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Influence of Geological Conditions on Drilled Shaft Excavation

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Abstract

This study delves into the excavation of a vertical shaft within fault zones, specifically within the context of a tunnel construction project. The construction process for this vertical shaft, a crucial element of a water pumping station, employed controlled blasting excavation methods to effectively address unforeseen geological conditions, geological hazards, and challenges associated with the seepage flow effect of underground water. The primary aim of this research is to scrutinize the areas that present risks in the stability analysis of the surrounding rock within the vertical shaft of a shallow tunnel constructed in weak and faulted rocks. Emphasis is placed on comprehending the effects of tunnel behaviors in these challenging geological conditions. The study highlights the critical importance of conducting a thorough risk assessment and implementing robust mitigation strategies to enhance the safety and stability of tunnel constructions in complex geological settings.

Keywords: (Ventilation Shaft, Geological Conditions, Fault Zones, Underground Water, Stability Analysis)

1. Introduction

Infrastructure projects in the Ping River fault zone (Zone II) require a comprehensive understanding of the geological model of the area. The construction of water delivery tunnels and associated structures, like buildings, for the water delivery tunnel project between Mae Taeng and Mae Ngat aims to boost water volume in the Mae Kuang Udom Thara Dam reservoir in Chiang Mai Province, Northern Thailand. This project is crucial for addressing water scarcity in the region. However, building mountain tunnels in this area comes with challenges due to various geological conditions, such as mixed-face ground, rock bursting, squeezing, swelling, high-water inflow, and the presence of fault fracture zones. It is generally advised to steer clear of active fault fracture zones when planning tunnel routes. Nonetheless, the intricacies of geological conditions, uncertainties in fault locations, and budget limitations often make it difficult to completely avoid faults during tunnel planning in mountainous regions**.** shows the Fig. 1 This presents a significant challenge for the long and deep-water diversion tunnel project in the mountainous terrain of northern Thailand, specifically the Mae Tang-Mae Ngad diversion tunnel project.

Fig.1 The Mae Tang-Mae Ngad diversion tunnel project located in Northern Thailand.[1]

In this case, project planners had to deal with the inevitability of encountering faults due to the intricate geological conditions of the region. The study focusing on the Ping River fault zone (Zone II) for constructing a water pumping tunnel beneath the Ping River detailed the lithological composition of the project area, as shown in shows the Fig. 2 Laboratory testing results revealed distinct rock properties in different zones. Zone, I exhibited high-quality rock properties, characterized as good rock. In contrast, Zone II displayed a range from moderate to weak rock quality. Finally, Zone III showed low-quality fair rock.[1] These findings highlight the importance of understanding the geological conditions specific to the Ping River fault zone, especially when implementing infrastructure projects such as water pumping tunnels. The variations in rock quality across different zones underscore the necessity for tailored engineering solutions to address the diverse challenges posed by the geological characteristics of the project area.

In the study presented here, a 3D numerical model assesses the potential impacts of water levels on the influence of shaft. Additionally, the study includes translations to facilitate understanding of this stability.

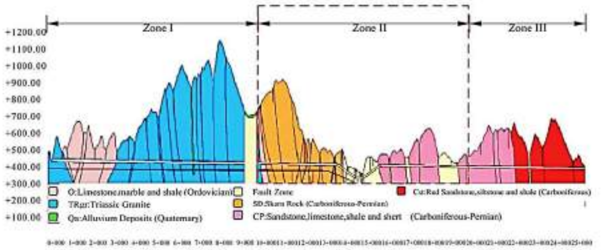

Fig.2 This study focusing on the Ping River fault zone (Zone II) [1].

2. Research Area

2.1 Project Overview

The Mae Taeng - Mae Ngat Water Tunnel Project, located in Chiang Mai Province, is an integral component of a long-term development strategy designed to augment the water storage capacity of the Mae Kuang Dudom Thara Dam reservoir. This project is segmented into two distinct sections: the Mae Taeng - Mae Ngat section, stretching 25.640 km with a 4.0 m diameter, and the Mae Ngat - Mae Kuang section, extending 22.975 kilometers with a 4.2 m diameter.

This study offers an exhaustive analysis of the geological and geotechnical facets pertinent to the Mae Taeng - Mae Ngat section of the water tunnel, with a particular emphasis on the construction of a water pump shaft along the Ping River Canal, especially from STA 13+00 to STA 15+00**.** Comprehensive investigations conducted during this study have identified a fault zone within the designated area. A critical component of this project is the pumping station located at STA 14+714, as illustrated in shows the Fig 3. This infrastructure features a vertical shaft with a circular cross-section, 12 m in diameter, constructed from reinforced concrete and steel, reaching a depth of approximately 43 m. The detection of a fault zone necessitates thorough geological and geotechnical assessments along the tunnel's route. shows the Fig 4 highlights the proximity of the pumping station, where an adjacent cut-slope, 14.5 m in height with a 45-degree incline, is composed of rock and soil. A 3-m bench is depicted shows the Fig 5. Additionally, to the east of the water pumping station, near the Ping River at 148 m from the location marked as 14+726, it is imperative to propose appropriate excavation and support techniques while aiming to mitigate potential risks associated with tunneling activities. The presents the findings from the examination of boring samples collected from specific measurement sites along the tunnel alignment, including RDH-2, RDH-3, and RDH-4. Furthermore, shows the Fig 6 provides a detailed depiction of the longitudinal profile and subsurface geology at the examined location. The Standard Penetration Test (SPT), conducted in accordance with ASTM D1586 standards,[2] identified layers of Sandy Lean Clay (CL) and Silty, Clayey Sand (SC-SM) within the 0.00 to 9.00 meters depth range, with SPT values ranging approximately from 9 to 70N.Moreover, a correlation between SPT-N values and the Friction Angle and Relative Density, [3,4] was utilized. Between depths of 9.00 and 30.00 m, fault breccia containing silty clay and gravel of siltstone was identified, transitioning to Sandstone Rock at depths between 30.00 and 50.00 m.

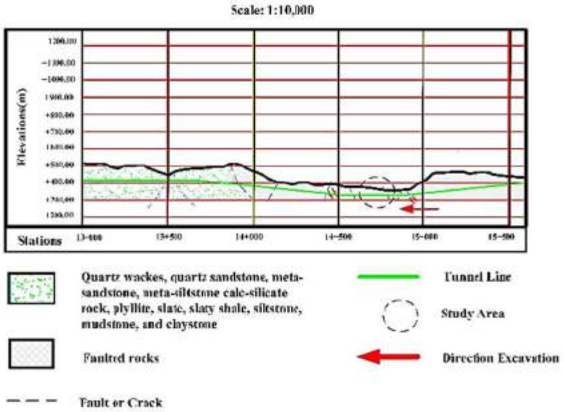

Fig. 3 The geological structure of the study area where the pumping station is located between STA. 14+500-14+775.

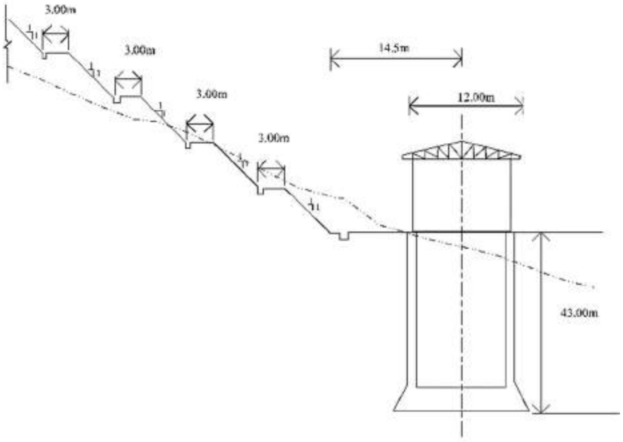

Fig. 4 illustrates the proximity of the pumping station, where the adjacent cut-slope

Fig. 5 illustrates the surrounding location near pumping STA 14+714 - 14+862

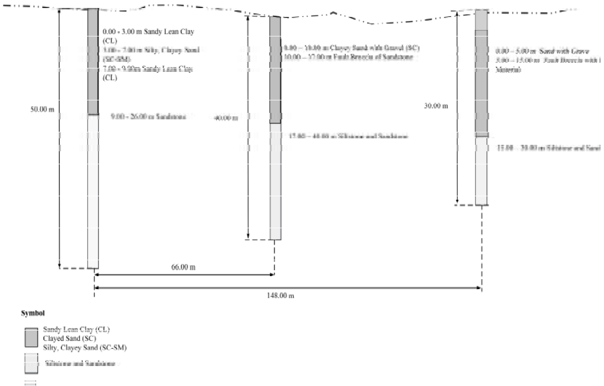

Fig. 6 presents geological column maps of coring samples from RDH-2, RDH-3, and RDH-4.

2.2 Analysis of permeability behavior

In addition, Permeability and average permeability coefficient are obtained via a Lugeon test. It is found that Rock quality designation (RQD) has a symmetrical relationship with rock mass permeability. [5] The boring samples extracted from soil and rock at designated measurement sites along the tunnel direction, namely RDH-2, RDH-3, and RDH-4 in tested using the Lugeon Test method it was found that the area where groundwater leakage was found was, so test shows the Fig 7 by testing by injecting clean water into the borehole. And measure the amount lost in the borehole using 3 different pressure values and test 5 times at 10 min intervals. The permeability of water in rock layers is measured in units of Lugeon.

$$k = \frac{10Q}{LP}$$

k = Water permeability value (Lugeon)

Q = percolation volume (liters/minute)

L = Test length range (meters)

P = pressure used in testing (bar)

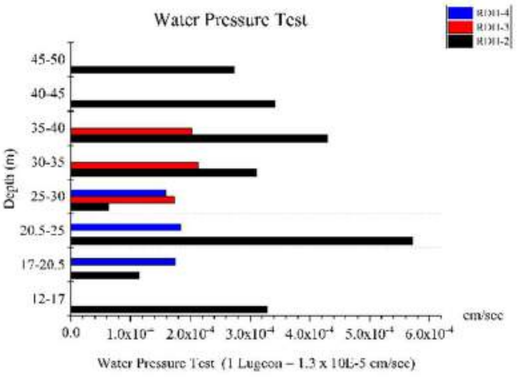

Fig. 7 illustrates the seepage behavior observed in the test results of samples RDH-**2**, RDH-**3**, and RDH-**4.**

From the test results water permeability Found that the permeability of water through the soil and rock layers can be mostly soil and rock layers according to the water leakage value as K. shows the Fig 8 [6] Water permeability can be checked (Rather - Pervious).

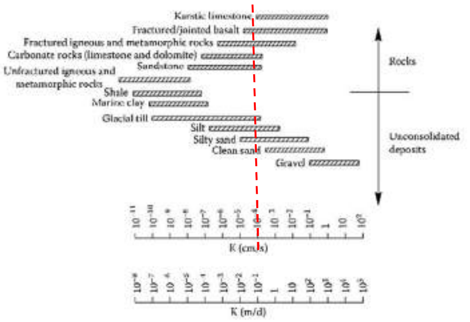

Fig. 8 Hydraulic conductivity of various geological units' values of various geologic materials [6].

3. Methodology

3.1. Construction of the water pump building shaft

The construction of the water pump building shaft, a vital element of the water pumping station situated at the Ping River tunnel's outlet, is meticulously detailed in this document.

This shaft, characterized by its vertical, circular cross-section and a 12 m diameter, is constructed from reinforced concrete and steel, extending to a depth of approximately 43 m. The initiation of construction was marked by the site's excavation. The project encountered numerous challenges, including the management of water ingress due to its proximity to the Ping River and the complexities posed by the geological fault zone. The construction methodology incorporated controlled blasting at intervals of 1.5 m from the surface, which had been previously leveled, utilizing the New Austrian Tunneling Method (NATM) for both the design and construction phases. This approach encompasses excavation and blasting (or Drilling and Blasting, D&B) from ground level in stages, in conjunction with the establishment of a support system.[7] For the upper soil layer, a primary support system comprising soil nails and shotcrete was designed, which included the installation of drainpipes to mitigate groundwater pressure. Additionally, a bracing system was implemented to ensure the excavation site's stability throughout the construction phase. This support system aimed at stabilizing the upper soil layer with soil nails and shotcrete, further enhanced by the installation of underground water pressure relief pipes to manage groundwater ingress effectively. In the lower rock layer, a support system was devised to augment strength and diminish groundwater seepage through the layer's cracks. This strategy entailed consolidation grouting, succeeded by the reinforcement of the rock mass with rock bolts and shotcrete. Where significant groundwater seepage persisted, further grouting was conducted to minimize the flow, and holes were drilled to alleviate groundwater pressure during the construction phase. This preparatory activity was crucial before continuing with additional blasting and the installation of a bracing system in the subsequent rock formation.

Fig.9 Excavation at Elevation 357-358 Fault material, (Date picture22/11/2017)

The design specifications for soil and rock support vary across different elevations. [11] At elevations between 366.00 - 357.00 m, characterized by a continuous dense sand layer beneath Sandy Lean Clay (CL) and Silty Clayey Sand (SC-SM), that are show Table 1 the support class necessitates Shotcrete of 50 mm thickness, Wire Mesh Ø 4 mm, Soil Nails of 6 m length, Drainage Holes, and Perforated Pipes Ø 75 mm, Length 6 m, amounting to 19 sets per round. shows the Fig.9 Transitioning to elevations 357.00 - 345.00 m, where fault material is encountered, the support class demands Shotcrete 25 cm thick, Wire Mesh Ø 4 mm, and Grouted Rock Bolts DB 25 mm, Length 6 m, totaling 15 sets per round. Finally, at elevations 345.00 - 323.00 m, where the fault material comprises Alt and sandstone, the support class requires Shotcrete 25 cm thick, Wire Mesh Ø 4 mm, and Grouted Rock Bolts DB 25 mm, Length 6 m, summing up to 19 sets per cycle.

Table.1 The primary support classes elements of Shaft and Tunnel [11]

Type Tunnel	Elevation	Depth (m)	Type	Support Class
Shaft	366.00 – 357.00	0-9 m	Sandy Lean Clay (CL) and Silty, Clayey Sand (SC-SM)	-Shotcrete Thick 50 mm -Wire Mesh Ø 4 mm -Soli Nail Length 6 m Drainage Hole and Perforated -Pipe Ø 75 mm Length 6 m = 19 Set/Round
	357.00 - 345.00	9-21 m	Fault material	-Shotcrete Thick 25 cm -Wire Mesh Ø 4 mm -Grouted Rock Bolts DB 25 mm, L 6 m = 15 Set/Round
	345.00 - 336.00	21-30 m	Fault material	-Shotcrete Thick 25 cm -Wire Mesh Ø 4 mm -Grouted Rock Bolts DB 25 mm, L 6 m = 19 Set/Round
	336.00 - 323.00	30–43 m	Sandstone Rock	- Shotcrete Thick 25 cm - Wire Mesh Ø 4 mm - Grouted Rock Bolts DB 25 mm, L 6m = 19 Set/Round
Diversion Tunnel	334.00 - 330.00	-	Sandstone Rock	- Shotcrete Thick 15 cm -Wire Mesh Ø 4 mm -Steel Arch H-150×150×31.5 -Grouted Rock Bolts DB 25 mm, L 3m

3.2 Numerical Modeling

The Finite Element Model (FEM) analysis of the this for understanding the behavior and the impact on the stability of shaft tunneling and the diversion tunnel route, a 3D numerical modeling study was conducted using GTS NX in use Hybrid-Mesh Algorithm [8,9] shows the Fig.10 The numerical model was 200 m long in the x-axis direction, 200 m long in the y-axis direction, and 55 m long in the z-axis direction.

The design specifications for soil and rock support vary across different elevations. Section of support system in the tunnel. Designing underground structures for safety and stability necessitates consideration of soil properties from soil surveys, such as soil type and Standard Penetration Test (SPT) values. Identified soil types include Sandy Lean Clay (CL) and Silty, with an average SPT value ranging from 9 to 70 N. The average SPT value at this depth was established at 39 N. These parameters were used in the Mohr-Coulomb model to analyze soil strength. Additionally, employing the Isotropic Elastic model aids in simulating the behavior of structures with elasticity that are show Table 2 Utilizing this data facilitates the analysis and design of underground structures to ensure safety and stability. Furthermore, understanding the behavior of the surrounding rock is also a key aspect of our study. The integrated the nonlinear Hoek-Brown criterion for rock masses, widely recognized and applied in numerous global projects. The Geological Strength Index (GSI) introduced [10] with intact rock properties, this allows for the estimation of the reduction in rock mass strength under various natural conditions. The rock mass comprises sandstone, mudstone, siltstone, and interbedded fault material. Rock mass types were classified based on parameters including rock type, layer thickness, the presence of fractures, strength, weathering, alteration, fracture characteristics, Uniaxial Compressive Strength (UCS), and Point Load tests. The GSI was evaluated, with intact rock strength values ranging from 10-50 MPa for rock and 0-10 MPa for fault material, according to E. Hoek's classification. as Showe [11].

Table 2 Geotechnical parameters of surrounding soil, rock, and Permeability zone. [11]

Depth (m)	Type	Unit Weight (kN/m^3)	Permeability (k), (Avg)	UCS (MPa)	Elastic modulus (GPa)	Poisson is ratio	Frication angle (°)	Cohesion (MPa)
0-9	Sandy Lean Clay (CL) and Silty, Clayey Sand (SC-SM)	18	3.3×10^{-4}	-	0.0073	-	32	0
9-30	Fault material	20	5.0×10^{-4}	38.0	1.75	0.35	25.26	0.11
30-50	Sandstone Rock	22.8	1.0×10^{-4}	52.8	7.08	0.20	37.49	0.25

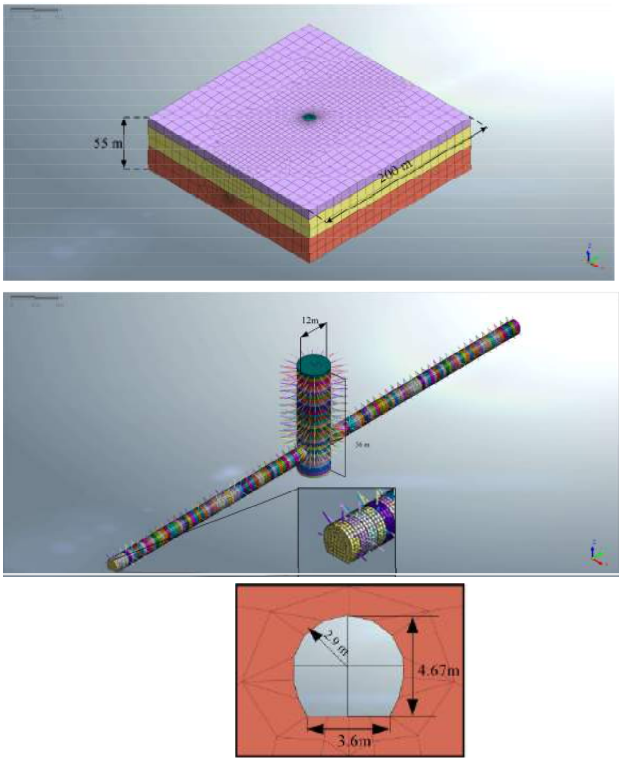

Fig. 10 3D Model of Tunnel-shaft Model

4. Results and Analysis

4.1 Tunnel inflow analysis

The influence of water on stability as assessed at water levels, the interpretation of data indicates that groundwater inflow in shaft- tunneling, and the diversion tunnel .

Water level in the dry shaft is at Elevation +323.00.

Table.3 Details of Shaft Stability Analysis

Case Study	Depth (m)	Water Elevation in shaft	Depth of groundwater	Surface settlements at shaft (mm)
Water level in the dry shaft is at Elevation +323.00	0-9	+323.00	+323.00	0.000
	9-30			0.000
	30-50			Shaft floor at 50 m 0.0090 m.

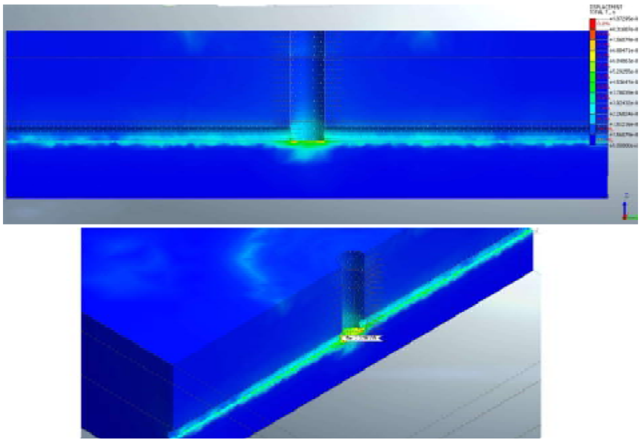

Fig. 11 Case Study Results: Water Level in the Dry Shaft the water

The stability of the Shaft-Diversion Tunnel is significantly impacted by water levels, that are show Table.3. Observations indicate that the water level in the dry shaft consistently matches the groundwater level and water elevation, all recorded at Elevation +323.00. This uniformity is critical for evaluating the structural integrity and stability of the tunnel.

Further analysis reveals that the settlement of the surrounding rock above the tunnel is closely linked to its specific location within the Shaft-Diversion Tunnel. Particularly noteworthy is the settlement observed at the lower bench of the shaft floor at Elevation +323, which is measured at a minimal 0.0090 mm. This indicates a stable condition at this specific site within the tunnel structure.

In addition, within the Fault material zone, which spans elevations from 357.00 to 345.00, there are no recorded impacts from surface settlements. This lack of surface settlement impacts in the fault zone suggests a stable geological environment at these higher elevations.

5. Conclusion

1. Water Level in the Dry Shaft at the Shaft-Diversion Tunnel is at Elevation +323.00: This level is closely related to the specific settlement at the lower bench of the shaft floor, which is measured at 0.0090 mm at the same elevation. This indicates that changes in the water level can affect the settlement of structures at the lower level of the shaft.

2. Condition Water Level in the Dry Shaft is at Elevation +323.00; No Influence Found from Surface Settlements at Shaft: At the Fault material zone, with elevations ranging from 357.00 to 345.00, no impacts from surface settlements were observed. This shows that the water level in the dry shaft does not affect this area.

3. Shaft-Diversion Tunnel Connection Problems are 3D Issues: These are influenced by multiple parameters, and therefore, choosing to address problems in tunnel works requires careful consideration.

These 3D problems may include structural stability analysis, water flow analysis, and the structure's response to water pressure and forces exerted by surrounding soil and rock.

This Monitoring and Adjusting Water Levels; Install automated water level monitoring systems in the shaft to continuously track changes. Use pumps to adjust water levels as needed to prevent any adverse effects on the settlement at the lower bench.

This study is considered preliminary, given that the water level in the dry shaft is maintained at an elevation of +323.00. For further research, it would be beneficial to conduct studies with a constant water level in both the shaft and the diversion tunnel, as well as to examine the effects of rapid changes in water levels.

Acknowledgement

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The study program was conducted using GTS NX for educational purposes only.

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