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Geotechnical Design Challenges in Tropical Zone

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ABSTRACT

Introduction. Designing for geotechnical stability in tropical zones presents a unique set of challenges due to the climatic, geological, and environmental factors prevalent in these regions. It requires a comprehensive understanding of the local soil conditions, climatic factors, and environmental challenges. Materials and methods. Tropical regions often experience heavy rainfall, leading to increased erosion and soil instability. The erosion can weaken soil structures, leading to slope failures, landslides, and foundation instability. Areas with geologically disturbed areas such as clay shale, colluvium, and deformed rock due to relic active tectonic activity are attributed to unexpected failure during construction. While area with problematic soil such as the soft soil zone exhibits large long-term compression and low bearing capacity challenges.
Results. Designing to accommodate the challenges of geologically disturbed areas and problematic soil is crucial to prevent structural damage. Tropical regions also often have high groundwater tables due to frequent rainfall and low evaporation rates. This can pose challenges for geotechnical and structural design as structures may be subjected to buoyancy forces and soil liquefaction during seismic events. Tropical ground requires careful consideration of material properties and behaviour, environmental conditions, and potential hazards. Engineers can solve the difficulties that come with these problematic grounds in tropical areas and guarantee the safety, stability, and sustainability of infrastructure projects by applying suitable geotechnical engineering techniques and mitigating measures.
Conclusions. Case studies about problematic tropical soil and solutions.

KEYWORDS: tropical soils, tropical design, prevention of structural damage

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Проблемы геотехнического проектирования в тропической зоне

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АННОТАЦИЯ

Введение. Проектирование в тропических зонах означает обеспечение геотехнической устойчивости и представляет собой уникальный набор задач, обусловленных климатическими, геологическими и экологическими факторами, преобладающими в таких регионах. Оно требует всестороннего понимания особенностей местных почв, климатических факторов и экологических проблем.
Материалы и методы. В тропических регионах часто выпадают обильные осадки, что усугубляет эрозию и нестабильность почвы. Эрозия может ослабить структуру почвы, грунтов, что может привести к обрушению откосов, оползням и сокращению прочности фундамента. В районах с геологическими нарушениями, такими как глинистые сланцы, коллювиальные отложения и деформации породы, вследствие активной тектонической деятельности возможны неожиданные провалы в процессе строительства. При этом для участков с проблемным грунтом, например для зон слабых грунтов, характерны показатели существенного длительного сжатия и низкой несущей способности.
Результаты. Проектирование с учетом геологических нарушений и проблемных грунтов имеет решающее значение для предотвращения повреждения конструкций. В тропических регионах также часто наблюдается высокий уровень грунтовых вод из-за частых дождей и низкой скорости испарения. Это может создать проблемы для геотехнического проектирования и проектирования строительных конструкций, поскольку во время сейсмических воздействий сооружения могут подвергаться подъемной силе и разжижению грунта. Тропический грунт требует тщательного учета свойств и работы материалов, условий окружающей среды и потенциальных опасностей. Инженеры могут решить вопросы, связанные с проблемными грунтами в тропических районах, и гарантировать безопасность, стабильность

и устойчивость инфраструктурных проектов, применяя адекватные инженерно-геологические методы и меры снижения воздействий.
Выводы. Рассмотрены конкретные примеры проблемных тропических грунтов и решения возникающих проблем.

КЛЮЧЕВЫЕ СЛОВА: тропические грунты, проектирование в тропических зонах, предотвращение повреждения конструкций

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INTRODUCTION

Geotechnical design in tropical zones presents a distinct set of challenges due to these regions' unique geological, climatic, and environmental conditions. The tropical climate is characterised by high temperatures, intense rainfall, and varying soil types, which significantly influence the behaviour of foundations, slopes, and other geotechnical structures. One of the primary challenges in geotechnical design for tropical zones is managing the effects of heavy rainfall and subsequent soil erosion. Intense rainfall can lead to soil instability, erosion, and landslides, particularly on steep slopes. Engineers must carefully consider drainage systems, erosion control measures, and slope stabilization techniques to mitigate these risks and ensure the stability of infrastructure. Additionally, the high humidity and temperature variations in tropical climates can impact the properties of soils, potentially leading to changes in soil strength, compressibility, and settlement over time. This necessitates thorough geotechnical investigations and analyses to accurately assess soil behaviour and select appropriate foundation types and designs. Another critical aspect of geotechnical design in tropical zones is the selection of suitable construction materials. Materials must be durable and resistant to degradation caused by high moisture levels, biological activity, and aggressive chemical reactions common in tropical soils. Special attention is also given to corrosion protection for foundations and retaining structures exposed to moisture and aggressive environmental conditions. Furthermore, the cultural and socio-economic aspects of tropical regions must be considered in geotechnical design. Local communities often have traditional building practices and knowledge of local soils and geological hazards that can inform and complement modern engineering solutions. Engaging with local stakeholders and integrating indigenous knowledge can lead to more effective and culturally sensitive geotechnical designs [1–10].

Geological disturbed zone in tropical region — Malaysia

The abundant occurrences of Triassic and Late Cretaceous-Palaeocene granites have resulted in the remagnetization of older rocks, and the interpreting of palaeomagnetic data unreliable (Richter and Fuller, 1996). Clockwise declinations have been measured in Late Triassic granites, Permian to Triassic volcanics, and remagnetized Paleozoic carbonates. The age of this magnetization is poorly understood and may be as old as the Late Triassic, or as young as the Middle or Late Cretaceous. The Middle Cretaceous to Palaeogene paleomagnetic data for the Peninsula are indistinguishable from the Late Eocene and Oligocene measurements from Borneo and Sulawesi. The similarity in anticlockwise rotations over such a large region suggests that regional block motions have been preserved and shows that much of southern Sundaland rotated approximately 30 to 40° anticlockwise relative to the Geocentric Axial Dipole between the Eocene and the Oligocene. These regional anticlockwise rotations are not consistent with simple extrusion-based tectonic models. However, they are consistent with anticlockwise oroclinal bending resulting from ongoing collisions in the Timor area of Indonesia. The Strong Complex and related Central Belt granitoids lie east of the Bentong-Raub Line. The zones of migmatite (Fig. 1) are intimately associated with Late Triassic as well as Late Cretaceous granites. The former suggests a genetic relationship to the Indosinian Orogeny; the latter suggests a considerably later reactivation of the migmatite zones. In many cases, the Late Cretaceous plutons are of homogeneous pink granite devoid of migmatization, and they are found as far south as Gunong Ledang (Mount Ophir) and Gunung Pulai. Richter et al. (1999) concluded that the palaeomagnetism measured in Late Triassic and older Peninsular Malaysian rocks may represent a Middle Cretaceous to Paleogene remagnetization caused by an important heat event of that time. This was the important heat event found in the migmatite zone of Fig. 1.

Granite constitutes about one-third of the land surface of Peninsular Malaysia. The granites of the Malay Peninsula were originally subdivided into three belts by Hutchison (1977); the Main Range Belt, the Central Belt, and the Eastern Belt. Cobbing et al. (1992) established that the granites of the Central Belt and the Eastern Belt were similar and defined two granite provinces within Peninsular Malaysia, each having its distinctive pattern of mineralization — the Main Range Province and the Eastern Province. Hutchison (1977) suggests that these features imply that the Main Range Belt has been uplifted by several kilometres since the Triassic. The margin of the Main Range granite, just west of the Bentong-Raub suture near Bentong is characterised by strongly gneissic granite and augen structures [11–19].

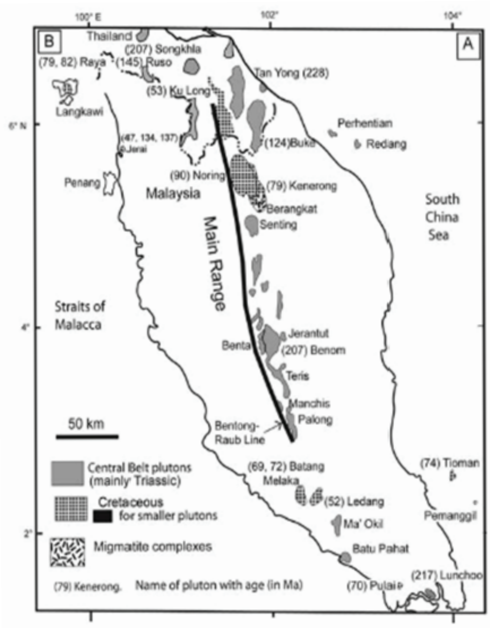

Fig. 1. Central Belt of Peninsular Malaysia. Redrawn and after Cobbing et al. (1992)

Рис. 1. Центральный пояс полуостровной Малайзии. Перерисовано с использованием материалов Коббинга и др. (1992)

Borneo is an island in Southeast Asia, and its base of rocks was formed over the last 400 million years by subduction-accretion because of convergence between the Asian, India-Australian, and Philippine Sea-Pacific plates, as well as arc-continent collisions and continent-continent collisions (Metcalfe I., 2013). It was located along the easternmost boundary between the Paleo-Pacific and the Meso-Tethys during the Late Cretaceous. It is one of the few places in SE Asia where sediments deposited between the Latest Cretaceous and Latest Eocene are preserved (Kayan, Ketungau and Rajang Group, and the Crocker Formation). The largest sedimentary basin in Borneo filled by the Rajang Group, contains a relatively continuous Late Cretaceous to Late Eocene sedimentary record, which can be used to provide provenance information to constrain sediment routing and resolve the paleogeographic setting at the time of deposition (Hutchison, 1996, 2005; Hall, 2012; Hall and Breitfeld, 2017; Galin et al., 2017). Since all of Borneo's volcanoes are extinct, the region's active geological processes are moderate (Hall R. et al. 2009). Three plate boundaries — the Java-Sumatra subduction boundary, the India-Eurasia continental collision, and the collisional zone in Sulawesi southeast of Borneo — are the geological forces sculpting Southeast Asia today (Publiler M. and Morley C.K., 2014). The geology of Borneo today is composed of volcanic deposits, sedimentary layers, and old crystalline foundation rocks. The island's complicated geological past has produced a diversified terrain that includes vast river systems, mountain ranges, and lush rainforests. Despite being less prone to earthquakes than some of its neighbours, Borneo is nonetheless affected by continual seismic activity due to its location at the intersection of many tectonic plates. Erosion and sedimentation are still occurring in the area, shaping the landforms and adding to the abundant biodiversity seen in Borneo's rainforests. Borneo's geological past provides evidence of the dynamic processes that have moulded the island over millions of years, giving rise to its distinctive and varied geological and biological traits. The distinctive characteristic of meta sediment and partly meta sediment development, particularly in the Sarawak region, sets the geological features apart from those of the Peninsular Malay. Fig. 2 shows the Geological formation of the Boneo about the kind of rock formation.

The construction of infrastructure was greatly influenced by the meta-sediment and partially meta-sediment rocks, especially in the Borneo region. The presence of volcanic breccia, tuff, and clay shale minerals has had several negative impacts, including ground movement and slope failure. This affects the economy and causes a delay in construction, which raises the cost of building.

META SEDIMENT MATERIALS IN CONSTRUCTION — CASE 1

Meta sediment materials dominate the base formation, especially in the Borneo region. Clay Shale is known to exist during the Miocene and late Oligocene Epoch. The Miocene epoch occurred in the Neogene period which, in turn, is part of the Cenozoic era approximately 5.3 to 23 million years ago. Clay shale reflects the island's complex geological history and diverse sedimentary environments. It is a fine-grained sedimentary rock that forms from the compression of clay and silt particles over millions of years. It is characterized by its smooth texture and often exhibits a laminated appearance. The primary components are clay, quartz and organic materials. The main geological settings where clay shale is prevalent are in the sedimentary basin and rivers and delta deposits.

Challenges for Infrastructure Construction in Lawas, Sarawak

The Sarawak Sabah Link Road (SSLR) Project is approximately 75 km new alignment and upgrading of the logger track project connecting Sarawak to Sabah. This project was designed and built under the surveillance of the Public Work Department of Malaysia. The area was located namely on the Setap and Temburong Formation which is mainly a new and old Clay Shale formation with a thickness of merely 200 m below ground level. The Setap Formation is generally a Miocene Clay Shale while the Temburong Formation is an Oligocene Clay Shale which is older than the latter. Fig. 3 shows the location of the site.

The problem that existed before the building of this route was the presence of 5–10-meter-thick colluvium (debris) covering a foundation rock made of clay shale. The site's hilly geography causes ongoing relic slope collapse, which is why the materials survive. The high

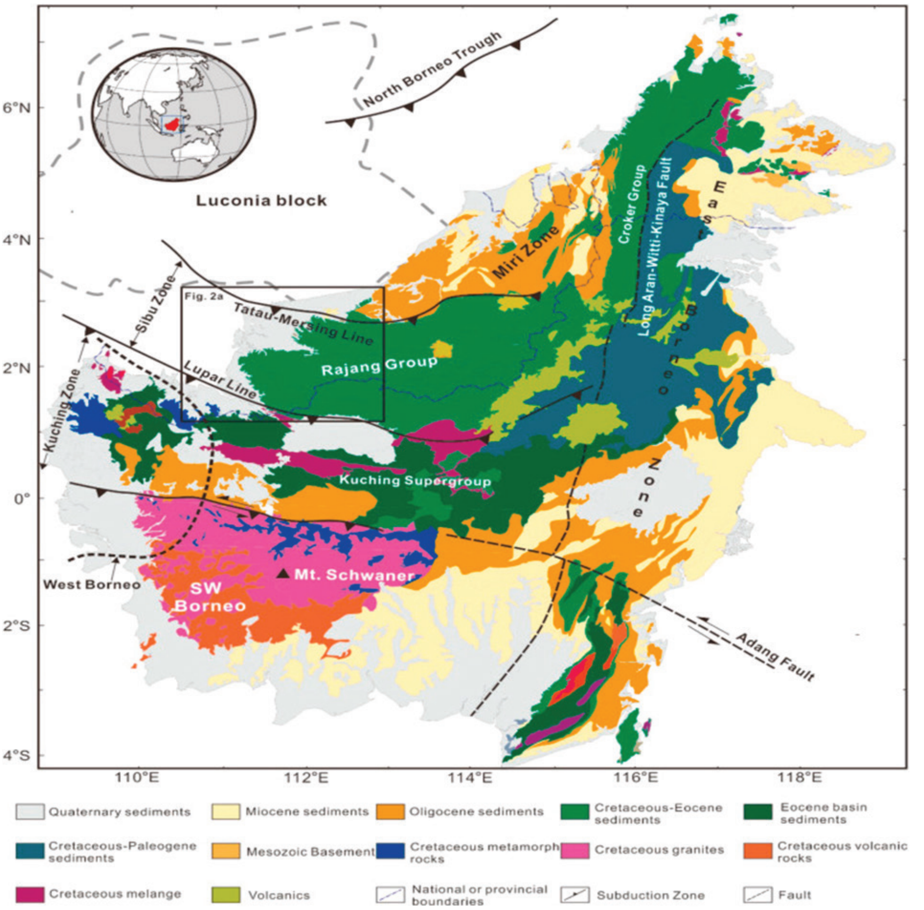

Fig. 2. Rock Formation Map by Zuofei Zhu et al. (2022)

Рис. 2. Карта горных пород, составленная Зуофей Чжу и др. (2022)

porosity of the colluvium materials is making the issue worse due to the intense rainfall that occurs more than 3,000 mm per year. Fig. 4 shows the cross-section of the Setap and Temburong formations which consist of clay shale overlying by colluvium on site.

Relic scars from the early phases of the construction were discovered all over the site. Since they were unfamiliar with the area's history, the circumstance did not worry the designer. It is well known among the locals that they call the area as "living land"; the ground that is always shifting. The movement began as the earthwork was done. Movement occurs along the alignment of the newly constructed road and perpendicular to its roadside drain. Fig. 5 shows a collective photo of the occurrence.

Fig. 3. Site location of SSLR Project (Red Line)

Рис. 3. Место расположения проекта хорды Сабах-Саравак (Красная линия)

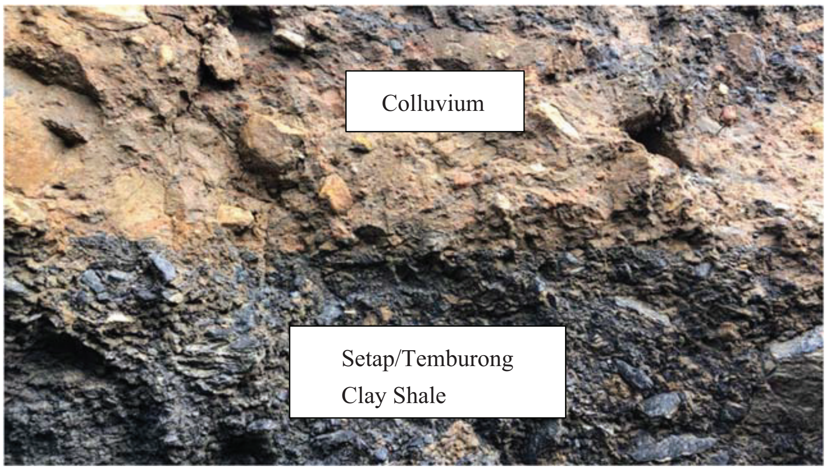

Fig. 4. Colluvium and Clay Shale stratification on Lawas, Sarawak site

Рис. 4. Стратификация коллювия и глинистых сланцев на участке Лавас, Саравак

Fig. 5. Movement of ground during construction on site

Рис. 5. Движение грунта во время строительства на участке

Geological Disturbed Zone

This tropical zone is referred to as a "geologically disturbed zone" by geologists. Tropical region is known to have high rainfall, seismic activity and progressive tectonic activities which cause frequent movement and failure of the ground. The behaviour of the ground will determine the approach taken in this area of infrastructure design, which presents significant challenges for engineers. The primary problem is the excessive rain. Water infiltration through the colluvium's highly porous surface has increased the pore pressure in the low permeability intersecting clay shale. The intersection layer becomes a soft seam mud layer due to clay shale's high and quick deterioration. This lubricating layer allows the overburden on top to move. Fig. 6 shows the deposition of deteriorated clay shale that forms a mud seam layer as mentioned above.

Water enters the colluvium during infiltration and creates a waterfront, leading to excess pore pressure development along the boundary. The differential in permeability between the colluvium and clay shale materials present at the location causes excess pressure to build along the boundary. The differential in permeability between the colluvium and clay shale materials present at the location causes excess pressure to build along the boundary. The differential in permeability between the colluvium and clay shale materials present at the location causes excess pressure to build along the boundary. The differential in permeability between the colluvium and clay shale materials present at the location

Fig. 6. Deposition of Mud seam layer form at the intersection of two different permeability layers

Рис. 6. Отложение слоя илистого грунта образуется на пересечении двух различных по проницаемости пластов

causes excess pressure to build along the boundary. The differential in permeability between the colluvium and clay shale materials present at the location causes excess pressure to build along the boundary. The differential in permeability between the colluvium and clay shale materials present at the location causes excess pressure to build along the boundary. Clay shale undergoing high deterioration develops soft clay elements on its surface that lubricate the intersection surface. The gravitational pull of the overburden combined with extra pore pressure causes the colluvium surface to flow.

In general, the difficulties faced by geologically disturbed zones have aided in the innovation of design solutions aided in the innovation of design solutions. Several strategies have been proposed to address the associated problems, including controlling the penetration of water, fortifying the slope with a drilled shaft, and reinforcing the exposed clay shale surface to slow down the weathering process.

Challenging Soil Zone in Tropical Region — Malaysia

Tropical areas have different climatic and environmental circumstances, which provide problems in geotechnical design. These difficulties are frequently caused by elements like heavy rain, severe weather, and warm temperatures. In tropical climates, the composition of the soil can vary greatly. The soil may be more likely to get soggy in certain places and dry up fast in others. Because soil structure varies, specific land use strategies are needed. Malaysia's geological landscape is characterized by a diverse range of soft soil formations, including alluvial deposits, marine clays, and peat swamps, which are prevalent across the country's coastal plains, river deltas, and low-lying areas. Fig. 7 shows the location of soft soil formation in the Malaysia region.

These soft soil deposits have been formed over millennia through the weathering and erosion of underlying bedrock, as well as sediment deposition from rivers and coastal processes. The tropical climate, with high rainfall and humidity, exacerbates the challenges posed by these soft soils, leading to issues such as soil erosion, slope instability, and groundwater fluctuations. Fig. 8 shows the deposition of soil in tropical regions by J.B. Cox, 1970. Infrastructure projects must be designed and constructed with careful regard for this dynamic behaviour to ensure its stability and longevity. Understanding the behaviour and challenges posed by tropical soft soils is crucial for successful infrastructure development in regions like Malaysia.

To mitigate the challenges posed by soft soils, Malaysia has adopted various ground improvement techniques. These techniques include soil stabilization using lime, cement, or fly ash, deep soil mixing, and stone column installation. These techniques increase the durability and performance of infrastructure projects by strengthening the soil and lowering the risk for settlement. The necessity of choosing the best ground improvement method based on project objectives and site-specific constraints is shown by Malaysia's experience. To overcome the limitations of tropical soft soils, an innovative foundation design is needed. Malaysia has developed technologies like as pile foundations, raft foundations, and soil-structure interaction studies to decrease settlement and effectively distribute loads. Furthermore, engineers may analyse the interaction between soil and structure and optimize foundation designs for performance and stability by using sophisticated numerical modelling tools.

CONSTRUCTION IN SOFT GROUND — CASE 2

Challenges for Building Construction in Batu Pahat, Johor

The new campus, known as University Tun Hussein Onn, is situated in the southern region of Malaysia, in the Batu Pahat district. It is about 25 km to the east of Batu Pahat Town. The area is considerably flat with existing ground level ranges generally between 1.2 to 2.4 m above Sea Level. The construction began in 2007 within an area

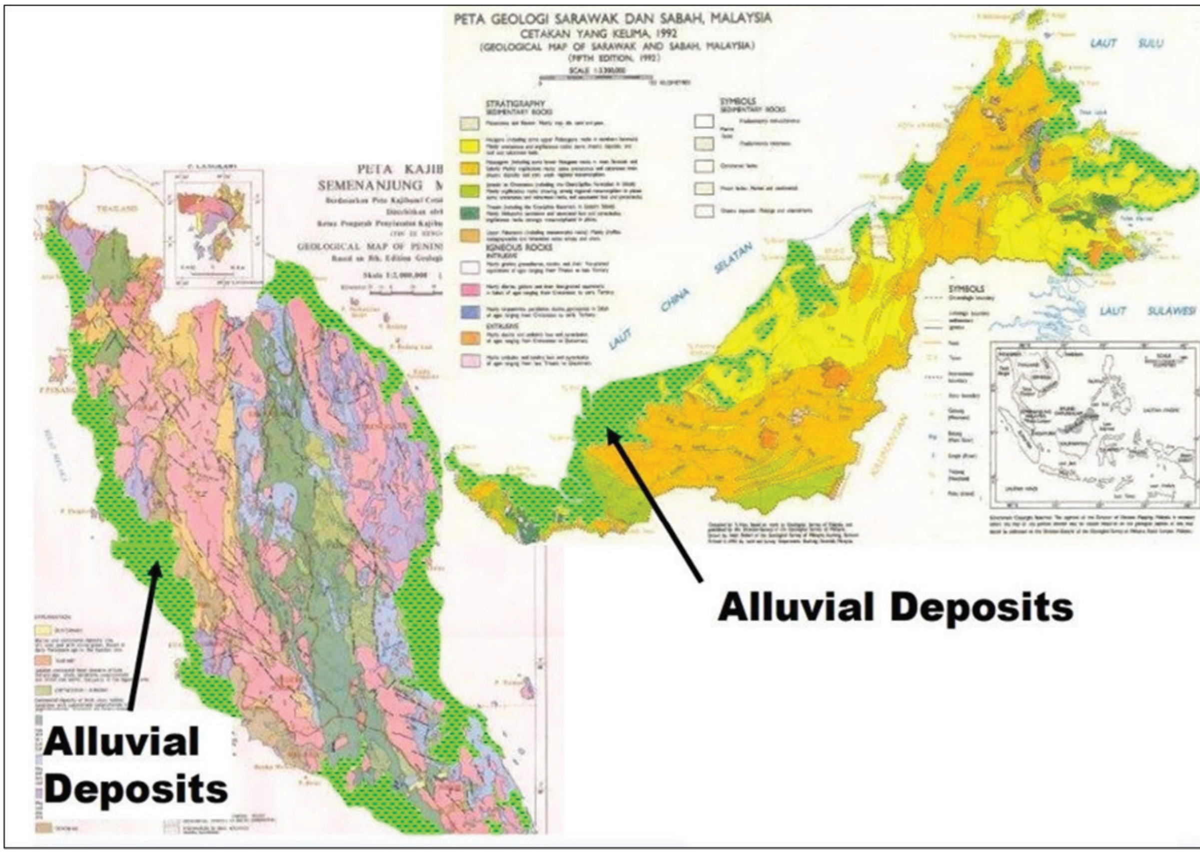

Fig. 7. Location of alluvial deposit in Malaysia region (Dept. of Geology and Mineral Science, Malaysia (1992))

Рис. 7. Расположение аллювиального месторождения в регионе Малайзии (Департамент геологии и минеральных наук Малайзии (1992))

of 145 Ha. It comprises construction for the Library and Chancellery, Faculty of Civil Engineering and Environment, Faculty of Electrical and Electronic Engineering, Faculty of Technology Information and Multimedia, Faculty of Mechanical Engineering and Manufacturing, Faculty of Technical Education and Lecture Hall. The existing

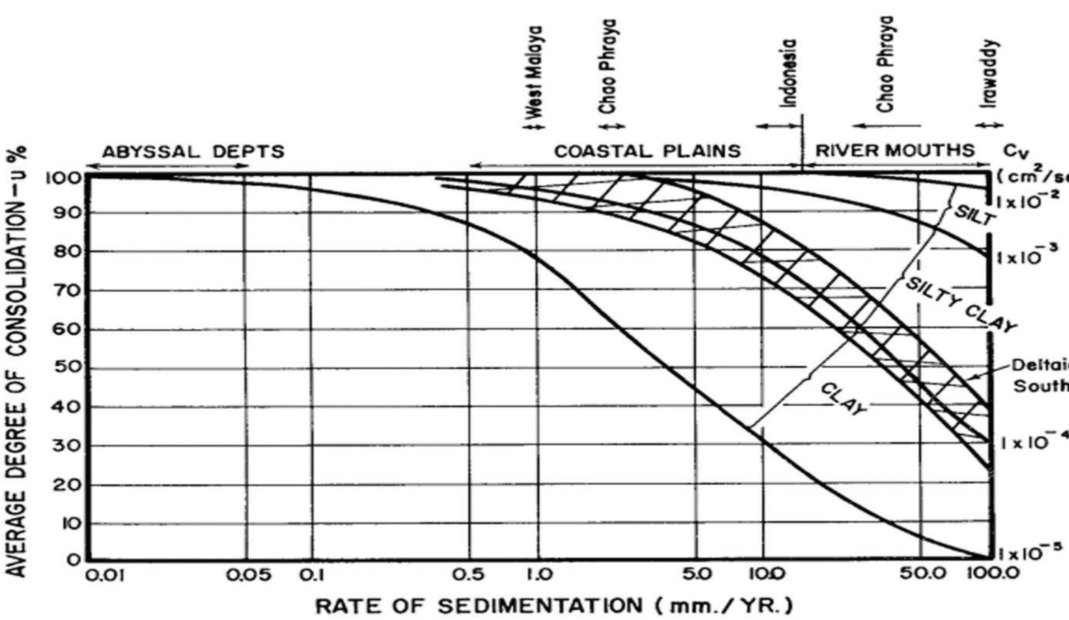

Fig. 8. Relation between rate of sedimentation and Degree of Consolidation for a 5 m thick layer of deposition

Рис. 8. Соотношение между скоростью выпадения осадка и степенью затвердевания для слоя отложений толщиной 5 м

Fig. 9. Location of new campus University Tun Hussein Onn, Batu Pahat

Рис. 9. Расположение нового кампуса университета Тун Хуссейн Онн, Бату Пахат

area which is to be developed as a Reduce Level varies from +1.4 to +1.8 m in the open area. A proposed final platform level will be RL 2.5 m since the flood contributed by the Semberong river and Simpang Kanan river was estimated to be at the highest level of +2.3 m. However, as a centre of attraction, the Library building will be placed on a higher level than others at an R. L of +3.5 m. The current existing level for the previous phase is ranging between R. L +1.8 m and R. L +2.1 m. The layout plan for the development area is shown in Fig. 9.

The whole area of the development sits on soft clay which is highly compressible. Excessive post-construction settlement of the area is the main challenge. Due to construction time constrain, a ground improvement needs to be done to expedite the settlement process of the area. A task of less than six months was given to improve the site before other infrastructure works commenced. To minimize the post-construction settlement, subsoil treatment is required. Various ground treatment methods have been considered. After consideration of time, cost, effectiveness and practicality of various subsoil treatment methods, Surcharge + Vertical Drain (Prefabricated Vertical Drain — PVD) was chosen. The surcharge method is one of the oldest and most efficient methods for the treatment of highly compressible subsoil (Hansbo, 1981). This method has been used for most of the projects in Malaysia that encounter the soft alluvial deposit. The basic principle of this method is to apply a surcharge on the proposed treated area which will expedite the process of settlement at a given time. When the targeted degree of consolidation settlement has occurred, the surcharge can be removed.

A ground improvement work was commenced in August 2007. The work was done in stages by dividing the area into three zones i.e. Zone A, Zone B and Zone C. The whole ground improvement program ended in November 2008. However, settlement at each zone reached its final value within 5 months. The surcharge height used was 2.5 m for both Zone A and B and 2.75 m for Zone C. The final settlement occurred were 490, 400 and 254 mm for Zone A, Zone B and Zone C respectively. Geotechnical instruments were installed to monitor the performance of the subsoil. Back analysis based on settlement monitoring results predicted using Asaoka's Observatory method (Asaoka, 1978) shows a reliable agreement with Terzaghi's one-dimensional consolidation. It was thought to be useful to understand the history of the development site before any settlement prediction is done to eliminate overestimating of surcharge materials which might incur extra costs in construction.

CONCLUSIONS

Engineers and planners facing similar obstacles throughout the world may learn a lot from Malaysia's experience with tropical ground challenges. To effectively manage either geologically disturbed or difficult soil conditions, a thorough site investigation, innovative ground improvement techniques, intelligent foundation design, and continuous monitoring and maintenance are essential. By planning and constructing infrastructure projects to withstand the demands of tropical environments, these lessons may be applied to make sure that the projects are robust and sustainable for future generations. In the tropical zone, parameters by themselves should not be depended upon for design. It needs to be combined with the site's behaviour, history, and local expertise to make the design more trustworthy. In conclusion, geotechnical design in tropical locations requires a holistic approach that considers geological, climatic, environmental, and sociocultural factors. By combining advanced engineering techniques, environmentally conscious methods, and Indigenous knowledge, engineers may build a safe and resilient infrastructure that can withstand the challenges posed by tropical climates.

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