The Role of Geotechnical Investigations in Enhancing the Safety and Sustainability of Hydropower Projects

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ABSTRACT

Aim: To examine the role of geotechnical investigations in enhancing the safety and sustainability of hydropower projects.

Objectives: The objectives are to examine the concepts, relevance and procedures of geotechnical investigations in hydropower projects.

Discussion: Geotechnical investigations are imperative for safe and sustainable hydropower projects prior the execution. The general required tasks for any geotechnical investigation were identified to include: (1) groundwater status and soil profile determination within the planned site, (2) recommendations for various building structures construction, foundation design and underground utilities, (3) recommendations for constructing parking locations and driveways and (4) recommendations for surface drainage and site preparation. The major types of geotechnical report were found to be geotechnical design report and geotechnical site investigation report. Also, reconnaissance, preliminary site investigation, detailed site investigation and site investigation report and recommendations are the stages involved in a geotechnical site investigation. Borings for exploration and in-situ tests are the identified methods of geotechnical site investigation.

Conclusion: In conclusion, geotechnical investigations are relevant for safe and sustainable hydropower projects.

Keywords: Hydropower Projects, Geotechnical Investigations, Surface Drainage, Site Preparation, soil profile determination

1. INTRODUCTION

The origin of structures constructing foundations are the site investigations which are achieved via obtaining relevant information about site subsurface conditions for the planned construction. Site investigations are important for any construction, and are the required step to attain an efficient, productive and safe construction environment. Geotechnical site investigations can be defined as the examination of soil and rock physical properties in order to identify and evaluate potential construction difficulties [1]. Geotechnical investigations are executed to acquire data on subsurface rock and soil conditions of the anticipated development site. It aids to comprehend the foundation requirements for the construction of any underground utilities, new infrastructures, surrounding parking areas and underground parking. These are important investigations needed structural and design engineers to suggest construction design criteria and design methodology for each project.

The general required tasks for any geotechnical investigation are stated thus: (1) groundwater status and soil profile determination within the planned site, (2) recommendations for various building structures construction, foundation design and underground utilities, (3) recommendations for constructing parking locations and driveways and (4) recommendations for surface drainage and site preparation. After geotechnical investigation, some geotechnical criteria are established regarding foundations, retaining walls, excavation, site grading and site drainage. These criteria assist civil and design engineers to predict and calculate the load-bearing capacities and lateral forces on various structural elements of construction like columns, plinth walls, slabs and beams [2]. Such precise calculations are serious in architectural drafting and layout planning. Geotechnical investigations are important for every construction site prior the process of building planning and drafting begins. Geotechnical engineers need to acquire perfect data from the site to affirm that the slopes and foundations are stable when constructed.

Once site investigation is completed, the geotechnical engineer is accountable for data generation and interpretation, site geology model construction, suitable geo-materials design variables selection, and design engineering analyses. Generally, the types of geotechnical report to be prepared are of two categories: (1) geotechnical design report and (2) geotechnical site investigation report. The geotechnical design report, is also being referred to as the foundation report. It typically provides possible geological threat conditions and presently available subsurface examination at the project site and renders geotechnical analyses. The geotechnical design report also provides proper commendations for the significant earth structures and foundation system design thereby retaining walls or the remaining important facilities. A geotechnical site investigation report registers the executed field investigations and laboratory activities and delivers the data collected. The preparation of Boring logs, Rock coring logs, CPT soundings and exploration logging should be according to the standard procedures and formats based on codes or agencies. In this report, the condition at subsurface interpretations and design recommendations are exempted. However, supplementary information regarding what data are offered in a geotechnical investigation report [3].

The soil unit and different rock having engineering importance must be stated in the report together with the recommended design parameters for each of the units present. Based on this, it is imperative to present the analysis and summary of all the genuine data to validate the recommended design attributes.

The conditions at the groundwater are primarily crucial for both the construction and design which are needed to be carefully measured. For any design issue, especially response to lateral loading, foundations axial resistance, group behavior, settlement analysis and so on must be addressed according to the recommended procedures. There should also be the availability of a site location plan for reference on a regional or local-scale map. Field tests locations, sampling and exploratory studies are expected to be clearly presented on the site scaled map. The plan must be a topographic map having a well-known benchmark and well-delineated elevation contours. Nonetheless, site location maps can be directly plotted on aerial photos, demonstrating true north (N) direction. Geotechnical reports are usually supported with the subsurface profiles presentation obtained from field test and laboratory data. Longitudinal profiles are normally formed along the project alignment, and a countable value of transverse profiles may be supplemented for key locations [2]. Subsurface profiles, together with geologic setting and judgment understanding, facilitate geotechnical engineer on subsurface conditions interpretation between the investigation sites.

Geotechnical specification writing is a technical specification written document delivered to the contractor by the owner who has the responsibility of carrying out the site investigation for a particular project. During site investigation, the contractor ought to follow the guidelines of the specification based on the agreement [1]. Geotechnical experts or professional engineers with adequate knowledge and experience prepare the Technical specifications. The purposes of the technical specifications of a geotechnical investigation include: (1) to ensure that the investigation is executed smoothly and completed timely (2) to ensure the site investigation is executed in a proper manner in order to collect the correct information based on the soil/rock properties available in the project site (3) to reduce project cost that might rise otherwise as a result of subsurface conditions ignorance (4) to curb any dispute between the contractor and the owner which could be financial related matters based on the scope of work, or requesting for extra payments as a result of unexpected subsurface conditions experienced at the site or as a result of low-quality work, or delaying of project completion by the contractor. In short, a good specification will assist in collecting applicable and accurate information about the project site just to save money and time. Any fault in the specification may cause imperfection in the design, construction and post construction periods. Thus, it is highly desirable that the technical specification be executed accurately and in a very cautious way [4].

The main aim of a site investigation is to estimate and recognize potential problems and thus avoid possible failures. A site investigation examines the appropriate construction methods required, assuring the appropriateness and bearing ability of the soil to evaluate the site appropriateness. Via this process, important information like the mechanical and physical properties of the soil and rock at the site will be appraised. A geotechnical engineer should possess extreme precision when carrying out such a key duty, as rocks and soils are complex engineering materials possessing parameters and properties that are usually not unique or constant. Ground improvement is another vital duty after site investigations. These methods are those which can enhance land characteristics such as an improvement in bearing capacity, reduction of swelling and cracking of soils, decrease in permeability and so on. All the land layers characteristics must be recorded to ensure successful completion of a site investigation and offer a perfect proposal [5].

2.0 STAGES OF A GEOTECHNICAL SITE INVESTIGATION

The execution of a deep site investigation calls for meticulous and precision detail. The various stages involved in a geotechnical site investigation are briefly summarized in Figure 1 which includes reconnaissance (preparatory phase), preliminary site investigation, detailed site investigation (contingent on preliminary investigation) and site investigation report and recommendations. The principal task in carrying out a site investigation is the reconnaissance or preparatory phase in which the initial information of the site is obtained. This involves the collection of climate conditions and surface conditions providing serious information necessary in the preliminary site investigation. This preliminary information can be obtained either remotely via public records or physically on-site [6]. Successively the existing information is gathered to describe the conditions at the site and guide the expansion of further stages in the investigation. Preliminary investigations comprises desktop study, which provides concrete data. In this stage, the site physical properties such as seismicity, nearby structures and surface and groundwater hydrology are obtained and recorded. These properties can be obtained in the form of test pits or borings and are beneficial in evaluating the thickness, depth and soil stratum composition at the site. With the proceeding preliminary investigation, a comprehensive site investigation will occur provisional on whether the findings of the preliminary investigation are sufficient or not [7].

However, a secondary investigation is required by many projects in which lab testing of rock and soil is necessary. Field tests will be executed to obtain soil properties in its natural form. Following the detailed investigation, a site investigation report will be prepared which includes all the data collected as a part of the investigation together with the site risk assessment. A structure should not be planned in isolation of its surroundings. Hence, the risk assessment includes the surrounding environment of the intended site as it is crucial for any construction. On finishing the major stages, foundation recommendations, further recommendations for ground improvement and suitability of the site are required.

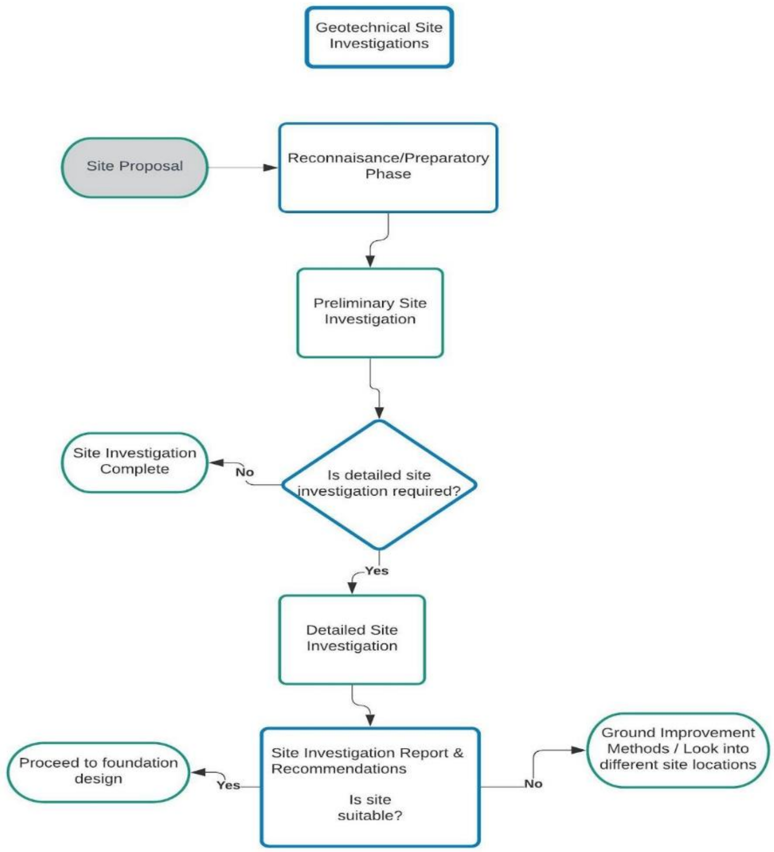

Figure 1: Stages of a geotechnical site investigation

2.1 METHODS OF GEOTECHNICAL SITE INVESTIGATION

2.1.1 BORINGS FOR EXPLORATION

There are several means of conducting a site investigation of which the basic method of preliminary site investigations exist in the form of test pits or borings. The rock pits involve understanding the site groundwater conditions and the site ground profile while borings include soil. This is a preferred method investigating site as they can elevated to greater depths and are utilized to examine the subsurface strata. Auger boring, percussion drilling, wash boring and rotary core drilling are the most common boring methods. Auger boring comprises helical screws drilled down the ground via rotation [5]. However, this method is labour demanding and has a depth constraint when compared with wash boring. Wash boring is made up of a drill rod rotated downwards such that the soil particles are slackened with the aid of a pressurized water jet located at the drill rod bottom. Percussion drilling is adopted for drilling holes in boulders, rocks and other hard strata. It entails the raising and dropping of a hammering bit or heavy cutting attached to a cable or rope and dropped into an open hole.

Rotary core-drilling offers good-quality samples when utilized with soft rock and is competent as the core is reserved within the core barrel [2].

2.1.2 IN-SITU TESTS

The most frequently used in-situ test for the determination of soil samples strength is the Standard Penetration Test (SPT). SPT is executed within boreholes in which holes are drilled to a preferred depth and a mass is released with a standard falling height. Another method used in characterizing the soil compressibility and strength is Cone Penetration Test (CPT). It evaluates the in situ resistance to soil penetration. CPT tests calculate the in situ resistance of the soils to penetration. The step requires dropping a hammer from a definite height at a controlled rate and data is taken at intermittent intervals. The cone penetrometer is equipped with a sensor at the tip which takes the penetration resistance.

Plate load tests and vane shear test are executed during detailed site investigations such that excavated soil & rock are subjected to lab testing to notice the land properties and its bearing capacity. Vane shear tests are adopted for the testing of shear strength of mainly clay soils via the use of a rod having four radial vanes at the edge. This test can be carried out in situ and even in a lab on a pitot scale. The vane shear is thrust into the ground till the test depth in a single movement after which it is rotated in order to evaluate the shear strength via the rod to resistance measurement. Plate load tests are structured to determine the load conveying capacity and to what extent the soil is subjected into settlement at a given load. All the collected samples from the detailed site investigation are subjected to lab testing for adequate characterization and classification [8].

2.2 DATA COLLECTION AND EVALUATION BY GIS

After the delineation of the land patterns for a particular investigation area, it is imperative to collect data in order to describe typical physical characteristics for a particular land facet. Soil data are usually collected via the excavation of a number of test pits, explaining the soil profiles and obtaining soil samples. Differences in soil properties for a particular land facet can be accorded with a number of reasons. These areas should be taken into account during data processing and evaluation.

After the completion of data collection, records should be taken and store in a database so as to enable the facilitation of data manipulation and evaluation. For these benefits, data should preferably be recorded and presented within a spatial database framework. Recent improvements in Geographical Information Systems (GIS) have influenced the ease of point data evaluation within a land facet classification context [6].

GIS gives an inestimable tool for the processing, capturing, presentation and evaluation of spatial data. Digital photogrammetric work stations enable direct digital capturing of aerial photo interpretations. Information from adjoining studies can be combined within present studies so as to assist the interpretation process. GIS allows different data source/layers to be overlain, thereby revealing patterns that may not have been recorded when the data sources were investigated separately [9]. Point data sources can be calculated based on its positions within a particular land facet. With point data properties captured in a database, data can be shown based on any of these characteristics, thereby revealing patterns and helping in data interpretation. Another major benefit of GIS is that data can be shown in any intended form by the end user. Maps can be gathered on any scale to show any of the data that was digitally captured within GIS. However, it is necessary that data should not be presented at a larger scale than the scale at which they were collected. This is because it may lead to data misinterpretation for the particular area. With reference to computerized tool, a major challenge of GIS is that the information shown may be as a result of insufficient data which may definitely mislead the end user considering the end product reliability and quality [10].

3. THE USE OF GEOTECHNICAL INVESTIGATIONS FOR A TYPICAL HYDROPOWER PROJECTS

This manuscript, presents the application of geotechnical investigations to the design of a hydropower project called Faizabad Hydroelectric Power Plant Project. This project was a an overflow river type hydroelectric project which is located at Kokcha River, Badakhshan Province in Afghanistan [11]. Essential construction works assigned to delivering of sustainable energy distribution to Afghanistan through the use of a sustainable water resource was included in the project. It comprises of a concrete dam was built across Kokcha River in order to generate an approximate gross head of 11m. Based on the design, electrical power of approximately 3 x 2.54 MW which is equal to 7.62 MW should be generated from the hydropower plant. As shown in Figure 2, the project was made up of a left bank gravity wall, Ogee crested unrestrained spillway with bridge, water intake structure, bottom outlet having three openings enhanced with three upright slice gates and stop logs, powerhouse with three different intakes and right bank gravity wall.

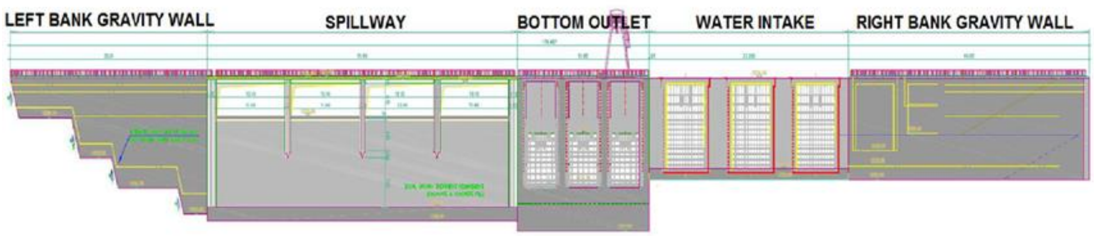

Figure 2: Diagram showing the cross-section on the dam axis [11]

For the evaluation of the required soil and rock properties alongside sound rock line that are important for Hydropower Plant project, geological and geotechnical investigations were carried out in two different main campaigns. There was sub-division of the first campaign into two phases (Phase 1 and Phase 2). A sum of fifteen boreholes were drilled having a sum of 298 (174 m core drilling) meters as a result of the two drilling phases. Ground water piezometers were not connected in the boreholes of this campaign. Campaign 2 acted as a supplement for the first 2015 drilling campaign while a second campaign started in 2016. The two major priorities include (1) rock surface fixing in areas with the right terrace plain, particularly in the latent foundation area of a power plant re-design, and (2) Clarifying dubious permeability testing results should be clarified in the soil and rock of the first drilling campaign. Figure 3 shows the locations of boreholes to power hydropower plant project [12].

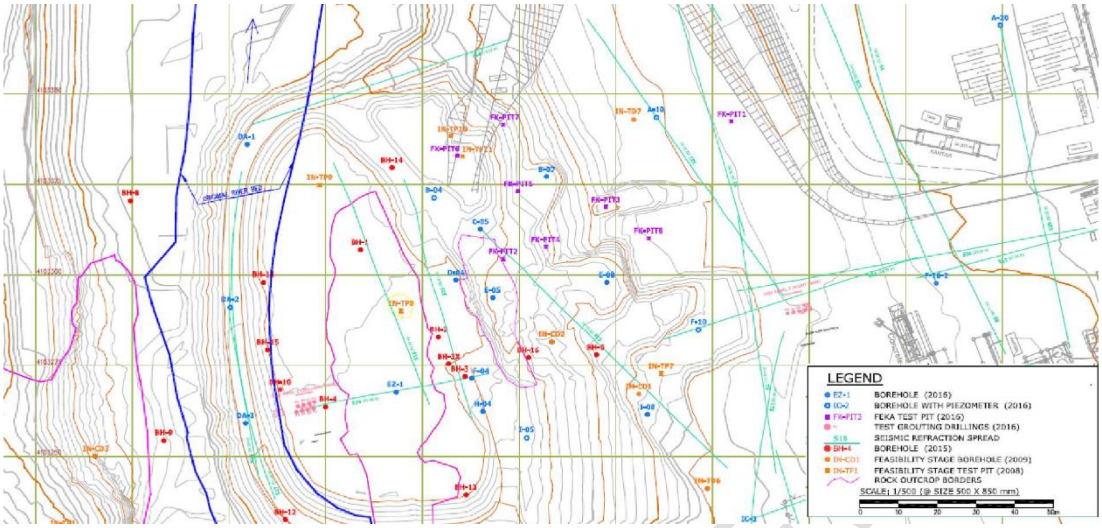

Figure 3: Boreholes locations of hydropower plant project [11]

Figure 4 represents the detailed geological engineering map showing the plant foundation area based on twenty exploration drillings conducted having first and second campaign to be 11 and 9 respectively which indicated that the geological condition at the foundation area was characterized by a highly patterned bedrock surface. The examined areas were marked with foundation level above the rock surface level as indicated in the foundation geological detail map [12]. This was executed based on the digital rock elevation model. This put all the bedrock surface elevation information into consideration such as outcrops, drillings, test pits and refraction seismic results. The detailed map exhibited that in the Kokcha River main channel, it is expected that the bedrock surface be located completely below the foundation level. However, it was placed in the deepest sections even more than twenty meter below that level.

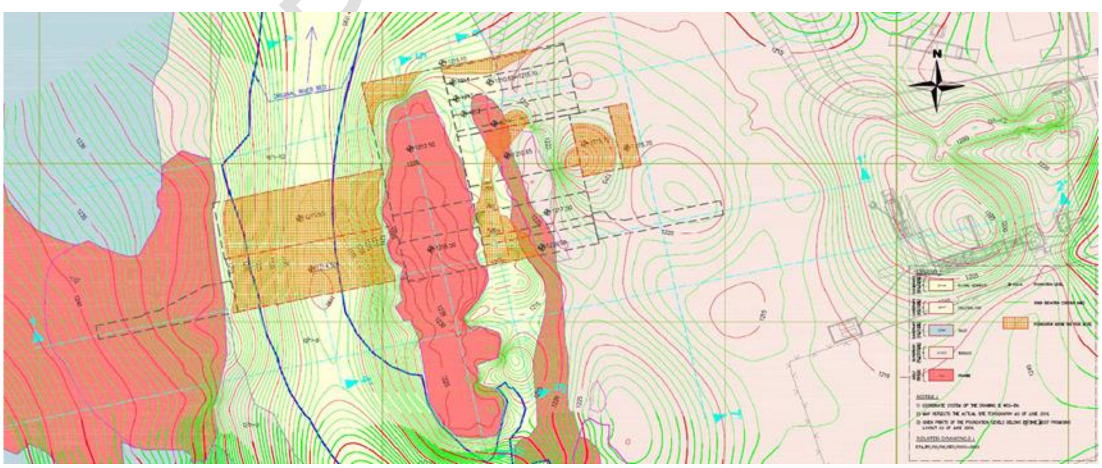

Figure 4: Detailed geological engineering map indicating plant foundation area [11]

The cross section of engineering geological view of the dam axis is shown in Figure 5. It exhibited the condition with the aim that the Kokcha River main channel turned into a deep of this cut and was occupied by glaciofluvial sands.

It revealed that the upper part have a thickness ranging between 10 to 12 m and comprised of Kokcha River Holocene fluvial sediments. The eastern channel available at the eastern place of the former granite island which dropped down to approximately eighteen meter, did not show the main channel glaciofluvial sands. It was completely occupied by fluvial sediments. Excepting the highest parts, deposits of sands and silty sands were observed exactly at high Kokcha River flood sediments. A layer of around 2 m thickness was formed. A granite ridge which runs in the north – south direction and paralleled to the granite island was utilized to construct the eastern slope of the eastern channel [13]. This ridge was terminating at a height of about 1.227 m asl and descended on the east side to a patterned rock surface platform ranging between 70 m to 80 m length while the elevations ranged between 1.215 and 1.225 m asl. The defined granite rock surface in the east of the ridge was totally buried below more than 30 m thick layer of Pleistocene terrace sediments. This consisted mainly of sandy gravel having boulders and cobble. Silty sand and sand lenses together with gravels layers were seen round this. The foundation area ground surface between the Kokcha Valley western slope toe to the terrace plain slope in the east was scattered with rock fall blocks, indicating volumes ranging between 10 and 12 m³ [14].

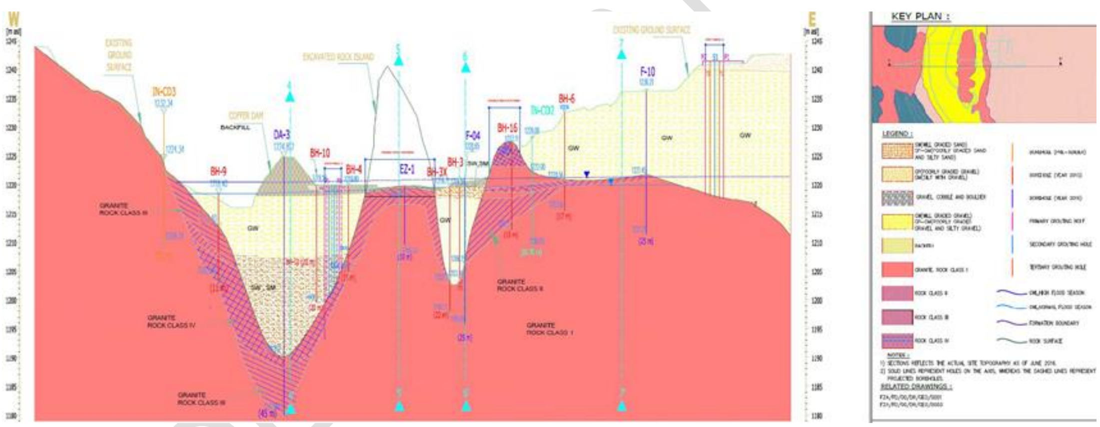

Figure 5: Engineering geological cross section at dam axis [11]

4. CONCLUSION

For safe and sustainable hydropower projects, it is imperative to conduct geotechnical investigations before project execution. The geotechnical investigations basic fundamental principles as related to hydropower projects were discussed. The general required tasks for any geotechnical investigation were identified to include: (1) groundwater status and soil profile determination within the planned site, (2) recommendations for various building structures construction, foundation design and underground utilities, (3) recommendations for constructing parking locations and driveways and (4) recommendations for surface drainage and site preparation. Geotechnical design report and geotechnical site investigation report were shown to be the major types of geotechnical report. Also, reconnaissance, preliminary site investigation, detailed site investigation and site investigation report and recommendations are the stages involved in a geotechnical site investigation. Borings for exploration and in-situ tests are the identified methods of geotechnical site investigation. In conclusion, geotechnical investigations are relevant for safe and sustainable hydropower projects.

REFERENCES

1. Sebbeh-Newton, S.; Shehu, S.A.; Ayawah, P.; Kaba, A.A.; Zabidi, H. Analytical and numerical assessment of a preliminary support design—A case study. Cogent Eng. 2022, 8, 1869367.

2. Xing, Y.; Kulatilake, P.H.S.W.; Sandbak, L.A. Stability Assessment and Support Design for Underground Tunnels Located in Complex Geologies and Subjected to Engineering Activities: Case Study. Int. J. Geomech. 2023, 19, 05019004.

3. Zhang, Q.; Jia, C.J.; Yu, J.; Zhou, J.W. Multisphere Representation of Convex Polyhedral Particles for DEM Simulation. Adv. Civ. Eng. 2021, 2023, 8846004

4. Xing, Y.; Kulatilake, P.H.S.W.; Sandbak, L.A. Effect of rock mass and discontinuity mechanical properties and delayed rock supporting on tunnel stability in an underground mine. Eng. Geol. 2022, 238, 62–75.

5. Yalcin, E.; Gurocak, Z.; Ghabchi, R.; Zaman, M. Numerical Analysis for a Realistic Support Design: Case Study of the Komurhan Tunnel in Eastern Turkey. Int. J. Geomech. 2021, 16, 05015001.

6. Barton, N.; Lien, R.; Lunde, J. Engineering classification of rock masses for the design of tunnel support. Rock Mech. 1974, 6, 189–236.

7. Yang, S.Q.; Chen, M.; Jing, H.W.; Chen, K.F.; Meng, B. A case study on large deformation failure mechanism of deep soft rock roadway in Xin'An coal mine, China. Eng. Geol. 2023, 217, 89–101.

8. Yuan, C.; Su, C. Structural characteristics of Panlong underground powerhouse considering excavation of all caverns. Adv. Sci. Technol. Water Resour. 2018, 38, 56–61.

9. Liu, Q.S.; Liu, J.P.; Pan, Y.C.; Kong, X.X.; Hong, K.R. A case study of TBM performance prediction using a Chinese rock mass classification system—Hydropower Classification (HC) method. Tunn. Undergr. Space Technol. 2017, 65, 140–154.

10. Hudson, J.A.; Cornet, F.H.; Christiansson, R. ISRM suggested methods for rock stress estimation-part 1: Strategy for rock stress estimation. Int. J. Rock Mech. Min. Sci. 2021, 40, 991–998.

11. Mahmudi M, Çakici S. Importance of Geological and Geotechnical Investigations in Hydropower Plant Projects-A Case Study. ENGGEO'2019: National Symposium on Engineering Geology and Geotechnics, 03-05 October 2019, PAU Denizli.

12. Shreedharan, S.; Kulatilake, P.H.S.W. Discontinuum-Equivalent Continuum Analysis of the Stability of Tunnels in a Deep Coal Mine Using the Distinct Element Method. Rock Mech. Rock Eng. 2016, 49, 1903–1922.

13. Kulatilake, P.H.S.W.; Park, J.; Um, J.-G. Estimation of rock mass strength and deformability in 3-D for a 30 m cube at a depth of 485m at Äspö Hard Rock Laboratory. Geotech. Geol. Eng. 2019, 22, 313–330.

14. Jing, L. A review of techniques, advances and outstanding issues in numerical modelling for rock mechanics and rock engineering. Int. J. Rock Mech. Min. Sci. 2018, 40, 283–353.