique of cable bolt installation. Minetech, vol. 20, no.1 pp. 41 - 44.

38. Venugopal Rao R., and Kameswara Rao N.S.V., (1999) Dynamic analysis of pile foundations in time-domain using lanczos Vectors, Journal of Computers and Geotechnique, vol. 24, No.4, Aug 1999, pp 297-322.

39. Venugopal Rao R., Sripad Naik and Gupta R.N., (1999) Discontinuum analysis and support design of road tunnels - A Case study. Proceedings of the 3rd International Conference on Advances of Computer Methods in Geotechnical & Geo-environmental Engg, Moscow, Feb 1-4, 2000, pp. 141 -150.

40. Venugopal Rao R., Sripad Naik and Reddy M.N., (1999) Stress analysis and design of support system for Bhatan tunnel of Mumbai-Pune Expressway". Proceedings of the

Workshop on Rock Mechanics & Tunnelling Techniques, CBIP, Shimla, Apr 14-17, pp. 180 -191

41. Venugopala Rao R., (1999) Dynamic Soil Structure Interaction Analysis Using Lanczos Vectors With Adaptive Time Integration Technique, International Journal of Numerical Analysis methods in Geomechanics, vol 23, 1999.

2000

1. Adhikari G.R. (2000) Empirical methods for the calculation of the specific charge for surface blast design, FRGBLAST- International Journal of Blasting and Fragmentation, Vol. 4, No. 1, 2000, 19-33.

2. Arora S.K., Willy Y.A., Srinivasan C. and Benady S., (2000) Local seismicity and near-field attenuation of Ground Motion due to Rockbursts in Kolar Gold Mining Region" – International Journal of Rock Mechanics and Mining Sciences.

3. Jayanthu S. and Das T.K., (2000) Impact of stress distribution during extraction of pillars in a cola seam – A case study. J. Mining, Metall. & Fuels, vol. 48, no. 3 & 4 (March - April, 2000), pp. 45 – 50.

4. Jayanthu S., Atul Gandhe and Gupta R.N., (2000) Dealing with pillaring in adverse roof conditions under high horizontal stress fields. J. Mining Engrs, vol. 2, no. 5, pp. 10 – 18.

5. Jayanthu S., Gupta R.N., Mitra S.K., Sibbal S.J. and Mozumdar T.K., (2000) Use of modern techniques for improving safety during depillaring under high horizontal stress fields. Proc. National Seminar on Health & Safety in Mining, Nagpur (26-27 Sept., 2000), pp. 75 – 89.

6. Jayanthu S., Atul Gandhe and Gupta R.N., (2000) Technology management for absorption of innovative trends in roof supports of underground coal mines. Proc Int Conf Tech. Management in Mining, Processing & Env., Kharagpur (1-3 Dec., 2000), pp. 35 – 48.

7. Jayanthu S., Gupta R.N. and Singh D.P., (2000) Traditional practices to innovative technologies in the new millennium for extraction of coal pillars by underground mining. Proc. National Seminar on Mining in the New Millennium, Hyderabad (10-11 Nov., 2000), pp. 63 – 74.

8. Jayanthu S., Jain R., Atul Gandhe and Gupta R.N., (2000) Environmental pollution due to underground coal mining - An appraisal. Proc Seminar on Environmental Pollution and its Effects on Human Health, KGF (26 Nov., 2000).

9. Jayanthu S., Srinivas A. and Damodara Reddy C., (2000) Technological measures for eco-friendly underground environment during exploitation of thick coal seams. Proceedings of the National Seminar on People and the Mining Industry - the Future, Jodhpur, Jan 24-25, 2000, pp. 172-180.

10. Jayanthu S., Venkateswarlu V. and Damodara Reddy C., (2000) Behaviour of rock mass reinforced with roof bolts and cable bolts in development and depillaring workings. Proceedings of the National Symposium on Rock Mass Reinforcement, Varanasi, Jan 28-29, 2000.

11. Narasimha Rao G.V. and Gupta R.N., (2000) Assessment of damage due to blasting, Proceedings of the National Seminar on Drilling and Blasting for the Next Millennium, DrillBlast-99, Bhubaneshwar, Jan 16-18, 2000, pp. 84-86.

12. Rajan Babu A., Subrahmanyam D.S. and Gupta R.N., (2000) Performance improvement in dimensional stone quarrying through affordable scientific approach – A case study, International conference on Technology Management for Mining, Processing and Environment (TMMPE – 2000) at IIT Kharagpur. pp 108-115, 2000.

13. Rajan Babu A., Subrahmanyam D.S., Chattopadhyay J. and Balachander R., (2000) Improving recovery and productivity in a granite quarry through scientific approach - A case

study, Proceedings of the National Seminar on Drilling and Blasting for the Next Millennium, DrillBlast-99, Bhubaneshwar, Jan 16-18, 2000, pp. 184-189.

14. Rao M.V.M.S., Srinivasan C., Shivakumar K. and Kusunose K., (2000) A Fractal Approach to the Study of Microseismicity Associated With Rockbursts in Deep Mines, Journal of Mines, Metals and Fsuels, vol. 48, Nos 1 & 2, Jan-Feb, 2000, pp. 8-15.
15. Sengupta S., Joseph D., Nagaraj C. and Gupta R.N., (2000) Stress perturbation - A tool to locate the presence of major geological structures ahead of excavation a case study. Workshop on “Challenges due to Geological Surprises in Water Resources Development Project” Organised by CWC, New Delhi.
16. Srinivasan C., Sagaya Benady and Sivakumar C., (2000) Fluid induced seismicity in Kolar Mining Region. Proc. On the Workshop on “Dam Safety, including instrumentation of Dams” 15-17, November 2000, Trivandrum.
17. Srinivasulu Tadisetty and Gupta R.N., (2000) Development and Application of Micro-controI1er based Remote Data Acquisition System for Underground Mining Applications, National Symposium on Instrumentation, Goa University, Goa, Feb 2-5, 2000.
18. Srinivasulu Tadisetty and Gupta R.N., (2000) PC based Condition Monitoring System, The Indian Mining & Engineering Journal, vol. 30, no.2, Feb 2000, pp. 23-24.
19. Srinivasulu Tadisetty and Gupta R.N., (2000) Development and application of wireless data logger based on networking for continuous monitoring of underground longwall mining machinery condition, Technical Conference on Measurement and Automation, 19 Oct., 2000 Bangalore.
20. Srinivasulu Tadisetty and Gupta R.N., (2000) Development and application of intelligent data acquisition and analysis system for double section BG workings - A case study, Silver Jubilee Conference on Instrumentation, 8-11 Nov, 2000, Indian Institute of Sciences, Bangalore.
21. Srinivasulu Tadisetty and Gupta R.N., (2000) Development of high pressure monitoring system, Silver jubilee conference on instrumentation, 1-3 Dec., 2000, Indian Institute of Sciences, Bangalore.
22. Srinivasulu Tadisetty, Gupta R.N. and Srinivasu Maka (2000) Internet based data acquisition system for effective longwall operations, International Conference on Technology Management for Mining, Processing and Environment, 1-3 Dec.2000, Indian Institute of Technology, Kharagpur.
23. Srinivasulu Tadisetty, Gupta R.N. and Maka S., (2000) Development of Intelligent Closure Detector, National Symposium on Intelligent Measurement and Control, Anna University, Chennai, Feb 25-26, 2000 .
24. Sripad Naik, Shende F.P. and Venugopala Rao R., (2000) Performance improvement of roof support system in longwall gate roads. Proc. Intl. Conf. Tunnels & Underground Structures, Singapore (26-29 Nov., 2000).
25. Sripad Naik, Venugopala Rao R. and Gupta R.N., (2000) Analysis of subsidence behaviour using discontinuum models for underground coal excavations. Proceedings of the 3rd International Conference on Advances of Computer Methods in Geotechnical & Geo-environmental Engg, Moscow, Feb 1-4, 2000, pp. 437- 443.
26. Subrahmanyam D.S. and Rajan Babu A., (2000) Role of geological and geotechnical investigations for the recovery improvement in dimensional stone quarrying, Proceedings of the National Workshop on Safety & Technology in Marble Mining and Processing in New Millennium, Udaipur, pp 39-43.
27. Subrahmanyam D.S., Gupta R.N. and Dominic Xavier S., (2000) A Study of existing practices of block splitting in dimensional stone quarrying, Journal of Mines, Metals & Fuels, June-July, pp 162-165, 2000.

28. Swapan Kumar Mohanty, Rajan Babu A., Nagaraja Rao G.M. and Gupta R.N., (2000) Application of Laboratory rock mechanics investigations for characterisation of dimensional stone granite for their global marketability. The Indian Mining & Engineering Journal December 2000, pp. 45-47

29. Theresraj A.I., Balachander R., Adhikari G.R. & Gupta R.N., (2000) Improving blasting efficiency for a tunnel excavation through modified blast designs and feedback, Proceedings of the National Seminar on Drilling and Blasting for the Next Millennium, DrillBlast-99, Bhubaneshwar, Jan 16-18, 2000, pp. 184-189.

30. Venkatesh H.S. and Adhikari G.R., (2000) Impact of mining on environment, “Seminar on Environmental Pollution and its Impact on Human Health, organised by Environmental and Human Care Society of India, Kolar Gold Fields, December 2000.

31. Venkatesh H.S., Adhikari G.R. and Theresraj A.I., (2000) Laser profiling survey system - A handy tool for optimisation of blast design, Proceedings of the National Seminar on Drilling and Blasting for the Nex1 Millennium, DrillBlast-99, Bhubaneshwar, Jan. 16-18, 2000, pp. 38-41.

32. Venkateswarlu V., (2000) Development of mobile drilling equipment for mechanized roof bolting operations in coal mines. Minetech, vol. 21, no. 3 & 4 (May-August, 2000), pp. 50 – 54.

33. Venkateswarlu V., Nagaraj C. and Damodara Reddy C., (2000) ntroduction of fast roof bolting technology in Indian coal mines. Proceedings of the National Symposium on Rock Mass Reinforcement, Varanasi, Jan. 28-29, 2000.

2001

1. Adhikari G.R., (2001) Blast design methodology for surface mines: An integrated approach to optimization, The Journal of Explosives Engineering, July/August & Sept./Oct. 2001, Part 1 in July/August 2001, pp. 40-42 and Part 2 in September/October 2001, pp. 36-40.

2. Adhikari G.R., Balachander R., Theresraj A.I. and Gupta R.N., (2001) All under control, Tunnels & Tunnelling International, September, 2001 pp. 20-22.

3. Adhikari G.R., Balachander R., Theresraj A.I. and Gupta R.N., (2001) Controlled blasting for removal of concrete plugs in draft tube tunnels at Sardar Sarovar Project, FRAGBLAST, International Journal for Blasting and Fragmentation, vol 5, no. 1, pp 221-234.

4. Arora S.K., Willy Y.A., Srinivasan C. and Benady S., (2001) Local Seismicity and Near - Field Attenuation of Ground Motion due to Rockbursts in Kolar Gold Mining Region, International Journal of Rock Mechanics and Mining Sciences, 38 (2001), 711-719.

5. Arun Kumar Das, Srinivasulu Tadisetty and Gupta R.N., (2001) Development trends in maintenance engineering for longwall mining machinery, National Seminar on Maintenance Engineering – The Recent Trends, Jan.31st – Feb.1st, 2001, Indian School of Mines, Dhanbad

6. Dewangan P., Mishra A.K, and Gupta R.N., (2001) Parameters influencing blast induced ground vibration - A Review - National Seminar on ROCKFRAG - 01, February 14-15, 2001.

7. Jayanthu S. & Gupta R.N., (2001) Characterization of strata around coal mine roadways supported by roof bolts and cable bolts. Proc. Int. Symp. Rock Bolting (6-7 June, 2001), Aachen, Germany.

8. Jayanthu S, Atul Gandhe and Gupta R.N., (2001) Strata behaviour during undermining in multiple coal seams. J of Mines, Metals & Fuels, vol. 49, no. 12 (December, 2001), pp. 449-453.

9. Jayanthu S, Atul Gandhe, Venkateswarlu V and Gupta R.N., (2001) Strata behaviour in a Blasting Gallery panel during extraction of bottom section pillars at greater depths”. The Indian Mining & Engg. J, (September-2001), pp. 19 - 23.

10. Jha P.C., Balsubramaniam V.R. and Sandeep N, (2001) Experience with Step Frequency GPR in mapping stratigraphy for canals, International Con. on “GPR in Sediments : Applications and Interpretations”, August 20-21, 2001, London.

11. Mishra A.K. and Gupta R.N., (2001) New approach of precision blasting, National Seminar on ROCKFRAG - 01, February 14-15, 2001.

12. Rajan Babu A. and Gupta R.N. (2001) Site-characterisation for determination of the block geometry and splitting direction in granite stone quarrying, National seminar on Rock Fragmentation ROCKFRAG-01, at Institute of Technology, Banaras Hindu University, Varanasi. 2001.

13. Rajan Babu A. and Gupta R.N., (2001) Classification of granite quarries – A base for technology management” Journal of Mines, Metals & Fuels, Aug-Sept 2001, pp 322-324.

14. Rajan Babu A. and Gupta R.N., (2001) Initiation Sequence For Primary Block Splitting In Granite Quarrying, Journal of the Indian Mining & Engineering, May-June 2001, pp 41-45.

15. Rajan Babu A., Swapan Kumar Mohanty and Behera A., (2001) Granite quarrying – Management, Utilisation and Disposal of waste, National Souvenir on Small Scale Mining, Jodhpur, March 5-6, 2001.

16. Rajan Babu, A. and Gupta R.N., (2001) Charge strength vis-à-vis charge distribution for block splitting in dimensional stone quarries” Journal of the Indian Mining & Engineering. March 2001, pp 15-21.

17. Rao M.V.M.S., Kumar A., Murthy, D.S.N., Rao G.M.N., Udayakumar S. and Mohanty S.K., (2001) Deformation and Failure Behaviour of Deccan Rhyolites Under Unconfined Stress: An Experimental Study”, The Journal of Indian Geophysical Union, vol. 05, no. 02, September 2001.

18. Sengupta S., Subrahmanyam D.S., Joseph D. and Gupta R.N., (2001) Stress perturbation due to the presence of suspected geological discontinuity at the proposed desilting chamber at Vishnuprayag hydroelectric project – A case study. Symposium on Advancing Rock mechanics Frontiers to Meet the Challenges of 21st Century, New Delhi, Organised by ISRM & CBIP.

19. Sengupta S., Subrahmanyam D.S., Joseph D. and Gupta R.N., (2001) Hydrofracture stress measurement at the proposed powerhouse and its use in the design of powerhouse at Vishnuprayag hydroelectric project -A case study. Workshop on “Rock Mechanics and Tunneling Techniques” Kathmandu, Nepal, organised by CBIP

20. Srinivasan C., Willy Y.A. and Benady S. (2001) Rockburst Seismic Intensity Attenuation Model for Kolar Gold Fields Hard Rock Mining Region, Rasim, Proc. On Rockburst and Seismicity in mines, September, 2001, South Africa.

21. Srinivasulu Tadisetty and Gupta R.N., (2001) Development of PXI based real time system for monitoring of various parameters of a Longwall powered support. National Seminar on Advances in Instrumentation, Jan. 29-31, 2001, Central Scientific Instruments Organisation, Chandigarh

22. Srinivasulu Tadisetty, Srinivasu Maka and Gupta R.N., (2001) Modeling of Geo-Mechanical behavior of Underground Mine workings by biased Trigonometric series, International Conference on Trends in Industrial Measurements and Automation, August 17-19, 2001 Chennai

23. Venkatesh H.S., Adhikari G.R. and Gupta R.N. (2001) Blast designs for canal excavation under high tension power lines, Indian Journal of Power and River Valley Development, January-February 2001, pp. 13-17.

24. Venkatesh H.S., Adhikari G.R., Theresraj A.I. and Gupta R.N., (2001) Improvement of fragmentation at a Limestone Mine, DGMS Centenary Seminar on Techno Economics of Surface Mining In Present Scenario, 29 - 30 Dec. 2001, Chennai,

2002

1. Adhikari G.R., Balachander R., Verma H.K. and Gupta R.N. (2002) Excavation of turbine pits for a hydroelectric project- a case study, Journal of Rock Mechanics and Tunnelling Technology, Vol. 8, No. 2, 2002, pp.127-139.

2. Adhikari G.R., (2002) Advances in Drilling and blasting in surfaces and underground applications, Engineering Staff College of India Campus, Hyderabad, (Invited talk) Oct 2002.

3. Adhikari G.R., Venkatesh H.S. and Gupta R.N. (2002) Prediction and control of air overpressure due to blasting, Mining Engineers' Journal, July 2002, pp. 9-13.

4. Balachander R., Adhikari G.R. and Gupta R.N. (2002) Excavation of draft tube tunnels for Sardar Sarovar Project, Proc. INDOROCK, New Delhi, November 28-29, 2002, pp. 253-259.

5. Ghosh G.K., Srinivasan C., Benady A.S., Sivakumar C. and Behera P.K., (2002) Study of background noise and correlation behaviour of seismic noise signal at Kolar Gold Mining Area using Broad Band Seismometer". Indian Geophysical Union. India, vol. 6, no I, January, 2002.

6. Jayanthu J., (2002) Variation of vertical stress during extraction of pillars in a thick coal seam". Mining Engineering Journal, vol. 4, no. 5, pp. 8 – 16, December, 2002.

7. Jayanthu J, Atul Gandhe and Gupta R.N. (2002) Extraction of pillars in multiple coal seams – Problems and issues. Mining Engineers' Journal, vol. 4, no. 2, pp. 7 – 9.

8. Jayanthu J., Singh S.K., Kaushik A.K. and Venkateswarlu V., (2002) Application of rock mass classification systems for understanding stability of jointed rock slopes in opencast mines. Mining Engineers' Journal, vol. 4, no. 3, pp. 9 - 13.

9. Jha P.C., Balasubramaniam V.R., Sandeep N., Gupta R.N. and Sivaram Y.V., (2002) Evaluating stability of excavations by borehole GPR profiling : a case study, ISRM Regional Symposium, New Delhi, September 2002.

10. Jha P.C., Balasubramaniam V.R., Sivaram Y.V., Gupta R.N. and Sandeep N., (2002) Engineering geophysical investigations for evaluating stability of excavations and foundations in hydroelectric projects, Geotechnique-2002, CMPDI, Ranchi, June 8-10, 2002.

11. Jha P.C., Balasubramanyam V.R., Sandeep N. and Sivaram Y. V., (2002) Mapping of barriers in coal mines: Some experiences with SFR, February 10-14, 2002, SAGEEP-2002, Las Vegas, USA.

12. Mohanty S.K., Rajan Babu A., Rao G.M.N. and Gupta R.N., (2000) Laboratory Rock Mechanics Investigations for Technical Evaluation of Dimensional Stones", Seminar on Geology, Mining – Mine Safety, Environment – Ecology & Rock Mechanics, Bangalore, February 07, 2002.

13. Nagaraja Rao,G.M. and Murthy, C.R.L., (2002) Study of Effect of Strain rate on Micro and Macro Crack Development in Granite by Acoustic Emission, NAWACE 2002, held on 18-19th October 2002, SHAR Center, Srihraikota.

14. Rajan Babu A., Behera P.K. and Gupta R.N., (2002) Influence of Joints on Block Splitting – Some Logistic Considerations" Seminar organised by Department of Mines & Geology, Stona'2002.

15. Rajan Babu A., Behera P.K. and Gupta R.N., (2002) Layout and design for dimensional stone quarries, Seminar organised by Department of Mines & Geology, Stona'2002.

16. Rao G.M.N., Mohanty S.K. and Udayakumar S., (2002) Laboratory Rock Mechanics Testing of Dimensional Stones – An Appraisal, Souvenir, 5th International Granites & Stone Fair, Bangalore, February 06-10, 2002.

17. Rao M.V.M.S., Kumar A., Murthy D.S.N., Rao G.M.N., Mohanty S.K. and Udayakumar S., (2002) Fracture and Failure behaviour of some dry and water saturated rocks under Triaxial Compression – A Laboratory Investigation", ISRM India Symposium on Advancing Rock Mechanics Frontiers to Meet the Challenges of 21st Century, New Delhi, September 2002.

18. Sengupta S., Subrahmanyam D.S., Joseph D. and Gupta R.N., (2002) Stress perturbation due to the presence of suspected geological discontinuity at the proposed desilting chamber site at Vishnuprayag hydroelectric project - A case study, ISRM India symposium on "Advancing Rock mechanics frontiers to meet the challenges of 21st Century- Held in New Delhi (24th –27th,September'2002).

19. Srinivasulu Tadisetty, Kikuo Matsui and Gupta R.N., (2002) Virtual Instrumentation System for Rock Mechanics Applications, 3rd ISRM Conference, Seoul, Korea July 22-24, 2002.

20. Srinivasulu Tadisetty, Kikuo Matsui and Gupta R.N., (2002) Virtual Instrumentation for real time analysis of powered supports behavior, Journal of Mines, metals and Fuels, Annual Review, December 2002.

21. Srinivasulu Tadisetty, Kikuo Matsui and Gupta R.N., (2002) Novel Internet Calibrator for automatic calibrating supports pressure transducers, Indian Rock Conference, 28-29 November, 2002, New Delhi

22. Syded Arif and Venugopala Rao, R., (2002) Stress analysis and support design of underground powerhouse of Ghatghar pump storage project – a case study, Sustainable mining technology: present and Future, March 2002, Anna University, Chennai

23. Syed Arif and Venugopala Rao R., (2002) State of the art of Fiber reinforced shotcrete" Sustainable mining technology: present and Future, March 2002, Anna University, Chennai

24. Theresraj A.I., Venkatesh H.S., Adhikari G.R. and Gupta R.N., (2002) Excavation of A Power House Close to A Dam Under Stringent Blast Vibration Restrictions" National Symposium on Sustainable Mining Technology: Present and Future. 14th & 15th March 2002, Department of Mining engineering, Anna University, Chennai, pp. 447 – 452.

25. Venkatesh H.S., Balachander R., Adhikari G.R. and Gupta R.N., (2002) Blast Initiation Systems in India, Present and Future, XIV National Convention of Mining Engineers, 25 - 27 February, 2002 Udaipur, pp. 245 – 251.

26. Venugopala Rao R. and Gupta R.N., (2002) Design of support systems for underground powerhouse of Sardar Sarovar project based on Stress analysis using discrete element modeling", AITES-ITA Down Under 2002 conference, Sydney, March 2002.

2003

1. Adhikari G. R., Balachander R., Theresraj A.I. and Gupta R.N., (2003) Damage control blast design for excavation of desilting chambers at Nathpa Jhakri Hydroelectric Project, J. of Rock Mech. & Tunnelling Tech. vol. 9. no. 2, 2003.

2. Gupta R.N., (2003) An insight into the status of Dimensional stone Quarrying in India, (Key Note Address), National seminar on Recent Development in machinery and Equipment for Dimensional Stone Mining, on 13-14 December 2003, Udaipur, Rajasthan.

3. Jayanthu S., Singh T.N. and Singh D.P., (2003) Applicability of existing guidelines for warning of roof falls in depillaring panels vis-à-vis convergence observations in the filed experimental studies", Mining Engineers Journal, vol 5, no 8.

4. Mohanty S.K., Rajan Babu A., Udayakumar S., Behera, P.K. and Gupta, R.N., (2003) Testing – A Pre-requisite for Indian Dimensional Stones, Stonemart 2003, February, 2003.

5. Rajan Babu A., Behera P.K. and Gupta R.N., (2003) Simplified Guided Procedure for Block Extraction in Granite Quarries, Seminar on Natural Construction Materials: NATCON 2003, 6th & 7th March 2003, Bangalore.

6. Rajan Babu A., Behera P.K. and Gupta R.N., (2003) Eco-Friendly Stone Quarrying - Some issues, Seminar on Safe & Environmental Friendly Quarrying @ Mining Engineers' Association of India, Bangalore – 20 September 2003.

7. Rajan Babu A., Behera P.K. and Gupta R.N., (2003) High Performance Quarrying of Dimensional Stones by Optimisation through Scientific Methods, National seminar on Recent Development in machinery and Equipment for Dimensional Stone Mining, on 13-14 December 2003, Udaipur, Rajasthan.

8. Rajan Babu A., Behera P.K. and Gupta R.N., (2003) Safety Evaluation of a Historic Temple in the neighbourhood of a granite quarry. International Stone Conference, 1st & 2nd February 2003, India StoneMart 2003, Jaipur.

9. Sengupta S., Subrahmanyam D.S., Joseph D. and Gupta R.N., (2003) State of stress in the Himalayas and its impact on the design of hydroelectric projects, Paper communicated – 3rd International Symposium on Rock Stress – RS Kumamoto'03.

10. Srinivasulu Tadisetty, Kikuo Matsui and Gupta R.N., (2003) Development and Application of Smart-Real time system for continuous monitoring of powered supports behavior and automatic evaluation of its performance-A case study, 3rd International Conference on High Performance Mine Production, June 11 and 12, 2003, Aachen, Germany.

11. Srinivasulu Tadisetty, Kikuo Matsui and Gupta R.N., (2003) Development and application of innovative wireless system for real time operations to evaluating longwall supports performance, National seminar on Tenth Plan Perspective of Electronics, Communication and IT in Indian Mining Sector, 11-12 January, 2003, Nagpur, India (Keynote address).

12. Srinivasulu Tadisetty, Kikuo Matsui and Gupta R.N., (2003) Frequency Hopping Techniques for Reliable Geomechanical Data Transmission, Journal of Instrument Society of India, Indian Institute of Sciences, Bangalore, Vol.33, No.1, March 2003.

13. Srinivasulu Tadisetty, Kikuo Matsui and Gupta R.N., (2003) PXI system for monitoring of longwall gate roads convergence, 12th International Conference on Mine Planning and Equipment Selection, April 23-25, 2003 Curtin University, Kalgoorlie, Western Australia

14. Srinivasulu Tadisetty, Kikuo Matsui and Gupta R.N., (2003) Trend analysis and interpretation of powered supports performance, International Symposium on New Equipment, New Technology, Management and Safety and Mineral based industries, 11-12 May 2003, Bhubaneswar.

15. Srinivasulu Tadisetty, Kikuo Matsui and Gupta, R.N., (2003) Development and application of wireless data acquisition system for continuous monitoring of longwall powered supports performance", 19th world mining congress, November 1-5, 2003, New Delhi, India.

16. Srinivasulu Tadisetty, Kikuo Matsui, and Gupta, R.N., (2003) Development and application of Intelligent Ethernet based system for longwall applications, CSIR diamond jubilee seminar on Geomechanics and ground control, 24-25th September, 2003, Dhanbad, India.

17. Srinivasulu Tadisetty, Kikuo Matsui and Gupta, R.N., (2003) Monitoring and analysis of chock shields behavior during longwall method of mining, The 3rd International symposium on rock stress, November 4-6, 2003, Kumamoto, Japan.

18. Srinivasulu Tadisetty, Kikuo Matsui, Hideki Shimada and Gupta, R.N., (2003) Wireless networking system to mining applications, 4th Indian conference on computer applications in mineral Industry, November 7-8th 2003, Bhubaneswar, India.

19. Srinivasulu Tadisetty, Kikuo Matsui, Hideki Shimada, and Gupta, R.N., (2003) Coal mining in India, MMIJ conference on September 22-24, 2003, Japan.

20. Srinivasulu Tadisetty, Kikuo Matsui, Hideki Shimada, and Gupta, R.N., (2003) Virtual Instrumentation System for chock shields performance monitoring and analysis, International workshop on earth science and technology, November 7, 2003, Kyushu University, Japan.

21. Venkatesh, H.S., Sharma, B.N., Dhir, M.C, Puri, P.K and Gupta R.N., (2003) Rock mass damage control in machine hall cavern of Tala Hydro Electric Project (Bhutan) by near field monitoring, International Seminar, 15-17 October, 2003, Gedu, Bhutan

2004

1. Adhikari, G.R., Theresraj, A.I. and Gupta, R.N., (2004) Response of concrete and masonry dams to ground vibration due to blasting, FRAGBLAST - International J. for Blasting and Fragmentation. vol. 8, no.1, pp. 41-49.

2. Adhikari, G.R., Theresraj, A.I., Venkatesh, H.S., Balachander, R. and Gupta, R.N. (2004) Ground vibration due to blasting in limestone quarries, FRAGBLAST - International J. for Blasting and Fragmentation, vol. 8, no. 2, 2004, pp. 85-94.

3. Adhikari, G.R., Venkatesh, H.S., Rajan Babu, A., Theresraj, A.I. and Gupta, R.N., (2004) Vibration monitoring and blast damage assessment in underground metal mines, J Mines, Metals & Fuels, May-June 2004, pp.78-83.

4. Adhikari, G.R., Jain, N.K. and Gupta, R.N., (2004) Categorisation of vibration frequency based on structure responses vis-à-vis vibration standards, J Mines, Metals & Fuels, November 2004, pp. 275-277, 268.

5. Jakki, S. and Gupta, R.N. (2004) Numerical modeling of ultimate pit slope using FLAC - A case study of NLC, Mine-1. Proc 16th National Convention of Mining Engineers, Neyveli.

6. Jayanthu, S. and Singh, D.P,, (2004) Numerical Model Studies For Understanding stress Distribution During Extraction of Pillars in a Thick Coal seam", TAMSEM-Conference on Technology and Management for Sustainable Exploitation of Minerals and Natural resources, 5-7 February 2004, Khargpur, India.

7. Jayanthu, S, Singh, T.N. and Singh, D.P. (2004) Stress distribution during extraction of pillars in a thick coal seam. Rock Mechanics & Rock Engineering, vol. 37, no 3, pp 171-192.

8. Jha, P.C, Balasubramaniam, V.R., Sandeep, N., Sivaram, Y.V. and Gupta, R.N. (2004) Frequency domain attenuation tomography (FDAT) : A new approach in defect mapping by using GPR. GPR 2004, Delft, Netherlands, pp 253-256.

9. Jha, P.C., Balasubramaniam, V.R., Sandeep, N., Sivaram, Y.V. and Gupta, R.N., (2004) GPR applications in mapping barrier thickness in coal mines. GPR 2004, Delft, Netherlands pp 605-608.

10. Nagaraja Rao G.M., Mohanty, S.K. and Udayakumar, S., (2004) Guide for testing of Dimension stone as per ASTM and European standards" Stona 2004 , Febrauary 4-8 , Bangalore.

11. Nagaraja Rao,G.M. and Gupta, R.N., (2004) Testing of Dimension stones- ASTM and European standards, Geology Seminar, STONA 2004, Febrauary 5,2004,Banaglore.

12. Rajan Babu A. and Gupta, R.N., (2004) Hole Spacing Calculation for Block Splitting in Dimensional Stone Quarries – Indian Reference, Indian Stone Souvenir, PP: 64-69, Stona-2004.

13. Roy, S. and Ghose, M.K., (2004) Application of environmental biotechnology for the treatment of coke plant effluent. Proc National Seminar on New Horizons in Environmental Science and Engineering in India, at Bangalore University, Bangalore, November 17 – 19, 2004.

14. Sengupta, S., Subrahmanyam, D.S., Joseph, D., Sinha, R.K. and Gupta, R.N., (2004) State of stress in the Himalayas and its impact on the design of hydroelectric projects. Tunnelling Asia 2004.

15. Sivakumar, C., Srinivasan, C. and Gupta, R.N., (2004) Prediction of roof falls at Rajendra longwall mine using microseismic technique. Geominetech Symposium, IME Journal, Bhubaneswar, May 2004.

16. Sivakumar, C., Srinivasan, C. and Gupta, R.N., (2004) Study of induced blasting effects on longwall roof at Rajendra colliery. Proc Int Conf Future of Indian Mineral Industry - Challenges and Opportunities, MGMI, Kolkata, 17th to 18th September 2004.

17. Srinivasulu, T. and Gupta, R.N., (2004) Development and application of new innovative system for reducing power consumption and improving efficiency of conventional coal mine hauler. Proc. Int. Conf. New Equipment - New Technology, Management & Safety in Mineral Based Industries, Bhubaneswar, 11th to 12th May 2004.

18. Srinivasulu, T. and Gupta, R.N., (2004) Microprocessor based solid state control system for improving efficiency of conventional coal mine hauler. Proc. 13th Int Conf Mine Planning and Equipment Selection, Wroclaw, Poland, 1s to 3rd September 2004.

19. Srinivasulu, T., Kikuo Matsui and Gupta, R.N., (2004) Forecasting of adverse strata behavior during longwall operations on real time. Proc. 3rd Asian Rock Mechanics Symp (ISRM-2004), Kyoto University, Japan, 8th to 10th November, 2004.

20. Srinivasulu, T., Kikuo Matsui and Gupta, R.N., (2004) Real time instrumentation system for effective longwall operations. Proc Int Conf Mining Science and Technology, Xuzhou, China, 20th to 22nd October 2004.

21. Srinivasulu, T., Kikuo Matsui, Hideki Shimada and Gupta, R.N., (2004) Innovative data acquisition system for effective longwall mining operations. Proc Int Conf Instrumentation, Pune, 19th to 21st December 2004.

22. Srinivasulu, T., Kikuo Matsui, Hideki Shimada and Gupta, R.N., (2004) Monitoring and analysis of hydraulic chock shields behavior on real time. Proc. 13th Int Conf Mine Planning and Equipment Selection, Wroclaw, Poland, 1st to 3rd September 2004.

23. Srinivasulu, T., Kikuo Matsui, Hideki Shimada and Gupta, R.N., (2004) Role of intrinsic safety in mining systems-a case study. Proc 2nd Int Workshop on Earth Science and Technology, Kyushu University, Fukuoka, Japan, December 6, 2004 .

24. Srinivasulu T., Kikuo Matsui, Hideki Shimada and Gupta, R.N., (2004) RT-GPS applications for Czech Republic mines. Proc Int Conf Instrumentation, Pune, 19th to 21st December 2004.

25. Srinivasulu, T., Kikuo Matsui, Hideki Shimada and Gupta, R.N., (2004) Virtual wireless system for effective longwall operations. Proc. Int. Conf. Trends in Industrial Measurements and Automation, Chennai, 15th to 18th December, 2004.

26. Srinivasulu Tadisetty, Kikuo Matsui, and Gupta, R.N., (2004) Role of time weighted average analysis in longwall strata caving, Journal of mining engineering, vol. 5, no.6, Jan. 2004

27. Srinivasulu Tadisetty, Kikuo Matsui, Shimada, H. and Gupta, R.N., (2004) A client-server instrumentation system-longwall mining applications, Conference on technology and management for sustainable exploitation of minerals and natural resources, 5-7 February, 2004, IIT Kharagpur

28. Sripad, K. Sudhakar, Rao, R.V., Gupta, R.N., Rajbal Singh and Goyal, D.P., (2004) Instrumentation for 23 km long HRT of Tala project in Bhutan Himalayas. Proc Conf on Large Dams and Hydropower Development, 26-28 May, 2004, New Delhi.

29. Theresraj, A.I., Adhikari, G.R. and Gupta, R.N., (2004) Possible reasons for higher blast vibrations at Neyveli Lignite mines, National Seminar on Rock fragmentation (NSRF-2004), BHU, Varanasi, January 23-24, 2004.

30. Venkatesh, H.S., Balachander, R. and Gupta, R.N. (2004) Excavation of shafts with special reference to hydroelectric projects, Proc. Conf. on Large Dams and Hydropower Development, 26-28 May, 2004, New Delhi.

31. Venugopala, Rao R., Raju, G.D., Gupta, R.N. and Chuahan, R.S., (2004) Optimization of support system for desilting chambers of Nathpa Jhakri hydro-electric project using discontinuum modeling. Indian J Power and River Valley Development, 2004.

32. Venugopala Rao R., Sudhakar, J., Raju, G.D. and Gupta, R.N., (2004) Three dimensional deformation monitoring of desilting chambers at Nathpa Jhakri Hydroelectric Project. Proc Tunneling Asia 2004, New Delhi.

33. Venugopala Rao R., Reddy, M.N., Jakki, S. and Gupta, R.N., (2004) Design of support system for shaft at Hutti gold mines using stress analysis. Indian Geotechnical J, August 2004.

34. Willy Y.A., Srinivasan, C. and Gupta, R.N., (2004) Post closure mine seismicity and its hazards in the mines of Kolar Gold Fields, Hazards 2004, NGRI, Hyderabad.

2005

1. Adhikari, G.R., Balachander, R., Theresraj, A.I., Venkatesh, H.S, and Gupta, R.N., (2005) Prediction of ground vibration from construction blasts, Journal of Rock Mechanics & Tunnelling Technology, vol. 11, no. 1, Jan-June, 2005, pp. 3-12.

2. Adhikari, G.R., Theresraj, A.I. and Gupta, R.N., (2005) Influence of transducer-ground coupling on ground vibration measurements, FRAGBLAST – International Journal for Blasting & Fragmentation vol. 9, no. 2, June 2005, pp. 79-92.

3. Adhikari, G.R., Theresraj, A.I., Balachander, R,, Venkatesh, H.S. and Gupta, R.N., (2005) Observed parameters of ground vibration at surface mines vis-à-vis the DGMS standard. Journal of Mines Metals & Fuels, November-December 2005, pp 298-302.

4. Atul Gandhe, Benady, S., Venkateswarlu, V. and Gupta, R.N. (2005) Experiences of longwall mining under varying strata conditions", presented in 3rd National Seminar on Rock Excavation Techniques ROCKEX'05, at Nagpur on 7th – 8th January, 2005.

5. Gandhe, A., Venkateswarlu, V. and Gupta, R.N., (2005) Extraction of coal under a surface water body – A strata control investigation. Journal of Rock Mechanics and Rock Engineering. Vol. 38, No. 5, November 2005, pp 399 – 410.

6. Ghose, M.K. and Roy, S., (2005) Approach for the use of mine discharge for public water supplies in coal mining areas. Proc All India seminar, IPHE (India), Bhubaneswar, February 11-12, 2005.

7. Jakki ,S., Venkateswarlu, V. and Gupta, R.N., (2005) Evluation of ground stability based on rock mechanics investigations at Hutti Gold Mine. The Indian Mining & Engg J (January, 2005), 16 – 20.

8. Jayanthu, S. and Gupta, R.N., (2005) Prospective research studies and policies on coal mine closure. Proceedings of the National Seminar on Policies, Statutes and Legislation in Mines (POSTALE-2005). Central Mining Research Institute, Dhanbad, 30-31 July, 2005.

9. Jayanthu, S. and Gupta, R.N. (2005) Closure Planning for underground mines - An appraisal. Proc. Conf. Technological Advancements and Environmental Challenges in Mining and Allied industries in the 21st Century (TECMAC-2005), Rourkela, 5th to 6th February 2005.

10. Jayanthu, S., (2005) Instrumentation for understanding strata behaviour in underground coal mines – Practice and possibilities. National Workshop on Rock Instrumentation – Practice and Possibilities, Banaras Hindu University, 17th March 2005.

11. Jayanthu. S., (2005) Strata behaviour during extraction of pillars in a thick coal seam vis-à-vis applicability of convergence data for warning of goaf falls. Proceedings of the International Symposium on Advances in Mining Technology and Management. Indian Institute of Technology, Kharagpur, 30 November - 2 December, 2005, pp. 337-344.

12. Jayanthu, S., Sathyanarayana, S., Victor, M, and Rao, G.M.N., (2005) Evaluation of condition of the drum shaft in winders vis-à-vis non-destructive testing. Proceedings of the National Symposium ENTMS-2005. Bhubaneswar, 11-12 May, 2005. pp. 16-20.

13. Karekal, S., Rao, M.V.M.S and Srinivasan, C. (2005) Mining associated seismicity in Kolar Gold Mines - Some case studies using multi-fractals. Poc 6th Int Symposium on Rockburst and Seismicity in Mines, Perth, Western Australia, on 9th to 11th March, 2005.

14. Rajan Babu A. and Gupta, R.N., (2005) Risk associated with dimensional stone granite quarrying in Indian conditions. Proceedings of the International Conference on Global Stone Technology Forum, December 2005, Jaipur.

15. Roy, S, and Ghose M.K., (2005) Environmental challenges in Indian mineral industry & Water resources, water demand and re-use of coal mine discharge in Raniganj coalfields area. Proceedings of the International Symposium on Advances in Mining Technology and Management. Indian Institute of Technology, Kharagpur, 30 November – 2 December, 2005.

16. Roy, S., (2005) Coal combustion residue - A useful fill material, Mining Engineer’s Journal, vol. 6, no. 6, pp. 22-26.

17. Roy, S., (2005) Environmental auditing – A tool for environmental management. Mining Engineer’s Journal, vol. 7, no. 2, pp. 11-15, September, 2005.

18. Roy, S., (2005) Environmental impact assessment for mining projects. Mining Engineer’s Journal, vol. 6, no. 11, pp. 29-33, June, 2005.

19. Roy, S., (2005) Geotechnical properties of coal fired thermal power plant ash. The Indian Mining & Engineering Journal, vol. 44, no. 10, pp. 17-20, October, 2005.

20. Roy, S., (2005) Use of coal combustion products in surface mine reclamation. Mining Engineers’ J, vol. 6, no. 8, pp. 9-11.

21. Sengupta, S., (2005) Hydraulic Fracture Method for the Determination of In-situ Stress with Special Reference to Indian Context. In “Engineering in Rocks” (for tunnels, foundations and slopes) - book published by CBIP.

22. Sivakumar, C., Srinivasan, C. and Gupta, R.N., (2005) Microseismic monitoring to study strata behaviour and predict roof fall on a longwall face at Rajendra colliery. Proc 6th Int Symposium on Rockburst and Seismicity in Mines, Perth, Western Australia, on 9th to 11th March, 2005.

23. Srinivasan, C., (2005) Short note on Sumatra earthquake on December 26, 2004, and its aftershocks as recorded at the Kolar Gold Fields Observatory, India. J Geological Society of India, vol.65, no.3, pp 370-373.

24. Srinivasan, C., Sivakumar, C. and Gupta, R.N., (2005) Analysis of seismicity parameters of roof falls in time and space for assessing the stability by micro-seismic technique at Rajendra longwall coal mine in India - A case study. Proceeding of the 24th International Conference on Ground Control, West Virginia University, USA, August, 2005.

25. Srinivasan, C., Sivakumar, C. and Gupta, R.N., (2005) Micro-seismic investigation of rock fracture and its application in assessing stability of longwall coal mine. Proceedings of the International Symposium on Advances in Mining Technology and Management. IIT, Kharagpur, December, 2005.

26. Srinivasan, C., Sivakumar, C. and Gupta, R.N., (2005) Source parameters of seismic events in coal mine in India. Proceeding of the 27th Symposium on Seismic Research Review. Ranch Mirage, Palm Spring, CA, USA, 20-22 September, 2005.

27. Srinivasulu, T., Kikuo Matsui and Gupta, R.N., (2005) Graphical programming applications to data acquisition and analysis of longwall powered supports behavior in real time. J Instrumentation, vol.35, no.1.
28. Srinivasulu, T., Kikuo Matsui and Gupta, R.N., (2005) Role of time weighted average analysis in longwall strata caving. J. Mining Engineering, vol.5, no.6.
29. Srinivasulu, T., Kikuo Matsui, Hideki Shimada and Gupta, R.N. (2005) Real time analysis of chock shields performance - A case study. Proc 32nd Int Conf Computer Applications in Minerals Industry, The University of Arizona, Arizona, USA, 30th March to 1st April, 2005.
30. Srinivasulu, T., Kikuo Matsui, Hideki Shimada and Gupta, R.N., (2005) High-tech automation in longwall mining. Proc Conf Technological Advancements and Environmental Challenges in Mining and Allied Industries in the 21st Century, National Institute of Technology, Rourkela, 5-6 February, 2005.
31. Srinivasulu, T., Kikuo Matsui, Hideki Shimada and Gupta, R.N., (2005) Virtual instrumentation applications - HITECH measurements of mining operations. Proc 5th Int R&D Conf, Bangalore, 15-18 February, 2005.
32. Sripad, Sudhakar K., Gupta, R.N., Rajbal Singh and Goyal, D.P., (2005) Instrumentation in desilting chambers of Tala Hydro-electric Project in Bhutan Himalayas. Proc Conf Development of Hydro-Power Projects – A Prospective Challenge. 20-22 April, 2005, Shimla.
33. Venkatesh, H.S., (2005) Influence of total charge in a blast on the intensity of ground vibrations - Field experiment and computer simulation. FRAGBLAST - International Journal for Blasting & Fragmentation, vol. 9, no. 2, June 2005, pp. 79-92.
34. Venkatesh, H.S., Balachander, R. and Gupta, R.N., (2005) Near field vibration monitoring for rock mass damage control. The Journal of Explosives Engineering, July-Aug. 2005.

2006

1. Theresraj, A.I. and Balachander, R., (2006) Blast design to control ground vibration at the toe of a flood protection bund at an opencast coal mine", Mining Engineers Journal, vol. 8, no. 1, August 2006, pp. 22-26.
2. Raju, G.D., Gangadhara, S., Venkatesh, H.S. and R. Venugopala Rao, (2006) Design of supports for an underground power house cavern using distinct element code", National Conference on Civil Engineering Advances and Challenges, Ambala, India, 2006.
3. Adhikari, G.R., Venkatesh, H.S., Theresraj, A.I., Balachander, R. and Gupta, R.N. (2006) Maximiing the yield of armourstone from Aligade quarry, Seabird project, Journal of Visfotak – Explosives Safety & Technology Safety, vol.1, no. 1, December 2006, pp.19-24.
4. Adhikari, G.R., Jain, N.K., Roy, S., Theresraj, A. I., Balachander, R., Venkatesh, H.S. and Gupta, R.N. (2006) Control measures for ground vibration induced by blasting at coal mines and assessment of damage to surface structures", Journal of Rock Mechanics and Tunnelling Technology, vol. 12, no. 1, 2006, pp. 4-19.
5. Nagaraja Rao, G.M. and Jayanthu, S., (2006) Electromagnetic Method of Testing the Wire Rope Vis-à-vis Calibration of Defects, Pro. National Seminar on Non-Destructive Evaluation Dec. 7-9, 2006, NDE 2006. Hyderabad.
6. Jayanthu, S. and Gupta, R.N., (2006) Application of rock mechanics with geotechnical Instrumentation for underground coal mines. Proceedings of the National Workshop on Rock Instrumentation - Practice and Possibilities, Banaras Hindu University, Varanasi, 17 March, 2006, pp. 135-151.
7. Jayanthu, S., (2006) Technical update on use of numerical modeling for design of rock slopes. Proceedings of the Workshop on Advances in Excavation Technology for Surface

Mines and Civil Constructions. The Institution of Engineers (India), Goa, 23 December, 2005. Chapter 1, 11 pp.

8. Jayanthu, S., (2006) Role of geotechnical investigations in optimum design of rock slopes for limestone mining - Case studies. Proc. National Workshop on Limestone Deposits - Conservation and Sustainable Development. Osmania University, Hyderabad. 25 March, 2006.

9. Jha, P.C., Balsubramaniam, V.R., Sandeep, N., Sivaram, Y.V. and Gupta R.N., (2006) Application of GPR survey for foundation evaluation studies – A case study with oil storage tank. Procedings of the 11th International Conference on Ground Penetrating Radar, Columbus, Ohio, USA.

10. Nagaraja Rao, G.M. and Jayanthu, S., (2006) Overview of properties of some Indian granites, Proceedings of the Seminar on Mining and Geology. Proceedings of the 7th International Granites and Stones Fair, Bangalore, 1- 5 February, 2006, pp. 52-58.

11. Balachander, R. and Theresraj, A. I., (2006) Controlled blasting for excavation of rock in small hydel projects – Case studies", Mining Engineers Journal, vol. 8, no. 2, September 2006, pp. 9 - 17.

12. Rajan Babu, A, and Gupta, R.N., (2006) Scientific quarrying for enhanced production and cost reduction, Stona 2006, Souvenir, Bangalore.

13. Roy, S., (2006) Dust pollution due to surface coal mines and its impact on human health and vegetation. Mining Engineer's Journal, vol. 7, no. 6, pp. 18-21, January, 2006.

14. Roy, S., (2006) Role of meteorological parameters on air pollution. Mining Engineer's Jounal, vol. 7, no. 7, pp. 8-12, February, 2006.

15. Roy, S., (2006) Air Pollution Dispersion Model for a Point Source, Mining Engineer's Journal, vol. 7, no. 11, pp. 15-21, June, 2006.

16. Sengupta, S., (2006) Determination of in-situ properties in rock. In "Engineering in Rocks for Tunnels, Foundations and Slopes". CBIP, New Delhi.

17. Srinivasan, C., Sivakumar, C. and Gupta, R.N., (2006) Application of rock mechanics and micro-seismic investigation in coal mining in India. Proceedings of the Workshop on Future of Coal Mining in India - Bord & Pillar or Longwall. Journal of Mines, Metals and Fuels, Kilkata, 19-20 January, 2006.

18. Sripad, Sudhakar, K., Gupta, R.N., Rajbal Singh and Khazanchi, R.N. (2006) Instrumentation at Head Race Tunnel under Adverse Geological conditions" International Symposium on Rock Mechanics, 4th Asian Rock Mechanics Sysmposium 8-10 November, 2006, Singapore.

2007

1. Adhikari, G.R., (2007) Examining blast design in India, Tunnels & Tunnelling International, November, pp. 25-28.

2. Adhikari, G.R., (2007) Ground vibration and structure response due to rock bursts at Kolar Gold Fields, India, Journal of Mines, Metals and Fuels, May, pp. 145-152.

3. Adhikari, G.R., Venkatesh, H.S., Theresraj, A.I. and Balachander, R., (2007) Ground vibrations from blasting in coal mines: The Indian scenario, MineTech, April-September, pp. 3-11.

4. Adhikari, G.R., Venkatesh, H.S., Theresraj, A.I. and Balachander, R., (2007) Measurement and analysis of air overpressure from blasting in surface mines, Journal of Visfotak – Explosives Safety & Technology Safety, vol.1, no. 2, October, pp. 21-26.

5. Adhikari, G.R., Venkatesh, H.S., Theresraj, A.I. and Balachander, R., (2007) Safe distance from blasting in stone quarries, Mining Engineers Journal, vol. 8, no. 9, April, pp. 9-15.

6. Balachander, R. and Theresraj, A.I., (2007) Ground vibration and air overpressure studies at two hydel projects in hilly terrain, Indian Mining Engineering Journal, September, pp. 47- 51.

7. Gandhe Atul and Venkateswarlu, V., (2007) Estimation of the extent of abutment loads in a stowing panel using FLAC3D, National Workshop on Application of Numerical Modelling in Strata Control for Coal Mines, 29-30 October, Dhanbad, pp. 89 – 99.

8. Ghose, M.K. and Roy. S., (2007) Contribution of small-scale mining to employment, development and sustainability - An Indian scenario, Journal of Environment, Development and Sustainability, vol. 9, no. 3, pp. 283-303.

9. Sinha, R.K., Sengupta, S., Subrahmanyam, D.S. and Joseph, D. (2007) Review of computational softwares used in design of structures in rock, Indian Mining congress on Emerging Trends in Mineral Industry, 13th –15th July,2007, Udaipur.

10. Rajan Babu, A., (2007) Role of joints in dimensional stone extraction by splitting technique, StoneMart2007- 4th International Stone Fair and Conference, February, Jaipur.

11. Rajan Babu, A., (2007) Significance of eco-friendly dimensional stone quarrying, International Conference on Global Stone Technology Forum, November, Jaipur.

12. Rajan Babu, A. and Mishra, V. P., (2007) Empirical relations for block spitting in dimensional stone quarries, Indian Mining Congress on Emerging Trends in Mineral Industry, Udaipur, July 13 -15.

13. Rao, G.M.N. and Jayanthu, S, (2007) Laboratory geotechnical investigations of a Himalayan Rock- A case study, National Seminar on Mining Technology –Present & Furture, Bhubaneswar, 21-22 Sept. 07, pp. 143-145.

14. Roy, S. and Adhikari, G. R, (2007) Worker noise exposures from diesel and electric surface coal mining machinery, Noise Control Engineering Journal, vol. 55, no. 5, September-October, pp. 434-437.

15. Roy, S., Adhikari, G.R. and Gupta, R.N, (2007) Use of gold mill tailings in making bricks – feasibility study, Journal of Waste Management & Research, UK, vol. 25 (5), pp. 475-482.

16. Sengupta, S., Subrahmanyam, D.S., Joseph, D. and Sinha, R.K., (2007) The role of National Institute of Rock Mechanicsin in-situ Geotechnical Investigations (1979 to 2002) at Tala hydroelectric project Bhutan, Workshop on 'Experiences Gained in design and construction of Tala hydroelectric project, Bhutan' , New Delhi 14th and 15th June 2007.

17. Sengupta, S., (2007) Hydraulic fracture method to determine in-situ stresses, chapter in a book on Engineering in Rocks for Slopes, Foundations and Tunnels (Edited by T. Ramamurthy), Prentice Hall, pp. 265-283.

18. Sengupta, S., (2007) Measurement of ground stress and its use in rock engineering. Proceedings on Rock Mechanics and Tunnelling Techniques, 10-12 October, Gangtok, Sikkim.

19. Sengupta, S., Subrahmanyam, D.S., Joseph, D. and Sinha, R.K., (2007) The role of National Institute of Rock Mechanics in in-situ geotechnical investigations (1997 to 2002) at Tala hydroelectric project, Bhutan. International Workshop on Experiences Gained in Design and Construction of Tala Hydroelectric Project, Bhutan, 14-15 June, New Delhi, pp. 150-172.

20. Sinha, R.K., Sengupta, S., Subrahmanyam, D.S. and Joseph, D.J. (2007) Review of computational softwares used for design of structures in rock. Indian Mining Congress on Emerging Trends in Mineral Industry, 13-15 July, Udaipur.

21. Sinha, R.K., Sengupta, S., Subrahmanyam, D.S. and Joseph, D. J. (2007) Verification of stress concentration and displacement around a circular tunnel using 3D Boundary Element Programme Examaine3D. National Seminar on Mining Technology- Present and Future, MineTech07, 22-27 September, Bhubaneswar.

22. Srinivasan, C., Sivakumar, C. and Ghose, G. K, (2007) Microseismic and b-value study in a

shallow subsurface coal mine in India, Indian Geophysical Union Conference, Khrukshetra University, November.

23. Sripad, (2007) A subsidence prediction model for Godavari Valley Coal Fields using UDEC. National workshop on Application of Numerical Modelling in Strata Control for Coal Mines, 29-30 October, Dhanbad.

24. Sripad, Singh, R., Sudhakar. K., Khazanchi, R. N. and Raju G. D, (2007) Instrumentation of underground excavations at Tala Hydroelectric project in Bhutan. International Workshop on Experiences Gained in Design and Construction of Tala Hydroelectric Project, Bhutan, 14-15 June, New Delhi.

25. Venkatesh, H.S. and Balachander, R., (2007) Blast design for accelerated excavation of power house cavern at Tala Hydroelectric Project, Bhutan, International Workshop on Experiences Gained in Design & Construction of Tala Hydroelectric Project, Bhutan, 14 – 15 June, New Delhi.

26. Venkateswarlu, V. and Gandhe, Atul, (2007) Rock mechanics aspects of slope stability in Goan iron ore mine, Workshop on Slope Stability in Iron Ore Mines of Goa, 29 September.

2008

1. Adhikari, G.R., Venkatesh, H.S., Theresraj, A.I. and Balachander, R., (2008) Assessment and control of stemming ejection at surface Mines," Journal of Visfotak Explosives Safety & Technology Safety, September 2008, pp. 25-31.

2. Gandhe Atul and Venkateswarlu, V., (2008) Slope stability study in iron ore mines of Sandur – a case study, National Seminar on Iron Ore Mining Industry in India, Bangalore, 11-12 January.

3. Mishra, S.B., Nagaraj, C., Venkateswarlu, V. and Adhikari, G.R. (2008) Measurement and analysis of pore water pressure in large caverns and shafts in a hydro-electric project, Geotechnical and Geological Engineering, vol. 16, pp. 367-374.

4. Nawani, P.C., (2008) Engineering geological investigations for water resources projects," Seminar on Emerging Trends in Geotechnology Challenges and Opportunities, Global Institute of Technology, Bangalore, November 7-8, 2008.

5. Nawani, P.C., (2008) Prediction of change in stress pattern, rock mass behaviour and stability of underground excavations using microseismics," Journal of Engineering Geology, Vol. XXXV (1-4), 2008, pp. 61-76.

6. Nawani, P.C. and Naik, Sripad, (2008) Need for a long term stability monitoring of Varunavat landslide treatment in Uttarakashi town, Uttarakhand Himalaya," National Seminar on Disaster Management, Department of Disaster Management, Govt. of Uttarakhand, June 27, 2008.

7. Rajan Babu, A.**,** (2008) Development and planning of granite quarries with reference to joints and their influence on block splitting," Indian Stone, Journal of All India Granite and Stone Association, 2008, pp. 18-29.

8. Rajan Babu, A., (2008) Significance of eco-friendly dimensional stone quarrying," Stonedge-Journal of Indian Dimensional Stone Industry, May-June 2008, pp. 8-19.

9. Rao Nagaraja, G. M., Udayakumar S., Rao, M.V.M.S., Prasana Lakshmi, Chary, K.B. and Vijaya Kumar, N.A. (2008) Stress induced micro-crack damage in Latur granite: a case study, Workshop on Rock Mechanics & Tunnelling Techniques, 24-26 April 2008, Manali.

10. Rao, G.M.N. and Jayanthu, S., (2008) Non-destructive evaluation of man riding ropes and other vital components of mining machinery, Conference on Emerging Trends in Mining & Allied Industries, NIT-Rourkela, Feb. 2-3, 2008, pp. 93-99.

11. Roy, S. and Adhikari, G.R., (2008) Seasonal variation in the suspended particulate matter vis-à-vis meteorological parameters at Kolar Gold Fields, India," International Journal of Environmental Engineering, 2008.

12. Roy, S. and Singh, T. N, (2008) Influence of rock and explosives properties and blast design parameters on dust generation during blasting in opencast coal mines: an approach," Mining Engineer's Journal, vol. 10, no. 4, November 2008, pp. 10-14.

13. Sivakumar, C. Willy, Y.A. and Nawani, P.C., (2008) Optimization of distressing blast location and time using microseismic data in a longwall coal mine, Synergy in Mineral Sector for Sustainable Development – Vision 2020, NITK Surathkal, October 4-5, 2008.

14. Sivakumar, C., Murthy, S.N., Rao, Y.V. and Nawani, P.C., (2008) Application of microseismic technology in underground space technology in India – a review," Synergy in Mineral Sector for Sustainable Development – Vision 2020, NITK Surathkal, October 4-5, 2008.

15. Sivakumar, C., Srinivasan, C., Murthy, S. N. and Rao, Y.V., (2008) Microseismic monitoring of longwall strata to provide real time instability indications to mine management at Rajendra coal mine in India, Proceedings of the 42^{nd} U. S. Rock Mechanics Symposium, San Francisco, 29 June -2 July, 2008.

16. Sivakumar, C., Srinivasan, C., Willy, Y.A. and Murthy, S.N. (2008) Real time microseismic monitoring to study geomechanics of underground structures,12^{th} International Association for Computer Methods and Advances in Geomechanics, Goa, October 1-6, 2008.

17. Srinivasan C., Willy, Y. A. and Sivakumar, C., (2008) Strong Motion studies in the mines of Kolar Gold Fields, Proceedings of the 30^{th} Monitoring Research Review: Ground-based Nuclear Explosion Monitoring Technologies, Portsmouth, Virginia 23-25 September, 2008.

18. Srinivasan, C., Sharma, M.L., Kotadia, J., and Willy, Y. A, (2008) Peak ground acceleration attenuation relationship for low magnitude at short distances in South Indian region," Proceedings of the 14^{th} World Conference on Earthquake Engineering, China, October, 2008.

19. Srinivasan, C., Willy, Y. A. and Sivakumar, C, (2008) Seismicity in the flooded mines of Kolar Gold Fields, Proceedings of the 7^{th} Asian Seismological Conference, Tsukuba, Japan, 24-28 November, 2008.

20. Sripad, N., Raju, G.D., Sudhakar, K. and Varma, P.S, (2008) Deformation monitoring of underground riverbed powerhouse complex at Sardar Sarovar project, Gujarat – A case study, Workshop on Rock Mechanics & Tunnelling Techniques, Kullu, 24-26 April 2008.

21. Subrahmanyam, D.S., (2008) A brief study on the migmatitic rocks in India for use as dimensional stones," Journal of Mines, Metals and Fuels, June 2008.

22. Venkatesh, H.S. and Rao, V.R., (2008) Reduction of blast induced ground vibrations with open trenches in surface mines, 12^{th} International Conference of International Association for Computer Methods in Geomechanics, October 1-6, 2008, Goa, India, pp. 4132-4139.

23. Venkatesh, H.S., Adhikari, G.R. and Theresraj, A.I, (2008) Variability in velocity of detonation of commercial explosives as measured in field trials," Mining Technology, vol. 117, no. 1, September 2008, pp. 6-11.

24. Venkatesh, H.S., Balachander, R. and Gupta, R.N., (2008) Handling the blockades while excavating the surge shaft at Tala hydroelectric project, Tunnelling and Underground Space Technology, vol. 23, no. 2, March, pp. 145-150.

2009

1. Adhikari, G.R., Venkatesh, H.S., Theresraj, A.I. and Balachander, R., (2009) Prediction of ground vibration and air overpressure from construction blasting, Journal of Mines Metals and Fuels, vol. 57, nos. 5&6, May-June, pp. 125-131.

2. Balsubramaniam, V.R., Jha, P.C., Nelliat, S., and Sivaram, Y.V., (2009) GPR survey for evaluating the efficacy of reinforcement in civil structure" National Seminar on Energy Security and Exploration for Non-Fossil Fuels, AEG, February 4-6, 2009, Hyderabad.

3. Biju John and Rajendran, C.P., (2009) Evidence of episodic brittle faulting in the cratonic part of the Peninsular India and its implications for seismic hazard in slow deforming regions, Tectonophysics, vol. 471, pp. 240-252.

4. Biju John, (2009) Earthquake hazard assessment based on geological data: an approach from crystalline terrain of Peninsular India, European Geosciences Union General Assembly, vol. 11, EGU2009-1932.

5. Jha, P.C., Balsubramaniam, V.R., Nelliat, S., and Sivaram, Y.V., (2009) Use of GPR survey to analyse the caving risk in opencast coal mines developed over old underground mines," International Symposium on Rock Mechanics and Geo-Environment in Mining and Allied Industries, February 12-14, 2009, IT-BHU, Varanasi.

6. Kandpal, G.C. and Biju John, (2009) Seismic microzonation studies of Jammu Urban Agglomeration. GSI Records, vol. 142 (8), pp. 137-138.

7. Kandpal, G.C. and Biju John, (2009) Seismic microzonation studies of Chandigarh Urban Complex. GSI Records, vol. 141 (8), pp. 147-148.

8. Kandpal, G.C., Biju John and Joshi, K.C., (2009) Geotechnical studies in relation to seismic microzonation of Union Territory of Chandigarh, J. Ind. Geophys. Union. vol.13, pp. 75-83.

9. Kumar. L. A., Raj, D.E.D., Renaldy, T.A. and Vinoth, S, (2009) Seismic monitoring in surface mines, Journal of Korean Society for Rock Mechanics, Tunnel and Underground Space, vol.19, no. 3, pp.174-180.

10. Naithani, A.K. and Rawat, G.S., (2009) Investigations of Bunga landslide and its mitigation – a case study from Pinder valley, Garhwal Himalaya, Uttarakhand. J. Indian Landslides, vol. 2, no. 1, pp. 9-22.

11. Naithani, A.K., Bhatt A.K. and Krishna Murthy, K.S., (2009) Geological and geotechnical investigations of Loharinag - Pala hydropower project, Garhwal Himalaya, Uttarakhand, J. Geological Society of India, vol. 73, no. 6, pp. 821-834.

12. Nawani, P.C., (2009) Geo-analytical approach in locating and executing spillway structures of Tehri Dam in Uttarakhand Himalaya, India, Proceeding of 7th Asian Regional Conference of IAEG, China, pp. 156-164.

13. Nawani, P.C., (2009) Stabilization of Varunavat landslide in Uttarkashi town, Uttarakhand Himalaya, Second Indian Disaster Management Congress, New Delhi, pp. 45-46.

14. Prakash, A., Lokhande R.D. and Singh, K.B., (2009) Surface ground deformation in Jharia and Raniganj coalfields over old mine workings, Indian Journal of Environmental Protection, vol. 29, no. 4, pp 289-293.

15. Rajan Babu, A. and Nawani, P.C., (2009) Extraction of dimensional blocks using advanced explosive splitting techniques, Journal of Indian Dimensional Stone Industry, March 2009, pp. 24-32.

16. Rajendran, C.P., Biju John, Sreekumari, K., and Rajendran, K., (2009) Reassessing the earthquake hazard in Kerala based on historical and current seismicity, J. Geol Soc. India, vol. 73, pp. 785-802.

17. Rao Nagaraja G.M., (2009) Data on Engineering Properties of Dimensional stones, Indian Stone, January 2009.

18. Rao Nagaraja, G. M. and Jayanthu, S., (2009) Analysis of acoustic emission trends in Kaiser Effect of rocks - a new approach, International Symposium on Rock Mechanics & Geo-Environment in Mining and Allied Industries, IT-BHU, Varanasi, February 12-14, 2009.

19. Rao Nagaraja, G.M., Rao, M.V.M.S., Prasana Lakshmi, K.B., Chary, Vijaya Kumar, N.A, (2009) Scaling of AE energy and its application in the investigation of brittle fracture of rock – Journal of Non-destructive Testing & Evaluation, vol. 7, Issue 4, March 2009, pp. 30-35.

20. Sengupta, S., Subrahmanyam, D.S., Joseph, D., and Sinha, R.K, (2009) Stress perturbation due to presence of an intrusive and numerical simulation to understand the effect-A case study, 21st National Convention of Mining Engineers and National Seminar on Technological Advancements in Mining Industry, December, Udaipur.

21. Srinivasan , C., Willy, Y.A., and Nawani P.C, (2009) Post-closure seismicity in the mines of Kolar Gold Fields, Proceedings of the 7th International Symposium on Rockburst and Seismicity in Mines, China, 21-23 August.

22. Srinivasan, C., Gupta, I.D. and Willy, Y.A, (2009) Estimation of local magnitude of rockbursts using strong motion accelerograms in the mines of Kolar Gold Fields, Journal Acta Geophysica, Vol. 58, No. 2. pp. 300-316.

23. Srinivasan, C., Willy, Y.A. and Nawani P.C, (2009) Source parameters of seismic events in the mines of Kolar Gold Fields, Proceedings of the Monitoring Research Review Symposium, 21-23 September, Tucson, Arizona.

24. Sripad Naik, Sudhakar, K. and Raju, G.D., (2009) Instrumentation and monitoring of underground structures of Nathpa Jhakri Hydro Power Station, SJVNL, Simla, H.P., INDOROCK-2009 Second Indian Rock Conference, 12-13, New Delhi.

25. Sundriyal, Y.P., Chaudhary, S., Rawat, G.S., Prasad, C. and Naithani, A.K., (2009) Signature of pre-glaciation drainage in Lower Bhagirathi Valley, Earth System Sciences, vol. 2, New Delhi, pp. 539-550.

26. Vardhan, H., Adhikari, G.R., Govinda Raj, M., (2009) Estimating rock properties using sound levels produced during drilling," International Journal of Rock Mechanics and Mining Sciences, vol. 46, no. 3, 2009.

27. Venkatesh H.S. and Balachander, R., (2009) Presplitting in surface excavations for final wall control, INDOROCK-2009, Second Indian Rock Conference, 12-13 November, New Delhi, pp. 407-413.

28. Venkatesh, H.S., Theresraj, A.I. and Balachander, R., (2009) Blast vibration studies by NIRM at different mines of NMDC," The Indian Mining and Engineering Journal, February 2009, pp. 58-63.

29. Venkatesh, H.S., Theresraj, A.I. and Balachander, R., (2009) Excavation of mini hydel projects close to dams" International Symposium on Rock Mechanics and Geo-environment in Mining Allied Industries, February 12-14, 2009, IT-BHU, Varanasi.

2010

1. Balasubramaniam, V.R. and Jha, P.C, (2010) Imaging for foundation defects using GPR, 13th International Conference on Ground Penetrating Radar, June 21-25, Lecce, Italy.

2. Gandhe, A. Benady, S. and Venkateswarlu, V., (2010) Experiences with wide-stall mining for partial extraction of coal in India, Proceeding of National Seminar on Meeting Rock Mechanics Challenge of Deep Underground Mining, CIMFR, Dhanbad, April 22-24.

3. Jennifer, P.D., Rao, G.M.N. and Nawani, P.C., (2010) Testing Standards for Sandstone, Limestone, Marble and Slate - Indian Stone, A house Journal of All India Granites & Stone Association.

4. Jha, A.K. and Adhikari, G.R., (2010) Surface blasting-Underground moniotirng: Influence of primimg methods on blast vibration, Visfotak Journal, September 2010, pp. 20-26.

5. Jha, P.C., Balasubramaniam, V.R., Nelliat,S. and Sivaram, Y.V., (2010) Mapping oil leak flow path and source of leakage using SFR, 13th International Conference on Ground Penetrating Radar, June 21-25, Lecce, Italy.

6. John, B. and Rajendran, C.P., (2010) Seismicity of Central Kerala: some observations, J. Engg. Geol. (ISEG).

7. John, B., Rao, D.T., Singh, Y., Sahoo, D. and Nawani, P.C, (2010) Neotectonic signatures in the southern Peninsular India and Gulf of Mannar, Sixth Nepal Geological Congress, Kathmandu, Nepal.

8. Joshi, D.D., John, B., Kandpal, G. C. and Pande, P., (2010) Paleoliquefaction Features from the Himalayan Frontal Belt, India and its Implications to the Status of 'Central Seismic Gap', Journal of South Asian Disaster Studies, vol. 2, pp. 139-154.

9. Lokhande, R.D., Murthy, V.M.S.R., Prakash, A. and Singh, K.B., (2010) An investigation of causes of pot-hole subsidence and its impact, Proceeding of National Seminar on Meeting Rock Mechanics Challenges of Deep Underground Mining, Dhanbad, April 22-24, pp 169-175.

10. Naithani, A.K. and Nawani, P.C, (2010) Impact of climate change on Himalayan glaciers (in Hindi), Vikalp, Publ. by Indian Institute of Petroleum, Dehradun, January-March 2010, pp. 21-22.

11. Nawani, P.C. and Srinivasan, C., (2010) Seismic hazards in Penninsular India, Workshop on Seismic hazards in India, Atomic Mineral Directorate for Exploration and Research, Jaipur.

12. Prakash, A., Lokhande, R.D. and Singh, K.B, (2010) Impact of Rainfall on Residual Subsidence in Old Coal Mine Workings, Journal of Environmental Science and Engineering, vol. 52, no. 1, pp. 75-80.

13. Rajan Babu, A., Meena, S.S., Naveen, G.C. and Nawani, P.C., (2010) Negotiating joints through stratigraphy mapping during dimensional stone extraction, Stona Souvenir, The 9th International Granite and Stone Fair – STONA 2010, 4-7 February, Bangalore

14. Rao, G.M.N., Udayakumar, S., Raju, G.D. and Jennifer, P.D, (2010) Post- failure deformation behavior of coal and rocks, ISRM International Symposium 2010 and the 6th Asian Rock Mechanics Symposium, October 23-27, New Delhi.

15. Roy, S., Adhikari, G.R. and Singh T.N, (2010) Development of emission factors for quantification of blasting dust at surface coal mines, Journal of Environmental Protection, vol. 1 (4), pp. 346-361.

16. Sastry, V.R. and Nair, R, (2010) Analysis of Stress Distribution in Longwall Barrier: A Case Study, International Journal of Mining and Mineral Engineering, vol. 2(1), pp. 1-17.

17. Sengupta, S., Subrahmanyam, D.S., Joseph, D. and Sinha, R.K., (2010) Design of a hydroelectric project affected by stress perturbation - a case study, ISRM International Symposium and the 6th Asian Rock Mechanics Symposium, October, New Delhi.

18. Sripad, Nair, R., Sudhakar, K. and Nawani, P.C., (2010) Need for systematic instrumentation in hydroelectric projects In the Himalayas, International Conference on Accelerated Development of Hydro Power in Bhutan – Opportunities and Challenges, Thimpu, Bhutan, November, 16-18.

19. Vamshidhar, K. and Venkatesh, H.S., (2010) Review of models for prediction of rock fragmentation due to blasting, Journal of Visfotak – Explosives Safety & Technology Safety, pp. 27-34.

2011

1. Divyalakshmi, K.S., Ram Mohan and Murty, M.V.R, (2011) Modification of Tsunami wave by submarine canyon: case study of multiple canyons at South East coast of India, Marine Geodesy, vol. 34, pp. 2-15.

2. Gandhe, A., Benady, S. and Venkateswarlu, V., (2011) Strata control experiences of blasting gallery method under varying geomining conditions in India, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore

3. Gupta, P. and Roy, S., (2011) Impact of underground space construction on water environment, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG (ICUST-2011), January 17-19, Bangalore.

4. Jain, P., Naithani, A.K. and Singh, T.N, (2011) Application of tunnel boring machine (TBM) for the construction of Maroshi-Ruparel College tunnel, Mumbai, India, Journal of Engineering Geology, vol. 37, no 1-4, pp. 144-152.

5. Jha, P.C., Balsubramaniam, V.R, Sandeep, N. and Sivaram, Y.V., (2011) Geophysical investigations for characterising underground space for crude oil storage, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG (ICUST-2011), January 17-19, Bangalore.

6. John, B., Rao, D.T., Singh, Y. and Nawani, P.C., (2011) Signatures of active faulting in Southern Peninsular India, International Conference on 2001 Bhuj Earthquake and Advances in Earthquake Science, January 22-27.

7. Kudtarkar, D.M., Patil, A., Mohanty, S.K. and Nawani, P.C, (2011) Site investigations and rock mass characterization for crude oil strategic storage cavern project, Visakhapatnam, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

8. Kumar, K.A., Raja, S., Nannuri, R., Manjunath, A. and Lokhande, R.D, (2011) Yield pillar technique with continuous miner – a new kind of extraction method, National Seminar on Recent Advancement in Engineering and Technology (RAET-2011), Dr T Thimmaiah Institute of Technology, Kolar Gold Fields, Karnataka, March.

9. Kumar, M., Roy, S. and Gupta, P., (2011) Assessment of traffic noise at Kolar Gold Fields, India, Journal of Environmental Science & Engineering.

10. Lokhande R.D. and Venkateswarlu, V., (2011) Strata control investigations in continuous miner panels" International Conference INDOROCK-2011, organized by ISRMTT at IIT Roorkee, October 13-15.

11. Lokhande, R.D., Murthy, V.M.S.R. and Singh, K.B., (2011) Role of geological structures on pot-hole subsidence development due to underground mining, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

12. Lokhande, R.D., Venkateswarlu, V., Varma, A.L.S.V., Srinivas, C.H. and Veeraswamy, H., (2011) Investigation and analysis of strata control problems in continuous miner workings, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

13. Mahesh, V.S., Senthilkumaran K., and Jha, P.C. (2011) 3D digitization of sub surface features using 3D GPR, ASME-2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference August 28-31, Washington, DC

14. Naik, S.R., Nair, R. and Nawani P.C., (2011) Stability Analysis Of Underground Powerhouse Caverns Using Discontinuum Numerical Modelling, Journal of Engineering Geology, vol. 37, no. 1-4, pp. 268-276.

15. Nair, R. and Sastry, V.R., (2011) Longwall barrier design: a perspective, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

16. Nair, R. and Sastry, V.R., (2011) Multiseam longwall mining: a parametric study using finite element method, Journal of Engineering Geology, vol. 37, no 1-4, pp. 227-334.

17. Naithani, A. K. and Nawani, P.C., (2011) Engineering geological investigations of Dik Chhu hydroelectric project, Sikkim Himalaya, India. Journal of Nepal Geological Society, Vol. 43, pp. 71-80.

18. Naithani, A.K., Rawat, G.S. and Nawani, P.C., (2011) Investigation of landslide events on 12 July 2007 due to cloudburst in Chamoli District, Uttarakhand, India, International Journal of Earth Sciences and Engineering, vol. 4, no. 5, pp. 777-786.

19. Naithani, A.K., Singh, L.G., Jain, P., Singh, D., Bhusan, R. and Nawani, P.C., (2011) Engineering geological evaluation of the underground water conducting system of Malshej Ghat PSS Project, Maharashtra, India, Journal of Engineering Geology, vol. 37, no 1-4, pp. 179-188.

20. Nawani P. C., (2011) Engineering geological investigations for underground excavations, Journal of Engineering Geology, vol. 37, no 1-4, pp. 98-119.

21. Nawani, P.C., Naithani A.K. and Naik, S.R., (2011) Stability Analysis of Underground Powerhouse of Malshej Ghat PSS Project, Maharashtra, India, Journal of Engineering Geology, vol. 37, no 1-4, pp. 303-311.

22. Ogasawara, H., Srinivasan, C., Cichowicz, A., Goldbach, O. and Koos, B, (2011) Water-ingress induced seismicity in mines in Japan, India and South Africa, ICDP Workshop Scientific Deep Drilling to Study Reservoir Triggered Earthquakes at Koyna, India, March 21 - 25, Hyderabad.

23. Rajan Babu, A., Adhikari, G.R. and Pitchumani, P. K, (2011) Excavations by controlled blasting for the construction of an underground LPG storage cavern at Vizag, Journal of Engineering Geology, vol. 37, no 1-4, pp. 381-410.

24. Rao, D.T., Rajan Babu, A., John, B. and Singh, Y., (2011) Role of Seismotectonics evaluation in underground space projects, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

25. Rao, G.M.N., Udayakumar, S. and Jennifer, P.D., (2011) Predicting rock mass properties for nuclear waste repositories from laboratory strength data, Journal of Engineering Geology, vol. 37, no 1-4, pp. 218-224.

26. Reddy, S.K. and Nagaraj, C., (2011) Development and application of deep-hole extensometers for estimation of roof caving behaviour in longwall panels, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

27. Renaldy, T. A. and Roy, S., (2011) Impact of air environment due to underground space construction, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG (ICUST-2011), January 17-19, Bangalore.

28. Roy, S., Adhikari, G.R., Renaldy T.A. and Jha, A.K, (2011) Development of multiple regression and neural network models for assessment of blasting dust at a large surface coal mine, Journal of Environmental Science and Technology, vol. 4 (3), pp. 284-30.

29. Roy, S., Adhikari, G.R., Renaldy T.A. and Singh T.N., (2011) Assessment of atmospheric and meteorological parameters for control of blasting dust at an Indian large surface coal mine, Research Journal of Environmental and Earth Sciences, vol. 3(3), pp. 234-248.

30. Sengupta, S., Subrahmanyam, D.S., Sinha, R.K. and Joseph, D., (2011) Investigation into the causes of severe roof problems in some Indian coal mines and formulation of guidelines

to reduce ground control problems, International Journal of Mining and Mineral Engineering, vol. 3, no. 4 pp. 290-302.

31. Sandeep, N., Jha, P.C., Sivaram, Y.V., Balsubramaniam, V.R. and Babu, B.B., (2011) Integrated geophysical investigations for site characterisation along a hydro tunnel under low overburden conditions, Journal of Engineering Geology, vol. 37, no. 1-4, pp. 153-160.

32. Sandeep, N., Sivaram, Y.V., Jha, P.C., Balsubramaniam, V.R. and Butchi Babu, B. (2011) A case study on electrical resistivity imaging and seismic refraction survey for site investigation in tunnel construction, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG (ICUST-2011), January 17-19, Bangalore.

33. Sengupta, S., Sinha, R.K., Subrahmanyam, D.S. and Joseph, D., (2011) Underground LPG facilities, in-situ stress considerations in the design of the cavern, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

34. Sengupta, S., Sinha, R.K., Subrahmanyam, D.S., Shyam, G., (2011) Assessment of impact of nearby excavations on the deformability and stress conditions around a proposed powerhouse by field and numerical modeling, Proc. 45th U. S. Rock Mechanics/ Geomechanics Symposium, June 26-29, San Francisco, California.

35. Sengupta, S., Subrahmanyam, D.S., Sinha, R.K. and Shyam, G., (2011) Estimation of the Stress Magnitudes from the Measured Deformability Parameters for the Design of a Powerhouse, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

36. Sivakumar, C., Srinivasan, C., Willy, Y.A. and Nawani P.C., (2011) Strata instabilities in mines–monitoring and prediction using microseismics in India: A Review. International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

37. Sivakumar, C., Srinivasan, C., Willy, Y.A. and Nawani, P.C., (2011) Power house cavern stability monitoring using Microseismics at Tala Hydro Power Project, Bhutan. International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

38. Srinivasan, C. and Willy, Y.S., (2011) Combating rockburst in underground excavations, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

39. Sripad, Nair, R. and Nawani, P.C., (2011) Stability analysis of underground powerhouse caverns using Discontinuum Numerical Modelling, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

40. Sripad, Sudhakar, K. and Nair, R., (2011) Instrumentation – A key to stability analysis of large caverns in hydroelectric projects, International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

41. Srivastava, H.N., Bhattacharya, S.N. and Rao, D.T. and Srivastava, S., (2011) Predictability of Valsad earthquake swams Gujarat, India, International conference on 2001 Bhuj Earthquake and Advances in Earthquake Science, January 22-27.

42. Vallinayagam, G. and Singh, L.G, (2011) Radioactive heat producing acid volcanic – plutonic rocks of Dhiran area, Malani igneous suite Northwest Peninsular India, E-Journal Earth Science, vol. 4(II), pp. 68-79.

43. Venkatesh, H.S., Nawani, P.C., Theresraj, A.I. and Balachander, R., (2011) Need for appropriate blasting for underground excavations in hydroelectric projects. International Conference on Underground Space Technology and the 8th Asian Regional Conference of IAEG, (ICUST – 2011), January 17-19, Bangalore.

44. Venkatesh, H.S., Theresraj, A.I. and Balachander, R., (2011) Improvement of blast design for tunnel excavation under adverse geological condition, National Seminar on Explosives & Blasting Techniques for Mining, Quarrying & Infrastructure Industry, NITK, Surathkal, February 18-19.

2012

1. Gopinath, G., Venkatesh, H.S, Balachander, R. and Theresraj, A.I. (2012) Pre-split blasting for final wall control in a nuclear power project , 10th International Symposium on Rock Fragmentation by Blasting, Fragblast10, November 24 - 29, New Delhi.

2. Gopinath, G., Vamshidhar, K. and Venkatesh, H. S, (2012) Ground vibration measurements at Sangam Kalan limestone mine, Souvenir Mines Environment & Minerals Conservation Week, Hyderabad Region, January, pp. 64-70.

3. Gupta P., Roy S. and Rajan Babu A., (2012) Study on noise levels generated due to jack hammer drills in granite quarries, Frontiers in Science, vol. 2, no. 3, pp. 47-52.

4. Gupta, P. and Roy, S., (2012) Evaluation of spatial and seasonal variations in groundwater quality at Kolar Gold Fields, India, American Journal of Environmental Engineering, vol. 2, no. 2, pp. 19-30.

5. John, B., Singh, Y., Rao, D.T. and Babu, K. K., (2012) Suspected Archeological evidence of an earthquake near Visakhapatnam. Indo-US Workshop on Intraplate Seismicity, Institute of Seismological Research, Gandhinagar, Gujarat, India, 16-18 January.

6. Kumar Reddy S. and Nagaraj, C., (2012) Longwall goaf monitoring using deep hole extensometer. International J of Earth Sciences & Engineering, vol. 5, no. 1, pp. 1402 – 1405

7. Kumar Reddy S. and Sastry V.R., (2012) Induced stresses in blasting gallery panel during depillaring based on field instrumentation – A case study, International Journal of Earth Sciences and Engineering, vol. 5, no. 6 (01), pp. 1820 - 1827.

8. Kumar Reddy S. and Sastry V.R., (2012) Strata monitoring studies during extraction of thick seams by Blasting Gallery Method - A case study, World Conference on Applied Science and Engineering Technology, 17-19 August 2012, Vijayawada.

9. Kumar Reddy S. and Sastry V.R., (2012) Strata monitoring studies with convergence stations in galleries of Blasting Gallery panel during depillaring – A case study. Seminar on Ground Control and Improvement, Central Board of Irrigation and Power, 20-21 September, 2012, New Delhi.

10. Kumar Reddy S., (2012) Coal as energy - Problems and issues related to mining industry, International Conference on Energy and Environment, 1-4 December 2012, Hyderabad.

11. Mohapatra, A.K., Mohanty, W.K., Khisley, K. and Tiampo, K.F., (2012) Earthquake Forecasting in Bhuj, Western India, Indo-US Workshop on Intraplate Seismicity, Institute of Seismological Research, Gandhinagar, Gujarat, India, 16-18 January.

12. Mohapatra, A.K., Mohanty, W.K., Khisley, K. and Tiampo, K.F., (2012) Earthquake forecasting in Northeastern India using pattern informatics method, Seismological Research Letters, vol. 83, no. 1, pp. 216.

13. Naithani, A.K., (2012) Underground rock caverns for strategic crude oil storage in India-nature of studies, design and construction. Current Science. vol. 103, no. 5, pp. 490-496.

14. Naithani, A.K., Singh, L.G., Rawat, Devendra Singh and Nawani, P.C., (2012) Engineering geological and geotechnical evaluation of Dam Spillway (II-C) of Bunakha Hydroelectric Project, Bhutan Himalaya. ISRM (India) Journal. vol. 1, no. 2, pp. 16-22.

15. Naithani, A.K., Kumar, M., Bhusan, R. and Nawani, P.C., (2012) Engineering geological investigations of rock mass from the excavated north wall face in the Pump House area of

Mahatma Gandhi Lift Irrigation Scheme-III, District Mahboobnagar, Andhra Pradesh, E-journal Earth Science India, Vol. 5, No. 1, pp. 1-11.

16. Nair, Roshan and Naik, Sripad R. (2012). Numerical analysis of an underground power-house in adverse geological conditions of Upper Himalayas, International Conference on Tunneling and Underground Space for Global SOCIETY – WTC2012 (TUTG and ITA-ALTIS), Bangkok, 8- 23 May 2012.
17. Roy, S., Gupta, P. and Renaldy, T.A, (2012) Impacts of gold mill tailings dumps on agriculture lands and its ecological restoration at Kolar Gold Fields, India, Resources and Environment, vol. 2, no. 1, pp. 67-79.
18. Roy, S, (2012) Prediction of particulate matter concentrations using artificial neural network, Resources and Environment, vol. 2, no. 2, pp. 30-36.
19. Sandeep, N., Jha, P.C., Sivaram, Y.V., Balasubramaniam, V.R. and B. Butchi Babu, (2012) Integrated geophysical surveys for site characterisation along hydro tunnel under low over-burden conditions Journal of engineering geology. vol. XXXVII, 1-4, pp. 161-168.
20. Sengupta, S., Subrahmanyam, D.S., Sinha, R.K. and Shyam, G., (2012) Estimation of the Impact of Mining on Stresses by actual Measurements in Pre and Post Mining Stages by Hydrofractue Method- A Case Study in a Copper Mine, Chapter in book titled "Effective and Sustainable Hydraulic Fracturing", ISBN 980-953-307-651-0
21. Singh, L.G. and Vallinayagam, G., (2012) Petrological and geochemical constraints in the origin and associated mineralization of A-Type granite suite of the Dhiran area, Northwestern Peninsular India. Geosciences. vol. 2, no. 4, pp. 66-80.
22. Srinivasan, C., Harbindu, A., Sharma, M.L .and Willy, Y.A., (2012) Strong ground motion predictive equation for low magnitude and near-field earthquake data for shield region in India, Proc. 15th World Conference on Earthquake Engineering, Lisbon, September, 2012
23. Subrahmanyam, D.S., Sengupta, S., Sinha, R.K. and Shyam, G., (2012) Determination of in-situ stress at Desilting Chamber of Punatsangchhu hydroelectric project (Bhutan), to re-confirm its orientation influenced by topography - A case study, 7th International Conference on Case Histories in Geotechnical Engineering, Chicago, USA.
24. Venkatesh, H.S., Theresraj, A.I., Balachander, R., Gopinath, G. and Vamshidhar, K., (2012) Ground vibration studies in Indian limestone mines vis-à-vis the mines of India Cements Limited, The Indian Mining & Engineering Journal. vol. 51 No. 09, September 2012, pp 25-29.
25. Venkatesh, H.S., Gopinath, G., Balachander, R., Theresraj, A.I. and Vamshidhar, K., (2012) Controlled blasting for a Metro Rail project in an urban environment, 10th International Symposium on Rock Fragmentation by Blasting, Fragblast10, November 24 - 29, New Delhi.
26. Venkatesh, H.S., Vamshidhar, K., Gopinath, G., Theresraj, A.I. and Balachander, R., (2012) Optimisation of blast design for an iron ore mine and assessment of fragmentation through image processing, 10th International Symposium on Rock Fragmentation by Blasting, Fragblast10, November 24 - 29, New Delhi.
27. Venkatesh, H.S., Balachander, R., Gopinath, G. and Theresraj, A.I. (2012) Controlled blasting for underground hydroelectric projects – NIRM experience, 10th International Symposium on Rock Fragmentation by Blasting, Fragblast10, November 24 - 29, New Delhi.

2013

1. Balasubramaniam, V.R., Jha, P.C., Chandrasekhar, E., Butchi Babu B., Sivaram, Y.V. and Sandeep, N., (2013) Imaging weak zones in the foundation using frequency domain attenuation tomography, Journal of Applied Geophysics.

2. Balasubramaniam, V.R., Jha P.C. and Chandrasekhar, E., (2013) Imaging near surface defects using step-frequency ground-penetrating radar, Near Surface Geophysics, vol. 11, pp. 19-27, doi : 10.3997/1873-0604. 2012044.

3. Biju John and Yogendra Singh, (2013) Precambrian Geology as background information to active tectonics in shield areas. In XII MSI National Seminar on “Current trends of Research in Precambrian Geology and Vision 2020” at Mysore University, Karnataka, India. pp. 149-150.

4. Biju John, Yogendra Singh, Sandeep Nelliat and Ganapathy, G.P., (2013) Morphotectonic evidence of active deformation - an example from Peninsular India. In Abstract Volume of International Symposium on Advances in Earthquake Science, Gandhinagar. pp. 32-33.

5. Kumar Reddy S. and Sastry V.R., (2013) Gallery supporting and monitoring in Blasting Gallery panel during depillaring - A case study, International Conference on Developments in Best Practices in Surface and Underground Mining and Innovative Developments in Mining Machinery, 28-30 January 2013, Kolkata.

6. Kumar Reddy S., (2013) Mass production technology in underground coal mines of SCCL – An emerging trend, 2nd World Conference on Applied Science and Engineering Technology, 8-9 March 2013, Hyderabad.

7. Lokhande, R.D., (2013) Pot hole subsidence in underground coal mining – Some Indian experiences. International J. of Geotechnical and Geological Engineering. vol. 31, no. 2, pp. 793 – 799.

8. Lokhande, R.D., (2013) Pot hole subsidence in underground coal mining – A case study. Indian Conference on Mine Surveying (ICMS-2012), Indian School of Mines, Dhanbad. pp. 255 – 262.

9. Manoj Kumar, Naithani, A.K. and Pijush Samui, (2013) Excavation and support for weak rock mass encountered during construction in large underground cavern, presenting in a National Workshop on Contemporary Practices in Engineering Geology and Geohazards, Hyderabad, 14th June, 2013, Organized by ISEG.

10. Manoj Kumar, and Pijush Samui (2013) Analysis of Epimetamorphic rock slopes using soft computing, International Journal of Shanghai Jiaotong University.

11. Manoj Kumar, Manav Mittal, and Pijush Samui, (2013) Performance assessment of genetic programming (GP) and minimax probability machine regression (MPMR) for prediction of seismic ultrasonic attenuation, Earthquake Science, vol, 26, no. 2, pp. 147-150.

12. Manoj Kumar, Pijush Samui and Bhairevi, G. Ayer, (2013) Machine Learning Techniques Applied to Uniaxial Compressive Strength of Oporto Granite, International Journal of Performability Engineering.

13. Manoj Kumar, Pijush Samui, and Naithani, A.K., (2013) Determination of uniaxial compressive strength and modulus of elasticity of travertine using machine learning techniques, International Journal of Advance soft computing application, vol. 5, no. 3,

14. Manoj Kumar, Jain, P., Naithani, A.K. and Pijush Samui, (2013) A study of Water Curtain system – Underground crude oil storage rock cavern Padur, Karnataka, India, presenting in a National Workshop on Contemporary Practices in Engineering Geology and Geohazards, Hyderabad, 14th June, 2013, Organized by ISEG

15. Naithani, A.K and Singh, L.G, (2013) Engineering geological investigations of surge pool and pump house (5 x 130 MW) area of Pranahitha - Chevella Sujala Sravanthi Lift Irrigation Scheme- 08, Karimnagar District, Andhra Pradesh. ISRM (India) Journal. vol.2, no. 2, pp. 9-18.

16. Naithani, A.K., Nawani, P.C., Singh, L.G., and Devendra Singh Rawat, (2013) Engineering Geological Evaluation of the Spillway of Dam II-B of Bunakha Hydroelectric Project, Chukha Dzong, Bhutan. Journal of Geological Society of India. vol. 81, no. 6, pp.835-843.

17. Rajendran, C.P., Rajendran, K., Biju John and Sanwal, J., (2013) Earthquake recurrence in the central Himalaya: Some outstanding issues. In EGU General Assembly. vol. 15, EGU2013-2688-1.

18. Singh, L.G., Naithani, A.K., Rawat, Devendra Singh and Nawani, P.C., (2013) Geological, lineament and landslide studies of the reservoir and its vicinity of Bunakha hydroelectric project, Bhutan Himalaya. Journal of Engineering Geology, vol. XXXVIII, no. 1, pp 90-111.

19. Srinivasan, C., Willy, Y.A. and Carter, R.M., (2013) Strong motion rockburst study in the flooded mines of Kolar Gold Fields. Proc. Symposium on Advances in Earthquake Sciences, Institute of Seismological Research, Gujarat, February, 2013.

LETTER OF SANCTION FOR NIRM ESTABLISHMENT

Institute file

BHARAT GOLD MINES LIMITED
611
1988
Managing Director

cc- 1) Chairman, Gmi
2) DGM/MPTS
3) DGM/Fin
4) Sri R. Krishnamurthy (CGM)
5) CMFS, RDLC
6) Secy
7) Contl. (CMO)
8) DGM/ES

No.14/22/87-Met.V
Government of India
Ministry of Steel & Mines
Department of Mines

New Delhi, the 27th Jan., 1988.

To

Shri P.A.K. Shettigar,
Managing Director,
Bharat Gold Mines Ltd.,
Suvarna Bhavan, Oorgaum P.O.
Kolar Gold Fields - 563120,
Karnataka.

Subject:- Sanction for establishment of Institute of Rock Mechanics and Ground Control at K.G.F.

Sir,

I am directed to refer to your letter No.362/S&T/30, dated [illegible].87 on the above subject and to convey the sanction of the President for establishment of the Institute of Rock Mechanics and Ground Control at KGF under Science & Technology (Plan) at a total expenditure not exceeding Rs.200 lakhs (Two hundred lakhs only) including a foreign exchange component of Rs.40.00 lakhs (Rupees Forty lakhs only) as per details given below:

	(Rs. in lakhs)
i) Building	15
ii) Equipments	108
iii) Recurring	77
Total	200

2. The expenditure involved in each year would be limited to the budget provision for the scheme made for that year and would be met out of the sanctioned budget.

3. This issues with the concurrence of the I.F. Division of the Deptt. vide their Dy.No.319/IF/88, dated 27.1.88.

Yours faithfully,

(V.C. Kulkarni)
Under Secretary to the Govt. of India

BHARAT GOLD MINES LIMITED
3/2/88
69
CHIEF SCIENTIST

NIRM REGISTRATION CERTIFICATE (1 of 2)

[illegible]

ನೋಂದಣಿ ಪ್ರಮಾಣ ಪತ್ರ No 60/88-89

[illegible]

[illegible] "KOLAR INSTITUTE OF ROCK MECHANICS AND GROUND CONTROL", Kolar Institute of Rock Mechanics and Ground Control, P.O.Champion Reefs, Kolar Gold Fields, Karnataka, PIN-56[illegible]

[illegible]

[illegible] Rupees Fifty paid as per receipt No.270336/22-7-88.

KOLAR [illegible] 88 [illegible] JULY [illegible] 23rd

[illegible]

[illegible] The Registrar [illegible] Kolar District, Kolar.

[illegible]

NIRM REGISTRATION CERTIFICATE (2 of 2)

Soc. 60/3/88-89

OFFICE OF THE REGISTRAR OF SOCIETIES.

Kolar.
Dated: 19/5/90

Received from the Secretary Kolar Institute of Rock Mechanics and Ground Control, Champion Reefs post, KGF.

with his letter No. F-35/90-91 dated 16/5/90

the under mentioned documents, as required by section 13 of Karnataka Societies Registrations Act 1960.

Fees paid Rs. One hundred and fifty only.

1. List of committee members and Balance Sheet with accounts is filed.

3. Amendments to Memorandum and Rules and Regulations filed.

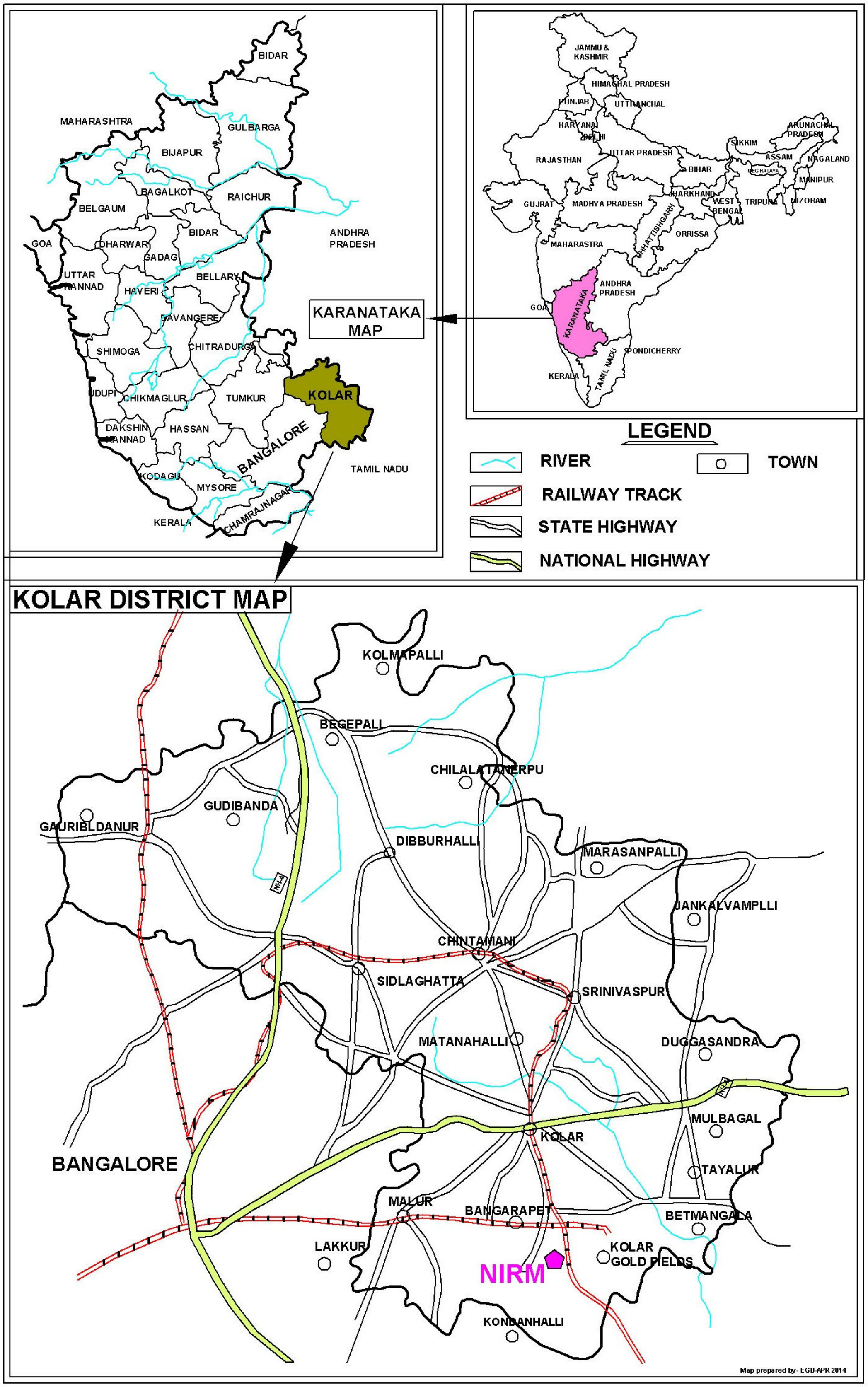
Amendment Regarding change of Name as "National Institute of Rock Mechanics, (Kolar) Champion Reefs post, KGF" is Approved.

Registrar of Societies,
Registrar of Societies,
Kolar District, Kolar.

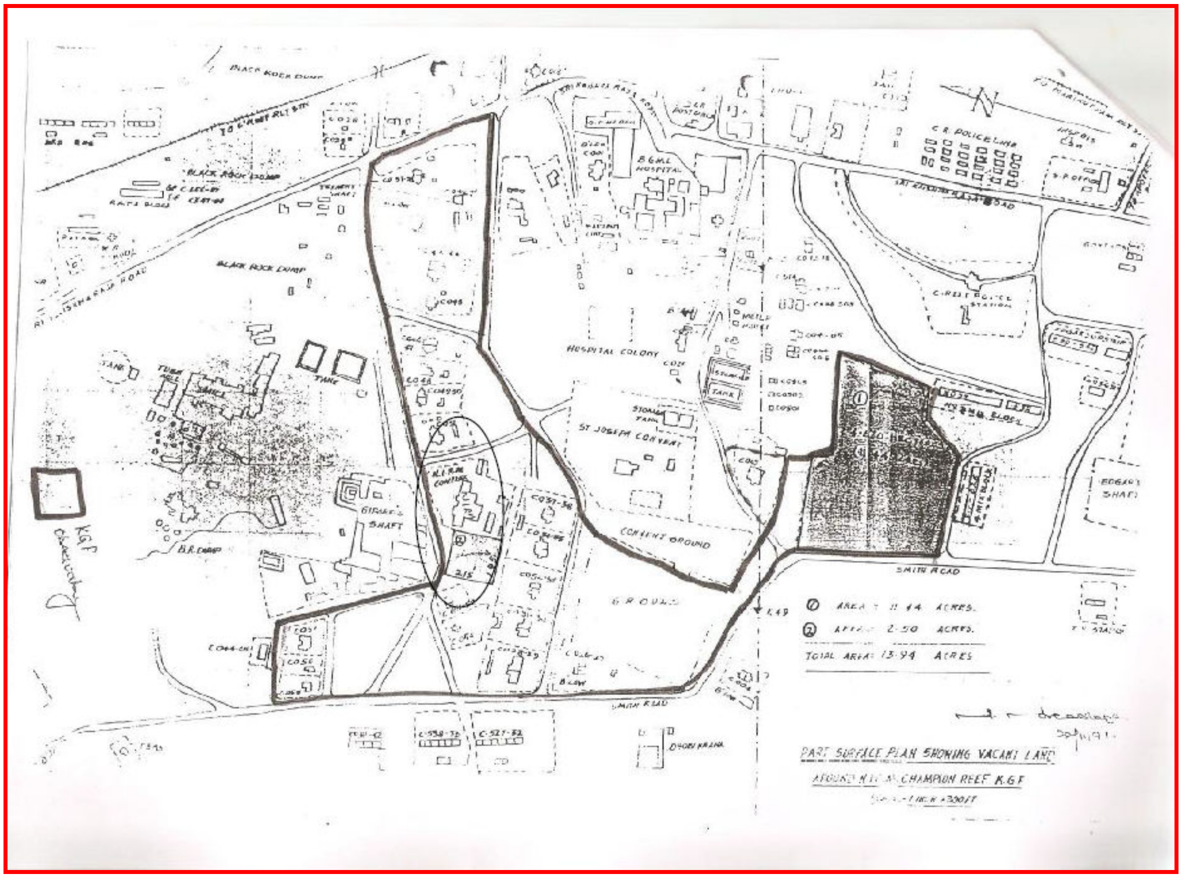
To
The Secretary,
of the Association.

MF/-

LOCATION MAP OF KGF



PLAN MAP OF CHAMPION REEFS AREA



The persons who formed the Society of the "Kolar Institute of Rock Mechanics & Ground Control" in 1988

	The General Body	The Governing Body
1	Sri BK Rao Secretary to the Govt. of India Department of Mines Ministry of Steel & Mines "Shastri Bhavan" New Delhi – 110 001	Sri BK Rao Secretary to the Govt. of India Department of Mines Ministry of Steel & Mines "Shastri Bhavan" New Delhi – 110 001
2	Sri PK Lahiri Additional Secretary Department of Mines Ministry of Steel & Mines "Shastri Bhavan" New Delhi -110 001	Sri PK Lahiri Additional Secretary Department of Mines Ministry of Steel & Mines "Shastri Bhavan" New Delhi -110 001
3	Sri S Panchapakesan Finance Adviser & Addl. Secretary Ministry of Steel & Mines Udyog Bhavan New Delhi	Sri S Panchapakesan Finance Adviser & Addl. Secretary Ministry of Steel & Mines Udyog Bhavan New Delhi
4	Sri IM Aga Chairman Bharat Gold Mines Ltd. Suvarna Bhavan OORGAUM - 563120 Kolar Gold Fields, Karnataka	Sri IM Aga Chairman Bharat Gold Mines Ltd. Suvarna Bhavan OORGAUM - 563120 Kolar Gold Fields, Karnataka
5	Sri PAK Shettigar Managing Director Bharat Gold Mines Ltd. Suvarna Bhavan OORGAUM - 563120 Kolar Gold Fields, Karnataka	Sri PAK Shettigar Managing Director Bharat Gold Mines Ltd. Suvarna Bhavan OORGAUM - 563120 Kolar Gold Fields, Karnataka
6	Sri HV Paliwal Director (Mining Operations) Hindustan Zinc Limited Yashad Garh, Yashad Bhawan Udaipur – 313 001 (Rajasthan)	Sri HV Paliwal Director (Mining Operations) Hindustan Zinc Limited Yashad Garh, Yashad Bhawan Udaipur – 313 001 (Rajasthan)
7	Sri MA Khan Director (Technical) Hindustan Copper Ltd Calcutta	Sri MA Khan Director (Technical) Hindustan Copper Ltd Calcutta

	The General Body	The Governing Body
8	Dr BB Dhar Professor of Mining Engineering Dept of Mining Engineering Institute of Technology Banaras Hindu University Varanasi – 221005	Dr BB Dhar Professor of Mining Engineering Dept of Mining Engineering Institute of Technology Banaras Hindu University Varanasi - 221005
9	Prof AK Ghose Professor of Mining Engineering Dept of Mining Engineering Indian School of Mines Dhanbad – 826 004	Prof AK Ghose Professor of Mining Engineering Dept of Mining Engineering Indian School of Mines Dhanbad – 826 004
10	Dr PK Iyengar Director Bhabha Atomic Research Centre Trombay, Bombay	
11	Sri DN Bhargava Controller General Indian Bureau of Mines, New Secretariat Buildings, Civil Lines, Nagpur	
12	Sri VC Varma Director General of Mines Safety DGMS, Dhanbad	
13	Prof GS Marwaha Retd. Director Indian School of Mines 8 Kannamwar Nagar, Wardha Road Nagpur – 440 025	
14	Sri R Krishnamurthy Consultant (Rock Mechanics) 511 Chinmaya Mission Hospital Road Indiranagar, Bangalore - 560 038	

Sri BK Rao
(Chairman, 1st Governing Body, NIRM)

Sri Bhamidipati Kukkuteswara Rao (BK Rao) was born in Akividu, West Godavari District, Andhra Pradesh. He graduated from Dantuluri Narayana Raju College, Bhimavaram, and did post-graduation in Geology from Andhra University, Vishakhapatnam. He was selected for All India Civil Services in 1958. He was Chittoor District Collector/Magistrate during 1961-63, Addl Secretary, Dept of Agriculture during Oct. 1969, and worked as the Commissioner, Commercial Taxes Dept, AP, during 1979.

Sri BK Rao was the Secretary to the Govt of India, Ministry of Mines, from 1985 till his retirement in June 1989. He conceptualized the creation of a national institute specialized in the field of rock mechanics, to be carved out of the R&D Unit of the Bharat Gold Mines Ltd, to continue the legacy of the ground control research being carried out at the Kolar gold mines. He worked to this end, and was thus instrumental in founding the Kolar Institute of Rock Mechanics and Ground Control, later renamed as National Institute of Rock Mechanics, at Kolar Gold Fields.

Presently he resides with his sons in USA.

Sri PK Lahiri

(Member, 1st Governing Body, NIRM)

Born on April 28, 1937, Mr PK Lahiri belonged to the 1959 batch of the IAS and was allotted to the Madhya Pradesh Cadre. He has a Masters Degree in Modern History from Allahabad University and also a Diploma in Development Studies (with distinction) from the University of Cambridge, UK.

Prior to his retirement from the IAS in 1995, he held the positions of Secretary to Government of India successively as Secretary, Ministry of Mines (1989-90) and then Revenue Secretary in the Ministry of Finance (1990-91), before serving as India's Executive Director in the Asian Development Bank, Manila with the rank of Ambassador (1991-95).

Mr Lahiri is currently Chairman of the General Council and Executive Board of the Indian School of Mines University, Dhanbad, a Deemed University, well known as a premier Engineering Institute in the country, with core specialization areas in Earth Sciences and Mining Engineering.

He served as an independent Director on the Boards of Tata Sponge Iron Ltd. (from 1997 to 2011) and is on the Boards of certain other Companies. He was the Co-Chairman of Management Council of the Atomic Minerals Division (AMD) of the Department of Atomic Energy, Government of India from 2007 to 2011. Earlier he chaired the Committee that submitted its report to the Department of Atomic Energy on Augmentation of Uranium Supplies.

He authored a book titled 'Decoding Intolerance – Riots and the Emergence of Terrorism in India' which has been published by Roli Books.

From 1996 to 2000 Mr Lahiri was Chairman of the Expert Committee for Infrastructure Development of Miscellaneous Projects under the Government of India's Ministry of Environment & Forests. After retirement from IAS, he served as the Secretary General of the Indian Newspaper Society (INS), a Central Body for the Press in India from 1997 to 2005.

In the State of Madhya Pradesh, he has held responsible positions, such as, Collector & District Magistrate successively in three districts (1964-69), i.e. Guna, Khandwa and Indore, Divisional Commissioner, Gwalior Division (1976-80), and Principal Secretary (Health) to the State Government, Bhopal (1985-86).

In his first deputation to the Central Government he served as General Manager, Panna Diamond Mines, NMDC (1969-1971). He also later served in the Central Government, on deputation, in different Ministries i.e. Ministry of Mines, Ministry of Coal and Ministry of Industry. In the Government of India he worked as Joint Secretary in the Ministry of Coal for over 5 years (1980-85) and, subsequently as Additional Secretary and then as Secretary in the Ministry of Mines (1986-89; 1989-90). Thereafter, he served as Secretary (Revenue) in the Ministry of Finance (1990-91). He retired from service in 1995 after serving as India's Executive Director, in the rank of Ambassador, in the Asian Development Bank, Manila, Philippines from December 1991 to June, 1995.

During his service period Mr Lahiri served as Nominee Director on the Boards of several major public sector undertakings in the coal and mining sectors, such as, Coal India Ltd, Neyveli Lignite Corporation, Eastern Coalfields Ltd, Singareni Collieries Company Ltd and Hindustan Zinc Ltd. He was also a Nominee Director on British India Corporation, Elgin Mills, Kanpur and Cawnpore Textiles, Kanpur.

Mr Lahiri has attended numerous international conferences abroad and led Government of India's delegation in four successive Annual Meetings of the International Lead Zinc Study Group (ILZSG) from 1986 to 1989, held alternately in Geneva and Vienna. In his capacity as Secretary (Mines) in the Government of India, he led Government of India's delegation to the World Mining Congress, held in Beijing in February, 1990. As Executive Director, ADB, he led the delegation of Board of Directors of ADB in visits to Malaysia, Indonesia, Mongolia, Sri Lanka and Peoples Republic of China during 1993-95.

Sri PAK Shettigar

(Member, 1st Governing Body, NIRM)

Sri PAK Shettigar graduated in Mining Engineering from the College of Engineering, Guindy, Madras, in the year 1960.

Sri Shettigar joined the KGF mines at the very commencement of his career as a mining engineer. After a short stint in KGF, he switched over to Mosaboni group of mines of Hindustan Copper Ltd (HCL). While serving in HCL, he introduced various mining practices of great practical importance to the mining industry.

Later he returned to Bharat Gold Mines Ltd (BGML), became its Director in the year 1984, and then took over the mantle of Managing Director in the year 1987. In BGML, he introduced newer concepts and modern technologies, such as sub-level method of stoping in narrow ore bodies, introduction of flotation in the metallurgical plant, implementation of carbon-in-pulp for improved gold recovery and also, the concept of treating old mill tailings for gold recovery by the CIP route, amongst many others. In view of the fast depleting reserves of gold in the KGF mines, he played a leading role in the diversification activities utilizing the expertise available with the company.

Sri Shettigar was the Branch Chairman for Mining, Geological & Metallurgical Institute of India (MGMI), and was the President of the KGF Mining and Metallurgical.

Sri HV Paliwal

(Member, 1st Governing Body, NIRM)

Sri Harihar V Paliwal was born on 11.11.1937 at Udaipur, had school education in Govt. Schools at Udaipur. After passing Intermediate Science from Udaipur, he joined the College of Mining and Metallurgy, Banaras Hindu University and obtained the degree of B.Sc. (Mining Engineering) standing first in order of merit. He was awarded BHU Gold medal and Roberton Medal of MGMI for the best student of 1958.

Sri Paliwal obtained First Class Mine Manager's Certificate of Competency, Coal in 1961, and Metal in 1964. After a brief spell of three years in coal mining, he joined the lead-zinc mines of Zawar, Rajasthan. Starting as Senior Mining Engineer in January 1962, he rose to the position of Director (Mining Operations), Hindustan Zinc Limited, in 1985. After 10 years as Director (MO), he retired from Hindustan Zinc Ltd. on 30.11.1995. He witnessed growth of HZL, from a 500 tpd ore mine to 10740 tpd ore mine, and foundation of Debari Zinc Smelter to commissioning of Rampura-Agucha Mines and Chanderiya Lead-Zinc Smelter, thus making significant contribution to the development of HZL.

From April 1996 to October 1999, he worked as Advisor to Binani Industries and carried out due diligence of Zambian Copper Mines and prepared the Business Plan for Luanshya Copper Mine for which Binani Industries offer was accepted. The Luanshya Copper Mines were transferred to Binani Industries in October 1997. From March 2000 to December 2004, Sri Paliwal worked as Advisor Metmin Finance & Holdings Pvt Ltd owned by Lord RK Bagri who was Chairman of LME for ten years. He advised Metmin on grass root exploration for base metals in Rajasthan and Madhya Pradesh. Sri Paliwal was retained by Indo Gold Mines Private Limited as Advisor for their gold exploration in Rajasthan from June 2005 to July 2012. Currently he is retained as Advisor Mining by Royal Salt Limited Nigeria since June 2012.

He has visited mines and smelters in Canada, USA, UK, Norway, Finland, Germany, Poland, USSR, China, Japan, Australia, Vietnam etc. He was member of the Indian delegation to USSR for Non Ferrous Metallurgy, World Mining Congress (1990) held at Beijing, China. He led a technical team to BRGM, France, to identify mineral prospects in other countries, where BRGM-GOI (GSI and PSUS) could have joint venture exploration and mining projects. This team identified Vietnam as a potential country with whom GOI/HZL had continued dialogue for a joint venture. He participated in Workshop on Environmental Problems of Non Ferrous Metals organized by United Nations Environmental Programme at Geneva and Workshop on Use of Radio Isotopes in Mineral Industry held in Bagoia, Philippines, by International Atomic Energy Commission. Accompanied Hon. Minister of Mines and Steel (GoI) on his official visit to Australia (1986) as Technical Expert, and Secretary Mines (GOI) on official visit to Australia in 1993.

Sri HV Paliwal was honored as distinguished Alumni by Department of Mining Engineering, BHU in 1983. He was awarded Sir J Coggin Brown Memorial Gold Medal by MGMI in the year 1989 for his contributions to base metal mining industry. He is a recipient of National Mineral Award for the year 1990-91 in recognition of his significant contributions in the field of mining technology, beneficiation of ores, metallurgy and by-product recoveries, mine planning and rock mechanics, and his productive work in the sphere of lead-zinc and silver metals. Recipient of Glimpses of Engineering Personalities 2008 Award from the Institution of Engineers (India) on the occasion of 23d Indian Engineering Congress at Warangal. He was presented a Gold Medal by the State Government of Rajasthan for his contribution to mineral development of the State in 1998. He was given Smt Gullapalli Sarladevi Memorial Life Time Achievement Award 2012 (to a mining engineer) by the Mining Engineers Association of India in June 2013.

He is a Member of various expert committees/governing bodies such as the Working Group for Mining and Environment, Standing Scientific Advisory Group, National Institute of Rock Mechanics, Board of Mining Examinations in India etc. He was member of the Expert Committee (Mining) of Ministry of Environment and Forests, from January 1996 to March 2007. He was a member of Augmentation of Uranium Supply Committee of Department of Atomic Energy from January 2006 to March 2007. He was member of the Council of Management of Atomic Minerals Directorate for Exploration and Research from August 2006 to March 2012.

Sri Paliwal is Fellow of Institution of Engineers (India), Member of Canadian Institute of Mining and Metallurgy; Mining Geological and Metallurgical Institute of India. His unstinted commitment and leadership as Working Chairman of the Organizing Committee led to the grand success of the 22^{nd} Indian Engineering Congress at Udaipur in December 2007.

Prof BB Dhar

(Member, 1^{st} Governing Body, NIRM)

Professor Bharat Bhushan Dhar (born 9-1-1938) is a well known expert of mining, environment and higher education in this country, and has significantly contributed to the development of mining education, research and sustainable development of mineral resources.

As a Member of the Task Force on MoU, Ministry of Heavy Industries and Public Enterprises, Department of Public Enterprises, Government of India, for over five years (till December 2009) with Mining and Metals Syndicate, Prof Dhar has shown his capability of assessment, analysis of assets and the role of Corporate Social Responsibility (CSR) as an effective tool for sustainable development, and, green initiatives in the corporate world. Prof Dhar has been actively involved in the decision making bodies of the country at various levels.

Even today he is actively involved in the following bodies:

1. Chairman Alternate, EIA Accreditation Committee, National Accreditation Board for Education and Training, Quality Council India, Government of India.
2. Vice-President and Founder Member, Centre for Techno-Economic Mineral Policy Options (C-TEMPO), Ministry of Mines, Government of India.
3. Director, Tamil Nadu Industrial Explosives Limited (TEL), a Government of Tamil Nadu Undertaking.
4. Member, Research Council CSIR-North Eastern Institute of Science & Technology (NEIST)
5. Member, Research Council, CSIR-National Environmental Engineering Research Institute (NEERI)
6. Hony. Member, Federation of Indian Mineral Industries (FIMI)
7. President, Kashmir Education, Culture and Science Society Regd. (KECSS) – A Global Socio-Cultural Organization in India.
8. Chairman, Mining Engineers' Association of India, Delhi Chapter
9. Member, Governing Body and General Body, National Institute of Rock Mechanics, Ministry of Mines, Government of India.

Besides, he is member on several other committees of CSIR/Ministry of Mines/ other Government organizations from time to time.

Prof Dhar is the former:

i) Sr. Vice-President, Ritnand Balved Education Foundation, the Sponsoring Body of Amity Universities, and Director, Research & Innovation, Amity University, NCR, New Delhi.
ii) Member of the First Academic Council, Central University of Himachal Pradesh. MHRD, Government of India (2010-2013)
iii) Chairman, Expert Group on Prevention, Abatement and Control of Pollution, Ministry of Environment and Forest, Government of India.
iv) Member, Research Council, Institute of Minerals & Materials Technology, CSIR, Bhubaneswar.
v) Member, Research Council, Advanced Minerals & Processes Research Institute, CSIR, Bhopal.
vi) Director (Research), Association of Indian Universities (AIU), New Delhi, the body coordinating the university education in the country.
vii) Director, Central Mining Research Institute (CMRI), Dhanbad (now CIMFR)

viii) Professor and Head, Department of Mining, Institute of Technology, Banaras Hindu University.

ix) Member, Standing Scientific Advisory Group (SSAG), Ministry of Mines, Government of India.

Prof Dhar has published over 120 scientific and technical papers and edited five books, including the Indian edition of ''UNDP Training Manual on Environmental Management of Mine Sites'' published by Oxford & IBH Publishing Co Ltd.

He authored a book on ‘Mining and Environment’, published by APH Publishing Corporation, New Delhi was released in 2000.

He was on the editorial board of three technical journals, two of which are published from abroad and was Editor in Chief, Journal of Mining Research’ published by Wiley Easter Ltd., New Delhi (till 1997).

He was also on the editorial committee of ‘University News’ (a weekly journal of higher education) published by the Association of Indian Universities, New Delhi (1999-2002).

He has several Awards to his credit, namely:

1. National Mineral Award, Ministry of Mines, Government of India, (1994)
2. CSIR Technology Award (1995)
3. NRDC Award for invention on the 1st Technology Day, on May 11, 1999
4. Dewan Bahadur DD Thacker Coal Mining Gold Medal of MGMI;
5. Rajendra Prasad Gold Medal of Institution of Engineers
6. “Award of Excellence-2002” by the “Society of Geoscientists and Allied Technologist”, Bhubaneswar.

Prof AK Ghose

(Member, 1st Governing Body, NIRM)

Prof Ajoy Kumar Ghose was born on 13th April 1934; he did graduation in Mining Engineering from Indian School of Mines, Dhanbad (First Class First in 1956 batch). He joined National Coal Board, UK (1957-59), during which he passed the Associate Membership Examination from Institution of Mining Engineers, London (1958) and received Laurence Holland Medal and Prize of the Institute. He passed First Class Manager's Certificate of Competency examination in the year 1960. He became a Senior Scientific Officer at the Central Mining Research Station, Dhanbad (1960-62), where he set up the Rock Mechanics and Hydraulic Stowing laboratories, undertook pioneering research work on coal mine ground control and roof bolting. At the age of 28 years, he became a Professor of Mining Engineering, and Foundation Head of Department of Mining at the Regional Engineering College, Srinagar (now the National Institute of Technology, Srinagar).

He joined the Mining Engineering Department at Indian School of Mines on 14th Nov 1966, and spent most of his career as Professor there. He set up the Centre of Rock Excavation Engineering, the Rock Mechanics Laboratory and the Experimental-cum-Training Mine (in collaboration with BCCL). He initiated new undergraduate and post-graduate programmes, and delved in research which included studies on strength and deformation properties of coal and coal measure rocks, ground control studies in bord and pillar and longwall mining, rock bolting, blast vibration studies and environmental impacts of mining. Amongst his notable research contributions is the formulation of ISM-CMRS rock mass classification system for coal mines for the purpose of selection of roof supports in bord and pillar development workings. He was among the first to initiate work on estimation of fracture toughness and abrasivity of rocks. He was the Director of Indian School of Mines from 1991 to 1994.

Prof Ghose was AICTE Emeritus Fellow, and is now Adjunct Professor, at the Bengal Engineering and Science University, Shibpur, and as Director of the Central Mine Planning and Design Institute of India. He was a Visiting Scientist, University of Ostrava (1971), Visiting Professor at the University of Newcastle-upon-Tyne (UK) (1973-74), and Honorary Professorial Fellow at the University of Wollongong (Australia). He is a Fellow of the Indian National Academy of Engineering, a Foreign Member of the Academy of Mining Sciences of Russia, and an Honorary Life Member of the Polish Association of Mining Engineers. He had extensive exposure to coal mining industry in U.K. China, Indonesia, Poland, Germany, Bulgaria, Czechoslovakia, USA.

He served as a Consultant to the World Bank, ILO, ESCAP, and others in India, Bhutan, Nepal, Indonesia and Tanzania. He was a consultant to IBP, Gujarat Heavy Chemicals, Development Consultants Limited amongst others. He was President, Mining Geological and Metallurgical Institute of India (1987-88; 1988-89). He was President of the Institution of Engineers (India), (1998-99). He was President, Federation of Engineering Institutions of South & Central Asia (1998-2000). Served as Member, Governing Council of Indian National Academy of Engineering, Member Board of Governors, Indian Institute of Coal Management, Birla Institute of Technology (Mesra), Member Executive Committee of the Central Mining Research Institute, Member Board of Mining Examinations(Coal) of the Ministry of Labour and Employment, Member of R & D Board of Neyveli Lignite Corporation etc. Prof. Ghose is a Foreign Member of the Academy of Mining Sciences of Russia, the only one from India and Far East.

Prof Ghose was assessor to Courts of Enquiry for mine disasters at Mahavir Colliery and New Kenda Colliery and Advisor (HRD) of Coal India. He Organized 12th and 19th World Mining Congresses at New Delhi as Chairman, National Organizing Committee and scores of International and National Conferences / Symposia / Congresses. He edited the proceedings of over

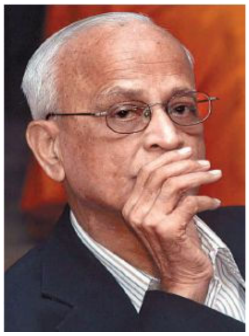
20 international and national symposia. He developed and organized 20 management programmes on Total Quality Management for the mining industry.

Prof Ghose has received many national and international honours, including the Krupinski Medal of the World Mining Congress (1987 and 2006), Honorary Doctorate from Technical University of Petrosani, Romania, Dewan Badadur DD Thacker Coal Mining Medal of the Mining, Geological & Metallurgical Institute of India, the National Design Award in 1987 and 1993, the National Mineral Award in 1995Foreign Membership of the Academy of Mining Sciences of Russia, and Honorary Life Membership of the Polish Association of Mining Engineers. He delivered several prestigious lectures, including the first Foundation Lecture of the Indian Geological Society, the first Kautilya Lecture, the 36th Nidhubhushan Memorial Lecture of the Institution of Engineers (India), and the 46th Holland Memorial Lecture of the MGMI. Prof Ghose is a Fellow of the Indian National Academy of Engineering (since 1987), the President of the Institution of Engineers (India) (1998), President of the Federation of Engineering Institutions of South and Central Asia (1998-2000), and President of the Mining, Geological & Metallurgical Institute of India (1987-88). Since 1987, he has been a Vice Chairman of the International Organizing Committee of the World Mining Congress.

Prof Ghose has published over 350 papers. His research contributions in the areas of rock mechanics, rock excavation engineering, innovative mining systems and sustainable mineral development are widely acknowledged. Prof Ghose also has several books to his credit. He is also the Editor of the Journal of Mines, Metals and Fuels, and Indian Journal of Power & River Valley Development.

Dr PK Iyengar

(Member, 1st General Body, NIRM)

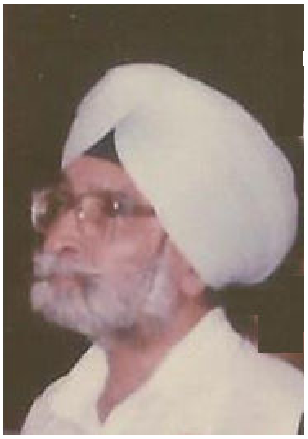


Dr Padmanabhan Krishnagopalan Iyengar was the Director, BARC, during 1984-1990. He pioneered the neutron scattering programme at Trombay. Along with Dr Ramanna, he recognized the importance of Neutron beam research, as a fertile training ground for Scientists, in the broader context of mastering reactor and nuclear technologies, which have put India firmly on the World map in studying condensed matter with neutrons. Following the 1964 IAEA meeting, a programme for introducing neutron scattering at nuclear reactors in South-East Asian countries was initiated by IAEA, and Dr Iyengar was also involved in the development of the fast reactor assembly, Purnima-1. Subsequently, Purnima-2 was also built; a critical assembly with a solution of uranyl nitrate as the core. Dr Iyengar's training at Italy and USSR on pulsed neutron sources was instrumental in his leadership role, in the planning of new accelerators at VECC, RRCAT and TIFR.

Dr PK Iyengar, passed away in December, 2011.

Prof GS Marwaha

(Member, 1st General Body, NIRM)



Professor Gurbachan Singh Marwaha was a 1947 batch Mining Engineering graduate from Indian School of Mines, Dhanbad. He worked for 22 years in the Directorate General of Mines Safety. In December 1972, he became the Director of Indian School of Mines, which he served for 13 years.

Prof GS Marwaha, FIME, F1MM, FIE (India), was associated with the Institution of Mining Engineers since 1945, and since 1967 he served as Co-opted Member for India on its Council. In 1973 he became the first recipient of the IME Overseas Award. A Member (later Fellow) of the Institution of Mining and Metallurgy since 1959, he represented India and Pakistan on its Council since 1968. Prof Marwaha served as President of the Association of Indian Universities, and as President of the Mining, Geological and Metallurgical Institute of India from 1980-81.

He chaired Advance Environment Planning Groups (1987-90) set up by the GOI Deptt. of Coal, and also the Expert Committee set up by the erstwhile GOI Deptt. of Environment, Forests & Wildlife on the updating of EMPs of the Supreme Court permitted limestone mines of the Dehradun Valley (1989). He was chairman of the Research Advisory Councils of (a) the erstwhile Central Mining Research Station, Dhanbad (1982-87) and (b) the National Geophysical Research Institute, Hyderabad (1982-84), and a member of the GoI Environment Appraisal Committee (Mining projects) for seven years (1983-90).

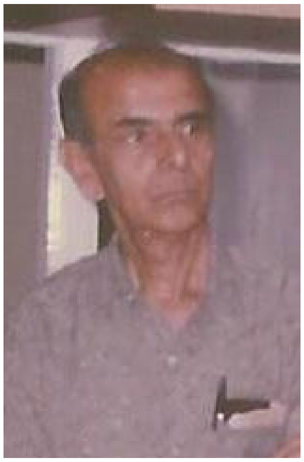
Prof Marwaha's experience spanned the disciplines of mine safety standards and development/review of mining education & research projects. In later years he developed expertise in the maintenance and protection of environment in mining areas. In 1990, he established a Mining and Environmental Consultancy at Nagpur where he settled down after retirement.

In recognition of the services rendered by him in the fields of mining standards, education and research, Prof Marwaha was conferred the Degree of Doctor of Science (Honoris Causa) by the Indian School of Mines in 1995.

Prof GS Marwaha died in May 2000 at Pune.

Sri R Krishnamurthy

(Member, 1st General Body, NIRM)



Sri R Krishnamurthy did MSc (Rock Mechanics) from New Castle-upon-Tyne University, UK. He joined the then Kolar Gold Mines Undertaking (KGMU) as an Engineer in its Rockburst Research Unit (RRU), and raised to the position of Chief Scientist heading the Research & Development Unit of Bharat Gold Mines Ltd. He was closely associated with Bhabha Atomic Research Centre in establishing the seismic & micro-seismic laboratories at the R&D Unit of BGML. He was also instrumental in establishing the Materials Testing Laboratory to conduct wire rope testing and both destructive & non-destructive testing on mining machineries.

He Superannuated as Manager (MP & TS), R&D Unit, BGML in 1986, and then served as Consultant (Rock Mechanics), BGML for three years.

Sri Krishnamurthy specialized in rock mechanics research including seismic and micro-seismic investigations pertaining to hard rock mines at depth. He served for about 38 years in this area, and had extensive experience in the field of strata monitoring, stability and seismic investigations. He was a recipient of National Mineral Award for his work on micro-seismic studies at KGF mines.

He authored and presented about 20 research papers in both national and international fora.

Sri Krishnamurthy passed away in the year 2009.

Prof DP Singh

(Chairman, Peer Review Committee (1999-2000), NIRM;
former Member, Governing Body, NIRM)

Professor DP Singh was born on September 03, 1938 in Jaunpur District of Uttar Pradesh. He graduated in Mining Engineering from Banaras Hindu University in 1960. He went on to complete his Masters in Engineering Science and PhD from the University of Melbourne in the years 1968 and 1971, respectively.

Prof Singh joined Banaras Hindu University as a faculty in 1962. He was Professor and Head of the Department of Mining Engineering. He was also the Coordinator of the Centre of Advanced Study in Rock Mechanics and Ground Control.

He has over 50 years of experience in teaching and research. He has published more that 200 papers in different national and international journals as well as proceedings of the seminars and symposia. Nineteen students have received their doctoral degrees (PhD) under his guidance. Prof Singh has delivered many invited Lectures and attended several seminars and symposia in India and abroad. He has completed 10 sponsored research projects and 22 consultancy projects.

Prof Singh has visited a number of countries including Australia in 1967, Thailand and Singapore in 1971, Germany and U.K. in 1976, USA and UK in 1980, Sweden and UK in 1983, Poland in 1984, Israel, China and Hong Kong in 1986, France and UK in 1989, Australia in 1992 and 1996, and Germany in 1996 and 1998, USA, UK, Canada, Sri Lanka, Egypt in 2003 and Japan in 2004, in connection with higher studies and for participation in various academic programs.

Prof Singh was the Vice-Chancellor of the Awadhesh Pratap Singh University, Rewa (MP) during 1991-1993, Vice-Chancellor of the University of Lucknow, Lucknow during 1999-2002 and Vice-Chancellor of the UP Rajarshi Tandon Open University, Allahabad, during 2002-2005.

In addition Prof Singh has held the prestigious positions of

- Director, Uranium Corporation of India
- Assessor, Court of Enquiry for New Kenda Colliery, Government of India
- Chairperson, Research Council, Central Mining Research Institute (CSIR)
- Co-Chairperson, Research Recruitment and Assessment Board (CSIR)
- Guest Professor, Technical University, Clausthal, Germany
- Emeritus Fellow, AICTE
- Professor Emeritus, Banaras Hindu University
- Honorary Colonel Commandant, NCC
- Chairman, Secondary Education Services Selection Board, Govt. of Uttar Pradesh
- Member, Government Delegation to the 5th UNESCO Meeting of E-9 Countries at Cairo

Prof Singh has been the member of several premier academic and decision making bodies like:

- Board of Governors, Indian Institute of Technology, Kanpur
- Board of Governors, Indian Institute of Technology, Roorkee
- Governing Body, Birla Institute of Technology, Mesra, Ranchi

- Governing Body and General Body of the National Institute of Rock Mechanics(Govt. of India)
- Society, Indian Institute of Management, Lucknow
- Council of Nuclear Science Centre, Delhi
- Council of Mining, Geological and Metallurgical Institute of India
- General Council, Indian School of Mines, Dhanbad
- National Committee of World Mining Congress
- National Committee on Tunnelling (Government of India)
- UP State Higher Education Council, Lucknow
- UP Science and Technology Council, Lucknow
- Academic Council. Assam University, Silchar
- Academic Council, University of Roorkee
- Academic Council, Indira Gandhi National Open University, New Delhi
- Senate, Indian Institute of Technology, Kanpur
- Fellow, Institution of Engineers (India)
- Chairman, Alumni cell, Banaras Hindu University, Varanasi

Prof Singh received the coveted National Mineral Award from the Government of India for the year 1996 in recognition of his significant contribution in the field of mining technology. In addition he was conferred numerous prestigious medals and fellowships like the Dr Rajendra Prasad Memorial Medal of Institute of Engineers (India) in 2000 and the Honorary Fellowship of Indian Society for Rock Mechanics and Tunneling Technology (ISRMTT) in 2002. He is a recipient of Rajarshi Tandan Award from the UP Open University for Higher Education and Distance Learning (2010). He was conferred Golden Jubilee Life Time Achievement Award of the Indian Mining and Engineering Journal at Mine–Tech 12 on May 4, 2012 at Bhubaneswar and "Fragblast –Veteran" at the 10th International symposium on rock Fragmentation by Blasting held on November 26-29, 2012 at Vigyan Bhawan, New Delhi. Prof Singh is also recipient of the Distinguished Alumnus Award and Life Time Achievement Award (2014) of the Department of Mining Engineering, IIT (BHU).

Prof Singh has devoted his life to exploring the frontier areas of knowledge and research in the field of Rock Mechanics.

Dr NM Raju

(The first Director, NIRM)

Dr Nadimpally Murthy Raju was born on May 20, 1937. He did graduation and post-graduation in Geology from Andhra University, and MS in Mining Engineering from Pennsylvania State Institute of Technology, USA. As a Pool Scientist of CSIR, he first served the UCIL mine in Jaduguda, and later joined the Central Mining Research Station, Dhanbad, in 1964. Through dedicated work, he had developed a number of roof support systems. For his tireless efforts in pursuing the introduction of roof bolting systems in underground coal and non-coal mines, he was invariably associated with roof bolting in India. He developed many types of support systems like the roof stitching system, quick setting triangular chock, safari clamps, pit props and other innovative systems replacing the conventional timber supports. These systems have not only been accepted by the industry, but have even received DGMS approval. He also formulated the design guidelines for selection of proper roof supports based on scientific methodology.

Dr Raju was instrumental in the introduction of mechanized depillaring and elimination of basket loading in a number of coal mines, which helped improve the production and productivity in the mines. He also made significant contributions to the non-coal mining sector in design of methods of work, support design and stoping parameters. For his contributions to the mineral industry, he was honoured with prestigious awards like the National Mineral Award by Govt of India, Dewan Bahadur DD Thacker Mining Gold Medal by MGMI, three Meritorious Invention Awards by NRDC.

After twenty-five years of illustrious service at CMRS, Dr Raju took over as the first Director of the National Institute of Rock Mechanics, KGF, in June 1989. He added a number of new departments in different areas of research, and seen to it that the Institute grew as a national Institute of excellence. Under his direction, the Institute has not only taken up several projects in metal mines, but has made significant strides into coal mining and civil engineering sectors. He was the Director of NIRM till his retirement in 1998.

Prof RN Gupta

(Director: 1998 – 2006)

Professor Rama Nand Gupta was born on 8th May 1942. He received BSc degree in 1960 from Agra University, and BE degree in Mining Engineering in 1964 from Govt. College of Engineering and Technology, Raipur under Saugar University.

Prof Gupta joined the Central Mining Research Station, Dhanbad, in 1967. He earned MTech degree in Mine Planning and System Design from Mining Engg Department, Indian School of Mines, Dhanbad, in 1975, and the PhD degree in Mining Engineering from University of New Castle Upon Tyne, UK, in 1982. As a Scientist at the Central Mining Research Station, Dhanbad, he established and developed the Drilling and Blasting Division during 1982 to 1988.

Prof Gupta, FNAE, was recipient of the Invention Promotion Board Award of the Govt. of India for design and development of strata control instruments. He was appointed as a consultant by the British Govt. for one of their longwall projects in India. He was also a World Bank Consultant for excavation of Power house Cavern of Sardar Sarovar Hydro Electric Project, Vadodara.

His areas of specialization are design of method of extraction of pillars and their stability, design of panel barriers and water dams in mines, drilling and blasting in opencast and underground mines for improved fragmentation, reduction in vibration and fly rocks, greater pulls in tunnels and design of blasting patterns in fire areas, design of controlled and smooth drilling and blasting patterns in tunnels and caverns in hydro-electric projects, and rock excavation engineering including mechanical cutting of rocks.

Prof Gupta became the Professor of Mining and Excavation Engineering at Indian School of Mines, Dhanbad, in May 1988. In addition to teaching and guiding research, he conducted several Executive Development Programmes to train the engineers from the industry in the areas of blasting, rock mechanics and strata control. He set up the Center of Rock Excavation Engineering at ISM in 1991. In March 1997 he was appointed as the Coordinator for the Center of Advanced Studies.

Prof RN Gupta joined the National Institute of Rock Mechanics, Kolar Gold Fields, in 1998 as its Director. While streamlining the administration at the Institute, his major contribution has been building up the Corpus Fund for the Institute, which at one time touched Rs. 9.5 crores. He retired as Director, NIRM, in 2006.

Dr PC Nawani
(Director, 2008 – 2011)

Dr Pramod Chandra Nawani was born on 11th July 1951. He did Masters degree in Geology, and then obtained PhD degree in Engineering Geology for his research work on “Foundation Evaluation of Tehri Dam vis-à-vis Rock Mass Structure".

He is an eminent Engineering Geologist and well respected in the field. He played a key role in the construction stage engineering geological investigations of 260.5 m high Tehri Dam (ranking fifth in the world). He has been associated with various committees and expert groups. Because of his expertise, the Bureau of Indian Standards (BIS) retained him as the Chairman for the Committee on Geological Investigations in his personal capacity. He was the President of Indian Society for Engineering Geology during 2008-2010. He is recipient of the prestigious “National Mineral Award” for the year 2001, for his distinguished contributions in the field of Engineering Geology.

Dr Nawani served in the Geological Survey of India for 35 years in various capacities. During his active service with GSI, he was associated with the geological and geotechnical studies of several important engineering projects in the Himalayan region, particularly Uttarakhand Himalayas, as well as with the marine geological investigations in the Indian Ocean. As the Director, GSI, at Dehradun, he headed Engineering Geology Projects in Uttarakhand Himalya, from July 2000 to February 2008.

Dr Nawani joined as Director of the National Institute of Rock Mechanics, Kolar Gold Fields, on 20th February 2008. He steered the Institute effortlessly. He was instrumental in visualizing and formation of an Engineering Geology Department. He started the Bangalore Unit of NIRM at the ITI premises in KR Puram. He publicized the activities of the Institute among the hydro-power and infrastructure sectors, and brought a name and a number of projects to the Institute. Dr Nawani was the Director of NIRM till his superannuation at the end of July, 2011.

NATIONAL INSTITUTE OF ROCK MECHANICS

(Formerly named as Kolar Institute of Rock Mechanics and Ground Control)

CHAMPION REEFS PO
Kolar Gold Fields
Karnataka State

MEMORANDUM OF ASSOCIATION

(Incorporating amendments made up to September, 2013)

MEMORANDUM OF ASSOCIATION
OF
THE NATIONAL INSTITUTE OF ROCK MECHANICS

1. The name of the Society is "National Institute of Rock Mechanics". [*Amendment no. 1 : The original name "**Kolar Institute of Rock Mechanics and Ground Control"** was changed to "**National Institute of Rock Mechanics"** by the 1st Special General Body of the Institute in the meeting held on 25-6-1990.*]

2. The Registered Office of the Society shall be situated in the State of Karnataka and at present it is at the following address:

   National Institute of Rock Mechanics,
   PO: CHAMPION REEFS,
   Kolar Gold Fields, Karnataka, PIN – 563 117

3. The objectives for which the National Institute of Rock Mechanics is established are:-

   a. To assimilate the technology available for assessment of the stability of underground excavations in mines under different mining conditions.

   b. To undertake, aid, promote, guide, manage, coordinate and execute research in Rock Mechanics including application of computerised techniques, and seismic and micro-seismic techniques to study the ground behaviour under different mining conditions in non-coal mines to find solutions to ground control problems.

   c. To develop technical knowhow in the analysis and interpretation of data obtained from field instruction.

   d. To develop by purchase, lease or otherwise in whole or in part, equipment and facilities to further the objectives of the Society.

   e. To evolve new mining methods to promote productivity, safety and conservation in non-coal mines.

   f. To establish, maintain and manage facilities for the acquisition, storage, retrieval, dissemination, evaluation, scrutiny and interpretation of information relating to technologies required in the field of rock mechanics.

   g. To collaborate with Scientific agencies, research centres and educational institutions on specific projects and undertake investigations in the field of technology relevant to the objectives of the Society.

   h. To conduct field experimentation and evaluation for proving the technologies in the field of Rock Mechanics in mining, construction activities, etc.

   i. To co-operate and collaborate with other national and/or foreign institutions and international organisations to further the objectives of the Society.

   j. To provide consultancy on charge to mining and other organisations in India and abroad on Rock Mechanics and Ground Control.

   k. To provide facilities for training of mining students and guide them to obtain higher proficiency, and to guide Rock Mechanics Engineers and Scientists from mining industry/establishments to obtain Doctorate in specialised fields through their respective educational institutions.

   l. To conduct training courses in Rock Mechanics for technical personnel engaged in mining and allied activities.

m. To publish periodically and disseminate the results of research, development, testing and evaluation conducted by the Society.

n. To register patents, designs and the technical know-how that may be developed by the Society and transfer any portion of such patents/designs/technical know-how and to receive royalty and such other payments that the Society may decide on such patents, designs and technical know-how.

o. Grant fellowship to top scientists in Rock Mechanics based on their record of work.

p. To receive funds, grants-in-aid, donations, fees, charges etc. and to invest such funds/money entrusted to the Society upon such securities or in such manner as may from time to time be determined by the Governing Body in line with the extant instructions of the Government.

q. To carry out all such other activities as the Society may consider necessary/incidental/ancillary to the attainment of the main objectives of the Society.

4. All incomes/earnings from movable or immovable assets including patents, designs, knowhow, etc., of the Society shall be solely utilised and applied towards the promotion of its aims and objectives only as set forth in the Memorandum of Association and no portion thereof shall be paid or transferred directly or indirectly by way of dividends, bonus, profits or in any manner whatsoever, to the present, or past members of the Society or to any person claiming through any one or more of the present or past members. No member of the Society shall have any personal claim on any movable or immovable assets of the Society or can make any profits whatsoever by virtue of his membership. Notwithstanding anything contained hereinabove, the Society shall not be debarred from making payment in good faith for remuneration to any member thereof or any other person in return for any service rendered to the Society or for travelling allowance, halting or other similar charges.

5. The Central Government may issue such directions to the Society as it may consider necessary for the furtherance of the objectives of the Society and for ensuring its proper and effective functioning, and the Society will carry out such directions.

6. The Technology study and Research of National Institute of Rock Mechanics shall be open to persons of either sex and of whatever race, religion, creed, caste or class.

7. The names, addresses, occupations and designations of the members of the Governing Body to whom the management of the Society was entrusted [in 1990] as required under Karnataka Societies Registration Act, 1960 (as amended upon 1987) and Karnataka Societies Registration Rules 1961 as applicable to the State of Karnataka were as under :

Sl. No.	Names	Designation of members	Designation in Society
1	Sri BK Rao	Secretary, Dept. of Mines	Chairman
2	Sri PK Lahiri	Addl. Secy., Dept. of Mines	Member
3	Sri S Pancha-pakesan	AS & FA; Ministry of Steel & Mines	,,
4	Sri IM Aga	Chairman, BGML Suvarna Bhavan, Oorgaum PO KGF, Karnataka	,,
5	Sri PAK Shettigar	Managing Director, BGML Suvarna Bhavan, Oorgaum PO KGF, Karnataka	,,
6	Sri HV Paliwal	Director (MO), HZL, Udaipur	,,

7	Sri MA Khan	Director (Technical), HCL, Calcutta	,,
8	Dr BB Dhar	Professor, Dept. of Mining Engg. Instt of Technology - BHU, Varanasi	,,
9	Prof AK Ghose	Professor of Mining Engg. Indian School of Mines, Dhanbad	,,

8. We the undersigned are desirous of forming a Society namely National Institute of Rock Mechanics under the Karnataka Societies Registration Act, 1960 as applicable to the State of Karnataka in pursuance of this Memorandum of Association of the Society.

Sl. No.	Name, Occupation and Address	Age	Designation in the Society	Signature
1	Sri BK Rao, Secretary to the Govt. of India, Department of Mines, Ministry of Steel & Mines, "Shastri Bhavan", NEW DELHI – 110 001	56 yrs.	Chairman	Sd/-
2	Dr PK Iyengar, Director, Bhabha Atomic Research Centre, Trombay, BOMBAY	57 yrs.	Member	Sd/-
3	Sri PK. Lahiri, Additional Secretary, Department of Mines, Ministry of Steel & Mines, "Shastri Bhavan", NEW DELHI-110 001	51 yrs.	Member	*Sd/-*
4	Sri S Panchapakesan, Finance Adviser & Additional Secretary to the Govt. of India, Ministry of Steel & Mines, Udyog Bhavan, NEW DELHI.	55 yrs.	Member	Sd/-
5	Sri DN Bhargava, Controller General, Indian Bureau of Mines, New Secretariat Buildings Civil Lines, NAGPUR.	57 yrs.	Member	Sd/-
6	Sri VC Varma Director General of Mines Safety, DGMS, DHANBAD	55 yrs.	Member	Sd/-
7	Sri IM Aga, Chairman, Bharat Gold Mines Ltd., PIN : 563120 Suvarna Bhavan, OORGAUM PO, KOLAR GOLD FIELDS, Karnataka –	60 yrs.	Member	Sd/-
8	Sri PAK Shettigar, Managing Director, Bharat Gold Mines Ltd., Suvarna Bhavan, Oorgaum P.O. Kolar Gold Fields, Karnataka – 563 120	49 yrs.	Member	Sd/-

Sl. No.	Name, Occupation and Address	Age	Designation in the Society	Signature
9	Sri HV Paliwal, Director (Mining Operations) Hindustan Zinc Limited, Yashad Garh, Yashad Bhawan, Udaupur, RAJASTHAN – 313 001	51 yrs.	Member	Sd/-
10	Sri MA Khan, Director (Technical), Hindustan Copper Ltd., CALCUTTA.	55 yrs.	Member	Sd/-
11	Dr BB Dhar, Professor of Mining Engineering, Deptt. of Mining Engineering, Institute of Technology, Banaras Hindu University, Varanasi-221005	50 yrs.	Member	Sd/-
12	Prof AK Ghose, Professor of Mining Engineering, Deptt. of Mining Engineering, Indian School of Mines, DHANBAD – 826 004	54 yrs.	Member	Sd/-
13	Prof GS Marwaha, Retd. Director, Indian School of Mines, 8, Kannamwar Nagar, Wardha Road, NAGPUR – 440 025	62 yrs.	Member	Sd/-
14	Sri R Krishnamurthy, Consultant (Rock Mechanics), 511, Chinmaya Mission Hospital Road, Indiranagar, BANGALORE-560 038	62 yrs.	Member	Sd/-

Signature of Witness : Sd/-
Name : VN Murthy
Age : 31 Years
Occupation & Address : Secretary
Bharat Gold Mines Limited
Suvarna Bhavan
Oorgaum PO, KGF – 563 120.

NATIONAL INSTITUTE OF ROCK MECHANICS

(Formerly named as Kolar Institute of Rock Mechanics and Ground Control)

CHAMPION REEFS PO
Kolar Gold Fields
Karnataka State

RULES & REGULATIONS

RULES & REGULATIONS
OF
THE NATIONAL INSTITUE OF ROCK MECHANICS

Title

1. These rules and regulations may be called the Rules & Regulations of the National Institute of Rock Mechanics.

Definitions

2. In these rules, the following words and abbreviations have the meaning given to them, unless there is anything contrary in the subject or context.

   a. The 'Society' shall mean the National Institute of Rock Mechanics
   b. The 'Governing body' shall mean the Governing Body of the Institute.
   c. The 'Chairman' shall mean the Chairman of the General Body/Governing Body.
   d. The 'Director' shall mean the Director appointed under these rules.
   e. The 'Secretary' shall mean the Secretary of the Institute appointed in accordance with the Rules & Regulations of the Society.
   f. 'Government', means Government of India.
   g. Words importing the singular number shall include the plural number and vice-versa. Words importing the masculine gender shall include the feminine gender.

Members of the Society

3. The Society shall consists of the following members:

Sl. No.	Designation of Members	Designation in Society
1	Secretary, Department of Mines	**Chairman**
2	Director, Bhabha Atomic Research Centre, Trombay, Bombay	Member
3	Additional Secretary, Deptt. of Mines	Member
4	Additional Secretary & F.A., Ministry of Steel & Mines	Member
5	Controller General, IBM, Nagpur	Member
6	Director General of Mines Safety, Dhanbad	Member
7	Chairman, BGML, Oorgaum PO, KGF, Karnataka	Member
8	Managing Director, BGML, Oorgaum PO, KGF, Karnataka	Member
9	Director (MO), HZL, Udaipur	Member
10	Director (Technical), HCL, Calcutta	Member
11	Prof. of Mining, Dept. of Mining Engg. BHU, Varanasi	Member
12	Professor of Mining, Indian School of Mines, Dhanbad	Member
13	Prof GS Marwaha, Consultant, Nagpur	Member
14	Sri R. Krishnamurthy Consultant	Member
15	Any other body or individual interested in academic research work of the Society, as the General Body may decide to admit.	

4. The Society shall keep a roll of members, giving their addresses and occupations and every member shall sign the same.

5. If a member of the Society changes his address, he shall notify his new address to the Secretary of the Society and the entry in the roll will be modified/corrected accordingly. In case he fails to do so, his address and/or occupations given in the roll of members shall be deemed to be correct for the purpose of the Society.

6. Should a person appointed, nominated or elected as a member of the Society, under Rule 3, be prevented from attending a meeting of the Society, a substitute to take his place at that meeting of the Society may be appointed, nominated or elected by the authority who is appointed, nominated or elected the member who is so prevented from attending the meeting and such substitute shall be entitled to take part in the proceedings of the meeting including the right to vote thereat.

Duration of Appointment

7. Member covered by Rule 3 would have a term of three years or such other period as may be fixed by the Government.

8. When a person becomes or is appointed or nominated as a member of the Society by virtue of an office held by him, his membership of the Society shall terminate when he ceases to hold that office and the vacancy so caused, shall be filled by his success to that office.

9. A member of the Society shall cease to be member on the happening of any of following events:

   If he resigns, becomes of unsound mind becomes insolvent
   or is convicted of a criminal offence involving moral turpitude,
   or his employer refuses to grant him permission to serve on the Society.

10. Whenever a member desires to resign from the membership of the Society, he shall forward a letter containing his resignation addressed to the Secretary and his resignation shall only take effect on its acceptance by the Chairman.

11. Each member of the Society shall continue as such for such period as may, from time to time, be determined by the appointing or nominating authority.

12. The Government may terminate the membership of any member or at one and the same time the membership of all members other than exofficio members of the Society. Upon such termination the vacancies shall be filled in accordance with the relevant provisions of the rules. The members whose membership is so terminated shall be eligible for reappointment.

13. The Society shall function not withstanding any vacancy in its body and no act or proceeding of the Society shall be invalid merely by reason of such vacancy or of any defect in the appointment of any of its members.

General Body: Composition, Powers & Functions

14. The General Body shall consist of members mentioned in Rule 3. The General body shall do all such acts as may be necessary for effectively carrying out of the aim and objectives of the Society. The General Body shall lay down broad general policy for the guidance and implementation by the Governing Body. The general Body would pass the annual accounts, consider the performance of the Society and transact any other business as may be necessary, subject to the approval of government, the General Body shall have powers to frame,

amend or repeal the rules and regulations of the Society.

Authorities & Officers of the Society

15. The following shall be the authorities and officers of the Society:

a) The General Body
b) The Governing Body
c) The Director
d) Such other authorities and officers as may be constituted orappointed by the Society, as per Rules and Regulations of the Society.

16. The Secretary, Department of Mines shall be the Chairman of the Governing Body.

17. The Society shall establish and maintain its own office and other establishment necessary to its purposes.

18. Appointment of persons to the various posts under the Society and fixation of their remuneration shall be made in accordance with the recruitment rules framed for the purpose by the Governing Body, with the approval of the General Body.

19. The Director of the National Institute of Rock Mechanics who shall be a distinguished scientist, shall be appointed by the General Body. He shall be the Principal Executive Officer of the Society.

20. The affairs of the Society shall be managed, administered, directed and controlled, subject to Rules & Regulations and orders of the Society, by the Governing Body. For this purpose, the Governing Body shall have the power subject to these Rules and Regulations, to frame by-laws. The Governing Body of the Society for the purpose of Karnataka Societies Registration Act 1960 (as amended u pto 1987) and the Karnataka Societies Registration Rules 1961, shall consist of the following:

Sl. No.	Name	Designation	Designation in Society
1	Sri BK Rao	Secretary, Deptt. of Mines	**Chairman**
2	Sri PK Lahiri	Addl. Secy. Deptt. of Mines	Member
3	Sri S Panchapakesan	AS &FA Ministry of Steel & Mines	Member
4	Sri IM Aga	Chairman, BGML Suvarna Bhavan, Oorgaum PO KGF, Karnataka	Member
5	Sri PAK Shettigar	Managing Director, BGML., Suvarna Bhavan, Oorgaum PO KGF, Karnataka	Member
6	Sri HV Paliwal	Director (MO) HZL, Udaipur.	Member
7	Sri MA Khan	Director (Technical) HCL Calcutta.	Member
8	Dr BB Dhar	Professor, Dept. of Mining Engg. Institute of Technology, BHU, Varanasi.	Member
9	Prof AK Ghose	Professor, Dept. of Mining Engg. Indian School of Mines, Dhanbad	Member

21. The official member of the Governing Body, or of any Committee appointed by it, shall not be entitled to any remuneration from the Society. The non-official members of the Governing Body, or any Committee appointed by it shall be paid by the Society such travelling and daily allowance as may be provided for in the Rules & Regulations to be made in this respect for the journeys undertaken by them for attending the meetings of the Governing Body or of Committee set-up by the Governing Body in connection with any business of the Society.

Proceedings of the Society

22. An Annual General Meeting of the Society shall be held at such time date and place as may be determined by the Chairman. At such Annual General Meeting, the governing Body Shall submit the Annual Report & Audited Accounts of the Society, together with the Auditor's Report thereon.

22. (a) The first annual general meeting shall be held by the Society within eighteen months of its registration. The next annual general meeting of the Society shall be held within nine months after the expiry of the calendar year in which the first annual meeting was held; and thereafter an annual general meeting shall be held within nine months after the expiry of each calendar year.

Provided that the Registrar may, for special reason extend the time within which an annual general meeting shall be held, by a further period not exceeding six months.

23. The Chairman may convene a Special General Meeting of the Society whenever he thinks fit, in accordance with Sec. 11(3) of the Karnataka Societies Registration Act, 1960.

24. The Chairman shall convene a Special General Meeting of the Society on the written requisition of not less than five members of the Society.

25. Any requisition so made by the members of the Society, shall express the object of the meeting proposed to be called and shall be left at the address of the Secretary or posted to his address.

26. At all special General Meetings, no subject other than that stated in the notice or requisition, as the case may be, shall be discussed except when specially authorised by the Chairman.

27. Exception as otherwise provided in these Rules, all meetings of the Society shall be called by Notice under the signature of the Secretary.

28. Every notice calling a meeting of the Society shall state the date, time and place at which such meeting will be held and shall be served upon every member of the Society not less than fifteen (15) clear days before the day appointed for the meeting.

29. The accidental omission to give notice to or the non-receipt of notice by any member, shall not invalidate the proceedings at the meeting.

30. the Chairman of the Society shall preside at all meetings of the Society. In the absence of the Chairman, the meeting shall be presided over by a member chosen from amongst themselves by members present to preside for the occasion.

31. Six members of the Society, present in person shall form a quorum at every meeting of the Society.

32. All disputed questions at meeting of the Society shall be determined by a majority of votes of

the members present and voting. In case of equality of votes, the Chairman shall have a casting vote.

33. Each member of the Society shall have one vote.

34. Once in every year, on or before the 14^{th} day succeeding the day on which the Annual General Meeting of the Society is held, a list of the names, addresses and occupations of the members of the Governing Body then entrusted with the management of the affairs of the Society shall be filed with the Registrar of Societies.

Notices of Meeting

35. A notice may be served upon any member of the Society either personally or by sending it through post in an envelope addressed to such member at the address mentioned in the roll of members.

36. Any notice so served by post shall be deemed to have been served on the day following that on which the letter, envelope or wrapper containing the same is posted and in providing such a service, it shall be sufficient to prove that cover containing such notice was properly addressed and put into the Post Office.

Functions & Powers of the Governing Body

37. The Governing Body shall generally carry out and pursue the objectives of the Society, as set forth in the Memorandum of Association. The management of all the affairs and funds of the Society shall, for this purpose, vest in the Governing Body.

38. The Governing Body shall exercise all the powers of the Society, subject nevertheless to such limitations as the General Body may, from time to time, impose in respect of the expenditure from the funds of the Society and of grants made by the Government; provided always that the Governing Body shall have no greater powers in the matter of expenditure from the funds of the Society than the Government possesses in respect of expenditure from public funds.

39. In particular and without prejudice to the generality of the foregoing provisions, the Governing Body shall have the power, subject to the provisions of these Rules and Regulations to:

1. consider the annual and supplementary budget placed before it by the Secretary from time to time and pass them with such modifications as the Governing Body may think fit:

2. create and abolish posts;

3. appoint various scientific, technical, administrative and other officers and staff of the Society, fix their remuneration and define their duties;

4. enter into arrangements with the Government and through them with foreign and international agencies and organisation, the State Governments and other public or private organsiations or individuals for securing and accepting grants-in-aid, endowments, donations or gifts to the Society, on mutually agreed terms and conditions; provided that such terms and conditions, if any, shall not be contrary to, inconsistent or in conflict with the objectives of the Society;

5. take over, acquire by purchase, gifts, exchange, lease or hire or otherwise from Government and through them from foreign and international agencies and organisations, the State Government and other public or private bodies or individuals, in-

stitutions, libraries, laboratories, immovable properties, endowments or other funds together with any attendant obligations and engagements not inconsistent with the objectives of the Society;

6. appoint a Research Advisory Council, Committees and Sub-committees; for such purposes and with such powers and for such periods and on such terms as it may deem fit, and dissolve any of them;

7. delegate such administrative and financial powers as it may think proper to the Chairman, the Director, the Secretary and such other officers of the Society as may be considered necessary; and

8. subject to the Rules, Regulations and bye-laws provide for the following matters:

   a) Preparation and sanction of budget estimates, sanctioning of expenditure, entering into an execution of contracts, investment of the funds of the Society, sale or alteration of such investment and maintenance of accounts and their audit;

   b) Procedure for recruitment of officers and establishment in the service of the Society;

   c) Terms and tenures of appointments, emoluments, allowances, rules of discipline and other conditions of service of the officers and establishments of the Society;

   d) Terms and conditions governing the grant of scholarship, fellowships and grants-in-aid for research schemes and projects not inconsistent with the objectives of the Society.

   e) Such other matters as may be necessary for the administration of the affairs and funds of the Society.

40. For the purposes of Section 15 of the Societies Registration Act of 1960, the Secretary shall be considered the Principal Officer to the Society and the Society may sue or be sued in the name of the Principal Officer of the Society.

41. Every meeting of the Governing Body shall be presided over by Chairman, and in the absence of Chairman, the meeting shall be presided over by a member chosen from amongst themselves by members present to preside for the occasion.

42. The Governing Body shall meet as frequently as necessary but not less than three* times a year. [* *Amendment no. 3 : the original number "four" was substituted by "three" in the 22nd Annual General Body meeting held on 2nd November, 2010*].

43. For the purpose of the last rule, each year shall be deemed to commence on the 1st day of April and terminate on the 31st day of March of the calendar year.

44. The Chairman may himself call, or by a requisition in writing signed by him may require the Secretary to call a meeting of the Governing Body at any time and on receipt of such a requisition, the Secretary shall forthwith call such a meeting.

45. Any business, which may be necessary for the Governing Body to perform, except such as may be placed before its annual meeting, may be performed by resolution in writing circulated among all its members and any such resolution so circulated and approved by a majority of the members signing shall be as effectual and binding as if such resolution had been passed at a meeting of Governing Body, provided that at least six members of the Governing Body have recorded their approval of the resolution.

Functions & Powers of the Chairman

46. The chairman shall exercise such powers for the conduct of the business of the Society as may be delegated to him by the Governing Body.

47. The Chairman may, in writing, delegate such of the powers as he may think necessary, to the Director.

Functions & Powers of the Director

48. Subject to any order that may be passed by the Government or by the Chairman in exercise of the powers delegated to him by the Governing Body, and the decisions of the Governing Body, the Director shall be responsible for the proper administration of the affairs and funds of the Society under the direction and guidance of the Governing Body. He shall be vested with such executive and administrative power of the Society as may be necessary or incidental for the purpose, subject to these Rules and Regulations.

49. Not later than the 1st February of each year, the Director will prepare detailed estimates of the receipts and expenditure and the anticipated opening and closing balance of the Society for the ensuing financial year.

50. The funds of Society will consist of the following:

a) Lumpsum and recurring grant made by the Government.
b) Fees and other charges received by the Society.
c) All other money received by the Society.

All funds of the Society shall be deposited into the Society's account with Reserve Bank of India, Branches of the State Bank of India and its subsidiaries and in a scheduled/nationalised bank and shall not be withdrawn except on cheques signed and countersigned by such officers as may be duly empowered by the Chairman.

51. The funds of the Society shall not be appropriated for expenditure on any item which has not been approved by the competent authority under these Rules and Regulations.

52. The funds provided in the sanctioned estimates shall be deemed to be at the disposal of the Director who will have full powers to appropriate sums therefrom to meet expenditure on each item which has been approved by the competent authority.

53. The Director shall have power to re-appropriate funds from one unit to another provided that:

i) The total sanctioned cost of each approved scheme be not thereby exceeded except to the extent permitted by the Rules & Regulations, and
ii) Such re-appropriation shall not have the effect of involving the Society into further outlay in the following years on the same scheme.

54. All investments of the funds of the Society shall be made in the name of the Society. All purchases, sales or alternations of such investments shall be effected on the authority of the Director and all contracts, transfer deeds or other documents necessary for purchasing, selling or altering the investments of the Society funds shall be executed by an Officer authorised by the Director.

54A. Investment Clause: The Institute shall follow the guidelines of the Department of Public Enterprise, Government of India, in respect of investments. [Amendment *no. 4: The Clause*

54A was inserted as approved in the 22nd Annual General Body meeting held on 2nd November, 2010.]

Accounts & Audit

55. The Accounts of the Society shall be audited by the Auditor appointed by the General Body.

Annual Report

56. The Annual Report of the proceedings of the Society and of all work undertaken during the year shall be prepared by the, Governing Body for the information of the Government and the members of the Society. This Report and the audited accounts of the Society along with the Auditor's Report thereon shall be placed before the Society at the Annual General Meeting.

Office of the Society

57. The Office of the Society shall be situated in Kolar Gold Fields in the State of Karnataka or at such other place as the Governing Body may decide.

Seal

58. The Governing Body shall provide a seal and also for its safe custody and the seal shall never be used except by the authority of the Governing Body previously given, and one member of the Governing Body shall sign every such instrument to which the seal is affixed and every such instrument shall be countersigned by the Secretary or by some other person appointed by the Governing Body for the purpose.

Contracts

59. Save as otherwise provided, all contracts shall be executed on behalf of the Society by an Officer or Officers of the Society as authorised by the Director and countersigned by such Officer or Officers as may be appointed by the Director for the purpose provided that in case of the staff recruited by the Society from outside India all contracts in relation thereto shall be executed on behalf of the Society by such person or persons as may from time to time be nominated for the purpose by the Director .

Alteration or Extension of the Purpose of the Society

60. Subject to the approval of the Government previously obtained, the Society may alter or extend the purposes for which it is established or be amalgamated either wholly or partially with any other Society by following the undermentioned procedure :-

   a) The Governing Body shall convene a Special General Meeting of the members of the Society according to these Rules for the consideration of the said proposition.

   b) The Governing Body shall submit the proposition for such alteration, extension or amalgamation as aforesaid to the members of the Society in a written Or printed report.

   c) Such report would be delivered or sent by post to every member of the Society fifteen (15) clear days previous to the said Special General Meeting.

   d) Such proposition be agreed to by the votes of three-fifths of the members of Society delivered in person or by proxy at the said Special General Meeting, and

e) Such proposition be confirmed by the votes of three-fifths of members of the Society present at the second Special General Meeting convened by the Governing Body at an interval of one month after the former meeting.

61. The rules of the Society may, with the sanction of the Government, be altered at any time, by a Resolution passed by a majority of the members of the Society present at any meeting of the Society which shall have been duly convened for, the purpose. These will have to be approved and got registered with the Registrar of Societies.

62. The Society may, with the approval of the Government, change its name as per the Societies Registration Act, 1960.

63. If three-fifths of the members shall have expressed a wish for dissolution of the Society by their votes delivered in person or proxy at a general meeting convened for the purpose, any number not less than three-fifths of the members of the Society, may, with the prior consent of the Government, determine that the Society shall be dissolved, thereupon, it shall be dissolved forthwith, or at the time then agreed upon, and all necessary steps shall be taken for disposal and settlement of the property of the Society, its claims and liabilities according to the rules of the Society applicable thereto, if any, and if not, then as the General Body shall find expedient.

64. If, on the winding up or dissolution of the Society, there shall remain after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the members of the Society or any of them, but shall be dealt with in such manner as the Government may determine.

65. a. All provisions contained in the Karnataka Societies Registration Act, 1960 (Amended upto 1987) and Karnataka Societies Registration Rules, 1961, as applicable to the State of Karnataka shall apply to this Society.

65. b. Calendar Year: The Calendar year of the Institute: will be from 1st of January to 3lst December of every year.

66. Certified that this is the correct copy of Rules and Regulations of the Society.

Sl. No.	Name, Occupation and address	Age	Designation in the Society	Signature
1	Sri BK Rao, Secretary to the Govt. of India, Department of Mines, Ministry of Steel & Mines, “Shastri Bhavan”, New Delhi – 110 001	56 yrs.	**Chairman**	**Sd/-**
2	Dr PK Iyengar, Director, Bhabha Atomic Research Centre, Trombay, Bombay	57 yrs.	Member	Sd/-
3	Sri PK Lahiri, Additional Secretary, Department of Mines, Ministry of Steel & Mines, “Shastri Bhavan”, New Delhi -110 001	51 yrs.	Member	*Sd/-*
4	Sri S Panchapakesan, Finance Adviser & Additional Secretary to the Govt. of India, Ministry of Steel & Mines, Udyog Bhavan, New Delhi	55 yrs.	Member	Sd/-
5	Sri DN Bhargava, Controller General, Indian Bureau of Mines, New Secretariat Buildings, Civil Lines, Nagpur	57 yrs.	Member	Sd/-

Sl. No.	Name, Occupation and address	Age	Designation in the Society	Signature
6	Sri VC Varma Director Genral, Mines Safety, Dhanbad	55 yrs.	Member	Sd/-
7	Sri IM Aga, Chairman, Bharat Gold Mines Ltd, Suvarna Bhavan, Oorgaum PO, Kolar Gold Fields, Karnataka – 563 120	60 yrs.	Member	Sd/-
8	Sri PAK Shettigar, Managing Director, Bharat Gold Mines Ltd, Suvarna Bhavan, Oorgaum PO, Kolar Gold Fields, Karnataka – 563 120	49 yrs.	Member	Sd/-
9	Sri HV Paliwal, Director (Mining Operations) Hindustan Zinc Limited, Yashad Garh, Yashad Bhawan, Udaupur, Rajasthan – 313 001	51 yrs.	Member	Sd/-
10	Sri MA Khan, Director (Technical), Hindustan Copper Ltd, Calcutta	55 yrs.	Member	Sd/-
11	Dr BB Dhar, Professor of Mining Engineering, Deptt. of Mining Engineering, Institute of Technology, Banaras Hindu University, Varanasi-221005	50 yrs.	Member	Sd/-
12	Prof AK Ghose, Professor of Mining Engineering, Deptt. of Mining Engineering, Indian School of Mines, Dhanbad – 826 004	54 yrs.	Member	Sd/-
13	Prof GS Marwaha, Retd. Director, Indian School of Mines, 8, Kannamwar Nagar, Wardha Road, Nagpur – 440 025	62 yrs.	Member	Sd/-
14	Sri R Krishnamurthy, Consultant (Rock Mechanics), 511, Chinmaya Mission Hospital Road, Indiranagar, Bangalore - 560 038	62 yrs.	Member	Sd/-

Signature of Witness : Sd/-
Name : VN Murthy
Age : 31 Years
Occupation & Address : Secretary
Bharat Gold Mines Limited
Suvarna Bhavan
Oorgaum PO, KGF – 563 120.

Sub-Committee to make the Technical Framework & Organizational Structure for NIRM - *appointed by the Governing Body* (March – August, 1989)

Prof AK Ghose Prof T Ramamurthy Prof BB Dhar Sri HV Paliwal Dr GS Murthy Dr MVMS Rao Sri R Krishnamurthy Director, NIRM (Dr NM Raju)	Recommended for the following Departments : ➢ Geomechanics & Ground Control ➢ Numerical Modelling & Mine Design ➢ Seismic /Micro-seismic Lab & Instrumentation ➢ Rock Blasting ➢ Testing services Recommended to have a total strength of 88, with Scientists – 36 Technical staff – 38 Administrative staff - 14

Group to Draft the Terms & Conditions of Service of Employees of NIRM - *appointed by the Governing Body of NIRM* (March – September, 1989)

Sri RSV Subrahmanian, Director (Finance), MoM Sri CPS Nair, Chief Technical Officer (TPPC), MoM Prof BB Dhar Sri IM Aga	Drafted and recommended the Pay Scales, TA/DA rules, etc. for the employees of NIRM; all other rules recommended as per Central Govt rules
The above Group was joined by the Director, NIRM (Dr NM Raju), in June, 1989	Drafted and recommended the Recruitment & Promotion Rules, Group Insurance Scheme, and the Conduct, Discipline & Appeal Rules for the employees of NIRM

Members of the NIRM General Body & Governing Body (1988 – 1994)

Designation in the Governing/General Body		1988–89	1989-90	1990-91	1991-92	1992-93	1993-94
Chairman	**Secretary, MoM**	Sri BK Rao	Sri PK Lahiri		Sri RK Dang	Sri V Krishnan	Sr IG Jhingran
***Ministry of Mines Officers* - Members**	**Addl. Secretary**	Sri PK Lahiri	Smt Usha Vohra	Sri M Gopalakrishna			(Sri ML Majumdar)
	AS/JS & FA	Sri S Panchapakesan			Sri AC Sen	Sri N Gopalan	Sri BP Mathur
	Chief Technical Adviser (TPPC)	-		Sri CPS Nair		Dr GRK Murthy	Sri ME Madhusudan
***Other Ex-Officio* Members**	**Chairman/MD, BGML**	Sri IM Aga		Sri PAK Shettigar			
	Director (Mining), HZL	Sri HV Paliwal					
	Director (Technical), HCL	Sri MA Khan		Sri RC Checker	Sri NM Biddappa		Dr SK Ghosh
***Non-Official* Members**		Prof BB Dhar					
		Prof AK Ghose				Dr VM Sharma	
***NIRM Director* – Member**		(Sri PAK Shettigar)		Dr NM Raju			
***Additional* Members in the General Body**	**Director, BARC**	Dr PK Iyengar		Dr R Chidambaram		Sri AN Prasad	
	Controller General IBM	Sri DN Bhargava			Sri SK Chowdhury		
	Director General, DGMS	Sri VC Varma			Sri K Paul	Sri BK Saran	Sri SK Banerjee
	Non-Official Members	Prof GS Marwaha				-	-
		Sri R Krishnamurthy				-	-

Members of the NIRM General Body & Governing Body (1994 – 2000)

Designation in the Governing/General Body		1994-95	1995–96	1996-97	1997-98	1998-99	1999-2000
Chairman	**Secretary, MoM**	Sri AC Sen		Sri BB Tandon		Sri Arvind Varma	Sri Dipak Chat-terjee
***Ministry of Mines Officers* - Members**	**Addl. Secretary**	Sri B Narasimhan	Sri ML Majumdar		Sri PK Mohanty		
	JS & FA	Sri BP Mathur	Sri A Prasad		Sri AH Jung		Sri S Behuria
	Director (Technical/S&T)	Sri SP Rastogi		Dr RL Munshi			
***Other Ex-Officio* Members**	**Advisor (Projects), MoC**	Sri ME Madhusudan				Sri NN Gautam	
	MD, BGML	Sri PAK Shettigar		Sri R Gupta			
	Director (Mining), HZL	Sri HV Paliwal					
	Director (Technical), HCL	Sri TK Majumdar					
***Non-Official* Members**		Prof BB Dhar	Sri Ravi Shanker				
		Dr VM Sharma	Prof DP Singh			Prof AK Ghose	
		-	Sri BKP Sinha				
***NIRM Director* – Member**		Dr NM Raju				Prof RN Gupta	
***Additional* Members in the General Body**	**Director General, DGMS**			Sri V Mahajan			Sri SN Padhi
	Controller General IBM		Sri OP Sachdeva	Sri M Mukherjee		Sri AN Bose	
	Member (D&R), CWC	-	-	-	-	Sri BK Mittal	
	MD, Gujarat State MDC	-	-	-	-	Sri VRS Cowlagi	
	MD, Rajasthan State MDC	-	-	-	-		
	MD, MP State MDC	-	-	-	-		

Members of the NIRM General Body & Governing Body (2000 - 2006)

Designation in the Governing/General Body		2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
Chairman	**Secretary, MoM**	Sri D Chatterjee	Sri AK Kundra		Sri CP Arha		Sri AKD Jadhav
***Ministry of Mines Officers* - Members**	**Addl. Secretary**	Sri SC Tripathi	Smt Adarsh Misra		Sri Madhu-kar Gupta	Sri RK Bhargava	Dr Pradeep Kumar
	JS & FA	Sri Sutanu Behuria				Sri Harbh-ajan Singh	Sri Sujit Gulati
	Director (Technical/S&T)	Sri AK Bhandari				Sri Deepak Srivastava	
***Other Ex-Officio* Members**	**Advisor (Projects), MoC**	Sri MK Thapar	Sri KP Verma				
	Controller General, IBM	Sri KS Raju				Sri SS Das	Sri CP Ambesh
	Member (D&R), CWC	Sri R Jayaseelan				Sri SK Das	
	CMD, NHPC	-	(Sri B De)	Sri Y Prasad			
	Director General, GSI	-					
***Non-Official* Members**		Sri Ravi Shanker					
		Prof AK Ghose					
			Prof DP Singh				
		Sri BKP Sinha					
***NIRM Director* – Member**		Prof RN Gupta					
***Additional* Members in the General Body**	**Director General, DGMS**	Sri AK Rudra		Sri Ravindra Sharma		Sri B Bhattacharjee	
	MD, Gujarat State MDC	Dr A Narayan	Mrs VR	Sri GC Murmu	Sri BK Sinha	Smt S Anchlia	
	Director, NIMH	-	Dr SK Dave				Dr AK Srivastava
	CMD, NTPC		Sri AN Dave				
	CMD, WAPCOS; Director (Mines), Govt of Jharkhand; Principal Secretary (I&C), Govt of Karnataka						

Members of the NIRM General Body & Governing Body (2006 – 2012)

Designation in the Governing/General Body		2006-07	2007-08	2008-09	2009-10	2010-11	2011-12
Chairman	**Secretary, MoM**	Sri AKD Jad-hav	Sri JP Singh	Sri Shanta-nu Kansal	Smt Santha Sheela Nair	Sri S Vijay Kumar	Dr Vishwapati Trivedi
***Ministry of Mines Offi-cers* - Members**	**Addl. Secretary**	Dr Pradeep Kr	Sri S Vijay Kumar			Sri SK Srivastava	
	JS & FA	Sri S Gulati	Sri Sanjiv Mittal			Smt Anjali Anand Srivastava	
	Director (Technical/S&T)	Sri D Srivastava	Dr K Ayyasami			Dr HSM Prakash	Sri GS Jaggi
***Other Ex-Officio* Members**	**Advisor (Projects), MoC**		Sri PR Mondal			Sri DN Prasad	
	Controller General, IBM		Sri CP Ambesh				
	Member (D&R), CWC		Sri DV Thareja			Sri SP Kak-ran	Sri AK Ganju
	Director (Projects), NHPC		Sri SK Dodeja			Sri JK Sharma	
	Director General, GSI		Sri PM Tejale	Sri NK Dutta	Sri Jaswant Singh	Sri A Sundaramoorthy	
	Director General, DGMS				Sri SJ SIbal	Sri Satish Puri	
***Non-Official* Members**		Sri Ravi Shanker					
		Prof AK Ghose					
		Sri BKP Sinha					
***NIRM Director* – Member**		(Dr VP Mish-ra)	-	Dr PC Nawani			
***Additional* Members in the General Body**	**Director, NIMH**	Dr S Mukhopadhyay					
	Director (Projects), NTPC		Sri KB Dubey	Sri SC Gupta	Sri SK Dodeja	Sri JK Shar-ma	
	Advisor (C-TEMPO)	Sri AK Bhandari					
	CMD, Gujarat Mineral Development Corporation; Secretary (SSI & Mines), Govt of Karnataka						

Members of the NIRM General Body & Governing Body (2012 – 2014)

Designation in the Governing/General Body		2012-13	2013-14	2014-15
Chairman	**Secretary, MoM**	Sri RH Khwaja		Dr Anup K Pujari
***Ministry of Mines Officers* - Members**	**Addl. Secretary**	Smt Gauri Kumar		Sri R Sridharan
	JS & FA	Smt AA Srivastava	Smt Sujata Prasad	
	Director (Technical/S&T)	Sri JS Jaggi	-	
	Economic Advisor	-	-	Smt Sunanda Sharma
***Other Ex-Officio* Members**	**Director (Projects), MoC**	Sri DN Prasad		
	Controller General IBM			---
	Member (D&R), CWC	Sri AB Pandya		
	Director (Projects), NHPC	Sri JK Sharma		Exec. Director (Geol.)
	Director General, GSI	Sri A Sundaramoorthy		
	Director General, DGMS	Sri AK Ganju		Sri Rahul Guha
	Director, CIMFR			Dr Amalendu Sinha
	Director, ISM			Prof DK Panigrahi
	Director (Op.), SCCL			Sri Ramesh Kumar
***Non-Official* Members**		Sri Ravi Shanker		Prof BB Dhar
		Prof AK Ghose		Sri AK Rudra
		Sri BKP Sinha		Sri A Sundaramoorthy
***NIRM Director* – Member**		(Dr V Venkateswarlu)	Dr V Venkateswarlu	
	Director, NIMH			-
	Director (Projects), NTPC			-
	Advisor (C-TEMPO)			-
	Director (Tech), THDC	Sri DV Singh		-

Members of the Peer Review Committee of NIRM (1999 – 2014)

<table>
<tr><th>Designation in the PRC</th><th>1999-2000</th><th>2001-04</th><th>2005-07</th><th>2008-13</th><th>2011-13</th><th>2014-16</th></tr>
<tr><td>Chairman</td><td>Prof DP Singh</td><td colspan="4">Sri Ravi Shanker</td><td>Sri AK Rudra</td></tr>
<tr><td rowspan="8">Members</td><td colspan="5">Prof AK Ghose</td><td>Sri A Sundaramoorthy</td></tr>
<tr><td colspan="5">Sri BKP Sinha / Director (CPP), SCCL</td><td>Prof VR Sastry</td></tr>
<tr><td>Dr DJ Nair</td><td>Dr JL Jethwa</td><td colspan="3">Advisor (C-TEMPO)</td><td>Advisor (C-TEMPO)</td></tr>
<tr><td colspan="5">Director (S&T), DGMS / Controller General , IBM</td><td>Director (S&T), DGMS</td></tr>
<tr><td colspan="2">CGM/GM (MT), CMPDIL / Prof M Jawed</td><td colspan="2">Director (S&T), CMPDIL</td><td>DG, CSIR/ Dr B Nara-yan, Sur-vey of India</td><td>GM (Geophy.), CMPDIL</td></tr>
<tr><td>Alternate : Prof BB Bhattacharya</td><td></td><td colspan="2">Director (Projects), NTPC</td><td>Project Director, NGF</td><td>GM (R&D), SCCL</td></tr>
<tr><td>-</td><td colspan="4">Member (D&R), CWC / Chairman, Civil Engg Dept., IISC</td><td>Sri Achyuta Kr. Ghosh</td></tr>
<tr><td colspan="6">Director, NIRM</td></tr>
</table>

List of NIRM Governing Body Meetings

GB no.	Date	Place	Chairman (Secretary, MoM)	NIRM Director	NIRM Secretary
1.	29-08-1988	New Delhi	Sri BK Rao	(Sri PAK Shettigar)	(Sri VN Murthy)
2.	27-12-1988	New Delhi	Sri BK Rao	(Sri PAK Shettigar)	(Sri VN Murthy)
3.	30-03-1989	New Delhi	(Sri PK Lahiri)	(Sri PAK Shettigar)	(Sri VN Murthy)
4.	29-06-1989	New Delhi	Sri BK Rao	Dr NM Raju	(Sri VN Murthy)
5.	25-09-1989	New Delhi	Sri PK Lahiri	Dr NM Raju	(Sri VN Murthy)
6.	11-12-1989	New Delhi	Sri PK Lahiri	Dr NM Raju	(Sri VN Murthy)
7.	25-04-1990	New Delhi	Sri PK Lahiri	Dr NM Raju	Sri V Radhakrishnan
8.	25-06-1990	New Delhi	Sri PK Lahiri	Dr NM Raju	Sri V Radhakrishnan
9.	23-10-1990	New Delhi	Sri PK Lahiri	Dr NM Raju	Sri V Radhakrishnan
10.	18-12-1990	New Delhi	Sri RK Dang	Dr NM Raju	Sri V Radhakrishnan
11.	02-04-1991	New Delhi	Sri RK Dang	Dr NM Raju	-
12.	19-06-1991	New Delhi	Sri RK Dang	Dr NM Raju	-
13.	29-10-1991	New Delhi	Sri V Krishnan	Dr NM Raju	Sri MR Muralidharan
14.	09-12-1991	New Delhi	Sri V Krishnan	Dr NM Raju	Sri MR Muralidharan
15.	25-03-1992	New Delhi	Sri V Krishnan	Dr NM Raju	Sri MR Muralidharan
16.	03-09-1992	New Delhi	Sri V Krishnan	Dr NM Raju	Sri MR Muralidharan
17.	09-12-1992	New Delhi	Sri V Krishnan	Dr NM Raju	Sri MR Muralidharan
18.	16-04-1993	New Delhi	Sri IG Jhingran	Dr NM Raju	Sri MR Muralidharan
19.	23-09-1993	New Delhi	Sri IG Jhingran	Dr NM Raju	Sri MR Muralidharan
20.	11-02-1994	New Delhi	Sri IG Jhingran	Dr NM Raju	Sri MR Muralidharan
21.	15-07-1994	New Delhi	Sri IG Jhingran	Dr NM Raju	Sri MR Muralidharan
22.	16-11-1994	New Delhi	Sri IG Jhingran	Dr NM Raju	Sri MR Muralidharan
23.	20-04-1995	New Delhi	Sri AC Sen	Dr NM Raju	Sri MR Muralidharan
24.	21-09-1995	New Delhi	(Sri B Narasimhan)	Dr NM Raju	Sri MR Muralidharan
25.	28-12-1995	New Delhi	Sri AC Sen	Dr NM Raju	Sri MR Muralidharan
26.	27-05-1996	New Delhi	Sri AC Sen	Dr NM Raju	Sri MR Muralidharan
27.	30-09-1996	New Delhi	Sri AC Sen	Dr NM Raju	Sri MR Muralidharan
28.	17-12-1996	New Delhi	Sri AC Sen	Dr NM Raju	Sri MR Muralidharan
29.	24-04-1997	New Delhi	Sri BB Tandon	Dr NM Raju	Sri MR Muralidharan
30.	19-12-1997	New Delhi	Sri BB Tandon	Mr J Chatopadhyay	Sri MR Muralidharan
31.	25-05-1998	New Delhi	Sri BB Tandon	Dr NM Raju	Sri MR Muralidharan
32.	29-06-1998	New Delhi	Sri BB Tandon	Dr NM Raju	Sri MR Muralidharan
33.	26-11-1998	New Delhi	Sri BB Tandon	Prof RN Gupta	Sri MR Muralidharan
34.	24-03-1999	New Delhi	Sri Arvind Verma	Prof RN Gupta	Sri MR Muralidharan
35.	16-07-1999	New Delhi	Sri Arvind Verma	Prof RN Gupta	Sri MR Muralidharan
36.	27-09-1999	New Delhi	Sri Arvind Verma	Prof RN Gupta	Sri MR Muralidharan
37.	19-01-2000	New Delhi	Sri Dipak Chatterjee	Prof RN Gupta	-
38.	06-06-2000	New Delhi	Sri Dipak Chatterjee	Prof RN Gupta	-
39.	21-09-2000	New Delhi	Sri Dipak Chatterjee	Prof RN Gupta	Sri AN Nagarajan
40.	15-01-2001	New Delhi	Sri Dipak Chatterjee	Prof RN Gupta	Sri AN Nagarajan
41.	04-06-2001	New Delhi	Sri Dipak Chatterjee	Prof RN Gupta	Sri AN Nagarajan

GB no.	Date	Place	Chairman (Secretary, MoM)	NIRM Director	NIRM Secretary
42.	19-09-2001	New Delhi	Sri Dipak Chatterjee	Prof RN Gupta	Sri AN Nagarajan
43.	20-12-2001	New Delhi	Sri Dipak Chatterjee	Prof RN Gupta	Sri AN Nagarajan
44.	29-04-2002	New Delhi	Dr AK Kundra	Prof RN Gupta	Sri AN Nagarajan
45.	02-09-2002	New Delhi	Dr AK Kundra	Prof RN Gupta	Sri AN Nagarajan
46.	10-02-2003	New Delhi	Dr AK Kundra	Prof RN Gupta	Sri AN Nagarajan
47.	22-03-2003	Bangalore	Dr AK Kundra	Prof RN Gupta	Sri AN Nagarajan
48.	22-08-2003	Bangalore	Sri CD Arha	Prof RN Gupta	Sri AN Nagarajan
49.	30-10-2003	New Delhi	Sri CD Arha	Prof RN Gupta	Sri AN Nagarajan
50.	19-03-2004	Hyderabad	Sri CD Arha	Prof RN Gupta	Sri AN Nagarajan
51.	27-10-2004	New Delhi	Sri CD Arha	Prof RN Gupta	Sri AN Nagarajan
52.	11-03-2005	New Delhi	Sri CD Arha	Prof RN Gupta	Sri AN Nagarajan
53.	11-08-2005	New Delhi	Sri AKD Jadhav	Prof RN Gupta	Sri AN Nagarajan
54.	30-11-2005	New Delhi	Sri AKD Jadhav	Prof RN Gupta	Sri AN Nagarajan
55.	23-03-2006	New Delhi	Sri AKD Jadhav	Prof RN Gupta	Sri AN Nagarajan
56.	08-10-2006	Bangalore	Sri AKD Jadhav	(Dr VP Misra)	Sri AN Nagarajan
57.	09-11-2006	New Delhi	Sri AKD Jadhav	(Dr VP Misra)	Sri AN Nagarajan
58.	31-05-2007	Bangalore	Sri JP Singh	(Dr VP Misra)	Sri AN Nagarajan
59.	18-12-2007	New Delhi	Sri JP Singh	-	Sri AN Nagarajan
60.	03-04-2008	New Delhi	Sri JP Singh	Dr PC Nawani	Sri AN Nagarajan
61.	18-11-2008	New Delhi	Sri Santanu Kansal	Dr PC Nawani	Sri AN Nagarajan
62.	29-5-2009	New Delhi	Ms Santha S Nair	Dr PC Nawani	Sri AN Nagarajan
63.	20-11-2009	New Delhi	Ms Santha S Nair	Dr PC Nawani	Sri AN Nagarajan
64.	18-08-2010	New Delhi	Sri S Vijay Kumar	Dr PC Nawani	Sri AN Nagarajan
65.	02-11-2010	New Delhi	Sri S Vijay Kumar	Dr PC Nawani	Sri AN Nagarajan
66.	03-06-2011	New Delhi	Sri S Vijay Kumar	Dr PC Nawani	Sri AN Nagarajan
67.	11-10-2011	New Delhi	Sri S Vijay Kumar	(Dr V Venkateswarlu)	Sri AN Nagarajan
68.	12-09-2012	New Delhi	Dr VP Trivedi	(Dr V Venkateswarlu)	Sri AN Nagarajan
69.	23-04-2013	New Delhi	Sri RH Khwaja	Dr V Venkateswarlu	Sri AN Nagarajan
70.	30-10-2013	New Delhi	Sri RH Khwaja	Dr V Venkateswarlu	Sri AN Nagarajan

List of NIRM Annual General Body Meetings

Meeting No. / Type	Date	Chairman (Secretary, MoM)	NIRM Director
1st Special General Body	07-11-1988	Sri BK Rao	(Sri PAK Shettigar)
2nd Special General Body	31-05-1989	Sri BK Rao	(Sri PAK Shettigar)
01 AGM	09-01-1990	Sri PK Lahiri	Dr NM Raju
3rd Special General Body	25-06-1990	Sri PK Lahiri	Dr NM Raju
02 AGM	18-12-1990	Sri RK Dang	Dr NM Raju
03 AGM	09-12-0991	Sri V Krishnan	Dr NM Raju
04 AGM	09-12-0992	Sri V Krishnan	Dr NM Raju
05 AGM	23-09-1993	Sri IG Jhingran	Dr NM Raju
06 AGM	16-11-1994	Sri IG Jhingran	Dr NM Raju
4th Special General Body	20-04-1995	Sri AC Sen	Dr NM Raju
07 AGM	28-12-1995	Sri AC Sen	Dr NM Raju
08 AGM	17-12-1996	Sri AC Sen	Dr NM Raju
09 AGM	19-12-1997	Sri BB Tandon	(Mr J Chatopadhyay)
5th Special General Body	29-06-1998	Sri BB Tandon	Dr NM Raju
10 AGM	26-11-1998	Sri BB Tandon	Prof RN Gupta
11 AGM	27-09-1999	Sri Arvind Varma	Prof RN Gupta
12 AGM	21-09-2000	Sri Dipak Chatterjee	Prof RN Gupta
13 AGM	19-09-2001	Sri Dipak Chatterjee	Prof RN Gupta
6th Special General Body	20-12-2001	Sri Dipak Chatterjee	Prof RN Gupta
14 AGM	02-09-2002	Dr AK Kundra	Prof RN Gupta
15 AGM	30-10-2003	Sri CD Arha	Prof RN Gupta
7th Special General Body	06-05-2004	Sri CD Arha	Prof RN Gupta
16 AGM	27-10-2004	Sri CD Arha	Prof RN Gupta
17 AGM	11-08-2005	Sri AKD Jadhav	Prof RN Gupta
8th Special General Body	30-11-2005	Sri AKD Jadhav	Prof RN Gupta
9th Special General Body	23-03-2006	Sri AKD Jadhav	Prof RN Gupta
18 AGM	08-10-2006	Sri AKD Jadhav	(Dr VP Mishra)
19 AGM	18-12-2007	Sri JP Singh	-
10th Special General Body	03-04-2008	Sri JP Singh	Dr PC Nawani
20 AGM	18-11-2008	Sri Santanu Kansal	Dr PC Nawani
21 AGM	20-11-2009	Ms Santha S Nair	Dr PC Nawani
22 AGM	02-11-2010	Sri S Vijay Kumar	Dr PC Nawani
23 AGM	11-10-2011	Sri S Vijay Kumar	(Dr V Venkateswarlu)
24 AGM	12-09-2012	Dr VP Trivedi	(Dr V Venkateswarlu)
11th Special General Body	23-04-2013	Sri RH Khwaja	Dr V Venkateswarlu
25 AGM	30-10-2013	Sri RH Khwaja	Dr V Venkateswarlu

List of Peer Review Committee Meetings

Meeting No.	Date	Place	Chairman	Director
01	26th & 27 Mar., 2000	KGF	Prof DP Singh	Prof RN Gupta
02	12th Nov., 2000	KGF	Prof DP Singh	Prof RN Gupta
03	14th & 15th July, 2001	KGF	Prof DP Singh	Prof RN Gupta
04	4th & 5th Mar., 2002	KGF	Sri Ravi Shanker	Prof RN Gupta
05	27th & 28th Nov., 2002	KGF	Sri Ravi Shanker	Prof RN Gupta
06	26th & 27th June, 2003	KGF	Sri Ravi Shanker	Prof RN Gupta
07	13th & 14th Mar., 2004	KGF	Sri Ravi Shanker	Prof RN Gupta
08	27th & 28th Dec., 2004	KGF	Sri Ravi Shanker	Prof RN Gupta
09	5th & 6th Aug., 2005	Bangalore	Sri Ravi Shanker	Prof RN Gupta
10	28th & 29th Apr., 2006	KGF	Sri Ravi Shanker	Prof RN Gupta
11	28th & 29th Dec., 2006	Bangalore	Sri Ravi Shanker	(Dr VP Mishra)
12	11th & 12th Mar., 2008	KGF	Sri Ravi Shanker	Dr PC Nawani
13	20th & 21st Mar., 2009	Bangalore	Sri Ravi Shanker	Dr PC Nawani
14	4th & 5th Jan., 2010	Bangalore	Sri Ravi Shanker	Dr PC Nawani
15	28th & 29th Dec., 2010	Bangalore	Sri Ravi Shanker	Dr PC Nawani
16	28th & 29th Nov., 2011	Bangalore	Sri Ravi Shanker	(Dr V Venkateswarlu)
17	19th & 20th Dec., 2012	Bangalore	Sri Ravi Shanker	(Dr V Venkateswarlu)
18	7th & 8th Oct., 2013	Bangalore	Sri Ravi Shanker	Dr V Venkateswarlu

Details about Past Staff

Sl. No.	Name	Designation at NIRM	Period of Service	
			From	To
1	Dr NM Raju	Director	14-6-1989	26-10-1998
2	Prof RN Gupta	Director	27-10-1998	31-5-2006
3	Dr PC Nawani	Director	20-2-2008	31-7-2011
4	Dr VP Misra	Director (Addl. Charge)	1-6-2006	31-12-2006
5	Dr MVMS Rao	Scientist-5	11-3-1992	18-2-1995
6	Sri J Chattopadhyay	Scientist-5	7-1-1993	30-4-2000
7	Mr PK Behera	Scientist-5	30-11-2000	25-12-2003
8	Prof BShrikant S	Scientist-4	1-1-1990	21-11-1994
9	Mr A Srikant	Scientist-3	30-1-1990	31-7-1995
10	Dr B Dasgupta	Scientist-3	18-3-1991	31-7-1995
11	Dr GM Nagaraja Rao	Scientist-5	1-1-1990	30-9-2013
12	Dr C Srinivasan	Scientist-5	1-1-1990	28-2-2014
13	Dr GR Adhikari	Scientist-5	9-3-1990	31-1-2013
14	Dr S Sengupta	Scientist-5	19-3-1990	31-12-2013
15	Dr SK Arora	Emeritus Scientist	1999	2000
16	Dr CV Krishnamohan	Scientist-3	31-12-1990	13-10-1997
17	Mr K Narendar Reddy	Scientist-3	9-3-1990	18-12-2000
18	Mr K Shiva Kumar	Scientist-3	13-12-1990	10-12-2001
19	Dr R Venugopala Rao	Scientist-3	27-2-1996	15-10-2005
20	Mr KS Nagarajan	Scientist-2	1-1-1990	1-5-1993
21	Sri V Radhakrishnan	Administrative Officer	11-1-1990	2-3-1991
22	Sri MR Muralidharan	Sr Administrative Officer	31-7-1991	28-4-2010
23	Mr SK Goyal	Finance & Accounts Officer	17-1-2000	4-5-2000
24	Mr Kailash Maheswari	Finance & Accounts Officer	24-6-2000	2-2-2002
25	Sri Biju Mathew	Finance & Accounts Officer	28-11-2003	30-4-2007
26	Mr KN Maniyan	Section Officer	6-6-1990	17-1-1998
27	Mr V Suresh	Office Asst.-2	4-9-2000	16-12-2009
28	Dr S Jayanthu	Scientist-4	31-3-1997	10-11-2006
29	Dr T Srinivasulu	Scientist-3	7-6-1990	31-5-2006
30	Mr SK Mohanty	Scientist-3	30-6-1997	19-4-2011
31	Dr Surendra Roy	Scientist-3	24-12-2002	29-5-2012
32	Mr DT Rao	Scientist-3	15-12-2008	30-4-2012
33	Mr A Shridhar Chavan	Scientist-2	1-1-1990	21-4-1997
34	Mr YL Visweswariah	Scientist-2	1-1-1990	31-7-2011
35	Mr GS Govinda Setty	Scientist-2	1-1-1990	28-2-2013
36	Mr S Sathyanarayana	Scientist-2	1-1-1990	31-5-2013
37	Mr G Ravi	Scientist-2	3-1-1990	1-9-1997

38	Dr N Kumar Pitchumani	Scientist-2	17-8-1992	15-12-1995
39	Mr Atul Gandhe	Scientist-2	30-11-2002	31-1-2011
40	Mr Seshapanpu Jakki	Scientist-2	9-12-2002	10-5-2005
41	Dr Gnananda Budi	Scientist-2	24-10-2008	31-3-2009
42	Dr Roshan Nair	Scientist-2	24-2-2010	21-9-2012
43	Mr P Srinivasa Moorthy	Scientist-1	1-1-1990	16-1-1995
44	Mr V Deshpande	Scientist-1	16-2-1990	4-6-1990
45	Mr Sitaram Nayak	Scientist-1	10-8-1990	19-12-1992
46	Mr YVS Babu Rao	Scientist-1	21-10-1990	25-8-1993
47	Mr JP Aglawe	Scientist-1	12-4-1991	31-8-1994
48	Mr FP Shende	Scientist-1	20-4-1993	27-8-1997
49	Mr P Venkata Reddy	Scientist-1	7-9-1993	13-1-1997
50	Mr A Venkata Babu	Scientist-1	27-1-1994	5-8-1994
51	Mr MN Reddy	Scientist-1	15-2-1995	20-2-2004
52	Mr S Abdul Khader	Scientist-1	12-2-1996	20-9-1996
53	Mr Mujib Rahman	Scientist-1	12-2-1996	20-9-1996
54	Mr A Srinivas	Scientist-1	12-2-1996	21-9-2000
55	Mr Abir Kar	Scientist-1	15-2-1996	10-1-2000
56	Mr P Ravi Kiran	Scientist-1	1-3-1997	31-6-1999
57	Mr S Patnayak	Scientist-1	30-6-1997	6-6-2001
58	Mr GV Narasimha Rao	Scientist-1	31-1-1998	20-6-2000
59	Mr Jayaram N Bukke	Scientist-1	17-10-2008	1-12-2008
60	Mr Ravi Dimri	Scientist-1	23-10-2008	9-5-2011
61	Dr Bijay Mihir Kunar	Scientist-1	27-10-2008	2-6-2009
62	Mr Debaprasad Sahoo	Scientist-1	29-10-2008	8-4-2010
63	Mr Sanjay KI Raut	Scientist-1	1-12-2008	10-2-2009
64	Dr Ritesh D Lokhande	Scientist-1	9-12-2008	9-7-2013
65	Vijendra Chourey	Scientist-1	26-8-2009	9-9-2009
66	Mr Piyush Gupta	Scientist-1	15-1-2010	8-3-2013
67	Mr C Damodhar Reddy	Scientific Asst-2	19-5-1998	6-6-2005
68	Mr RK Jade	Scientific Asst.-3	25-4-2000	15-8-2000
69	Mr D Sampath	Technician-3	1-1-1990	31-3-2010
70	Mr T Anjaneyappa	Technician-3	1-1-1990	31-5-2010
71	Mr Abdul Majid	Technician-3	1-1-1990	31-8-2012
72	Mr G Mohandass	Technician-3	1-1-1990	30-6-2013
73	Mr MS Nagaraj	Technician-3	1-1-1990	31-1-2013
74	Mr T Krishnaswamy	Driver	1-1-1990	31-8-1998
75	Mr Abdul Kareem	Driver	1-1-1990	31-10-2006
76	Mr A Yesupadam	Driver	1-1-1990	31-12-2011

Deceased

IM Aga	Member, 1st Governing Body	
PAK Shettigar	Acting Director till 1989	
Dr PK Iyengar	Member, 1st Governing Body	21-12-2011
Prof GS Marwaha	Member, 1st Governing Body	20-5-2000
R Krishnamurthy	Member, 1st Governing Body	
N Sethumadhavan	Scientist-1 (1-1-1990 – 31-3-1997)	
S Varadaraj	Scientific Asst.-3 (with NIRM from 1-1-1990)	18-8-2004*
A Narayanaswamy	Scientist-2 (with NIRM from 1-1-1990)	8-9-2011*
P Srinivasa Varma	Scientific Asst.-3 (with NIRM from 1-1-1992)	1-2-2012*
D James	Lab Asst. (1-1-1990 – 30-6-2001)	
T Krishnaswamy	Driver (1-1-1990 – 1-8-1998)	5-10-2013
M Lakshmipathy	Lab Asst.-3 (with NIRM from 1-1-1990)	2-3-2014*

* Died in harness

Distinguished Visitors to the Institute

Visitor	Date
Prof Ove Stephansson & Ulf Mattila Lulea University of Technology, Lulea, Sweden	9-2-1990
Dr R Chidambaram Director, BARC, Trombay, Bombay	19-7-1990
Dr J Pathak CANMET, St Ottawa, Ontario, Canada	26, 27-7-1990
Sri CPS Nair Chief Technical Adviser, Dept of Mines, Govt of India	16-8-1990; 18-3-1992
Sri HV Paliwal Director (Mining Operations), Hindustan Zinc Ltd, Udaipur	13-11-1990
Dr E Shekarchi (US Bureau of Mines) Dr U Bajulu (Univ. of Ljubljana, Yugoslavia) Dr R Wustrich, L Weber & G Stesk (Vienna, Austria)	23-11-1990
Dr VM Sharma Director, CSMRS, New Delhi	23-11-1990
Sri PK Lahiri Secretary to the Govt of India, Dept of Mines	30-11-1990
Sri M Gopalakrishna Addl. Secretary to the Govt of India, Dept of Mines	23-1-1991
Sri RK Dang Secretary, Ministry of Mines. Govt of India	14-2-1991
Sri SN Thakar Dy DGMS (SZ), Hyderabad	22-2-1991
Sri V Muniyappa MP Kolar & Minister of State for Sericulture, Govt of Karnataka	30-7-1991
Sri Balram Singh Yadava Minister for Mines, Govt of India	30-7-1991
Sri K Paul Director General of Mines, Dhanbad	25-8-1991
Dr Ray Sterling Director, Underground Space Centre, University of Minnesota, USA	4-11-1991
Prof Jaak Daemen Professor & Chair, Mining Engineer Mackay School of Mines, University of Nevada, Rino, USA	
Dr Michael Barker Consulting Planner, Warren, VT, USA	
Prof CS Desai Regents' Professor, Dept of Civil Eng & Eng Mech. University of Arizona, Tucsan, AZ, USA	18-11-1991
Prof GC Sen Department of Mining Engineering, University of New South Wales, Australia	17-12-1991
Dr Ripudaman Lama Kembla Coal & Coke P/L, Wollongong, NSW, Australia	29-12-1001 to 10-1-1992
Sri V Krishnan Secretary, Ministry of Mines, Govt of India	7-10-1992

Visitor	Date
Sri BK Rao Former Secretary, MoM, GoI	18-10-1992
Prof J Zschau Kiel University, Germany	22-11-1992
Sri IG Jhingran Secretary to the Govt of India, Ministry of Mines	2-3-1993
Sri IM Aga Former Chairman, BGML	11-6-1993
Sri GL Tandon Former Chairman, Coal India Ltd	8-7-1993
Prof BB Dhar Director, CMRS, Dhanbad	13-10-1993
Dr Baldev Raj Director, Metallurgy & Materials Group Indira Gandhi Centre for Atomic Research, Kalpakkam	27-12-1993
Dr Oto Akio Geological Survey of Japan, Tokyo	18-2-1994
Prof AK Ghose Indian School of Mines, Dhanbad	19-2-1994
Dr Kinichiro Kusunose Geological Survey of Japan, Tanaka, Japan	18-1-1995
Sri B Narasimhan Addl. Secretary, Ministry of Mines, Govt of India	11-9-1995
Dr Suzanne Lacasse Director, Norwegian Geotechnical Institute, Oslo	11-11-1995
Sri Birendra Prasad Baishya Union Minister for Steel & Mines, Govt of India	19-8-1996
Sri BB Tandon Secretary, Ministry of Mines, Govt of India	24-1-1997
Sri Vinay Mahajan Director General of Mines Safety, Dhanbad	20-8-1997
Sri Ravi Shanker Sr Dy Director General, Geological Survey of India, Lucknow	25-7-1998
Sri Arvind Varma, IAS Secretary to the Govt of India, Dept of Mines Ministry of Steel & Mines, Govt of India, New Delhi	5-2-1999
Sri PK Mohanty, IAS Addl. Secretary to the Govt of India Ministry of Mines, New Delhi	13-7-1999
Sri AH Jung, IAS Addl Secretary & Financial Advisor, Dept of Mines Ministry of Steel & Mines, Govt of India, New Delhi	30-8-1999
Sri Dipak Chatterjee, IAS Secretary to the Govt of India, Department of Mines Ministry of Mines & Minerals, New Delhi	11-11-1999
His Excellency Truls Hanevold Ambassador of Norway, New Delhi	7-3-2000

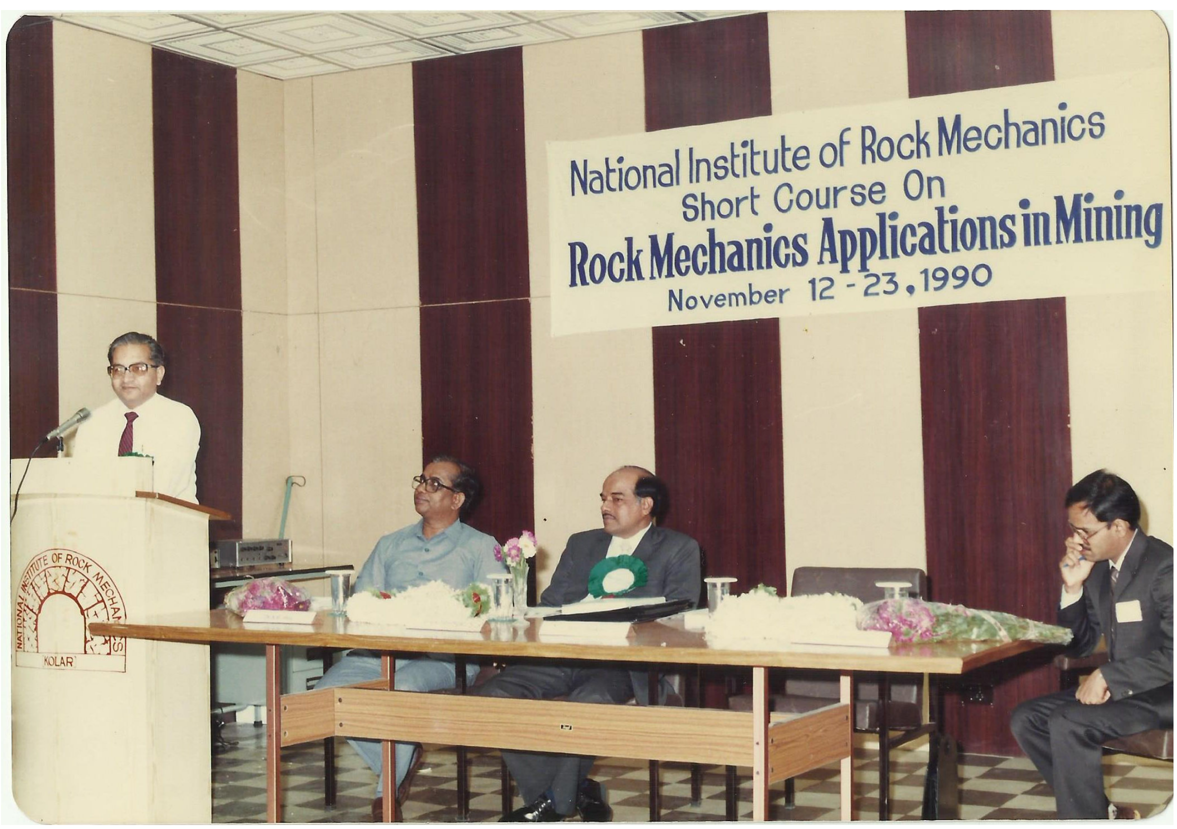
Visitor	Date
Sri Sushil Chandra Tripathi, IAS Addl Secretary to Govt of India, Ministry of Mines, New Delhi	28-1-2001
Dr AK Kundra, IAS Secretary to the Govt of India, Department of Mines, New Delhi	6-4-2002
Sri PC Mandal Director General, Geological Survey of India, Calcutta	29-12-2002
Sri V Madhu, IAS Managing Director, Hutti Gold Mines Co Ltd, Bangalore	3-3-2003
Sri CD Arha, IAS Secretary to Govt of India, Ministry of Mines, New Delhi	21-8-2003
Smt Sudha Pillai, IAS Addl. Secretary to Govt of India, Department of Mines, Ministry of Coal & Mines, New Delhi	8-5-2004
Sri RH Khwaja, IAS Chairman & Managing Director, Singareni Collieries Co Ltd	24-7-2005
Hon'ble Justice Bilal Nazki Chief Justice, High Court of Andhra Pradesh	13-8-2005
Sri KP Lall Advisor, TPPC, Ministry of Mines, New Delhi	29-5-2006
Dr Pradeep Kumar, IAS Addl. Secretary, Ministry of Mines, Govt of India, New Delhi	11-1-2007
Sri PM Tejale Director General, Geological Survey of India	12-6-2008
Dr Mareh Kwadmeinski Professor of Rock Mechanics, Silesian University of Technology, Poland	7-10-2008
Dr Hiroshi Ogasawara College of Science & Engineering, Ritsumeikan University, Japan	18-3-2011
Sri Kencho Dorji, Chief Engineer, Tala Hydro Power Plan Druk Green Power Corporation, Bhutan	15-5-2012
Dr Gopal Dhawan Chairman & Managing Director, Mineral Exploration Corporation Ltd, Nagpur	27-9-2013
Sri R Sridharan Addl. Secretary, Ministry of Mines, Govt of India, New Delhi	8-11-2013

Visitors Gallery

Sri BK Rao, former Secretary, along with Director, Dr NM Raju

Sri PK Lahiri, Secretary, Dept. of Mines (30-11-1990)

Sri VC Varma, Director General of Mines Safety, inaugurating a Workshop at NIRM; others in the picture are : Dr NM Raju, Sri IM Aga and Sri SC Mahanti



Sri HV Paliwal inaugurating a Short Course at NIRM

Prof GS Marawaha & Sri R. Krishnammurty (17-5-1991)

Sri V Krishnan, Secretary, Ministry of Mines (7-10-1992)

Prof BB Dhar, Prof AK Ghose, anon., Sri BK Rao, Dr NM Raju,
Sri Shrikant B Shringarputale

Sri IG Jhingran, Secretary, Ministry of Mines (2-3-1993)

Dr. Tore Lasse, Head Rock Engineering Division, Norwegian Geotechnical Institute, along with Dr VM Sharma, Director, CSMRS (15-10-1994)

Sri R Krishnamurthy and Sri MHR Rao during an event of NIRM

Sri R Gupta, Dr NM Raju, anon., Scientist from NGI, Dr Axel Makurat, NGI

The First Peer Review Committee

Sri Aravind Varma, Secretary, Ministry of Mines (5-2-1999)

Sri PK Mohanty, Additional Secretary, Ministry of Mines (13-7-1999)

Sri AH Jung, Additional Secretary, Ministry of Mines (30-8-1999)

Dr PC Jha, Prof DP Singh & Dr Axel Makurat (NGI), at the International Conference on Rock Engineering Techniques for Site Characterization (ROCKSITE) on 6.12.1999

Sri SC Tripathi, Additional Secretary, Ministry of Mines (28-1-2001)

Sri V Madhu, Managing Director, HGML (3-3-2002)

Dr AK Kundra, Secretary, Ministry of Mines (6-4-2002)

Sri CD Arha, Secretary, Ministry of Mines (21-8-2003)

Sri RH Khwaja, IAS, Chairman-cum-Managing Director, SCCL
delivering the Foundation Day Lecture at NIRM (24-7-2005)

Hon’ble Chief Justice of Andhra Pradesh High Court, Mr Justice B Nazki
(13-8-2005)

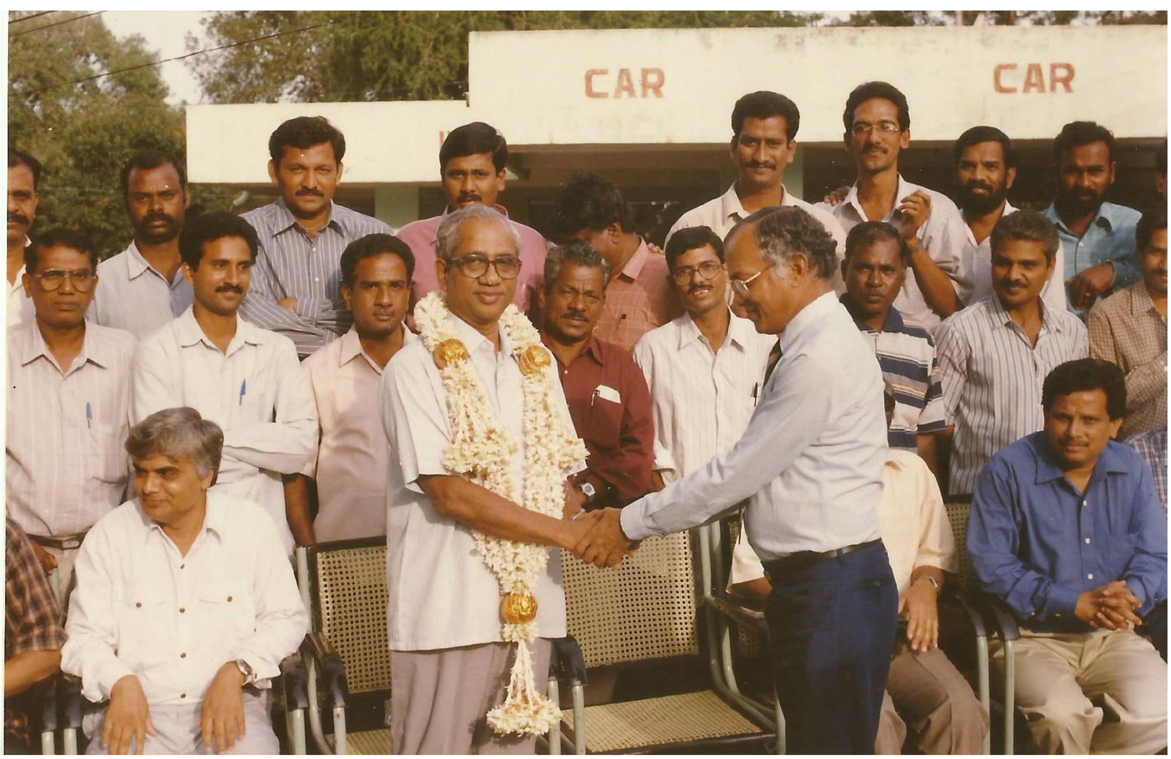
Sri R Sridharan, Addl Secretary, MoM, visiting NIRM laboratories on 8-11-2013

Director Dr PC Nawani, flanked by Dr V Venkateswarlu and Sr Ravi Shanker;
others in the picture are : Ms Ann Williams & Dr Brian Hawkins

Training programme conducted for THDC

Director, Dr PC Nawani, Course Coordinator, Mr Sripad R Naik, and partici-pants at the inaugra-tion of training course on numerical modelling (1-4-2009)

Dr JL Jethwa (CMRI), Sri A Dharma Rao (DGMS), Dr PR SHeorey (CMRI), Dr NM Raju (NIRM), Sri AK Rudra (DGMS) (from L to R in the first row, with the Scientists of NIRM



Dr NM Raju, the first Director being felicitated by Prof RN Gupta, the new Director on 26-10-1998

NIRM Employees Past and Present

50th Independence Day Celebrations (15-8-1998)

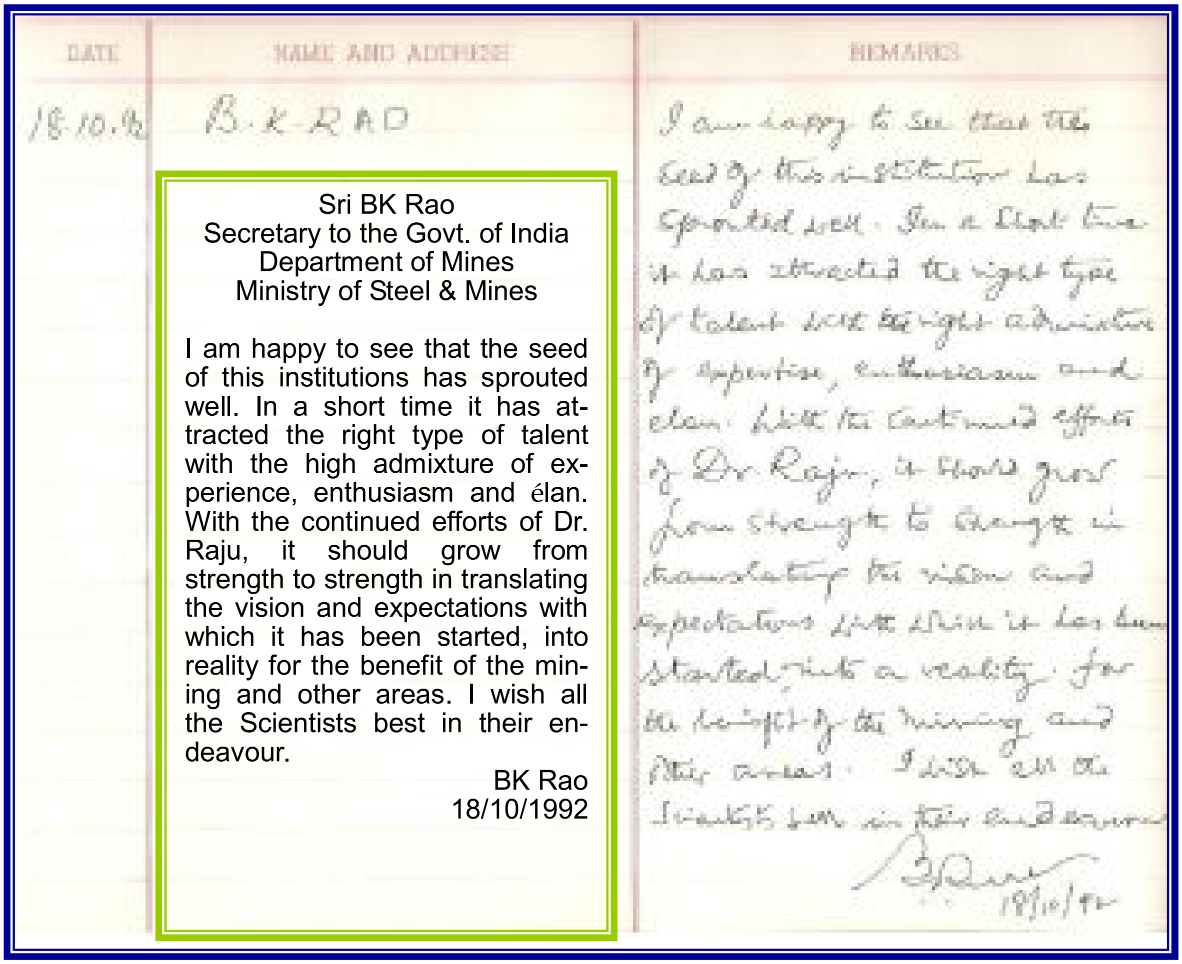
Director, Dr NM Raju, addressing the gathering after flag hoisting on the 50th Independence Day

Group Photograph on the occasion of 50th Independence Day, on background Gifford's shaft


GOLDEN JUB LEE CEL EBR ATI ON OF INDEPENDENC
NIRM


ATI ON OF INDEPENDENCE DAY

Excerpt from Visitor Book



Sri BK Rao
Secretary to the Govt. of India
Department of Mines
Ministry of Steel & Mines

I am happy to see that the seed of this institutions has sprouted well. In a short time it has attracted the right type of talent with the high admixture of experience, enthusiasm and élan. With the continued efforts of Dr. Raju, it should grow from strength to strength in translating the vision and expectations with which it has been started, into reality for the benefit of the mining and other areas. I wish all the Scientists best in their endeavour.

BK Rao
18/10/1992

INDIAN EXPRESS Bangalore, Thursday February 4 1988

Institute of rock mechanics to be set up at KGF

Express News Service

Hyderabad, Feb. 3: A National level institute of rock mechanics and ground control will be set up at the Kolar Gold Fields, Karnataka to utilise the expertise and infrastructure available there for the benefit of the mining industry.

Disclosing this Union Minister of State for Mines Ramdulari Sinha said the Government had recently sanctioned Rs. 2 crore for the establishment of the advanced-level Mining Research Institute.

Mrs Sinha was inaugurating the fifth plenary scientific session of the working group on "rock burst" of the International Bureau of Strata Mechanics, at the Regional Research Laboratory here on Tuesday. The sessions include a visit to Bangalore and the Kolar Gold Fields (KGF).

Prof. A. Kidybineski, Chairman, International Bureau of Strata Mechanics, pointed out that rock burst, a sudden violent "failure" of a mass of rock was one of the severest hazards in mining. The Kolar Gold Fields, particularly plagued by rock bursts since the beginning of the century would yield valuable lessons for the understanding of the mechanics of rock burst.

Cultural Programme and Sports


CELEBRATIONS 2013 -14
DATION DAY
27 July, 2013
OF ROCK MECHANICS
N I R M


NATIONAL INSTITUTE OF ROCK MECHANICS
CHAMPION REEFS, KOLAR GOLD FIELDS - 563117
स्वा
ग
त
म्


23/07/2011


17/07/2011


NATIONAL INSTITUTE OF ROCK MECHANICS
CHAMPION REEFS, KOLAR GOLD FIELDS - 563117


NO PARKING

Engineering Geological Investigations for Preparation of Detail Project Report (DPR) of Hydroelectric Projects – State-of-the-Art

A.K. NAITHANI

Engineering Geology Department, National Institute of Rock Mechanics, Kolar Gold Fields

INTRODUCTION

The inputs from engineering geological investigations are pre-requisite for economic and safe designing of all hydroelectric projects. This manuscript has been prepared based on experience gained by the use of Indian Standards and to reflect the current practice in the engineering geology field. National Institute of Rock Mechanics (NIRM) is doing DPR stage investigations for hydroelectric projects from 2008. For every water resources project preparation of a Detail Project Report (DPR) is a statutory requirement. It provides a road map of the project so that various governmental agencies, can examine its different aspects including the viability and techno-economic justification of the project. A DPR is a document which can give enough confidence to the lending agencies that each component of the proposed project has been adequately explored in such a way that there will be very limited scope of deviation and nature of work would not undergo major changes during construction stage. The constraints and uncertainties are well understood and suitable provisions are made in design so that these are not met as surprises. The main requirement of a DPR is the assurance of the project being constructed within the estimated cost and time schedule. Inadequate engineering geological investigation can substantially increase the risk of encountering unknown adverse conditions or "geological surprises" that can seriously delay or even stop construction, with costly consequences. On the other hand techno-economic evaluations of a project can be done properly by doing optimum investigations at DPR stage. By carrying out appropriate investigations during the DPR stage, great savings can be made. This is where really expensive mistakes can be avoided.

Kharagwasla and Panshet dams in Maharashtra and Kaddam dam in Andhra Pradesh were failed because of inadequate assessment of design flood, while R. K. Puram dam in Little Andaman was failed because it was constructed in cavernous limestone. Multiple problems were encountered during the construction in few other projects also. During the construction of HRT of Loktak HEP and Ranganadi HEP in north eastern part of India casualties happened because of encountering methane gas. During DPR stage investigation itself, all exploratory holes should be checked for the presence of gases. TBM had to be buried during the excavation of Dul-Hasti project of Jammu and Kashmir (J&K) and excavation of HRT could be completed with great difficulty by DBM. During the excavation of HRT of Nathpa Jhakri HEP, Himachal Pradesh numbers of problem were encountered like hot spring, thick shear zones and low cover zone in HRT. Hot water zones (Temp. 54^{o} – 60^{o}) were encountered with a discharge of 60 lit/sec in some reaches of the head pace tunnel (27 km. long) of Naptha Jhakri HEP. These geothermal occurrences were already identified during investigation stage. Hence, high temperature inside the tunnel was brought down by sprinking cold water and placing ice blocks near the working face. For the Tapovan-Vishnugad HEP, Uttarakhand, excavation of HRT using TBM is extremely challenging because of the heavy ingress of muddy water. During the construction of Tala HEP, Bhutan multiple problems were encountered. Stress related problem was reported in underground desilting chambers, thick shear zones in HRT, squeezing, tunnel collapse and chimney formations; heavy seepage, resulting in tunnel detour. Lifting of muck from top flooding of construction adit was done for surge shaft and pressure shaft because of choking of pilot hole of surge shaft and of pressure shaft. Other problems were roof collapse of underground powerhouse, rib erection, powerhouse floor heaving, failure of rock bolts from powerhouse area and detouring of TRT alignment. Suitable construction materials were also not available in the surrounding area of Tala HEP.

The amount of exploration to be done on any given project site is usually determined by experience and budgetary provision. For every project geological mapping and exploration for river valley projects are usually undertaken in four different stages:

a) Reconnaissance stage
b) Preliminary investigation stage
c) Detailed geological investigation stage
d) Construction stage

In some cases, the detailed geological investigations may be taken up just prior to construction, when these would also be termed as pre-construction stage investigations. In order to meet the requirement of planning, design and construction at various stages of the project, geological surveys are undertaken on different scales. Out of the above, a DPR incorporates the above three stages of investigations. In DPR stage, the dam and its appurtenant structures should be surveyed on 1:1000 topo-maps having contour interval at 2 m. The DPR stage engineering geological investigation programmes which are planned in above three stages should provide geological and geotechnical data required for rock mass characterization and also to identify potential hazard zones at project sites.

DPR STAGE INVESTIGATIONS FOR HYDROELECTRIC PROJECTS

DPR stage investigations can broadly be grouped under three heads i.e. (a) topographical survey, (b) hydro-meteorological investigations and (c) geological and geotechnical investigations. NIRM is having the expertise for geological and geotechnical investigations. Topographical survey includes establishment of Bench Marks (BMs) with the help of Survey of India (SoI) followed by detailed topographical survey of reservoir and different component of the project (IS: 5497-2008). Every project is allocated a pair of elevations along the river viz. the Full Reservoir Level (FRL) and the Tail Water Level (TWL) for development. This is to avoid interference with the immediate upstream and downstream projects and for full utilization of the basin potentiality. Under hydro-metereological investigations the hydrological data such as discharge, rainfall, catchment area and its characteristics, snow fed area etc. are collected which are vital to work-out the power potential and maximum flood discharge.

GEOLOGICAL AND GEOTECHNICAL INVESTIGATIONS

The geological and geotechnical investigations cover from catchment area to tail race outfall. The catchment area from water divide to dam / barrage site is studied with the help of Satellite Imagery, Arial Photographs and SoI Toposheets. All the available literature, relevant to the catchment area are consulted and desk study (area determination, snow /rain fed areas morphometric analysis etc.) followed by optimum traverse mapping.

Alternative studies with regard to type and location of dam or barrage, desilting basin, alignment of HRT, surge shaft, powerhouse, diversion channels/tunnels are carried out during investigations. These studies are based on geological mapping, geophysical explorations and subsurface investigations.

Reservoir Area Investigations

Topographical survey of the reservoir area is carried out on 1:10,000 scale. Geology (lithology, structure and slope morphology) of the reservoir area is studied and developed by consulting available literature, satellite imageries and aerial photographs followed by optimum traverse mapping. Distribution of snow fed (if any) and rain fed areas should be demarcated. If there are chances of Glacial Lake Outburst Flood (GLOF), that factor should be taken into account towards Probable Maximum Flood (PMF) calculation. Stability and competency of the reservoir has to be established. Presence of major tectonic planes and their impact on Reservoir Induced

Seismicity (RIS) should be studied. Landslides falling under diurnal fluctuation zone and above and their impact in reservoir sedimentation and wave generation should be studied in detail. The other important things of the proposed reservoir areas that need to be studied are: existing landuse pattern, need of road diversion because of submergence, green house effect, presence of any mineral deposit or occurrence, and presence of any archaeological/historical important structures.

Cofferdam Investigations

Cofferdams are temporary barriers constructed to facilitate excavation of the foundation of main dam. When the construction of the main dam is completed, the cofferdams usually are demolished or removed. Sometimes the upstream cofferdam becomes part of the main dam. The investigations for cofferdam include geological mapping, drill holes to decipher the depth to bedrock and cut off and preparation of geological map and sections.

Diversion Tunnel Investigations

Diversion Tunnel is usually a temporary structure constructed to divert the river water during construction of the main dam or barrage. Sometimes the diversion tunnel is used as spillway. If there is space, a diversion channel may be planned to economize the project cost. The minimum required geological investigations for diversion tunnel include: detail geological mapping along the tunnel alignment, assessment of vertical and horizontal rock cover along the alignment, drill holes to fix the portals, to determine the rock mass class along the tunnel alignment, stability of the inlet and outlet portals, joint analysis to determine the vulnerable wedges and workout the protective measures.

Concrete Gravity Dam Investigations (Concrete, Arch)

Along the dam axis detailed geological mapping preferably on 1:500/1000/2000 scale are carried out. Alternatives (type and location) are generally studied to select final site on techno-economic consideration. Geological maps upto 200 m u/s and 300 m d/s are prepared to show all the structures of dam complex. Geological sections along dam axis, bucket portion, plunge pool from the surface and sub-surface geological data are prepared. Drill holes are drilled along the dam axis including abutments and deepest part of the river, bucket area and energy dissipation area. About 2 holes, 2/3rd H depth at the axis, where H is the height from depth of foundation to FRL are drilled. One hole at bucket portion down to H depth is also drilled. Depending upon the complexity of the geology, vertical / inclined core drilling at 30 m to 50 m interval along the dam axis to establish the bedrock profile are drilled. Provisions for few more holes are generally also kept to investigate certain special features like buried channels etc. Groutability tests are conducted at DPR stage to establish the grout parameters for an effective grout intake.

The drill cores are generally logged and presented as per IS code. Drill core logging by geologists and also by using acoustic / optic televiewers is also done for getting continuous information. The bedrock depth obtained from drilling investigations is utilized to develop a bedrock contour plan of the proposed dam area in some projects. The drill holes locations around the proposed dam site and abutments should are shown on a map. Water Percolation Test (WPT) is conducted in all the holes as per IS codes and test records are presented in the DPR. A summary of drill core logs is also given in the DPR. Photographs of all drill cores are taken systematically and given in DPR. In many projects all drill cores are preserved in a core library as per IS: 4078-1980 but it should be applied to all projects. Rock mechanical tests on drill cores are carried out at laboratory to assess the characters of foundation grade rocks. It is recommended that core samples should be selected by Senior Geologist, so that representative samples can be selected from the all components and desired locations. Site specific seismic parameters are determined for almost all the projects and same data incorporated in design (Fig. 1).

Exploratory drifts (1.8 m x 2 m) on both banks with cross cuts should be excavated to assess rock mass condition at the proposed location. The length of drift and cross cuts should be as per BIS guidelines. Number of drifts depends upon the dam height. Drifts can be excavated at about 50 m interval considering the deepest foundation level. For a dam up to 30 m height drift exploration is not required. For a dam up to 50 m height one drift on each abutment should be excavated. For a dam up to 100 m height two drifts on either abutments and for a dam more than 100 m height three or more drifts preferably at 50 m El. intervals may be excavated. Each drift 3-D geological logged, and stripping limits should be established. These drifts are also used for insitu testing for stress measurement and deformability of rock mass.

Rock fill, Concrete Faced Rock Fill and Earth Fill Dams Investigations

The geological and geotechnical investigations for a rock fill, concrete faced rock fill and earth fill dam are almost similar to a concrete gravity dam except that here emphasis are given to the nature and characteristics of the river borne deposits also, because the rock fill, concrete faced rock fill and earth fill dams are founded generally on the River Borne Materials (RBM). Geological and geotechnical investigations for a rock fill, concrete faced rock fill and earth fill dam includes drill hole as per concrete dam. If any thick sand layers encountered within the RBM at proposed dam site, that should be investigated for liquefaction potentiality. Standard Penetration Test (SPT) should be conducted as per BIS code to determine the 'N' value. Cross bore hole tomography and MASW should be carried out. Bearing capacity of the foundation should also be determined as per IS code and drifts may be required to know the extent of slumped rock mass at the abutments (Fig. 2).

Fig. 1. View of Srisailam Dam

Fig. 2. A panoramic view of Tehri Dam

Barrage Investigations

Barrage is a low height, light weight diversion structure, can also be built on permeable foundation with no provision for storage. Like a rock fill, CFRD or earth fill dam, barrages are also constructed on river borne materials. Since it is not tied with the abutments, drift exploration is not essential. If any thick sand layers, encountered within the RBM at proposed barrage site, that should be investigated for liquefaction potential. Bearing capacity of the foundation should also be determined.

Water Conductor System (WCS)

The WCS carries the water from reservoir to powerhouse through power intake, desilting basin, Head Race Tunnel (HRT), Head Race Channel (HRC) / flume path, surge shaft and pressure shaft. The WCS of a hydro power project starts with a power intake structure. The intake structure should preferably be founded within competent bedrock. The proposed intake site is explored by surface geological mapping and drilling to establish the bedrock position. Stability of the cut slope above the intake structure is studied in detailed.

Power Intake

In the power intake area investigations are carried out includes geology of intake portal, availability of fresh rock, detailed geological section along and across the structure, drill hole to know the depth and nature of bedrock, cut slope study and analysis of discontinuity planes.

Desilting Arrangement

To minimize the rate of turbine abrasion it is desired that the feeding water to turbine is devoid of suspended silt particles greater than 0.2 mm size. This is done by providing desilting arrangement in the proposed project. The structure may be surface desilting basin or an underground desilting chambers. If space is available, surface desilting basin is more economic than the underground desilting chambers. In desilting basin / chamber geological mapping of the area is carried out. Geological section along and across the structure, sections along the adits and silt flushing tunnels based on surface mapping and sub-surface exploration are generated. In almost all the projects drift along the entire length of chambers is excavated. Studies pertain to rock mass, discontinuity planes and wedge analysis is carried out. Hydro-fracture test to assess in-situ stress field and orientation of chambers are done in many projects. Drill holes were drilled to know the rock mass condition above the cavern; adequacy of rock cover above the cavern and the lateral cover including between the chambers.

Head Race Tunnel (HRT)

The required geological and geotechnical investigations at DPR stage for a proposed HRT includes geological mapping on 1:5000 scale; establish the adequacy of vertical and horizontal rock covers along the HRT by drilling or otherwise; tentative rock mass classification along the HRT alignment is assessed based on surface and sub-surface explorations. Geological sections of HRT and adits are developed. Numbers of adits are determined based on topography and length of HRT. Length of excavation from one adit may not be more than 2.5 km. Drill holes were drilled to know the minimum rock cover, nature of shear/ fault if present along HRT and adits including portals and stability of adit portals. Drilling is done 10-20 m below the proposed invert level. Based on the geological and geophysical information, the exploratory drilling is planned. Drilling is done by core and non-coring or reverse circulation (RC) drilling. Rock mechanical tests on drill cores are carried out at laboratory to know the characteristics of intact rock at tunnel grade. Ground water regime / depth of water table along the proposed HRT alignment was also assessed and incorporated in the DPR. Water leakage makes the tunnel difficult to drive and if it is excessive leakage it may lead to lowering of the ground water level in the vicinity. Possibility of encountering hot spring /hot zone/poisonous gases along the HRT is explored in many projects. Provision of advance probing may be kept in the construction schedule to anticipate the problem in advance and plan accordingly. Provision of instrumentation should be kept to monitor the development of stresses and resulting deformation during and after excavation. The head race tunnels that have been investigated more thoroughly have fewer cost overruns and fewer disputes during construction. The U.S. National Committee on Tunnelling Technology (USNC/TT) in 1984, made a comprehensive study of exploration practices in the US to determine if a greater level of geotechnical investigation effort could reduce the final construction cost of tunnel projects. It was found that claims of unexpected subsurface conditions were a significant part of the total cost of a tunnel. Claims payments averaged nearly 12% of the original basic construction cost. Some were as high as 50% over the engineer’s estimate (of the completed cost).

Surge Shaft

Provision of surge shaft is required if the length of HRT is more than four times of the design head. Depending upon the site conditions the surge shaft may be underground or open to sky. Geological mapping and adequacy in lateral cover for open to sky surge shaft investigations are carried out. For open to sky surge shaft, an exploratory hole, 5 m down to bottom level of surge shaft may be drilled to know the rock mass condition. For underground surge shaft, drift at bottom and top level of surge shaft to know the slump limit should be done. Structural analysis may be carried out. The structural data of the drift may be utilized to assess the geological condition along the surge shaft. Holes may also be drilled from the drifts to explore the surge shaft. Water Percolation Test (WPT) may be carried in the holes drilled. Geological sections of construction adits should also be developed. Holes may be drilled to fix the portals of adits. Stability of the portals may be ensured.

Pressure Shaft

Depending upon the topography and situation there may be a surface penstock or under-ground pressure shaft. The proposed sites are well explored by surface geological mapping. The overburden thickness, rock mass characteristics, orientation of discontinuity planes are studied in detailed. Sections along surge shaft – pressure shaft are developed. Holes may be drilled as per geological conditions.

Power House

Depending upon the site condition the powerhouse of a project may be surface powerhouse or underground powerhouse. Surface powerhouse is more economic and easy to construct than underground powerhouse. For surface powerhouse to know the foundation surface geological mapping is carried out. Depending upon the size of the turbines a surface powerhouse may be founded on bedrock or on overburden. About 4-5 holes should be drilled to delineate the bedrock configuration as well as rock mass condition. The stability of back slopes should be ensured.

Underground power house is eco-friendly. For underground powerhouse geological mapping to know the rock types, discontinuity planes, shears or faults is carried out. Adequacy of rock cover is established by drilling. The orientation of the cavern is primarily decided by geological set-up of the area and hydraulics. Later optimization of orientation is done according to underground stress field determined by hydro-fracture tests. Rock mass above the crown of the cavern should be explored. A drift should be explored along the proposed long axis of the powerhouse with some cross cuts to assess the rock mass characteristics. In-situ tests like hydro-fracture test, modulus of deformation test may be carried out. The aim of investigations should be to obtain as complete a picture as possible of the sub-surface geological conditions and arrive at techno-economic evaluation of the project.

Tail Race Arrangement

After generation of power by the turbines in the powerhouse the tail water is brought back to the river either by a Tail Race Channel (TRC) or by Tail Race Tunnel (TRT). The exploration of TRT is similar to that of HRT. Stability of the outlet should be ensured by proper surface and subsurface exploration.

CONSTRUCTION MATERIALS AVAILABILITY

Quantities of coarse and fine aggregates required for wearing and non-wearing surfaces and fines for impervious core of cofferdam or rock fill / earth fill dam should be estimated. Location of various rock quarries and borrow areas around the proposed project preferably be identified within a reasonable distance and should be represented by a location map in the DPR. Each collected sample for testing should be given a unique Sample No. and its location should be marked on the location map. The title of figure may be - Detail map of individual prospect area with sample locations. The quarry sites and borrow areas should be surveyed on 1:2000 scale with contour interval at 4 m. For suitability of coarse aggregates the following tests are as given in Table 1a are required

Table 1a. Tests details for the suitability of coarse aggregates

Sr. No.	Name of Test	Reference to Standard Followed
1	Specific Gravity	IS : 2386 (Part 3) – 1963
2	Water Absorption	IS : 2386 (Part 3) – 1963
3	Aggregate Abrasion Value (Los-Angeles)	IS : 2386 (Part 4) – 1963
4	Aggregate Crushing Value	IS : 2386 (Part 4) – 1963
5	Aggregate Impact Value	IS : 2386 (Part 4) – 1963
6	Soundness (5 cycles) (Sodium Sulphate)	IS : 2386 (Part 5) – 1963
7	Flakiness Index	IS : 2386 (Part 1) – 1963
8	Elongation Index	IS : 2386 (Part 1) – 1963
9	Petrographic Examination	IS : 2386 (Part 8) – 1963

If substantial amount of strain quartz with high extinction angle is present in the aggregate, the following chemical tests given in Table 1b also to be carried out.

Table 1b. Details of chemical tests

Sr. No.	Name of Test	Reference to Standard Followed
10	Potential Alkali Reactivity of Aggregate (Chemical Method)	IS : 2386 (Part 7) – 1963
11	Alkali Aggregate Reactivity by Mortar Bar Method (Accelerated Technique)	ASTM Designation: C 1260-01

Based on the acceptability values of each test only the suitable materials should be taken into account for availability calculation and in this way the adequacies of suitable construction materials to be established and proper mining plan should be planned to extract the materials.

Geological mapping of access roads to various construction sites and the mapping of plants sites may be done on 1:3000 scale having contour interval of 5 m.

HOW TO IMPROVE THE DPR

DPR can be improved by quality geological mapping; quality drilling; use of softwares for data interpretation; suitable time frame for preparation of DPR and resources of the agencies preparing DPR. Quality geological mapping means outcrop geological map and its interpretation; faithful recording of geological data and its interpretation; presentation of map on suitable scale for appraisal of data clearly. There is tendency to club the different lithounits into a single unit even all units are mappable. Such as amygdaloidal basalt – compact basalt, though amygdaloidal basalt and compact basalt can be mapped separately in many cases. All mappable units should be shown in the geological map and sections so that the foundation condition of the dam can be assessed properly. Again the anticipated litho units to be present at the power house / desilting caverns site specially at the crown portion, so that the cavern may be shifted to competent rock units.

Though drilling gives point information but is one of the most important tool to have an assessment of sub-surface geology and as such proper interpretation of drill holes data plays a vital role for a DPR. It is frequently mentioned in the DPR that 2000/3000 m drilling has been done in the project, to focus sufficient work. Achievement of drilling is considered as m/week or m/month but quality of drilling is hardly considered. Core recovery should be considered for projection of drilling work. It is difficult to interpret the rock mass condition from low core recovery. 80% or more core recovery should be ensured through drilling for a realistic interpretation. There are examples that very poor rock mass condition was interpreted from poor core recovery which was contradictory to surface geological condition and drifts were excavated to know the actual rock mass condition. It was surprising that no support was provided in the drifts owing to good rock mass condition. Core recovery can be increased by using good quality drilling bit and drilling rod; controlling rotation and vibration of machine; controlling circulation of water; using short runs; triple tube core barrel be used in weak zones and soft rocks. Driller's observations should also be reflected in the DPR such as sudden drop of drill bit due to presence of cavity, rate of penetration, water loss, colour of return water etc. Core should be properly numbered and maintained. Number of core pieces in a run may also be noted while logging. This can help to assess the rock mass condition, spacing of discontinuities, mechanical breakage etc.

Preparation of geological map, bedrock contour map, interpretation of discontinuity data through stereoplots to decipher direction and inclination of anchors/rockbolts for effective stitching, direction and angle of grout holes etc., wedge analysis, interpretation of core recovery-RQD- Rock Mass Quality (Q) - permeability of the rock mass etc. are being widely carried out using softwares. Softwares like AutoCAD, Surfer, DIPS, Unwedge, Swedge, Slide, RockFall, RocPlane, ROCDATA, Stereoplot, SlopeW are useful. Many of the project authorities are using these softwares for quick interpretation of the data. The presentation of data in the DPR is also of good quality. The input for using the software should be realistic to have a proper interpretation. For example in case of wedge analysis, the angle of internal friction of rock mass is taken from insitu rock mechanic test in the drift for the dam which is valid for failure towards d/s of the dam. The angle of internal friction of the rock mass should be different and will be influenced by the presence of valley ward dipping and other joints. Sometimes angle of internal friction to the tune of 75^o has been considered in the DPR, though it may be less. With such high angle of internal friction of rock it is often found that the wedges are stable but at the same time suitable protective measures like rock bolting, anchoring etc. are being kept in the design. This contradiction doubts the reliability of the input data. Therefore, purity of input data should be ensured for using the softwares.

Stereoplot is a very effective tool for analysis of discontinuity data and should be worked out in all the projects. All the discontinuity data can be analysed at a time through stereoplots and is not dependent on high technology software's. Analysis of data can be done by contouring of poles of the discontinuities and determination of average plane; determination of plunge of intersection of different joints i.e., wedges; plotting of angle of internal friction and cut slope/walls and crown of tunnel/cavern and identifying the vulnerable wedges and drawing of great circle containing the line of intersection of joints. The vulnerable wedges will be between the envelope of cut slope and more than the angle of internal friction. Deciphering the direction and inclination of anchors/rockbolts for cut slopes/tunnel walls and crown. This should be a point on the great circle perpendicular to the great circle containing wedges/intersection of joints. Gradation of joints may be done on the characteristics (frequency, continuity, joint alteration, filling, joint surface etc.) and thrust should be given accordingly. Direction of rock bolting is generally kept perpendicular to the cut surface. It is often found that rockbolts are parallel to the vertical/sub vertical transverse joints along the walls of the tunnel or parallel to the longitudinal vertical joints at the crown along the tunnels. In both the cases rock bolts become ornamental. Therefore, calculated orientation of rockbolts would enhance the safety of the project.

Generally, grouting through vertical holes or providing slightly inclination towards u/s are conventionally used in many projects. In such a case there are little chances of grouting the vertical joints or sub vertical joints and as such preferred orientation of grout holes to intersect all the joints is required to make effective sealing of the joints. The direction of inclination of grout holes for effective grouting will be same as rock bolts.

The software Unwedge is a very good tool for analysis of wedges. Purity of input data should be ensured while using this software. It has been found in many cases that there are no vulnerable wedges though rockbolting has been suggested in the design. This indicates doubt about the reliability of data by the owner of the DPR. Correlation be made between core recovery, RQD and permeability. In general core recovery/RQD inversely proportional to permeability. Any anomaly between the above may indicate weak zones. In normal cases core recovery will increase and permeability will decrease below the riverbed where both weathering and erosion are active. However, in the slopes and abutments permeability will increase upto the depth of weathering/ distressing, where only weathering is active.

Time frame for preparation of DPR should be based on complexity of geology, accessibility of the terrain, working time period, resources of agencies etc. Time frame for preparation of a DPR in Maharashtra or Andhra Pradesh and interior areas in Uttarakhand or Jammu and Kashmir can not be compared. Generally, 2-3 years are being provided arbitrarily for preparation of a DPR of hydroelectric projects. Time frame for preparation of DPR should be fixed judiciously. Similarly, adequacy of resources of the agencies preparing DPR should also be ensured to prepare a realistic, good quality DPR. The cost of geological and geotechnical investigations generally range from 0.5 to 3 percent of the total cost of the project, although sometimes cost upto 8% have been reported. As a matter of fact, the expenditures for geological/geotechnical investigation and explorations should be increased to an average of 3% of estimated cost of the project, for better overall results. Critical attention must be given to the prospective use of state-of-the-art techniques of geological/structural data collection, geophysical surveys, exploration by drilling, hydrogeological studies, in-situ stress measurements, laboratory studies and modeling by numerical methods.

NIRM CONTRIBUTIONS

Since 2008 NIRM has carried out geological / geotechnical investigations for the preparation of DPRs for Bunakha hydroelectric project (180 MW) (BHEP), Bhutan and for Malshej Ghat PSS project (700 MW) (MGPSS), Maharashtra. For BHEP engineering geological mapping of 197 m high dam, spillway, intake structure, pressure shaft, power house and tail race channel was carried out on 1:1000 scale (Fig. 3). Geological logging of drill holes (total depth 1994 m) and seven exploratory drifts was carried out on 1:100 scale. Geological, geophysical, in-situ permeability and laboratory test data was interpreted and inferences & recommendations for the economic and safe design of the structures have been given for each component. Geological mapping of reservoir area has been carried out on 1:10,000 scale from landslide and slope stability point of view using high resolution satellite imageries and field traverses. The reservoir impounded by Bunakha dam would be spread in 3.745 sq. km. area (at FRL 2006m) with length (linear) of 19.5 km has been studied. The basic purpose of these investigations was to identify / map different rock types and structures (lineaments) and also to comment on reservoir rim stability and reservoir competency. Earlier the DPR of this project was prepared by Water and Power Consultancy Services (India) Ltd (WAPCOS) in January 1995 and a dam axis where detailed investigations were carried out is named as II-A. After detailed investigations along II-A axis, when different design components were laid out on the ground; it was observed that the stilling basin gets positioned in front of Sherjalum chhu, a left bank nala joining Wang chhu about 300 m d/s of the dam axis II-A. It was feared that the Nala has potential to bring down heavy debris load in the event of any cloud burst in its catchment and may cause damage to the stilling basin. It was also observed that the river takes a sharp turn just d/s of the stilling basin hampering smooth outflow conditions. In November 2010, NIRM Scientists visited the site and finalized the new dam axis alignment, which is 50 m upstream of the II-A axis. This dam axis was referred as II-B and detailed investigations were carried out during 2010-11 by NIRM based on Dam axis alignment II-B, which is 3.25 km upstream of the existing Chukha dam. This dam axis was again reviewed after submitting the DPR draft report by NIRM on II-B. After consultation with the designer, the right edge of dam axis is rotated at an angle of 8.244 degrees downstream keeping the left edge same. This dam axis is referred as II-C and considered as final dam axis for planning & layout of project. By doing this the length of dam crest is reduced to 430 m from 500 m and reduction in the excavation in the right bank for the construction of flip bucket. Substantial reduction in excavation and concreting of dam will reduce the cost and time schedule of the project. Earlier shaft type power house was proposed and after NIRM detailed investigations it is now toe to dam surface power house.

For MGPSS engineering geological mapping on 1:1000 scale were carried out for upper Roller Compacted Concrete Dam (L-2450 m, H-35.25 m) & lower Roller Compacted Concrete Dam (L-682 m, H-62.00 m), upper and lower dam spillway areas, intake structure of upper dam, head race tunnel (L-350 m, 1no.), pressure shaft (L-650 m, 1no.), surge shaft ((H-150 m, 1 no.), underground power house (120 m x 25 m x 52 m), tail race tunnel (L-1000 m, 1 no.), main access tunnel, intermediate adit to pressure shaft, cable/ventilation tunnel, switch yard area and lower dam quarry site. Engineering geological mapping of upper and lower dam reservoir areas have been carried out on 1:5000 scale and total 3.80 sq.km area was mapped. From the landslide and slope stability point of view, the catchment area was investigated on 1:10000 scale and total 30.32 sq.km area was mapped. Exploratory drill hole logging (2398 mts) and petrographical studies of rock core samples were also carried out. In addition to above mentioned investigations delineation of tectonic features based on remote sensing data, geomorphological and neo-tectonic/active tectonic studies of the project area were also done. Engineering geological, geophysical, insitu permeability, laboratory test and environmental studies (injurious material likely to create health hazards on submergence) carried out by NIRM was interpreted and inferences & recommendations for the economic and safe design of the structures have been given for each component. The basic purpose of these investigations was to identify / map different rocks and structures and to determine engineering properties of rocks and rock masses by lab testing and in-situ testing and also to comment on reservoir rim stability and reservoir competency. Earlier the DPR of this project was prepared by Irrigation Department (ID), Govt. of Maharashtra in November 1996 and they proposed seven kinks in the upper dam. The upper dam axis proposed by ID was changed by NIRM after detail investigations and accordingly the location of its appurtenant structures have also been changed from left abutment to right abutment. The left and right dam edges are at the same locations but all the kinks have been removed and now proposed dam axis is straight. The upper dam length is now reduced to 2450m from 2595m thus substantial reduction in excavation and concrete of dam thereby reduction in cost and schedule of the project. The capacity of upper dam reservoir is also increased by changing the dam axis. The installed capacity is increased from 600 MW to 700 MW. The lower dam location has been shifted about 1 km downstream to reduce the area of submergence of forest land and at this location the length of dam is least. MGPSS project DPR was prepared in a record period of 11 months.

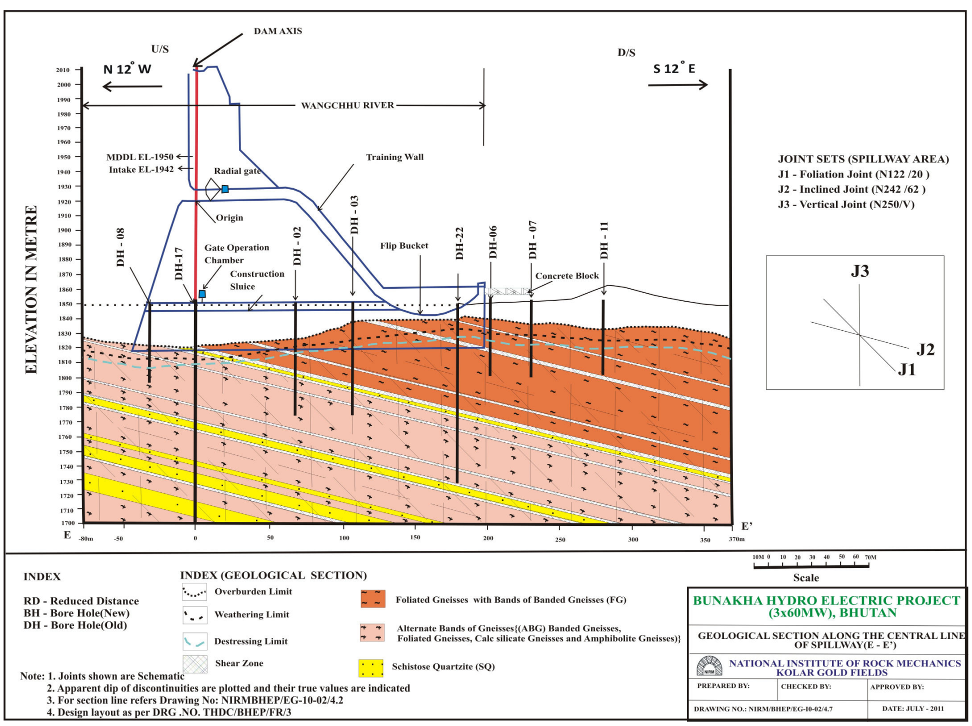


Fig. 3. Geological section along the central line of spillway of BHEP

CONCLUSIONS

A good DPR of a proposed hydro electric project should contain all the essential inputs. Proper steps of investigations should be adhered such as reconnoitaray traverse, photogeological / imagery study, detail geological mapping, drilling and lastly drifting. A quality geological investigation is essential for a good DPR. Faithful recording of geological data is essential, interpretation may change but geology should not change. Adequate sub-surface exploration be made to avoid geological surprises, especially in the dam and powerhouse complexes. The description should be brief but comprehensive. Repetition of the contents should be avoided. As much as possible the language of a DPR should be clear and simple so that it can be understood by all. Due care should be taken so that navigation becomes easy.

Success in dam and its appurtenant structures construction means constructing in the best geological environment. Prior knowledge of impending geological complexities is helpful in considering pre-emptive engineering solutions. Need for adequate engineering geological investigations are emphasized so as to minimize the risk of encountering unknown adverse geological conditions. The purpose of geological and geotechnical investigation is to provide basic data for economic and fail-safe design and construction of the hydroelectric projects.

References

Anon, (2010) A detailed report on engineering geological, geophysical and geotechnical investigations of Malshej Ghat PSS project (700 MW), Maharashtra. NIRM Report No. NIRM/TSD/NPCIL/PP02/007, text & figures 422 pages and drawings 92 pages.

Anon, (2011) A detailed report on engineering geological investigations of Bunakha hydro electric project (180 MW),Chukha Dzong, Bhutan. Unpubld. NIRM Report No. EG1002 & EG1103, text & figures 196 pages and drawings 53 nos.

IS: 2386 (Part 1) (1963) Methods of test for aggregates for concrete, Part 1 – Particle Size and Shape, Reaffirmed 1997.

IS: 2386 (Part 3) (1963) Methods of test for aggregates for concrete, Part 3 – Specific Gravity, Density, Voids, Absorption and Bulking, Reaffirmed 2002.

IS: 2386 (Part 4) (1963) Methods of test for aggregates for concrete, Part 4 – Mechanical Properties, Reaffirmed 1997.

IS: 2386 (Part 5) (1963) Methods of test for aggregates for concrete, Part 5 – Soundness, Reaffirmed 1997.

IS: 2386 (Part 7) (1963) Methods of test for aggregates for concrete, Part 7 – Alkali Aggregate Reactivity, Reaffirmed 1997.

IS: 2386 (Part 8) (1963) Methods of test for aggregates for concrete, Part 8 – Petrographic Examination, Reaffirmed 1997.

IS: 4078 (1980) Code of practice for indexing and storage of drill cores.

IS: 5497 (2008) Guide for topographic surveys for river valley projects (First Revision).

Engineering Geophysical Methods – NIRM Leads the Way in Probing Ahead

P.C. JHA

Engineering Geophysics Department, National Institute of Rock Mechanics, Kolar Gold Fields

INTRODUCTION

Engineering Geophysics deals with the application of geophysical methods for site charcaterisation, i.e., the roles of the sub-surface materials on the design and construction of structures and vice versa, i.e., the influence of any construction in modifying the subsurface properties. Geophysics provides a wide range of very useful and powerful tools for exploration and probing, which when used correctly and in the right situation produce useful information. Each geophysical method is associated with the measurement of the variation of the one of the typical physical properties of the medium. Few geophysical methods provide a unique solution to a particular geological situation whereas some other needs verification of result by a complementary method.

FOUNDATION OF GEOPHYSICAL METHODS

In geophysical method, the response of a signal from known source is measured at preset distance as it is made to pass through the medium under scan or survey. The observed or recorded signal contains the response from the target in the form a typical signature which is conventionally called the geophysical anomaly. This anomaly is segregated from the regional pattern and then subjected to interpretation. Interpretation of this anomaly in geophysics is done mostly by inversion technique wherein the target depth and size is interpolated by computerized techniques. There is always an ambiguity in the depth and size of the target while inverting the anomaly. Hence there is a practical trade-off in the interpretation wherein the unambiguous location of target is restricted to 10% of the depth of scan/ survey. Within this trade-off most of the exploration techniques work in isolation. The success of a geophysical survey depends upon the choice of the geophysical method, which is selected based on the criteria of its sensitivity to the variations in the ground properties associated with the target. In order to increase the confidence limit and this ambiguity barrier, often twin survey or cross-confirmation by borehole data is used as a control tool in the interpretation of the geophysical data. Geophysical surveys can be done both from surface and from borehole. As long as there is surface access, a surface survey is preferred. However for steeper terrains and survey across water-body, borehole survey is the ideal choice.

ENGINEERING GEOPHYSICS

Engineering geophysics is basically an extension of exploration geophysical technique in which conventional exploration tools are used on a smaller scale to improve upon the accuracy of measurements. Because of its application in engineering judgment of site characteristics and post-failure investigations, these tools are quite popular under the generic name of engineering geophysics. Besides they also serve to connect the civil and environmental engineering investigations by linking the measured static geophysical property to the dynamic properties of the medium by empirical relationships. NIRM was the first Institute in India to start a dedicated discipline of Engineering Geophysics way back in 1996 under Institutional collaboration programme between NIRM & NGI, Norway. Some of the conventional engineering geophysical investigation techniques used by NIRM are :

1. Seismic refraction survey
2. Electrical resistivity survey
3. GPR survey

When used from surface, they measure the physical properties of the subsurface upto a maximum depth of 100-120m. At this time, they are called mapping or imaging tools. The same survey tools can be used from boreholes (either single or between two holes). When used from single borehole, they are called profiling or logging tools and used across two borehole, they are called cross-hole survey or tomographic imaging. Of the three methods (Seismic, Electrical and GPR), seismic and GPR methods use time varying or decaying signal and electrical method uses time-invariant DC current as source. For all time variant signals, three properties are looked into for modification due to target body :

1. Time difference upon arrival
2. Modification of signal amplitude and decay pattern
3. Modification in the frequency content (spectrum) of the signal

Depending upon the property under investigation, these methods are known by a different trade name. At NIRM, first two types of signal properties are investigated and the third type, i.e., the spectral studies is to be added shortly. For time invariant DC signal (electrical methods), different techniques are essentially due to different ways of transmitter and receiver arrays for data transmission and collection. In this backdrop, of the working principle of these geophysical methods are our experiences with then are presented here in brief.

SEISMIC REFRACTION SURVEY

Seismic Refraction Survey (SRS) is the first and the most common tool of engineering exploration where only the time-difference of arrival is the measurable quantity. Ignoring all other aspects of the signal, this methods banks upon the time of the first arrival of a vibratory signal in the receiver as it travels from the source. Though it appears simple, it has very wide usages in the subsurface strata classification into various category (soil, weathered rock or hard rock) and mapping of prominent anomalous zones like shear and fault planes within the investigated depth. This depth of investigation depends upon two factors :

1. Strength of the source signal and
2. Spread length of the receiver array

In order to increase the depth of investigation, we have to use high energy source like explosive or mechanical vibrator. The depth of investigation is spread dependent and is normally one fourth to one sixth of the receiver spread. With a conventional 24-channel geophone array used as receiver, the only option to increase the depth of investigation remains to increase the channel to channel spread and use explosive source.

The underlying theory of seismic refraction survey is that whenever a seismic wave impinges on the boundary separating two media, energy is partly reflected and partly transmitted (Fig. 1). Hence by choosing the first arrival alone, we can relate the delay in the arrival times of refracted seismic waves at different locations to a lateral or transverse variation in the velocity of different subsurface layers. In a seismic refraction survey, waves are generated by a hammer blow or explosive shot. By recording the first arrival time in different sensors spread along the line of survey, the velocity of the two layers involved in the refraction as well as the depth to the refracting layer are determined. In fact, the entire stratigraphy of the area as deciphered from the seismic refraction survey is a velocity section along the line of survey.

Later this variation in velocity is correlated to the local geology by few borehole tests or by using standard table of seismic wave velocities in different geologic medium. Therefore, a knowledge of the seismic velocities in various geologic media is basic to the interpretation of seismic refraction data. Since the seismic velocity (V_p) in rockmass is an engineering property of rock, this can be correlated to other engineering properties by site specific empirical relationship. With the computerised waveform inversion technique being used at NIRM, the error margin in the seismic velocity section is < 10%.

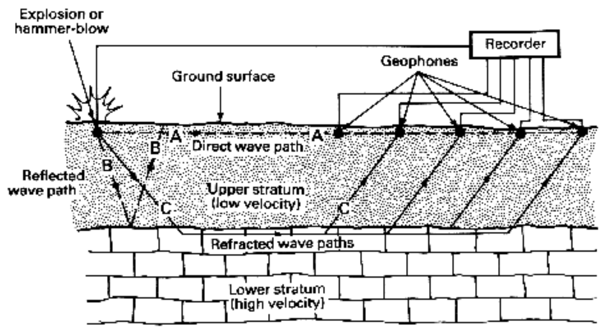


Fig. 1. Schematic ray diagram in case of seismic refraction survey

NIRM Experience WITH SRS

NIRM has been using the seismic refraction survey since the launching of the engineering geophysics discipline. Since last 20 years, we have used this method in a number of sites in both hydroelectric and infrastructure project sites. Some of the key associations with this technique are as under :

- In hydel project site of KSEB, we mapped a fault plane at the dam axis resulting in the alternation of the dam site location for Athirapally project. Later we have carried out seismic refraction survey for more than ten project sites of KSEB and located a number of adverse site conditions.
- In the Sengulam augmentation scheme, we suggested an alternate HRT route as the proposed alignment was not feasible for safe tunnelling operation.
- In the Srisailam hydel project, we could map the precise location of seven cluster of water-filled cavities occupying 4250 cubic meter space was confirmed by both GPR and seismic survey (Fig.2), and results were confirmed during grouting.

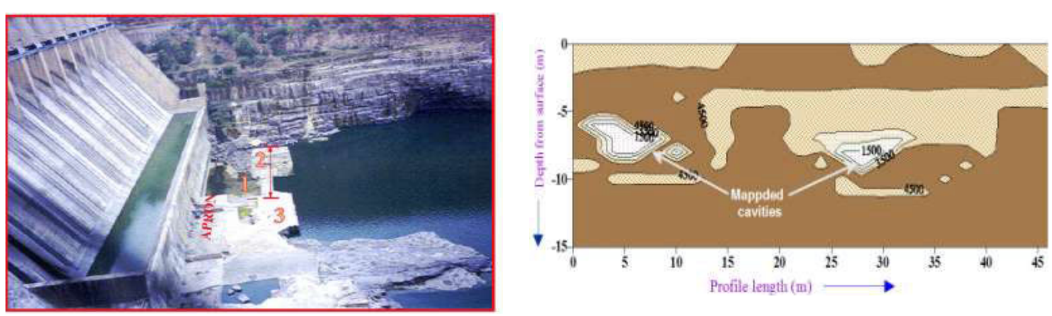


Fig.2. Cavity mapping in the apron of Srisailam dam using Seismic survey

- Apart from these trouble-shooting operations, we have used seismic refraction survey for thirty more hydel projects for reconnaissance survey during which some of the projects were shelved due to adverse geological conditions like the presence of the shear zone or fault at the dam axis location or other surface structures.
- For non-hydel projects also, seismic refraction survey was effectively used for J&K rail-link projects for deciphering the tunnelling medium and the conditions at the bridge abutments. In 2-3 cases, the rail alignment was altered due to adverse conditions for the tunnelling.

Thus over a period of last 20 years, there are more than sixty projects where seismic refraction survey was effectively used.

Future Development

Now a days the use of surface wave in the seismic survey is gaining momentum. This is useful particularly when the zone of the weakness is to be characterised in terms of strength bearing capacity. NIRM is yet to venture into this area, but we plan to expand our capability by adding a portable surface wave source. Similarly, high resolution seismic survey based on reflection measurements is yet another area in seismic investigation which can be effective in engineering investigations for both reconnaissance and trouble shooting operations. This technique too is our radar for integration in our investigation portfolio for seismic methods.

ELECTRICAL RESISTIVITY SURVEY

The Electrical Resistivity survey is based on measurement of the pattern of distribution of direct current (DC) into the subsurface when such a current is sent from a known source. For a homogenous ground, the current should linearly fall both with depth and distance, but this is never the case. Thus by measuring the anomalous pattern of current distribution over an area, the subsurface inhomogeneity can be deciphered. In this method, two short steel bars are used for injecting current into the ground from a source (12v battery). Resulting current distribution in the area is then measured by measuring the current and voltage across two points using identical steel bars. With these values, the resistivity of the ground across the measured points is calculated. By measuring this resistivity values across a number of such points, they are systematically plotted in terms of their distribution pattern in the X-Z plane. As the resistivity value is an important material property, this plot directly gives information about the inhomogeneity in the subsurface. Like the seismic method, the depth of investigation n this case too depends upon two prime factors :

1. Strength of the source signal and
2. Pattern of electrical array (T_x & R_x)

For deeper investigations, the strength of the current and its electrode separation is increased and so is the spread of the receiver array. Some of the common elcterical array used in the resistivity survey are :

a. Schlumberger array (sounding)
b. Wenner array (profiling)
c. Pole-dipole array (exploration) and
d. Dipole-dipole array (imaging)

Of them the first array is used in the ground water exploration and characterisation of aquifer. When combined with the seismic refraction method, this method can also be used in the characterisation of dimensional stone reserve. The second array is conventionally used is various types of exploratory survey for base metals. Dipole-dipole array of late has become a popular imaging tool for engineering investigations.

Basic principle of the electrical resistivity measurement is explained in figure-3 in which current is injected into the ground through two current electrodes (A and B), and measuring the resulting voltage difference at two potential electrodes (M and N). From the current (I) and voltage (V) values, an apparent resistivity (ρ_a) of the ground (medium) is calculated. The mutual disposition of A,B and M,N forms the electrical array.

The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. Based on this dependence, electrical resistivity surveys have been used for many decades in geotechnical investigations. Just as knowledge of variation of seismic velocity in different geological media is essential in the interpretation of seismic refraction survey results, the knowledge of typical resistivity values for different geological material is essential in interpreting the electrical survey results for correlation with local geological conditions. The resistivity value depends greatly on the degree of fracturing, and the percentage of the fractures filled with ground water.

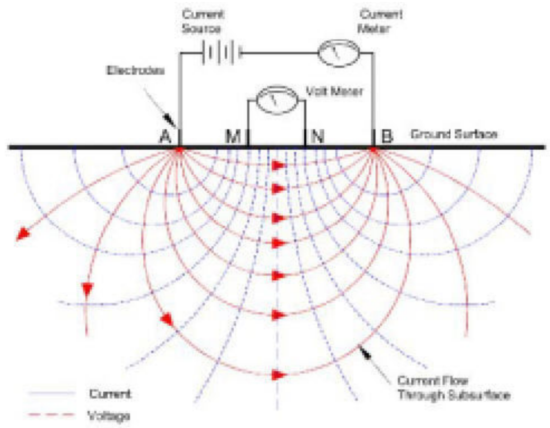


Fig. 3. Basic principle of electrical resistivity measurement

As explained earlier, depending upon the objectives of survey, various types of electrode arrays (configuration of current and potential electrodes) are used in the resistivity survey. Two most common array are that are used in engineering investigations for site characterisation purpose include :

(i) <u>Vertical Electrical Sounding (VES)</u> : VES as the name implies is a method of investigating the change in resistivity value at a particular point in a vertical plane. Here the measurement is made by receiver array in a horizontal plane but the measured value is progressively plotted at the centre of receiver in vertical plane. This is achieved by using Schlumberger array for current and potential electrodes disposition, in which potential electrode spacing is sequentially advanced symmetrically around the current electrode to get information about the deeper horizons. Thus finally the information about subsurface strata is obtained vertical section at the centre of the current electrodes. This is commonly used for water-table and fracture mapping. The most severe limitation of the resistivity sounding method is that horizontal (or lateral) changes in the subsurface resistivity are rarely found.

(ii) <u>Electrical Resistivity Imaging (ERI)</u> : ERI is used to generate the sub-surface resistivity profile along a line. This is done using the dipole-dipole array, which is very sensitive to horizontal changes in resistivity. In this method the plotting point is the intersection of the centre of current and potential electrodes, intersected through a 45^0 line. The end result from these measurements is an integrated plot of sub-surface image called a pseudo-section. The word pseudo signifies the fact that this plot is more of an indicative nature rather than exact replica of what is expected below the receiver electrodes. The depth of scan and the resolution of the imaging depends upon the overall spread length of the profile line and the distance between successive electrodes. It has become popular only after the computerized inversion method (like one used in seismic tomography) was adopted in the plotting method due to which this method is also often referred as electrical resistivity tomography (ERT). Thus even though this method was first reported in 1985, it has got the fancy of investigators since last 10-12 years after the improvement in the data processing techniques.

NIRM Experience with Resistivity Techniques

NIRM has been using the Electrical Resistivity Technique since last five years. We have fully computerized 48-channel resistivity unit in which data acquisition parameters are preset by defining the array pattern in the PC and then importing this array in the resistivity meter. Once imported the resistivity meter acquires data in this pre-defined array by altering the Tx and Rx accordingly in the channel spread. Once the data is acquired, it is exported to PC and then processed by PC-based software. The data can be acquired both in 2-D and 3-D set-up and can be processed accordingly. During last five years, we have used resistivity survey at more than 10 sites wherein we used both sounding and imaging set-up.

- In one of the sites, we have used resistivity sounding for fracture characterisation in a dimensional stone reserve in the Kolar district.
- At Padur in Karnataka, we used resistivity imaging in combination with seismic refraction method to identify a shear zone in the crown area of the proposed subsurface oil storage cavern. Due to this inherent anomaly, this site was rejected.
- In two typical case studies with the pipelines stability investigations, we used resistivity imaging to identify the shallow subsurface cavities around the pipeline with the potential of getting caved in resulting in subsidence and consequential damage to the pipeline.
- Resistivity imaging was also used in the surveying the alignment of HRT in the water-bearing strata of the mini hydel project (KHP) near Mangalore (Fig.4). Series of water-charged zone in the crown area was successfully mapped which led to proper planning of the excavation sequence.
- Apart from them, there are few other troubleshooting operations with urban infrastructure projects (metro) where resistivity imaging was used to identify the potential weak zones.

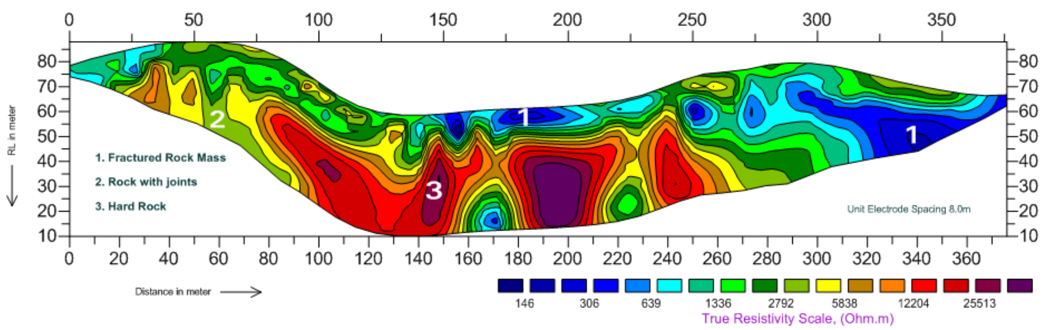


Fig. 4. Typical resistivity imaging profile along HRT of Kumaradhara Hydel Project

Future Development

Now a days the use of AC source in the resistivity survey is being practiced. This is quite useful in bedrock survey and is seen as potential replacement for shallow reflection technique being used for this purpose. Though bed rock cannot be characterised in terms of their engineering property, they can be profiled very fast. This is useful when the founding depth has to be decided over a larger area. NIRM is yet to acquire an AC resistivity unit, but with increase in requirement from the industry, we may expand our capability with this add-on also. Similarly, cross-hole resistivity measurement can also supplement various types of borehole measurements in removing the measurement ambiguity and we have to add that portfolio also in the near future.

GPR SURVEY

Ground Penetrating Radar (GPR) is the most recent tool added to the family of exploration geophysics. It is essentially a high-resolution technique of imaging shallow soil and ground structures using electromagnetic (EM) waves in the frequency band of 10-3000 MHz. GPR survey can be done both from survey and boreholes. Essentially, a GPR has three main units as shown in fig. 5 :

1. Transmitter-Receiver Unit (Control Unit)
2. Transmitter & receiver antennas
3. Data display and storage unit (a PC)

Based on the variants of source, two types of GPR are in use. The first one is Impulse GPR (I-GPR) which uses a short-impulse (of the order of nanosecond) RF signal as the source. In the second variant known as the Stepped Frequency GPR (SF-GPR), a calibrated frequency source is used as the input signal. The receiver though in both cases remained frequency coupled antennas. Apart from the three components of GPR explained above, amplifiers and data transmission cables form an important constituent of a SF-GPR. NIRM uses the second variant, i.e., the SF-GPR. The constituent units of GPR are shown in figure 3 in a schematic layout. GPR uses the variation in the conductivity (σ) and the dielectric constant (κ) of rocks to identify and map various subsurface horizons (reflectors).

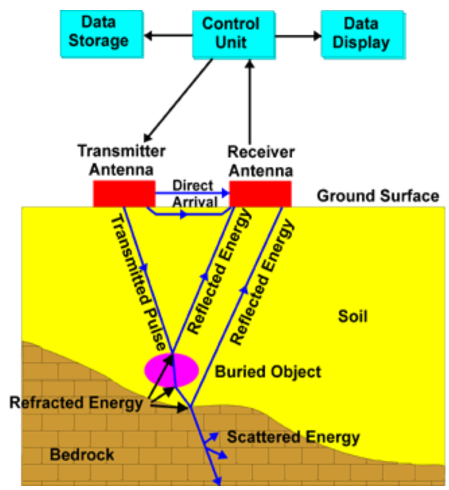


Fig. 5. Schematic representation of the operating principle of GPR

During operation, a stream of radio waves in the preset frequency band is sent into the ground (subsurface) by the transmitter antenna. These waves undergo the process of reflection, refraction and scattering in the underground at various interfaces depending upon their σ and κ values. The reflected wave from the interface is detected by the receiver antenna optimally placed on the surface. By the time difference of the arrival of the reflected wave, the depth to the interface is determined using a preset medium velocity for radio waves. Theoretically, there is no depth bar in detecting the interface by using GPR survey but when the outcoming (reflected) wave becomes too weak to be detected by the receiver antenna, the reflector is no longer identified. Thus the attenuation properties of the medium impose a practical limit to the depth of scan.

Unlike other two methods, where the source strength plays a role in increasing the depth of investigation, this can be achieved in the GPR survey by the choice of input frequency. A higher frequency (above 500 Mhz) scans shallower (<5m) with high resolution and a lower frequency (upto 250 MHz) does the same job for a depth of 30m. Depending upon the mode of data collection, GPR survey cane be used for profiling (reflection measurements from subsurface), sounding (vertical probing down at a location) or tomography (cross-hole transmission measurements).

At each point of data collection, the GPR generates a subsurface array of reflectors based on the time difference of arrival of reflected waves. When a number of time sections obtained for a profile line are integrated by a software, they make up the radio-image of the subsurface called radargram. Later a velocity survey of the area is carried out to convert the time section into depth section, which is used for interpreting various types of subsurface features based on their radar signatures. The radargram or GPR section is conventionally plotted in colours made by generating colour code based on strength of reflection at each depth level.

Unlike other two methods, where the interfaces or medium is identified by the medium property, GPR survey does this job based solely on the strength of the reflected signals and the specific geometrical pattern of the reflector. Thus GPR survey is ideally suited for defect mapping rather than for exploration as with other geophysical methods.

The application areas of GPR include geotechnical and environmental investigations, mine and ground water exploration, as well as road, building and other civil construction projects. GPR survey is the fastest growing geophysical exploration tool. Its wide acceptance by the user industry is due to its sole advantage of being the fastest and totally non-destructive imaging tool with a high degree of accuracy and coherency.

NIRM Experience with GPR Survey

NIRM has been using GPR survey since last 20 Years. In fact NIRM was the first to bring GPR to India in 1995. Since then GPR survey has been used in at least 20-25 projects in trouble\shooting operations with defect mapping.

- We have accomplished an S&T project in which the use of GPR survey is demonstrated for mapping of barrier against water-logged workings for a distance of 60m. This was duly notified as a viable alternative by DGMS.
- In the NJPC project, GPR survey was used to identify a buried channel leading to instability of the retaining wall over the TRT area.
- At MRPL, we used GPR survey for analyzing the foundation defect in the oil tank and later for identifying the source of oil-leak from the refinery.
- In the Tala project of Bhutan, GPR survey was used for mapping of crack in the dam block and in the crown of the desilting chambers.
- In the stability analysis of the oil pipelines, GPR survey was used in conjunction with the resistivity survey for mapping shallow cavity pockets.
- Application of borehole GPR survey under various inaccessible conditions like the one in Tala and in the bottom gallery of the Koteswar project is the hallmark of our innovative application areas.
- Similar innovative experiments with GPR were done in identifying damages in the shaft lining of Mochia mines and in the detection of the buried landmines (Fig.6).

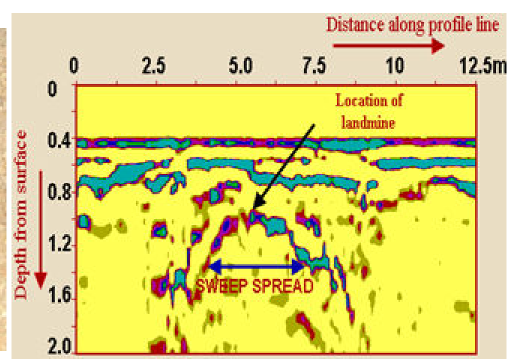


Fig. 6. GPR survey for detection of buried non-mettalic landmine

- We have also mastered directional probing and borehole profiling with GPR. The lists with GPR survey is numerous and we are still the leader in using this method in adverse conditions.

Future Development

Most of the GPR survey worldwide is done using impulse variant of GPR. NIRM is yet to acquire commercial impulse radar for hands-on experience with this system. The scope of GPR too needs to be widened from a mere defect mapping by reflector pattern to investigating the material property so that it becomes a more effective tool.

TOMOGRAPHY SURVEY

The geophysical survey techniques discussed thus far is for surface survey. However, when the surface area is inaccessible like on steep slopes or across water-body (flowing river), borehole survey is preferred. In this mode, one borehole is used for source and the other one for receiver. This type of survey is called Cross-Hole Tomography (CHT) or Tomography survey. This can be done using seismic or electrical or GPR source depending upon the objective of survey. It can be done in velocity or attenuation mode. In this survey (velocity mode) the travel time of seismic or GPR pulse transmitted between two or more boreholes is measured in order to define an image of medium velocity in the intervening ground. Travel times are collected at regular intervals (usually 0.5m to 2m) all the way down the hole(s) for each source position. Measurement of arrival times for series of source locations, at each position in the receiver borehole, results in a network of overlapping ray paths which is displayed as a ray density profile (Fig. 7). This can then be used to model the velocity profile between the two holes.

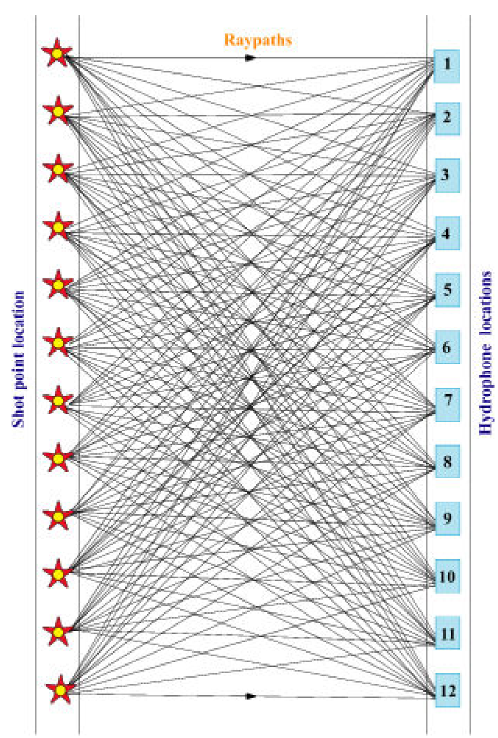


Fig. 7. Schematic layout for cross-hole tomography survey

This raw travel-time data matrix is input into the modelling software and the entire data set is inverted in one go using finite difference modelling software using SIRT technique. The plane separating the source and receiver holes is divided into a mesh of grid cells known as finite elements. Each element in the mesh is assigned a starting velocity and the synthetic travel time for the portion of each ray path passing through it is calculated. In this way the total travel time for each ray path is built up and then compared to the measured travel time. The velocities assigned to the various elements are then adjusted iteratively until the calculated and measured travel times for the ray paths are the same. As many of this element cells are intersected by a number of ray paths, this inversion process results in very accurate estimates of the velocity for each cell.

The resulting velocity image is termed a tomogram and enables identification of anomalous velocity zones lying between the boreholes as well as imaging individual velocity layers. The primary application of borehole seismic tomography is in engineering studies for the identification of features such as fault zones and voids. When combined with an S-wave survey, the data can additionally be used to provide information on material stiffness properties. Similarly waveform attenuation is carried out resulting in the generation of attenuation tomogram which provides information on the shear zone.

When used with GPR source, we get similar tomographic sections for GPR velocity and attenuation section between two boreholes. Electrical source generates resistivity tomogram. Each of these methods is used in different situations either in isolation or combination.

NIRM Experience with Tomography

NIRM has been using both GPR and seismic tomography. We have developed our own way of processing tomography data by using FDAT technique which helps in target enhancement in the tomogram. Both 2-D and 3-D tomography survey has been done in the time (velocity) and amplitude (attenuation) domain.

- The classical case of tomography in the is in the Tala project of Bhutan, where GPR tomography was used in the crown of the desilting chamber for mapping the extent of weak zone responsible for the fall of blocks.
- In the Koteswar project, tomography was done to map the un-treated shear zone in the dam foundation.
- We have used SRS for foundation evaluation exercise too using both surface and borehole survey. In the case of National Highway projects, we have used cross-hole tomography survey for deciphering the adverse foundation situation at three piling locations. Similarly 3-D seismic tomography was done barrage axis for mapping a sand lens (Fig.8).
- FDAT with GPR was done in the coal mines to identify the in-seam faults.
- In Teesta Stage-III hydel project, seismic tomography across the river was done to map the rock profile in the river bed (Fig.9).

Till date more than 20 tomography projects have been done using both seismic and GPR tools to decipher either the weak zone or the hidden defect in both parallel and non-parallel boreholes.

Future Development

All the tomography data have been processed with our own tailor-made software developed in association with NGI. It does not have the facility of slicing along any arbitrary plane. Procurement of professional software with full visualisation package will aid to our efforts in this technique also. This needs to be added in the near future.

SPECTRAL SURVEY

So far all survey methods focus on the time domain properties of the signal using either the travel time or waveform attenuation properties. However, there is yet another method which relies upon the frequency spectrum of the signal and their attenuation or dispersion with time.

Obviously this method has to use the full waveform of the signal rather than the first arrival alone (refraction) or peak amplitude (attenuation) alone. In the spectral processing technique, the signature of the source in its entirety is examined for its frequency attenuation (dispersive) properties with distance and depth. This applies to seismic signals because their attenuation with distance speaks a lot about the medium properties in terms of its stiffness or settlement potential. Normally this survey is done with the S-wave and is commonly used in microzonation studies. NIRM is building up resources for this method and plans to develop its application in engineering studies in the near future.

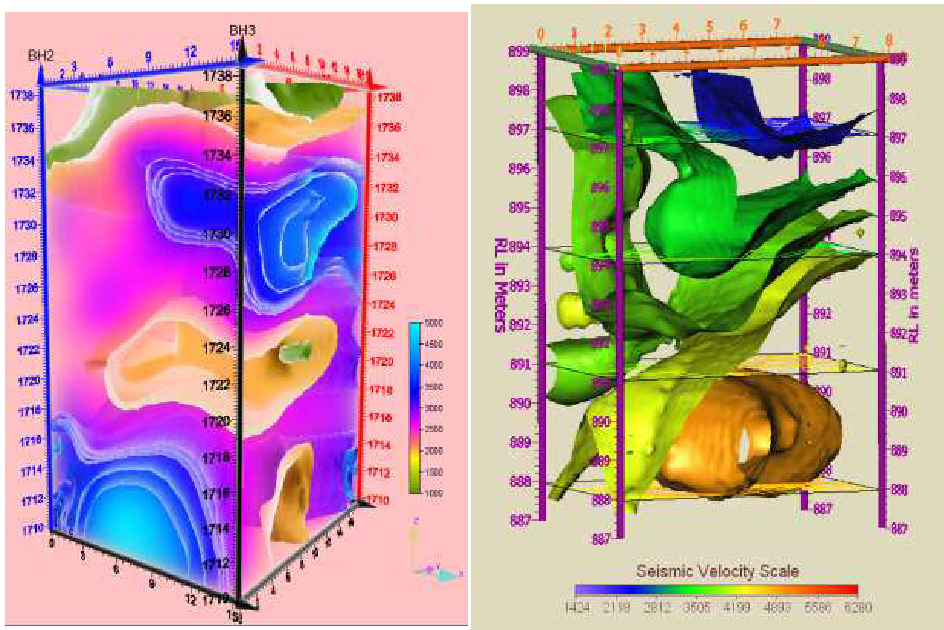


Fig. 8. Sample 3-D tomogram for mapping defects in the foundation

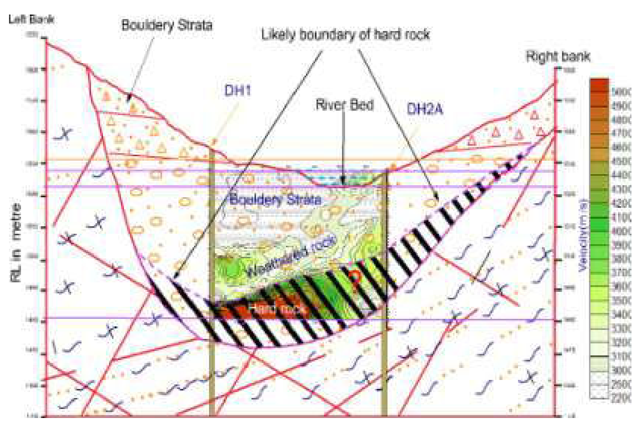


Fig. 9. Sample seismic tomogram across Teesta river for determining the depth of dam foundation

These are the various geophysical survey techniques being used by NIRM in engineering geophysical methods of investigation for varieties of site characterisation studies and troubleshooting applications in both pre-construction and post-failure cases of various hydel and infrastructure projects. NIRM is the only institution in India with a specialized Engineering Geophysics Group within the framework of rock mechanics investigations. We do hope that with the addition of new facilities as enumerated above, NIRM shall be the national leader in this field of investigation with the most modern range of investigation tools.

In-situ Rock Mass Properties - Unique contribution by NIRM

D.S. SUBRAHMANYAM

Geotechnical Engineering Department, National Institute of Rock Mechanics, Bangalore

INTRODUCTION

In-situ geotechnical investigations are an essential and integral part of any civil and mining engineering project for safe and economic designing. In all the major projects for civil engineering works where rock excavation is involved such as tunnels and underground power plants and dams, and in mining underground or in large open cuts, the design has to be made based on in-situ geotechnical investigations for a reliable prediction of the behavior of the structures.

In general, the mechanical behavior of rock mass cannot be determined purely from laboratory tests. Large scale in-situ tests form an extremely important part of the investigations for data generation. Accordingly a wide range of in-situ rock mechanics tests have been developed. It is only by an understanding of these in-situ tests that we can more confidently predict the behavior of the rocks in prototype structures. Three important parameters that are essential for the for economic and safe designing of any underground excavations or construction of underground caverns and structures are:

1) In-situ stress,
2) In-situ deformability, and
3) In-situ shear parameters.

IN-SITU STRESS

In general, the distribution and magnitude of in-situ stresses affect geometry, shape, dimensioning, excavation sequence and orientation of underground excavations like caverns, tunnels, etc. The orientation of long dimension of the cavern should be parallel to the maximum horizontal principal stress. The shape of the cavern should be selected to minimize the stress concentration especially in the region of high stresses. The layout of the complex should be planned so as to avoid crack propagation from one cavern to the other. Pressure tunnel, penstock and similar structures can be constructed and operated without lining if the minimum principal horizontal stress is greater than the internal water pressure. In other situations like support design, the knowledge of the state of stresses can be integrated with design process along with the geological information.

In mining engineering application, especially in underground mines, the knowledge of the magnitude and orientation of the horizontal stress field can have a major impact on decision regarding mining method, size and orientation of roadways and support practices.

Hydraulic fracturing (or simply, ‘hydro-frac’) method is used for the determination of stress measurements in a vertical hole at desired locations (Fig. 1). Results of the stress measurements give both direction of maximum horizontal stress and the magnitude of principal stress tensors at a particular depth.

MODULUS OF DEFORMABILITY

The rock behavior during frequent loading and unloading process is determined by its Modulus of Deformability and Modulus of Elasticity. These parameters are determined by various methods by in-situ testing on foundation and surrounding rocks on which a heavy structure is to be placed. For example, in concrete dams the ratio between moduli of deformation of rock mass and concrete can give a basic idea of the safety of dam. If the ratio between E_d (deformability modulus of rock) and E_c (deformability modulus of concrete) is < 8, it would be safe for the dam, and when Ec/Ed > 16, it may create moderate to serious problem for the dam. A wide variation in deformability values along the axis of dam means differential settlement which can induce stresses in the concrete sufficient to develop cracking.

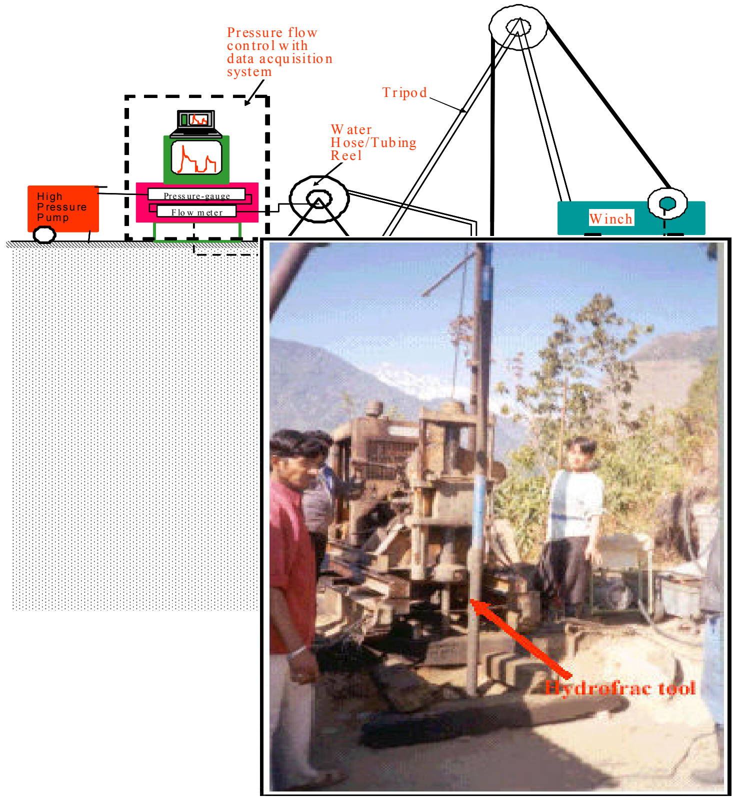


Fig. 1. Hydro-frac test set-up

Plate-bearing method is one of the most common methods to determine the deformability of rock mass in-situ (Fig. 2). In this method, a load is applied to a specially prepared flat surface by means of a rigid or semi rigid finite plate and measuring the deformation at two point on the rock mass. Thus rock modulus can be calculated using the relationships developed depending on the shape of the loading plate and nature of the rock.

Dilatometer is another equipment used for determination of in situ deformability of rock mass inside a borehole (Fig. 3). The Elastmeter-2 is new version of lateral load tester capable of testing wide range ground from soft rock to hard rock. Highly accurate transducers and related electrical circuitry are built in the probe to improve the measurement accuracy, reliability and operability. With the two arms stretched inside the rubber packer, the system converts the displacement with the inner radius of the rubber packer into that representing the deformation with the borehole diameter.

SHEAR STRENGTH

The shear strength of rock is one of the most important parameters used in design of dams and other underground structures. Its determination involves the measurement of two related parameters - cohesion and angle of internal friction. Shear tests are mainly conducted on existing planes of discontinuities such as bedding planes, joints, foliations etc. for obtaining information about sliding stability of concrete gravity dam and for the prediction of shear strength in foundation discontinuities when subjected to loads brought about by the structure (Fig. 4).

The best way of evaluating shear strength parameters is by conducting in-situ shear test as described in ISRM (1974) and IS 7746 (1975). The shear strength of concrete to rock depends upon number of factors such as strength of concrete, strength of rock, saturation, rate of loading, rate of shearing etc.

Fig. 2. Plate load testing equipment

Fig. 3. OYO Dilatometer

Fig. 4. Direct shear testing set-up

ACHIEVEMENTS BY NIRM

During last 25 years, in-situ tests were carried out at more than 135 projects sites for different organizations. The organizations include:

Hydroelectric Sector

- National Hydroelectric Power Corporation
- Water and Power Consultancy Services
- Andhra Pradesh State Electricity Board
- Himachal State Electricity Board
- Patel Group of Industries
- Jai Prakash Group of Industries
- Jindal Power
- Tala Hydro Power Authority, Bhutan
- Mangdechhu Hydro Power Authority, Bhutan
- Nathpa Jhakri Power Corporation
- Tamil Nadu State Electricity Board
- Satluj Jal Vidyut Nigam Ltd
- Tehri Hydro Development Corporation
- Hydro engineering Development Company, Nepal
- LNJ Bhilwara
- Larsen & Toubro
- Uttaranchal Jal Vidyut Nigam Ltd

Mining Sector

- Singareni Collieries Company Ltd
- Western Coalfields Ltd
- Bhabha Atomic Research Centre (Shahapur Mines)
- Associated Soap Stone Industries
- Hindustan Zinc Ltd
- Hindustan Copper Ltd
- Tamil Nadu Minerals Ltd

Infrastructure Sector

- Cauvery Technical Cell
- Erudite Industries ltd
- North Eastern Power Corporation
- Nuclear Power Corporation of India Ltd
- RITES
- Hindusthan Construction Company Ltd
- Central Water Commission
- Konkan Railway Corporation

Earlier the in-situ stress measurements used to be carried out by flat jack method which gives induced stresses and not virgin in-situ stress. NIRM was the first in India to introduce hydrofrac tool as stress measurement device in hydel projects and in Himalayas (Lakhwar HEP in Uttarakhand in the year 1994)

Earlier in the coal mines they used to assume that vertical stress is the maximum stress and roof collapses are due to vertical stress. But there was no answer for roof collapses at shallow depths. Introduction of hydro-fracture stress measurements at the coal mines has changed the concept. It is found that one of the horizontal stresses is maximum stress and is responsible for roof collapses in coal mines. In this context, NIRM can be proud that it was the first in India to introduce hydro-fracture system in the measurement of in-situ stress extensively in coal mines in the year 1999.

Usually stress measurements beyond 200 m depth are carried out by truck mounted device (as with NGRI); but such equipment cannot be deployed in mountainous areas without any road. NIRM was the first in India to carry out the hydro-frac stress measurements up to a depth of 350 m in a mountainous inaccessible project, as at Punatsangchu project in Bhutan.

The Institute made a complete upgradation of its data acquisition systems from manual / analog to real time digital for all the equipment available with it. This has helped in improving the quality and speed of data collection and helped in building confidence of the clients especially international clients.

Some of the recent major and challenging projects executed by NIRM are : determination of in-situ stress tensor in heavily fractured and watery gound conditions, for the design of the powerhouse of Vishnugad-Pipalkoti Hydroelectric project, Uttarakhand; determination of in-situ stress tensor for Pala Maneri HE project, Uttarakhand; determination of in-situ stress parameters by Flat Jack method at highly crushed zone at Katra Quazigund Railway Project , Jammu & Kashmir; and geotechnical studies to ascertain the safety of Mullai Periyar Dam.

The projects executed are of national importance, including those located in strategic locations in the Himalayas at Bhutan, Nepal, Arunachal Pradesh, Sikkim, Himachal Pradesh, Uttaranchal and Jammu& Kashmir, in inhospitable and most difficult terrain. Many of the project reports of NIRM were reviewed by foreign experts like Coyne et Bellier (France), Lahmeyer International (Germany), Nippon Koe (Japan), Geostock (France) et al. Many of the projects for hydro-electric, irrigation and construction industries are located at remote places and in inhospitable conditions in the states of J&K, Uttaranchal and Himachal Pradesh, and in the extreme north eastern states like Arunachal Pradesh, Sikkim.

FUTURE RESEARCH AND VISION

i. To conduct in-situ stress measurements inside deep boreholes up to 800 to 1000m.
ii. To find out the Influence of Geological structures on in-situ stresses.
iii. Detailed Investigations on Topography induced high in-situ stress in Himalayas.
iv. Preparation of Stress map of India to contribute for World stress map.
v. To find out the relationship of in-situ stress magnitude with laboratory derived Kaiser Effect.
vi. To find out an empirical relationship between Deformability modulus and RMR/Q rock classification systems especially for Himalayas using our huge data bank collected over a period of 25 years.

Laboratory Rock Mechanics Investigations at NIRM

A. RAJAN BABU and G.D. RAJU

Centre for Testing Services, National Institute of Rock Mechanics, Kolar Gold Fields

INTRODUCTION

Field and laboratory investigation of rock properties are critical steps in all the rock engineering problems. Moreover the material in the rock engineering is natural and requires establishing the properties of material including the in situ stress state to relate to the engineering objective such as design of an underground structure or design of slope stability. The deformability, strength and failure of intact rock under dry and saturated conditions are essential for understanding the basic behaviour of the rock during construction. Better understanding of intact rock behaviour is also useful in determining and designing the support requirements based on rock failure conditions during laboratory investigations conducted on the intact rock samples. In some of the cases, determination of post failure behaviour of the rock is of utmost important. In this cases the post failure studies conducted in the lab scale will aid in designing the structures for their post peak capability, for example coal pillar/barrier pillar design in an underground coal mines

The Rock Fracture Mechanics (RFM) laboratory was established in the year 1990, and is now one of the divisions under the Centre for Testing Services (CTS). This division is equipped with the most modern laboratory facilities to carry out basic research on rock fracture mechanics and determining the engineering properties of rocks and dimension stones as per the national & international standards. It is engaged in some of the frontier areas of research like thermo-mechanical behavior of rocks, geotechnical investigation on rock properties for modeling the underground excavations, parameters for optimum design of mud fluid for oil exploration, determining the rock mechanics properties of oil shales for wellbore studies, in-situ stress estimation from rock core samples and application of acoustic emission to understand the mechanism of fracture and failure of rocks. The laboratory has the expertise and facilities for the following :

- **Fracture Mechanics of Rocks**
  - Thermo-mechanical behaviour of rocks
  - Ultrasonic C-scan imaging
  - Micro & macro crack growth by acoustic emission
  - Estimation of in-situ stress of rock mass by AE technique
  - Fracture toughness as per ISRM suggested method (level I & II)
  - Deformation studies under elevated temperatures

- **Physico-mechanical Properties of Rocks**
  - Multiple failure triaxial compression test
  - Post failure studies under uniaxial & triaxial stress conditions
  - Characterization of rock joints
  - Failure criteria of rocks such as , Mohr-Coulomb, Hoek –Brown and Barton – Bandis failure criteria for rock joints
  - Rock mass properties from the laboratory strength data

MAJOR ACHIEVEMENTS DURING THE LAST 25 YEARS

The expertise available in the NIRM laboratory was also utilized by various foreign consultants like Geostock, France; RMT, UK; CSIRO, Australia; and SK E&C, Korea who are working in India for various projects.

The Rock Fracture Mechanics laboratory was established with an objective to carry out research on the fracture and failure of rocks. It was equipped with highly advanced laboratory facilities to determine the properties of rocks required for designing and modeling the underground excavations. Some additional facilities created were Rock Joint Testing Laboratory and the Granite and Dimensional Testing Laboratory.

The major R&D contributions by the laboratory include:

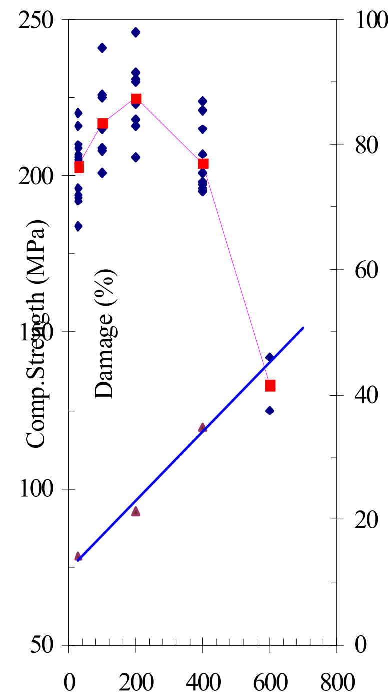
- Laboratory method of determining the in-situ stress of rock mass using Kaiser Effect (acoustic emission method).
- Characterizing the rocks for nuclear waste disposal and underground storage of petroleum products.
- Thermo mechanical behaviour of rocks.
- Development of new theory for the post failure of rocks and coals.
- Acoustic emission signal analysis for understanding the deformation mechanism of rocks and for the determination of Critical cracking temperature.
- Dual role of micro cracks i.e. toughening and degradation.
- Characterisation of micro and macro cracks in rocks by Acoustic Emission and Ultrasonic C-scan imaging.
- Measurement of deformation using strain gages under uniaxial and triaxial stress conditions at elevated temperatures (up to 200^0C).
- Data bank on intact rock properties and rock joints.
- Non-destructive testing and evaluation of process zone development during rock fracture
- Characterization of Dimensional Stone Granite of Southern India.
- Burst proneness index of rocks
- Studies on negative Poisson's ratio
- Measurement of strain under triaxial stress conditions in pores rocks
- Post failure deformation mechanism of coal – a new mechanism
- Prediction of rock mass properties using the laboratory strength data.
- Multistage Triaxial Compression testing as per ISRM suggested method and determination of Young's modulus by loading and unloading.
- Direct Shear testing on contact planes of sedimentary rocks.

DUAL ROLE OF MICRO-CRACKS - TOUGHENING AND DEGRADATION

Micro-cracks play a dual role. They can stabilize a macro-crack by softening the material around the tip, thereby reducing the effect of the applied load - a shielding mechanism. Alternatively, micro-cracks can reduce the resistance of the material to fracture, causing the crack to initiate at a lower load - a degradation mechanism. Depending on the orientation, density and spacing of micro-cracks toughening and degradation mechanisms operate. With the increase of damage initially micro-cracks provide toughening, later when the cracks are close to each other both crack coalescence and toughening occurs, finally when the cracks are very close to each other, only crack coalescence takes place, resulting degradation. This phenomenon was observed during Uniaxial compression testing of thermally treated granite.

ULTRASONIC IMAGING OF MICRO- AND MACRO-CRACK DAMAGE

A conventional method of characterizing micro-cracks and pores in rock materials is by microscopic examination using optical and electron microscopes. Some major disadvantages of microscopic examination are - a) laborious sample preparation, b) alteration of the original defects during sample preparation and c) the possibility of examining only a small section of the sample. Several alternative non-destructive techniques have been attempted to characterize micro-cracks. Ultrasonic C-scan imaging technique is a non-destructive technique, which provides the image of defective regions for visual observation. This technique was used to image the micro-crack damage in granites. A typical C-scan image for granite shows both micro and macro-crack damage.



Comp.str & Damage Vs Heat Treatment temperature

CHARACTERIZATION OF MICRO- AND MACRO- CRACKS IN ROCKS BY AE

Acoustic emission is a real time, on line monitoring technique used to study the crack growth in rocks. AE events are classified into four groups based on the recorded wave form parameters as α ,β, γ. All these four types of events appear at different stress levels. They initiate at a particular stress level, increase slowly in rate with the increase of stress, and beyond a stress level the event rate increases rapidly. α and β type events(< 70 dB) represent micro-crack initiation and extension. γ and δ type events (> 70 dB) represent macro-crack initiation and extension. Classification of events into micro- and macro- crack phases gives a better understanding of fault formation in rock materials and also the effect of stress, temperature, macrostructure, mineralogy etc.

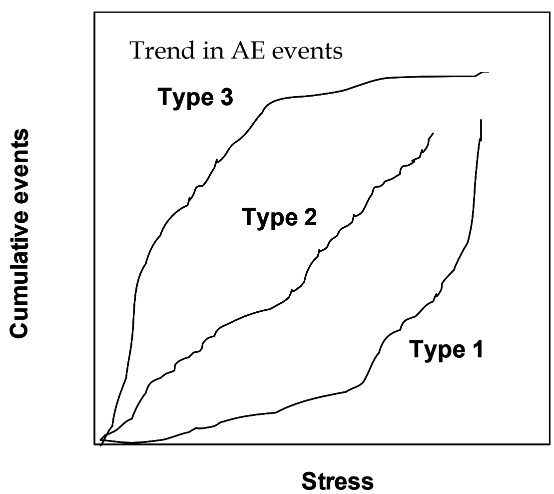
POST FAILURE DEFORMATION MECHANISM OF COAL

Post failure deformation behavior of coal is required for designing pillars in underground coal mines. In the underground the fractured rock mass is still able to withstand the load. To understand the behavior of fractured rock, extensive investigations are being carried out worldwide to understand the failure mechanism of rock beyond the peak strength. Pre and post peak slopes are the input parameters for numerical analysis. A typical post failure curve shows a rise and fall in stress with continued deformation. The deformation curve for rocks in the post failure region as reported in the literature is a smooth curve. However the experiment carried out on coal samples shows a trend which appears to be unusual.

In order to explain these typical patterns and to obtain the post failure deformation curve a new post failure deformation mechanism for coal is proposed. Failure of coal occurs due the initiation, growth and coalescence of large number fractures. Following the peak stress, coal sample always contain fractures. After the peak stress the load bearing capacity cannot decrease monotonically; there will be an increase and decrease in load bearing capacity depending on the volume of fractured coal. As the fractures cannot develop in 100% of the volume of coal instantaneously, the fracture formation occurs in discrete steps. Whenever there is fracture there will be drop in load and its magnitude depends on the size of fracture. As the un-fractured volume is able to withstand the load, the load will again increase with continued deformation till some more portion of the coal sample is fractured. This continues till the coal is fully fractured. Accordingly, there will be an increase and decrease in load/stress vs. axial strain curve. The progressive fracturing of coal is mainly responsible for the peaks and valleys in the post failure region. In post peak region, every peak point of the load corresponds to fracturing of a small or larger portion of the sample. The number of peak points available in the post peak region depends on the fracture density of coal sample. These points may be defined as the localized failure points. If the envelope is drawn through these points, it will produce a post failure curve.

DETERMINING THE IN-SITU STRESS OF ROCK MASS USING KAISER EFFECT

In-situ stress of rock mass is one of the essential input parameter into models for underground design and stability analyses. Several methods have been proposed for estimating in- situ stress in the laboratory from rock core samples collected from the boreholes. Among them Acoustic Emission (AE) method based on Kaiser effect is the simplest where an extensive work is being carried out worldwide. A large number of bore hole drilled samples were investigated. Based on the AE data analysis three types trends were identified and named as Type 1, 2 & 3. It is easy to identify the Kaiser stress if the trend is of Type 1. Type 2 & 3 trends do not show any perceptible change in the slope of the curve and it is impossible to identify the Kaiser stress. Hence a new method of signal based on absolute energy was proposed to identify the Kaiser stress. Introduction of new method of analysis is very significant for the practical application of the technique. There was a good agreement between the laboratory determined in-situ stress values and the field values.



Knowledge of the state of stress in a rock mass is of utmost concern in many underground applications. Extensive research is being carried out worldwide to estimate the in-situ stress of rock mass using drilled core. Among the various methods Acoustic Emission (AE) method based on Kaiser effect is the simplest. Rock samples from different sites were collected, samples were prepared and compressed using MTS compression testing machine. Acoustic emission data's were recorded. A new method of AE data analysis was proposed to identify the Kaiser stress i.e in-situ stress. In-situ stress estimated by laboratory method was compared with the in-situ value determined by Hydro fracturing method. Data from eight sites were compared, out of which for seven sites there was a good agreement between the two methods. This research is useful to estimate the in-situ stress for deep underground space technology utilization.

MULTISTAGE TRIAXIAL TESTING AND DETERMINATION OF YOUNG'S MODULUS

Triaxial compression test is very important for any rock mechanics application. Conventional method of testing is to make use of large number of samples to calculate the cohesion, friction angle and Hoek Brown parameters. The results are unreliable due to variation between the samples. The latest trend is to make use of a single sample to determine failure strength at different confining pressure based on multi stage failure method. NIRM developed the expertise on Multistage Triaxial Compression testing as per ISRM suggested method and determination of Young's modulus.

CHARACTERIZATION OF DIMENSIONAL STONE GRANITE OF SOUTHERN INDIA

To establish a data bank on the properties of dimension stones of southern India, more than 30 different varieties of granite rocks were collected and the properties were determined as per the ASTM standards. The data base is useful for both exporter and user to select the stone for a particular application.

BURST PRONENESS INDEX OF ROCKS

Rock burst is a mining induced rock failure accompanied by a release of elastic strain energy stored in the rock, which is of sufficient magnitude to cause physical damage to mine workings, personnel and equipment. The burst proneness index is a simple and reliable method, which can be used as a yardstick to indicate rocks liable to bursting. Based on the laboratory studied an arbitrary scale for the bursting liability of rocks was proposed.

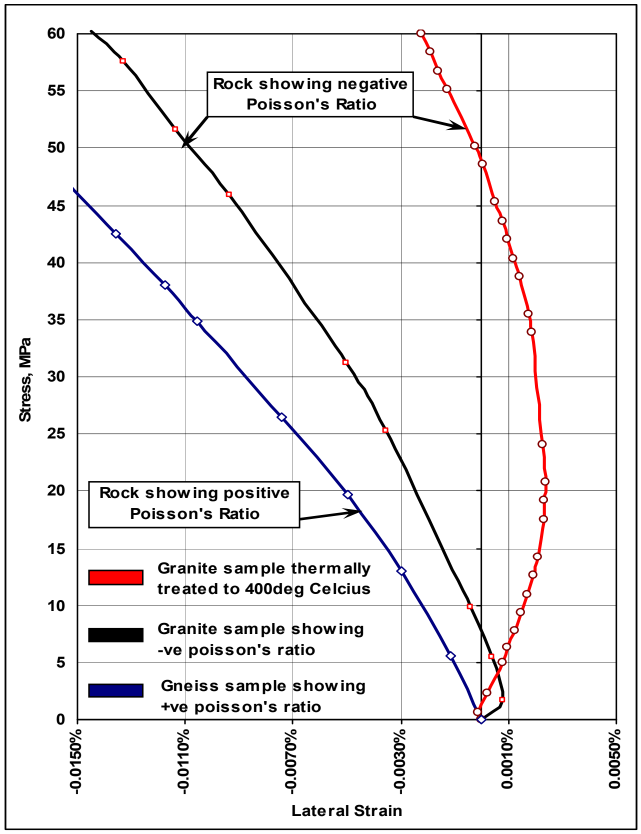
Burst Proneness Index	Bursting Liability
< 10	Low
10-15	Medium
>15	High

STUDIES ON 'm', THE CONSTANT IN HOEK BROWN FAILURE CRITERION

On the advice of Dr Vutukuri, the renowned in rock mechanics scientist, during his visits to NIRM, studies were carried out on the value of 'm' – a constant in Hoek Brown failure criterion, on thermally treated granite samples. As reported by Hoek in his papers, as 'm' increases, the quality of rock increases. But the opposite trend was observed in a few of our laboratory experiments. Dr Vutukuri has done considerable amount work on variation of 'm'. He also observed that 'm' increases with the decrease of uniaxial compressive strength. In order to confirm the observations, a series of triaxial compression tests were planned under controlled conditions, on thermally treated granites. Granite specimens were heated to 300^{o}C, 600^{o}C and 800^{o}C for 6 hours to obtain specimens with varying damage due to micro-cracking. Triaxial compression tests were conducted and analyzed. The value of 'm' increased as the compressive strength is decreased, which confirmed the earlier observations.

STUDIES ON NEGATIVE POISSON'S RATIO

Poisson's ratio is the ratio of lateral strain to axial strain. When a rock material is compressed, it contracts in the axial direction and expands in the lateral direction. Similarly, a metal under tensile load elongates in the axial direction and contracts in the lateral direction. By convention the Poisson's ratio is treated as positive and varies from 0 to 0.5 in almost all the materials. However, some materials contract in the transverse direction under uniaxial compression or expand laterally when stretched. These materials are said to have negative Poisson's ratios. They are usually called as auxetic materials, e.g. polymer foams. In the laboratory a few rock types showed negative Poisson's ratio similar to synthetic materials for a small stress range under uniaxial compression testing as shown the figure. Similar trend was also observed in the case of thermally treated granites. The negative Poisson's ratio may be due to porous structure and the residual stress of the material.



Lateral strain versus stress showing negative Poisson's ratio

ROCK FRACTURE MECHANICS – THE FUTURE

New developments in the field of rock mechanics, such as mechanical excavation methods are fast replacing conventional methods of rock excavation (drill blast). To keep upto date with these new developments, a testing facility needs to be equipped with the appropriate equipment to test the abrassivity, drillability and cuttability parameters of the rock for designing and selecting suitable Tunnel Boring Machines (TBM) and other mechanical excavation and drilling machines for different rock types.

NIRM is already in the process of establishing the state of art testing facilities to cater to the needs of oil and natural gas sector.

On the other hand, Indian dimensional stone industry is facing difficulties in placing their products in the European and other foreign markets as it is mandatory for them to get their product tested and Marked (ex: CE Marking) as per their norms (Ex: European Norms(EN) before placing the product in these markets. To full fill this urgent need of the industry NIRM is gearing up to establish the full-fledged facilities for CE Marking of dimensional stone products.

The material testing laboratory (wire ropes, mechanical parts etc) of NIRM is approved by Directorate General of Mines Safety (DGMS). Additional facilities for Non Destructive Testing (NDT) are also proposed and will be available soon in the laboratory so as to provide this service to industry.

Numerical modeling is widely used in the field of rock mechanics to study and understand the failure behavior of rocks under uniaxial and triaxial stress conditions. NIRM is already having the appropriate facilities in this regard to simulate the laboratory testing conditions; however, it is proposed to acquire the latest available software to keep abreast with the technology.

Although the in-house research on estimating in situ stress in the laboratory using rock core samples with acoustic emission technique is ongoing, it is intended to attempt to estimate the in situ stress using rock core samples for mining and civil engineering projects. In this regard efforts are on to have latest state of the art facilities at NIRM in the near future.

Testing of large size samples for extrapolating the laboratory results to rock mass scale is another important area, that NIRM is focusing and the required facilities will be established in future for this purpose.

Materials Testing Services by NIRM

A. RAJAN BABU

Centre for Testing Services, National Institute of Rock Mechanics, Kolar Gold Fields

INTRODUCTION

Material Testing Laboratory at NIRM caters to the needs of mining and other industries for testing of wire ropes and vital parts of mine machinery and its accessories involving Destructive and Non Destructive Testing (NDT) over 30 years. NIRM has state-of-the-art facilities and infrastructure to carry out test as per various standards and statutory regulations including DGMS guidelines. It is one of the unique laboratories in India manned by qualified and experienced scientific personnel.

In today's world wire ropes are used for various applications including transportation of men and material in civil and mining industries. Aerial ropeways, lifts, conveyor belts driver, winder, cranes etc. have become a basic necessity and their daily usages involves high risk unless they are safeguarded through adequate safety/quality measures.

Several accidents are reported due to non-compliance of safety measures. Unless there is a systematic programme for monitoring and assuring the quality of ropes, winders and support conveyors the accident will continue to occur. NIRM has taken a lead role in providing services to assess the compliance with respect to various safety standards including DGMS, International road transport etc.

ESTABLISHMENT OF MATERIALS TESTING LABORATORY

Materials Testing Laboratory was primarily established at Kolar Gold Fields (KGF) to cater to the needs of erstwhile Bharat Gold Mines Limited. BGML which produced gold at KGF was one of the big mining companies in India. It had operations in KGF, Yeppamana, Bisanatham, Ramagiri and Chikarigunta with more than 60 shafts at its peak production time. The total length of shafts, tunnels and underground roadways combined together was approximately 417 km. Heavy duty winders and wire ropes were used for its day-to-day operations. To ensure safety, periodic checks were conducted on winders by experts from abroad. The winding wire ropes were sent to Calcutta for determining their strength properties. BGML authorities felt the need to have a test house set up in KGF for carrying out the safety audit on Winders and Wire Ropes. As a result, Materials Testing Laboratory was established in 1979, funded by Government of India with Department of Science and Technology as the nodal agency.

Since 1979, the Materials Testing Laboratory (MTL) has been functioning in KGF as DGMS approved laboratory for both Destructive and Non-Destructive Testing of Mine Machinery and Wire Ropes.

In India, the safety norms complied by the mining industries during all their operations are monitored and controlled by the Directorate General of Mines Safety (DGMS), Ministry of Labour & Employment. Transportation of men and material for mining activities are carried out using heavy duty machinery such as Winders, Haulers, Winches, Man-riding systems, Conveyors etc. Mining is done at both surface (open-cast) and sub-surface (underground). Underground working points are reached through shafts (vertical and inclined shafts) and tunnels which require hoists operated by winders and cage/buckets with the help of wire ropes. Materials Testing Laboratory has been the test house of BGML for conducting both destructive tests on wire ropes and non-destructive tests on vital components of mine machinery. Expertise was gained in these areas and the test services were extended to other mining companies in South India.

National Institute of Rock Mechanics which was established in 1988, as an autonomous body under the Ministry of Mines, took over the Materials Testing Laboratory and continued to cater to the needs of all mining companies in India. Diversification into activities such as estimation of parametric values of rock samples, proof load tests in the laboratory and in-situ non-destructive tests in actual field conditions at project sites were taken up. Thus the testing services of Materials Testing Laboratory have spread throughout the country. International tie-ups will be a reality in the near future.

FACILITIES AVAILABLE

The laboratory has the state of art facilities for both non-destructive/destructive tests and now caters to all the mining companies in India.

NON-DESTRUCTIVE TESTING

Ultrasonic Testing

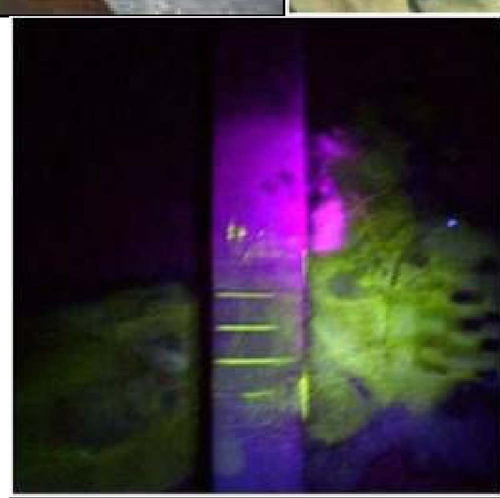
The principle involved in this technique is that high frequency Ultrasonic waves are passed through the components and any flaws which are present inside the component will be displayed in the form of sharp indications of various amplitudes on the Cathode Ray Screen. Sizing and evaluation of the defects will also be done with suitable methods and further usability of the components will be decided based on the BIS specifications pertaining to this technique.

In this method of test, Ultrasonic Flaw Detector with high frequency, normal and angle beam probes are used for detecting the flaws inside the components. Tests are conducted on the vital parts of the mining machinery and also other associated accessories. This service is extended to every other ancillary industry within the country. It is our endeavour to enter into international arena in a big way.

Magnetic Particle Testing

In this method, flaws present in any Ferro-magnetic material, both on surface and within the component (sub surface) up to 6 mm size are detected. For this purpose, Magnetic Yoke type Crack detector (Mobile type) is used.

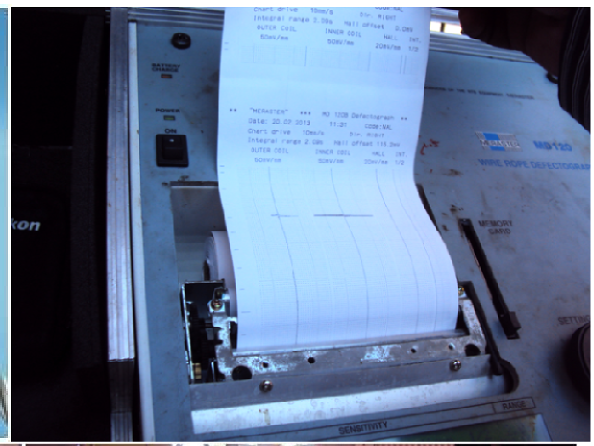


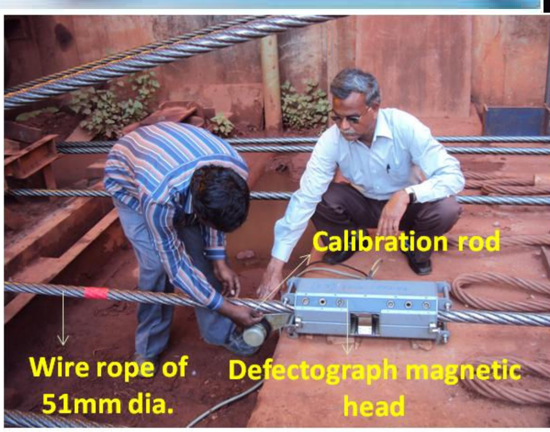


The principle involved in this type of testing technique is that a component is magnetized after thorough cleaning of the component with suitable liquid and a thin layer of mixture of ferric powder and kerosene oil is sprayed on the component and any surface flaws and sub-surface flaws that are present and which intercepts the magnetic lines of forces are viewed with the help of Ultra-violet lamp. This technique is used on all the vital components of the mine machinery. With this method the presence of surface and sub-surface flaws in the components can be evaluated and decide on their usability.

Non-Destructive Testing on Wire Ropes

Tests on the wire ropes of the mining industries, haulage winch ropes and also ropes that are in use in other ancillary industries have to be periodically done. Without disturbing the production, the wire ropes in use at various mining companies are to be tested in in-situ condition. The equipment used for this is Wire rope Defectograph. The principle involved in this technique is that a wire rope is passed through the powerful magnetic heads and any defects in the wire rope in the form of broken wires, corrosion and loss of metallic area will be indicated on the running graph paper attached to the equipment. The defects can also be recorded and viewed online. The evaluation of the defects and further usability of the wire rope will be assessed based on the BIS specifications pertaining to this technique.





DESTRUCTIVE TESTING ON WIRE ROPES

Wire ropes are essential parts of the mining industries. These are being used for the hoisting of men and materials underground. These are also used in winches and haulers. These ropes are to be tested periodically as they undergo wear and tear because of repeated cycles of operation. Director General of Mines Safety has made it mandatory on any mining agency to subject the wire ropes in use to periodical assessment for its deteriorating characteristics and to decide upon their continuance in service.

Different types of ropes that are being tested in our laboratory are:

Full locked Coil ropes from 16 mm to 52 mm dia.
Right Hand/ Left Hands Langs lay from 16 mm to 52 mm dia.
Multi-strand ropes from 16 mm to 52 mm dia.

As such different tests on various types of ropes that are being used by mining industries are tested to evaluate strength parameters.
The tests conducted are:

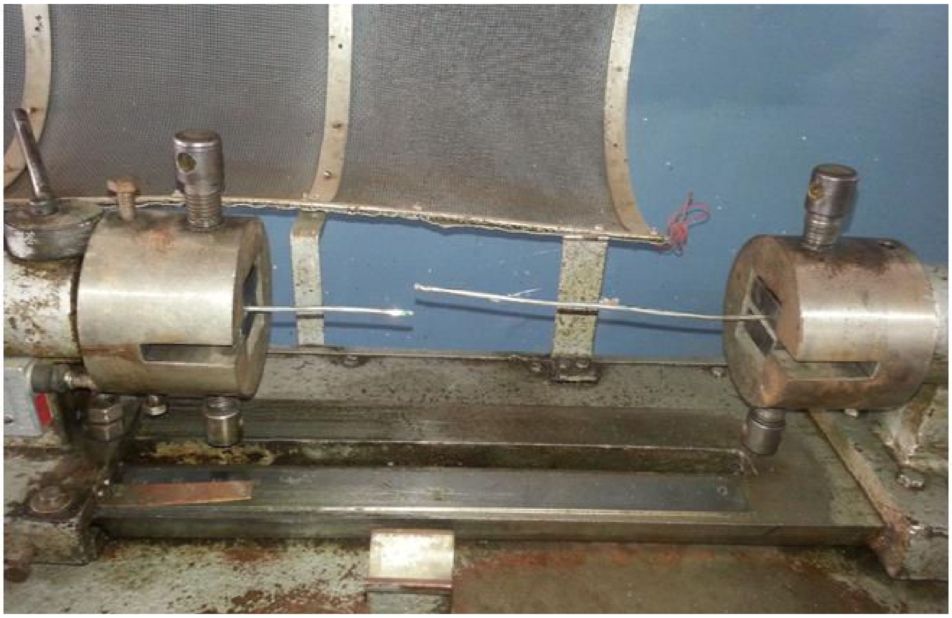
1. Tensile Test on individual wires
2. Torsion Test on individual wires
3. Reverse Bend Test on individual wires
4. Tensile Test on rope sample as a whole

Tensile Test on Individual Wires
This test is used to find out the Tensile Strength of the individual wires. For this purpose, 20 ton capacity Vertical Uniaxial Testing Machine is used. Appropriate lengths of wires are cut keeping allowance for gripping of the wires. The wires are gripped between the upper and lower jaws of the machine and load from the Hydraulic Unit is applied gradually and breaking load of the wire is recorded in Kilo Newtons. Tensile strength of the wires is calculated with these values. Anomalies if any in the recorded break load of wires are corroborated with the deterioration on the wires resulting out of corrosion, pitting and wear.

Torsion Test

This test gives a picture of the torsional property of the individual wires. Torsion Testing Machine is used for this purpose where an individual wire is gripped between a fixed head and a movable head. It is then kept rotated with the help of an electric motor through the reduction gears. These can be adjusted according to the size of the specimen wires.

Appropriate length of the individual wires are cut which varies according to the diameter of the wires. These wires are fixed between the sets of Torsional grips of the machine and tensioned with the weight on the pan placed at the end of the wire rope fixed to the movable head, and the clamping length is adjusted with the help of a scale on the rail. This is provided with a counter to read the number of twists in 360 degrees of the specimen after the breakage of the wires. Tests are conducted as per IS: 1717 – 1971. The total turns recorded will be based on the torsional properties of the individual wires which are affected by corrosion, pitting and wear caused by continuous usage of the ropes. This test is an important parameter to assess the deteriorating characteristics of the wire rope in use.



Reverse Bend Test

This test is conducted to find out the ductility of the individual wires. The equipment used to conduct this test on wires/ round bars up to 8 mm diameter is Reverse Bend Testing Machine. This is a hand operated and supplied with a set of grips and dies suitable for gripping the round and shaped wires. After suitably gripping the wires, handle of the machine is turned to 180 degrees repeatedly until the specimen wire breaks. The total reverse bends are recorded. The process is repeated for wires of different types and diameters. Reverse bend count for a particular set of wire varies depending upon the ductile property. The test is conducted as per IS: 1716 – 1971.

Tensile Test on Rope Sample

This test is conducted to determine the breaking load of the rope sample. The machine used for this purpose is 200 Ton Universal Horizontal Testing machine. This machine is used for testing materials both under tension and compression.

This machine consists of main unit, pendulum dynamometer, Electric system – Hydraulic Pump unit and Auto recording device. Oil pressure produced by Electric System Hydraulic unit is transmitted to main unit to give loading to test specimens. It is also transmitted to pendulum system dynamometer for measuring test load on a dial indicator and an auto recording device.

Specimen wire rope sample is cut to a suitable length as per the BIS specifications and both ends of the wire rope samples are arrested with binding steel wires to a suitable length by keeping allowance for opening of the individual wires. The individual wires are bent on both sides of the rope sample which results in a flowered shape. These flowered ends of the rope samples are fixed in cast Iron moulds and white metal, of suitable composition specified by BIS, is heated to 360 degrees and poured into the mould containing flowered end of the wire rope samples. This moulded white metal with rope sample is removed and cured for 15 hours and this will be ready for testing.

Prepared wire rope sample is introduced into the fixture of the 200 Ton U.T.M. and fixed tightly with nuts and bolts. These ends are arrested with pins between fixed and movable cross heads. Load ranges (50 Ton, 100 Ton and 200 Ton) are selected by changing the weights in the Dynamometer pendulum, which depends on the diameter of the rope sample. A graph paper and pen is fixed to the Auto recording device of the machine to give a Load Vs Extension representation. Load is applied on the specimen rope sample gradually until the sample breaks. Breaking Load indicated on the dial gauge of the machine and Load Vs Extension of the sample are recorded simultaneously. After the break test, location of break on the sample, position with respect to metal cone, type of wire nesting, percentage of destruction etc are noted. Breaking load depends on the diameter of the rope sample, type of the rope and deteriorating characteristics of the rope.

A detailed report is made using Tensile strength values, Torsion values and Reverse Bend values of the wires coupled with Breaking Load of the rope sample with Load-Extension diagram. A thorough visual inspection of the individual wires and the rope sample for its wear, corrosion, pitting and number of broken wires is also incorporated in the report. These parameters are useful to decide the continuance of the use of the rope even beyond the statutory period. Any deteriorating characteristics of the wire rope as reflected by various tests and visual observations are notified to the end users. The anomalies in the recorded values and observations inhibit the usage of the ropes whenever it necessitates as a safety and preventive measure.

Proof Load Testing

Proof Load Testing of vital parts of the mining machinery components and other accessories are done by using 200 Ton Universal Testing machine. The components are fixed between the fixed and movable cross heads of the machine by using suitable fixtures and load is applied gradually up to a calculated Proof load value and suitable markings are made on the components before the test and any elongation of the component subsequent to test is measured.

Proof load test on components like lifting chain slings, hooks, heavy duty pins, ‘O’ Rings etc are undertaken. Parallel tests are conducted using strain gauges affixed on to the components for measurement of strain values.

FUTURE PLANS

Centre for Testing Services (CTS) is the prime Centre of Excellence created by National Institute of Rock Mechanics, KGF integrating the Materials Testing Laboratory, Rock Fracture Mechanics Laboratory, Environmental Engineering Division, Dimensional Stone Technology & Soil Mechanics Laboratory. The future plans are:

- To bring rock and material testing facilities required by Mining, Civil & Petroleum Sectors under one umbrella.
- Special emphasis on testing in the field of Basic Rock Engineering and testing for safety of Mining machinery.
- Venture into new areas such as Non-Invasive Technology for Non-Destructive Testing including Nano-Technology for Materials Testing.
- To set new trends in Testing Services above existing global standards.

Dimensional Stone Technology – A Perspective

A. RAJAN BABU

Centre for Testing Services, National Institute of Rock Mechanics, Kolar Gold Fields

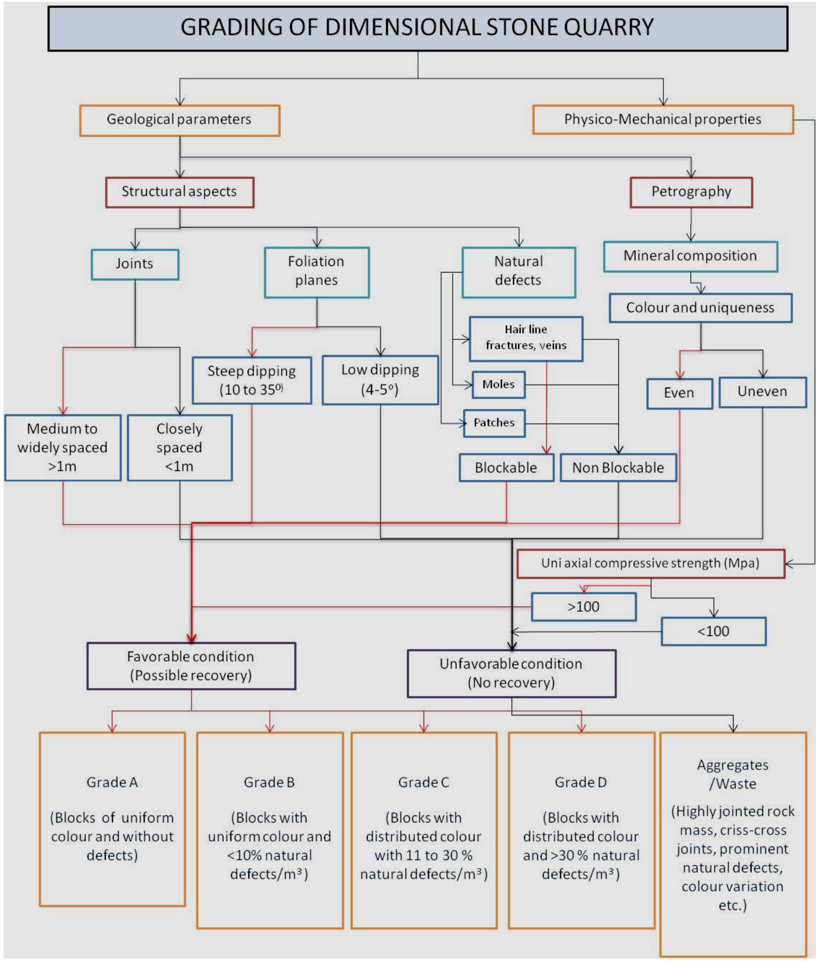
INTRODUCTION

The Indian dimensional stone industry contributes nearly 25% of the export revenue generation to the Government's exchequer. The growing demand for Indian stones worldwide has been causing tremendous pressure for rapid production of quality stones. The quarrying process demands for discrete extraction technology owing to large variations in their geological, geotechnical and physico-mechanical characteristics. On the other hand, the industry has been suffering from poor recovery (< 10%), low productivity and excessive waste generation mainly due to lack of scientific guidelines and affordable technology. Recognizing the need of dimensional stone industry for scientific exploitation, the Department of Dimensional Stone Technology (DDST) was established at NIRM in 1997. This is the first of its kind in the country carrying out research in this area.

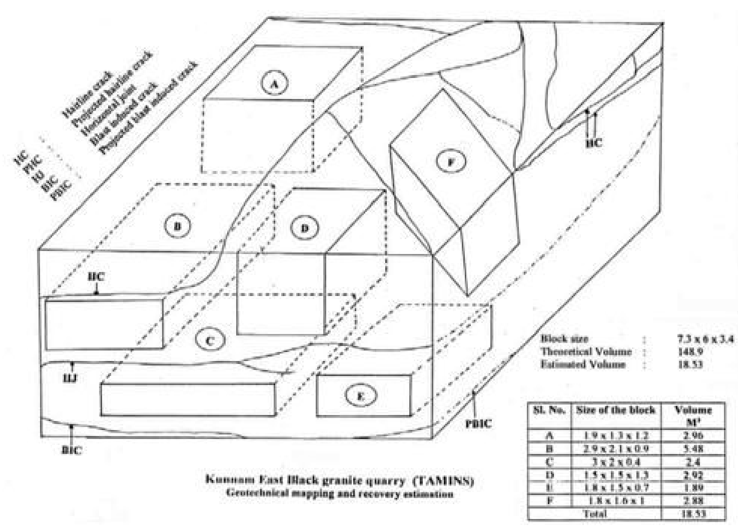
The Institute helped the entrepreneurs in characterisation of the deposits and scientific design of quarries. The rock testing facilities available at the institute are of international standard and were further augmented as per the industry's requirement. Investigations related to improving recovery, geological-cum-geotechnical studies, testing of physico-mechanical properties, blasting designs, etc were completed in several quarries. Advice was given to the industry on improvement in recovery through proper planning and site specific extraction designs for every activity of block extraction.

GEOTECHNICAL STUDIES FOR RECOVERY ESTIMATION

The quarrying of dimensional stone demands expert technique, extensive experience and thorough knowledge of geological-cum-geotechnical conditions. The uncertainty to predict the jointing patterns, bedding planes and fault systems is a serious disadvantage, which controls the block layout and recovery. Technologies for sub-surface mapping including the latest GPR techniques have failed to address the typical problems associated with dimensional stones to predict their quality in terms of defect free blocks such as moles, black patches, thin veins etc. However, the said technologies have been used with limited success for forecasting the jointing patterns and other geological weaknesses. Nevertheless, the technique was not widely adopted in quarries due to high costs involved in carrying out such investigations. With a view to overcome this problem, the three-dimensional geotechnical mapping system was used to estimate the recovery from an identified block. The strike & dip of joints, foliation etc. were measured along with details of visible cracks, moles, black patches, quartz veins etc. The data was then plotted on a graph sheet for estimation of possible recovery. This system has been successfully adopted for identifying the block geometry, orientation of faces, design of suitable splitting technique and overall improvement of recovery.



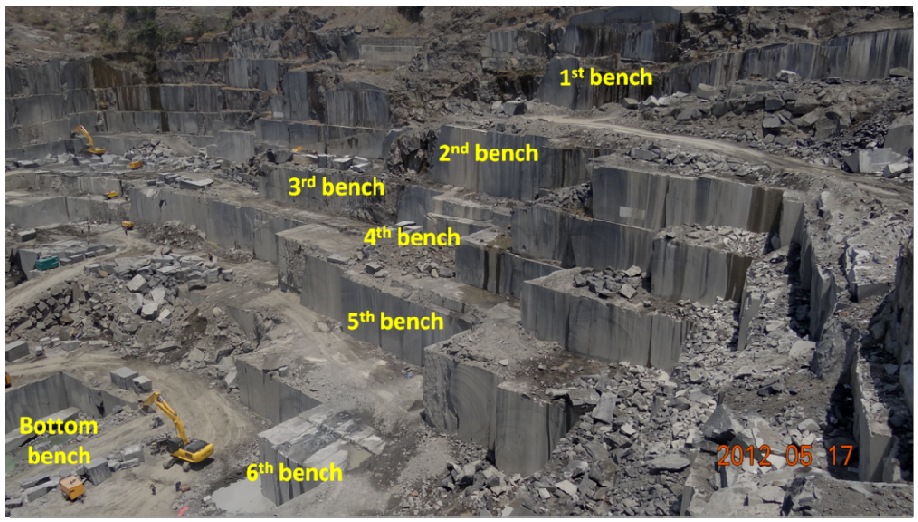
Flow chart for grading of dimensional stone blocks



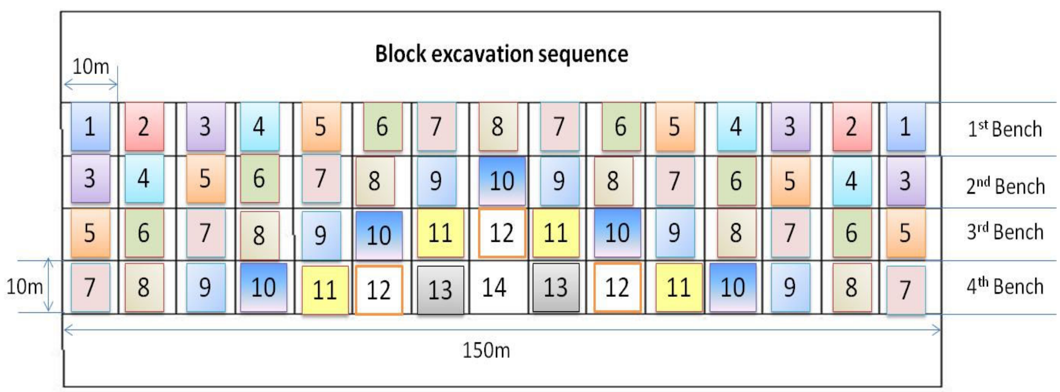
A typical example of geotechnical mapping and recovery estimation of a block

PLANNING THE QUARRY FOR ECONOMIC EXPLOITATION

The bench configuration in weathered rock and in hard rock is entirely different. The slope angle in the weathered rock should be always less when compared to the slope angle in the hard rock. The lesser slope angle leads to prevent and minimize damage and danger from rock falls. This depends on how weathered the rocks is, and the type of rock, and also how many structural weaknesses occur and their orientation within the rock mass, such as a fault, shears, joints or foliations. The bench configuration also depends on the quarry lease area and its orientation. In small quarry lease area, the operating space and depth is limited. Where as in large quarry lease areas the operation can be done in selected areas to increase the production and the risk of accidents is also less. Generally the benches are designed depending on the capacity of the machinery that is being used. The bench has inclined section of the wall i.e. is known as the batter, and the flat part of the step is known as the bench or berm. The steps (berms) in the walls help to prevent rock falls continuing down the entire face of the wall. A haul road is usually situated at the side of the pit (in stable rock mass) forming a ramp in which trucks can drive, carrying block and waste rock.



Planning of quarry layout for optimum recovery



Block excavation sequences for optimum productivity

CONTROLLED BLAST DESIGNS FOR BLOCK SPLITTING

The last two decades have witnessed tremendous advancements in the extraction technology for the exploitation of dimensional stones. However the explosive application for block splitting continues to dominate the industry primarily due to its cost effectiveness and easy to handle procedures. It is imbibed that explosive splitting alone contributes for more than 25 % damage to the valuable rock. In order to overcome the undesirable effect of explosive splitting several new techniques were developed and used. These include diamond wire cutting, perforation (slot drilling), jet burner cutting, hydraulic rock splitter, use of chemicals such as expanding cement and water jet cutting. These techniques did not produce consistent results in all types of rocks and quarries and their utility was largely controlled by the techno-economics of operation and the ability for the huge initial investment. Due to this, the most successful techniques like diamond wire cutting, perforation and flame jet cutting were adopted in combination with explosive splitting.

The forecast is that, use of explosive splitting will continue to play a dominant role in block splitting application atleast for another two to three decades in one or the other form. The advances made in the manufacture of explosives and accessories for variety of utilities offers great flexibility for more accurate blast designs.

The major disadvantage with drilling and blasting is the potential threat from induced cracks. With the modernised tools of drilling and blasting a great deal of the damage could be controlled within acceptable limits. The use of explosive splitting could be justified only when scientific approach is applied for the drilling and blast design and genuinely implemented by a competent person. The validity of a prudent drilling and blast design may become questionable if proper sequencing of splitting is not followed.

Mechanised drilling of 32 mm dia drill holes and modern wire saw cutting

Hole to hole splitting with detonating cord

A perfect and smooth face as a result of controlled block splitting

With the above, the recovery has been improved by 3 to 6 times. The drilling cost was reduced by 40% with a reduction of 33% in the cost of explosive consumption. The average cost on production was reduced by 33% while the rate of production was increased to more than double.

The Table below shows improvement in production and savings realised in the respective quarries

Particulars	Increase in Production/ month (m^3)	Savings per m^3 (Rs./m^3)	Aggregate Savings Rs./month
Soolamalai	60	5080	304800
Chendarapalli	30	3635	109050
Raj Granites	85	6850	582250
Kunnam	15	5623	84345
Redlawada	40	5400	216000
Ilkal	70	3910	273700

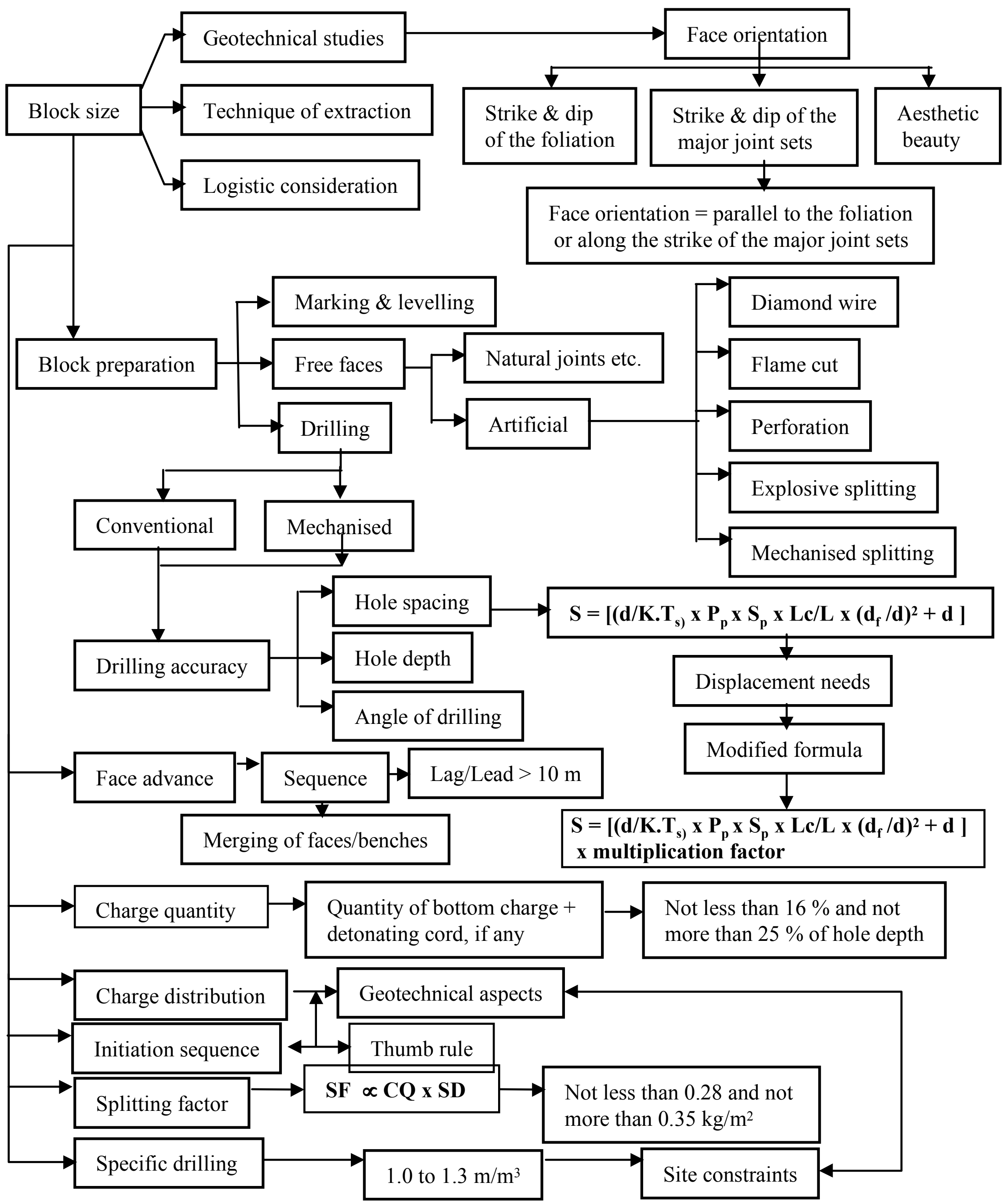
OPTIMISATION OF RECOVERY

A ten step guided procedure was developed for optimising the recovery of saleable blocks. The optimisation procedure is presented in the form of a master flow chart.

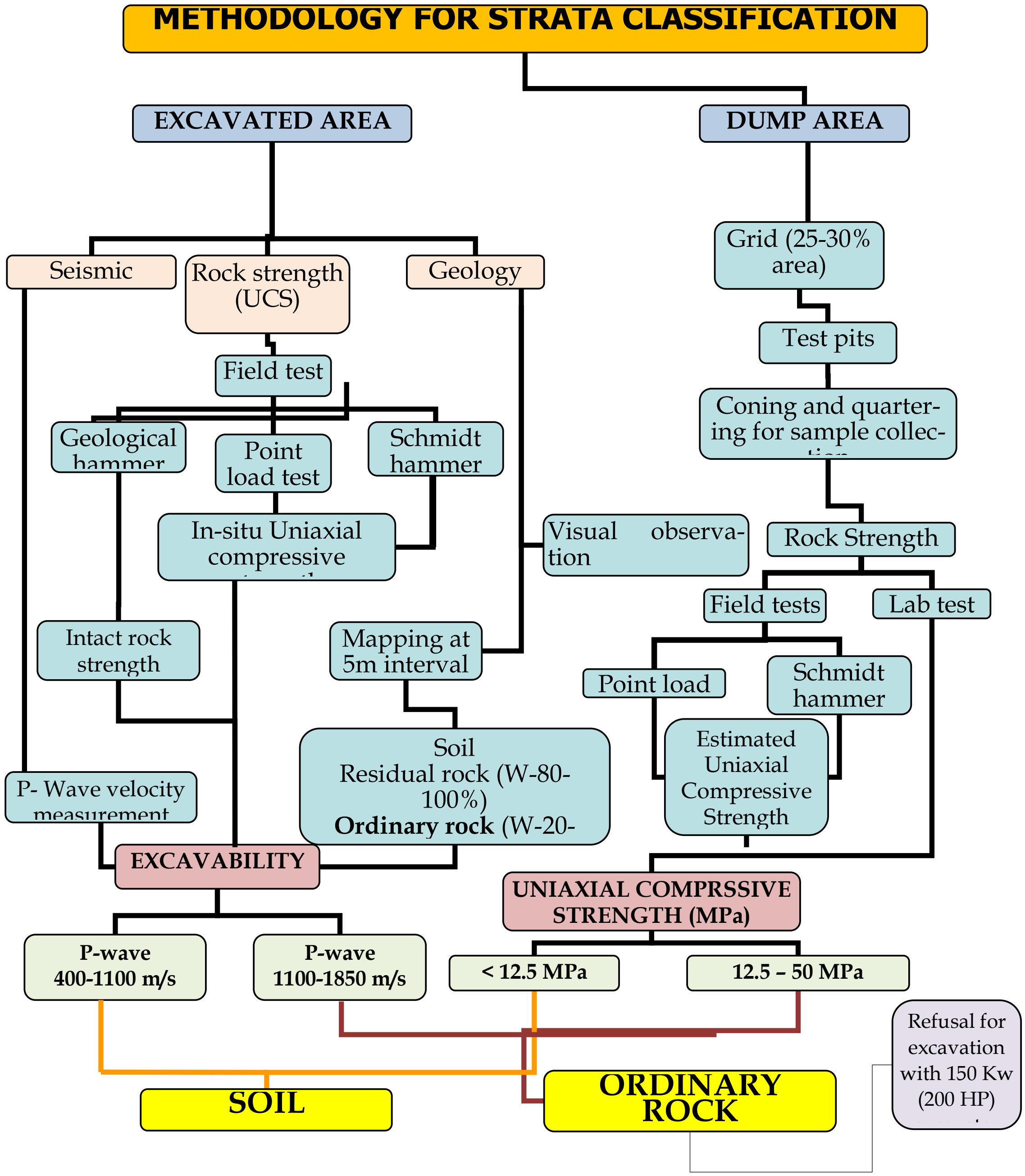
STRATA CLASSIFICATION WITH RESPECT TO RIPPABILITY AND EXCAVABILITY

The ease with which an earth material can be excavated is known as the Excavability. Different techniques of excavation vary in terms of cost and productivity. Selection of a particular method for excavation depends on several factors but mainly depends on properties related to hardness, strength and in-situ conditions of the material to be excavated. In geological sense, the strata/earth material includes very loose, cohesion less, granular soil or very soft cohesive soil through extremely hard massive rock.

FLOW CHART FOR GUIDED PROCEDURE



Master Flow Chart for optimization of block splitting operations



Flow chart for strata classification

Rock Blasting and Excavation Engineering in India - Contributions by NIRM

H.S. VENKATESH

Rock Blasting and Excavation Engineering Department, National Institute of Rock Mechanics

Bangalore

INTRODUCTION

Blasting is the backbone of the mining, hydel and infrastructure industry. Over the period of time the blasting industry has evolved and India too has caught up with the rapid pace of the technological developments of the industry. Application of technology grew exponentially during the past 25 years and NIRM too has been playing a major role since its inception in 1988. Nineties saw the globalisation in India and the mining industry too dreamt big. The explosive and equipment industries geared up to meet the National supply demands. Indigenous technologies and global tie ups strived and Indian research too supplemented the excavation industries growth.

The Rock Blasting & Excavation Engineering department at NIRM has been providing innovative solutions to challenging problems in blasting for various mining, hydroelectric and civil engineering projects for the past 25 years. Apart from providing solutions to conventional blasting problems, NIRM has been providing customized solutions to Metro rail projects, controlled blasting problems, graded material requirements (rip rap / armour rock / aggregate), pre-splitting for high wall stability, underground caverns (power houses / crude & gas storages), TBM, integrating blasting and other excavation techniques etc. The department is carrying out the preparation of blasting related pre-construction reports, method statement, proof checking etc. The Rock Blasting & Excavation Engineering Department has provided technical solutions in more than 150 projects (Sponsored and S&T), published over 100 technical papers and extended its services to more than 90 organizations. An attempt is made in this paper to present the current status of blasting research in India and its passage through 25 years by reviewing blasting instrumentation and some important case studies.

DETAILS OF BLASTING INSTRUMENTATION

In order to assess and evaluate the blasting results many organizations in India are conducting research and Table 1 gives the status of Indian practices vis-à-vis the global practices. The details of the instruments and the general procedure followed in the blasting studies is discussed in the sections below:

Ground Vibration and Air Overpressure

The instruments used for monitoring blast vibration (ground vibration and air overpressure) is a seismograph. There are many manufactures who supply the seismographs and one of the versatile instrument with NIRM is the Minimate Plus Seismograph from Instantel, Canada (8 channels). Conventional tri-axial geophones are used for monitoring ground vibration at farther distances and while monitoring ground vibration at near field, high frequency tri-axial geophones (28Hz to 2KHz) are used. In order to study the response of rockmass, sensors are mounted on bolts anchored in the rock mass. The seismographs are microprocessor-based, portable units and each unit consists of a standard external tri-axial transducer for monitoring ground vibration and a mike for measuring air overpressure.

Table 1. Status of Indian practices vis-à-vis global practices

Activity	Global Status/ Operating Procedures	Indian Status/ Operating Procedures
Blast Design	Empirical formulae	Empirical formulae
	Regional design considerations and local database	Regional design considerations and local database
Measurements	Digital cameras	Digital cameras
	High speed camera	High speed camera
	Continuous VOD measurement	Continuous VOD measurement
	Through commercial image processing tools	Through commercial image processing tools
	Laser face profiling	Laser face profiling
	Signature hole analysis	Signature hole analysis
	Bore hole pressure measurements	Bore hole pressure measurements
	Commercial Blast design software's	Commercial Blast design software's
	Numerical modeling/Simulation study – Auto Dyne/3DEC	Numerical modeling/Simulation study – Auto Dyne/3DEC
Ground Vibration & Air Over Pressure	Seismographs with AOP measurements	Seismographs with AOP measurements
	Distance measurements with GPS/Conventional laser based survey	Distance measurements with GPS/Conventional laser based survey
	Field measurements as per ISEE	Field measurements as per ISEE
	Standards differ country wise	IS Code 14881:2001* and DGMS (Tech)(S&T) Circular No. 7 of 1997**
Rock Mass Damage studies in U/G Cavern & Tunnel	Conventional vibration monitoring	Conventional vibration monitoring
	Half cast factor	Half cast factor
	Monitoring with High frequency geo-phone	Monitoring with High frequency geophone
	Bore hole camera	Bore hole camera
	Rock characterisation pre & post through seismic survey	Rock characterisation pre & post through seismic survey
	Strain measurements	Strain measurements
Over break control in U/G & Tunnels	Customised perimeter explosive used	Not readily available in India
	Bulk explosives for U/G applications	Just introduced in India
	Electronic detonators	Just introduced in surface mines. Still using conventional electric detonators and shock tubes.
Controlled blasting in urban environment	Rubber mats and Rope mats	Rubber mats. Additionally we use link mesh, sand bags, Rubber tyres.
	Shock tubes/electronic detonators	Shock tubes

* Anon (2001) ** Anon (1997)

Apart from ground vibration, air overpressure from blasting is generally an annoyance problem and may not cause damage but may result in confrontation between the operator and those affected. Air overpressure is not simply the sound that is heard, but it is an atmospheric pressure wave consisting of high frequency sound that is audible and low frequency sound or concussion that is inaudible. The weakest component of structures that may be affected is glass panes which is unlikely unless air overpressure levels exceed 160 dB. The air overpressure levels at critical structures are restricted to below 133dB being the permissible level as per US Bureau of Mines and IS code. At sound pressure levels below 130dB there will be audible rattle, mainly from windows and doors and from objects standing on shelves. With increasing amplitude, window panes begin to break at about 152dB. Most windows in an area would break at amplitude of 172dB, and structure damage would occur at 182dB or over (Siskind et al. 1980, Anon. 1998, Konya et al. 1990). People living nearby blasting sites often complain about ground vibration if the noise produced from blasting is high, they feel that the vibration is high. Although it is not directly related to increased overpressures, another factor of interest is the time related to the occupancy of the area and residential activities. Certain times may be unfavorable for the residents of a given area, such as night, evening, early morning, or times when most of the people in the area are home and conditions are relatively quiet.

Structural Response

In order to assess the structural response it is essential that we have the vibration measurements done at different locations in a structure (at the foundation and on the upper floors) and the sensors have to trigger at the same time. With this we can study the amplification, role of frequency, attenuation etc of the vibration and the response of the structure and study the damages (creation of new cracks, extension of old cracks etc). The conventional seismographs have standalone geophones and placing multiple instruments leads to difference in arrival times needing synchronising through software. Minimate Pro6 and – Series IV is one of the instruments used for monitoring structural response, consists of two standard tri-axial geophones to monitor vibration from the source at two different locations and gets triggered at the same time.

Generally houses contain numerous cracks of which the owner is unaware and which continue to increase in number and size each year with passage of time. Studies have indicated that the formation and extension of cracks is also a function of time and thermal variations. People are concerned that the existing cracks widen or new cracks are formed in their structure due to tunnel blasting. In India generally a permissible limit 5mm/s is recommended (Kutcha and cement and brick construction) and in cases structures with RCC and if the frequency is above 8hz, a higher limit of 10mm/s as per DGMS standards are recommended. Adrian et al. (2002) from their studies with regard to structural response of brick veneer houses to blast vibration observed from their experiments in Australia that environmental strains and rainfall contribute to the extension of existing cracks in a structure and the strain induced due to these environmental loads upon conversion to equivalent PPV are much higher than from blasting. They reported, no observable damage occurred until the ground vibration levels (PPV) exceeded 70mm/s. The damage at vibration levels of 70 - 220 mm/s was confined to the lengthening of existing cracks and the formation of new cracks in plasterboard. Studies on structural response to blasting in India by (Adhikari et al. 2005) have shown that no new damage or extension of existing cracks were observed in residential structures at PPV exceeding just above 20 mm/s.

Human Perception to Ground Vibration

Human beings are far more sensitive to ground vibrations and noise than structures. People inside buildings will respond differently than people outside and will respond more adversely inside their own houses than when they are inside other buildings. People tend to complain about ground vibrations even when the vibration level is below the minimum permissible limit of 5mm/s (Anon, 1997). One of the most important factors for complaining is the presence of secondary sounds such as rattling windows and doors. The threshold of perception for motion (without sound effects) is roughly 0.51mm/s (Anon, 1998) for most people at typical blasting frequencies. During a recent study by NIRM at Bangalore, blasting in rock was carried out in different locations of an excavation area. In total 27 blasts were carried out during the field studies period of 12 days. The closest and farthest distance between the residence at fern paradise layout and blasting location was 30m and 115m respectively. It is worthwhile to mention that though the vibrations were limited below the permissible limit of 5mm/s at the structures belonging to Fern Paradise, the human perceptions were that whenever the vibrations were below 1.5mm/s there were no complaints from the residents, and when the vibrations were between 1.5mm/s and 2mm/s they were uncomfortable and when the vibrations were above 2mm/s they complained of excessive vibrations (Balchander et al. 2014).

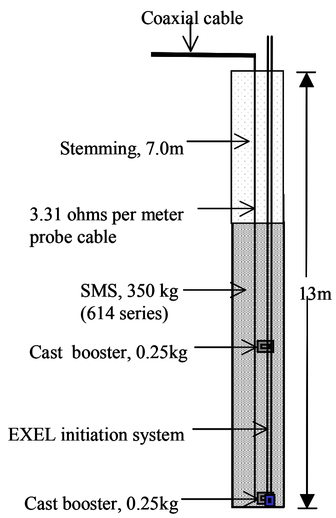
Flyrock Studies

Viewing the blasts in high quality slow motion will allow the designer to make decisions for improvements in rock breakage, movement, flyrock control and timing. Now a days the conventional low cost HD digital cameras are being used to capture the blasting in real time and are analysed through motion analysis software (commercially available or evaluation versions). This kind of analysis is more than sufficient to review and assess the blast designs (Fig. 1). Conventional low cost HD cameras are filming at 200 fps and these are proving to be equally helpful for recording high speed events at a low cost. However, specific studies with regard to measurements like flyrock trajectory and velocity, burden movement, stemming ejection velocity etc need high speed cameras. Most of the high speed cameras have 8 s recording duration (upto 10,000 fps) but cameras with higher duration too are available. In order to capture high speed events indefinitely these cameras store the event in a circular buffer with a pre-trigger setting. The cameras are armed through a remote switch that activates along with the initiation. In this way no event is missed. As most of the blasting events are captured from a distance of about 300 m and above, during clear sunny days 1000 to 2000 fps settings is good. Beyond which the clarity generally deteriorates.

Fig. 1. Observation of a blast using conventional video camera

Measuring Velocity of Detonation of Explosive

A large quantity of explosives is used for blasting in surface mines and quarries. The explosives are characterised by their properties such as strength, density, fume characteristics, water resistance, velocity of detonation (VOD), etc. Of these properties, the VOD is directly linked with the performance of the explosives. VOD of an explosive is defined as the rate at which the detonation front travels through a column of explosive. Every explosive has an ultimate or ideal detonation velocity known as steady state velocity of the explosive. VOD of an explosive is influenced by its chemical composition, diameter of the charge, confinement, temperature, degree of priming, etc. Evaluation of a blast design is carried out with the assumption that the explosives have performed as per the specifications, which may not be true in all cases. A reduction in the VOD will result in a reduction in the detonation pressure as well as in the availability of the shock energy of the explosive. An explosive will detonate reasonably when suitably confined and initiated by a high explosive of sufficient intensity and the reaction progresses along the explosive column with a speed equal to the VOD. The explosive pressure Pe which denotes the gas pressure applied to the borehole walls just after detonation is approximately one-half of the detonation pressure. The detonation pressure is directly proportional to the VOD of an explosive and any change in VOD is bound to affect the performance of a blast. During the early 1990s, NIRM carried out extensive VOD field measurements using discrete system in India. However, the discrete measurements did not provide comprehensive information along the charge length as the calculated VOD was only the average velocity of the explosive between two points. Subsequently when continuous systems were commercially available, NIRM carried out exhaustive studies to study the influence of various explosive and blast design parameters on VOD of an explosive (Venkatesh et al. 2001). There are instruments like Micro-trap, Datatrap, VODmate etc to monitor explosives continuous VOD in real time. These instruments are capable to measure the VOD of explosives in single or multiple holes. When recording VODs, the recorders output a low voltage (< 5 VDC) and an extremely low current (<50 mA) to the probes. This low excitation signal ensures that the instrument will not prematurely initiate explosives and /or detonators. These instrument measure the rate of change in probe cable length (known resistance) which is analysed through a software provided with the instruments to plot the VOD graphs and carry out further analysis of the traces. A typical experimental setup and a VOD trace is shown in Fig. 2.



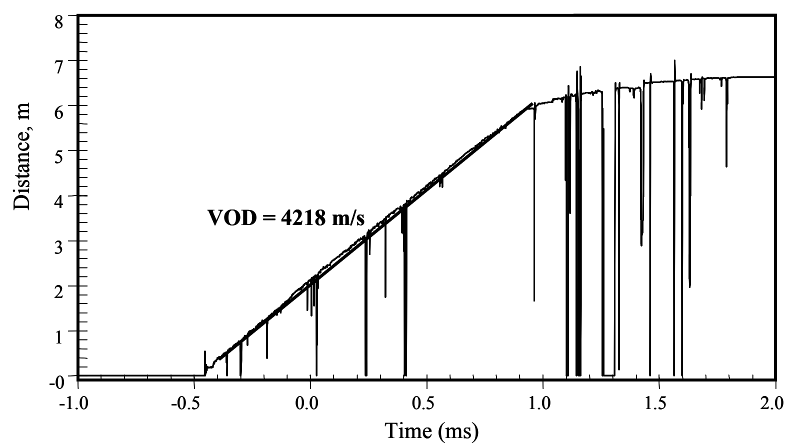


Fig. 2. VOD monitoring field set up and a VOD trace

Nowadays we have integrated instruments to measure the borehole pressure along with other measurements. Datatrap II is one such advanced data acquisition system that records the real time VOD of the explosive, delay time of the delay detonators, pressure, strain etc. It can also record near field blast vibrations using high G uniaxial and tri-axial accelerometers. The instrument is capable to record VODs of up to 8 explosives samples simultaneously and up to 32 blastholes and determine the delay times between holes and decks of explosives. Using Datatrap II it is possible to connect accelerometers (or other sensors like pressure probe, strain gauges) on several channels and VOD on other channels to determine the explosives performance and the effects on the rock walls simultaneously in one blast on a common time base.

Rock Mass Damage

Ground vibrations having sufficient energy can cause damage to the rock mass. The extent of damage is not solely a function of vibration level but is also related to site-specific parameters such as rock strength, geological features, ground support system, etc. As the severity of blast vibration increases, the damage done to the rock mass also increases. Various codes and standards have been prescribed for ground vibration limits in different countries for surface structures. There are no universally recognized standards for blast vibration for underground structures. Some researchers have concluded that the extension of existing cracks in the rock mass is limited to a distance of 80 to 108 blasthole diameters (charge diameters) or 4.5 m at the most in case of underground excavations. Particle velocities at this distance were 300 to 400 mm/s. Venkatesh et al. 2005 observed that vibration levels above 212 mm/s have resulted in minor spalling of the rock mass in the drainage galleries and the construction adits of an underground cavern in Himalayan rock mass. Some researchers have correlated induced tensile stress developed by particle velocity with that of the tensile strength of the rock mass. Richards and Moore (2002) observed in a coal mine that strain induced by blast vibrations leading to damage was about 10 percent of the tensile failure strain of the rock mass. Ramulu and Sitharam (2010), carried out research work on the effect of repeated dynamic loading imparted on the jointed rock mass from subsequent blasts in the vicinity at a hydroelectric project. The blast induced damage was monitored by borehole extensometers, borehole camera inspection surveys and vibration measurements using tri-axial geophones. The observations also showed that the rock mass damage was limited to less than 4m from the tunnel. Thus, there are different methods for damage assessment and they are: visual inspection, scan line surveys, scaling time, empirical rock mass rating systems, sounding of roof and walls, geophysical methods, bore hole video observation, near field vibration analysis, strain measurement, P-Wave velocity measurements, half cast factor etc. Of late bore hole camera observations of pre and post blast crack presence/propagation/creation and their correlation with near field vibration measurements are becoming popular in assessing the rock mass damages.

Fragmentation Assessment

Fragmentation in opencast mines is a key issue and the productivity of the mines has a direct dependence on the fragment size being produced from blasting. The fragment size and uniformity of the blasted material, effects the cost of the 'unit operations of mining' and thereby the productivity. Physical counting of fragments can correlate very closely to the actual size distribution in the muckpile but it is very cumbersome, time consuming and exhaustive. Other means is the sieving of the muck pile and this too is time consuming, expensive, intrudes into the mining operations, shall alter the fragment size distribution etc. Considering this, researchers have been working over a period of time to evolve methods to assess fragmentation. Image processing techniques proved to be suitable and effective in establishing the fragment size distribution in a muckpile. Fig. 3 shows the boundary zoning of the fragments in an image and an output comparing the fragment size distribution from field experiments at a mine. Of the image processing softwares developed for the assessment of fragmentation over the period, WipFrag (Maerz et al. 1996), SPLIT (Kemeny, 1994) and Fragalyst (Raina et al. 2002) are commercially available.

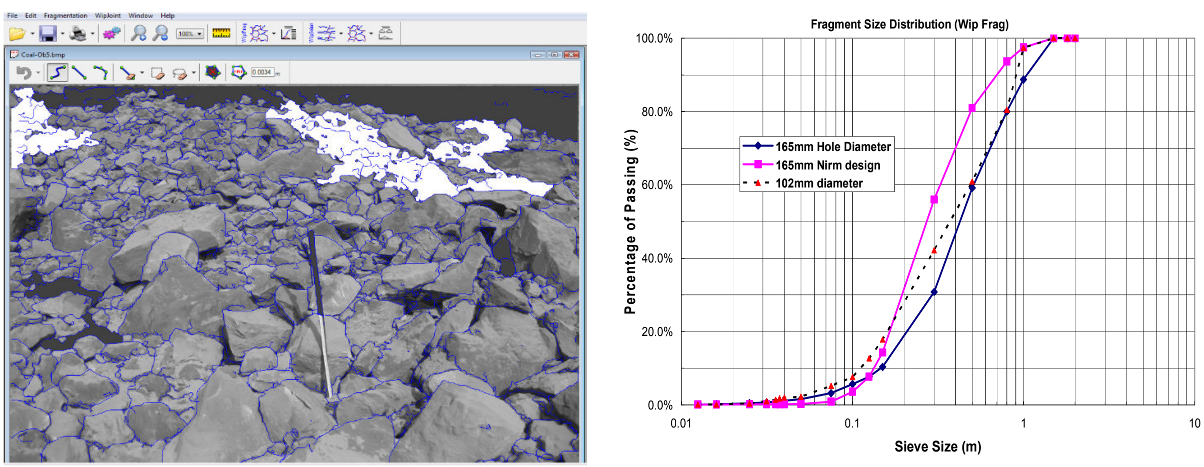
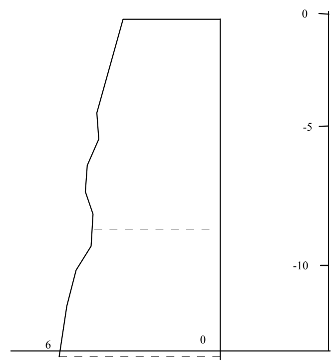


Fig. 3. Showing the fragmentation analysis using image processing technique

Laser Profiling Survey System

Blast results are dependent on a number of parameters related to the rock, explosives, blast geometry, delay timing and initiation sequence. The knowledge of probable crest and toe burdens will help in designing the blast and also in proper deployment of drilling machines. The placement of front row holes would considerably affect the blast results and it may lead to flyrock, airblast, toe or even a blast failure. There are several methods to measure the burden against hole depth, but the most popular has been the fishing rod method. Even though the method is simple, it is time consuming and cumbersome. Now a days, microprocessor based rock face survey systems are available for this purpose. The laser profiler is a tripod mounted instrument designed to record inclined distance, horizontal and vertical angles during rock profiling operations. The target is viewed through an eyepiece and laser light is emitted through a transmit aperture and admitted through a receiver aperture. The laser system bounces a pulsed beam of laser off the rock face. The instrument uses a pulsed semiconductor laser diode system which makes it capable of ranging rock up to 400 m and targets up to 10,000 m fitted with multi-retro reflectors. An internal electronic clock measures the `time of flight' of the pulse and the distance is calculated from the speed of light. Simultaneously vertical and horizontal angles are measured indicating the direction of the observation. Multiple observations across the face are stored and filed automatically in the instrument's memory. This is retrieved and processed at the site office through analysis program (Figure 4). These profilers can also profile the blasted muck but this needs a separate analysis program for characterizing the muckpile.



Face No. 1 Hole depth 13.2 m
Along face = 0 m Offset 3.7 m

Point	Depth	Burden
1		
2	1	3.9
3	2	4.1
4	3	4.3
5	4	4.5
6	5	4.3
7	6	4.4
8	7	4.4
9	8	4
10	9	3.9
11	10	4.5
12	11	4.9
13	12	5.1
14	13	5.3
15	13.2	5.4

Fig. 4. Profile for one of the holes with 3.7 m offset

CASE STUDIES IN BLASTING

NIRM and other researchers have contributed in providing solutions to practical blasting problems in India. Some of the important case studies over the past 25 years are briefly presented below.

Mass Pillar Blast

Mochia mine fired 145 tonnes of explosive to blast an underground pillar to yield 0.55 millon tonnes of ore in June 1994. To protect the main mine structures (situated at a distance of 250 to 350m from the blast) the maximum charge per delay was restricted to 2300 kg. Vibrations produced from stope blasts, development and pillar blasts were monitored by NIRM (Adhikari et al. 1993). Post-blast observations revealed that no damage was caused to the structures. The damage assessment survey of the mine workings situated in close proximity revealed a general trend in consonance with the distance from the blast and found to be well correlated with peak particle velocity (Rajmeny et al. 1995).

Improvement in Fragmentation

NIRM studied the nature, dimension and probable causes for the formation of boulders. It was observed that the fragments from the blasts were usually smaller than 1 m, but the problem of choking at the chutes due to boulders in shrinkage stopes was very severe. There was heavy pile up of boulders in the vicinity of the grizzlies. The prime cause for the formation of boulders in the stopes was due to spalling of the stope back and the side walls. Pre-reinforcement of the rock helped in controlling this problem. Cut thickness lower than the bolted length resulted in better fragmentation. Blasting damage to the stope was minimised by altering the blast design parameters, initiation system and lightly charging the periphery holes (Venkatesh et al. 1992).

Pre-Splitting

Pre-splitting was envisaged for achieving steeper slope angle at Rampura Agucha mine in India. Singh et al. (2009) designed and successfully guided the pre-split blasting operations to ensure stable pit slopes with minimal over break (Fig. 5).

Fig. 5. Pre-split blasting at Rampura Agucha mine

Initially the available drill machine was of 115 mm diameter and was not able to drill inclined holes. A master plan of the vertical pre-split holes position at spacing of 1.2 m was prepared. The pre-split line was designed at 1 m away from the final crest line from the berm to be left. The available explosive was in the cartridge diameter of 25 mm which provided decoupling by factor of 4.56. In the experimental trials the mouths of the pre-split holes were left without explosives from 0.8 to 2.7 m. In the latter stage the inclined holes of 80°, 70° and 60° with 115 mm diameter were experimented. The charge factor of 0.44 to 0.90 kg/m was experimented depending upon the rock types. The best results were encountered when pre-split holes were drilled with 60° inclination and the top portion were uncharged by 2.2-2.7 m.

In order to minimise the volume of excavation to construct a surface nuclear power plant in proximity to existing nuclear power plant in India it was decided to have vertical slopes. The stability of these high-walls become very important as they have to serve for decades. Therefore damage to the wall rock was controlled by adopting pre-split blasting. Based on the suggested blast designs by NIRM about 1.6 million cubic meter of hard rock was excavated for site grading and foundation excavations in close proximity to an operating nuclear power plant. The suggested blast design for pre-splitting controlled the damage to the rock mass in laminated sandstone and ensured stable 14 m high walls (Figure 6). In total, 45,000 m2 was successfully pre-split using 115 mm dia holes from about 200 blasts. The average half cast factor (HCF) achieved with a spacing of 0.8 m and a charge density of 0.55 kg/m2 was 80% (Gopinath et al. 2012).

Fig. 6. Pre-split blast wall and the subsequent civil constructions of the nuclear plant

Influence of Total Charge on the Intensity of Ground Vibrations

There are apprehensions with regard to a number of factors that influence the generation, propagation and intensity of ground vibrations. However, there were conflicting opinions with regard to the influence of the blast size on the intensity of ground vibrations. NIRM carried out extensive field studies in an opencast coal mines in India and computer simulation study (Venkatesh, 2005). Studies clearly indicated that the total explosive charge in a blast has insignificant influence on the intensity of ground vibrations, for distances between 100 m and 3000 m (Fig. 7).

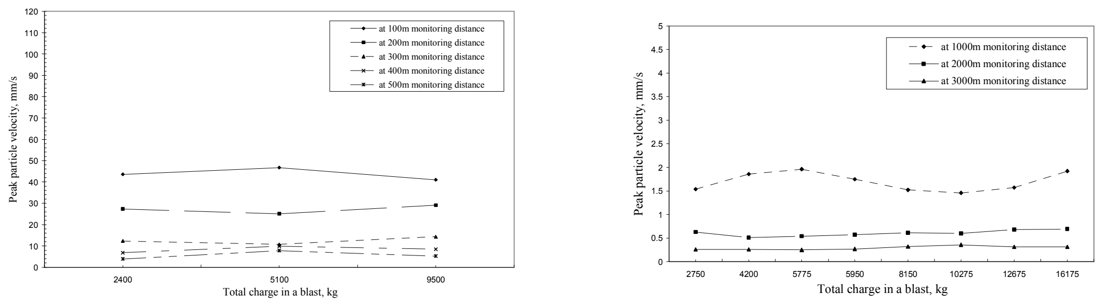


Fig. 7. Peak particle velocity vs total charge for a constant maximum charge per delay

Evaluation of Explosives Performance

NIRM carried out elaborate studies under an S&T project (Venkatesh et al. 2001) on the evaluation of explosive performance through in-the-hole VOD measurements. The VOD values monitored for cartridges explosives were higher than those quoted by their manufacturers. In case of bulk explosives, the VOD values were almost matching with the quoted ones. It could be concluded from the experiments that any increase in the quantity of primer beyond the recommended levels did not increase the VOD of the explosives. Single point priming was sufficient to reliably initiate and sustain the steady state VOD of explosives up to 10m long column without any additional booster charge. The contamination of SMS explosive while charging resulted in lower VOD. The analysis of VOD records in dragline benches confirmed that SMS explosives can be loaded in blastholes up to depth of 30m without the risk of attaining dead density of the explosive due to hydrostatic pressure. The experiments conducted with SMS explosives containing 0 to 9 per cent of aluminium powder indicated that the VOD values did not increase with the increasing aluminium percentage. The experiments in completely wet holes were not successful due to inefficient shorting of probe cable. The VOD decreased by about 25 per cent when SMS 654 had a sleep time of 25 days. The VOD value of ANFO was greater in 250 mm diameter than in 115 mm diameter holes. However, the influence of blast hole diameter was not so conclusive for bulk explosives tested in 150 mm and 250 mm diameter holes. Provided that the stemming length was adequate, the VOD of explosives did not vary with the stemming length.

Controlled Blasting for Bangalore Metro Rail Project

Growth in infrastructure projects in India has created huge scope for excavation activities throughout the country. One of the major activities in any city is the development of public transport and metro rail is the most preferred one. The underground component of metro rail predominantly constitutes the tunnels and the stations in soil and hard rock. The tunnels were made by tunnel boring machines while the underground stations were planned to be excavated by drill-blast method (cut & cover). In general, each station box is about 20 m wide, 272 m long and 20 m high. NIRM carried out the preliminary blasting studies at an alternate site during 2008 and submitted a method statement to BMRCL. During 2012, NIRM technically guided the excavations at the four station box areas along the East-West metro corridor. Based on the site specific ground vibration studies, condition of the structures and the prevailing norms, a permissible limit of 10 mm/s was decided. The suggested muffling in conjunction with heavy rubber blasting mats restricted the flyrock distance within 10 m. The blasthole diameter was restricted to 45 mm while the maximum charge per delay was kept below 2.5 kg. The specific charge was between 0.5 and 0.6 kg/m3. Bench heights were gradually increased from 1.5 to 3.0 m and a production higher than the targeted production of 300 m3 per day was achieved many times (Fig. 8). In total about 500 controlled blasts were successfully conducted by NIRM during the study period (Balachander et al. 2011). Controlled blast designs and the guidance on sequencing of benching operations facilitated to avoid the excavation of a launching shaft for the TBM at Sir M V Visveshwaraya station area. This brought down the need for hard rock excavation and also saved time as the TBM launching could be done from the station area itself.

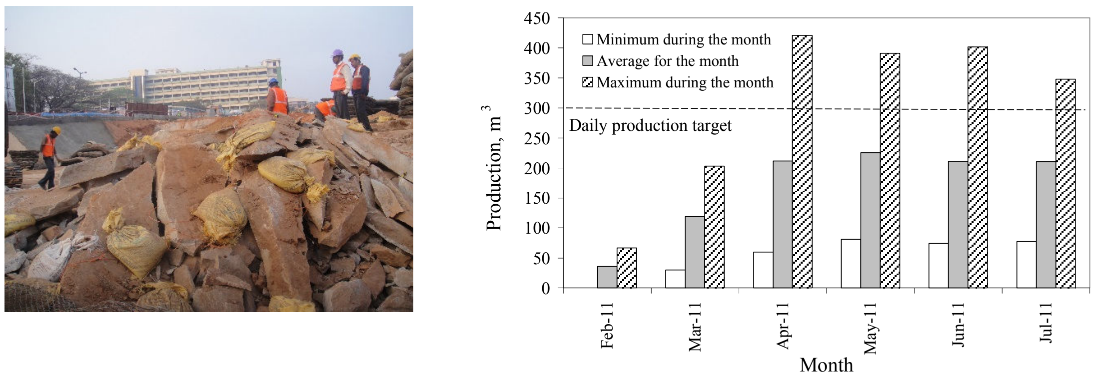


Fig. 8. Blasted muck and consolidated production details at Sir M V station

Shaft Sinking

Excavation of shafts has been a difficult, costly and time consuming process. In recent times there has been some mechanization, however, the conventional and semi mechanized methods still seem to dominate. Different methods have been followed for excavation of shafts and conventional drill blast methods is still the most opted method (Fig. 9). NIRM was associated with the excavation of a surge shaft in a hydro electric project in Bhutan. About 900kg explosive per blast was used on a regular basis. An average advance of 3.2m per blast was achieved for a drilled depth of 3.5m. Unfavorable geological conditions encountered during excavation not only caused problems in excavation but also resulted in blockades which were successfully tackled (Venkatesh et al. 2004).

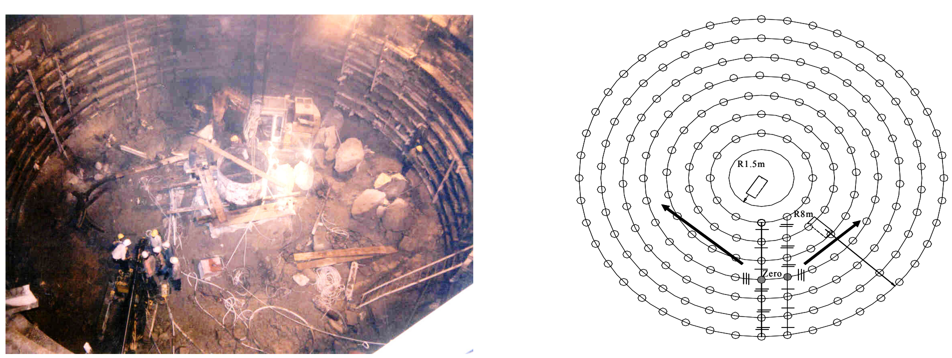


Fig. 9. Full face blasting of 16 m dia surge shaft

Underwater Blasting

Underwater blasting forms a major part of rock dredging projects in ports. A rock dredging projects covering an area of about 1,30,000m2 involving 4,00,000 um of hard rock mass was taken up in Tuticorin Port, India, in front of Berth No. 8. STADDPro analysis was carried out for determining the natural frequency of Birth No. 8. Under water blasts were planned with varying configurations at different locations from the structure in order to maintain the vibration levels to within threshold values prescribed. In total 1900 underwater blasts were carried out using 95t of explosives (Sastry et al. 2013). Under water blasts should be designed judiciously, as any error has huge ramifications in terms of delay in project duration, cost escalation and on the performance of the dredging equipment. Continuous monitoring of underwater blasts with effective instrumentation immensely contributed in minimising the environmental effects but in generating data bank about the blast effects on structures too. Fig. 10 shows the underwater blasting in progress.

Fig. 10. Underwater blasting in progress

Blasting Gallery

Extraction of seams thicker than 4.8m has always been technical problem for the mining industry and Blasting Gallery method of mining is considered to be one of the most economical and viable technology for thick seam extraction. In BG method, the entire seam thickness can be excavated in one lift by drilling a set of holes in a ring pattern with percentage of coal recovery ranging from 65 to 85%. BG method was initially introduced for extraction of already developed pillars at East Kartras Colliery (BCCL) and Chora-10 pit Colliery(ECL). It was subsequently extended for exploitation of vigin thick coal seam at GDK-10 Incline of SCCL. Induced caving by blasting (or in short induced blasting) has become an integral part of BG method for controlling the roof strata. CIMFR has been carrying out extensive research in the area of induced blasting for BG panels and has been guiding the industry in this regard.

Rip Rap

The purpose of blasting is normally to achieve smaller size of fragments to reduce the overall mining costs. In some case like in breakwater projects, the purpose of blasting is to produce bigger size of fragments (Fig. 11). The Seabird project at Karwar in Karnataka envisaged construction of three breakwaters with a total length of 5.25 km with a height of 16 m and a base width of 120 to 130 m. Rock blocks of specified size gradations termed armourstone gradings were supplied from a nearby quarry on Aligadde hillock. During January 2002, the project was facing an acute shortage of certain weight ranges of armourstone. This shortfall in armourstone was adversely affecting the progress of the construction of the breakwaters. The primary reason for this shortfall was that the quarry was unable to produce the armour sizes at the required rate of supply. The average quarry yield of armourstone (defined for this project as being from 1 to 10 t in weight) was about 23% while the production of rock pieces less than 1 t accounted for 77%. Increasing the yield of armourstone from the quarry was very crucial not only to reduce the cost but also to avoid delays in the completion of the project. Keeping this in view, this study was conducted by NIRM to maximise the production of armourstone (1 to 10 t size). The natural blocks suitable for the specified armourstone in the quarry was low due to joints and intrusions present in the rock mass. Furthermore, there was inevitable breakage of the natural blocks, reducing potential armourstone yields by approximately 15% due to quarrying operations including primary and secondary blasting. Despite strong influences of local geology, the yield of armourstone (1-10 t) increased to over 30% compared to pre-investigation period yield of 25 % (Adhikari et al. 2002).

Fig. 11. Blasted armour rock and the finished break water on the sea

Indira Sagar Polavaram Hydro Electric Project (960MW) is to be constructed across river Godhavari, 42km upstream of Rajahmundry by the Govt. of Andhra Pradesh. As part of this project 2454m long earth cum rock fill dam across the river is to be constructed. The main dam is proposed to be constructed with rock fill material (Rip rap) of 150mm to 600mm and 500mm to 1000mm for revetment shall be obtained from excavation of spill way, power house etc. In order to maximise the output of the graded material from blasting, NIRM carried out preliminary site investigation and recommended the blast design parameters (Gopinath et al. 2013).

Tunnelling

In Karnataka a twin tunnels through the hills adjacent to the Tungha Bhadra dam and under an operating railway line were being planned for road connectivity. The cover above these tunnels is about 14m. While blasting under the railway zone, the monitored ground vibration on the track was safe and were lower than the vibration levels due to passage of the train itself. The levels measured before and after blasting on the track in the railway zone showed insignificant ground settlement. Suggested blast designs and sequence of excavation in the tunnels ensured the completion of these tunnels under the operating railway line (Balachander et al. 2012) (Fig. 12).

Fig. 12. The tunnel under construction and under operation

Blasting at TBM Sites

The work of 6.75km long Dulhasti project head race tunnel of 8.3m excavated diameter was started with gripper type hard rock TBM. The rockmass was predominantly hard and highly abrasive quartzite. While tunnelling, the TBM was inundated with a water inflow of over 1000 l/s. The TBM could bore only 2.86km and finally was abandoned. The project has subsequently been completed by conventional D&B method. At the head race tunnel for Parbati Stage-II project, an incident similar to Dulhasti project tunnel occurred in May 2007 when routine probing ahead of a 6.8m diameter TBM tunnel in sheared and faulted quartzite at 900m overburden cover punctured a water bearing horizon which resulted in flow of water of over 120 l/s containing about 40% sand and silt debris. The inflow was sudden and occurred at a high pressure which could not be contained. Eventually over 7500m3 of sand and silt debris buried the TBM. The project supposed to be commissioned in 2007 is delayed for about 10 years. National Thermal Power Corporation (NTPC) is constructing the Tapovan-Vishnugad hydroelectric power project (TVHEP) with installed capacity of 520MW (4 x 130MW). The project has HRT of length approximately 12.1 km, of which 8.6 km has been planned to be excavated using a double shield TBM. The remaining 3.5km of the HRT is being excavated by conventional D&B method. During the excavation, the TBM encountered a large fault zone. A major portion of rock detached and dented the shield of the TBM and the TBM got trapped. Subsequently, a bypass tunnel was excavated by conventional D&B to recover the buried TBM. The TBM has been recovered, repaired and again put to use in the same tunnel (Goel et al. 2014).

CONCLUDING REMARKS

Over the past twenty five years blasting which was more or less confined to mineral exploitation in remote locations has evolved and reached the door steps of urban environment. It has become an integral part of any development activity. The technological developments in drilling, explosives and initiations systems assisted with instrumentation and computer aided blast designs have made blasting a safe, economical and rapid means of rock excavation. The varied case studies discussed and the measurements carried out with the latest instruments show that, India too caught up with the global trends and the blasting researchers in India have placed on par with their international counter parts. FRAGBLAST 10 International Conference which was held during November 2012 for the 1st time in India (being conducted over last 40 years once in every four years) stands as a testimony to the contribution of the India blasting researchers to global advancement.

RESEARCHERS WHO CONTRIBUTED TO INDIAN BLASTING FOR THE PAST 25 YEARS ARRANGED ALPHABETICALLY

Dr GR Adhikari, Late Prof HR Anireddy, Shri A Bagchi, Shri R Balachander, Prof S Bhandari, Shri V Bhushan, Late Dr A K Chakraborty, Prof (Dr) B B Dhar, Dr A Dey, Shri G Gopinath, Prof (Dr) R N Gupta, Shri A N Gupta, Prof A K Ghosh, Shri N Jayaraman, Dr J L Jethwa, Dr J C Jhanwar, Shri A Joshi, Shri S R Kate, Dr S K Mondal, Dr A K Mishra, Prof (Dr) V M S R Murthy, Dr Md Nabiullah, Dr C B Navalkar, Dr A G Paithankar, Dr G K Pradhan, Dr A J Prakash, Dr P Pal Roy, Shri A Rajan Babu, Dr Rajiv Bhadal, Dr S S Rathor, Shri B C K Reddy, Shri G V N Reddy, Dr A K Raina, Dr P K Rajmeny, Dr M Ramulu, Dr K Ramachander, Shri P V S Sarma, Dr K S Sarma, Dr V R Sastry, Dr A Singh, Prof (Dr) D P Singh, Dr M M Singh, Dr P K Singh, Dr R B Singh, Prof (Dr) T N Singh, Shri M S Sandhu, Shri M O Sarathy, Shri H N Srihari, Prof (Dr) K Srinivas, Shri A K Sen, Prof (Dr) N R Thote, Shri A I Theresraj, Shri H K Verma, Dr H S Venkatesh, Shri D Vidyarthi and all other unsung blasting experts & blasters. If any names are missed it is unintentional

References

Adhikari, G.R., Venkatesh, H.S., Rajan Babu, A. and Theresraj, A.I. (1993) “Maximum charge per delay for pillar blast at Mochia mine, HZL” NIRM report: ID 9002E, Dec.

Adhikari, G.R., Venkatesh, H.S., Subrahmanyam, D.S., Theresraj, A.I., Balachander, R. and R Gupta, R. N. (2002) “Maximising the Yield of Armour Rock from Aligadde Quarry, Seabird Project”, April

Adhikari, G.R., Venkatesh, H.S., Theresraj, A.I., Surendra Roy., Balachander, R., Nitin Kumar Jain and Gupta, R.N. (2005) “Role of blast design parameters on ground vibration and correlation of vibration level to blasting damage to surface structures”, S&T Project: MT/134/02, Research Funded by Min. of Coal, Govt. of India

Adrian Moore., Alan Richards., Thomas Lewandowski., John Wilson., Emad Gad., Adrian Page., Stephen Fityus., and Goran Simundic. (2002) “Structure response to blast vibration”, Australian Coal Association Research Program (ACARP) reference no. C9040

Anon (1997) "Damage of structures due to blast induced ground vibrations in the mining areas", DGMS (Tech)(S&T) Circular No. 7 of 1997 dated 29.08.1997

Anon (1998) “ISEE, Blaster’s Hand Book”

Anon (2001) “Method for Blast Vibration monitoring – Guidelines” Indian Standard IS code 14881:2001

Balachander, R., Gopinath, G., Theresraj, A.I., Vamshidhar, K. and Venkatesh, H.S. (2011) “Report on Technical guidance for rock blasting and monitoring of ground vibration, air overpressure and flyrock during excavation at Underground stations from Chinnaswamy stadium to City railway station, BMRCL site”. NIRM Project: RB 1006C

Balachander, R., Gopinath, G., Theresraj, A.I., Vamshidhar, K. and Venkatesh, H.S. (2012) “Report on Technical guidance on blast design for twin tunnel tubes and monitoring of vibration near railway track while excavating the tunnels, Hungund-Hospet Section, NH 13”, NIRM Project: RB 1103C.

Balachander, R., Naveen, G.C., Theresraj. A.I., Gopinath, G. and Venkatesh, H.S. (2014) Interim Report on “Technical guidance on controlled blasting and monitoring blast vibration at Bagmane Constellation Business Park”, Outer Ring Road, Bangalore, NIRM Report RB1309.

Goel, R.K. (2014) “Experiences, Challenges and Developments in Rock Tunnelling”, Proc. Nat. Sem. on Innovative Practices in Rock Mechanics (IPRM - 2014), Bangalore 6th - 7th, Feb. pp. 9 – 21.

Gopinath, G., Theresraj, A.I., Balachander, R., Naveen, G.C., and Venkatesh, H.S. (2013) “Technical advice on Rip rap blasting for the construction of earth cum rock fill dam, Indirasagar, Polavaram”, Nov.

Gopinath, G., Venkatesh, H. S, Balachander, R. and Theresraj, A. I. (2012) “Pre-split blasting for final wall control in a Nuclear power project”, FRAGBLAST 10, Int. Symp. On Rock Fragmentation by Blasting, Vigyan Bhavan, New Delhi, Nov 25- 29, pp.731-740.

Kemeny, J. M. (1994) “Practical technique for determining the size distribution of blasted benches, waste dump and heap leach sites”, Min. Engg. pp.1281-1284.

Konya, C. J. and Walter, E. J. (1990) “ Surface Blast Design” Prentice-Hall,Inc.

Maerz, N. H. Palangio, T. C. and Franklin, J. A. (1996) “WipFrag image based granulometry system”, In: Franklin, J. A. and Katsabanis, P. D. (eds), Measurement of blast fragmentation. Rotterdam: Balkema. 91–98.

Raina, A. K., Choudhury, P. B., Ramulu, M., Chrakraborty, A. K. and Dudhankar, A. S. (2002) “Fragalyst – an indigenous digital image analysis system for grain size measurement in mines” Jl. Geol. Soc. India 59: 561–569.

Rajmeny, P.K., Joshi, A. and Agrawal. A. (1995) "Assessment of rock damage during 145 tonne blast at Mochia", Proc. EXPLO’95 Conference, Brisbane, 4-7 September, pp. 375-382.

Ramulu, M. and Sitharam, T.G. (2010) ”Blast induced damage due to repeated vibrations in jointed gneiss rock formation”, Int. Jl. of Geotechnical earthquake Engineering (IJGEE), Vol. 1, Issue 1, pp. 110-134.

Richards, A.B. and Moore, A. J. (2002) “Ground vibration and air blast”, Indian Conf. – INDOROCK, New Delhi, India.

Sastry, V.R. and Jyothy, N. (2013) “Design & implementation of underwater blasting operations and protection of marine structures”, Nat. Sem. on Explosives and Blasting Techniques for Mining, Quarrying and Infr. Industry, pp. 314-321.

Singh, P.K., Roy, M.P., Joshi, A. and Joshi, V.P. (2009) “Controlled blasting (Pre-splitting) in an open-pit mine in India”, Proc. of the 9th Int. Sym. on Rock Fragmentation by Blasting, pp. 481-489.

Siskind, D.E., Stakhura, V.J., Stagg, M.S. and Kopp, J.W. (1980) "Structure response and damage produced by air blast from surface mining", USBM RI 8485.

Venkatesh, H.S. (2005) “Influence of total charge in a blast on the intensity of ground vibrations-field experiment and computer simulation,” FRAGBLAST - International Journal for Blasting and Fragmentation Vol. 9, No. 3, September, pp. 127 – 138.

Venkatesh, H.S., Balachander, R. and Gupta, R.N. (2005) “Near field vibration monitoring for rockmass damage control”, Jl. of Explosives Engineering, USA, July-Aug.

Venkatesh, H.S., Balachander., R, Adhikari, G.R., Theresraj, A.I. and Gupta, R. N. (2004) “Optimisation of blast design parameters for Powerhouse complex at Tala Hydroelectric Project, Bhutan”, September - Project No: RB 02 03 C and RB 03 02 C.

Venkatesh, H.S., Adhikari, G.R., Theresraj, A.I., Verma, H.K. and Gupta, R. N. (2001) “Evaluation of explosives performance through in-the hole detonation velocity measurement”, S&T Project: RB 96 04, August.

Venkatesh, H.S. and Adhikari, G.R. (1992) “Design and Experimentation of Sub-Level Stoping in Zone I, HGML Improvement of fragmentation in shrinkage and cut-and-fill stopes at Hutti Gold Mine, HGML”, NIRM report: ID 90 04 C and ID 90 04 D, October.

Numerical Modelling Studies for Stability Evaluation in Civil and Mining Sectors by NIRM

Sripad R Naik

Numerical Modelling Department, National Institute of Rock Mechanics, Bangalore

INTRODUCTION

The complex nature of rock mass and the associated problems of rock mechanics together form a complex engineering problem. The prediction of the rock mass response to the excavation of tunnel/cavern under various geological conditions needs much more than traditional techniques. The interest of the design engineer is to assess the stability condition of the tunnel or cavern when no support is installed and when suitable support system is installed. Such assessment requires understanding the rock mass in terms of geological, geotechnical, insitu stress and hydrological parameters. Further, the fundamental components of rock mass behaviour needs to be accounted for by using appropriate methods for the analysis of stresses and displacements in the rock mass around the tunnel and the associated structural components.

A number of methods of stress analysis are available from the closed form solutions to numerical models. Numerical modeling is a stress analysis technique, which uses the power of modern computers, numerical analysis technique and the principle of mechanics. With the rapid advancements in computer technology, numerical methods provide extremely powerful tools for analysis and design of engineering systems with complex factors that was not possible or very difficult with the use of the conventional methods, often based on closed form analytical solutions.

Rock mechanics problems of practical concern can not be solved analytically as the rock mass is inhomogeneous and the constitutive relations for the rock mass are non-linear and mathematical formulation of the problem is difficult. In such cases, approximate solutions may be found by using computer-based numerical methods. In recent years, the development in the area of computational methods, numerical methods and rock mechanics has evolved many tools, which the rock mechanics engineer can use for the analysis.

NUMERICAL MODELLING METHODS

Numerical methods of stress and deformation analysis can be divided into two categories

- Differential methods
- Integral methods.

Differential methods

In differential methods, the problem domain is discretised into a set of sub-domains or elements (as shown in Fig. 1 a). This method requires that physical or mathematical approximations be made throughout a bounded region. Solution procedure is based on numerical approximations of the governing equations, i.e. the differential equations of equilibrium, the strain displacement relations and stress-strain equations, as in classical finite difference methods.

Alternatively, this procedure may exploit approximations to the connectivity of the elements and continuity of displacements and stresses between elements (as in finite element method). The following methods fall in to this category

a) Finite Element Method
b) Finite Difference Method

c) Distinct Element Method

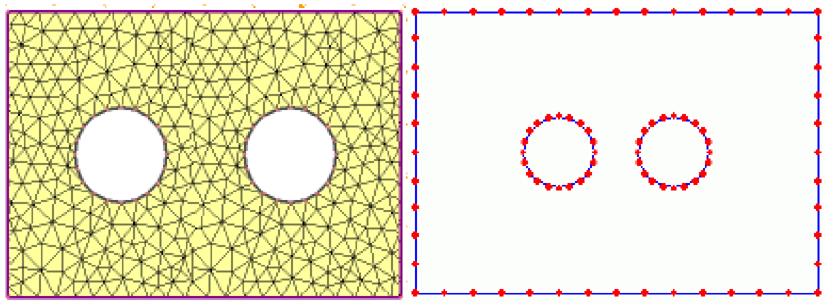


Fig. 1a. Differential Method & **1b.** Integral Method

The advantage of this method is that non-liner and heterogeneous material properties can be incorporated. However, these methods take longer solution run times.

Integral Methods

In the integral methods, only the problem boundary is defined and discretised (as shown in Figure 1b). Numerical solutions use analytical solution for simple singular problems in such a way as to satisfy approximately for each element the boundary conditions in terms of imposed tractions and displacements. Integral methods effectively provide a unit reduction in the dimensional order of a given problem since only the problem boundary is defined and discretised. This reduces the size of the system of equations to be solved and offers significant advantages in computational efficiency over differential methods. Integral methods model far-field boundary conditions correctly, restrict discretisation errors to the problem boundary and ensure continuous variation of stress and displacement throughout the material.

The boundary element method fall in to this category. Although, computationaly efficient, these method are suited for homogeneous materials and linear material behaviour.

APPROACHES OF NUMERICAL MODELLING

Rock mass is largely discontinuous, anisotropic and inhomogeneous in natural geological state. Difficulties arise in numerical modelling due to such complex and non-homogeneous geological conditions of rock mass.

Generally two types of approaches are adopted for modeling of the rock mass:

- Continuum Approach
- Dis-continuum Approach

Continuum Approach

Here the rock mass is treated as a continuum and the properties are equal in all directions throughout the model. Linear elasticity is commonly used, although nonlinear elastic constitutive equations can also be adopted. If the attention is posed on the progressive failure of the rock mass, the elasto-plastic models need to be utilized in order to describe the “post-peak” response.

The continuum modelling procedures generally exploits approximations to the connectivity of elements and continuity of displacements and stresses between the elements. Continuum methods divide the rock/soil continuum in to a set of simple sub-domains called ‘elements’. These elements can be of any geometric shape that allows computation of the solution or, provides the necessary relation to the value of the solution at the selected points called ‘nodes’ (as shown in Fig. 2).

Table 1. briefly summarizes the advantages and limitations inherent in these different numerical modeling approaches.

Analysis method	Critical input parameters	Advantages	Limitations
Continuum Modelling (e.g. finite-element, finite-difference)	Representative slope geometry; constitutive criteria (e.g. elastic, elasto-plastic, creep etc.); groundwater characteristics; shear strength of surfaces; *in situ* stress state.	Allows for material deformation and failure. Can model complex behaviour and mechanisms. Capability of 3-D modelling. Can model effects of groundwater and pore pressures. Able to assess effects of parameter variations on instability. Recent advances in computing hardware allow complex models to be solved on PC's with reasonable run times. Can incorporate creep deformation. Can incorporate dynamic analysis.	Users must be well trained, experienced and observe good modelling practice. Need to be aware of model/software limitations (e.g. boundary effects, mesh aspect ratios, symmetry, hardware memory restrictions). Availability of input data generally poor. Required input parameters not routinely measured. Inability to model effects of highly jointed rock. Can be difficult to perform sensitivity analysis due to run time constraints.
Discontinuum Modelling (e.g. distinct-element, discrete-element)	Representative slope and discontinuity geometry; intact constitutive criteria; discontinuity stiffness and shear strength; groundwater characteristics; *in situ* stress state.	Allows for block deformation and movement of blocks relative to each other. Can model complex behaviour and mechanisms (combined material and discontinuity behaviour coupled with hydro-mechanical and dynamic analysis). Able to assess effects of parameter variations on instability.	As above, experienced user required to observe good modelling practice. General limitations similar to those listed above. Need to be aware of scale effects. Need to simulate representative discontinuity geometry (spacing, persistence, etc.). Limited data on joint properties available (e.g. jkn, jks).
Hybrid/Coupled Modelling	Combination of input parameters listed above for stand-alone models.	Coupled finite-element/distinct-element models able to simulate intact fracture propagation and fragmentation of jointed and bedded media.	Complex problems require high memory capacity. Comparatively little practical experience in use. Requires ongoing calibration and constraints.

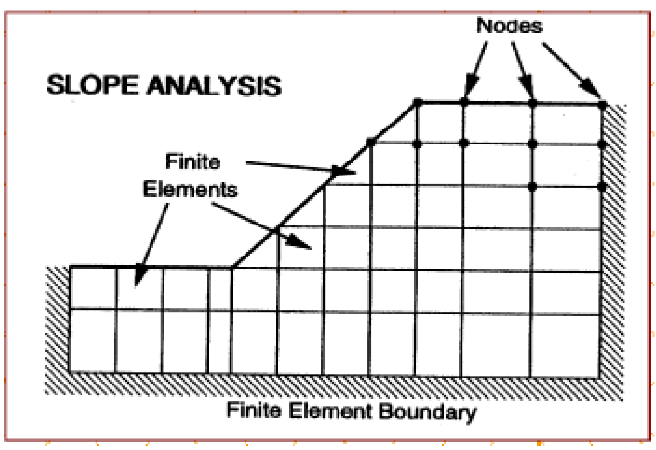


Fig. 2. Continuum modeling

This technique allows representation of the complex geometries and inclusion of dissimilar materials. The local effects of stress and strain concentration can be effectively modeled. Three popular methods in use for continuum modeling are

- Finite Element Method
- Finite Difference Method
- Boundary Element Method

Finite Element Method

Finite element is the most widely employed numerical method for rock mechanics and rock engineering. Much of the FEM developments have been specifically oriented towards rock mechanics since early 1960s. This is mainly due to its flexibility for treatment of heterogeneity, non-linear deformability, in situ stresses, complex boundary conditions and gravity.

FEM is widely used due to its generality and flexibility to handle material heterogeneity, non-linearity and boundary conditions, with many well developed commercial codes with large capacity in terms of computing power, material complexity and user friendliness. It is one of several well-developed techniques that can provide useful information for engineering surface and underground excavations in rock.

Some of the commercial packages available are as follows:

- ANSYS (ANSYS Inc.) - http://www.ansys.com
- Phase2 (Rock Science) - http://www.rockscience.com
- PLAXIS (PLAXIS BV) - http://www.plaxis.nl
- Midas GTS - - http://www.midas-diana.com/

Finite Difference Method (FDM)

This is one of the oldest numerical techniques used for the solution of sets of differential equations, given initial values and/or boundary values. The difference equations for a triangle are derived from the generalized form of Gauss' divergence theorem. Differential equations are solved by dividing the domain into connected series of discrete points called nodes. These nodes are the sampling points for the solution and are linked using finite difference operators to the governing equations. It is not necessary to combine the element matrices into a large global stiffness matrix as in the FE model. Instead, the FD method regenerates finite difference equations at each step. Derivatives of governing equations are replaced directly by algebraic expressions written in terms of field variables, e.g. stress or displacement, at discrete points in space (nodes).

The Finite Difference method allows one to follow a complicated loading path and highly non-linear behaviour without requiring the complex iterative procedure of a standard implicit code. Finite difference method can be used to discretize both time and space. It also provides easy error estimation techniques. It is particularly suitable for large, non-linear problem which may involve collapse or progressive failure.

Finite difference method is difficult to use for irregular shape domain because the fine meshing required near the singularity cannot be easily reduced for the rest of the domain. The conventional FD method with regular grid systems does suffer from shortcomings, most of all in its inflexibility in dealing with fractures, complex boundary conditions and material heterogeneity. This makes the standard FD method generally unsuitable for modelling practical rock mechanics problems. However, with the use of irregular meshes (triangular grid or Voronoi grid systems), which leads to Control Volume or Finite Volume techniques, significant progress has been made FLAC (Itasca, USA – http://www.itascacg.com)is the most well-known computer code for stress analysis for engineering problems using FVM/FDM approach. Explicit representation of fractures is not easy in FD method as they require continuity of the functions between the neighbouring grid points. In addition, it is not possible to have special fracture elements as in FE method. However, this is the most popular numerical methods in rock engineering with applications covering from all aspects of rock mechanics, e.g., slope stability, underground openings, coupled hydro-mechanical etc.

Boundary Element Method (BEM)

Rock mass is predominantly very large and for practical purposes can be assumed to be of infinite extent. Because of its volume discretisation the Finite element is not very well suited for problems with a low ratio of boundary surface to volume since a large number of elements are required to model the response of the domain. Boundary element method is particularly attractive for such analyses in rock mechanics where the surface of the excavation has to be discretised. The amount of input data required to describe a problem is greatly reduced and the influence of infinite rock mass is automatically considered in the rock mass.

Some notable applications of BEM in rock mechanics include:

- stress analysis of underground excavations with and without fractures,
- simulation of mining in faulted rock,
- dynamic problems,
- back analysis of in situ stress and elastic properties,
- borehole tests for permeability measurements.

Discontinuum Approach

Rock joints and discontinuities in a rockmass play a key role in the response of a tunnel or excavation, i.e. joints can create loose blocks near the tunnel profile and cause local instability; joints weaken the rock and enlarge the displacement zone caused by excavation; joints change the water flow system in the vicinity of the excavation. The use of discontinuum modelling has been gaining progressive attention in tunnel engineering mainly through the use of the UDEC and 3DEC codes (Itasca, USA), for 2D and 3D discontinuum modelling respectively.

In the distinct element method, the rock mass is represented as an assemblage of discrete blocks which may be considered either "not deformable" or "deformable". Joints and discontinuities are viewed as interfaces between distinct bodies. The important features of this method which make it appropriate in order to capture the important mechanisms characterising a discontinuous medium are

(i) the method allows finite displacements detachment (as shown in Fig. 3)

(ii) the method recognizes new contacts automatically as the calculation progresses.

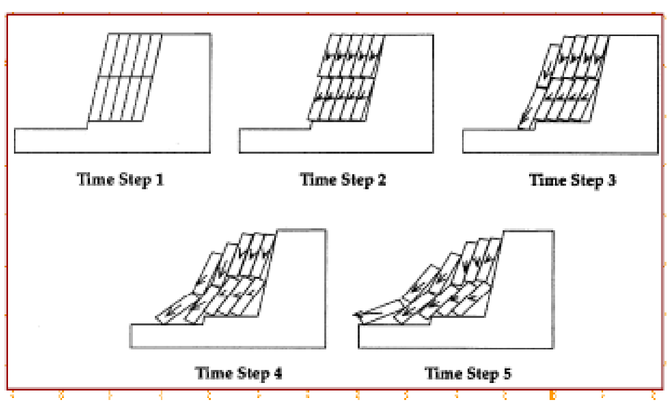


Fig. 3. A discontinuum model

In order to apply the distinct element method to the solution of tunnel problems, there are two crucial issues which include the joint geometry data and the material properties assigned to the joints.

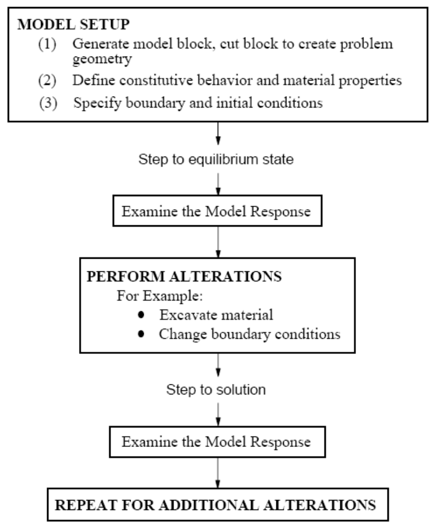
The distinct element method is the popular method in the discontinuum approach.

NUMERICAL MODELLING STAGES

The stress analysis of a problem domain is carried out in the following stages:

- Build geometry
- Meshing of the region
- Choose constitutive models and material properties
- Define boundary and initial conditions
- Apply insitu stresses
- Compute
- Visualization and interpretation of the results

This can be shown in the form of a flow chart



General solution procedure for static analysis

APPLICATION OF NUMERICAL MODELLING IN INDIA AND AT NIRM

In India, application of numerical modelling methods for rock mechanics related problems has been in use for decades. Research institutes and academic institutes like CIMFER, CSMRS, BHU, ISM, IIT Delhi, IIT Madras, IIT Bombay, IIT Rourkee, IISc, Bangalore have used Finite Element Modelling traditionally to solve rock mechanics problems in mining and hydroelectric projects. However it was NIRM that started use of discontinumm modelling tools in civil and mining engineering sectors. At NIRM Dr. B. Dasgupta (who was at Itasca USA before joining NIRM) started to use 2D and 3D distinct element codes like UDEC and 3DEC and made its use popular particularly in the hydroelectric project sector. Today NIRM is equipped with all the latest numerical modelling tools to handle complex rock mechanics problems.

Some of the notable contributors in the area of Numerical modelling at NIRM are

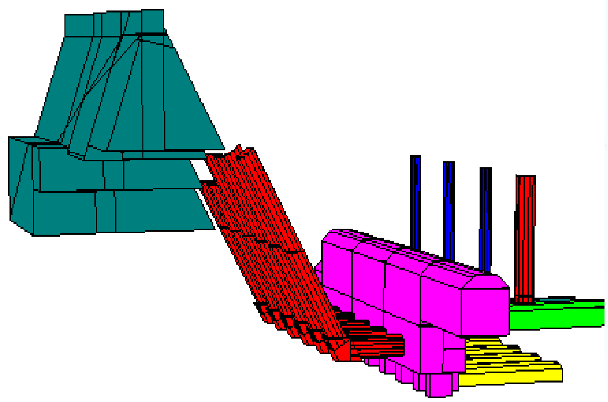
Dr B Dasgupta
Dr A Srikant
Mr G Ravi
Mr MN Reddy
Dr Kumar Pitchumani
Dr Venugopala Rao
Dr Roshan Nair

A FEW NUMERICAL MODELLING CASE STUDIES AT NIRM

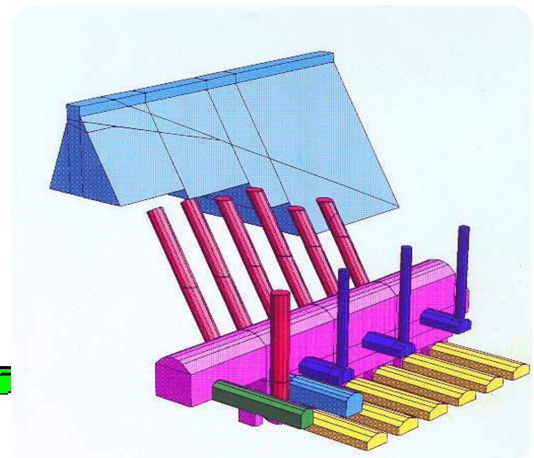
NIRM has worked on several challenging problems in hydroelectric project and mining sectors and offered solution to the problem with the help of extensive three dimensional models. Some of the projects worked are as follows:

Large Caverns

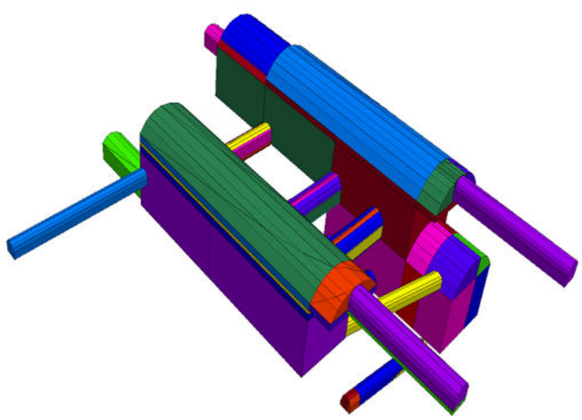
- Nathpa Jhakri hydroelectric power project, Himachal Pradesh
- Ghatghar pumped storage project, Maharashtra
- Pancheshwar multipurpose hydroelectric power project
- Sardar Sarovar project, Gujarat
- Tala hydroelectric project, Bhutan
- Mangdechu hydroelectric project, Bhutan
- Tapovan Vishnugad hydroelectric project, Uttarakhand
- Tehri Pumped Storage project, Uttarakhand
- Srisailam hydroelectric project, Andhra Pradesh
- Pykara hydroelectric project, Tamilnadu



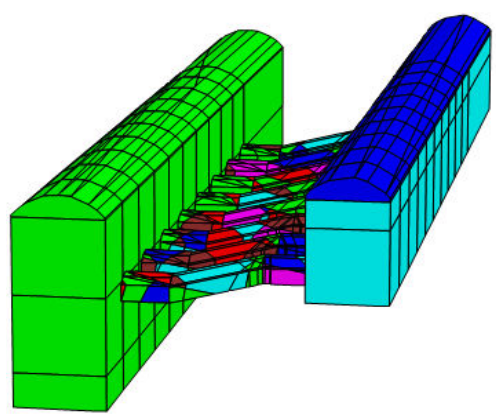
Nathpa Jhakri hydroelectric project, Himachal Pradesh



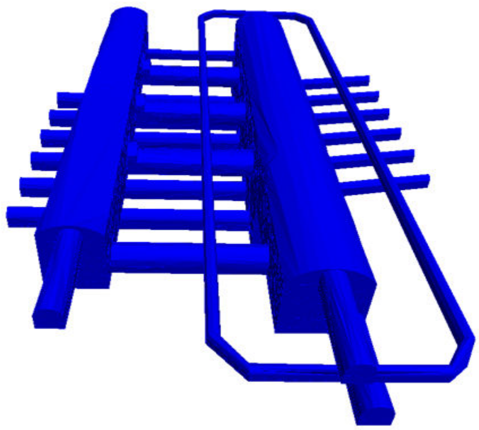
Sardar Sarovar Project, Gujarat



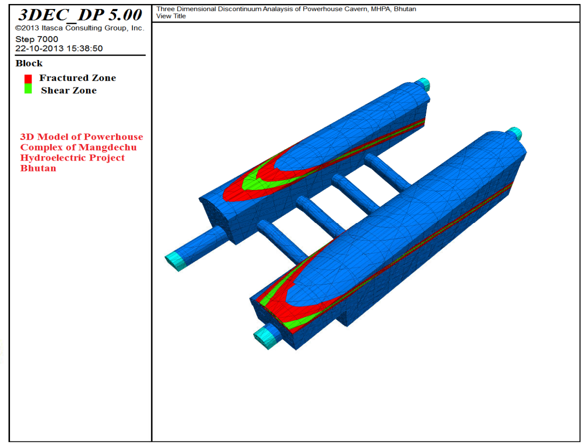
Ghatghar hydroelectric project, Maharashtra



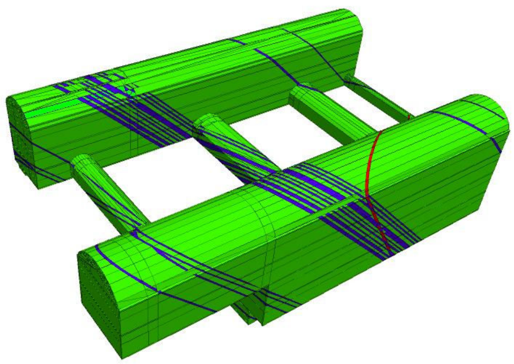
Pancheshwar multipurpose Hydroelectric Power Project, Indo Nepal border



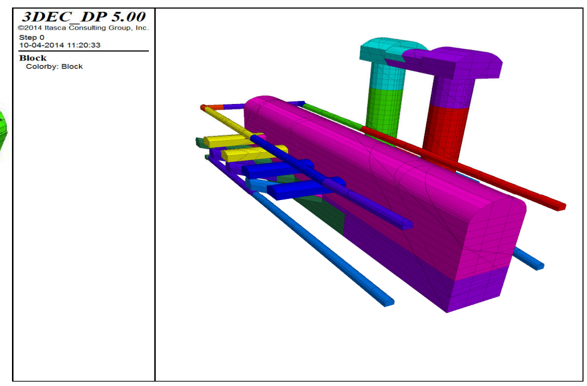
Tala hydroelectric project, Bhutan



Mangdechu hydroelectric project, Bhutan



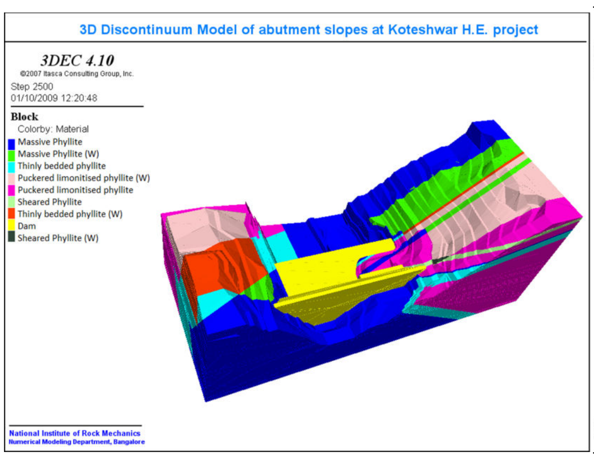
Tapovan Vishnugad hydroelectric project



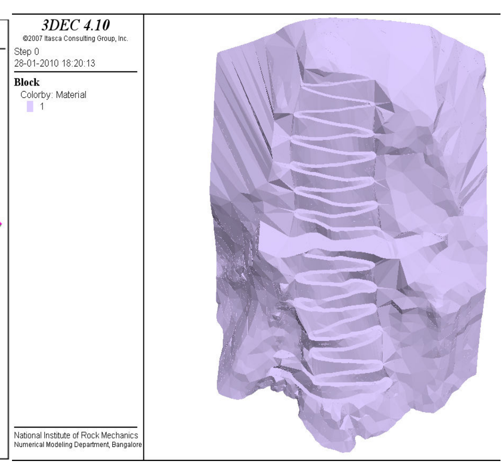
Tehri PSP hydroelectric project

Landslide and Slope Stability

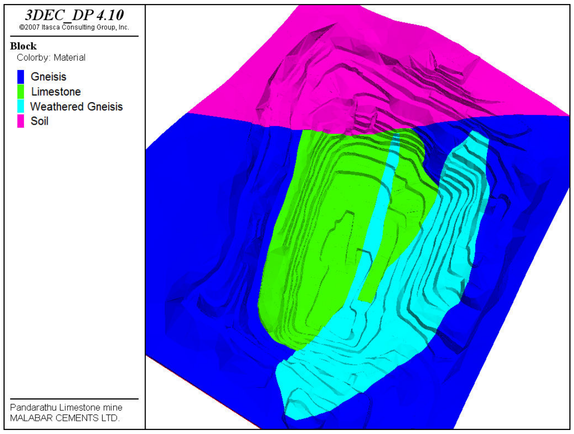
- Koteshwar hydroelectric Project, Uttarakhand
- Varunavat Parvat, Uttarakashi
- Malabar Cements, Kerala
- Bicholim iron ore mine, Goa



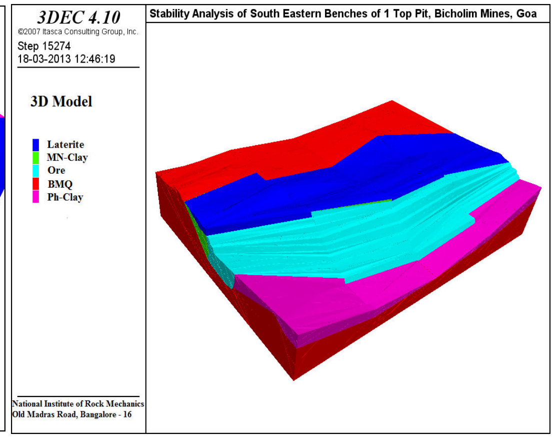
Koteshwar hydroelectric project



Varunavat Parvat, Uttarakashi



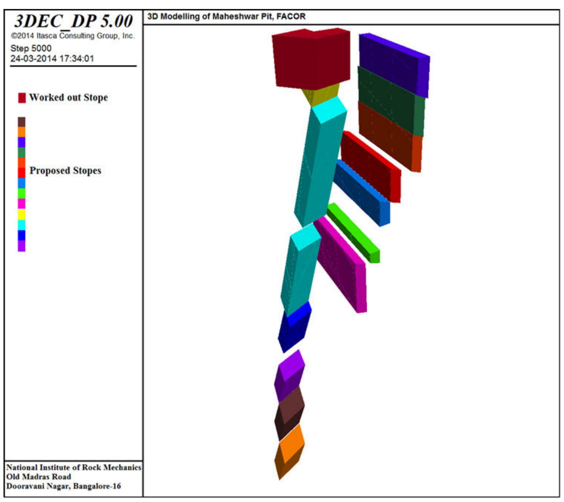
Malabar Cements, Kerala



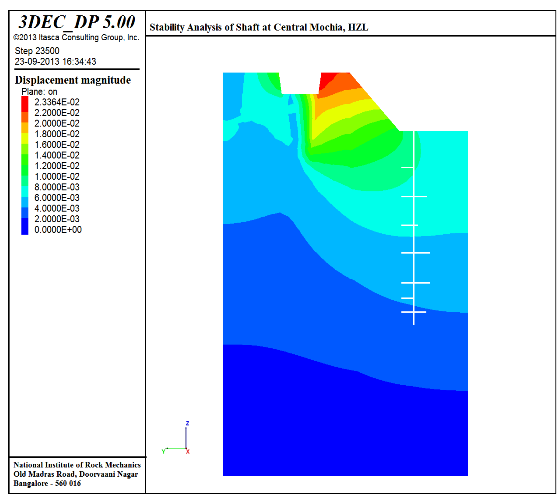
Bicholim Iron ore Mine, Goa

Mining

Hindustan zinc, Rajasthan
Balasore Alloys, Orissa
Facor Chromite Mine, Odisha
IMFA Chromite Mine, Odisha
Sonshi Mine, Goa
Indu Projects, Hyderabad



Facor Chromite Mine, Odisha

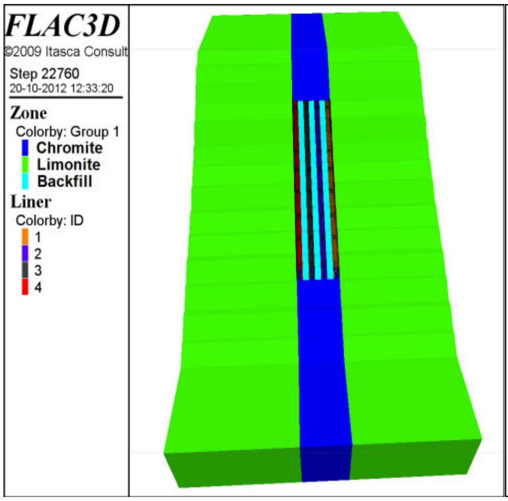


Central Mochia Mine, Hindustan Zinc Ltd.

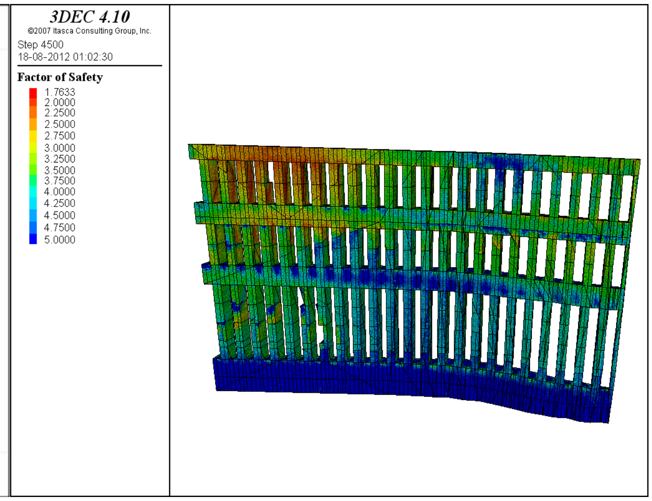
CONCLUDING REMARKS

There have been significant advances in computational methods over the last decade, specifically in numerical methods in solving rock mechanics problems. Formulation of conceptual models and mathematical theories integrating diverse information about geology, physics, construction techniques, economy, the environment and their interactions have been possible due to the development of numerical methods and computing techniques today. This has led to the development of modern rock mechanics from the traditional empirical art of rock deformability and strength estimation and support design to the rationalism of modern mechanics.

Due to the inherent nature of rock mass containing discontinuity, fractures and inhomogeneity, numerical modelling has become more challenging. Success of numerical modelling for rock mechanics can entirely depend upon the quality of the characterisation of the fracture system geometry, physical behaviour of the individual fractures and their interaction. Today's numerical modelling capability can handle very large scale and complex equation systems, but still there are limitations in the quantitative representation of the physics of fractured rocks.



Kaliapani Chromite Mines, Balasore



IMFA Chromite Mines, Odisha

It is not possible to completely validate numerical models by experiments in rock mechanics due to the assumptions in mathematical models and complexities like fracture in rock mass. However, numerical models can be calibrated against laboratory and in situ experiments and the output of the results used to successfully analyse practical problems. This needs a combined scientific and engineering support is needed for applying numerical methods to rock mechanics and rock engineering.

Status of Rock Reinforcement Systems in India & NIRM Contributions

V. VENKATESWARLU

Director, National Institute of Rock Mechanics

INTRODUCTION

Rock reinforcement techniques have gained acceptance worldwide as the most effective ground support systems in underground civil and mining excavations. Since the eighties, the age-old concept of installing heavy timber supports in mines has been slowly replaced by the simple and more effective method of rock reinforcement. Undoubtedly, rock bolting has now become the predominant support system in the mining industry in India. Though the system is being practised for a number of years in India, only recently has there been a recognition of the need for introduction of faster and mechanized systems in mining engineering projects.

PRINCIPLES OF REINFORCEMENT

Despite its brittleness, rock retains appreciable residual strength even after failure, provided the frictional contact between the fragments is maintained. Therefore, friction and a little constraint can inhibit the relative movement of the close fitting assembly of rock blocks in the fracture zone around an opening. The resulting stress environment causes considerable back pressure in the transitional zone between the fractured and solid rock. Often, this back pressure is sufficient to inhibit the growth of the fracture zone. Taking advantage of this self supporting nature of the rock, rock bolts are designed to help in the reinforcement of rock mass by improving the internal strength and deformation characteristics of the rock mass. Unlike the externally placed inert supports which work by resistance to bending, rock anchors work in tension, as they are placed internally in the rock.

The principal structural advantage of rock bolting is that it applies a positive force to the rock. Wooden props, steel sets and other passive supports, on the other hand, cannot exert full restraining force on the rock until the rock has already moved, with the result that they ultimately have to support a greater weight of the rock than should have been necessary. The practical advantages with rock bolting are that it can be carried out simultaneously with face drilling and other routine work, and it is non-obstructive.

The reinforcement action of the rock bolts is achieved by the interaction of the reinforcing element with the movement of the discontinuities in the rock mass. The four basic functions of rock reinforcement are suspension, beam building, arching and keying.

Rock bolts provide reinforcement action both by axial restraint and by shear resistance. All types of rock reinforcement essentially provide the axial restraint. The shear stiffness and the peak shear capacity of the bolts depend on the cross sectional area and the strength of the bolt.

TYPES OF ROCK BOLTS

The bolts used in India for rock reinforcement in mines can be categorized broadly into four types :

1. Mechanically anchored, tensioned bolts
2. Grouted bolts
3. Cable bolts
4. Friction anchored bolts

In mechanical anchors, the bolt end is anchored to the strata using expansion shell. The second category includes full column grouted bolts. The grouting material can be either cementitious grout or resin grout. Cement grout is commonly used as it is economical and easy to grout longer bolts/cables. Full-column grouted bolts are generally untensioned, but post-tensioning would help to support the immediate strata. The third category is full-column grouted long anchors. The cable bolt may be pre-tensioned and subsequently grouted to full length to provide permanent bond between the rock and the steel bolt. In the fourth category, rock anchors provide frictional resistance throughout the length of the bolt. Split Set and Swellex bolts come under this category. These bolts are normally short (1.5 to 2.5 m) and are used for providing immediate and temporary support.

While the history of rock bolting in India started with introduction of mechanical bolts such as split & wedge-type and expansion shell bolts, they were quickly replaced with grouted type bolts in view of their more efficient performance.

In grouted bolt, there is no stress concentration at any place. The movement at any weak plane will provide immediate shear resistance in the bolt at the vicinity of the weak plane. The principal method of load transfer from the bolt to the rock is through the grout column, and the deformation of the rock mass and the reinforcement cannot be separated. The load is distributed over a limited distance from the rock joint (approximately 5 to 20 times the bolt diameter). Thus, the full-column grouted bolt would provide more resistance to prevent movement at the weak plane. The grout also provides corrosion protection.

Cement-grouted bolts ruled the roost till recently. Quick-setting cement capsules have become popular in the market, with cut-throat competition in price, but unfortunately resulting in deterioration of quality. The need for faster reinforcement action, and mechanized bolting operations, necessitated the adoption of resin grout as an alternative. In view of the high cost of resin, its introduction has been halting. But the stepping in of more players into the resin manufacturing industry, it has now become less expensive and more acceptable.

Cable bolts are widely used in the metal mining industry in India for hangwall support. In the coal mines, their use is limited to junction supports and in wider galleries requiring longer reinforcement.

Friction anchored bolts have found limited application in India. But future deep mining conditions may require the use of different types of dynamic-type rock bolts. These bolts are similar to the fully grouted bolt, but they will slip before the ultimate load bearing capacity of the steel tube is reached.

Steel wire mesh, W-strap and steel channels are some of the accessories frequently used along with rock bolting under difficult ground conditions. Shotcreting in mines has not been popular because of the dust problems and the heavy equipment requirements. On the other hand, cement grouting and chemical foam grouting methods are adopted for cavity filling and for consolidating very poor and soft ground.

DESIGN METHODOLOGIES

The length (L) of the rock bolts is selected using the following thumb rule for different width (B) of galleries :

$L = 0.5 * B$ for weak roofs

and $= 0.33 * B$ for strong roofs

However, for excavations with 18 to 30 m wide spans, the recommended bolt length is 0.25 B, and for excavation heights more than 18 m, it should be 0.2 B. Another thumb rule is that the bolt length should be more than twice the bolt spacing. (Conversely, bolt spacing should not exceed half the bolt length). Based on the above estimates, it is prudent to take the optimum figures for bolt length. It may be noted that bolt length depends more on the excavation dimensions rather than rock mass quality.

The support density is more rationally estimated based on the Rock Mass Rating (RMR) approach developed by CIMFR-ISM and accepted by the DGMS (CMRS, 1987; Paul Committee, 1990). Isolated attempts were made for application of CMRR approach (Molinda & Mark, 2010) and the methodology using Geological Hazard Mapping.

For hard rock conditions, the updated support chart (Fig. 1) developed by Grimstad and Barton (1993) for tunnelling conditions, can be equally used for mining excavations as well. This chart is based on rock mass quality, Q, estimated for the rock mass surrounding the opening, and includes rock bolting and shotcreting also.

The design of reinforcement systems has been more rational in recent years due to the emergence of numerical modelling as a powerful tool for stress analysis. This technique is being used in several projects in combination with empirical classification approaches and systematic strata monitoring.

ANCHORAGE STRENGTH

Except when used to support the dead weight of unstable blocks by suspension action, the load taken by the bolts is small compared with the loads acting in the rock. This is how the rock bolts enable the rock mass to be "self supporting". For this reason, the stiffness of the bolts or the anchorage capacity of the bolts is important to understand the efficacy of the bolting system. The anchorage strength of a grouted bolt is a combination of different factors, such as :

a) rock mass strength,
b) shear strength of the rock-grout interface,
c) shear strength of the grout-steel interface, and
d) strength of the steel bolt head.

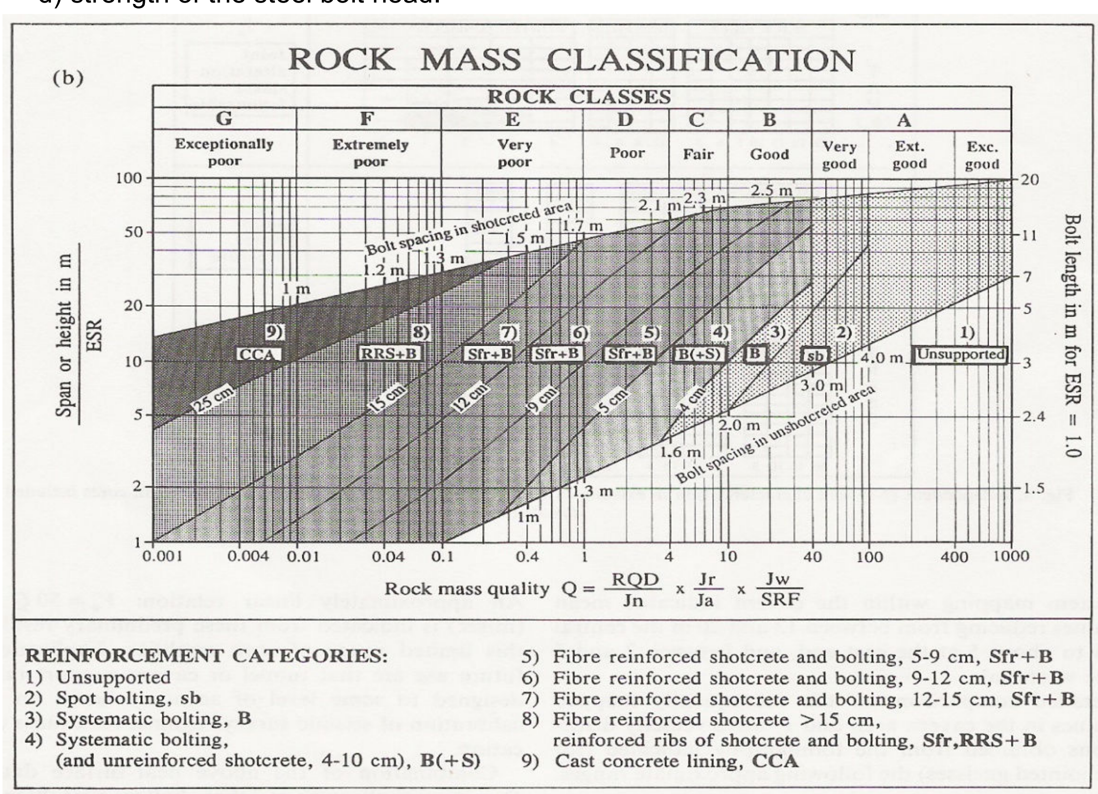


Fig. 1. An updated tunnel and cavern support design chart based on rock mass quality, Q (Grimstad and Barton, 1993)

The pull-out capacity of the anchor (P) is given by the relation : $P = \pi\ d\ l\ \tau$, where d is the anchor diameter, l is its length, and τ is the working bond stress of the anchor-grout or grout-rock interface (whichever is less). The bond strength of the grouted bolts can be established through a systematic testing procedure involving 'short encapsulated' bolts.

The steel-to-grout bond strength is the controlling factor in determining the anchorage strength in cement grouted bolts. Both steel-grout and grout-rock shear strengths could be increased by improving the grout strength. The steel-grout bond strength would be 3.45 MPa at a water-to-cement ratio of 0.45. The rock-to-grout bond strength varies considerably depending on the rock type, even in similar rock types. In massive rocks, the $\tau_{rock\text{-}grout}$ may be taken as 1/10th of the σ_c of the grout. The general range of $\tau_{rock\text{-}grout}$ values is 0.35 to 1.4 MPa.

In case of resin grouted bolts, since both rock-to-grout and grout-to-steel bond strengths are high, it is more convenient to consider the stiffness of the system. A plot of the bolt deformation against the load gives the stiffness of the bond provided by the grout, and it is given as 'load / deformation', estimated in the range of 3 to 7 t. Resin grouted bolts can achieve a minimum bond strength of 10 t (100 kN), and a stiffness of 18 t/mm (180 kN/mm).

The anchorage strength of the friction bolt depends on the frictional resistance between the bolt and the hole wall.

For ensuring reliability of the systems, it is essential to carry out periodic testing of the reinforcement elements and evaluate their performance. The equipment required to carry out anchorage strength test ("pull-out" test) is a 250 to 300 kN capacity hydraulic jack with a central hole and a pull bar attached to the threaded end of the bolt (Fig. 2). The test involves tensioning the bolt system, sometimes till failure. The bolt displacement is also measured. At least 2% of the bolts should be tested till failure to check the minimum anchorage capacity. Bolts longer than 2 m cannot be tested using conventional testing jacks, in which case one has to rely on the bond strength and stiffness tests conducted on short encapsulated bolts.

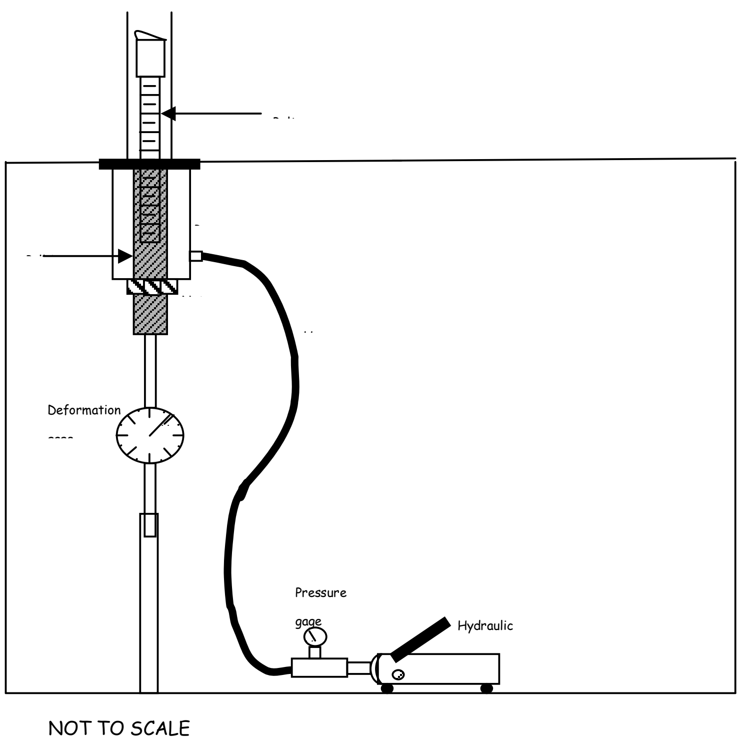


Fig.2. Arrangement for anchorage testing of bolts

Non-destructive testing techniques (such as the use of "boltometer") are preferable, particularly in the case of longer grouted bolts; however, till date these systems are not totally reliable.

Since there is no direct positive testing method available for verifying the integrity of the grouted bolt and for checking the quality of the grout material, it is essential that the grouting operations be carried out under good supervision to ensure grout quality.

IMPORTANCE OF DRILL HOLE DIAMETER AND MECHANIZED DRILLING

Bore hole diameter is critical for most of the rock bolting systems. There is an optimum diameter for each system. In the case of grouted bolts, the grout annulus is very effective in transfer ring the bolt load on to the rock. For full column cement grouted bolts, the hole diameter should be 10 to 12 mm larger than the bolt diameter. The general practice in coal mines in the country has been to use the manual electrical face drills for drilling holes in the roof also. In view of the practical problems like inability to drill vertical holes, slow drilling rate and difficult drilling in hard sandstone, there has been a realization now for going for mechanized drilling – either hydraulic or pneumatic (rotary) drill machines. With mechanized drilling, the hole diameter could be well controlled and proper grouting of the bolts can be ensured.

For resin grouted bolts, the optimum difference in diameters between the hole and the rebar was found to be 6.5 mm (Nitzsche & Haas, 1976). A larger difference would increase the grout consumption, and results in poor mixing of the grout constituents. It was also found by Ulrich and others (1989) that for a 20 mm bar, the optimum annulus thickness is 3 mm for ensuring good resin mix quality and better axial stiffness. The very process of installation of resin grouted bolts implies mechanized bolting operations.

In case of cables, cement grouting is to be done after the cable is inserted in the hole along with the breather tube, and the grout tube attached for about 50 cm at the bottom end. Therefore, the required hole diameter varies from 35 to 105 mm, depending on the cable, breather tube and grout tube diameters. For a 16 mm diameter cable, the hole diameter is 51 to 57 mm. For multi-strand cable tendons, 80 to 102 mm holes are drilled to facilitate cable insertion and grout injection.

For Split Set bolt, the bore hole should have a slightly smaller diameter than the bolt. Bore hole diameter is of critical importance, and incorrect hole diameter would cause failure of the system. If the hole diameter is too small, it is difficult to install the bolt; and if the hole is too large, there will not be sufficient holding force. Hole diameter is not of much significance in case of the Swellex bolt. These bolts have to be installed invariably using the machines supplied along with the bolts.

APPLICATION OF ROCK BOLTING IN INDIAN MINES & ROLE OF NIRM

The pioneer of rock bolting application in Indian mines was Dr NM Raju from Central Mining Research Station (CMRS), Dhanbad. He educated the mining industry on the benefits of replacing the conventional wooden and steel supports with roof bolting systems, by holding a number of Workshops all over the mining areas. The credit for developing the design methodology for selection of the bolting system should go to Prof AK Ghose of Indian School of Mines (ISM), Dhanbad. He developed, in collaboration with CMRS, the CMRS-ISM Rock Mass Rating (RMR) system for assessing the roof conditions in coal mines in India, and suggested guidelines for bolt design based on it.

The role of Directorate General of Mines Safety (DGMS) in popularizing the rock bolting system in Indian mines has been commendable. They have brought out Circulars standardizing the bolting material as well as the grout material, and have updated them from time to time by conducting periodic Workshops in collaboration with the user industries and the manufacturing companies (DGMS, 2010).

Since its inception, NIRM has been involved in (i) rock mass characterization, and estimation of rock loads, (ii) estimation of support requirement, and design of supports, (iii) design of rock re-inforcement and shotcrete systems. The Institute has established itself as an expert authority in these areas.

NIRM has introduced roof bolting system in a number of coal and metal mines. It helped in the application of fast bolting technology in WCL mines by introducing pneumatic roof bolters at Tandsi mine (Fig. 3). The Scientists carried out extensive monitoring, and evaluated the support behaviour; and thus established the resin bolting systems there for the first time in the country. They also designed the support system for workings below 240 m depth at Tandsi mine based on instrumentation to confirm the efficacy of the system. The system has now been extended to several other mines in WCL and SCCL.

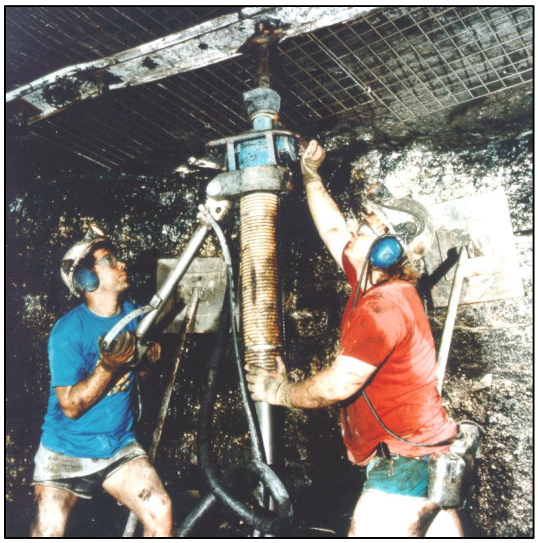


Fig. 3. Mechanized roof bolting system in practice at Tandsi mine, WCL

NIRM made a conceptual design of a self-propelled, mobile hydraulic roof bolting equipment under an S&T scheme, and developed a proto-type for this (Fig. 4). One manufacturing company has developed an equipment on commercial basis using the mobile system concept. In addition, NIRM also developed a road header-mounted and an SDL-mounted equipment for use in mechanized drivages. NIRM Scientists tried for introduction of smaller diameter drill rods and bits. NIRM has been advocating the use of mechanized roof bolting systems in all coal mines.

NIRM introduced the cable bolting system for adverse ground conditions in the development galleries of SCCL mines, and as a replacement for square-sets in MOIL mines. An S&T project, funded by the Ministry of Coal, was successfully executed for introduction of cable bolting in coal mines. As part of this, an innovative, simple clamp arrangement was developed for installation of the cables grouted with cement capsules (Fig. 5).

This system has helped in dispensing with the cumbersome cement grouting procedure for upward holes, and helped in faster installation of cables using the drill machine for their insertion. Later this system was extended to the longwall gate gate roads in SCCL.

NIRM Scientists have been trying for application of shotcrete technique in mines. An S&T project was taken up and executed for introduction of shotcrete systems in mines, and another S&T project for popularizing the fiber reinforced shotcrete system in tunnels and large caverns. For testing the bond strength of the rock-shotcrete interface, NIRM developed a special mechanism (Fig. 6), which is simpler and more reliable as compared to those existing elsewhere. Successful trials with this were carried out in NJPC desilting chambers and in the cross-cuts of Rajpura-Dariba mine as part of the two S&T projects.

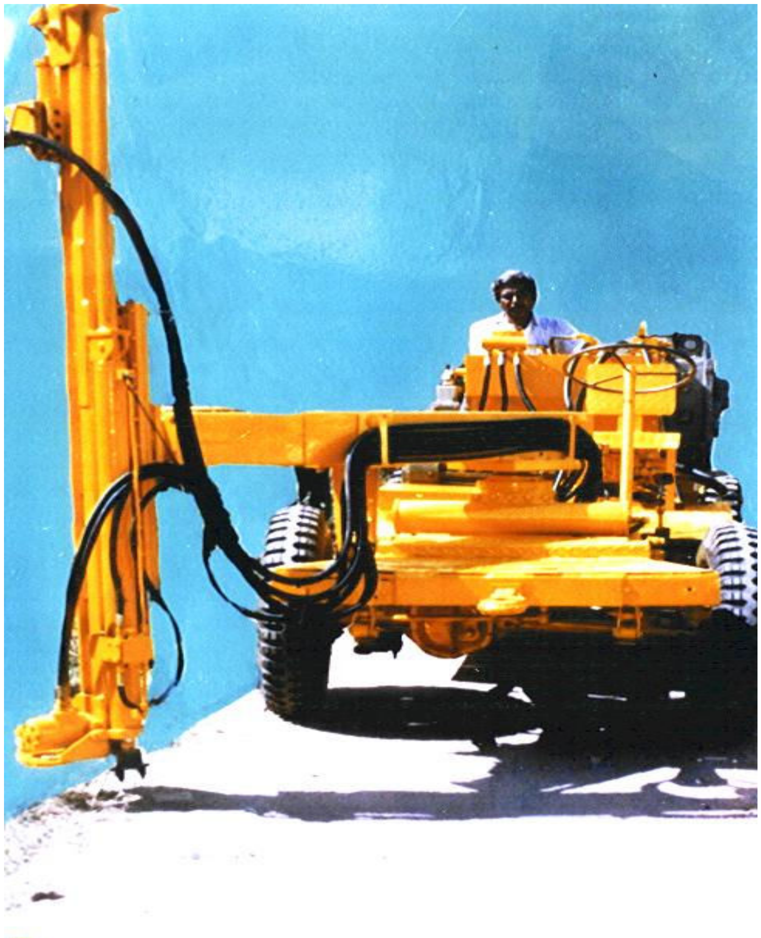


Fig. 4. Prototype of chassis mounted, mobile roof bolting equipment

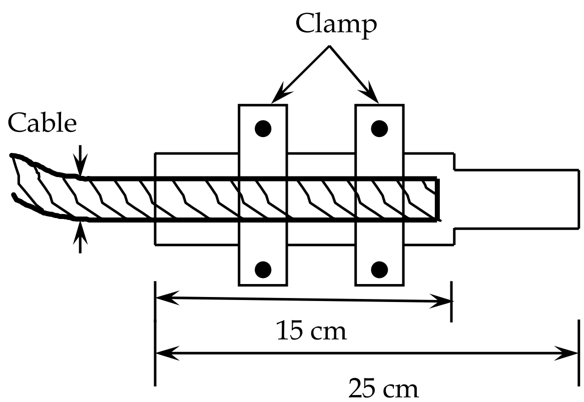


Fig. 5. Clamping arrangement developed for cable bolt installation

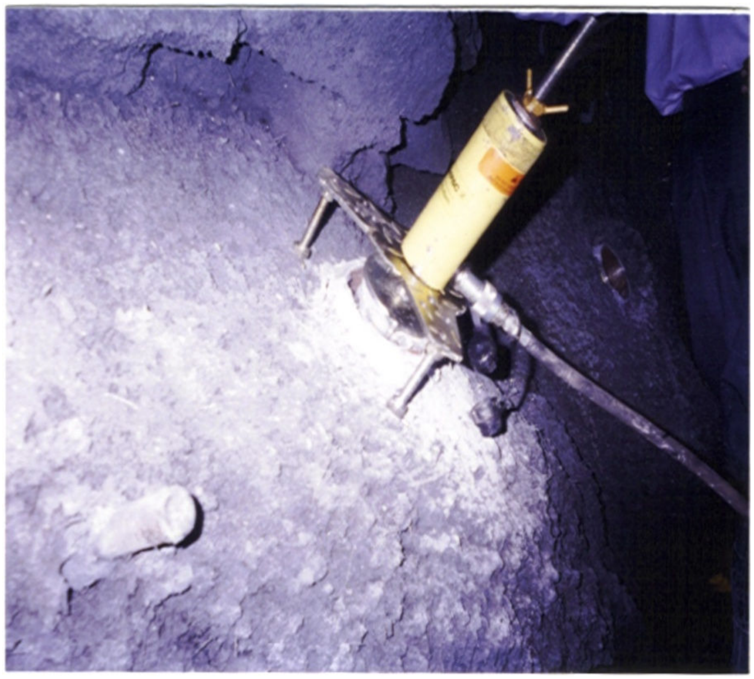


Fig.6. Shotcrete bond strength testing equipment developed by NIRM

Following are some of the mining, hydel and other project sites where NIRM carried out comprehensive studies involving rock mass characterization, support design and strata monitoring to establish the efficacy of rock reinforcement systems during the last 25 years :

- ✓ application of fast bolting technology at Tandsi project, using pneumatic roof bolters
- ✓ for the difficult roof conditions at Tandsi project, based on in-situ stress values
- ✓ the sandstone drifts in Chasnalla colliery, IISCo, dispensing with the expensive steel arches
- ✓ 17 Special seam Jankowice longwall workings at Chasnalla colliery, IISCo, thus introducing roof bolting in a working longwall face
- ✓ ten mines covering different coal seams in SCCL
- ✓ under High Flood Level at Indaram Khani 1A incline, SCCL
- ✓ optimization of bolting parameters in three SCCL mines, based on strata monitoring
- ✓ longwall gate roads at JK-5 Incline, Yellandu Area, SCCL, for developing two longwall panels under a thin parting below already worked out longwall goafs
- ✓ extraction of Bottom seam below thin parting of King seam Bottom Section goaf at PVK-5 Incline, Kothagudem Area, SCCL
- ✓ 62 LN gate road of 1 seam at Vakeelpally block A, GDK-9 Incline, RG-2 Area, SCCL, whose progress was otherwise dismal
- ✓ design of support pattern for development workings at at Chennur mines, Srirampur Area, SCCL
- ✓ support design for development workings in all the seams at KTK inclines, and for the gateroads in KTK longwall, of Bhupalpalli Area, SCCL
- ✓ longwall gate roads in 1 seam of GDK-10A Incline, RG-2 Area, SCCL
- ✓ design of improved support systems for the 4.2 m wide galleries at Savner Mine no. 2, Nagpur Area, WCL
- ✓ improvement of support system for the heavy watery seam no. 7 at Murpar mine, Umrer Area, WCL
- ✓ Rajur & Eklehra collieries, WCL
- ✓ the devolatilized coal seams of Kanhan area, WCL
- ✓ the shale roof of Chincholi mine, Ballarpur Area, WCL

- ✓ Ballarpur mine no. 1, Ballarpur Area, WCL
- ✓ Nandgaon incline, Chandrapur Area, WCL
- ✓ design of support system at DRC-6,7&8 inclines, Chandrapur Area, WCL
- ✓ Ingaldhal copper mine, HGML
- ✓ different reefs of Hutti gold mine, HGML, at different depths
- ✓ Saladipura phosphorite mine, PPCL
- ✓ Sargipalli lead-zinc mine, HZL
- ✓ Zawarmala mine, HZL
- ✓ Khetri mine, HCL
- ✓ Balaghat, Chikla, Kandri and Gumgaon mines, MOIL
- ✓ Boula chromite mine, FACOR
- ✓ Bangur chromite mine, OMC
- ✓ different reefs of Hutti gold mine, HGML, to take care of slabbing type failure in the stope backs, introducing bolting in the mine
- ✓ Balaghat mine, MOIL, introducing cable bolting for support of the weak hangwall formations, dispensing with square set stoping
- ✓ support for lining for the vertical shaft at Mahagiri chromite mine of IMFA, Orissa
- ✓ the exploratory adits of Gandamardhan iron ore project, MECL
- ✓ fire affected areas in Kadamparai hydel project
- ✓ support design for the Gandikota Tunnel of the GNSS Flood Flow Canal Works, Kadapa District, AP
- ✓ Bogada & Chelama railway tunnels of IRCON, near Nandyala, AP

THE FUTURE TRENDS IN ROCK REINFORCEMENT

As the depth of mining increases, the mine openings will be subjected to high stresses, and there is a possibility of the problem of mining induced seismicity and dynamic rock failures in Indian coal mines also. Under these conditions, there is a need to managing the damage by appropriate energy absorbing (“yielding”) support systems. Li (2010), Raju et al. (2011) and Li and Doucet (2012) described a number of yielding type bolts, and their performance details. Conventional rock bolts such as encapsulated rebar (grouted bolts) and Split Set (friction bolts) absorb little energy because of their small deformation capacity or small load bearing capacity. The most common yielding type rock bolts used in high stress conditions in Canada and South Africa are Cone bolt, the D-Bolt, Yield-Lok, Durabar, Garford dynamic bolt, hydrabolt, and the dynamic bolt developed by Dywidag Systems International (DSI), called dynatork.

The yielding rock bolts accommodate rock dilation and absorb energies via either ploughing of the anchor in the grout (cone bolt and Yield- Lok) or slippage of the bolt shank through the anchor/grout (Garford bolt, and Durabar). A common factor among them is that they are all two-point anchored in boreholes.

Self-drilling / self-anchoring bolts, hollow injection bolts and chemical injection method to reinforce or consolidate the rock mass may find application only in special circumstances. These systems are yet to be tried in India.

With various types of reinforcement techniques available in the country, rock reinforcement practices in India are technologically at par with other countries. By making improvements in some of the systems, giving wider publicity and by introducing more mechanized equipment, rock bolting can be made a more effective system of support in all underground mines.

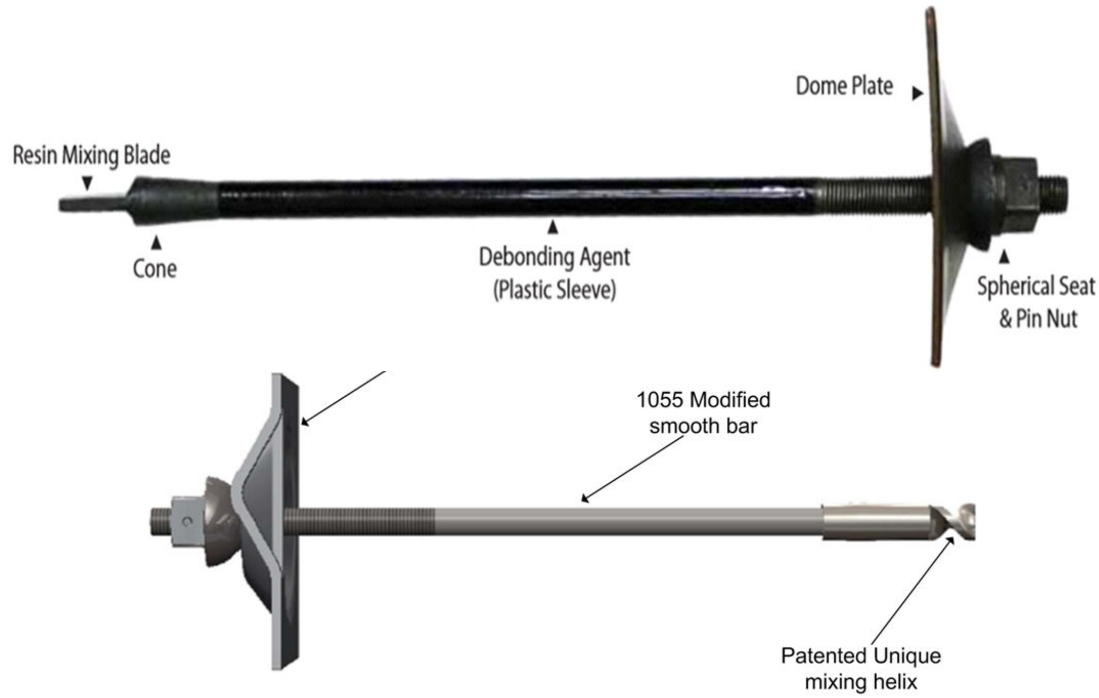


Fig. 7. Cone bolt (top) and dynatork (bottom) yielding-type bolts

References

Barton, N.R., Lien, R., and Lunde J. (1974) Engineering classification of rock masses for the design of tunnel support. Rock Mechanics - 6 (4), 189-239.

Barton, N.R. and Grimstad, E. 1994. The Q-system following twenty years of application in NMT support selection. Felsbau - 12 (6), 428-436.

CMRS (1986) Geomechanical Classification of Coal Measures Roof Rocks vis-à-vis Roof Supports, Coal S&T Project Report GAP-V-3-1981, Central Mining Research Station, Dhanbad (68 pp).

DGMS (2010) DGMS Technical Circular (Approval) No. 3 dated 3-6-2010, No. 4 dated 15-6-2010, and No. 5 dated 27-12-2010.

Raju, D., Hani Mitri and Denis Thibodeau (2011) Mine safety enhancement by designing dynamic rock supports. Procedia Engineering, vol. 26, pp 1591-1602.

Grimstad, E. and Barton, N.R. (1993) Updating of the Q-system for NMT. Proc. Int. Symp. Sprayed Concrete, Fagernes, Norway, (Eds. Kompen, Opsah & Berg), Norwegian Concrete Association, 46-66.

Greg Molinda and Christopher Mark (2010) Ground failures in coal mines with weak roof, The Electronic Journal of Geotechnical Engineering (EJGE), Vol.15, 2010, pp 547-588.

Li, C.C. (2010) A new energy-absorbing bolt for rock support in high stress rock masses. Intl J Rock Mechanics & Mining Sciences, vol. 47, pp 396–404.

Li, C,C, and Doucet (20120 Performance of D-Bolts under dynamic loading, Rock Mechanics & Rock Engineering, vol. 45, pp 193–204.

NIRM (1993) State-of-the-Art on Rock Reinforcement Practices in Hydro-Electric Projects in India. S&T Project Report no. NIRM/GM-93-02, Ministry of Water Resources, GoI, New Delhi.

Paul Committee (1990) Report of the Expert Group on Guidelines for Drawing up Support Plans in Bord & Pillar Workings in Coal Mines. Directorate General of Mines Safety, Dhanbad.

Rock Mechanics Field Instrumentation, and Ground Stability Evaluation Studies by NIRM

V. VENKATESWARLU

Director, National Institute of Rock Mechanics

INTRODUCTION

Underground excavations in rock are designed using different numerical and empirical methods. The design is optimized and stability of the openings evaluated based on rock mechanics instrumentation data. Monitoring of the strata behaviour through extensive instrumentation, provides vital information on ground movement and stress build up in the surrounding rock, and thus enables to check the validity of the design. Strata monitoring in general is essential for generation of data about the rock mass behaviour for a proper understanding of the rock mass. Monitoring also allows for extrapolation of the results for a long term assessment of the rock mass behaviour. Thus, it is an integral part of the observational method of design of excavations in rock.

Rock in-situ is in its naturally stable state, except for the stresses and strains already inherited and stored in it by virtue of its geological and tectonic history. However, when an excavation is made in the rock, its natural state is disturbed, and it tries to move towards the free space available, and thus undergoes deformations. When the deformations are restricted, stresses get built up. The deformations can also take place due to the relaxation of the rock, and time dependent deformation of the rock.

IMPORTANCE OF INSTRUMENTATION AND MONITORING

Mining and hydel projects are very expensive and involve high risks. In the absence of a knowledge about the rock mass behaviour, the excavation design would necessarily be conservative. An understanding of the rock stresses and deformations can result in potentially large cost savings in future construction. Thus instrumentation can effectively help in design verification. With reliable instrumentation programme, one can work with a safety factor near unity. Under such conditions, monitoring would provide warning of potential problems for advance action.

Strata monitoring is required

a) to know whether the excavation would be stable or not,
b) to understand its long term behaviour,
c) to design the required support system, and
d) to take additional measures with respect to its design for the excavation to serve its designated purpose.

Prediction of strata behaviour by theoretical analysis become unreliable due to almost impossibility of simulation of the real field conditions in mathematical, physical or numerical models. Thus actual in-situ measurement of strata behaviour parameters is the only way to understand the stability of the excavations.

Physical observations are a great aid to monitor the strata behaviour, but the observations tend to be descriptive, and subjective with respect to the person observing, and so cannot be used for any quantitative applications.

Therefore, to get quantitative measurements, instruments are used with proper calibration. Realizing the importance of monitoring the stresses and deformations, instrumentation work has been taken up in recent years at several rock excavation projects, such as mines, tunnels and large caverns. However, in view of the cost and time involved, the extent of instrumentation work has been limited to some important and critical sites only. Monitoring is resorted to only at the insistence of statutory bodies like the Directorate General of Mines Safety and Central Water Commission.

Quantum of Instrumentation

It is often asked as to how much instrumentation is actually required to monitor the different strata parameters, and how long do they work. Questions are also raised about the reliability of the instrumentation results.

The number and type of instruments to be used depends on the output expected from the instrumentation work, based on the results of numerical modeling or other design methods, and past experience under similar conditions. The selection of instruments should be done prudently so as to obtain maximum data with minimum instrumentation. Cost of the instruments, cost of installation (including drilling costs, cabling, etc.) and reliability of the results vis-à-vis the criticality of the structure, have to be kept in mind while deciding the quantum of instrumentation.

The number and type of instruments to be used depends on the output expected from the instrumentation work, based on the results of numerical modeling or other design methods, and past experience under similar conditions. The selection of instruments should be done prudently so as to obtain maximum data with minimum instrumentation. Cost of the instruments, cost of installation (including drilling costs, cabling, etc.) and reliability of the results vis-à-vis the criticality of the structure, have to be kept in mind while deciding the quantum of instrumentation.

Conventionally, for routine monitoring in development galleries in mines, the minimum instrumentation programme may consist of :

a) roof-to-floor convergence stations at the junctions,
b) extensometer points anchored up to the main roof, and
c) stress cells in at least on pillar out of three pillars being extracted.

In depillaring panels, the area close to the goaf should be monitored using convergence points as well as load cells. Ribs may be monitored using stress cells.

It is suggested that wherever faults having a throw of less than 3 m are encountered, they should be negotiated with adequate precautions in the galleries and the pillars should also be extracted through systematic and additional supports in the splits, and slices.

Analysis of the recorded data by NIRM indicated that, it was sufficient to monitor the galleries, splits and original junctions up to 30 m in advance of the goaf line, or within the area of the pillar under extraction. The influence beyond this zone was not significant.

INSTRUMENT SPECIFICATIONS

For selecting the required instruments, we need to identify the appropriate specifications. The specifications of the instruments depend on the on the quantity to be measured. Irrespective of the parameter to be measured, for every instrument we should define the ‘range’ of values to be measured and to what ‘accuracy’ and ‘precision’.

Sensitivity is the ratio of change in instrument output to change in measured value. **Resolution** is the smallest change that can be displayed on a read-out unit; it is the “least count”; typically it should not be greater than 0.1% of the full scale range of the instrument; it decreases (that is the numerical value of resolution increases) as the range increases. **Precision**, or **repeatability**, represents how close a set of repeated readings can approach a mean reading; "reproducibility", "consistency"; it is expressed as +/- some value. **Accuracy** is the degree to which the measured readings match the true value; it too is given as +/- % of range; it should not be more than +/- 0.5%.

The main requirements for instruments for use in strata monitoring are that they should be :

a) simple to work,
b) easy to install
c) reliable, and
d) rugged.

Further,

1) The instruments should be simple to repair in case of any malfunctioning.
2) There should be provision for checking the calibration of the instrument.
3) Additional protection may be required in case of sensitive instruments and those installed in hostile environment.

Regional monitoring can be carried out through micro-seismic or acoustic emission techniques, by measuring the elastic/sonic wave velocities through the strata, and determining the variations in their character. The present study is restricted to small scale monitoring. A brief description of the instruments used in rock mechanics field investigations, and the utilization of these results for evaluating ground stability are discussed.

The field instrumentation may be broadly categorized as follows :

a) strata monitoring -- (i) ground movement
(ii) stress changes
(iii) groundwater

b) support monitoring -- (i) support deformation
(ii) load on supports

Three essential features of instrumentation are : a) proper layout - location of instruments, type and number are determined in advance according to the requirements of the project; b) accuracy - a good instrumentation programme should have reliable instruments with the required accuracy; c) recording - frequency and duration of the monitoring scheme should be strictly followed as decided during layout stage. Two things to be noted about the instruments are : i) **resolution** or **sensitivity** of the instrument is the least count (the smallest value it can measure and we can read from the unit), which should not be greater than 0.1 percent of the full scale (range) of the instrument; and ii) **accuracy** or **repeatability** is the range within which the instrument can reproduce the readings taken in succession at a particular time, and is expressed in terms of +/- percent of the full scale reading (it should not be more than +/- 0.5%).

TYPES OF INSTRUMENTS

A - MONITORING GROUND MOVEMENT

Excavation of large underground openings such as power house caverns, results in movement of the roof and wall rocks. Ground movement monitoring will provide useful information to evaluate the stability of these openings. Depending on the distance between the two measuring points and the accuracy required, closure meters or extensometers are used. Closuremeters measure the distance between two fixed points on the opposite sides of any opening. Borehole extensometers are used to measure the movement of the exposed rock surface or the rock mass in the immediate vicinity of the opening with respect to more stable rock mass.

Closuremeters

Telescopic closuremeter, or convergence indicator, is a very simple instrument consisting of a graduated rod (with a least count of 0.5 to 1 mm) fitted in a pipe for telescopic movement over a length of 2 to 4 m. The measuring points ("reference stations") are metal rods grouted in the rock at the desired locations. Measurements are taken by simply stretching the telescopic rod between the reference points, and reading the graduations on the rod. To measure closure at inaccessible locations, electrical closuremeter can be used. In this instrument, a rheostat is fixed to the telescopic portion of the rod, and a pointer is attached to the pipe in which the telescopic rod moves over a high tension spring. The whole instrument is permanently fixed between the reference points. Measurements are taken by connecting the wires from the rheostat and the pointer to a ohmmeter, and reading out the variation in the resistance of the circuit. These instruments could be used where the distance between the two measuring points is within 4 m, such as in tunnels. However, if the distance between the two measuring points is large and more accuracy is required, tape extensometer is used.

Tape extensometers can be used to measure closure between points upto 30 m apart, with an accuracy of 0.05 to 0.2 mm. The tape extensometer is made of precision stainless steel measuring tape, with equally spaced (at 5 cm intervals) punched holes. For taking the readings, the free end of the steel tape is hooked to the remote reference point, and the instrument is hooked to the nearest point. The steel tape is pulled taut, and the instrument is fixed at one of the perforations on the tape. The main body incorporates a tape tensioning device coupled to a sliding scale and dial gauge arrangement. The micrometer drum on the instrument is rotated to provide a fixed amount of tension to the tape. The dial gauge reading after tensioning plus the visible pin hole position on the tape at the instrument nose, is the reading for the site.

It has been observed at several sites that a sharp increase in the rate of closure has resulted in subsequent ground failure. The absolute values depend on the rock type and the type of excavation.

Borehole extensometers

For monitoring the extent of movement inside the wall rocks (or in the pillars), borehole extensometers of various types are in use. The simplest and economical type is single or double point mechanical extensometer consisting of anchors, rods and a head piece (reference point). The anchors are fixed inside the borehole at desired depths using expansion shells or by grouting. Grouted type anchors are used to prevent the anchors from slipping due to disturbance from blast vibrations. The position of the free ends of the rods extending from each of the anchors is monitored with respect to a reference point. These instruments could be used to monitor the stability of the formations as well as to determine the effectiveness of the supports. In case of bolted roof, anchors could be installed in the roof, one within the bolted horizon and the second beyond the bolted horizon, to determine the efficacy of the bolting. Rod type extensometers can also be fully grouted (including the rod portion) with thin cement mixture, as the rods can still move within the cement medium while the anchors remain where they are fixed.

For monitoring the movement at greater depths, multi-point borehole extensometers are used. These can be fixed easily up to 30 m depth. Multi-point extensometers are of various types including wire type and magnetic type. The magnetic extensometers are used where a number of stations are to be fixed at close intervals within the borehole; however, the accuracy of this system is less compared to the other two instruments. The wire type extensometers are much economical.

In the wire-type multi-point extensometer, expansion shells are used as anchors. A stainless steel wire of 1 to 2 mm diameter is attached to the anchor. The free end of the steel wire is passed through a button and screw arrangement. The "collar station" is a steel pipe provided with two screws or a male threading to facilitate the attachment of a portable readout unit. The steel wires from the individual anchors pass through the collar station and hang freely out of the borehole. The readout unit consists of a micrometer head and a dial gauge that serve both as tensioning and measuring devices; accuracy of the instrument is 0.01 mm (Fig. 2). The displacement of the rock mass is regularly monitored by measuring the movement of the collar station with respect to each individual anchor.

For taking measurements in areas which are not safe, remote indicating instruments are used.

B - Rock Stress Monitoring

The measurement of in-situ rock stress is essential for any excavation design. In-situ stress can be measured by various techniques, such as hydro-fracturing technique and over coring techniques using CSIRO cell and USBM borehole deformation gauge. (Details of these measurements are out of the purview of the present lecture).

Stressmeters, particularly vibrating wire type, are widely used to monitor the stress changes in rock. They indicate the increase of stress in the pillars as the excavation continues. If there is a sudden increase in the stress, or a gradual increase exceeding the strength of the rock mass, it may result in failure of the rock in that region. Therefore, stressmeter observations provide valuable information to predict the stability of the openings. Generally, vibrating-wire type instruments are more reliable for long term monitoring than strain-gauge based instruments.

The basic principle of the vibrating-wire transducer is that the change in natural frequency of a stretched wire depends on the change of the tension in the wire. In the vibrating wire stressmeter, the gauge wire (piano wire) is stretched diametrically across the walls of a hollow steel cylinder. The stressmeter capsule (about 40 mm in length and 38 mm diameter) is tightly fixed into the borehole by means of a sliding wedge and platen assembly. In softer formations, wide platens are used to lower the contact stresses on the borehole wall. Stress changes in the surrounding rock cause small changes in the diameter of the cylinder, which are measured as changes in the natural frequency of vibration of the steel wire. Time for one cycle of vibration has been related to the magnitude of stress change for a range of rock types. The stress meter is unidirectional.

C - Load on Supports

While using the conventional steel supports, the load coming on the steel supports could be monitored using load cells. The load measurements are useful in evaluating the effectiveness of the support systems. The load cells are mechanical, hydraulic or electrical. Of these, electrical load cells give precise readings. These could be strain-gauge or vibrating wire type. In strain-gauge load cells, electrical resistance strain gauges are bonded to the periphery of a spool of high strength heat treated steel or aluminium cell. The gauges are mounted in a full bridge configuration that compensates for unevenly distributed loads. They can be remotely read.

Rock bolt load cells are used to measure the variation in bolt load. In case of full-column grouted bolts strain gauges are fixed on the bolt at different intervals (instrumented bolt, or "Irad bolt") so that the stress transfer from the ground to the bolt at different horizons could be monitored.

Rock bolt pull out test is commonly used to evaluate the bolt anchorage strength. In recent years, a boltometer has been developed for evaluating the bonding between the grout and the rock bolt. This instruments uses the principle of diffusion of compression and flexural waves in uniform medium, and wherever flaws are encountered, the waves are reflected back. But there are some practical difficulties in using this system for regular monitoring of the rock bolts.

Shotcrete stress cells are used to monitor the radial and tangential stresses developing within the shotcrete. The instrument consists of two rectangular steel plates welded together at the periphery in the form of a flat jack. The flat jack is filled with a hydraulic fluid (mercury, in the case of those used by NIRM), and a re-pressurizing tube is also connected to the cell. The cell is connected to a vibrating-wire pressure transducer. The changes in the stress on the cell results in variations of frequency in the vibrating wire sensor. This frequency is recorded by a digital read-out unit connected to the sensor through a cable, and is converted into stress using calibration charts.

D - Monitoring of Groundwater Pressure

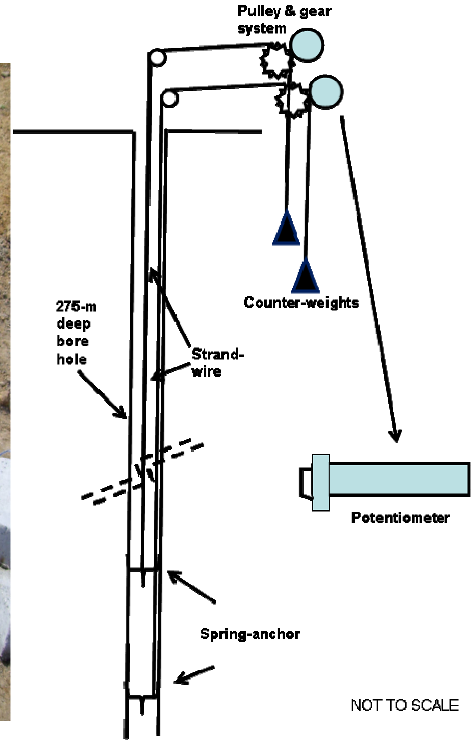
Excessive water seepage or abnormal water pressure build-up within the strata could adversely affect the stability of excavations in rock. Piezometers (pneumatic or electrical) are used to monitor the groundwater pressures. For remote reading, electronic piezometers are available particularly for underground applications, which can be used in either horizontal or upward holes. In the case of vibrating wire systems, fluid pressure applied to the membrane causes deflection of the membrane with consequent change in the tension of the wire and its resonant frequency. Thus the frequency of the gauge wire is a measure of the deflection of the membrane which is proportional to the pressure change. Pneumatic piezometers have the advantage of distant monitoring (up to 500 m away), and an accuracy of 0.2 m head of water. But they are not suitable for long term measurement of negative water pressure.

INSTRUMENTATION & MONITORING STUDIES BY NIRM

NIRM carried out strata and support monitoring in a number of mining, civil engineering and infrastructure excavations by installing various types of instruments, and monitoring the rock mass and excavation behavior with time and with progress of the excavation/construction. Following is a list of some of the projects undertaken by NIRM :

- Srisailam Left Bank Hydro-Electric Scheme, APSEB
- PH & TC at Nathpa Jhakri Power Corporation, HP
- Underground power house excavation at Pykara Hydro-Electric Project, TNEB
- All the excavation components at Larji Hydro-Electric Project, HPSEB
- Twin tunnels of the Pune-Mumbai Expressway
- A number of depillaring districts in different seams / different mines in SCCL
- Strata control investigations in a number of longwall panels in SCCL
- Roof deformation investigations at Tandsi mine, WCL
- Instrumentation monitoring in a number of widestall panels in WCL
- Investigations in continuous miner panels at VK-7 incline, SCCL
- The open stopes at Hutti gold mine, HGML
- The Blasting Gallery panels in SCCL
- The Sub-Barrier Pillar in BG-3 Panel at GDK-8 Incline, RG-2 Area, SCCL
- While extracting under Janagaon Tank at GDK-3 Incline, RG-1 Area, SCCL
- A number of stowing panels below surface structures in SCCL and WCL
- The Open Stopes at HGML
- Instrumentation and data analysis of underground powerhouse complex, surge shaft, HRT and desilting chambers of Tala Hydro Electric Project, Bhutan
- Optical deformation monitoring of underground powerhouse cavern of Sardar Sarovar Project, Gujarat
- Optical deformation monitoring of desilting chambers of NJHEP of SJVN.

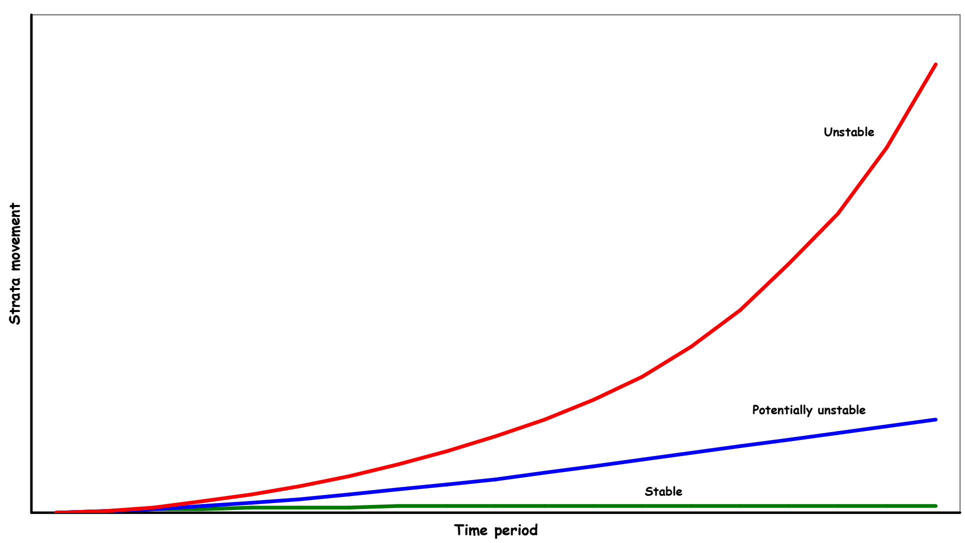
As part of the investigations, and for specific needs of instrumentation, NIRM Scientists designed their own instruments, such as the tailor-made tape extensometers and the micro-meter read-out unit for the wire-type extenometer. NIRM also designed a deep hole multi-point borehole extensometer, and installed it for the first time in India from the surface to a depth of about 250 m over a working longwall panel at GDK-10A incline of SCCL. This is an innovative technique, and the only approach for monitoring the caveability of the roof strata due to longwall mining.



BROAD CONCLUSIONS BASED ON STRATA MONITORING RESULTS

Based on long term roof convergence and the rat of movements, the following classification can be made for the stability of the excavations :

a) "**Stable**" – there is no significant increase in movement, and the rate of increase in movement is less than 0.1 mm per day
b) "**Potentially unstable**" or "**Short-term stability**" – the rate of increase of movement is constant
c) "**Unstable**" – when the movements accelerate within a short period



Degrees of stability of an excavation based on rock deformation

However, in massive or brittle rock formations, failure can take place suddenly without any indication of deformations or stress buildup.

One of the main objectives of the strata and support monitoring in rock excavations is to understand the safe, allowable limits of deformation and stresses, and to derive any advance warning limits with respect to the parameters being measured.

Development Galleries

Based on extensometer readings, the strains for each meter height in the roof are estimated based on the deformations measured between the consecutive horizons. A strain of 10 mm/m is generally considered as the limiting value before failure can take place at that particular horizon.

For a bolted roof, a total roof movement of less than 10 mm in junctions is considered safe. However, when the movements exceed 20 mm, normal bolting alone may not be sufficient to hold the roof.

Depillaring Panels

In depillaring areas in coal mines, irrespective of the type of support system used, deformations at the goaf edge will be up to 20 mm (rate of convergence more than 5 mm/day), and the load on the goaf edge supports will be recorded in excess of 5 t (rate of increase may be 2 t/day). The supports installed will only prevent the breaking up and falling down of the immediate roof strata within the working places.

In the extraction areas, the rock bolts installed do not hinder the caving process in the goaf, but at the most only delay the caving.

The following Convergence Indices were derived earlier by CMRI for panels developed on bord & pillar method :

Index-I, I_1 = r
Index-II, I_2 = r/r'
Index-III, I_3 = $(R - R') / (R' - R_O) * (N-4 / 4)$

where, r = rate of convergence, mm/day
r' = average daily convergence up to previous day, mm
R = reading after lapse of 4 days after initial initiation of movement,
R' = reading on the 4th day,
RO = initial reading prior to initiation of movement,
N = total number of days of observation after initial movement.

The available norm of $I_1 > 2$ mm/day as warning of roof falls is not applicable in most of the conditions. However, adverse conditions may occur if r > 2 mm/day with 90% probability. For the Index-II, a norm of $I_2 > 20$ may be followed, which may indicate 80% of the roof falls. For the index I_3, the norm of $I_3 > 10$ may be adopted to indicate the adverse roof conditions, which may indicate 80% of the roof falls.

Strain limit for sandstone formation was about 10 mm/m (CMRI, 1987).

It is not possible to fix any specific limits for convergence and load prior to a fall, however, based on the data recorded in a single panel. The roof falls in the goaf may take place when the cumulative convergence exceeds 8 mm, and the total load over the supports near the goaf edge exceeds 6 t. However these limits may not be applicable to the next panel.

Blasting Gallery Panels

Based on NIRM experience in strata monitoring in Blasting Gallery panels (panel no. 1 at VK-7 incline, panel no. 1A of Block C at GDK-10 incline and panel no. II/1 at GDK-8 incline, SCCL), the following early warning limits for the impending roof falls in the goaf are suggested :

Limits for strata monitoring parameters in BG panels

1	Roof to floor convergence	5 mm/day within 5 m from the goaf edge
2	Bed separation	maximum 10 mm between the main roof, and the immediate roof layers
3	Stress developed in pillars	5 kg/cm^2 per day
4	Load over the roof bolts/props	2 t/day within 5 m from the goaf edge

However, advance fore-warning of the impending roof falls is not possible based only on the above, as the strata conditions differ from mine to mine. The above values may be taken only as indicative, and the exact limits would have to be established based on further monitoring within this panel. By collating a large amount of data from more number of extraction panels, and analysis of the parameters involved, it may be possible for prediction of any impending roof fall. However, all abnormally high values of deformations and loads/stresses should be analyzed for their potential as indicators for fall.

Longwall Gate Roads

Under bolted roof in longwall gate roads, the normally observed convergence rates are 0.8 to 2 mm per day. However, rates of the order of 4 to 8 mm per day are considered high, and additional support measures should be provided in such areas. During the consolidation stage (about 50 to 100 days after extraction), the convergence rates may be 0.1 to 0.4 mm/day.

The maximum convergence recorded under competent strata conditions supported by roof bolting was 60 to 65 mm within 30 m from the face. Comparatively higher values of convergence are normally observed in the Bottom (Main) gate road than in the Top (Tail) gate road.

From the analysis of convergence data from a number of bord and pillar caving panels, it is concluded that the rate of roof movement (convergence per day) is a better indicator of the likely fall in the goaf, rather than the other indices (like C_1/C_2 ratio) which are based on convergence over a variable time scale.

SUGGESTIONS FOR FUTURE STUDIES

Geological and discontinuity mapping of the project site should form an integral part of the strata monitoring. The location and type of instruments should be selected based on the geological and geotechnical features present in the area.

Continuous monitoring of strata behaviour in terms of convergence of openings in advance on either side of the extraction line, and stress levels over pillars, stooks in advance of the extraction and ribs in the goaf was required through remote monitoring instruments for understanding the strata mechanics at critical conditions of roof falls. Continuous monitoring of support pressures has to be attempted to investigate the rock mass response to mechanised pillar extraction (Follington and Huchinson, 1993).

Integrated Seismic System (ISS) was introduced by NIRM for an experimental trial at Rajendra mine, SECL, for prediction of strata movement during coal extraction by longwall mining (NIRM, 1998, 1999, 2000). The system developed by South Africa works on the principle of monitoring microseismic activities through geophones. The concept of tele-monitoring or online monitoring is also well established now, and it can improve the safety aspects in underground coal mining. The use of Borehole TV Camera for caveability studies is the need of the hour for detailed analysis of strata behaviour during mining. Integrated Seismic System (ISS) is useful for identification of potential failure zones in a large area.

Prediction of strata behaviour by theoretical analysis become unreliable due to almost impossibility of simulation of the real field conditions in mathematical, physical or numerical models. Thus, empirical formulation, based on in-situ measurements of strata behaviour parameters, is an accepted way to estimate the strata behaviour. However, numerical modeling should also be carried out in all critical projects to assess the ground conditions prior to the excavation.

Continuous monitoring (on-line monitoring) of the strata deformation and stress variation is required for timely remedial action in critical conditions. For this, data acquisition and data logging systems should be increasingly made use of.

Remote monitoring and tele-monitoring of strata behaviour using wireless and other innovative technologies is the need of the hour for understanding the strata mechanics particularly in abandoned and inaccessible places.

NIRM - The Pioneer in Rock Burst Research & Engineering Seismology in India

C. SRINIVASAN[1] and C. SIVAKUMAR[2]

[1]Former Head, Engineering Seismology Department, National Institute of Rock Mechanics

Kolar Gold Fields

[2]Microseismics & Engineering Seismology Department, National Institute of Rock Mechanics,

Bangalore

INTRODUCTION

The Research & Development Unit of Bharat Gold Mines Limited at Kolar Gold Fields was functioning since pre-independence. The Seismic and Micro-seismic Cell of this Unit was established in 1978 with the collaboration of Bhabha Atomic Research Centre evaluation and prediction of ground stability in mine excavations prone to rock burst. Seismic technique was used for the first time in India to monitor the rockburst activity in underground mines. Seismological analysis of the stress regime of mine excavations was carried out to delineate regions of high insitu stress. The Seismic and Micro-seismic Cell of the BGML R&D Unit was the nucleus for formation of the National Institute of Rock Mechanics.

ROCKBURSTS RESEARCH IN THE MINES OF KGF

The Cell has generated enormous data by way of round-the-clock monitoring of the micro-seismic activity in the mines during and after the active mining operations in BGML. Seismic and micro-seismic techniques, supplemented with conventional strata monitoring system, were successfully adopted to monitor the seismic activity, and to predict rock bursts. They provided support to the mining engineers by identifying the location of high stress zones, and giving information about the sites of rock bursts. The investigations being carried out by the Seismic and Micro-seismic Cell of this Unit were recognized internationally. The techniques used were acknowledged as to be of very high standard in the opinion of UNDP / ILO experts who visited the R&D Unit.

The major achievements of NIRM in the field of Engineering Seismology are :

a) Location of rockbursts during the active mining period and after the mines are closed.
b) Delineation of underground high stress zones.
c) Assessing the stability of both shallow and deep level mine workings
d) Development of velocity model of the Kolar Gold Field workings.
e) Long-term rockburst prediction.
f) Capacity building for micro-seismic monitoring for deep mines, nuclear plants and dams

In technical collaboration with BARC, real time monitoring of deeper level workings of Champion Reef mine was carried out for rockburst prediction. The analysis of the data related to a large number of micro-seismic events has revealed the following precursory pattern:

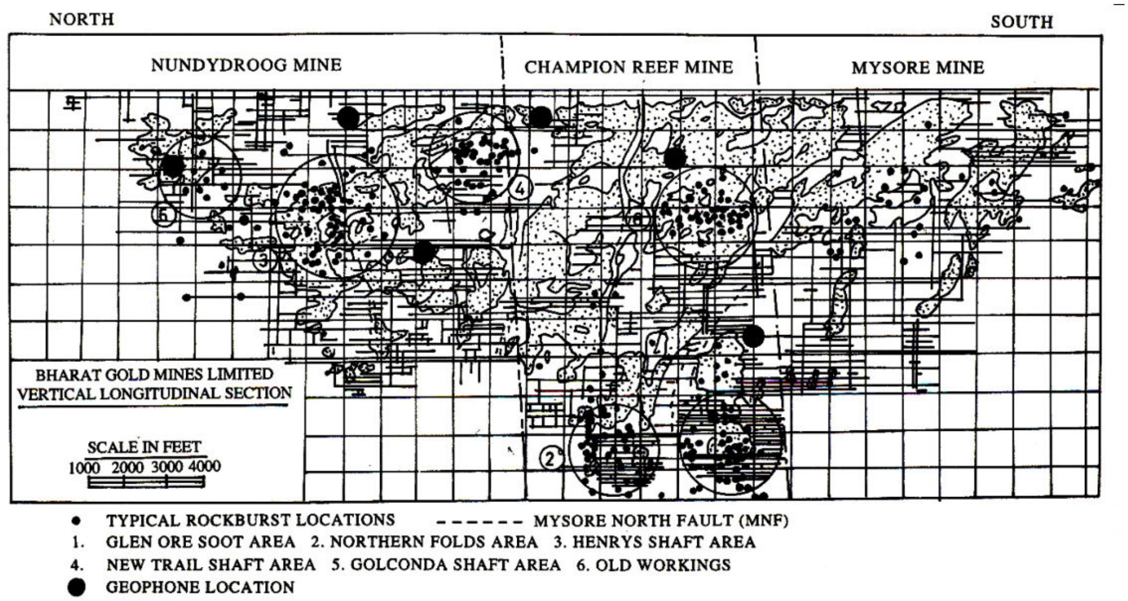


Fig. 1. Longitudinal (north-south) section through KGF showing typical spatial distribution of rockbursts in one year. The bigger dots indicate the geophone locations; the small dots indicate location of rockbursts identified from seismic data.

i. Prior to the rockburst, high rate of micro-seismic emission is observed, followed by a low rate.
ii. A gradual increase in the micro-seismic energy will take place before a rockburst.
iii. A distinct decrease in the frequency content is perceptive preceding the occurrence of rockburst.
iv. Before a major rockburst, there will be a drop in fractal dimension (d) value.
v. Spatial distribution of the micro-seismic events before and after rockbursts reflects massive clustering before the rockburst.

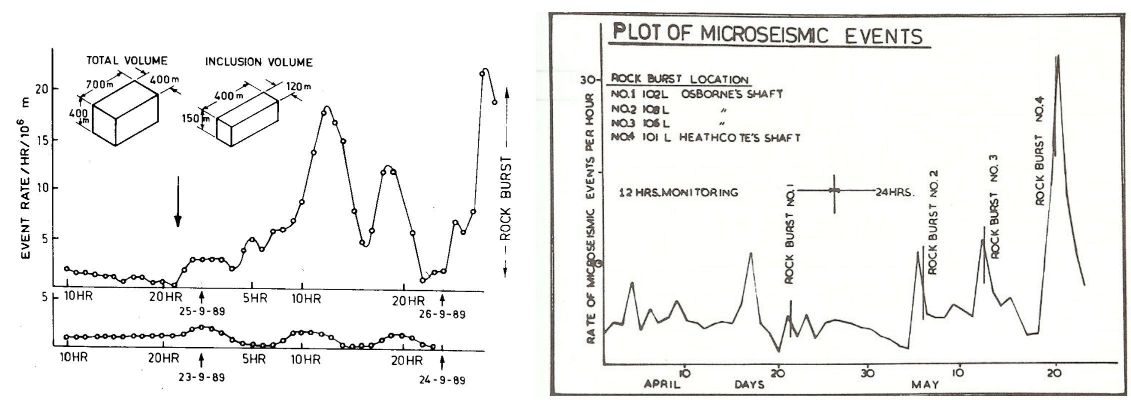


Fig. 2. The micro-seismic event density rate plot for four rockbursts

Real time monitoring of Nundydroog mine was also carried out under an Indo-Japan collaborative research project between NIRM and Geological Survey of Japan for the evaluation of stability of deep underground caverns by applying micro-seismic and acoustic emission techniques.

A digital seismological recording system along with short-period seismometers in network was commissioned in the mines of Kolar Gold Fields to study the behavior of Mysore North fault under water and its role in the stability of the mining region.

MICRO-SEISMIC MONITORING IN OTHER MINES

The successful implementation of the micro-seismic monitoring technique at KGF helped in extending it to other hard rock and coal mines in India. The extensive analysis of the seismic and micro-seismic data has resulted in evaluation of stability of mine workings and prediction oriented research.

Microseismic monitoring of Mochia mine was carried out for evaluating ground stability before and after a massive pillar blast in June 1994 as required by the Directorate of Mines Safety. In one of the largest blasts in the history of underground mining in India, 145 T of explosives were used in one go to extract around 0.55 MT of high grade lead-zinc ore trapped in barrier pillar. The result of monitoring showed an excellent correlation between micro-seismic event release rate (ERR) and ground stability. Based on this monitoring, mining was allowed to be resumed on 13th day after the mass blast.

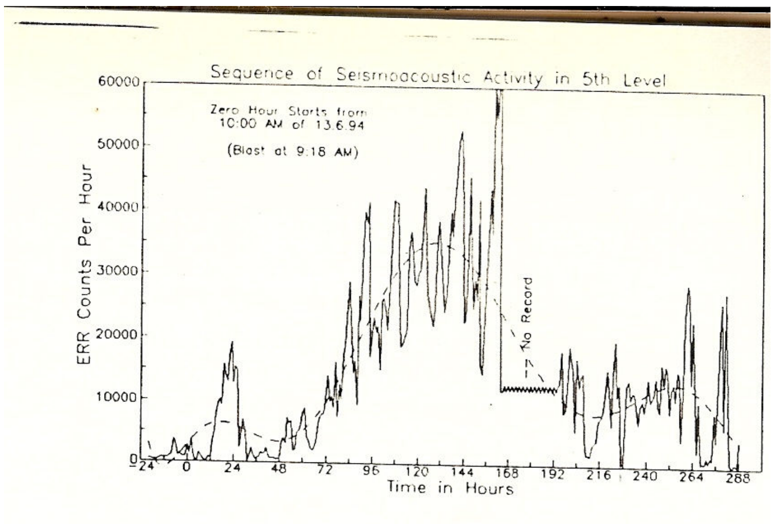


Fig. 3. Micro-seismic activity monitored during a massive blast at Mochia mine, HZL, in June, 1994

Later the system was adopted for roof fall monitoring in a bord and pillar panel at Churcha West coal mine, SECL. It was also used for prediction of roof fall in the Rajendra Longwall underground coal mine. It also helped in identifying the high stress zones and assisted in carrying out induced blasts.

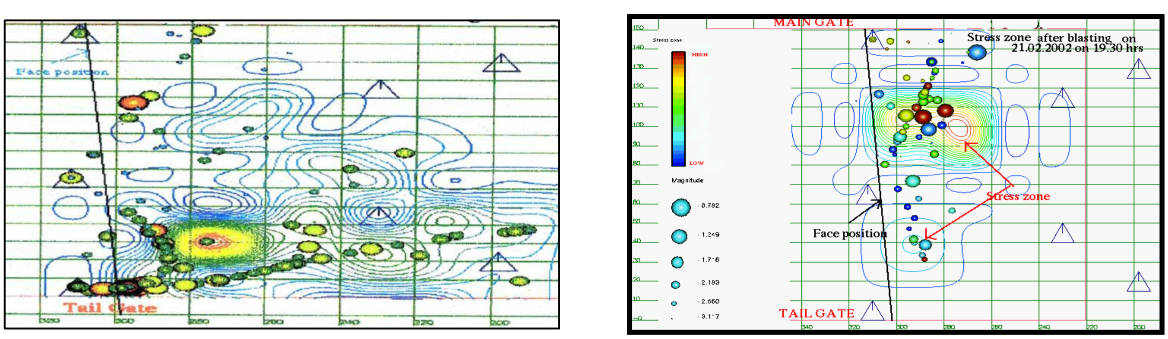


Fig. 4. High stress zone before and after induced blasting over a longwall panel at Rajendra mine, SECL (on 21-2-2002)

The micro-seismic monitoring technique was successfully experimented to study the rock slope behavior at the upstream side of the Naptha dam of NJPC, Himachal Pradesh. NIRM also monitored and analyzed the seismic events recorded at the Wangkha dam, Bhutan. NIRM helped in establishing a seismic network for monitoring the high stress zones around the power house and other caverns at Tala Hydro-Electric Project in Bhutan.

BROADBAND SEISMIC MONITORING

After the Latur earthquake, the Department of Science and Technology has established the Broad Band Station at the Central Seismic Station (KGF Observatory) under the World Bank assisted project on Seismology to Upgrade the Seismological Observatories in the Peninsular Shield of India. NIRM was given the charge to operate and maintain it, and to continuously monitor earthquakes of different magnitude from regional and teleseismic region of the shield area.

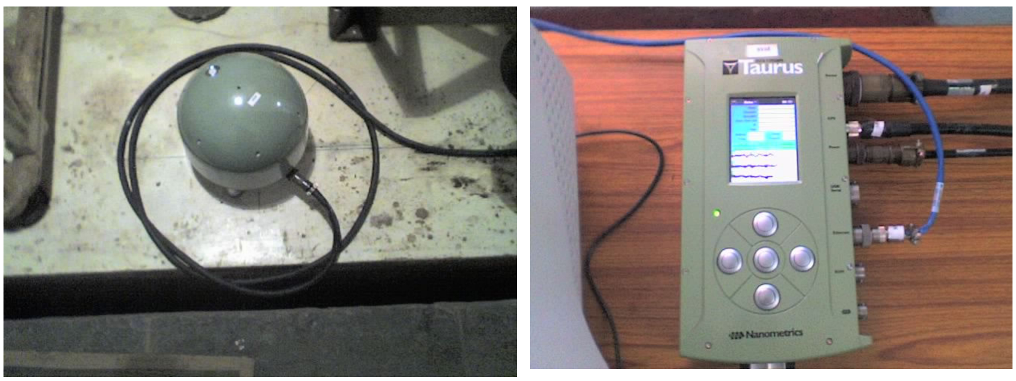


Fig.5. Broadband sensor and recorder

Using the strong motion data of rockbursts, NIRM determined the local magnitude, and correlated the rockbursts of Kolar Gold Fields and earthquakes recorded at Koyna dam, and found some similarity in the mechanism.

Details about Present Staff

	Name	Designation	Date of Joining
1	Dr V Venkateswarlu	Director	7-Mar-1990
2	C Sivakumar	Scientist – 5	1-Jan-1990
3	A Rajan Babu	Scientist – 5	8-Jan-1990
4	Dr HS Venkatesh	Scientist – 5	19-Mar-1990
5	Dr PC Jha	Scientist – 5	20-Apr-1990
6	Sripad R Naik	Scientist – 5	30-Apr-1992
7	Dr VR Balasubramaniam	Scientist – 4	11-Mar-1996
8	Dr DS Subrahmanyam	Scientist – 4	13-Aug-1997
9	Sandeep Nelliat	Scientist – 3	29-Nov-2002
10	Dr Ajay Kumar Naithani	Scientist – 3	3-Nov-2008
11	Y Ahnoch Willy	Scientist – 2	1-Jan-1990
12	C Nagaraj	Scientist – 2	1-Jan-1990
13	M Victor	Scientist – 2	1-Jan-1990
14	A Vijay Kumar	Scientist – 2	1-Jan-1990
15	AI Theresraj	Scientist – 2	1-Jan-1990
16	D Joseph	Scientist – 2	1-Jan-1990
17	Sagaya Benady	Scientist – 2	1-Jan-1990
18	S Uday Kumar	Scientist – 2	1-Jan-1990
19	Dr G Doraswamy Raju	Scientist – 2	2-Jan-1995
20	Dr RK Sinha	Scientist – 2	6-Mar-2003
21	G Gopinath	Scientist – 2	30-Oct-2008
22	Dr Biju John	Scientist – 2	16-Dec-2008
23	YV Sivaram	Scientist – 1	16-Mar-1992
24	K Sudhakar	Scientist – 1	25-Jan-1995
25	R Balachandar	Scientist – 1	1-Aug-1996
26	G Shyam	Scientist – 1	6-Oct-2008
27	Amrith T Renaldy	Scientist – 1	10-Oct-2008
28	Dr Devendra Singh Rawat	Scientist – 1	14-Oct-2008
29	Dr L Gopeshwor Singh	Scientist – 1	14-Oct-2008
30	Sultan Singh Meena	Scientist – 1	16-Oct-2008
31	S Kumar Reddy	Scientist – 1	17-Oct-2008
32	Mrs Praveena Das Jennifer	Scientist – 1	17-Oct-2008
33	Dr Rabi Bhusan	Scientist – 1	20-Oct-2008
34	Mrs KS Divyalakshmi	Scientist – 1	20-Oct-2008
35	GC Naveen	Scientist – 1	20-Oct-2008
36	Yogendra Singh	Scientist – 1	29-Oct-2008

	Name	Designation	Date of Joining
37	K Vamshidhar	Scientist – 1	30-Oct-2008
38	Prasnna Jain	Scientist – 1	6-Jul-2009
39	B Butchi Babu	Scientist – 1	1-Jan-2010
40	Vikalp Kumar	Scientist – 1	11-Apr-2011
41	Manoj Kumar	Scientist – 1	2-May-2011
42	BH Vijay Sekhar	Scientist – 1	29-Jul-2013
43	AN Nagarajan	Registrar	1-Jan-1990
44	S Ravi	Purchase & Stores Officer	1-May-1991
45	Pankaj Kumar	Administrative Officer	2-May-2011
46	Mrs S Lourdu Mary	Section Officer	1-Jan-1990
47	Mrs CV Lalitha	Section Officer	22-Dec-1993
48	J Viswanatha Sastry	Section Officer	1-Jan-1994
49	N Jothiappa	Office Asst. – 3	19-Apr-1991
50	J Raja	Office Asst. – 3	8-March-1993
51	Syed Asghar	Technician – 4	1-Jan-1990
52	N Soundarrajan	Lab Asst. – 4	1-Jan-1990
53	N Selvaraj	Lab Asst. – 4	1-Jan-1990
54	K Venkata Reddy	Driver	2-Sep-1998
55	K Manjunath	Driver	20-Dec-2013

NIRM Present Staff


Dr V Venkateswarlu

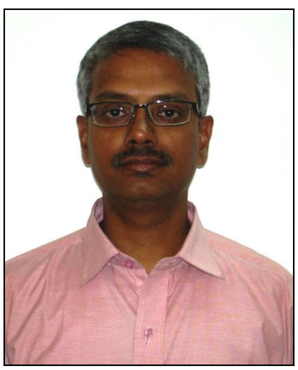

C Sivakumar


A Rajan Babu


Dr HS Venkatesh

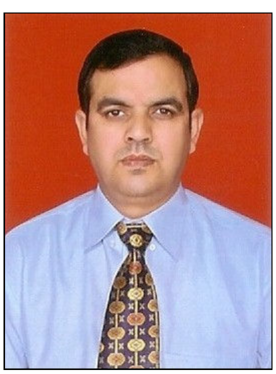

Dr PC Jha


Sripad R Naik


Dr VR Balasubramaniam


Dr DS Subrahmanyam


Sandeep Nelliat


Dr Ajay Kumar Naithani


Y Ahnoch Willy


C Nagaraj

M Victor

A Vijay Kumar

AI Theresraj

D Joseph

Sagaya Benady

S Uday Kumar

Dr G Doraswamy Raju

Dr RK Sinha

G Gopinath

Dr Biju John

YV Sivaram

K Sudhakar


R Balachandar


G Shyam


Amrith T Renaldy


Dr Devendra Singh Rawat


Dr L Gopeshwor Singh


Sultan Singh Meena


S Kumar Reddy


Mrs Praveena Das Jennifer


Dr Rabi Bhusan


Mrs KS Divyalakshmi


GC Naveen


Yogendra Singh


K Vamshidhar


Prasnna Jain


B Butchi Babu


Vikalp Kumar


Manoj Kumar


BH Vijay Sekhar


AN Nagarajan


S Ravi


Pankaj Kumar


Mrs S Lourdu Mary


Mrs CV Lalitha


J Viswanatha Sastry

N Jothiappa

J Raja

Syed Asghar

N Soundarrajan

N Selvaraj

K Venkata Reddy

K Manjunath

DATE	NAME AND ADDRESS	REMARKS
18.10.92	B. K. RAO	I am happy to see that the seed of this institution has sprouted well. In a short time it has attracted the right type of talent with the right admixture of expertise, enthusiasm and elan. With the continued efforts of Dr. Raju, it should grow from strength to strength in translating the vision and expectations with which it has been started, into a reality. for the benefit of the mining and other areas. I wish all the scientists well in their endeavour [illegible] 18/10/92

राष्ट्रीय शिला यांत्रिकी संस्थान

National Institute of Rock Mechanics

(Ministry of Mines, Government of India)
An ISO 9001:2008 Certified Research Institute

Head Office:
Champion Reefs Po,
Kolar Gold Fields -563117,
Karnataka, India
Phone : +91-8153-275004 - 275009
Fax : +91-8153-275002

Bangalore Unit:
ITI Bhawan Annexe, Old Madras Road,
Dooravaninagar, Bangalore – 560 016
Karnataka, India.
Phone No: +91-80-25619697
Fax No.: +91-80-25612795

e-mail: dto@nirm.in; nirm@vsnl.com
Web: www.nirm.in