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Abstract of PhD Theses

Abstract 1:

Title of Thesis: Applicability of Unlined/Shotcrete Lined Pressure Tunnels for Hydropower Projects in the Himalaya

Name of PhD Candidate: Chhatra Bahadur Basnet
Supervisor: Prof. Dr. Krishna Kanta Panthi, NTNU, Norway
Year of Award: 2018
University/Institute: Norwegian University of Science and Technology (NTNU), Norway

Abstract

Nowadays, unlined or shotcrete lined pressure tunnels and shafts are used in hydropower projects worldwide. The prime requirements for these tunnels and shafts are that they should be economically attractive and should be able to operate without any significant problems in the long run. The concepts and design principles behind these conduits developed from the Norwegian planning, design, construction and operational experiences have been crucial for their successful implementation. However, by virtue of the different topographical, geological and tectonic environment of the Himalaya than that of the Scandinavia, the implementation of unlined pressure tunnels in the Himalaya has been emerging as a challenging issue. As a matter of fact, it was realized that a clear gap exists between the success of the unlined pressure tunnel concept in Norway and the challenge of its implementation in the Himalaya. To fulfill this gap, this PhD research project was formulated to study the possibility of implementing the unlined or shotcrete lined pressure tunnels in the Himalaya.

First of all, the economical attractiveness of the shotcrete lined pressure tunnel of the Himalayan hydropower projects was evaluated. Since the tunnel roughness is one of the decisive parameters for cost effectiveness, a methodology was developed to estimate the roughness of shotcrete lined tunnel. It was found that the shotcrete lined tunnels are one of the economically attractive solutions in the waterway system of hydropower projects. The PhD work further reviewed the Norwegian design principles for unlined pressure tunnel and their applicability in different topographical, geological and tectonic environments. The review process revealed that in an unlined tunnel, the confining pressure from the rock mass should be able to counteract the water pressure inside the tunnel for the safety of unlined tunnel against hydraulic jacking of rock mass. To estimate the confining pressure, the Norwegian confinement criteria use both vertical and lateral rock covers. In addition, the state-of-the-are stress criterion states that the magnitude of minimum principal stress in the rock mass gives limiting confining pressure to counteract the water pressure.

The Norwegian design concepts and criteria were then applied to Upper Tamakoshi Hydroelectric Project (UTHP) in Nepal. The extensive assessments were carried at the UTHP concluded that the good quality rock mass with tight joints is suitable for unlined / shotcrete lined tunnel provided that the stress requirement is fulfilled. However, the PhD research further concluded that the presence of weakness zones, local shear bands, unfavorable jointing, and destressed area had made the use of unlined / shotcrete lined tunnel more challenging. Even though the Norwegian confinement criteria showed that the headrace tunnel alignment is safe for unlined tunnel concept, the detailed rock engineering assessment, stress state analysis, fluid flow and leakage analyses indicated some critical locations along the headrace tunnel alignment which are still vulnerable for the unlined / shotcrete lined tunnel concept. The analysis showed that the weakness zones considerably attenuate the in-situ stress state and the open joints, the joints filled with silt and clay having low stiffness are vulnerable for hydraulic jacking and water leakages even though the stress conditions are fulfilled. The PhD thesis finally highlighted the need for the modification of the Norwegian confinement criteria for unlined tunnels in order to successfully apply in the Himalayan rock mass conditions so that presence of complex topography, geology and tectonic environment of the region are well covered.

Abstract 2:

Title of Thesis:	Integrating Computer Vision, Drone Technology, and Virtual Reality for Developing a Realtime Monitoring framework to Optimize Dragline Operational Environment in Large Surface Coal Mines
Name of PhD Candidate:	Piyush Singh
Supervisor(s):	Prof. V.M.S.R. Murthy, Supervisor, IIT (ISM) Dhanbad, India Prof. Dheeraj Kumar, Co-Supervisor, IIT (ISM) Dhanbad, India Prof. Simit Raval, External Supervisor, The University of New South Wales, Sydney, Australia
Year of Award:	2024
University/Institute:	Indian Institute of Technology (Indian School of Mines [IIT (ISM)], Dhanbad, India

Abstract

This thesis investigates the integration of drones, LiDAR, photogrammetry, and VR/AR in surface mining, focusing on dragline operational area. It introduces the use of 3D computer vision for automating point cloud data classification and analysis. The research uses experimental setups and brings advanced technologies for monitoring dragline mining areas, especially dragline dumps and operational areas, in real time. The thesis also explores using 2D computer vision AI, explicitly employing the YOLO (You Only Look Once) algorithm, for real-time monitoring and managing spoil pile heights in dragline dumps. The system's effectiveness is demonstrated through high F1-confidence and mAP scores, validated against traditional photo grammetry methods, including SFM-MVS & NeRF, showcasing its capability as a viable and efficient alternative. This AI-driven approach ensures optimal in-pit volume use and enhances safety by maintaining stable and safe

dump heights. A key achievement of this research is developing a tool that offers virtual walkthroughs of the Singrauli open-cast mine, managed by Northern Coalfields Limited (NCL), focusing on the dragline areas. This immersive tool aids in mine inspection and improves communication between engineers, designers, and project teams, allowing for a detailed examination of the bench face angle and proactive prevention of accidents related to dump failure. Even VR technology can enable mining engineers to perform extensive virtual reconnaissance surveys of the dragline area before fieldwork. At IIT (ISM) Dhanbad, the developed simulator workbench facilitates virtual navigation to the mining site, complete with measurement tools for evaluating ground conditions and assessing slope failure risks. The developed simulator uniquely combines drone-derived terrain data using SfM to produce photorealistic point clouds. It enhances georeferenced data manipulation and geometric measurements, offering a superior alternative to traditional visualization tools for mining planning. In conclusion, this thesis corroborates the potential of utilizing drone technology, LiDAR, photogrammetry, computer vision, and VR/AR with AI analytics for advancing dragline monitoring solutions. The implications of this research extend beyond theoretical innovation, offering practical solutions and operational improvements for the mining industry, setting a new benchmark for safety, efficiency, and productivity in dragline surface mining operations.

Abstract 3:

Title of Thesis:	Stability Evaluation of Hill Slopes: New Perspectives to Rock Material and Rock Mass Characterization
Name of PhD Candidate:	Jagadish Kundu
Supervisor(s):	Prof. Kripamoy Sarkar, Supervisor, IIT (ISM) Dhanbad, India Prof. T.N. Singh, External Supervisor, IIT Bombay, India Prof. A. K. Verma, External Co-Supervisor, IIT Patna
Year of Award:	2020
University/Institute:	Indian Institute of Technology (Indian School of Mines [IIT (ISM)], Dhanbad, India

Abstract

Instability of hill slopes is a worldwide phenomenon which directly or indirectly affects life, property and environment primarily caused by gravity and triggered by various natural and anthropogenic factors. Hence, stability evaluation of hill slopes is paramount due to its direct association with social or economic infrastructures and risk to human lives. The degree of failure susceptibility of hill slopes depends upon the micro-scale to macro-scale parameters of slope masses. It is difficult to establish a single methodology to evaluate the stability of any Earth (rock, soil or composite) slope and to detect the landslide-prone zones, as instability depends upon a vast spectrum of causative factors including both intrinsic and extrinsic phenomena. In case of rock masses containing discontinuities, its geometrical arrangement with the surface morphology plays a vital role in the stability of engineered or natural rock slopes. Depending on the type of rock mass and scale of investigation, there are different methodologies based on empirical, geometrical, analytical or numerical approaches to determine the stability of vulnerable rock masses. All the diverse causative factors involved in landslides make it difficult to investigate the stability or

susceptibility of a natural or engineered slope. There are also limitations observed in some of the popular geometrical and empirical methods that are frequently used for rock mass stability evaluation. Therefore, this thesis aims to give possible solutions to specified problems; intended to make the characterization and stability analysis of rocky hill slopes effective and easier by extending, modifying and, computerizing some of the popular geometric and empirical methods. Consequently, the thesis presents new or modified analysis, methods, and digital tools to improve rock material characterization, hillslope stability analysis, and preliminary detection of vulnerable landslide zones on jointed rocky slopes. Major objectives that are addressed in this thesis are; (i) Strength anisotropy characterization in lineated rock materials. (ii) Development in methods and tools for convenience and accuracy in the determination of RMR and SMR (iii) Determination of regional stability of hilly region in a GIS environment (iv) Improvement in landslide susceptibility zonation for jointed rock slopes.

Field investigations were carried out majorly along the National Highway (NH - 05) in the young and tectonically active Himalayan hill slopes of Himachal Pradesh, India. The study area, especially along NH – 05, is highly prone to discontinuity-driven slope failures which contain various rock types such as quartzites, schists, gneisses and amphibolite. Micro and mesoscale rock parameters play a vital role in the instability of anisotropic rock masses in surface and subsurface conditions. Therefore, the anisotropic geomechanical and fracture behaviour of the lineated schist rock has been investigated. Investigation shows that inherent strength anisotropy is due to the characteristic preferred orientation of platy minerals such as mica. Though planar anisotropic behaviour of foliated rocks is well known in dry condition, little attempt has been made to examine its behaviour in a saturated state. When it comes to lineated schistose rock, a comprehensive investigation of strength behaviour and fracture pattern is very limited in the literature. So, lineated schistose rock has been investigated in the unconfined and confined conditions under both dry and saturated states. The rock cores for the experiments were drilled from blocks of rock samples in seven different directions, i.e. (0°, 15°, 30°, 45°, 60°, 75° and 90°) from which standard cylindrical and disc specimens were prepared, tested and analyzed under Brazilian tensile, Uniaxial and low confining Triaxial compression conditions.

The thesis has proposed modifications and enhancements to rock mass classification systems, namely Rock Mass Rating (RMR) and Slope Mass Rating (SMR). The subjective RMR parameters which need an expert judgement for the accurate ratings have been quantified by suggesting continuous functions for the lump ratings of each parameter in the two frequently used versions of RMR, i.e. RMR89 and RMR14. Roughness and weathering, two entirely descriptive and subjective sub-parameters in the RMR system, have been quantified using Joint Roughness Coefficient and indices of surface weakening. To ease the computation process through proposed continuous functions, a windows application with a graphic user interface, named “QuickRMR”, has been developed for both RMR89 and RMR14. A modified technique for kinematic analysis of curved jointed hill slope using stereographic projection method has also been proposed considering undulating curvature of slope faces along hilly highways. SMR is a well-known Rock Mass classification system to determine the stability condition of natural or excavated rock slopes intersected by discontinuities. However, manual calculation of SMR is tedious and time-consuming; particularly, when a large number of joints are involved. Therefore, a graphic user interface-based windows computer application named “EasySMR” written in C# language has been developed to automate and ease the calculation process. The application determines the kinematic stability of the slope along with simultaneous SMR calculation. The study also gives an insight into the SMR of single-plane wedge failure and the same is implemented in the computer application for correct SMR calculation. Finally, the hill (rock) slope stability evaluation on a regional scale has been assessed through kinematic analysis and SMR rating of the region with the help of GISMR, a computer application developed by the author. The effect of discontinuity-driven failures on

Landslide Susceptibility Zonation (LSZ) has also been studied to more precisely and rapidly predict the vulnerable hilly rock slopes. The algorithms of GISMR are based on pixel-based computation and are capable of determining kinematic stability, Slope Mass Rating (SMR) and optimized slope angle for construction of safe engineered rock slopes. The kinematic analysis has been modified to give a failure susceptibility percentage of a pixel rather than a crisp value of 0 or 1 (which means either fail or do not fail). The application works on a four-stage method; (1) Defining structurally homogenous zones, (2) categorizing the discontinuities into different sets based on orientation similarity (3) Interpolation of discontinuity data inside each of the zones, and (4) finally, kinematic Susceptibility and SMR assessment. The developed application has been validated in the landslide-prone study area. A landslide inventory was prepared based on multi-temporal observation of Google Earth Images, and the results from the regional stability analysis have been validated using the frequency ratio method. The resultant kinematic susceptibility and SMR layer have been used as additional factors for making Landslide susceptibility zonation (LSZ) map. A significant increase in the accuracy of the LSZ map is observed with the addition of discontinuity failure susceptibility layers.

Abstract 4:

Title of Thesis:	Stress and Deformational Behaviour of Weak Jointed Rock Mass During Tunnelling
Name of PhD Candidate:	Ratan Das
Supervisor(s):	Prof. T.N. Singh, Supervisor, IIT Bombay, India
Year of Award:	2019
University/Institute:	Indian Institute of Technology Bombay, India

Abstract

The growing demand for sustainable urban development necessitates increased use of underground facilities, particularly for transportation and environmental preservation. The stability of underground excavations depends on factors such as the size and shape of openings, in-situ stresses, induced stress fields, and the associated deformations. Understanding the stress distribution around tunnels is crucial for their safe and economical construction. This study examines the stability of two asymmetric tunnels in the Kainchi-mod Nerchowck area of Himachal Pradesh, India, focusing on the impact of topography, geometry, and rock-support interaction. The host rock in the study area consists mainly of medium to highly jointed grey sandstone, maroon sandstone, and siltstones. Unlike equidimensional tunnels, where maximum subsidence occurs vertically above the tunnel centerline, the results reveal a shift in maximum subsidence, attributed to undulating topography and non-circular tunnel shapes. The study employed the finite element method to assess the effects of joint spacing and orientation on the size and shape of the disturbed zone around tunnels. Numerical simulations revealed that jointed rock masses create a progressively enlarging disturbed zone, eventually forming failure zones like roof collapses. Variations in joint orientation and stress states significantly influence the size and extent of the EDZ, providing critical insights into loose block failure patterns and shear zone development.

A tunnel physical model test was also performed. Acoustic emission techniques were used to monitor the progressive failure of rock tunnels under uniaxial loading. Tests conducted on homogeneous sandstone blocks with intact, horizontal jointed, and vertical jointed configurations revealed distinct failure behaviors. Intact blocks showed continuous crack propagation, while horizontal jointed blocks exhibited stepwise cracking. Vertical jointed blocks demonstrated deformation along joint-parallel extensions. AE analysis identified a sudden drop followed by a

quiet period as precursors to rock burst hazards, with b-value changes indicating impending failures. These findings were corroborated through finite element simulations. The influence of rock bolt parameters, such as length and diameter, on tunnel stability was assessed using finite element analysis for three jointing systems: Type A (normal joint closure), Type B (normal and shear joint closure), and Type C (predominantly shear-loaded joints). Increasing bolt diameter significantly reduced tunnel boundary displacement, while bolt length had a minimal impact. This suggests that optimizing bolt diameter can reduce costs without compromising stability. The study highlights the importance of accounting for topography, tunnel geometry, and rock mass characteristics in underground construction. It emphasizes the role of advanced physical modeling, numerical simulations, and acoustic monitoring in understanding tunnel behavior and ensuring safety. The findings on rock bolt optimization offer practical solutions for cost-effective tunnel reinforcement. Overall, the research contributes to the development of strategies for sustainable and resilient underground infrastructure.

Abstract 5:

Title of Thesis:	A Stability Assessment of Geoengineering Materials in West Coast Maharashtra: Ensuring Highway Infrastructure Resilience
Name of PhD Candidate:	Anurag Niyogi
Supervisor(s):	Prof. Kripamoy Sarkar, Supervisor, IIT (ISM) Dhanbad, India Prof. T.N. Singh, External Supervisor, IIT Bombay, India
Year of Award:	2022
University/Institute:	Indian Institute of Technology (Indian School of Mines [IIT (ISM)], Dhanbad, India

Abstract

The Western Ghats in India are known for their distinctive mountainous landscapes, but slope instability is a significant cause of landslide hazards. Excavated slopes of rock and soil are associated with rockfall, debris slide, and soil creep. Factors such as unplanned excavation, precipitation, and intrinsic parameters play a crucial role in destabilizing slopes. High precipitation actively degrades geomaterials, leading to weathering-related failures. This PhD research focused on rock and soil-debris slopes with differential weathering intensities on National Highway (NH) 66, passing through Ratnagiri-Sangameshwar, which is facing severe threats from crumbling unstable geomaterials falls in the Deccan Volcanic Province of Maharashtra. Geochemical analyses were used to quantify weathering grades. Rock slopes were evaluated using kinematic analysis, and different Geo-Engineering Classification (GEC) systems were used to classify locations. The mode of failure potentialities and rock quality were assessed.

A new class in Rock Deterioration Assessment (RDA) was introduced for igneous rocks susceptible to high deterioration. Soil-debris slopes were characterized based on influencing parameters of soil material affecting their stability. Software-based stability assessments have improved understanding of slope stability mechanisms and failure stature. Selective Limit Equilibrium Methods (LEM) and Finite Element Method (FEM) simulation techniques have been used to assess failure potentiality in soil-debris slopes. Rock slopes, primarily discontinuity controlled with variable weathering gradation, have been numerically simulated using FEM and DEM. These findings are crucial for rockfall hazard assessment. The characteristics of rockfall were determined for rockfall-prone locations, and a Ditch effectiveness study was performed to eliminate future hazards and subsequent risks. Comprehensive examination for design optimization of ditches led to site-wise improvement from recommendations suggested by Ritchie charts. This study generates cost-effective and sustainable preventive measures for effective hazard treatment.