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Building Information Model (BIM) and Geotechnical Baseline Report (GBR) for improving Project Management Tools of Underground Works

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Abstract: Among various risk factors that need managing in large scale complex infrastructure projects, geotechnical risk is one of the most prominent factor particularly for underground works like tunnels. Uncertainties in soil conditions cannot be avoided 100% even after extensive geotechnical investigations. Therefore, underground works face large delays and cost overrun especially for hydropower projects in developing countries. Its uncertainty ex ante and ex post directly cause increased transaction cost in terms of contract administration, claims, variation orders and disputes. It also reduces trust and increases opportunistic behaviors due to asymmetric information between the parties. Subsequently, parties are spending more time on claim management rather than handling the project execution. Traditional project management tools are becoming less effective under these conditions.

FIDIC published the Conditions of Contract for Underground Works wherein a Geotechnical Baseline Report (GBR) sets out the allocation of risks between the parties for subsurface physical conditions determining the foreseeable and unforeseeable conditions. At the same time, Building Information Modeling (BIM) is being adopted for efficient design, quality control and cost management. In this study, soil classification along the tunnel alignment for on-going hydropower projects is modelled in the virtual environment of Autodesk Revit (2024). The actual soil encountered along the tunnel during construction stage can be compared with the baseline conditions. In addition, BIM serves as a central source providing symmetric information to the Parties to develop an environment of trust and coordination. It is anticipated that these tools will improve the project management skills for underground works through minimizing the opportunistic behavior and transaction cost.

Key words: Soil Uncertainty, Risk Allocation, Project Performance

1. INTRODUCTION

Construction activities around the world were estimated as USD 10.7 trillion during the year 2020 and are anticipated to increase to USD 15.2 trillion between 2021 to 2030 showing a growth of 42% [1]. During the same period, global hydropower capacity is set to increase by 17% or 230 GW by developing countries especially in Asia Pacific comprising of complex network of underground works [2]. Demands for underground infrastructure is increasing around the world especially in Japan due to its geography and hilly terrain for economic growth through expansion of transportation network [3].

Underground projects are complex due to uncertainty in subsurface condition, limited construction space, higher expectations and demands for early project completion by the governments and/or financing institutions. Geology and behavior of subsurface soil encountered during construction phase are often different compared to anticipated during planning stage. Recently, incidents of tunnel failures have been reported which are mainly caused by subsurface soil or poor support. These incidents include Sardasht Dam in Iran [4], Chameliya Hydroelectric Project in Nepal [5], Neelum Jhelum Hydropower

Project in Pakistan [6] and Uttarakhand Tunnel in India [7] which occurred either during construction or operation phase endangering human safety and economic loss. Subsurface soil risks are unique in terms of anticipation, allocation and mitigation and lead to delays in completion, cost overrun, loss of resources and construction claims. Consequently, contracting parties face costly disputes and mistrust.

International Federation of Consulting Engineers (FIDIC) has introduced “Emerald Book” defining the “Conditions of Contract for Underground Works” [8]. It has incorporated a new framework for allocation of subsurface risks between the employer and the contractor through Geotechnical Baseline Report (GBR). GBR defines an agreed level of anticipated subsurface conditions based on geological and geotechnical investigations completed during planning stage. It also acknowledges that subsurface soil conditions cannot be established precisely and require a balanced risk sharing approach. In the FIDIC proposed GBR, risks associated with foreseeable conditions are allocated to the contractor and risk of unforeseeable conditions remains with the employer. This balanced risk allocation approach will benefit the employer for the cases where actual ground conditions are better than baseline established in GBR and vice versa. Emerald Book is flexible towards the parties due to in-built mechanism for adjustment in time for completion of works as the baseline production rates are also included in the schedule.

Rapid development in the BIM provides an opportunity for the construction industry to utilize its capabilities in underground works to improve project performance. Adaptation of BIM is increasing globally by public and private organizations for increased productivity and efficiency. BIM facilitates early interdisciplinary coordination among projects teams in the virtual environment to share latest information, update design and collaboration.

The main objective of this study is to (i) examine the impact on uncertainty in subsurface soil on project performance through a case study of an under-construction hydropower project and analyze the role of GBR and BIM as project management tools to improve project performance.

2. LITERATURE REVIEW

Performance of construction projects is evaluated in terms of construction quality, cost overrun or underrun compared to contract price and late or early completion compared to contractual date. It is not only impacted by contractor’s effort but also influenced by the uncertainties beyond control [9]. Transactions performed in uncertain environment have physical contingencies with opportunistic behavior by better informed party [10, 11]. Huge information asymmetry exists between employer and contractor during construction stage [12] as former can neither grasp true information nor fully understand construction methodologies [13] providing opportunity to the later for seeking additional benefits compromising quality and performance. In an uncertain environment, contractors often reduce the profit margins while submitting the bids to win the project and seek profits through claims during the construction stage [13], negatively influencing project performance. Contractor is also uncertain about approvals of its claims for the extension of time and/or additional payment and reduces effort level to safeguard its interests [11].

FIDIC conditions of contracts are being widely used in the international construction projects stressing appropriate risk allocation to the party better able to manage and/or mitigate it [14]. However, employers generally amend contract clauses and allocate subsurface soil risks to contractor to avoid future claims for additional time and/or cost. Employer provides site investigation reports in the bidding documents for information only but does not accept its interpretation and completeness [15]. Resultantly, contractor either assumes higher risks in the bid quoting higher prices or did not assume actual risks influencing project performance [15, 16].

FIDIC Emerald Book is the first international form of contract explicitly designed for underground works aspiring balanced allocation of subsurface soil risks between the parties through GBR. GBR establishes the baseline conditions for excavation, preliminary support and lining works in various rock conditions. Employer is required to carry out in-depth subsurface investigations to establish baseline rock classes along tunnel alignment thereby revealing complete geological and geotechnical interpretation at the tender stage. Project delays, cost over-run and claims are mainly developed from poor definition and management of GBR [16].

Main challenge in underground works is to deal with the inherent soil uncertainty from the heterogeneous strata of geological formations changing irregularly along the tunnel alignment. Although extensive soil investigations are usually carried out during planning phases, but contracting parties still face surprises during construction. In conventional tunneling, excavation design, preliminary support and lining type are determined based on field mapping of actual rock formation of the tunnel after each blast. Consequently, varying support is provided along the tunnel alignment considering the particular rock class contributing significantly to construction cost. Therefore, subsurface uncertainties demand flexible support with balanced risk allocation [3, 16, 17, 18].

BIM has undergone rapid growth in AEC industry during the past decade either because of national / international requirements or its tremendous benefits in terms of quality, cost, time and productivity [19]. It provides a common platform for identification and assessment of risks through 3D digital modelling [20] for complete life cycle of project. BIM has been explored for risk identification [21], risk management [22], contractual issues [23] and legal issues [24].

Despite efficient use of BIM in AEC industry, very less efforts have been made for development and use of BIM in the geotechnical works due to difficulties in modelling of subsurface soil conditions [19]. Therefore, application of BIM in underground works is lagging [17] and is being focused for rapid development [25, 26]. Previously, it was mainly used for filing, updating and sharing geotechnical and geological data. Commercial softwares are being developed for three dimensional (3D) modelling of underground geological strata based on boreholes data and field mapping [18, 19, 25]. However, very limited evidence was collected for 3D soil modelling for use in BIM process [18]. Inclusion of information into subsurface BIM model can be utilized as a definite support for decisions during the life cycle of any tunnel project [19].

Erharter etal. proposed to split the ground modelling into three sub-models namely i). Factual Data Model, ii). Geotechnical Model, and iii). Geotechnical Synthesis Model [26]. Factual data model is the geotechnical data report of a project containing the information of field mapping, borehole data and laboratory testing. Geotechnical models are prepared by interpretating and/or interpolating factual data for the areas where less investigations are completed. Finally, geotechnical synthesis model contains the one-dimensional (1D) information defining the geological strata along the tunnel alignment and it is proposed as a common document providing the contractual basis for expected ground conditions to be encountered during construction [16, 26]. However, this proposed 1D model is limited to define the geological strata along the length without defining the rock class along the underground tunnels which are used as baseline for payment to contractor and determining completion time. Baseline rock classes are essential in the GBR to differentiate the level of effort, advance rate, preliminary rock support and lining requirements due to varying properties of rock mass encountered.

Norwegian Geotechnical Institute (NGI) developed Q-system is commonly used to determine the rock class and required preliminary support along the underground tunnels [27]. The classification is based on six (6) rock mass parameters and is used as a guideline for defining different kinds of permanent support system. Q method can also be used during pre-invetigations for defining the detailed description of the rock mass. The estimated Q-value is based on the data from the core drilling and field mapping and can provide a rough impression of Q-value which is helpful during design and construction stage.

Bieniawski has also developed the Rock Mass Classification (RMR) System which utilizes six rock mass parameters to determine the rock class. These parameters can be measured in the actual site and are also determined during borehole investigations [28]. RMR classification is also commonly used at site for determining the rock classification and type of preliminary rock support. Correlation between RMR system and Q-system of classification has also been developed.

3. CASE STUDY

3.1 Contractual background

Project data of an under-construction hydropower project is analyzed to evaluate the impact of uncertainty in subsurface soil on the project performance. FIDIC-MDB Harmonized Edition (2010), also known as “Pink Book” is used to define the conditions of contract between employer (government) and contractor’s joint venture. Construction works commenced in 2019 and works on diversion scheme are still in progress indicating a delay of approximately three years for various events including subsurface physical conditions.

Extensive site investigations comprising of borehole drilling, water pressure measurement, scanline survey, seismic refraction, field mapping etc. were conducted during design stage. This factual data report and 1D synthesis model defining the rock strata along the tunnel (**Fig. 1**) were provided to the perspective bidders at procurement stage for information only. The route geology along diversion tunnels route comprises of quartz talcosic schist (QTS), chlorite mica schist (CMS), metadolorite (MDL) / dolorite (DL), green schist / amphibolite (GSA), calcareous carbonaceous / graphitic schist with limestone lenses (CGS), garnet mica schist (GMS) and quartz mica schist (QMS). However, baseline proportions of different rock classes based on Q-system or RMR system were not established.

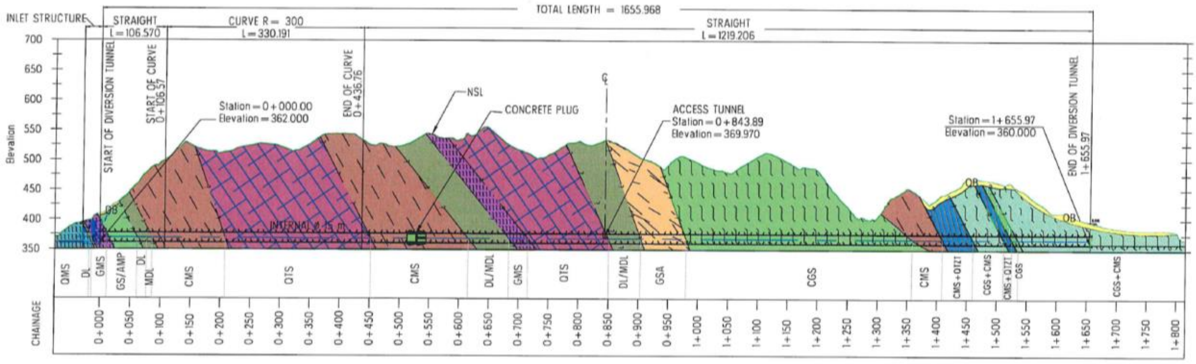

Fig. 1. 1D Geotechnical synthesis model describing rock strata along diversion tunnel [29]

The employer neither accepted responsibility for accuracy of data nor its interpretation, thereby, allocating all the foreseeable and unforeseeable soil risks to the contractor. Variation in subsurface geology or rock class and provision of additional support are not accepted as a base for claiming extension of time and/or additional payment. These amendments are against the spirit of balanced risk sharing principle and became a source of claims and disputes between contracting parties.

Six (6) rock classes are defined in the contract documents to differentiate the effort level due to varying properties of rock mass. Rock class is determined jointly by the contractor and the engineer based on NGI Q-system before each blast to decide excavation diameter, round length and primary support requirements. Table 1 outlines the rock classes, Q-value and excavation round length for diversion tunnels from project data:

Table 1. Excavation, Support and Linning Classes for Diversion Tunnels

Rock Class	Description	Q-Value	Round Length (m)
A	Very Good	40 ~ 100	2.4
B	Good	10 ~ 40	2.0
C	Fair	4 ~ 10	1.6
D	Poor	1 ~ 4	1.2
E	Very Poor	0.1 ~ 1	0.8
F	Extra Ordinary Poor Ground Tunnel *	0.01 ~ 0.1	-

** Excavation of tunnel portals on either end shall be classified as Class F for special rock support treatment*

3.2 Underground Works

The project consists of a network of underground tunnels comprising of access tunnels and diversion tunnels. Access tunnels are constructed to provide an intermediate construction access for the two diversion tunnels falling on the initial critical path and permanent access to various control structures for future operation. The geometry is horseshoed to modified horseshoe shaped with an equivalent diameter of approximately 7 m to allow efficient vehicle movement.

Two parallel diversion tunnels of 15 m circular diameter are being constructed to divert the water for construction of the main dam body and other appurtenant structures. It is the first critical activity and any delay prolongs the entire construction period. The invert level of these tunnels varies between the elevation of 360 masl to 373 masl and intersect the access tunnels. The layout plan of the underground tunnels including borehole locations, plotted in a BIM software (Autodesk Revit-2024) is shown in Fig. 2. It depicts that “Class B” and “Class C” are mainly determined along the access tunnels and “Class C” and “Class D” are classified along the diversion tunnels during execution. However, different rock classes are determined at the intersection of these tunnels, although the geological conditions are the same. Similarly, “Class D” is determined near end portals of each tunnel ignoring the contract to provide “Class F” support (Table 1). This scenario illustrates the gaps in the rock classifications for the tunnels.

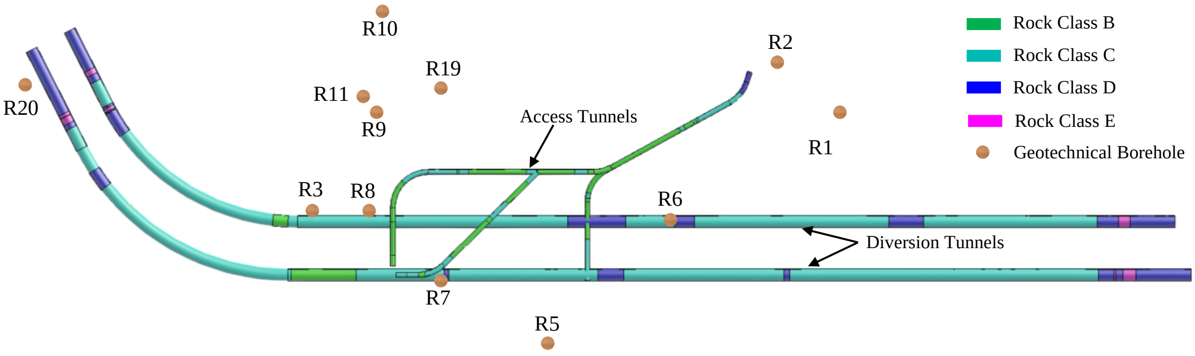

Fig. 2. Layout plan of underground tunnel and borehole logs for soil investigation

Diversion tunnels were facing convergence end near portals of diversion tunnels after installation of preliminary support and even exceeding the permissible convergence limits at few points. It also resulted in the origination of surface cracks in the inlet portal excavation leading to stoppage of construction activities as safety reasons and delayed the project. The contractor was instructed to install supplementary support to control the convergence and it paved the way for claims to additional time and/or cost for the contractor. Later, the inlet portal of the inner diversion tunnel collapsed during a flood abandoning the tunnel intake and parties are being forced to construct 3rd diversion tunnel leading to extraordinary delay, contractor's claims and insurance disputes.

To explore the gap in classification at end portals and junction, NGI Q-value was estimated based on surface field mapping and borehole investigation data available in the design reports. Q-value is used to determine variation in rock class for each borehole at an interval of 5m. Finally, rock classification of each borehole is plotted in BIM software (3D) to visualize variation in rock class at site. Fig. 4 shows a comparison of the rock class determined for each borehole from design reports and actual rock classification for underground tunnels at the project site.

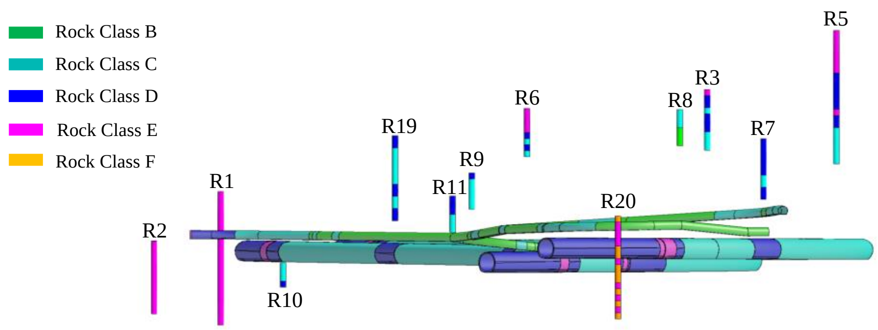

Fig. 3. Rock classification of along boreholes and underground tunnels

Fig. 2 and Fig. 3 show that eight (8) boreholes are drilled for investigation in the vicinity of underground tunnels and only two (2) boreholes reach the required depth of tunnels. This fact is outlined in Table 2 and demonstrates poor subsurface investigation at the design phases of the project. Therefore, baseline GBR for underground works could not be prepared and the employer transferred all the subsurface soil risks to the contractor. Preparation of baseline GBR considering balanced risk sharing defined in FIDIC Emerald Book can highlight such deficiencies in geotechnical investigations at planning stage and will encourage the employer to invest more for ascertaining the actual soil conditions to be encountered during future construction.

Table 2. Rock Classes along various boreholes of tunnels based on NGI

Borehole	R1	R2	R3	R5	R6	R7	R8	R20
Access Tunnels	-	Class E (Class D*)	-	-	-	-	-	-
Diversion Tunnels	-	-	-	-	-	-	-	Class F (Class D*)

(*) determined jointly by the contractor and the engineer for Interim Payment Certificate (IPC)

Fig. 3 also shows that "Class C" and "Class D" are dominant in the project area. Determination of "Class B" along the access tunnels may be either because of lower experience of engineer's personnel or influence of contractor's expertise. Therefore, to explore this fact, comparison of excavated quantities from Bill of Quantities (BOQ), Interim Payment Certificate (IPC) and Autodesk Revit (2024) based BIM (BIM) along with distribution of unit rate is plotted in Fig. 4.

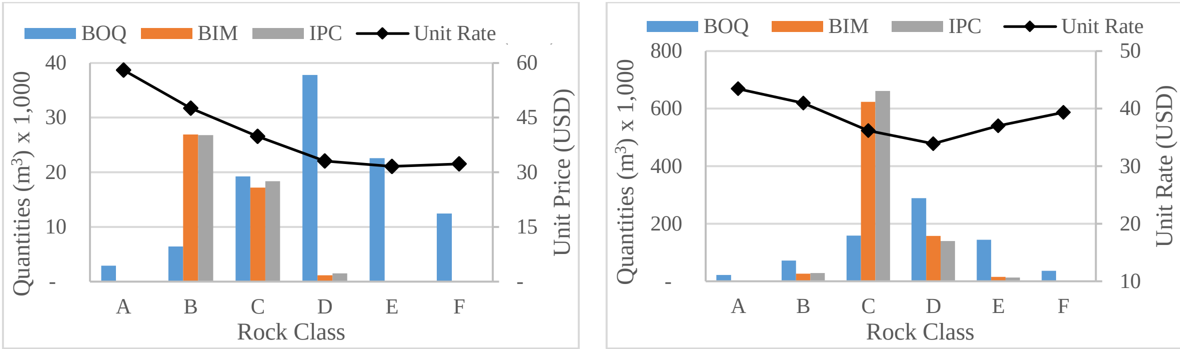

Fig. 4. Comparison of unit price and excavation quantities for tunnels

Comparing IPC quantities with BOQ confirms an enormous shift from poor rock class towards better rock class. This scenario is providing additional payment to the contractor in terms of unit rate and early completion of preliminary support for better rock class, shortening the construction period. If so, this opportunistic behavior not only benefited the contractor but also compromised the safety of the tunnel, reducing the project performance. However, employer may also have artificially developed the BOQ defining conservative rock classes with an attempt to transfer all the soil risks to the contractor showing opportunistic behavior. It is quite natural tendency of the employer to be conservative due to uncertainties based on limited investigations and poor knowledge of geological stratifications. Therefore, BOQ may not reflect the actual site conditions and probably has backfired providing benefits to the contractor.

This study highlights the importance of adequate borehole investigation and field mapping to define the factual GBR baseline for underground works. Borehole data and Q-System for rock mass classification can provide a reasonable base to determine the variation in rock classes at any project site. Visualization of borehole rock classification in BIM virtual environment can assist the parties to envisage variation in rock classification along the tunnel for construction planning and collaborative decision making reducing the opportunistic behavior. GBR and BIM combinedly can also serve as a management tool for the employer to monitor the behavior of contractor and the engineer to determine rock class and preliminary support system.

3.3 Claims and Disputes

The contract allocates all the foreseeable and unforeseeable risks related to subsurface soil to the contractor to avoid future claims arising from uncertainty. Although better rock class has been jointly determined along the tunnels, but the contractor has submitted various claims related to weak geological conditions and scope of work. The summary of claims is provided in Table 3 below:

Table 3. Claim for extension of time within 29-months

S/No	Description	Claim (days)
1	Weak geological conditions at diversion tunnels	325
2	Increase in preliminary rock support in diversion tunnels	299
3	Variation in scope at junction of tunnels	30
4	Increase in length of diversion tunnels	140
5	Delay due to occurrence of flood at diversion tunnels	148
6	Additional scope of construction of 3rd tunnel and intake	Not Submitted Yet

Repeated claim notices by the contractor and continuous rejection by the engineer have aroused disputes and developed an environment of mistrust. The parties are now spending more time on data collection, analysis and claim management rather than actual construction activities. GBR can shorten the construction period considering the presence of better rock class at site, improving project performance for employer. It can also safeguard the contractor's interests to claim events related to change in scope for excavation and preliminary support considering balanced risk sharing approach.

3.4 BIM for Quantity Take-Off

Initially the project suffered a delay of 118 days for an increase in quantities of surface excavation of portals for the diversion tunnels. Surface excavation is the first activity before the start of underground excavation for tunnels. Underestimation of quantities provides an opportunity for the contractor to quote higher rates and lower production rate at tender stage to gain extra benefits through claims during construction. Like architectural and structural component, Autodesk Revit (2024) can estimate the quantities as shown in Table 4 below:

Table 4. Comparison of surface excavation quantities

S/No	Description	BOQ	IFC Drawings	IPC*	BIM
1	Access Tunnel	1,920	-	2,057	2,967
2	Diversion Tunnels	205,200	751,365	811,742	870,357
3	Power Tunnel	586,389	1,097,446	-	1,470,381

*Excavation activities are still in progress.

CONCLUSION

This paper contributes to provide factual evidence towards opportunistic behavior demonstrated by the parties under uncertain soil conditions caused by poor subsurface soil investigations and negatively influencing the project performance by compromising safety, cost overrun and delays. BIM and FIDIC Emerald Book proposed GBR can provide a factual baseline for rock classes along the tunnel visualizing the borehole data which has the potential to create collaborative environment improving the project performance.

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