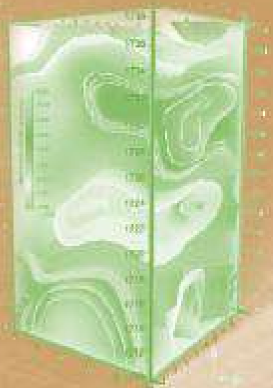
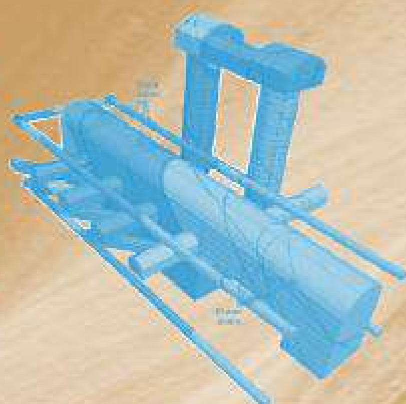
TECHNICAL SOUVENIR

Published on the occasion of Conference with Industry partners on Future Strategies





February 18, 2019
Taj Yeshwantpur, Bengaluru

National Institute of Rock Mechanics

Head Office : Bengaluru - 560070

Registered Office : Kolar Gold Fields - 563117

(Ministry of Mines, Govt. of India)

Web: https://www.nirm.in e-mail: dto@nirm.in

A Premier Research Institute for Rock Mechanics serving the nation for last 30 Years

Technical Souvenir

(Spectrum of activities of NIRM across various sectors)

Published on the occasion of Conference with Industry Partners on Future Strategies

Taj Yeswantpur, Bengaluru
February 18, 2019

National institute of Rock Mechanics
Bengaluru - 560070

Compiled & edited by :

Dr P C Jha, Scientist &Head, Engineering Geophysics Department
Dr. Sripad R Naik, Scientist & Head, Numerical Modelling Department

About this Conference

Ever since being established as an Independent Autonomous Institute under Ministry of Mines, Govt. of India, NIRM was catering to the Mining fraternity - both Coal and Metal mines and established itself with a niche status among mining industry. From the year 2000, NIRM diversified its activity to power and infrastructure projects (apart from mining) to address the concern of these sectors with excavation, modelling of excavation, geophysical investigations for trouble shooting operations and in-situ testing for crucial geotechnical parameters. We continued working for the referral problems from the industry. We have now decided to integrate our work areas and take on the industrial problems with a coherent unified multi-dimensional investigation so that a best possible solution is given to the industry. In this process, we worked on developing couple of DPRs and reviewing some other DPR for hydel projects.

Synergy with modelling and instrumentation has given a new insight into validating the numerical model by re-calibration; geophysics and blasting group worked together to study the dynamic analysis of vibration-induced instability. We have proposed multi-modal investigations for dump/ overburden instability in open-cast coal mines. Many more such types of projects will be on anvil in the future.

This workshop is being organised with the partner industries to hear about their future requirements and expectations from NIRM. While we are upgrading and modernising our hardware and software base with the addition of OTDR tool, drone-based mapping and sophisticated 3D & 4D analysis software, our ultimate goal remains applied research for the benefit of the industry. Therefore, we aim to seek the guidance and words of advice from partner industries so that we synergise our development to maximise the value addition in solving the crucial problems that still remain unsolved within the domain of rock mechanics and rock engineering for enabling timely execution of projects.

FOREWORD

This "Conference with Industry Partners on Future Strategies" is a carefully planned event both to thank and solicit support from our esteemed clients in shaping the future of the Institute in years to come. I take this opportunity to express my gratitude to the industry partners who are the real torch-bearers of our Institute in the industrial arena. I am extremely thankful to Dr. K. Rajeswara Rao, Addl. Secretary, Ministry of Mines, Government of India for visualizing this interactive conference and gracing this event as the Chief Guest.

I do hope that deliberations and mutual interactions at this conference will provide us both directions and support in chartering our future course of action in our aim to expand further both in terms of manpower and technical resources to meet the future needs of the industry.

With a humble beginning in 1988, NIRM over a period of last 30 years has grown from strength to strength in terms of technical skills and areas of investigation. Apart from its core service area of mining sector, today NIRM has its presence across entire spectrum of energy sector and most of the urban infrastructure. On this occasion, I feel proud to release this "Technical Souvenir" which describes various diverse areas of Rock Engineering and Rock Mechanics wherein NIRM extends its expertise at present.

The financial and technical support by the Ministry of Mines, Government of India, has been a constant driving force in our quest for excellence. With the active support from our esteemed Industry Partners, I wish to see that in proximate future, our work areas get multiplied many fold with the most modern and efficient investigation tools.

H S Venkaetsh
DIRECTOR

CONTENTS

National Institute of Rock Mechanics

(Ministry of Mines, Govt, of India)

The National Institute of Rock Mechanics (NIRM) was established as an autonomous research Institute under the Ministry of Mines, Government of India, in 1988. NIRM is a premier centre for research and consultancy in the field of rock mechanics and rock engineering, and is the only one of its kind in Southeast Asia. During the last 30 years, NIRM has carved a niche for itself in the national arena in the field of rock mechanics and rock engineering by providing innovative solutions to the civil and mining engineering sectors in the area of enabling technologies. The Institute has been extending its technical support to mining, power, oil and gas sectors, infrastructure development, irrigation projects, and geohazards and environment management in India and abroad. It has made significant contributions to the following industries:

- Metal Mines
- Coal Mines
- Power Sector – Hydel, Thermal & Nuclear
- Rock Excavation
- Underground Storage Caverns
- Railways / Metro
- Water Canals and River Linking
- Landslides Mitigation and Monitoring

NIRM offers its expertise through following broad disciplines :

- Engineering Geological Investigations
- Engineering Geophysical Investigations
- In-situ Geotechnical Investigations
- Engineering Seismology & Seismotectonics
- Rock Blasting and Excavation Engineering
- Numerical Modelling and Instrumentation
- Geomechanics and Ground Control
- Materials Testing & NDT
- Rock testing & Fracture Mechanics

Each of these disciplines are well-equipped with the latest hardware and software and a trained pool of scientific personnel. Activities of these disciplines are described in brief in the following pages with illustrated case studies.

Registered Office of NIRM at KGF

Head Office of NIRM at Bengaluru

Engineering Geological Investigations for various Projects

Engineering geological inputs are pre-requisite for economic and safe designing of all civil construction projects related to power sector (hydel, thermal, nuclear), crude oil storage project, lift irrigation sector, communication sector (metros, rails, tunnels, roads, bridges) and mining sector as well as for geohazard assessment and mitigation. This department caters to this need of the construction industry and undertakes works related to engineering geological investigations in various stages of the project developments, i.e., feasibility report (FR), detailed project report (DPR), construction and post construction stages. The main aims of the engineering geological investigations are: characterization of rock mass, recommendation of support design and modification of design as per actual site conditions. Following are important sectors where engineering geological investigations are very much required:

- Power sector (hydro, thermal or nuclear)
- Underground crude oil storage sector
- Lift irrigation sector
- Communication sector (metros, rails, tunnels, roads & bridges)
- Mining sector
- Disaster management, geohazard assessment and mitigation

Capabilities (Areas of Expertise)

With its expertise in engineering geology, this department offers its services in the following areas:

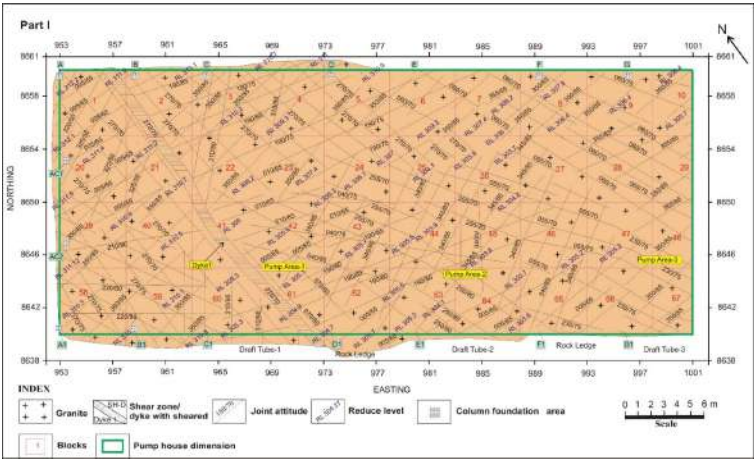
- Compilation and analysis of geological and tectonic map of the area
- Detailed geological mapping on 1:500 to 1:1000 scale
- Drill–core logging and 3-D mapping on 1:100 scale of exploratory drifts
- Foundation evaluation and mapping on 1:100 to 1:500 scales for delineation of fault, shear & weak zones and recommendation for remedial measures
- 3-D mapping of tunnels, shafts, penstocks/pressure shafts and other U/G structures on 1:100 scales
- Rock mass assessment and advice on suitable support system
- Stability analysis of cut/natural slopes and surface excavations

- Reservoir rim stability and leakages of reservoir studies
- Petrographic studies of rocks
- Investigation for construction material, mass wasting activity and hazard zonation mapping
- Landslide hazard zonation mapping
- Engineering geological modelling

Major Scientific Works		
1.	FR/DPR stage engineering geological investigations of hydroelectric and lift irrigation projects Large scale geological mapping • Drill hole logging • Drift logging • Collection and interpretation of geological and geotechnical data • Review and interpretation of previous geological, geotechnical and seismological investigation data	• Large scale (1:500 to 1:1000) mapping using total station • Auto Cad drawings • Rock Mass Classification using RMR and Q systems • Recommendation of support system • Recommendation of remedial measures
2.	DPR stage investigations of hydroelectric project reservoir area	• Indian Remote Sensing Satellite data • Image processing in ERDAS Imagine 9.3 • Digitization and analysis in Arc GIS 9.3 • Field checking / verification
3.	Construction stage engineering geological / geotechnical investigations of underground crude oil storage project and recommendation of support as per design and site conditions	• 3-D geological mapping and classification of rock mass as per Q-system • As per Q-system and site geological conditions recommendation of permanent support
4.	Construction stage engineering geological / geotechnical mapping of foundations and walls of nuclear power project	• Large scale (1:60 & 1:100) mapping using total station • Rock Mass Classification using RMR • Recommendations for the foundation treatment

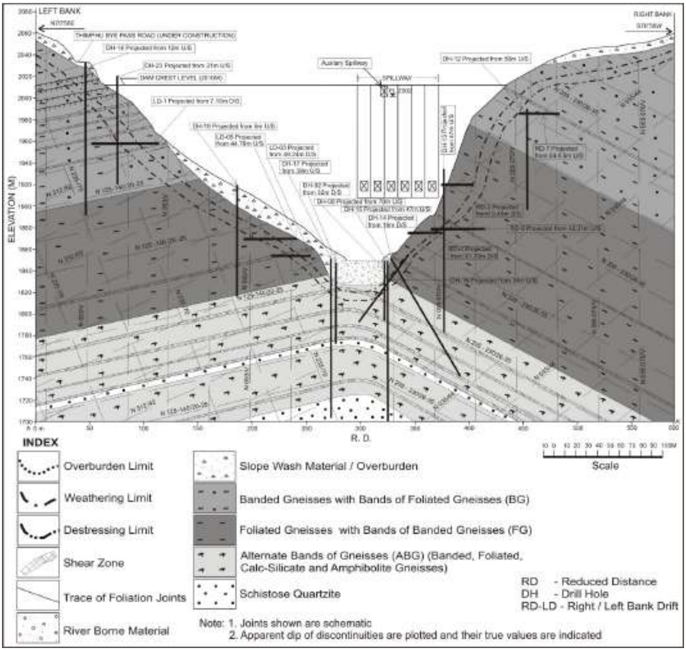
5.	Construction stage engineering geological mapping of foundations and walls of open lift irrigation projects	• Large scale (1:200) mapping using total station • Rock Mass Classification using RMR and Q-system • Recommendation for the foundation treatment and vertical walls for open excavation.
6.	Construction stage engineering geological mapping of underground lift irrigation projects	• 3-D geological mapping and classification of rock mass as per Q-system • As per Q-system recommendation of permanent support
7.	Construction stage engineering geological investigations of road tunnel	• 3-D geological mapping and classification of rock mass as per Q-system • As per Q-system recommendation of permanent support
8.	Assessment of the excavatability of rock mass	• Large scale (1:100) geological mapping and classification of rock mass as per rock mass rating system and tunnel quality index • As per RMR & Q-systems and revised exacavatability graph, assessment of the excavatability of rock mass
9.	Assessment of cut/natural rock slope stability	• Assessment of cut slope based on Slope Mass Rating (SMR), Global Slope Performance Index and Q-slope • Based on above methods, recommendations of long term stable slope angle, and permanent support systems

Some Illustrated Results



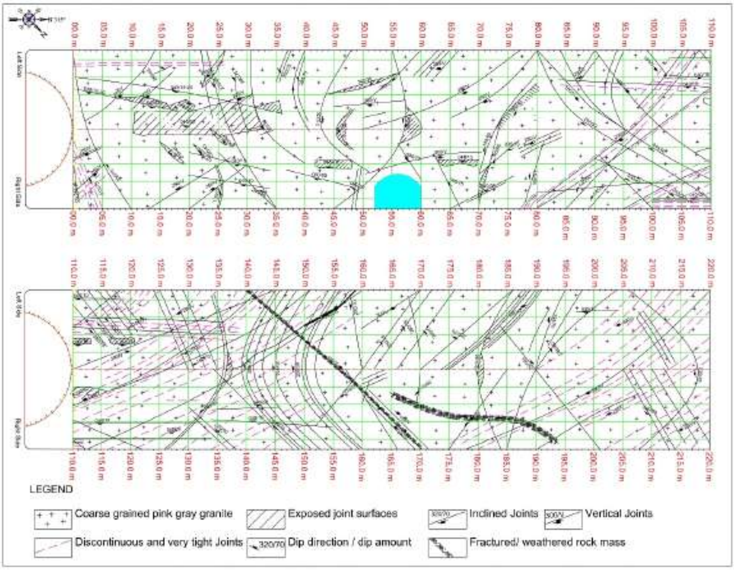
Engineering geological map of the pump house foundation of Mahatma Gandhi Kalwakurthi lift irrigation scheme-II, Telangana State

Collection of engineering geological data from surge pool foundation



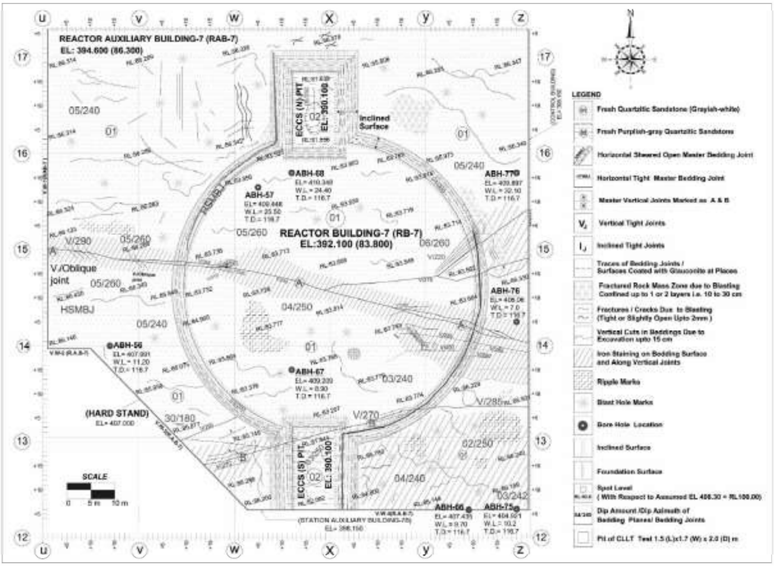
Geological section along the dam axis, Bunakha HEP, Bhutan

Collection of engineering geological data from outcrop for the DPR stage investigation of HEP



3D geological map of the heading portion of surge pool, PCSSLIS P-8, Telangana State

Excavation of tunnel portals, back and side slopes



Geological plan of the nuclear building

Engineering Geophysical Investigations – NIRM Leads the Way

Engineering Geophysics deals with the application of geophysical methods for site characterisation, 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 produces useful information. Each geophysical method is associated with the measurement of the variation of 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.

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. Some of the conventional exploration geophysical investigation techniques used by NIRM in Engineering Geophysics are :

1. Seismic refraction survey
2. Electrical resistivity survey
3. GPR survey
4. Spectral Survey with Surface Waves (MASW)
5. Borehole survey techniques

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 borehole profiling or logging tools and used across two borehole, they are called cross-hole survey or tomographic imaging. In this case they are used for precision mapping of defects, foundation stability or hidden targets. Depending upon the property under investigation, these methods are known by a different trade name. Some of the important sectors where engineering geophysical investigations have been done include :

- Power sector (hydro, thermal or nuclear)
- Coal mines/ metal mines
- Tunnels, roads & bridges; Irrigation sector
- Railways, metro, archaeology & other areas
- Foundation mapping, reinforcement/ stability analysis

Capabilities (Areas of Expertise)

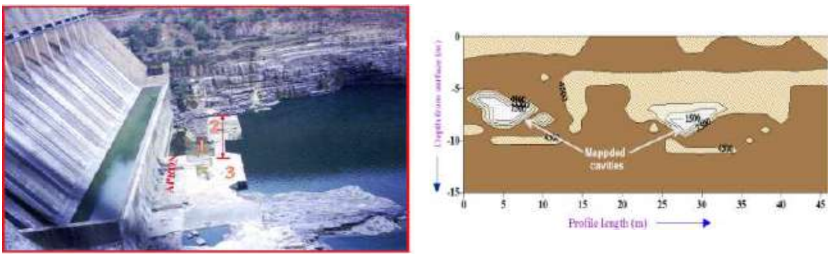
This department offers its services in the following areas:

- Seismic refraction survey for stratigraphic mapping
- Detailed subsurface mapping for anomalous conditions
- Resistivity imaging for fracture/ water-table/ cavity mapping
- GPR survey for subsurface targets – buried landmines, archaeological structures/ artefacts/ foundation defects etc.
- Surface wave survey for settlement studies, stability analysis
- Rock mass classification for excavation purpose
- Foundation stability analysis by cross-hole tomography
- Structural stability studies by multiple methods
- Imaging of construction defects, trouble-shooting targets
- Tailored-investigation for various types of dynamic properties
- Investigation for subsidence/ settlement potential
- Spectral characterisation of minute defects

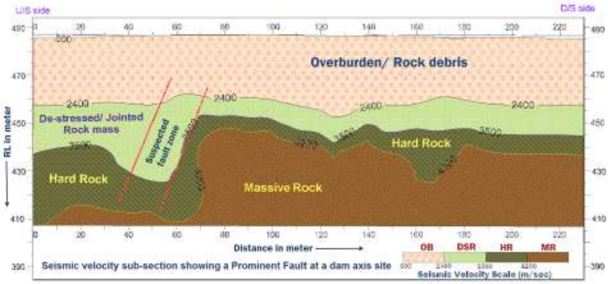
Some case studies :

(A) Seismic Refraction Survey

NIRM has carried out SRS investigations at a number of sites in both hydroelectric and infrastructure project sites. Some typical case studies are illustrated as under :



Cavity mapping in the apron of Srisailam dam using Seismic survey



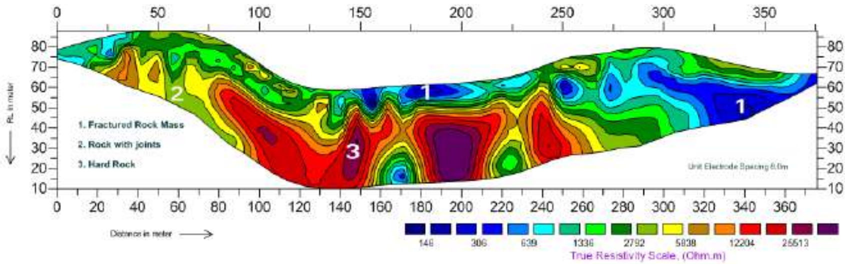
Seismic refraction survey at a dam axis showing presence of a major fault plane

Apart from various trouble-shooting operations, seismic refraction survey was used for reconnaissance survey to confirm presence of adverse geological conditions like shear zone or fault at crucial locations of major surface structures like dam axis, powerhouse, bridge pillars etc. This survey was also used for various tunnelling projects for deciphering the tunnelling medium. In some cases even the rail alignment was altered due to adverse conditions for the tunnelling. So far more than sixty projects where seismic refraction survey was effectively used.

With the use of surface wave survey gaining momentum, NIRM has been in the forefront in using methods like MASW for the evaluation of surface settlement potential and subsidence risk analysis.

(B) Electrical Resistivity Survey

NIRM has been using the Electrical Resistivity Technique for both sounding and imaging set-up. 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. In case studies with the oil 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. 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. In troubleshooting operations with urban infrastructure projects (metro), resistivity imaging was used to identify the potential weak zones.

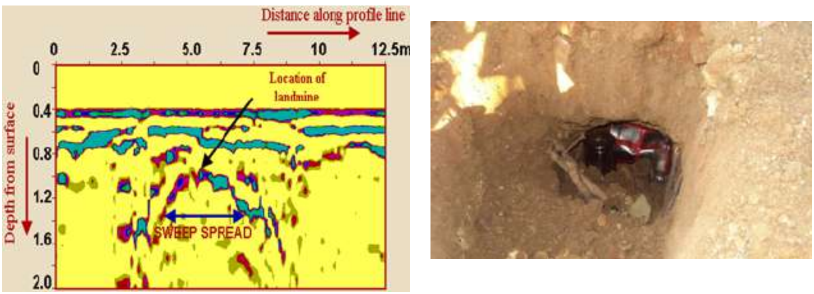


Typical resistivity imaging profile along HRT of Kumaradhara Hydel Project

(C) GPR Survey

NIRM was the first to bring the frequency variant of GPR to India in 1995. We accomplished an S&T project in which the use of GPR survey is demonstrated for mapping of barrier against water-logged workings in coal mines for a distance of 60m. In hydel projects, GPR survey was used to identify a buried channel leading to instability of the retaining wall over the TRT area. This survey was used for analyzing the foundation defect in the oil tank and for identifying the source of oil-leak from the MRPL refinery. In Tala project of Bhutan, GPR survey was used for mapping of crack in the dam block and in the crown of the desilting chambers.

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.

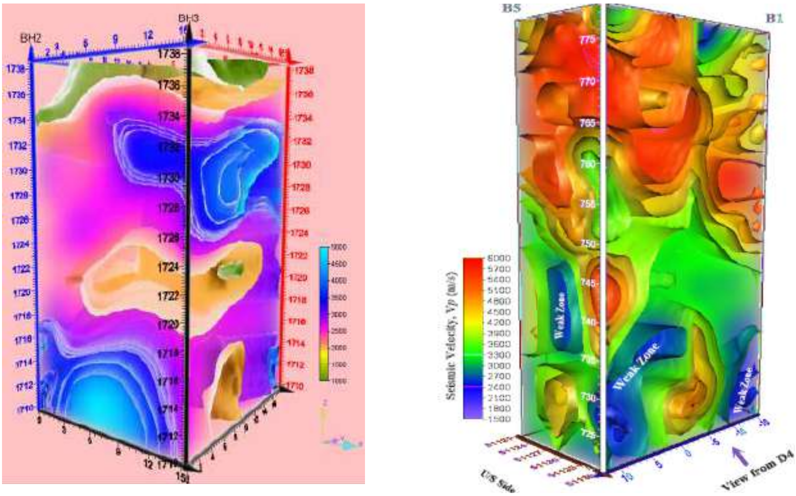


GPR survey for detection of buried non-mettalic landmine

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. NIRM has mastered directional probing and borehole profiling with GPR. With over 40 major case studies using GPR survey, we are the leader in using this method in adverse conditions.

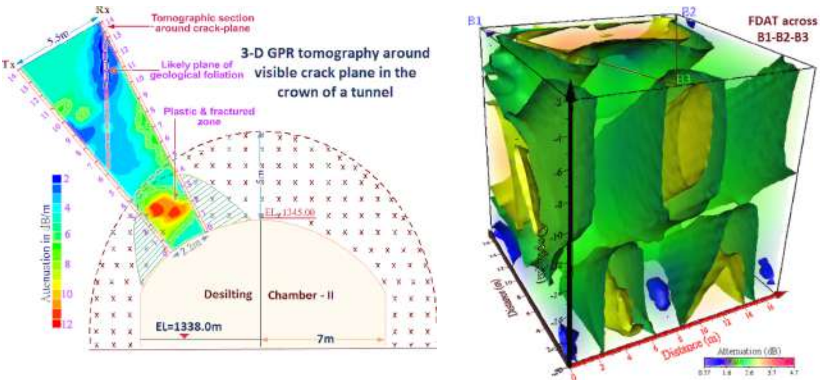
(D) Tomography Survey

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. 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.



3-D tomogram showing results for mapping defects in the foundation at a dam axis and at a bridge foundation using seismic method

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 . 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.



2-D and 3-D tomograms showing results for mapping defects in the crown of tunnel (left) and buried structure in the subsurface using GPR method (right)

NIRM is using engineering geophysical methods of investigation for varieties of site characterisation studies and trouble-shooting 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. With our experience and addition of the latest investigation tools NIRM is the national leader in this field of investigation with the most modern range of investigation tools.

Geotechnical Investigations for in-situ Rockmass Properties

In general, the mechanical behaviour 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 behaviour of the rocks in prototype structures. In all the major projects for civil engineering works where rock excavation is involved such as tunnels and underground space, dams, or in underground mining or in large open cuts, the design has to be made based on in-situ geotechnical investigations for a reliable prediction of the behaviour of the 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 general, the distribution and magnitude of in-situ stresses affect geometry, shape, dimensioning and excavation sequence. 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 underground mining, 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. Results of the stress measurements give both direction of maximum horizontal stress and the magnitude of principal stress tensors at a particular depth.

The rock behaviour 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. 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. Plate-bearing method is one of the most common methods to determine the deformability of rock mass in-situ. 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 points on the rock mass. Dilatometer is equipment used for determination of in situ deformability of rock mass inside a borehole. The Elastmeter-2 is new version of lateral load tester for measuring deformation within the borehole.

The shear strength of rock is one of the most important parameters used in design of dams and other underground structures. 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. Its determination involves the measurement of two related parameters - cohesion and angle of internal friction. 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.

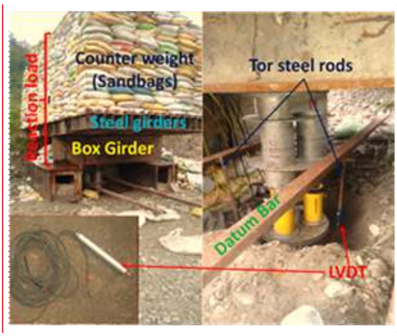
Till date NIRM has carried out in-situ tests at more than 135 projects sites and is the national leader in this field of investigation. This tests has been carried out across all sectors be it hydroelectric, mining or infrastructure.

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 way back in 1994. 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. NIRM 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; 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 using portable equipment. 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 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.

Some of the case studies with in-situ geotechnical parameter determinations are illustrated below :



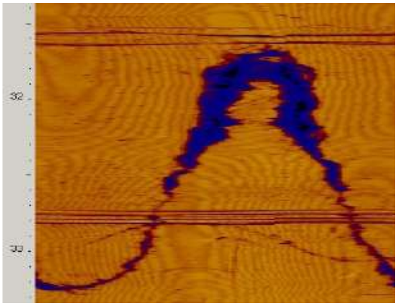
Modulus of Subgrade reaction of Soil tests at Teesta Low dam Stage-III H.E. Project

Determination of safe bearing capacity at Punatsangchhu H.E. Project, Bhutan

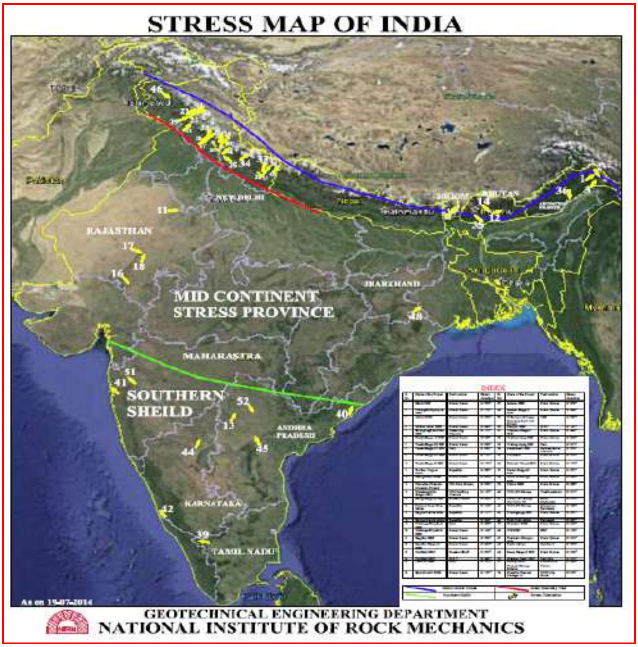
In-situ stress measurement in progress at a coal mining site

Plate load equipment setup to determine modulus of Deformability

In-situ Direct Shear tests (inside the tunnel) at Dibang H.E. Project, Arunachal Pradesh



Acoustic Borehole Televiewer tests at the depth of 600m at Singareni Collieries



Updating stress map of India based on in-situ data measurements

Highlights of NIRM activities

a) A new technique has been developed to measure the insitu stresses using manipulation of flow rate in fractured and porous rock mass. This technique would be helpful in conducting the stress measurements in fractured rocks especially in Himalayan terrains where the rock mass is generally porous or highly fractured.

b) Due to highly fractured nature of the joints in the Himalayas, the normal hydro fracturing tool is ineffective due to longer length of the injection unit of the hydro fracturing tool, and a special site specific hydrofracture tool is designed and developed as an innovative method to address this problem.

c) The **Stress Map of India** has been prepared and periodically updated for quick and reliable information regarding

d) By measuring stress directions at various places of India, NIRM hs made a significant *contribution* towards world stress map. The database that is available from Stress map of India will not only be helpful in academic researches but also for commercial and economical investigations.

e) Stress measurements are conducted at various hydroelectric project sites at the depth of 350 m from the surface and at 600m depth in Coal mines.

f) NIRM has Applied for obtaining patent from Controller General of Patents, Designs & Trademarks, Govt. of India. viz. titled:
   a. In-situ stress measurements in fractured rock mass by using high flow rate technique.
   b. In-situ stress measurements in porous rock mass by using high viscous liquid.

Engineering Seismology & Seismotectonics – Pioneering contribution by NIRM

Microseismic 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 induced stresses. Engineering Seismology department at NIRM is a unique group of rock mechanics which carries out real time monitoring around excavations and mines for dynamic stability evaluation. This monitoring is done by a tailor-made microseismic network as per site reqirement. This technique can be used for stability evaluation of

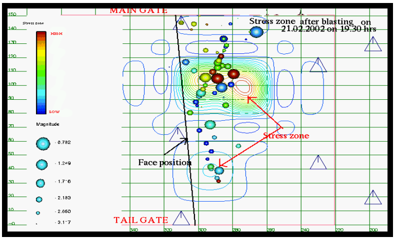
- Mining (both hard rock and coal mine)
- Geotechnical (underground space)
- Hydrocarbon (reservoir monitoring)
- Regional seismic monitoring
- Teleseismic activities

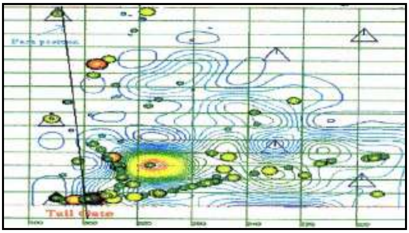
Based on monitoring data, NIRM does the quantification of seismic rick and provides prior information on rockmass instability during and/or post excavation. Major achievements of Engineering Seismology department are :

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) Long-term rockburst prediction.

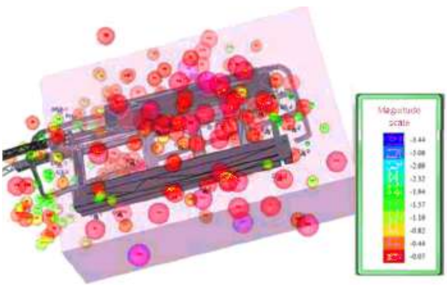
The successful implementation of the microseismic monitoring technique at KGF helped in extending it to other hard rock and coal mines in India. Microseismic monitoring of Mochia mine was carried out for evaluating ground stability before and after a massive pillar blast in June 1994. The result of monitoring showed an excellent correlation between micro-seismic event release rate (ERR) and ground stability. 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.

Later this technique was used for investigating the rock slope behaviour at the upstream side of the Naptha dam of NJPC, Himachal Pradesh. A seismic network for monitoring the high stress zones around the power house and other caverns at Tala Hydro-Electric Project in Bhutan and another one for monitoring the vulnerable zones in the crown of powerhouse of Tapovan-Vishnugarh project are still being operated by NIRM. NIRM also monitored and analyzed the seismic events recorded at the Wangkha dam, Bhutan. Some of the classical results of microseismic monitoring activities are illustrated hereunder:

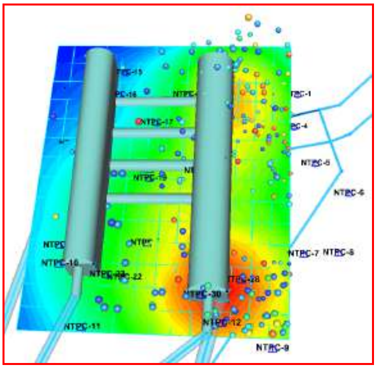




High stress zone before and after induced blasting over a longwall panel at Rajendra mine, SECL (on



Spatial variation of microseismic activity precursor to formation of minor crack inside the rockmass

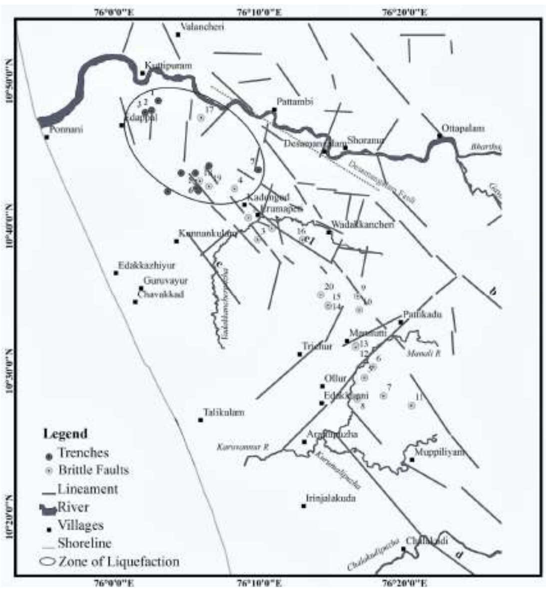


Displacement contour at TVHPP,Joshimath

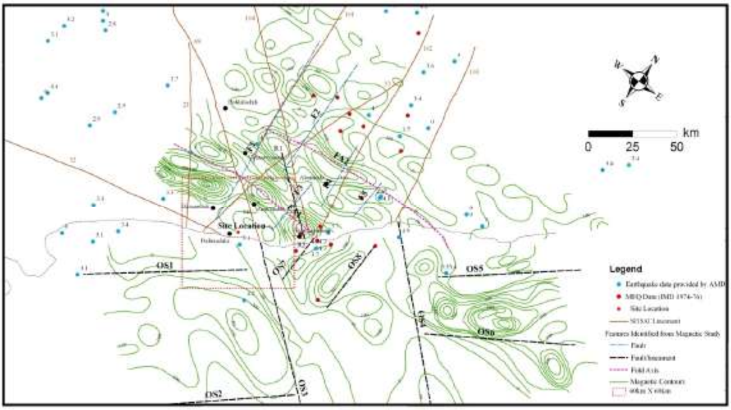
Seismotectonics : NIRM is actively engaged in seismotectonic evaluation for nuclear power sites as per the guidelines of AERB (Atomic Energy Regulatory Board) and IAEA (International Atomic Energy Agency). Seismotectonic evaluation of the region around any major developmental project is a prerequisite for its design. Over the years the Institute has made some path breaking findings related with Indian seismicity. NIRM also formulated a methodology for seismotectonic evaluations for siting nuclear power sites in India. NIRM is equipped with a state-of-art Remote Sensing and GIS Lab and uses Landsat, LISS4, Cartosat stereo, SRTM, Aster etc., images. Geomorphic analysis and lineament map is prepared using ERDAS, LPS and Arc GIS software. The expertise developed at NIRM in the field of seismotectonic studies include :

- Lineament Analysis
- Active Fault Mapping
- Structural Mapping
- Paleoseismic studies
- Tsunami related studies
- Evaluation of pipeline and underground tunnel route
- Seismotectonic evaluation of Dam site
- Seismic Source Characterization

NPCIL, AMD, DST, and MoES are the major funding agencies for the projects being executed by the Seismotectonic Cell. Some of the results of classical works carried out by this group are illustrated below :

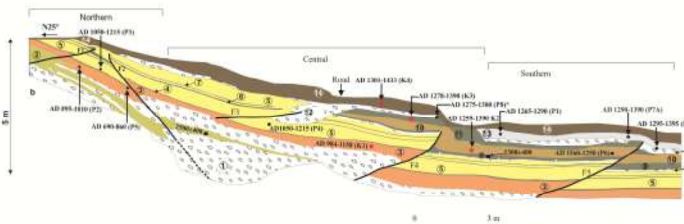


Studies carried out for the identification of potential seismic source zone in Peninsular India



Identified onshore continuity of an offshore fault based on multiple datasets in Andhra Pradesh coast

World's deepest trench studied for the Paleosiesmological evidences



Trench studies exposed two faulting events in Central Seismic Gap in Himalaya

Rock Blasting and Excavation Engineering - Contributions by NIRM

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 has grown exponentially during the past 25 years. Since its inception in 1988, the Rock Blasting & Excavation Engineering Department (RB & EE) is striving for sustainable development of Mining and Civil Engineering projects by providing innovative solutions to challenging problems in blasting for various surface and underground excavations in mining, hydroelectric, infrastructure and other civil engineering projects for more than three decades. 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. It is also involved in projects undertaken pertaining to optimization of blast design to maximise the fragmentation, monitoring blast vibrations and air overpressure for ensuring safe charge limit and advising on controlled blast design with minimum or no flyrock.

With an experienced team of Scientists and equipped with the latest instruments: seismographs, VOD measuring systems, laser based survey systems, fragmentation assessment system, vibration analysis system (Signature hole), state-of-the art software for blast design and digital video camera, this department is carrying out the preparation of blasting related pre-construction reports, method statement, proof checking etc. It has provided technical solutions in more than 200 projects (Sponsored and S&T), published over 120 technical papers and extended their services to more than 105 clients. The department has been organizing customized training programs and workshops to officers of various organisations.

Capabilities (Areas of Expertise)

The major expertise of this department include :

- Blast design for surface and underground excavations and computerised analysis.
- Monitoring and mitigation of ground vibration, air overpressure and flyrock and computerised wave form signature hole analysis for delay sequencing.
- Rock mass damage control and near field vibration monitoring with high frequency triaxial transducers.
- Controlled blasting (urban blasting, metro underground stations, trench blasting, blasting near structures/habitants, dams etc.).
- Special blasting for armour rock, site grading, road and under water.
- Evaluation of explosives performance through in-the-hole continuous VOD monitoring.
- Assessment of fragmentation through Image processing and computerized sieve analysis.
- Suggestions on alternative to blasting and mechanical excavation.
- Problem solving through innovative approaches to evolve site specific solutions

Some typical case studies with safe blasting practices :

➢ Provided technical guidance on controlled blasting at an urban environment at Bangalore in close proximity (20m) to residential buildings. Completed the excavation of 41000 m^3 containing environmental effects of blasting. Enhanced the awareness among the community around the blasting area.

Controlled blasting in an urban environment, Bengaluru, Karnataka

➢ For a nuclear power project at Rajasthan, onsite guidance and solution was provided to accelerate the production and to achieve final stable wall. Figure Illustrates pre-split result of 20 m high wall and in total around 45000 m^2 was successfully pre-split Suggested blast design accelerated the production of about 13 lakhs m^3 of hard rock which was excavated safely within the scheduled time.

Pre-split result of 20 m high wall at nuclear power project (RAPP 7&8), Rajasthan

- Controlled blasting was successfully carried under a railway track with a cover of 4m for the construction of D-shaped twin tunnel of 15.0m diameter at Hospet, Karnataka.

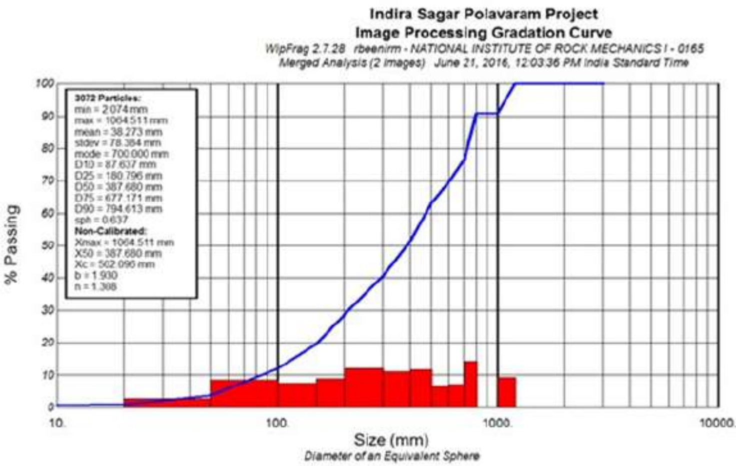
Under construction — Traffic in operation

Controlled blasting under a railway track for the construction of traffic twin tunnel, Hospet, Karnataka

- Blast design was suggested for tunnel portal at left bank abutment of Tala concrete dam, Bhutan. The suggested method has safely excavated without damaging the dam structure

Successful excavation of tunnel at left bank abutment, Tala concrete dam, Bhutan

- Technical Advice on Rip Rap Blasting for the Construction of Earth Cum Rock Filled Dam, Indira Sagar Polavaram Project, Polavaram, Andhra Pradesh.



Sieve Size, mm	2000	1200	1000	600	300	200	150	100	50
Percentage of passing	100%	100%	90.7%	69.5%	40.3%	28.4%	19.5%	12.1%	3.6%

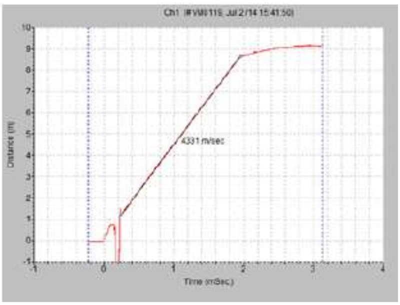
Fragmentation analysis results of a stone quarry

Some site work photographs illustrating various types of blasting projects:

1) Controlled Blasting at Bangalore Metro, BMRCL

Controlled blasting at different underground stations, BMRCL

2) Velocity of detonation measurement at an Opencast Coal Mine, SCCL



Evaluation of explosives performance

3) Blast monitoring for the construction of unit 3 & 4 of Kudankulam Nuclear Power Plant (KKNPP), Kudankulam, Tamilnadu

Blast monitoring adjacent to reactor building, KKNPP, Kudankulam, Tamilnadu

4) Controlled blast design and monitoring blast vibration adjacent to operating powerhouse complex, KSEB, Kerala

Blasting close to operating powerhouse, KSEB

5) Controlled blasting techniques and monitoring ground vibration for mini hydel project, Tungabhadra Dam, Karnataka

Technical guidance on controlled blasting procedure close to Tungabhadra masonry dam, Karnataka

Numerical Modelling Studies for Stability Evaluation in Civil and Mining Sectors

Numerical modelling is a stress analysis technique, which uses the power of modern computers, numerical analysis technique and the principle of mechanics. It is one of the major and widely accepted tools in ‘Rock Engineering’ for design of excavations. The complex nature of rock mass and the associated problems of rock mechanics together form a complex engineering problem. Such 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. 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.

The Numerical Modelling Department at NIRM has a highly qualified and experienced team of geologist, civil, mining and instrumentation engineers, having expertise in providing solutions to varied problems related to excavations in rock. Anticipated rock mass behaviour around an excavation can be reliably predicted using numerical modelling tools based on the latest Finite Element Method (FEM), Finite Difference Method (FDM) and Discrete Element Method (DEM). Department also carries out planning, design and implementation of instrumentation for mines, tunnels, caverns, slopes, dams etc.

Numerical Modelling Methods

Numerical methods of stress and deformation analysis can be divided into two broad categories viz (1) Differential methods and (2) Integral methods. In differential methods, the problem domain is discretised into a set of sub-domains or elements . This method requires that physical or mathematical approximations be made throughout a bounded region.

Finite Element Method, Finite Difference Method and Distinct Element Method of modelling fall in this category. The advantage of this method is that non-liner and heterogeneous material properties can be incorporated. However, these methods take longer solution run times.

In the integral methods, only the problem boundary is defined and discretised. 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. The boundary element method falls in this category. Although, computationally efficient, these method are suited for homogeneous materials and linear material behaviour.

Approaches in 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 modelling of the rock mass e.g., (1) Continuum approach, and (2) Discontinuum approach.

Continuum Approach : Here the rock mass is treated as a continuum and the properties are equal in all directions throughout the model. 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'.

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.

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 in-situ stresses
- Compute
- Visualization and interpretation of the results

At NIRM both Continuum and Discontinuum numerical modelling is carried out using the following software tools :

- FLAC3D
- 3DEC
- FLAC2D
- MIDAS GTS NX
- KUBRIX
- UDEC
- RHINOCEROS
- SPSS

Capabilities (Areas of Expertise)

Today NIRM is equipped with all the latest numerical modelling tools to handle complex rock mechanics problems. It extends its services to various mining, hydel and infrastructure projects. The major expertise of this department (sector-wise) include :

Mining

- Optimisation of stoping parameters and design of supports in metal mines using 3D numerical modelling
- Feasibility of alternative mining methods
- Design of pillars in coal and metal mines
- Design of mining methods below surface structures
- Rock mass characterization studies, and formulation of support plans

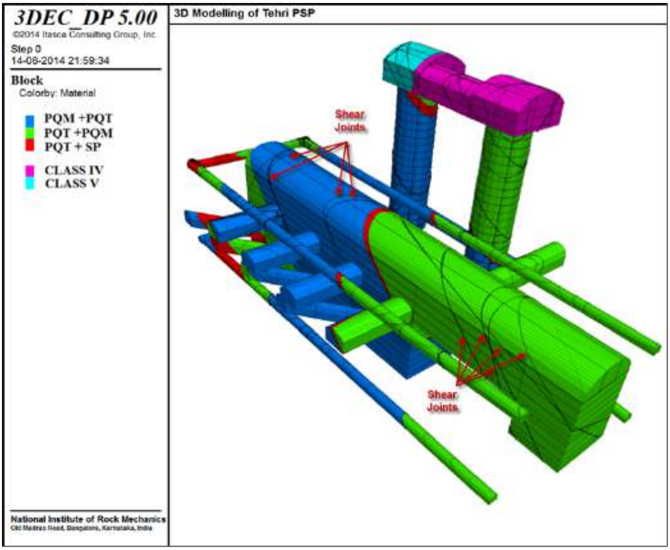
- Design of supports in bord and pillar workings, longwall gate roads
- Prediction of subsidence using numerical modelling and empirical methods
- Instrumentation monitoring and data analysis in coal and metal mining
- Dynamic analysis using 3D models for assessing the rock mass damage
- Audit of ground control management plan
- Assessment of stress and displacement limits based on instrumentation data and 3D models
- Establishing the dimensions of cap rock.
- Slope stability analysis to optimize the ore recovery vis-à-vis safe mining benches
- Design and analysis of dump slopes
- Strata monitoring in underground coal and metal mines

Hydropower /Infrastructure Projects

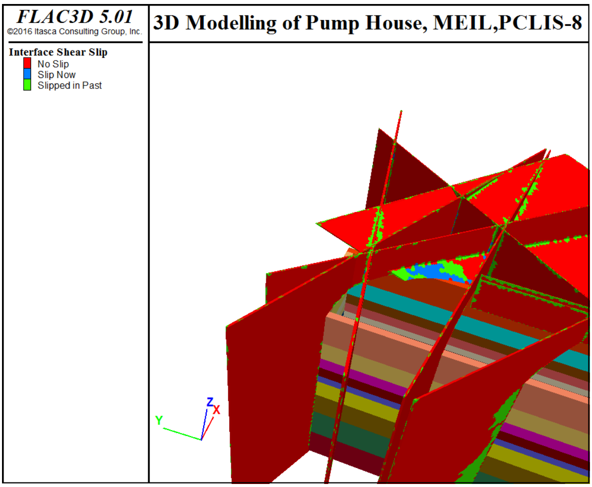
- 3D stress analysis and design of caverns using continuum (FLAC3D) and discontinuum (3DEC) numerical modelling tools.
- Advice on sequence and parameters of excavations during various stages of excavation while excavating single caverns or multiple caverns
- Back analysis of behaviour of rock mass using instrumentation data in tunnels/caverns and 3D models
- Optimum design of temporary and permanent supports for various stages of excavation in tunnels and caverns.
- Planning, design, implementation of instrumentation and monitoring
- Comprehensive analysis of instrumentation data
- Dynamic analysis for structures in seismic or earthquake zones
- Optimum design of cut slopes and stability analysis of landslide prone zones using 3D models and other methods.
- Analysis of creep i.e. time-dependent material behaviour of rock using latest numerical modelling software
- Geological structural analysis of rock mass

Numerical Modelling Case Studies at NIRM

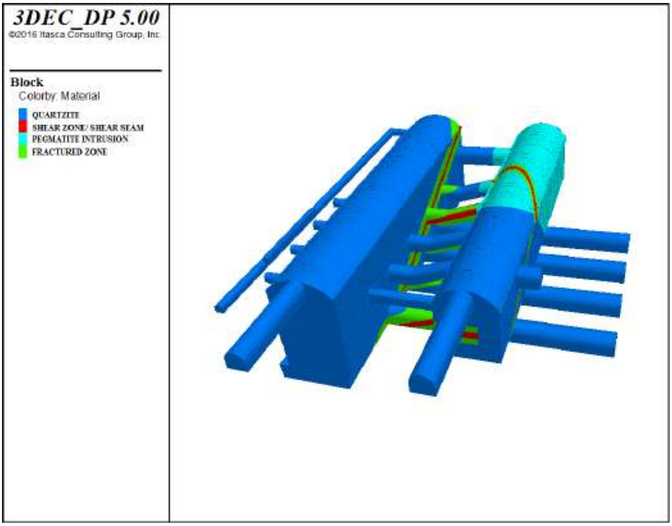
NIRM has worked on several challenging problems in hydroelectric project and mining sectors and offered solution to the problem with the help of extensive three dimensional models. Some of the case studies with illustrated results are shown hereunder.



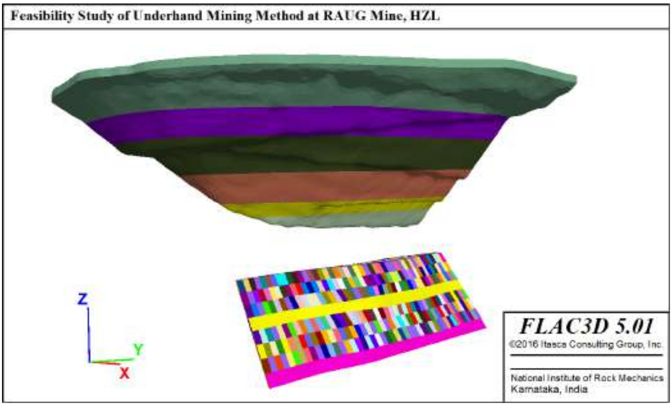
3D discontinuum model of Tehri Pump Storage Powerhouse (PSP)



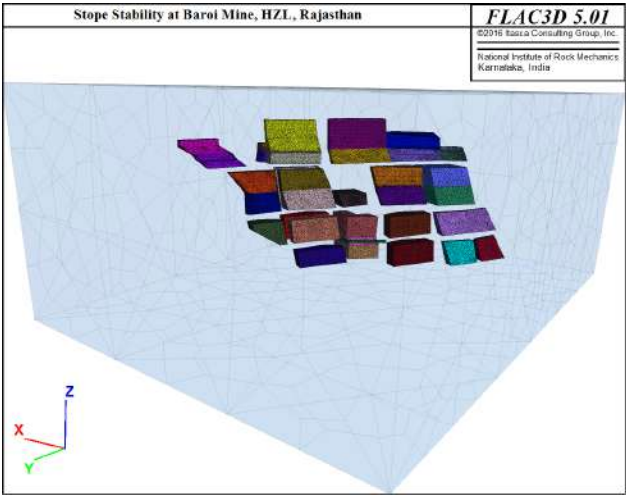
3D view of the shear zones showing “Slip Now” behaviour at location of the roof fall



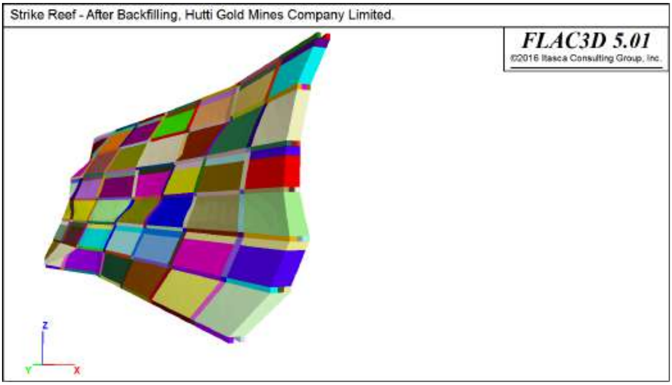
3D model of Mangdechhu powerhouse with different materials assigned



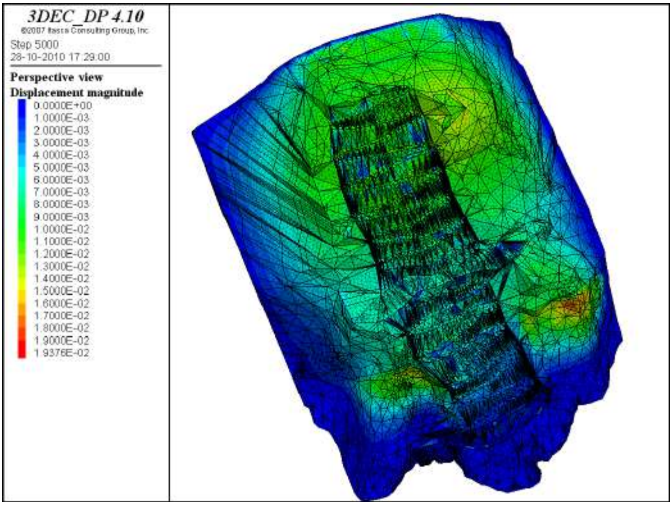
3D model of open cast and underground workings to study the feasibility of underhand mining



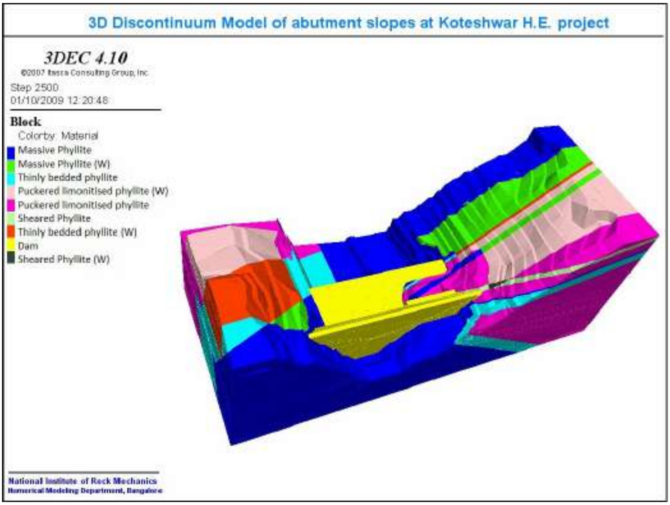
3D model of Baroi Mine, Hindustan Zinc Ltd.



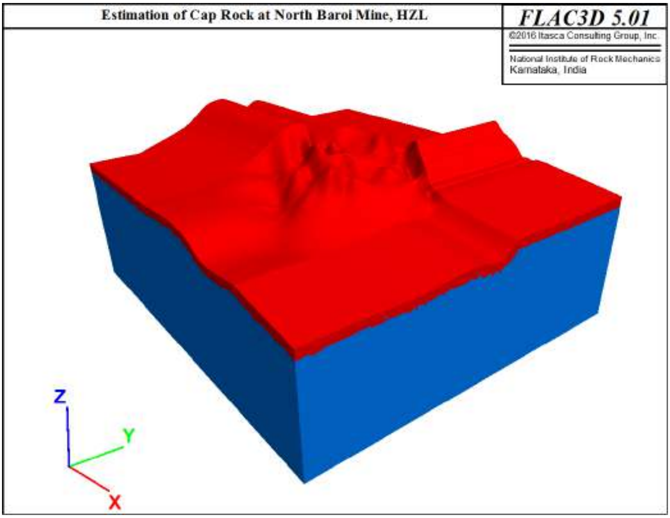
3D model of Strike Reef, Hutti Gold Mines Ltd.



3D model of Varunavat Parvat, Uttarakhand showing displacement magnitude

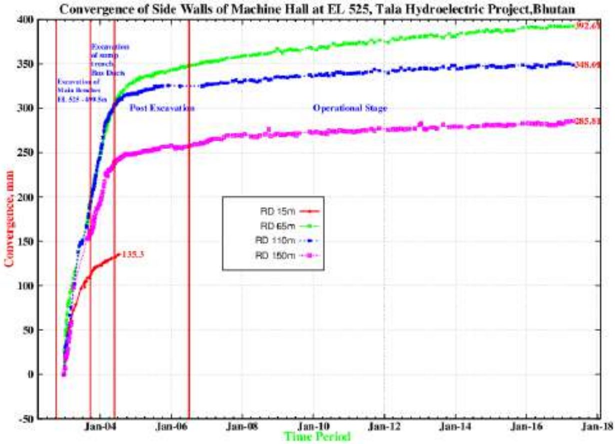


3D model of the left and right abutment slopes at Koteshwar HE Project.

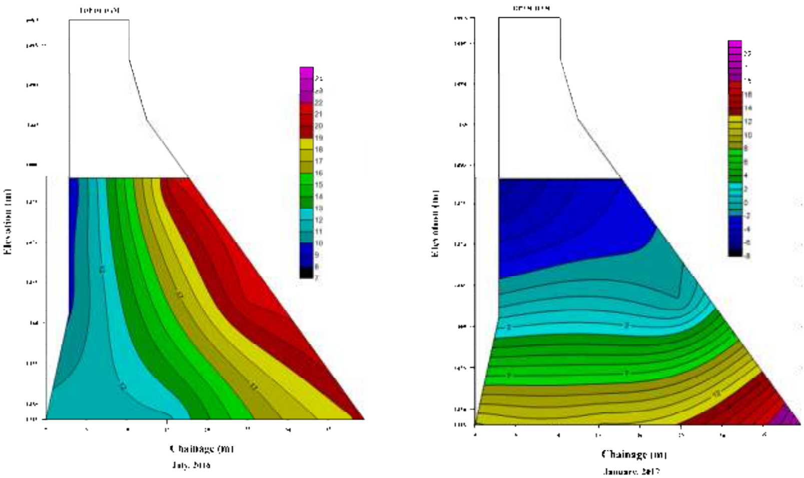


3D model of Baroi mine to establish the cap rock dimension.

Geodetic monitoring of Sardar Sarovar Dam.



Side wall convergence at Powerhouse complex of Tala Hydroelectric Project, Bhutan for a period of 15 years



Temperature gradient in Block 3, Nathpa Jhakri Dam, Himachal Pradesh

Geomechanics and Ground Control

Ground control investigations and support design are essential for safe design of underground mining methods and to validate the designs. The main objective of the department is to contribute to the safe and economic design of excavations (with proper support design), embankments, earth dams, landfills, and spoil heaps. This department is actively involved in rock mass characterization, support design, strata monitoring and design of safe extraction of coal and other different minerals. 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.

Slope stability evaluations are concerned with identifying critical geological, material, environmental, and economic parameters that will affect the project, as well as understanding the nature, magnitude, and frequency of potential slope problems. The areas of the involvement (working areas) of the department are given below:

- Mine design
- Underground subsidence, monitoring and instrumentation
- Optimization of pit slope parameters.
- Slope stability studies in coal mines, iron ore mines, limestone mines etc.
- Feasibility of extraction of locked up ore opencast benches by innovative methods.
- Design of waste dump slopes.
- Stability analysis of waste dump slopes.
- Optimization of blasting parameters in opencast mines.
- Monitoring and mitigation of ground vibration, air overpressure and flyrock and computerized wave form signature hole analysis for delay sequencing in opencast mines.

- Blast design and computerized analysis.
- Evaluation of explosives performance.
- Assessment of fragmentation and computerized sieve analysis

Capabilities of the Department

The department is pioneer in conducting various scientific studies and providing solutions on various issues related to mining industry. Capabilities of the department include :

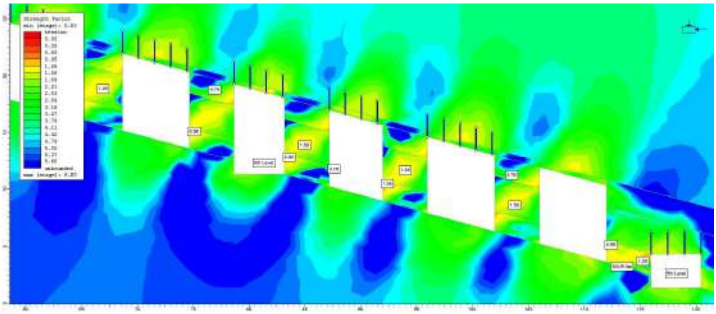
- Dimensional stone mining (Granite, Marble, Sandstone, Slate, etc) – total package studies, including feasibility studies, design, methods of extraction, controlled blasting, controlled splitting, strata classification, slope stability, Environment Impact Assessment, laboratory testing, training of personnel etc,
- Geological studies and site investigation procedures
- Design and implementation of the support systems for underground openings
- Characterisation of critical aspects of various types of slope stability problems
- Stability of Underground openings and structures
- Surface subsidence, and extraction under surface structures in mines
- Strata monitoring in underground mines
- Assessment of the cavability of roof strata
- Strata control investigations and support monitoring in longwall panels

These mining projects are very expensive and involve high risks. An understanding of the rock stresses and deformations by analyzing the instrumented and monitored behaviour 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 data would provide a realistic warning signal of potential budding problems for planning proper counter measures.

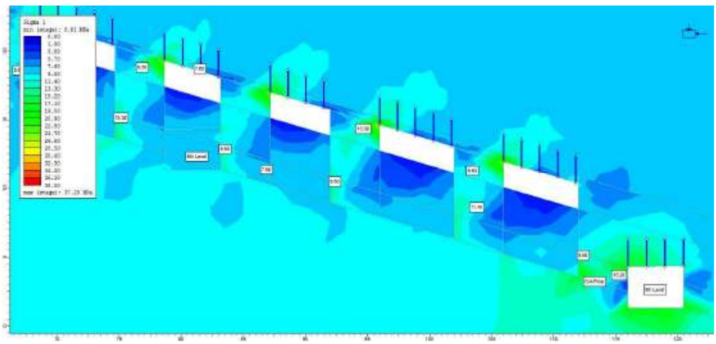
Available software : For executing projects, numerical models are made to run with the available physico-mechanical properties of the soil sample. To run such models software like Galena 7.0, RS2 , RS3 , FLAC 2D/3D etc are used. These helps in the scientific studies in the design of slopes, to assess the slope stability, to recommend optimum design for pit slope and bench geometry and monitoring of slopes and waste dumps.

Case Studies Illustrated :

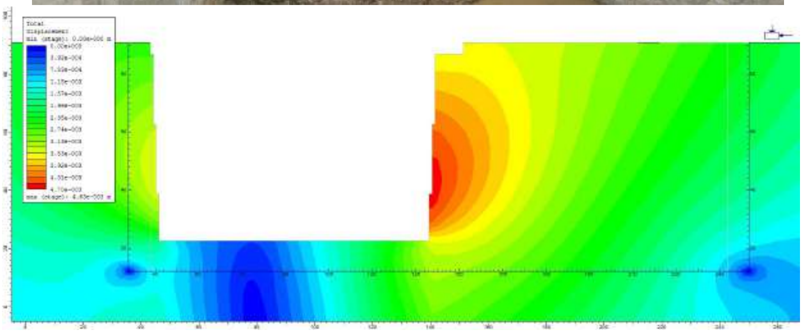
The department carried out strata and support monitoring in a number of mining projects by installing various types of instruments, and monitoring the rock mass and excavation behaviour with time and with progress of the excavation/construction. Results of some of such case studies are illustrated below :



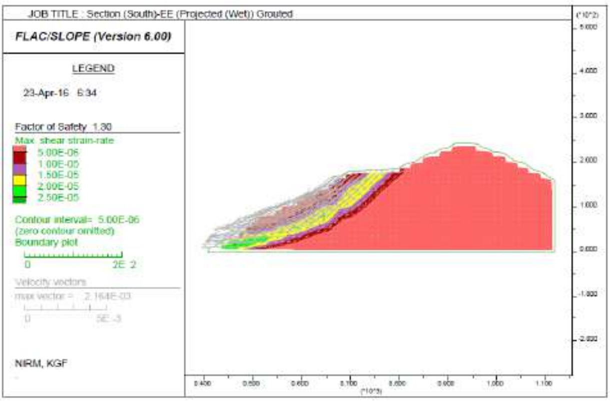
FoS Values around the pillars after FW, Parting & HW lode mining without backfilling.



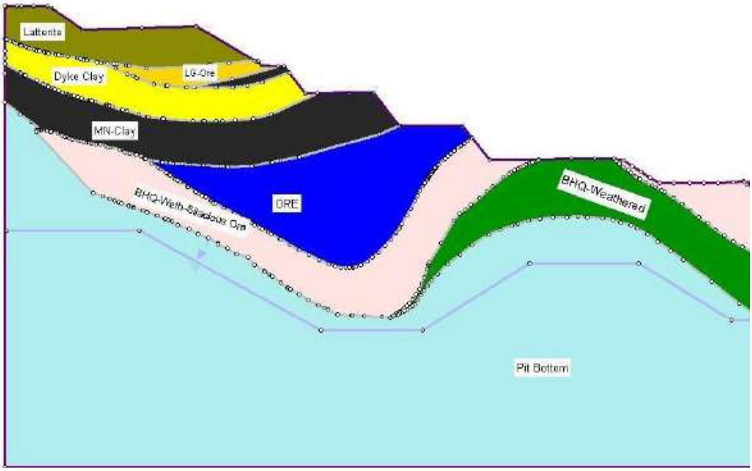
Mining Induced Stresses around the remnant pillars after FW lode, Parting & HW lode mining with back filling of FW lode & Parting



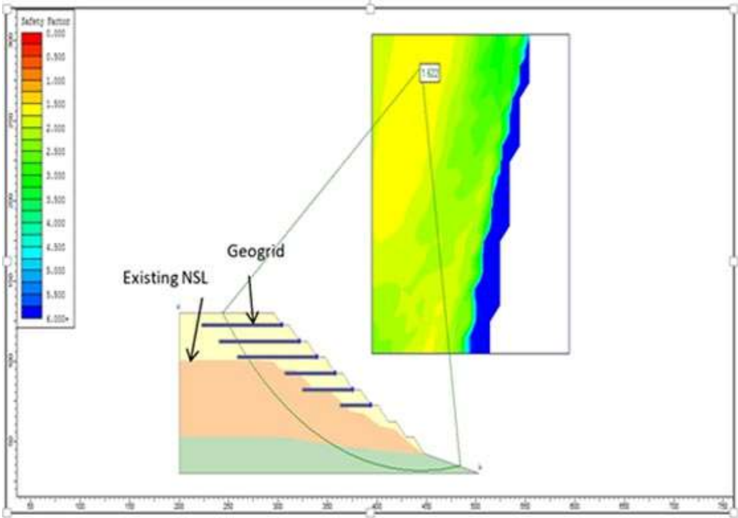
Maximum displacement across a section of the above granite quarry



Stability analysis of a critical section of dump slope with Permeation Grouting

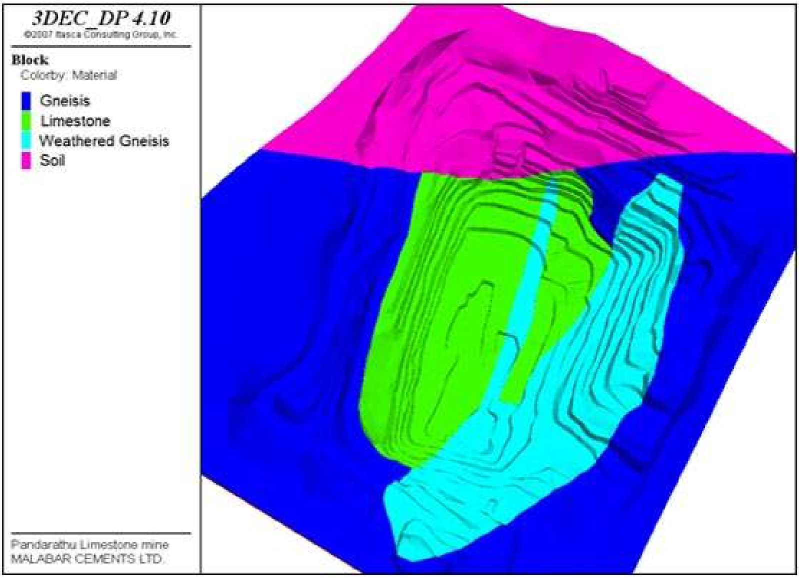


Numerical modelling analysis for ultimate pit slope angle



Factor of Safety for a dump section with geogrids – Limit Equilibrium Analysis

Sample collection for slope stability analysis at an opencast mine site



3D Model of a limestone mine for Slope Stability Analysis

Centre for Testing Services

In today's industrialised world, aerial ropeways, lifts, conveyor belt drivers, winders, cranes etc. have become a basic necessity. Their daily usage involves high risk unless they are periodically certified as safe after subjecting them to necessary tests and following thorough safety/quality measures. Several accidents occur due to non-compliance of safety norms. 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. Centre for Testing Services (CTS) at NIRM basically caters to this field. It is a 'National Testing Facility' with DGMS approved laboratories for testing and certification of various mining components. The Materials Testing Laboratory (MTL) at NIRM has state-of-the-art facilities and infrastructure to carry out tests as per various standards, such as BIS, ISNT, ASME and statutory regulations including DGMS guidelines. It is one of the unique laboratories in India equipped with all the testing facilities to conduct both Non-Destructive and Destructive Testing. It is the prime centre of excellence located at the Registered Office of NIRM at Kolar Gold Fields. It is equipped with the state-of-the-art facilities and manned by trained and experienced professionals. It has capabilities to provide the clientele with accurate and reliable results in par with international standards mainly in the following areas:

- Destructive tests and
- Non-destructive tests

While most of the destructive testing is done at our laboratory, the non-destructive testing is done both at our laboratory as well as at site in in-situ conditions on various mining components and wire ropes. The destructive tests are conducted on steel wire ropes (diameter range from 8 to 55 mm) conforms to the procedures laid out as per BIS and other national and international standards. The breaking load of steel wire rope samples sent from various mining companies is determined periodically at CTS to determine the residual life of the wire rope. In addition to this, tensile tests, reverse bend tests and torsion tests are conducted on individual wires of the rope samples to determine the change in parametric values.

Proof Load and Break Load Tests which too are destructive in nature are carried out to assess the quality of manufacture, efficiency and efficacy parameters of components such as steel wire ropes, chains, links etc. CTS has well chalked out expansion plans in the area of safety training, safety audit, certification, research and development of safety bench marks for mining, civil and petroleum sectors.

Material testing laboratory of NIRM

The non-destructive tests carried out for assessing the hidden flaws and defects on vital components used in the industry. They comprises different methods such as visual testing, dye-penetration testing, ultrasonic flaw detection and magnetic particle testing. These tests are requisites for the safe working of mining and allied industries as per ASTM and Indian standards. Winders, vital mining machinery components, heavy earth moving machineries, large ore/coal handling plants etc are subjected to these NDT tests.

Wire rope defectograph studies are conducted on ropeways, transport systems for men/material movements in underground mines, inclines, passenger car transport systems at hydro-electric project sites, hill stations and pilgrim centres etc., in accordance with prescribed safety standards. This microstructure study of wire rope and structural studies of the various components used in mining and ancillary industries will be the salient feature of testing in the years to come.

Most of the equipment at CTS are now upgraded with new and latest models to provide efficient services to all the stakeholders. With this addition of modern facilities and latest equipment, the laboratory is poised to be in the fore-front of testing services in India. Over the past 30 years, CTS has catered to the needs of more than 150 companies which includes almost entire spectrum of mining industry and various other service sectors like rail, aerial ropeways, transport etc.

A systematic programme for monitoring and assuring the quality of ropes, winders and support conveyors used for various applications including transportation of men and material in civil and mining industries is adopted. Some of the testing work being carried out by this department both in the laboratory and under in-situ condition at the field are illustrated below :

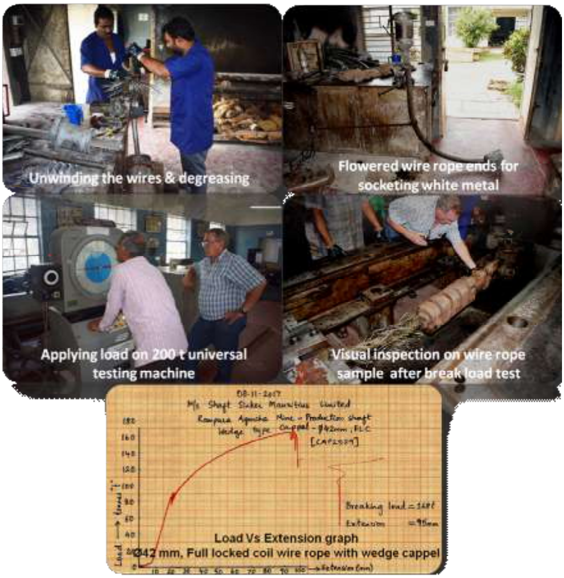
Illustrated testing services :

A view of the Palani temple Haulage Winch with bogies evaluated by CTS-NIRM using NDT and Defectograph studies

Non destructive evaluation of a 80 Hp Winch in Tamilnadu

Infrared Thermography studies on an Aerial Rope Way system, Shimla

Investigation on cage suspension gear parts& wire ropesof Chasnalla Mine



Sequence of tests on service &production hoist components of M/s SSML

Load cell test setup and cyclic loading of200 t load cell

Conducting non-destructive tests on mine machineries.

Rock Fracture Mechanics : Apart from materials testing laboratory, Rock Fracture Mechanics Laboratory too is an integral part of the Centre for Testing Services (CTS). It caters to the testing of roc samples as per established Standards. This lab is equipped with the state-of-art facilities for determining various physico-mechanical properties of the intact rock as well as on rock joints.

Intact Rock properties determined:

- Physico-mechanical properties of rocks, such as: Density, Bulk Specific Gravity, Porosity, P-Wave Velocity, Water Absorption, Water Content, Void Index, Porosity, Permeability, Hardness and Slake Durability, Uniaxial Compressive Strength, Tensile Strength, Elastic Constants, Cohesion, Friction Angle, Elastic Constants under triaxial stress condition, Tensile Strength, Shear Strength, Point Load Strength Index and Fracture Toughness.
- Joint properties, such as: Tilt Angle, Basic Friction Angle and Residual Friction Angle, Joint Roughness Coefficient and Joint Wall Compressive Strength, Peak Shear Strength, Normal Stiffness and Shear Stiffness, Cohesion and Friction Angle.
- Properties of dimensional stones including: Density, Bulk Specific Gravity, Absorption by Weight, Porosity, Permeability, P-Wave Velocity and Hardness. Compressive & Tensile Strengths, elastic constants, Flexural Strength, Modulus of Rupture, Abrasion Resistance and Rupture Energy.
- Post failure studies under uniaxial and triaxial stress conditions.

Major Equipment

- Rock block cutting and polishing machine, Rock core drilling, cutting and surface grinding machine
- 150 ton MTS computer controlled compression testing machine, 200 ton tensile testing machine, 300 ton compression testing machine, Triaxial cell (Hoek and SBEL), Direct shear testing machine for rock joints
- P-wave velocity measuring instrument, Hardness tester, Polarizing microscope, Acoustic emission monitoring system

Specialized facilities:

- Deformation under uniaxial and triaxial stress conditions at elevated temperature (up to 150°C).
- Post failure studies under uniaxial and triaxial stress conditions.
- Multiple failure triaxial compression tests.

- Testing of dimensional stones as per ASTM, European Standards.
- Fracture toughness as per ISRM standard (Level I & II).
- Rock joint testing

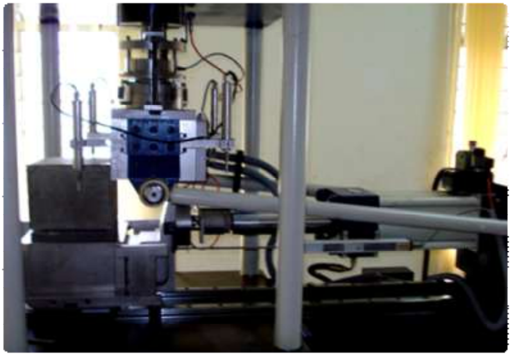

150T MTS Servo controlled Testing Machine and Triaxial Testing Equipment



Set-up for various types of tests on rock samples

P & S Wave velocity measuring equipment

300T Compression Testing Machine



Direct Shear testing Equipment

Acoustic Emission Sensor

Soil Mechanics : Soil Testing is an integral part of soil mechanics and foundation engineering. A proper evaluation of soil samples and analysis of test results are essential to determine physico-mechanical properties of soil which will act as the input parameters in simulation of numerical models and execution of various S&T and Consultancy projects. The soil mechanics laboratory is equipped with the most modern facilities to carry out basic research on soil mechanics and determining the engineering properties of soils as per the international standards. With the facilities available, the following are the tests carried in the laboratory.

- Soil Moisture Content
- Soil Specific Gravity
- Soil Particle Size Distribution (Sieve Analysis)

- Soil Atterberg Limits
- Soil Permeability
- Field Density by core cutter method and sand replacement method
- Soil Direct Shear Test
- Soil Unconfined Compressive Strength
- Soil Triaxial Compression
- Shrinkage limit and shrinkage ratio of the soil.
- Shear strength of the soil by Undrained Triaxial Test.
- Shear strength of the soil by drained Triaxial Test.
- Bearing capacity of soil by Plate load test.
- Penetration value of given as soil by the SPT method
- Relative density of given coarse grained material.

Laboratory setup of Direct Shear Testing Machine

Static Triaxial Testing Machine available in Laboratory

* * *

Important Contacts

Dr. H S Venkatesh
Director

Telephone: 080-26934400 (Direct);
080-26934402 (PA) Fax: 080-26934401
Mobile: 9845176287 **e-mail :** dto@nirm.in

Sl. No.	Department	Head of Department	Telephone (Office/ Mobile)	e-mail
1.	Engineering Geology	Dr. A K Naithani	080-26934411/ 9481434153	egd.nirm @gmail.com
2.	Engineering Geophysics	Dr. P C Jha	080-26934407/ 9448044647	egp.nirm @gmail.com
3.	Geotechnical Engineering	Dr. D S Subrahmanyam	080-26934415/ 9448402572	ged.nirm @gmail.com
4.	Centre for Testing Services	Mr. A Rajan Babu	08153-275000/ 9845188807	cts.nirm @gmail.com
5.	Numerical Modelling	Dr. Sripad R Naik	080-26934408/ 9449225973	nmd.nirm @gmail.com
6.	Rock Blasting & Excavation Engg.	Dr. H S Venkatesh	080-26934409/ 9845176287	rbee.nirm @gmail.com
7.	Geomechanics & Ground Control	Mr. A Rajan Babu	08153-275000/ 9845188807	ggcd.nirm @gmail.com
8.	Engineering Seismology	Mr. C Sivakumar	080-26934412/ 9036681157	csk.nirm @gmail.com

Notes

National Institute of Rock Mechanics
(Ministry of Mines, Govt. of India)
Outer Ring Road, Banashankari II Stage
BENGALURU – 560 070
Regd. Office : Champion Reefs
Kolar Gold Fields - 563 117

Head Office @ Bengaluru
Phone : 080-2693 4401-4415
Fax : 080-2693 4402

Regd office @ KGF
Phone : 08153 275001
Fax : 08153 275002

Web : https://www.nirm.in
e-mail: dto@nirm.in