Journal of Rock Mechanics and Tunnelling Technology (JRMTT)
31(2) 2025 pp 163-168

Available online at www.isrmtt.com

Abstract of PhD Theses

Abstract 1:

Title of Thesis:	Geomechanical Risk Assessment and Capacity Estimation in Subsurface Fluid Storage
Name of PhD Candidate:	Yashvardhan Verma
Supervisor:	Prof. Vikram Vishal
Year of Award:	2024
University/Institute:	Indian Institute of Technology Bombay, Mumbai, India and Monash University, Australia

Abstract

The thesis focuses on developing methodologies for geomechanical risk assessment and capacity estimation in subsurface fluid storage, addressing the challenges of mitigating greenhouse gas emissions and transitioning to a low-carbon economy. Carbon Capture and Storage (CCS) and hydrogen storage are highlighted as essential technologies to combat climate change. The research develops an effective workflow for storage projects in three major steps. The first step involves the development of a reliable site-screening mechanism to select suitable storage sites. The research analyses the effect of various reservoir properties on pressure buildup and CO2 plume migration. The simulations indicate that porosity and permeability are major factors in determining the suitability of a site. The second step entails a detailed assessment of India's geological formations which estimates CO2 storage capacities ranging between 395–614 Gt, distributed among depleted oil fields, unmineable coal formations, saline aquifers, and basalts. Hydrogen storage potential in Indian sedimentary basins is estimated at approximately 574 Mt, indicating substantial opportunities for energy storage. The basins are ranked based on storage feasibility and capacity, which provides vital assistance to operators and policymakers in developing large-scale storage projects. The third step constitutes an assessment of the geomechanical risks involved in storage, including induced seismicity for depleted oil fields in the Cambay basin. Fault slip potential (FSP) analyses and probabilistic Monte Carlo simulations were conducted, identifying critical factors such as fault proximity, orientation, and length and the effect of multiple-well injection strategies. Finally, an artificial neural network is built to estimate the magnitude of induced seismicity based on the rise in pore pressure. This helps in understanding and mitigating the damage that can be caused by subsurface fluid storage. The thesis provides a robust framework integrating geomechanical considerations into site selection, storage optimization, and risk management, significantly advancing subsurface fluid storage strategies.

Abstract 2:

Title of Thesis:	Development of a New Finite Element Code for Thermo-Hydro-Mechanical Coupling in Geomechanics and Its Application to Deep Borehole Disposal of Radioactive Waste
Name of PhD Candidate:	Hwajung Yoo
Supervisor:	Prof. Ki-Bok Min
Year of Award:	2025
University/Institute:	Seoul National University, Seoul, South Korea

Abstract

An open-source finite element code was developed for thermo-hydro-mechanical (THM) simulations in geomechanics, specializing in modeling linear thermoporoelasticity in porous rock systems. The software, named GeomechX, has been verified for both THM coupled processes and single-component models, demonstrating its applicability across a wide range of geomechanical studies. Built on the PETSc library, GeomechX provides a reliable and scalable computational framework with verified applications such as poroelastic and thermoelastic stress responses, thermal pressurization, and surface deformation. Its compatibility with popular open-source tools such as Gmsh and ParaView for pre- and post-processing enhances accessibility and usability. This dissertation presents the overall structure of GeomechX, verification cases confirming its accuracy against analytical solutions, and a field-scale application focused on the geomechanical analysis of deep borehole disposal (DBD) for high-level radioactive waste (HLW). With its adaptable and extensible architecture, GeomechX equips researchers with a powerful tool for investigating a variety of geomechanical applications, including nuclear waste disposal, and offers potential extensions to geothermal energy and CO2 sequestration, advancing sustainable subsurface engineering. This code offers another independent framework for computing coupled thermal, hydraulic and mechanical processes in geological medium.

The developed software was applied to the deep borehole disposal (DBD) of high-level radioactive waste (HLW). DBD is an alternative disposal concept in which spent nuclear fuels are placed in boreholes at depths of approximately 3 to 5 km. While the DBD concept offers advantages, such as greater natural isolation from the surface environment, the impacts of its concentrated decay heat at deeper depths over distances spanning kilometers from the disposal system and timeframes exceeding hundreds of thousands of years require further investigation. This dissertation conducted three- dimensional thermo-mechanical coupled modeling using GeomechX, assuming the disposal of expected spent nuclear fuel from South Korea into a DBD system. The primary objectives were to assess ground uplift and shear slip potential. For comparison, the geological disposal (DGD) concept was also simulated, considering the improved Korean Reference Disposal System (KRS+), which places HLW at depths of approximately 500 m. The comparison of simulation results suggested smaller and slower ground uplifts at the surface and a higher shear slip potential at greater depths in the DBD system compared to the DGD concept. These differences are attributed to the greater depth of the DBD system and differences in repository geometry.

Abstract 3:

Title of Thesis:	Hybrid Evolutionary Computation Algorithm Based on Gene Expression Programming and Particle Swarm Optimization for Prediction of Mechanical Rock Excavation performance

Name of PhD Candidate: Shahabedin Hojjati
Supervisor: Prof. Seokwon Jeon
Year of Award: 2022
University/Institute: Seoul National University, Seoul, South Korea

Abstract

With the advances in mechanical excavation technology, increasing number of underground spaces are built using mechanical excavation rather than the conventional drilling and blasting method. In the field of mechanical rock excavation, there are a fair number of deterministic solutions for the relations between different variables. However, in many cases, it is extremely difficult to establish a deterministic relation between variables. As a result, many researchers try to explain those relations using regression analysis. Due to the complex and non-linear nature of rock cutting phenomenon, it is not easy to reasonably determine the form of the non-linear functions that fit to the statistical data as it is required by the conventional non-linear function fitting techniques. As a result, a combination of Gene Expression Programming (GEP) and Particle Swarm Optimization (PSO) was used for data analysis in this study in order to solve problems in the field of mechanical excavation. GEP and PSO are evolutionary computation techniques and the GEP-PSO algorithm is capable of automatically finding the form and constants of a non-linear function that fits on a data set. The algorithm was used in order to develop a performance prediction model for impact hammer, a prediction model for specific energy required by point attack picks, and models for prediction of cutting, normal, and side force acting on a point attack pick. In all cases, the results generated using the GEP-PSO algorithm produced significantly high prediction accuracy in comparison to those generated by multiple linear regression. When possible, comparisons were made between the results generated by the GEP-PSO algorithm and the prediction models developed by other researchers to show the advantages of the models developed over the course of the present study. In addition to high level of accuracy, the models developed using GEP-PSO algorithm could overcome shortcomings of the existing prediction models to a fair extent. The developed models are more advantageous as they provide more reliability/accuracy while requiring few easy-to-obtain input parameters, and/or they include the significant input parameters that have been neglected by the existing prediction models.

Abstract 4:

Title of Thesis: Shear Strength Behaviour of Talus Deposits
Name of PhD Candidate: B. Venkateswarlu
Supervisor: Prof. Mahendra Singh
Year of Award: 2022
University/Institute: Indian Institute of Technology Roorkee, India

Abstract

Talus deposits, comprising heterogeneous rock-soil mixtures with a wide range of particle sizes and shapes, are frequently encountered in the landslide-prone areas of the Lesser Himalayas. Accurate assessment of the shear strength of these deposits is crucial for the design and analysis of slopes, foundations, and other geotechnical structures. However, conducting laboratory tests on samples with actual field gradation is extremely challenging due to the presence of large-sized particles, making testing both time-consuming and sometimes unfeasible. To address this, engineers often use alternative methods such as the parallel gradation technique, where larger

particles are proportionally reduced. Despite these methods, true shear strength behaviour is often not captured, prompting the need for more robust techniques. The present study focuses on a comprehensive experimental investigation aimed at better understanding the shear strength behaviour of rock-soil mixtures through large-scale direct shear tests and proposing improved predictive approaches.

Four types of rock-soil mixtures, sourced from talus slopes and a quarry, were selected for the study. These included mixtures originating from flaky-angular phyllitic rocks, rounded riverbed materials, angular dolomitic limestone, and angular quarzitic limestone. A series of index property tests were performed, including field unit weight, moisture content, particle size distribution, Atterberg limits, and specific gravity, alongside assessments of individual particle properties such as aspect ratio, roundness, and strength. Direct shear tests were conducted using three different shear box sizes (large: $750\times750\times1000$ mm^3, medium: $300\times300\times200$ mm^3, and small: $60\times60\times25$ mm^3) with corresponding maximum particle sizes of 125 mm, 40 mm, and 4.75 mm, respectively. The effects of varying gravel content, as well as the influence of geogrid reinforcement at different orientations to the shear plane, were also studied.

Test results reveal that shear strength increases with the size and proportion of angular rock particles, primarily due to enhanced interlocking and dilatancy effects. This phenomenon is significantly less pronounced in mixtures with rounded particles. At lower stress levels, an increase in gravel content leads to higher shear strength, more so for angular particles. However, at higher normal stress levels, the influence of particle shape diminishes, with both angular and rounded particles showing similar shear strength behaviour. Geogrid reinforcement, particularly at 45° to the shear plane, significantly enhances the shear strength, especially for angular materials. Furthermore, peak friction and dilatancy angles were found to decrease with increasing normal stress, tending to stabilize beyond certain stress levels.

Existing shear strength models, including Bolton's stress-dilatancy relationship and power curve failure envelopes, were evaluated against the test data but showed significant deviations, particularly for large-sized specimens. Alternative models, such as the Barton JRC-JCS shear strength criterion and the Barton and Kjaernsli model for rockfills, were found to better describe the non-linear shear strength behaviour when suitably modified. Corrections for equivalent roughness considering gravel content, effective particle size, and stress level were proposed. Similarly, suggestions have been made to assess the Modified Mohr-Coulomb (Singh and Singh, 2012) criterion parameters for rock soil mixtures. Additionally, the Deere-Miller classification chart was extended to assess equivalent uniaxial compressive strength for rock-soil mixtures. Finally, a regression model incorporating key particle characteristics was developed to predict the shear strength of these mixtures. The findings contribute to a more accurate and practical understanding of talus deposit behaviour, offering improved methodologies for geotechnical design in mountainous and landslide-prone regions.

Abstract 5:

Title of Thesis: Slope Stability Analysis of the Sections in and around Bhowali-Almora Region, Uttarakhand, India

Name of PhD Candidate: Rahul Kumar Verma

Supervisor(s): Dr. Rajesh Singh
Year of Award: 2023
University/Institute: University of Lucknow, India

Abstract

The slope instability problem is a major challenge in India's mountainous region; this natural hazard covers almost 12.6% of the Indian landmass. Landslide occurrence increases in the rainy season all over India and highly affects the Himalayan region. The Himalayas are the world's newest NW-SE trending mountain range system, measuring around 2400 km in length and 230 km in width. Researchers are enchanted by its complex geological setting, tectonic setting, erosion, mass movement, landslide, etc. Nainital and Almora districts are situated in the Kumaun Himalaya. Due to its geographical situation and human activities, the area is vulnerable to natural disasters like landslides. Landslides are among the natural and anthropogenic risks that impact tourism. The Bhowali-Almora area is prone to rockfall, road subsidence, and full slope collapse. The slope failure mechanisms in and around the Bhowali-Almora region along NH-109 have been systematically studied. This is based on several investigations and analyses, including geotechnical studies such as field observations and laboratory studies, as well as kinematic analysis, Slope Mass Rating (SMR), chart method, numerical modelling, and Landslide Hazard Zonation (LHZ). The shear strength of rock is very crucial for rock stability therefore; basic friction angles have been measured using the Tilt-meter test. During fieldwork, various necessary parameters of slopes, discontinuities, Schmidt hammer rebound number, groundwater condition, Geological Strength Index, etc., have been estimated. It found at least three discontinuity/joint sets, sometimes four sets were also observed. Mostly, joint sets were closely spaced with a tight aperture. A total of 39 slope sections were considered for the study, including 10 highly vulnerable slope sections consisting of rock types such as Quartzite, Meta-basic, and Quartz mica schist primarily.

The Rock Quality Designation (RQD) was estimated based on the joint volume count. Based on RQD, rock mass in the study area has complete classification from the lowest value of zero to the highest value of 100. The basic Rock Mass Rating (RMR_b) was computed based on the strength of the material, RQD, joint spacing, joint condition, and groundwater condition. Based on the RMR_b, the rock mass is classified from very good rock mass at location BA28(A) to very poor rock mass at location BA23. The kinematic analysis showed multiple modes of failure possibility; however, wedge failure is the dominating mode of failure, followed by planar and toppling failure. Another classification used in slope stability estimation of rock mass is SMR. Wedge, planar, and toppling failures were found in 34 sections out of 39 sections. For these slopes, SMR and its stability class have been determined. The partially stable class is the most dominant (39%), followed by an equal percentage (23%) for the stable and unstable classes, and completely unstable class (13%). Based on the FoS estimated from the Chart method, the slopes were classified into three classes (1) stable, (2) partially stable, and (3) unstable. The wedge stability condition, Chart methods showed that unstable condition (80%), followed by a partially stable condition (20%).

The Numerical simulation was conducted for 14 vulnerable slopes identified based on the SMR and Chart method. The Factor of Safety (FoS) was calculated for these vulnerable slope sections. Based on FoS, it was found that one slope is unstable, three slopes show partial stability, and one slope may be partially stable with some triggering factors. Partially stable slope conditions obtained from numerical simulation were also estimated as unstable from the chart and SMR. This provides confidence in the decision for stability, as slopes were unstable in all methods. Based on studies, a few effective landslide hazard mitigation preventive measures, such as rock bolting,

wire meshing, wire meshing with shotcrete, and rock bolting, wire meshing with shotcrete, have been suggested. The LHZ study was carried out in the study area to provide an overview of landslides. It covers 171.2 km^2 of the National Highway, classified into low, moderate, high, and very high-hazard zones. The moderate hazard zone covered the largest area (60%), followed by high hazard zone (25%), low hazard zone (12%), and very high hazard zone (3%). A total of 63 previous landslide locations were marked, of which 12 fall in the very high hazard zone, 32 in the high hazard zone, 18 in the moderate hazard zone, and 1 in the low hazard zone. The Receiver Operating Characteristic (ROC) curve found in the study of good quality (AUC = 71.2%). The findings provide valuable insights for informed decision-making in infrastructure development and risk management, contributing to the sustainable growth and protection of the region's livelihood.