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REVIEW

An overview of excavatability classification for bedded and non bedded rock in a tropical region

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Abstract Surface excavation works in tropically weathered rock are often reported to be challenging due to too many uncertainties such as rock mass and rock properties, environment, selection of the best excavation method, machine characteristics, cost and production rate. The purpose of this study is to present an overview of previous assessments of excavatability and demonstrate the reliability of these methods for assessing the weathered state of rocks in tropical regions. In surface excavation operations, the heterogeneity of the rock mass presents significant issues, particularly in sedimentary locations where the same rock mass contains multiple rock layers with varying weathering grades and strengths. Furthermore, the non-bedded rock mass displays a distinct profile, with boulders occurring throughout the entire zone of highly weathered rock. In tropical weathered rocks, the weathering profile of the rock mass can be very erratic, changeable, and dominant in dictating the behavior of the rock. Disputes in rock engineering properties for practitioners involved in construction work, due to weathering and other issues such as the complex behavior of soil-like and rock-like material arise at the site. These disputes affect practitioners working in the field. A critical review of the current excavatability assessment was conducted. The parameters are then contrasted with the current excavatability assessment procedure, and the outcomes are also specified. At the end of the study, the significance parameter on geological, geotechnical, and geophysics could be determined for various types of rock; thus a reliable classification system could be proposed for efficient assessment. Additionally, a classification system that takes into account the geological factors that are important for surface excavation in tropical areas is greatly needed to assess excavatability.

Keywords Surface excavation · Bedded and non-bedded rock mass · Weathered rock mass · Tropical area · Excavatability

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1 Introduction

A tropical country experiences year-round sunny flux, high levels of atmospheric and subsurface moisture,

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significant precipitation (> 1200 mm), and 28 °C groundwater temperatures (Tang 2019). In other words, tropical countries like Malaysia have high humidity, temperature and rain throughout the year. These features have greatly influenced the chemical weathering process, rain and high temperatures have accelerated the weathering process. One well-known study that is often cited in research on weathering in tropical regions is that of Komoo (1995), which has carried out a study to comprehend the geotechnical characteristics in the tropical region of Peninsular Malaysia. Humid tropical regions undergo weathering processes that result in a broad weathering profile made up of multiple zones with various properties. The results show that weathering has caused major changes in material properties and rock mass properties, from fresh rock to residual soil. These profiles are usually composed of multiple separate zones, each of which has its characteristics resulting from weathering, such as varied rock and soil properties. This issue is very significant in tropical climates (Abad et al. 2015). Therefore, a thorough investigation is crucial to determine the rock mass weathering profile in an area. Tropically weathered rock has a diverse and uncertain weathering profile, which plays a significant role in determining the rock behavior.

Tropical regions have distinct weathering processes resulting from high temperatures, humidity, and heavy rainfall, which can drastically alter rock characteristics. This can result in complex weathering profiles, with the rock mass transitioning from highly weathered at the surface to fresh rock at depth. Initial comprehensive debates and assessments of weathering surfaced in the 1950s (Moye 1955) among pioneering scholars delineating the weathering profile conditions in the sub-tropical regions of Western Australia. More than a decade later, (Little 1969) integrated the research of Moye, Ruxton, and Berry to propose a taxonomy of weathering profiles grounded in the concept of weathering grades. The classification systems proposed for weathered granitic rock were analyzed by (Lee and de Freitas 1989).

A similar study was conducted by (Ruxton and Berry 1957) on granite rock terrain in Hong Kong. They identify the upper section of the zone as zone I, which is composed of fragments of grus or waste mixed with sandy clay or clayey sand. Zone II is primarily characterized by the presence of boulders, subordinates, and small stones or core stones, which make up 0 to 50% of the solid rock. These materials are found inside a grus matrix or soil pieces. Within zone III, which encompasses 50–90% of the area, there are rectangular and interlocking massive boulders, also known as core rocks. The bottom zone comprises zone IV, which is predominantly composed of over 90% partially weathered rocks and has minimal iron staining. The presence of rindlets encircling rocks in weathered granitic formations demonstrates the crucial interplay between weathering processes and the prevailing environmental factors.

Tsidzi (1997) employed the rock-to-soil ratio as a criterion to categorize weathering levels into six unique classifications during the classification process. The classification levels of weathering are established by measuring the percentage of rock present. He classified weathering into distinct zones according to the degree of weathering. Fresh rock (Zone 1) represents less than 10% weathering. The moderately weathered zone (Zone 2) encompasses up to 10% weathering. Moderate weathering (Zone 3) includes 10–35% weathering. Zone 4 of high weathering corresponds to 35–75% weathering. Fully weathered (Zone 5) indicates over 75% weathering. Residual soil (Zone 6) shows complete weathering. However, there is an absence of classification based on the physical characteristics and geomechanical properties of the rock, as well as each weathering zone, specifically for slope design.

The whole excavation process, including the selection and advancement of necessary techniques or equipment, may benefit greatly from a trustworthy excavation assessment. As a result, thorough and organized geological, geotechnical, and geophysical data is essential for assisting practitioners in determining the pertinent and important factors when creating a strategy to deal with this problem. The optimum way to excavate is sometimes unclear to clients and contractors due to this difficulty. The project's viability may also be severely impacted by a lack of precise knowledge about the rock mass, including weathering states, rock density, and material qualities. To anticipate excavatability in a tropically weathered rock mass, a pertinent and useful tropical rock mass assessment that provides clear criteria is required. According to Price (1995), the fundamental systems for comprehending weathering define the material and mass's weathered state and forecast how weathering would affect engineering operations.

When creating design criteria for engineering work, it might be cost- and time-effective to have a basic understanding of the complex characteristics of each weathering profile (Abad et al. 2016).

Excavatability is defined as the capability of a surface excavation method (i.e. breaking by mechanical and blasting) to ultimately produce a smaller and more manageable rock size (Tsiambaos and Saroglou 2010a, b; Mohamad et al. 2005, 2019). Excavatability is influenced by numerous factors such as rock properties, geological features, and the excavation method. An increase in excavatability is very necessary to optimize the efficiency and cost-effectiveness of excavation operations. As such, the selection of equipment that suits site-specific conditions and safety factors plays an important role in determining excavatability. Hence, employing a quantitative approach that considers relevant rock mass and material qualities will yield a straightforward and reliable classification system for selecting the best excavation method. This is important to avoid uncertain interpretations.

Other techniques in mining and civil engineering are geological and geotechnical characteristics, which are crucial for assessing rock masses and choosing the best excavation techniques. This combination of geological and geotechnical information allows detailed site information to be obtained and all possible risks and problems have been taken into account with the rock mass. Thus, it is possible to reduce the difficulties associated with site study by combining geophysical techniques with traditional approaches. The government has suffered numerous losses and project delays as a result of the cost and variation order (VO) it must deal with for earthwork, which is expected to be the largest VO in comparison to other VO. Additionally, as noted by the High Court of Kuala Lumpur, this problem is at the center of numerous arbitrary and legal cases involving contractors and owners. Teong Kim Constructions Sdn. Bhd v. Soo Boo (2003), Gan Kee Earthwork Sdn Bhd v. Lim Ee Kheng (2019), Kerajaan Malaysia v. Perwira Bintang Holdings Sdn Bhd (2014), Pembinaan Yeng Tong Sdn Bhd v. Zelan Construction Sdn Bhd (2020). Therefore, a comprehensive analysis of site conditions during excavation is necessary to ensure that unexpected challenges can be dealt with properly and reduce the problem of disputes on the site.

Indeed, one of the most important factors in classifying rocks is the selection of key characteristics, a crucial issue in the classification of rocks. It is crucial for mining and geotechnical engineering that geologists and engineers comprehend the characteristics and behaviors of various types of rock through accurate classification. Determining the key parameter that determines the excavatability of tropically weathered rock is a crucial step in developing technology and planning earthworks for surface mines and civil engineering projects (Jovanovski et al. 2011). Applying a single parameter will not yield a satisfactory description of the rock mass; instead, a combination of multiple parameters is important. As an example, researchers have spent the previous thirty years examining the discontinuities and rock strength, and this information has been incorporated into the creation of an excavation classification system that is still in use today. In the tropical region, each rock typically exhibits significant differences in various parameters (Mohamad et al. 2008, 2013, 2013, 2015; Mohamad et al. 2011a, b; Abang Hasbollah et al. 2019). As a result, research efforts should be focused on developing surface excavation techniques in tropically weathered rock, considering factors like strength index, joint spacing, moisture content, and blockiness index.

Due to the distinctiveness of these characteristics in tropical weathering environments, it is necessary to establish a precise classification and framework that precisely elucidates the unique processes and patterns observed in the tropics. By integrating these attributes into a categorization framework, scientists and professionals can gain a deeper comprehension of and effectively handle the erosion processes in tropical regions, while tackling the distinct obstacles and possibilities they offer. Based on studies of current systems, it is common for climatic and geological variables to differ from those found in tropical regions. Hence, it is plausible that the distinct attributes of the tropics are not adequately included in current categorizations. The weathering profiles of rock masses in tropical weathered rocks exhibit a diverse and unpredictable nature and can have a significant influence on the behavior of rocks. Various factors related to eroded rock can impact the process of surface excavation in this area. Weathering can cause substantial variation in the characteristics of the eroded rock formation. The existing categorization primarily overlooks the exploration of unique features. This is mainly because most of the existing classification systems were designed elsewhere. Assessing the condition of weathered rocks is a challenging undertaking. However, attempting to alter the various engineering characteristics of weathered rocks is not dependable and does not adhere to certain mathematical methods (Ceryan et al. 2008; Patel 2017).

Hence, the absence of a categorization that adequately suits the circumstances of tropical nations is a significant problem and is highly restricted when compared to the existing classifications. It is crucial to take into account the characterization of materials in different weathering circumstances to facilitate the evaluation process. Furthermore, the criteria considered for determining excavatability are up to interpretation. Thus, a thorough classification system should be both uncomplicated and sufficiently resilient. The evaluation process should take into account both quantitative and qualitative characteristics, which may vary depending on the level of expertise and comprehension among professionals. With the ongoing advancements in technology, it is crucial to reevaluate and enhance the current evaluation methodologies used to estimate the feasibility of excavation operations. This study aims to investigate the key factors contributing to issues in the tropical region for various types of rock formations, using the findings from a direct and pragmatic assessment. Considering the significant difficulties associated with certain areas of engineering projects, such as surface excavation, it is important to address the issue of soil-like material or hard mass that exhibits properties similar to both soil and rock.

2 Excavation classification system

To ascertain the most effective way to carry out excavation based on the mass characteristics and rock properties, excavation classification systems have been developed and examined. They have to do with using tools and machinery. Therefore, economic considerations should be made. It is imperative to consider the application of cutting-edge technologies and criteria when excavating. In addition, it is critical to ascertain the techniques utilized and the rocks' excavatability with the technique chosen. This is because each of these elements will have an impact on planning, operational expenses, and work efficiency. Seismic velocity-based, grading and graphical approximations are the three categories into which the methodologies used to assess surface excavation techniques can be divided. To determine the actual performance of the machines and the excavatability of rocks, the results of a field test conducted under real geological settings should be compared with the graphical technique, which should only be used as a reference. However, because excavation technology is developing so quickly, all approaches must be reviewed periodically (Pettifer and Fookes 1994).

Over the past 30 years, numerous research has been carried out to investigate excavatability utilizing indirect approaches. These methods include the graphical method by (Franklin et al. 1971; Bozdag 1988a, b; Pettifer and Fookes 1994; Dagdelenler et al. 2020), while grading method by (Weaver 1975, Abdullatif and Cruden 1983, Scoble and Muftuoglu 1984, J.Smith 1987, Smith 1986, Singh et al. 1987, H. Basarir and Karpuz 2004a, b) and the seismic methods by Atkinson (1971), Bailey (1975) and Church (1981). The purpose of this study is to assess the rock mass's rippability. Quantitatively assessing the characteristics of geological rocks is difficult, particularly for weathered rocks in tropical climates. During surface excavation work, indirect methods are more difficult to get than direct methods due to their respective limitations. Consequently, more research is required to get over these obstacles.

Assessments of rock excavations carried out in the past have been subjected to critical analysis utilizing a variety of techniques. Digging assessments in tropical nations have been the subject of more and more recent literature (Akip et al. 2021, Mohamad et al. 2006, 2017a, b, Tating et al. 2014, Md Dan et al. 2016a, b, Akip et al. 2018, Mohamad et al. 2011a, b, Nezhad Khalil Abad 2014, Liang 2016, Siti Norsalkini 2019). (Liang et al. 2015a, b) contribute to the discourse on the overview of current excavatability assessments and their reliability in evaluating the condition of bedded weathered rocks, particularly in Nusajaya, Johor, Malaysia. Many current excavatability evaluation methods are deemed unreliable due to the neglect of geological factors, lithology, and weathering conditions across different rock mass strata. A comparison with existing excavation methods was carried out by (Dagdelenler et al. 2020) more flexible method was introduced by considering the geological strength index (GSI) and the point load strength index $Is_{(50)}$. This condition is introduced considering that (Dagdelenler et al. 2020) assert that

(Pettifer and Fookes 1994) and (Franklin et al. 1971) did not consider discontinuity characteristics in their assessment.

Numerous criteria had been taken into consideration when comparing the ratings. Included are the type of rock, parameters related to geology, geotechnical, and geophysics, excavation techniques, machine specifications, and more. As technology advances, there is a pressing need for trustworthy and straightforward excavation assessments that take into account the particularities of a tropical environment. As a result, research is required to use seismic velocity (Caterpillar 2000) and graphical approaches to determine rippability in tropical regions. It is advised to employ these two approaches as the main approach to achieve excavatability in a particular section of the site because they are highly reliable. The techniques derived from these two excavatability evaluations are appropriate for this location and offer financial advantages. In studies on the application of the geophysical approach in surface excavation, it is now being employed by numerous researchers (Ismail et al. 2018; Aziman et al. 2019; Muztaza et al. 2022; Akingboye & Bery 2022; Jug et al. 2020 and Ndiaye et al. 2020). (Muztaza et al. 2022) investigated the subsurface conditions for excavation evaluation before quarry development The study demonstrates that the seismic refraction method may analyze geological subsurface conditions and estimate the amount of rippability for excavatability evaluation in quarrying and mining operations. (Akip et al. 2021) had conducted a study on the integration of geophysical interrogation and geomechanical assessment for sedimentary rock mass classification, Iskandar Puteri, Johor, Malaysia.

2.1 Review of proposed excavatability assessments

There are many classification systems developed to determine rock rippability. Rock rippability, or the ease with which rocks can be removed by ripping or tearing equipment like bulldozers or excavators equipped with ripper attachments, is measured by several classification systems. These classification schemes aid in forecasting the functionality of such equipment under various rock kinds and circumstances. The evaluation of excavatability of rock can be grouped into direct and indirect methods. If trial excavation cannot be carried out at the site, this indirect method is very useful for estimating rock rippability. In mining applications, engineers and geologists utilize the data gathered from these systems to make well-informed decisions on equipment selection, project planning, and excavation techniques.

The surface excavation assessment can be categorized into three methods: approximation based on seismic velocity, graphical and grading methods. Later, these assessments became more complicated due to the strong interactions between rock mass and material properties. Excavation assessments had mostly focused on the excavation mode in the initial phase several decades ago. These assessment methods were extended to integrate other factors, including type of machinery and production. The literature depicts a range of rock mass classifications and rippability assessment methods for surface excavation. As such, this section reviews the commonly used and reliable methods of rippability estimation.

2.2 Evaluation of seismic method

Seismic methods are used to get a broad picture of the surface profile to assess the excavatability of rocks. Using seismic techniques, geological features and underlying structures can be inferred by launching seismic waves into the ground and monitoring their refractions. Seismic refraction data can provide valuable insights into the overall structure and stratigraphy of the subsurface, to assess the excavatability of rocks and plan excavation projects accordingly. Excavatability is based on a variety of factors, including the type, weathering stage, thickness, and total depth of the bedrock. In keeping with the most recent advancements in tractor technology, Caterpillar adopted seismograph refraction in 1958 to detect seismic velocity and assess rippability (Caterpillar 2000). The rippability chart (Fig. 1) of bedded and non-bedded rock types from the Caterpillar Performance Handbook widely used, shows that rock is rippable, marginal and unrippable. Atkinson (1971) was the first to use the seismic approach for assessing excavatability; Bailey (1975) and Church (1981) followed. Seismic refraction is a widely used technique to assess the rippability of a rock mass, according to Atkinson (1971). However, because it must be used to determine the rock mass and material features, this method does not offer a comprehensive assessment of the excavation (Mohamad

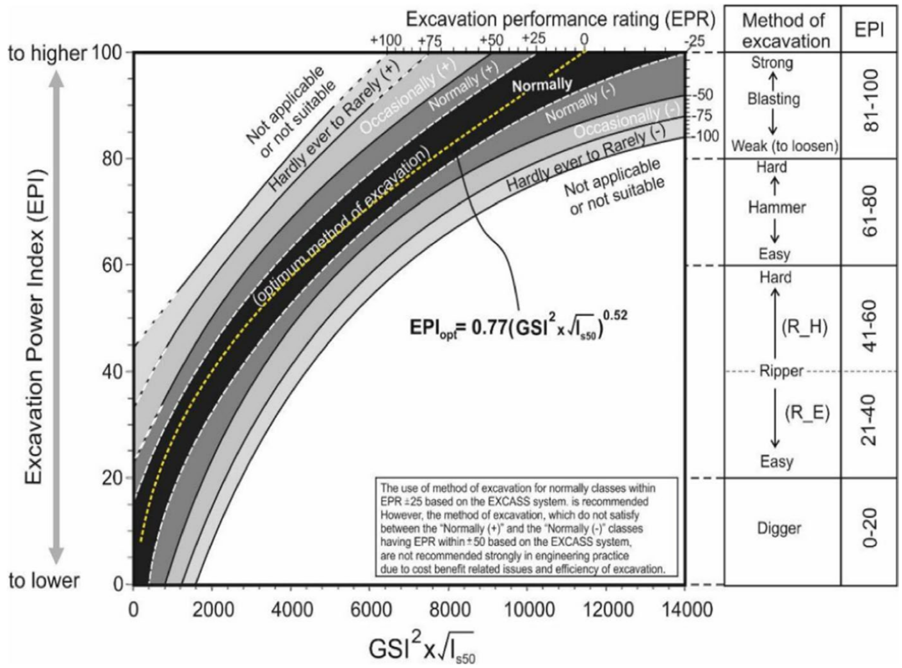

Fig. 1 Excavation assessment (EXCASS) system chart (Dagdelenler et al. 2020)

et al. 2010). A geophysics survey classification scheme for sedimentary rocks, which incorporates seismic velocity and two-dimensional resistivity, has been proposed by (Siti Norsalkini 2019). The suggested excavatability table includes rock type, weathering, strength, and rock mass characteristics. Recently, Jug et al. (2020) proposed a new method for evaluating the excavatability of sedimentary rocks by using seismic methods. As shown in Table 1, indicated one of the developments in the relationship between measured Vs with rippability, which can be used as a reference in the future in addition to improving the existing data base. The seismic S-wave velocities were determined by the use of multichannel analysis of surface waves, which were then used to establish the excavatability classification system.

2.3 Evaluation of graphical method

The graphical method is frequently applied for rapid assessment because it is more practical and understandable. An early, recognized study by Franklin et al. (1971) is often cited in studies of the excavatability assessment approach. By taking into account the fracture spacing index (If) and the Point Load Index (Is(50)), the Size-Strength Excavatability Graph was produced. Even though there was no evidence to support their claim that these two variables were the most significant, they insisted that they vital and meaningly affected the granite mass's strength and deformability. Next, Bozdag (1988a, b) comprehensively examined some open mines owned by the Turkish Coal Enterprise and made clarifications of the on-site tests. Based on the results, an excavatability chart was created, and the ripper type was

Table 1 Classification system of sedimentary rock mass (Jug et al. 2020)

Class of sedimentary rock mass	Measured Vs (m/s)	Appropriate excavation method
I	1200	Blasting (blast holes and explosive)
II	1000–1200	Breaking (hydraulic hammer)
III	600–1000	Ripping (dozer ripper)
IV	< 600	Digging (bucket excavator)

identified using the changes made to the Franklin et al. (1971) chart. The chart provides an estimate of the ripper equipment utilized and is divided into different areas.

Pettifer and Fookes (1994) introduced simple graphs that are suitable for any civil engineering project, especially those that involve roads. These graphs are quick to create and straightforward to assess. Nevertheless, the type of rock study to be used is not specified in these procedures. The rock strength and the average discontinuity spacing are the two factors used in this graph to compare the real production results. It was reported by Pettifer and Fookes (1994) that there is no perfect system, including their graphical system because only field tests can determine accurately the rock excavatability method. The proposed graphical system merely serves as useful guidance when disputes spark during excavation work, although it does not necessarily resolve the issues of equipment selection and cost. There is insufficient comparison to the excavatability of rock masses because these significant characteristics are disregarded for the tropics. Still, the majority of categories demonstrate that it is irrational to attempt to adapt to rock weathered by tropical conditions. Dagdelenler et al. (2020) claim that discontinuous characteristics are not considered by Pettifer and Fookes (1994) and Franklin et al. (1971).

Tsiambaos and Saroglou (2010a, b) initiated a new classification system to determine the excavatability of rock masses based on Geological Strength Index (GSI) and point load strength of intact rock. Studies on the various structures of sedimentary and metamorphic rock masses were performed on discontinuity surfaces and conditions that controlled excavation. Nevertheless, this method is inapplicable to examine excavations in heterogeneous rock mass and weak rock/hard soil. Based on $Is_{(50)}$ values, the GSI classification was divided into two groups: less than 3 MPa and more than 3 MPa. This made it possible to determine the type of excavation—blasting, ripping, digging, or hydraulic braking—and how to proceed. Khamehchiyan et al. (2014) developed a classification system based on the Rock Mass Index (RMI) and block volume, considering some significant geological engineering and geotechnical criteria. These included the following: aperture, continuity, orientation, seismic velocity, uniaxial compressive strength (UCS), weathering grade, discontinuity spacing, and wall roughness at the joints. The five sections of the graphic charts were blasting, ripper (D7), ripper (D8-D9), hammer, and digging. Recently Dagdelenler et al. (2020) created a flexible excavation evaluation (EXCASS) method that used the two metrics GSI and $Is_{(50)}$ in a study that included 61 sites in Greece and 12 sites in Turkey. The two main terms utilized in this method to assess the choice of appropriate excavation techniques are the excavation power index (EPI) and the excavation performance rating (EPR) as shown in Fig. 1.

2.4 Evaluation of grading system

Since the rock mass properties greatly influence rippability, it is essential to establish specific assumptions and probabilities to conduct a comparative assessment (Smith 1986). The interrelated features that are involved include seismic wave velocity, strength, and weathering. Other geological factors influencing the rippability assessment include rock type, hardness, weathering, structure, and fabric in addition to seismic wave velocity (Weaver 1975; Smith 1986). Weaver (1975) considers the aforementioned elements for creating a rippability chart. While seismic techniques are commonly used in rock excavation, they are insufficient to yield accurate findings. There are additional geological factors that need to be considered. Furthermore, on perhaps tough rocks, this seismic approach is unnoticeable. A comprehensive summary was provided by Hadjigeorgiou and Poulin (1998) developed a method for estimating excavatability that facilitates the selection of reasonably priced equipment. The weights given to the parameters—block size, relative ground structure index, weathering influence, and strength—determine how this system works. Stickiness, roughness, and seismic velocity are additional factors taken into account.

A diggability index was first presented by Karpuz (1990) and considers five classification parameters: weathering, mean of joint spacing, seismic wave velocity (Vp), Schmidt Hardness value, and UCS. This index provides information about the equipment used in the excavation process as well as a rock quality indicator. Considering the diggability, which considers the rock characteristics and the efficiency of the equipment employed, the system is also incredibly thorough. The grading method bases its assessment on the material qualities that can impact excavatability as well as the importance of the rock mass. Within more specific criteria, many scholars have proposed the grading system (Weaver 1975; Kirsten 1982; Abdullatif and Cruden 1983; Scoble and Muftuoglu 1984; Smith 1987; Singh et al. 1987; Karpuz 1990; Macgregor et al. 1994; Kramadibrata 1996; Basarir and Karpuz 2004a, b). Nevertheless, given the heft and material characteristics of the rock, comprehending the system used by practitioners is not simple. Thus, additional research is needed to evaluate the techniques that impact excavatability. Unlike graphical methods that immediately present information based on the parameters, the weighting and sum of the method might be subject to many interpretations and viewpoints.

After examining the existing methods of rippability prediction, Macgregor et al. (1994) introduced a system to determine the variables impacting bulldozer efficiency and anticipate ripping productivity for complex settings. The proposed approach was executed by utilizing field work data collected from 15 locations and 242 regions, encompassing both bedded and non-bedded rocks, through the use of diverse apparatus and under different geological conditions. As a result, 527 ripping datasets were captured. The study was conducted by Abdullatif and Cruden (1983), who gathered information on the features of discontinuities and the techniques used in rock excavation. There are three different classification methods were used in this study to determine the Rock Mass Rating. That is point load strength and fracture spacing by Franklin et al. (1971), Bieniawski's Rock Mass Rating (1976) and Barton et al.'s NGI Quality Index Q (1977). Results indicate that, when compared to other techniques, RMR provided the most accurate estimate of the rock mass for excavation purposes. They advised excavating rock mass with an RMR value of up and around to thirty. Drilling and blasting could be done when RMR was above 60, although ripping could be done when RMR was up to 60.

The diggability index introduced by Scoble and Muftuoglu (1984) is a grading system that sums up the values of strength, weathering degree, as well as joint and bedding spacing. It correlates with the performance of excavators for some criteria, including weathering, strength, block size, and shape. This indexing method pertains to the type and capacity of machinery and is necessary for usage in the future as machinery technology advances. Rocks are categorized using this system or method according to their mass and other material characteristics that have a major impact on how easily they may be excavated. When rippability cannot be ascertained due to some circumstances, trial excavation is conducted as a reference to obtain a ripping production rate. It is a useful and affordable method for determining the potential for ripping production and streamlining ripping processes in rock excavation projects. Project planning can be enhanced and the effectiveness and productivity of ripping operations can be maximized by utilizing the insights obtained from trial excavations (Hakan Basarir and Karpuz 2004a, b). Hourly production estimation and rippability classes for different dozers may be quickly and simply determined using the rippability classification. According to Kirsten (1982) a quantitative word is a crucial component in the classification of excavation to prevent misunderstandings about interpretations. Regardless of the size or type of excavation equipment, the given index is unique and may be used on everything from the hardest rocks to the weakest soils. The excavatability index parameter values and engineering features that affect the excavation process comprise the suggested classification system (Table 1). He thinks this technique can resolve the conflicts and issues that come up during building. The Q system, first presented by Barton et al. (1974), serves as the foundation for the Excavatability Index, N specified. However, other factors—such as the impact on groundwater and soil stress are ignored.

On the other hand, Singh et al. (1987) propose a new rippability index for mining applications that accounts for the rock abrasiveness, discontinuity spacings, seismic velocity, degree of weathering, and tensile strength. Several case studies have been provided to demonstrate how the new rippability index should be applied. The production rate of rippable rock mass is contingent upon the type of ripping and the size of the machinery involved. They believe that rock mass rippability might be attained by a shank penetration exceeding 0.6 m at least a speed of 2.5 km/h. Additionally, an attachable dozer is divided into multiple groups based on its weight and power. The newly presented classification has demonstrated that the ripper's lifespan and production rate are impacted by the abrasiveness of the rock.

Excavating in sandstone and shale-dominated weathered sedimentary rock presents difficulties, according to Liang et al. (2015a, b), particularly in the sub-zones of moderate and highly weathered rock. They contend that because numerous crucial factors are overlooked, most techniques are unreliable in tropical regions. Thus, an excavation classification is created by considering some crucial factors that have a big impact on excavatability. Kramadibrata (1996) developed a link between the Q system, the Excavatability Index and the Rock Mass Rating (RMR). According to this study, the most effective way to evaluate excavatability is to use the Excavatability Index. He then looked at the current excavatability assessment and the empirical formula used to determine the productivity of digging. The rock characteristics, rock grade, dozer type, and productivity are indicated by the rippability classification scheme put forward by Hakan Basarir and Karpuz (2004a, b). Additionally, dozers similar to the CATD8N type were displayed. A significant addition has been made by the system that is being presented: specific energy has a strong link with UCS.

Numerous scholars have suggested a variety of empirical prediction techniques, the most popular of which is the rock mass classification system, which facilitates excavation and identifies the kind of equipment that is employed. Nonetheless, frequent flaws may raise questions about how they should be used in practice (M. Iphar and Goktan 2006). Excavation classes identified by excavatability classification systems demonstrate comparable techniques during the excavation stage based on an evaluation of the outcomes. According to Iphar (2016), there are certain drawbacks to the current classification systems, and practicing them can be difficult. He provides possible ways to get over these shortcomings by carrying out a more grounded assessment. He knew there were abrupt changes in two neighboring classes, would be difficult to categorize a rock excavation. He thinks the solution to this issue is "continuous ratings," as opposed to constant ratings.

Some characteristics influencing the excavation have been identified and taken into consideration based on the current evaluation of the excavation. The Is(50), UCS, discontinuity spacing, weathering degree, and seismic velocities are the most favored input and often utilized characteristics, according to Table 2. Through the summary shown in Table 2, it can be seen some of the significance of the parameters found to affect the excavatability of each type of rock found throughout the country. This table shows that it has developed well over the last 30 years, making it suitable for reference in excavatability issues. However, the existing system of classification ignores many important factors that are specific to the tropics and concentrates solely on one type of rock. One of the most important parameters in the rock mass attributes is the scale of discontinuities, which is frequently disregarded in current evaluations. The blockiness of the rock bulk, joints, and bedding are all included in these discontinuity scales. The state of the research and the building industry also indicate that, despite frequent disagreement among practitioners, emphasis should be placed on hard mass confirmation, which typically involves weathering grades III and IV. The efficiency of machinery used in earthworks is also crucial, and to keep up with the present, rapid advancement of technology, the specific machinery requirements must be updated regularly. Because there are many kinds of machines with varying functions and specifications, machine variables are also another crucial topic that needs to be researched in the excavatability evaluation process. Additionally, this study will consider the fact that the production rate is dependent on some affecting factors. Because of this, practitioners in tropical regions need a simplified approach to classifying bedded and non-bedded rock. This will boost efficiency and lower earthwork costs by making the most use of geological data and selecting precise excavation techniques.

The graphical method is commonly used for fast estimates since more straightforwardly applied. For example, this method is also simpler, than Pettifer and Fookes (1994) graph, which only involves two parameters, that is discontinuity spacing Index and Is(50). However, most of the classification systems introduced in Malaysia are mostly grading methods (Liang 2016). This classification system is also difficult to practice in the field. The overall value is obtained by adding the values for each different parameter, subject to understanding and different verdicts. Although seismic methods are commonly employed in rock excavation, they are not sufficient to yield precise findings. Several factors are not taken into account in this method. Pettifer and Fookes (1994) introduced easy-to-use graphs for direct and quick evaluation suitable for all civil and infrastructure projects. However, the graphs omit the rock type. The excavatability is characterized

Table 2 Summary of Geotechnical parameters used by researchers in assessing the excavatability assessment method

Assessment Method	Rock Type	RQD	Geophysics		Strength			Joint/ Discontinuity								Bedding Spacing	Density	Abrasiveness	Weathering	Machinery Machineries
			Resistivity	Seismic Velocity	UCS	Point Load Index	Rock Hardness	No. of Joint Set	Joint Alteration	Joint Roughness	Discontinuity Spacing	Joint Persistence	Joint Separation	Blockiness	Joint Orientation					
Caterpillar (2000)				–																–
Franklin et al. (1971)	General					–					–		–		–					
Bailey (1975)	General			–																
Weaver (1975)	General			–			–				–	–	–		–				–	–
Church (1981)	General			–																
Kirsten (1982)	General	–			–			–	–	–	–		–		–					
Abdullatif et al. (1983)	General					–					–									
Minty and Kearns (1983)				–		–					–	–	–						–	–
Scoble and Muftuoglu (1984)	Sedimentary				–						–				–				–	–
Smith (1986)	General				–														–	
Singh et al. (1987)	Sedimentary			–		–					–	–	–					–	–	
Komatsu (1987)				–																

Table 2 (continued)

Assessment Method	Rock Type	RQD	Geophysics		Strength			Joint/ Discontinuity								Bedding Spacing	Density	Abrasiveness	Weathering	Machinery Machineries
			Resistivity	Seismic Velocity	UCS	Point Load Index	Rock Hardness	No. of Joint Set	Joint Alteration	Joint Roughness	Discontinuity Spacing	Joint Persistence	Joint Separation	Blockiness	Joint Orientation					
Karpuz (1990)	Sedimentary			–	–		–				–								–	–
Hadjigeorgiou and Poulin (1998)	General					–		–			–			–					–	
MacGregor et al. (1994)	General			–	–			–		–										
Pettifer and Fookes (1994)	Sedimentary					–					–				–				–	
Kramadibrata (1998)	General	–			–	–				–	–									
Atkinson (1971)	General			–																
Mutfuoglu (1983)	General				–	–					–					–			–	
Basarir and Karpuz (2004a, b)	Sedimentary			–	–	–													–	–
Tsiambaos and Saroglou (2010a, b)	General					–					–	–	–		–				–	
Iphar and Goktan (2006)	General																			
Alavi (2014)	Granite									–	–	–	–		–				–	

Table 2 (continued)

Assessment Method	Rock Type	RQD	Geophysics		Strength			Joint/ Discontinuity								Bedding Spacing	Density	Abrasiveness	Weathering	Machinery Machineries
			Resistivity	Seismic Velocity	UCS	Point Load Index	Rock Hardness	No. of Joint Set	Joint Alteration	Joint Roughness	Discontinuity Spacing	Joint Persistence	Joint Separation	Blockiness	Joint Orientation					
Liang (2016)	Sedimentary				–	–	–	–	–	–	–	–	–	–		–	–		–	–
Norsalkini (2019)	Sedimentary		–	–		–													–	–
Dagdelenler (2021)						–				–								–		

into 'easy', 'hard', 'very hard', 'extremely hard', and 'blasting'. Because other crucial factors are taken into account, comparisons to the excavatability of rock masses are therefore inadequate, particularly those related to tropical climates. He stated that rock excavatability depends on the material's geotechnical properties, working method, and the specification of excavation equipment. Besides, cost considerations and environmental constraints need to be considered before ripping, or blasting is made. However, most of the proposed excavation methods in Malaysia (Jamaluddin and Sundaram 2000; Liang et al. 2017) and other tropical countries where Muyideen Alade (2014) uses his classification although it is not specifically stated to be suitable for tropical areas.

The selection of key characteristics is a crucial issue in the classification of rocks. Applying a single parameter will not yield a satisfactory description of the rock mass; instead, a combination of multiple parameters is important. Researchers have spent the previous thirty years examining the discontinuities and strength of the rock properties, and this information has been incorporated into the creation of an excavation classification system that is still in use today. However, this method does not take into account other factors like topography, lithology, discontinuities, moisture content, joint characterization, and bedding thickness (Nezhad et al. 2015). In the tropical region, each rock typically exhibits significant differences in various parameters (Mohamad et al. 2008, Mohamad et al. 2011a, b; Mohammed et al. 2013; Abang Hasbollah et al. 2019). As a result, research efforts should be focused on developing surface excavation techniques in tropically weathered rock, taking into account factors like strength index, joint spacing, moisture content, and blockiness index. Using the results of a straightforward and practical assessment, this study attempts to explore the most important elements associated with problems in the tropical region for different types of rock mass. Similarly, given the serious challenges with some aspects of engineering works, particularly surface excavation, the problem of soil-like material or hard mass, which gives characteristics on the scale of mass and rock, should be taken into consideration.

3 Excavation classification system in tropical region

The evaluation of the excavation classification system has revealed several important factors that influence the excavation process and should be considered when choosing the most effective surface excavation technique will be discussed in this paper. Excavatability assessment methods that have been introduced by previous researchers have been found to have taken into account several parameters that are believed to affect excavatability. The parameters used are obtained through site tests and laboratory tests including geophysical tests. Rock mass and material properties obtained can improve the understanding of the various rock physical and mechanical properties. However, there are still loopholes in the evaluation which will be discussed in this journal. Therefore, the excavatability classification system appears to be an effective tool because it shows the influence of more dominant parameters more regularly. As indicated in Table 3, numerous investigations carried out in tropical regions have contributed to the development of a more thorough excavatability classification system for weathered rock mass. This table shows that the research carried out in Malaysia is used as a reference for the improvement and advancement of rock excavatability in tropical areas.

Table 3 Classification System proposed by Malaysia researcher for tropical region

Author and year	Type of rock	Parameter	Enhance research
Vahid Alavi (2014)	Non-bedded (Granite)	1. Schmidt Hammer Value (SHV) 2. Joint Trace Length (JL) 3. Joint aperture (Ja) 4. Joint Infilling Material (Jf) 5. Degree of Jointing (Jd) 6. Groundwater Condition (Gw) 7. Boulder Occurrence 8. Relative Ground Condition (RGC) 9. Rock: Soil Ratio (RSR) 10. Mass Homogeneity (Ho)	Specific features in granitic should be given attention in surface excavation A more appropriate approach is also necessary to determine the surface excavation rate of tropically weathered granite (i.e., to adapt geophysics with an existing method for better results and findings)
Liang (2016)	Bedded (Weathered sandstone and shale)	Strength Rebound Hammer Value UCS Density Indirect Tensile Strength Joint Spacing Joint Direction Iron Pan Existence Moisture Content	It is proposed that a refined method to estimate the block volume for wet tropically weathered sedimentary rocks should be further examined
Norsalkini (2019)	Bedded (Sedimentary rock)	Rock Mass Rating (RMR) Q System Rating Point Load Strength, Is(50) Resistivity Index Seismic Velocity Index	Since this study solely focuses on bedded rock, more research on other rock types should be done In tropically weathered rock, the creation of subsurface caverns and sinkholes presents a challenge
Ramesh (2020)	Non bedded (Granite)	1. Weathering Index (WI)—Porosity, water absorption, PLI strength, Blockiness Index 2. Blastability Index (BI)- burden, stemming length, powder factor, and WI/	Therefore, this study developed and utilized the WI and BWI and similar parameters need to be determined for other rock types in the tropical regions Key blast design parameters, BI and WI need to be incorporated to predict the blast performance in other types of rocks WI can be utilized to examine geotechnical challenges such as slope stability, excavation, and foundation in tropical regions

It is found that a majority of the classifications' development was completed in foreign countries, distinctive features like the presence of boulders, iron pan, moisture content and conditions of discontinuities are among the typical characteristics that were not adequately addressed in the previous classifications. As shown in Table 2, the study was done in the location of an area that has different rock types with different grades of weathering in Peninsular Malaysia. This study shows that productivity is dependent on several factors that are influenced by weathering grades. As reported by Liang et al. (2015a, bohamad, et al. (2015), existing excavatability assessment methods for tropically weathered sedimentary rocks are less reliable due to factors like nature, lithology, and weathering state at various layers. An Excavation Index of Sedimentary Rock (EISR) was proposed by Liang (2016) after analyzing factors that influenced the excavatability of a sedimentary rock mass. To determine the EISR value, the parameters were measured in each zone in turn, and the results were compared to the production rate that was extracted from the actual excavation. Relative ground and joint properties were also taken into account. There are five grades in the EISR, ranging from blasting or ripping to quite readily excavated. In EISR, values 0 and 50 denote no excavation work can be executed and very easy excavation work, respectively. The EISR is suitable for excavation work involving tropically-weathered sandstone and shale.

While according to Bhatawdekar Ramesh Maulidhar (2020), conducted research on granite, tropical weathered rock masses are divided into three categories: massive, blocky, and fractured rock, to make the assessment of development blasting performance easier. The strength index qualities, porosity, and water absorption of rocks are the basis for the introduction of the Weathering Index (WI). On the other hand, the Block Weathering Index (BWI) is developed using computational models and fictitious values from exploration data. Many rock characterizations, including the strength and range of weathered rock in various zones, have an impact on the environment as a result of blasting. The porosity, water absorption, and Is (50) of rocks are the basis for the introduction of the Weathering Index (WI).

Research conducted by Siti Norsalkini (2020) contributed to the development of the assessment of excavatability in the field of geophysics for sedimentary rocks in Malaysia. In terms of excavation performance, the suggested resistivity and velocity index scheme, which is based on sedimentary rock mass that has weathered tropically, is noticeably more advanced than the current evaluation. The classification deploys rock type, weathering state, $Is_{(50)}$, field characteristic of rock mass, RMR, Q system, resistivity value, and seismic velocity index to evaluate excavatability performance. A study was conducted to assess the ability of geophysical methods as one of the pre-assessment methods before excavation work. Four sites covered by residual soil and sandstone alternating with shale at varied weathering levels were examined. The excavation classification was developed based on the assessment of rock mass against geophysical surveys. This classification denotes a significant improvement over the existing ones in the geophysical aspect of sedimentary rock mass in tropical climates.

On the other hand, Excavation Index in Granite (EIG) was presented by Abad et al. (2014). It was created using data from field and laboratory tests. Excavatability conditions range from very easy to blasting, and five classes in the excavatability chart represent different excavation rates. The EIG model was compared with results retrieved from practical excavation at other sites. The study disclosed that the geomechanical model could forecast the excavatability of weathered granite by using a hydraulic excavator. The discoveries of this study contribute to the growth of the assessment of mining by suggesting resistivity and seismic velocity indices for the bedded rock mass, significantly innovative compared to existing evaluations. This work has answered many issues found in the tropics and shows that there is a need to form a classification system for a more comprehensive evaluation of the mineability for weathered bedded and non-bedded rock masses.

Numerous empirical predictive approaches have been suggested by various authors, with the rock mass classification system being the main approach for assessing excavatability, hence facilitating excavation and determining the type of equipment required. Nevertheless, prevalent deficiencies may induce uncertainty in their practical implementation (Iphar and Goktan 2006). Most of the proposed excavation methods in Malaysia (Jamaluddin and Sundaram 2000 and Liang et al. 2017) and other tropical countries (Muyideen Alade and Abdulazeez 2014) use his classification although it is not specifically stated to be suitable for tropical areas. The study evaluated the optimum excavation technique for limestone deposits in Obajana in Kogi State, Nigeria. The graphical method is commonly used for fast estimates since more straightforwardly applied. For example, this method is also simpler, than (Pettifer and Fookes 1994) graph, which only involves two parameters, that is discontinuity spacing and $Is_{(50)}$. He stated that rock excavatability depends on the material's geotechnical properties, working method and the specification of excavation equipment. However, most of the classification systems introduced in Malaysia are mostly grading methods (Liang et al. 2015a, b). This classification system is also difficult to practice in the field. The total value, which is open to interpretation and differing opinions, is calculated by summing the values for each different parameter. Although seismic methods are commonly employed in rock excavation, they are not sufficient to yield precise findings. Several factors are not taken into account in this method.

The comparison of the proposed classification systems indicates that several improvements are essential in tropical regions. It includes improvements to weathering parameters, to increase relevance for tropical excavations, improvements in weathering parameters and joint characteristics can make each system more easier and practical to use. The current approach can be enhanced by include by integrating a wider range of parameters, such as rock mass weathering index, discontinuity spacing, and block volume to reflect the complexity of geological conditions more accurately. This issue also attempts to address the complex transition zone among soil-rock, unweathered, and weathered rock. The utilization of geophysical techniques, machine learning, or statistical analysis can enhance the accuracy and precision of excavatability classification predictions, overcoming the limitations of traditional data collection and analysis methods. Future mineralization categorization systems must integrate the diversity of tropical soils and rock formations, considering changes in weathering profiles, mineralogical composition, and structural discontinuities explicit to tropical environments. The application of geophysical methods, machine learning, or Artificial Intelligence (AI) methods can improve the accuracy and precision of the classification of excavatability predictions, addressing the limitations of conventional approaches in data collection and analysis. Currently, the relationship between soil profile and seismic velocity has advanced significantly. Consequently, the classification system's predictions regarding geophysical data for various rock types yield numerous advantages. Furthermore, an improved classification system should integrate data regarding the performance and constraints of current mining and excavated machinery, thereby establishing a direct correlation between material characteristics and equipment functionalities. This situation will simplify in determining the production rate for machines with different specifications. On the other hand, integrating machine learning models with advanced statistical techniques enhanced the reliability and prediction capacity of the excavatability classification system, particularly in heterogeneous and complex tropical regions. These improvements aim to make the excavatability classification system more reliable, flexible, and aligned with more difficult rock engineering challenges and practices.

4 Significance parameter in determining the surface excavation

Through a literature review, some commonly used geotechnical, geological and geophysical criteria and their importance to excavation were determined based on the evaluation. Determining the level of importance of related factors is important to develop a more accurate classification system. The excavation method developed by this research will reduce the cost and challenge of excavation by determining rock characteristics using field and laboratory data. Based on the evaluation of rock mass and material properties against previous research, several parameters are observed to be significant and need to be preparing an excavatability classification system for tropical regions. The determination of these significant parameters however needs to be differentiated to obtain the level of accuracy of the parameters by conducting statistical analysis to gain higher confidence and improved results.

4.1 Seismic velocity

In the site investigation scope of work, borehole investigation is widely used as a site investigation method to provide valuable insights into soil stratum at discrete locations. Thus there may be gaps in the understanding of subsurface conditions between boreholes. However, recently resistivity and seismic velocity most employed by practitioners have been applied widely to solve problems inherent in more conventional site investigation methods. As reported by Bačić et al. (2020), the borehole approach guarantees more reliable geotechnical characteristics, but it also depends on human factors, time, and cost. Therefore, geophysical concerns may be among the more effective ways to address this new problem and mitigate all the limitations that occurred. Besides, this integrated approach helps to enhance the understanding of the uniqueness of subsurface conditions, including cavities, and dissolution features in carbonate rocks and boulders (Azrief Azahar et al. 2019). It is found that the correlation between geotechnics and geophysics provides benefits to performing earthworks on site, especially for surface excavation. Geophysics should be considered in this study as an initial evaluation before beginning earthwork and as a standard for the depth and volume of rock that must be excavated in the area. By addressing other difficulties, this preliminary evaluation will resolve other issues and save costs and time associated with rock excavation operations.

Resistivity is influenced by various geological characteristics, including a percentage of water saturation in rocks, porosity, and the minerals and fluids content. There is a large variety in resistivity values for all types of rock and soil. Resistivity readings can therefore be related to information found in drill records or outcrop surfaces, but they cannot be correctly understood in terms of soil type or lithology. As the study area does not have any borehole records, weathering grades of the ground are determined based on a similar case study of a published journal paper. The relationship between resistivity and weathering grade can be referred to in the summary conducted by Olona et al. (2010) and Haryati et al. (2017).

Seismic velocity, on the other hand, is a geophysical tool that can provide the variance of subsurface materials which also requires good interpretation from the user and judgment based on extensive knowledge and experience in this field. This is because this seismic involves mapping the sequence of rocks that have certain layers and detecting the boundaries of layers below the surface for excavation assessment for certain types of materials (Akip et al. 2021). Techniques based on seismic velocity that take into account the P-wave seismic velocities of rocks. The values of seismic surveys can be validated using data from (Sjogren et al. 1979; Rofiqul, 2005, Santi 2006) and Kausarian et al. (2014)

4.2 Strength

Rocks are divided into bedded and non-bedded based on their formation method, abundance, texture and minerals type involved, the degree of metamorphism, and others. The strengths are essential in the design process. Some unique rock properties need to be considered since they affect surface excavation and underground works. The strength of rock has been acknowledged as one of the most important parameters in characterizing rock mass properties. This parameter may be considered in terms of compressive, tensile, and shear strength. Rocks are classified based on their strength value (UCS and Is(50)) (Singh and Goel 2011). Goel and Subhash (2015) claimed that the strength of intact rocks is a factor that is influenced by weathering, besides the conditions and spacing of discontinuities. There are anisotropic, sheet minerals, hard and abrasive minerals, slaking rocks, swelling minerals and rocks, soluble minerals, porous rocks, and weathering and alteration of rocks (Palmstrom and Stille 2015). The $Is_{(50)}$ can effectively determine UCS in pyroclastic rocks with UCS values less than 50 MPa (Kahraman 2014)**.** A limit value is set during the UCS test for soft rocks that are affected by weathering. Rocks that record a UCS value below 50 MPa for structural building design work should be given due attention. Weathering causes weak contact between grains in rocks. Upon evaluating the texture of rocks, Ozturk and Nasuf (2013) found that matrices and grains influence the strength of a rock. In addition, correlations were observed among the properties of texture and mechanical coefficients, rock drilling, and excavatability. Apart from their impacts on the shear strength and deformability of rocks, changes in weathering characteristics must be determined when predicting long-term problems for engineering purposes.

The selection of significant parameters is a major issue in rock classification. A good description of the rock mass cannot be obtained by applying merely a single parameter but requires a combination of several parameters. Since the strength of rock properties is a crucial parameter because it informs the strength limit of the rock mass, UCS is commonly retrieved for field work (Bieniawski 1993). The maximum strength of a rock has a significant role in the selection of the most suitable equipment to carry out excavation work (Tatiya 2005). Several classifications that revolved around rock strength and modulus of elasticity were proposed by Bieniawski (1989). As the Deere-Miller classification does not display a range of less than 25 MPa, ISRM recommends a different range. According to Hawkins (1998), an accurate description of rock strength below 50 MPa is important for excavation purposes. Rocks with a strength value of less than 5 MPa can be dug with a backhoe regardless of the discontinuity factor. Layered rocks that are less than 20 mm and rock strength at 12 to 15 MPa can still be excavated. Nonetheless, it is rather difficult to excavate rocks that record strength values ranging from 20 to 25 MPa.

Bieniawski (1989) explained that the UCS value of 1 MPa refers to the lowest strength limit for rock and is considered soil following soil mechanic practice. In the rippability assessment of rocks, it is important to determine the variance between material and mass properties. Problems often emerge when selecting the best excavation method on moderately strong rock types (hard materials lie between soils (<1 MPa) and rocks (>70 MPa) and rocks in fresh states (i.e., igneous, sedimentary, and metamorphic rocks). Disputes often spark between contractors and clients due to efficiency factors, as well as the selection of between ripping and blasting methods (Tawaf et al. 2018). Weak rocks in moderately to completely weathered states often lead to a different interpretation when evaluating the excavation method (Mohd Amin 1995; Mohamad et al. 2005; Jamaluddin and Sundaram 2000). Estimating the strength of weak rock mass is thrilling due to its complex nature and the present empirical approach is typically based on rock matrix, joint characteristics and other external aspects (Zhai et al. 2017).

The point-load strength test provides a rapid, portable index test for rock strength, with a direct correlation to UCS when using a cylindrical core and diametral test. Because of the microfractures and the weakening of the grain bonds, weathered rock has less strength. Orthoclase phenocryst dimensions have a significant inverse relationship with Is(50) values in granitic rocks, highlighting the need to minimize their influence in engineering geological studies (Fener and Ince 2012). The weathered rock has less strength due to the presence of microfractures and the weakening of the grains bonding. Anisotropic metamorphic rocks in Hamedan Province, Iran, show that mineral types and amounts influence physical and mechanical properties, with porosity and water absorption also affecting mechanical indices (Khanlari et al. 2014). The Is(50) has a strong correlation with UCS for various Indian rock types, making it a flexible and useful tool for the estimation of UCS values in geomechanical classification (Singh et al. 2012). The study presents a reliable relationship between UCS and PLT for various rock types, making it a useful tool for geotechnical applications (Mohammed et al. 2015).

Moderately weathered granite rock presents varied situations, although granite and quartz have a significant correlation with weathering. For rocks exhibiting slightly to moderately weathering, the $Is_{(50)}$ reveals a declining trend accompanied by low standard deviation rates. This indicates that the $Is_{(50)}$ exhibits greater consistency and that the strength variance was reduced for completely weathered rock (Frederick Tating et al. 2014). The test findings indicated readings below 0.1, approaching 0, interpreting them too negligible for consideration. This tendency aligns with the findings of (Lan et al., 2003; Gokceoglu et al., 2009; Soehady Erfen 2017; Marques et al. 2017; Mang et al. 2018 and Mang and Md Rafek 2018). A higher weathering grade results in a greater reduction in strength, and the degree of that reduction relies on the weathering grade, petrographic elements, and water absorption (Mohamad et al. 2015). The PLT is applicable for evaluating both strong and weak rocks, offering an indirect measurement of the UCS or tensile strength of the material (Li and Wong 2013). For rock exhibiting slightly to moderately weathered, the $Is_{(50)}$ reveals a decreasing trend accompanied by low standard deviation rates. This indicates that the $Is_{(50)}$ exhibits greater consistency and that the strength variance was reduced for completely weathered rock, (Frederick Tating et al. 2014). In rocks like granite, basalt, and quartzite, the stiffness ratio and failure mode consistently diminish with increased weathering conditions.

The UCS for bedded rock is derived from the correlation proposed by (Singh et al. 2012 and Kaya and Karaman 2016) for comparable massive rock. This test is quite difficult to carry out because the rocks are weak and it is quite impossible to prepare the required samples in the laboratory. Overall, the UCS values across all sites exhibit a comparable range for weaker bedded rock, particularly shale. This aligns with the research undertaken by (Anikoh and Olaleye 2013). (Zein and Sandal 2018) suggested that the current correlation may induce inaccuracies if not applied to site conditions and rock types. A correlation has been established for sandstone; nevertheless, it necessitates further investigation and validation before application (Hamzah and Mat Yusof 2022). At each granite rock location, it is evident that an increase in weathering grade correlates with a decrease in UCS value. This aligns with the statement made by (Khanlari et al., 2012).

4.3 Moisture content

The presence of moisture content in rock mass in tropical areas is a unique characteristic that needs to be given special attention in issues related to the weathering process. Tropical climates result in varied material characteristics and thick weathering profiles based on moisture content and weather. Even though studies on these characteristics date back to the 1940s, there haven't been many done in Malaysia. The tropical region's weathered rocks are greatly impacted by the amount of moisture present. The challenge of forecasting the performance of excavation in highly and completely weathered rock is one of the problems. As such, it ought to be taken into account while evaluating whether surface excavation work can be excavated. Numerous scholars have even suggested in earlier literature that the rock's strength and deformability are highly influenced by its moisture content (L.S.Burshtein 1970, Dyke and Dobereiner 1991, Balazs Vásárhelyi 2005, B. Vásárhelyi and Ván 2006). The impact of moisture content on deformability has also been investigated by some researchers (Togashi et al. 2021). As a result, it's critical to draw attention to the way that moisture content influences excavatability throughout various weathering grades. Research on how moisture content affects sandstone discontinuities mostly looks at the joints' shear strength. This statement is agreed by Naghadehi et al. (2010) who studied the effects on mechanical and geometrical parameters indirectly due to water in various situations such as pore voids. The results showed that moisture affects the shear strength and friction angles of discontinuities. (Małkowski et al. 2017).

delineate the attributes and alterations of the geomechanical properties of claystones to their mineral composition. The result is that the structure of the examined claystone is compromised not only due to the internal absorption of water by minerals but also by the influence of water molecules on mineral surfaces, which weaken the intramolecular bonds. B. Vásárhelyi and Ván (2006) examined the apparent effect of moisture content on the petrophysical properties of rocks and initiated the effect on strength that occurs only after one percent of water saturation. Thus, they introduced a calculation method for the impact of water content by re-analyzing the outcomes of Hawkins and McConnell (1992).

The issue of 'soil rock' in tropical areas has been reported by scholars as causing problems, especially during heavy rains (Mohamad et al. 2011a, b). The presence of 'weak rock' which has certain characteristics (i.e., low strength, high plasticity, slaking) is a critical condition and requires it to be understood very well. Its main characteristic in terms of intermediate strength is between soil and hard rock, causing difficulties in performing tests in the laboratory. This situation requires judgment and experience by engineers to deal with such sites (Kanji 2014). Li et al. (2017) described that clay minerals show the weathering process that has affected the rock sample, in addition to influencing the strength of the rock because of the variation of moisture content. Therefore, this study has considered the effect and relationship between clay content and moisture content for the three types of rocks, shale, sandstone and granite.

According to research done by Mohamad et al. (2015), the $Is_{(50)}$ is impacted by the moisture level of sandstone. The Is(50) of sandstones with high weathering grades significantly decreases. Sandstones with high weathering grades absorb more water than sandstones with low weathering grades (Grades II to III), which is caused by an increase in clay minerals. According to the research, granite that had weathering classes I through III lost 80% of its initial strength. The impact of moisture content on the Is(50) and anisotropy index of sandstone and shale was then compared by Abang Hasbollah et al. (2019). It was concluded that the shale strength tremendously decreased to the sandstone with moisture content. Overall, moisture content and strength are significant to the weathering grade and need to be studied in more detail, especially among rocks with fabric characteristics, degree of micro fracturing and pore (due to weathering effects), probably from class IV and V materials. This understanding is necessary for engineers and geologists to implement the design and solve problems at the working sites. Therefore, the focus should be given to issues related to the influence of moisture in excavation works. Table tabulated as a summary of the study offers some important insights into moisture content in tropical regions. This emphasizes the implication of moisture content as a significant parameter, particularly in tropical regions c4haracterized by high temperatures and consistent rainfall, highlighting the necessity for its study to enhance excavatability.

This study shows that there are variations in the moisture content of bedded and non-bedded rock types as a result of differences in lithology and environmental conditions. This variation occurs in any study area even though all study sites are located in the tropics. A perceived limitation is that tests conducted in the laboratory certainly do not reflect the moisture content found on site. In addition, there is a limitation of tests that cannot be performed on clay because there are more expensive and time-efficient methods of analysis. This study aims to investigate the most significant factors related to issues in the tropics for various types of rock mass through the results of a practical and simple assessment proposed. Moisture content is also one of the important parameters of rock mass and material that affects excavation and is identified to be included in the classification of excavation systems in tropical areas.

Sandstone exhibits diminished strength values when subjected to increased weathering grades and elevated moisture content; the sensitivity of the material is primarily influenced by its microfabric and the proportions of quartz and clay minerals present (Hawkins and McConnell 1992). Shale exhibits greater sensitivity to water compared to sandstone; a 7.4% rise in moisture content can lead to an 80% reduction in the shale strength index (Abang Hasbollah et al. 2019). According to (Lu et al. 2019), the data indicated that the moisture content in sandstone influences its mechanical characteristics and the energy released inside its material structure. Sandstone with increased weathering grade and elevated moisture content demonstrates diminished strength values (Mohamad, Liang, et al. 2015a, b). Compressive strength, tensile strength, and elastic modulus reduce when the moisture content of sandstone increases (Li et al. 2020). (Awang et al. 2021) stated that granite with reduced clay mineral composition in lower weathering grades exhibits reduced susceptibility to variations in moisture content relative to weaker granites, specifically for higher grades. Conversely, an increased number of pores results in more water absorption at higher weathering grades. The strength has been compromised by the increase in pores, which also arises when natural minerals are converted into fine clay. Tropical-weathered granite loses strength due to water contact that diminishes the interlocking of rock particles during weathering (Hasan et al. 2019).

4.4 Boulders occurrence

At the study location, it is apparent that there are rocks and soil formations in various weathering zones. (Fig. 2). The granite rock mass in this location has generally fragmented the granite into several phases of weathering by the weathering process. In tropical regions, boulders are typically found in conjunction with excavation projects utilizing volcanic rocks, such as granite. However, in Malaysia, there is little research and understanding of the connection between rock size and shape and how far the rock is from the bedrock when it originated (Nordiana et al. 2013). As a result, boulders can be described as having distinct physical qualities that are influenced by weathering and ought to be taken into account as a crucial design element in engineering. It was discovered that certain researchers had researched granite rock weathering (Md Dan et al. 2015, Md Dan Azlan et al. 2020, Mohd Firdaus Md Dan et al. 2016a, b). He concluded in 2016 that boulders are described as having special physical qualities influenced by weathering. He explained that boulders consist of coral, rindlets, and saprolite, which have different physical properties. It was found that the boulders' shape varies on the size and location of the weathering zone. It was discovered that the granite rocks in the residual soil (RS) and fully weathered rock (CW) were found to be scattered and unaffected by the weathering profile. He believes this characteristic can be used and considered as an essential parameter in engineering design.

Table 4 Summary of scholars on moisture content in a tropical region

No	Researcher	Year	Type of Rock	Issues	Results
1	Mohamad et al. (2008)	2008	Sandstone	The impact of moisture content on micro-structure, strength, and weathering grade	Moisture content increases as weathering grades increase, more affected to Grade III, IV and V and porosity also increases Strength decreases, more obvious in grade IV as moisture content increases As weathering grade rises, dry unit weight falls and water adsorption rises; this relationship is especially pronounced in grade IV. The least amount of absorption is shown in Grade II, while the highest is seen in Grade V
2	Mohamad et al. (2011a, b)	2011	Fresh to Completely Weathered Granite	The impact of moisture content on strength variation The effect of weathering on mineralogical content	Moisture Content increases and strength index decreases (Grades IV and V), with not much effect on Grades I and II Moisture content increases, clayey content and swelling also increases Density and strength diminish with weathering, whereas deformability rises Strong relationship between the amount of clay changed from granite and the absorption of moisture
3	Mohamad et al. (2013)	2013	Fresh to Highly weathered shale	The effect of moisture content on strength and anisotropy Index (Ia(50))	The increase in moisture content reduces the strength index (Is(50) and Ia(50)) Moisture absorption increases when the weathering grade increases (grade I to IV)
4	Mohamad et al. (2015)	2015	Weathered coarse-grained granite (fresh to completely weathered)	the effect of moisture content on the strength	Moisture content increases and strength Index decreases but not much effect on Grades I and II Granite of a high weathering grade (III, IV, and V) deteriorates due to its high moisture absorption, weak strength, high potential for swelling and low durability
6	Abang Hasbollah et al. (2019)	2019	Moderately weathered shale and sandstone	the impact of moisture content on anisotropy and strength	Correlation strength vs anisotropy index Shale strength and anisotropy index are more impacted by moisture content than sandstone

Fig. 2 Overview of studied site consists of boulders occurence

Abad et al. (2016) divided the granite weathering profile into eight zones after the discovery of boulders in both completely and highly weathered granite zones. These zones included a completely weathered zone with/without rounded boulders (diameter: up to 6.5 m) and a highly weathered zone with or without angular boulders (diameter: up to 4 m). The weathering zone classification developed by Alavi Nezhad Khalil Abad et al. (2015, 2016), however, omitted boulders in moderately weathered zone. The weathering granite profile did not classify the engineering and physical characteristics of boulders and ringlets. The imperfect categorization of boulders within the weathering granite profile implies that the current weathering classifications are not well-suited for tropical granitic rock, especially in areas with varying temperatures. Figure 2 shows a boulder occurrence in the granitic area in one of the case studies.

4.5 Discontinuity characteristics and block volume

Discontinuities such as joints, faults, bedding planes, and fractures are common features found in rock masses. These discontinuities play an important role in influencing the behavior of rocks under various conditions, including mechanical strength and deformation. Discontinuities are crucial factors for tropical regions like Malaysia, and they require special attention during excavation work. According to Jamaluddin and Sundaram (2000), the discontinuity and strength of the rock are the geotechnical features that have a major impact on the excavatability of the rock mass. An excavation classification system that is still in use today was developed over the last three decades by numerous researchers who studied discontinuities (Franklin et al. 1971; Scoble and Muftuoglu 1984; Singh et al. 1987; Pettifer and Fookes 1994) and Tsiambaos and Saroglou (2010a, b). The literature has extensively addressed the significance of identifying the discontinuity condition in a rock mass (Ehlen 2002, Tating et al. 2014, Nezhad et al. 2015) and Hack (2020). It assesses slope stability, permeability, and shear strength along discontinuities. Wet tropical weathering also causes moisture content to be an essential parameter, as its presence will disrupt discontinuities, reduce strength, and complicate the rock excavation process. This condition is seen to have a relatively significant impact on bedded and non-bedded rocks in the tropics. There are suggestions by Priest and Hudson (1976) for how discontinuity spacing data should be presented, how long the scanline should be to estimate discontinuity frequency reasonably, and how many sample values should be included in a discontinuity survey. Joint spacing is a crucial component in defining the rock block size. Joint spacing is one of the most important variables that control the block volume, permeability, strength, and deformability of rock masses (Wong et al. 2018).

The significance of the discontinuities condition in rock mass (i.e., shear strength, permeability, and slope stability) and ways to determine them are thoroughly discussed in the literature (Ehlen 2002, Tating, 2015, Nezhad et al. 2015, Hack 2020). Characterizing discontinuities in rock mass involves field identification of geological factors that influence their shear strength, systematic measurement, and description of discontinuities (mostly joints) (Hencher 2013). To develop a reliable physical and mechanical characterization of the discontinuities, the integration of observation, measurement, and judgment is indeed relevant and necessary (Feng 2017). Mohamad et al. (2011a, b) discovered that, even for highly strong rocks, the discontinuity scale is a key factor in determining rock rippability resistance. Figure 3 portrays that a closely spaced joint can influence rippabilty. Discontinuity assessments, including the orientation, direction, and scale for discontinuity, should be conducted before excavation work. Small-scale discontinuity refers to lamination, foliation, joints, and any other types of discontinuity that measure less than 10 cm. The orientation and direction of big- and small-scale discontinuities must be assessed before ripping work. Bedding and lamination, for example, may incline in a certain direction and the joints may be scattered.

Weathering profiles on metamorphic and sedimentary rocks are characterized by their thinness, sharpness, and structural control (Marques et al. 2017). In tropical sandstone, as weathering increases, discontinuity spacing diminishes, undermining rock quality due to the material's tendency to fracture along weak joints. Consequently, the excavation process is facilitated and yields an increased production rate. Consequently, further investigation is required to address any engineering challenges. This is consistent with the studies performed by (Hachinohe et al. 1999; Tian et al. 2012; Frederick Tating et al. 2014 and Ghobadi and Babazadeh 2015). On the other hand, the mean joint spacing in completely weathered granite rock exhibits the highest distance relative to other types. The conclusions of this granite site are supported as shown by (Ehlen 2002). In tropically weathered granite, the average joint spacing reduces progressively from fresh to moderately weathered zones, subsequently increasing in highly and completely weathered zones (Abad et al. 2015).

Among the most crucial elements in classifying rock masses is block size. Its definition is the mean diameter of a corresponding sphere with the same volume. It is measured using the Jv, which is the total of joint numbers crossing a volume unit of the rock mass, or the block size index (Ib), which is the average dimension of a typical block. Another block size metric that is connected to Jn is RQD (Joint Set Number). One term for a block size is RQD/Jn. The greater block size, since $Jn = 1/2$. The smaller block size is $Jn > 2$. There are also many forms and sizes of blocks. according to the description provided by W.R.Dearman (1991) for every kind of shape. Massive rocks are characterized by few joints or extremely broad spacing. Blocky has around the same dimensions. One dimension that is significantly lesser than the other two is tabular. One dimension that is significantly greater than the other two is columnar. Block size and shape deviations are known as irregular. Sugar cubes are strongly bonded to crushed.

Despite its difficulty in direct measurement, block size is a crucial parameter in rock engineering calculation and estimates. The size and shape of individual blocks from linear samples must be determined for geotechnical rock mass categorization and assessment. This information helps with important design decisions and the comprehension of rock mass deformation. It is estimated as one of the following three indices: Rock quality designation (RQD), Volumetric joint count (Jv), and Block

Fig. 3 Closely-spaced joints help the ripping process

Size Index (Ib). Block size can be determined by using simple rock mass parameters, namely true spacing, joint set orientation, and persistence. Notably, orientation and spacing are measured easily (Maerz and Germain 1996). The different block size or joint degree measures were shown by Palmstrom (2005), who claimed that block volume (Vb) and Jv measurements provided superior block-measuring properties (Fig. 4).

One of the often used techniques is the Palmstrom (2005) formula, which calculates the volume of a block created by the intersection of three sets of discontinuities existing in a rock mass. Apart from that, the problem that occurs in block size determination is the difficulty in clearly determining each block's precise dimensions and form. Hence, it can be determined by using the judgment and wisdom of the researcher based on his understanding and experience in understanding block size. Therefore, according to Turanboy and Ülker (2012), the most common method of predicting block size is a direct measurement on-site, believing that this method is more successful in mining activities. Many researchers have reviewed the literature, and the majority of them state that it is challenging to evaluate joints and their properties in the rock mass. The majority of joint measuring work is performed in the borehole, which involves only one dimension, and along the rock scan line, which involves two dimensions. The situation is more difficult and complex when the connections found in the rock are irregular and have variations in size and length. As a result, determining the block size is more challenging, particularly in tropical regions where the weathered rock mass has undergone more weathering.

The block volume reduces as the weathering grade increases, transitioning from massive to blocky, in both shale and sandstone. The block volume exhibits a significant reduction from slightly to moderately weathered, as the degree of blockiness transitions from large to very small, according to (Palmstrom 2005) for bedded rock, specifically slate and quartz. A method is suggested for determining block sizes based on joint persistence, potentially leading to a greater quantity of removable blocks and diminished rock mass strengths (Kim et al. 2007). The results indicate that the block size of granite and quartz rock varies from large to small volume as weathering progresses from slightly to completely weathered. One of the more significant findings to emerge from this study is that block volume was found to experience a drastic reduction from slightly weathered to moderately weathered for the granite site. Figure 5 shows a range plot of block volume versus weathering state for bedded and massive sites.

4.6 The existence of iron pan

Apart from observing parameters related to machinery properties that affect rippability, identifying the existence of iron pan found on the surface of discontinuities is also essential in determining rippability. Iron pan is a unique characteristic found on the surface of joints in tropical regions (Fig. 4). It is a secondary product that occurs due to the accumulation of

Fig. 4 Blocky rock mass with cubical blocks defined by rough, slightly weathered joints. It is challenging to blast smooth faces because of ragged excavation surfaces caused by small wedge or block failures

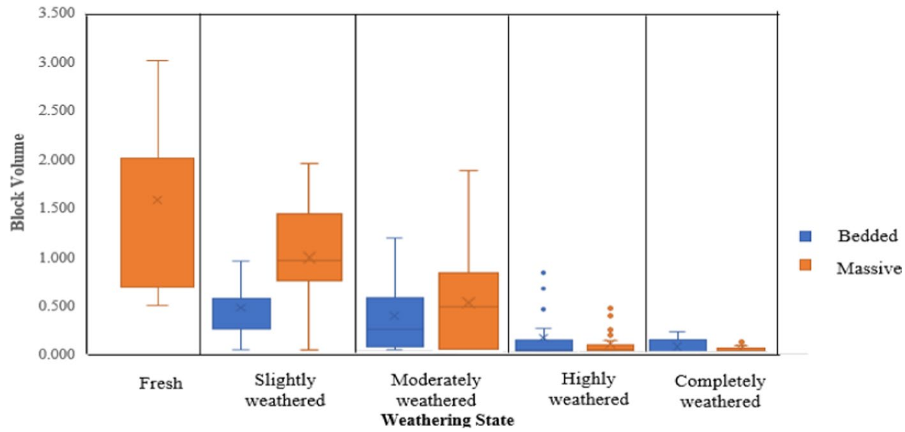

Fig. 5 Range plot of block volume versus weathering state for bedded and massive sites

mineral substances in rocks, as shown in Fig. 5. This coincides with the findings by Tating et al. (2019), a study on the existence of oxidation processes in detail in tropical areas, giving influence rock mass properties and shear strength discontinuities. This situation further affects the ripping works, causing difficulties. In addition, all geological features affecting excavation performance must be studied for each lithological zone, such as bedding, joint spacing and roughness, number of joint sets, and iron pan and boulders (Tan Boon Kong 2017). The description of rock masses describes rock masses, determining structure, the distribution of the different rocks, describing weathering profile, and disseminating any effects due to alteration. The joint's surface is slightly rough and an iron pan has been found on the surface discontinuities. This rock breaks easily under hand pressure, even when dry. These rocks also turn to soil easily when wet. The diagram shows some sites where iron pans have covered sandstone and shale, weathering grades III and IV and preventing the ripper from penetrating the rock mass (Fig. 6).

5 Discussion

It is essential to comprehend the challenges related to evaluating mineralization in weathered rock in tropical areas due to the significant impact of climate conditions, geological processes, and engineering limitations. The tropical climate, characterized by intense weathering and high temperatures, significantly affects the mechanical and physical properties of rock masses. Weathering often leads to the formation of complex geological structures, such as discontinuities, joints, and cracks, which affect the difficulty of excavation. Therefore, a more accurate assessment of excavatability can be achieved by obtaining a comprehensive and detailed understanding of geological and environmental factors. Moreover, it is obtained by field testing methods such as geological mapping and geotechnical research, among others, to improve the efficiency of engineering practices.

Assessing the significance of factors that impact the ease of excavation in tropical regions is crucial for achieving optimal outcomes in engineering design, construction planning, and the successful execution of projects in this demanding climate. Adverse consequences will arise if the identification of these factors is unsuccessful. These factors encompass escalated project expenses, prolonged construction times involving intense work, and unforeseen safety hazards like as instability and rock falls. Stakeholders and engineers can do this through the implementation of various ways. One way to improve the evaluation process is by incorporating important parameters into the classification system. This classification system serves as an intermediary that offers standardized work, plateful as a means of communication and delivery amongst stakeholders. This classification system serves as a vital tool for estimating the costs of an overall project indirectly.

Through the assessment of the excavatability of a location using relevant factors, project planners may make precise estimations of the necessary time, resources, and equipment for excavation work. This allows them to avoid excessive expenses and delays in project completion. Incorporating essential

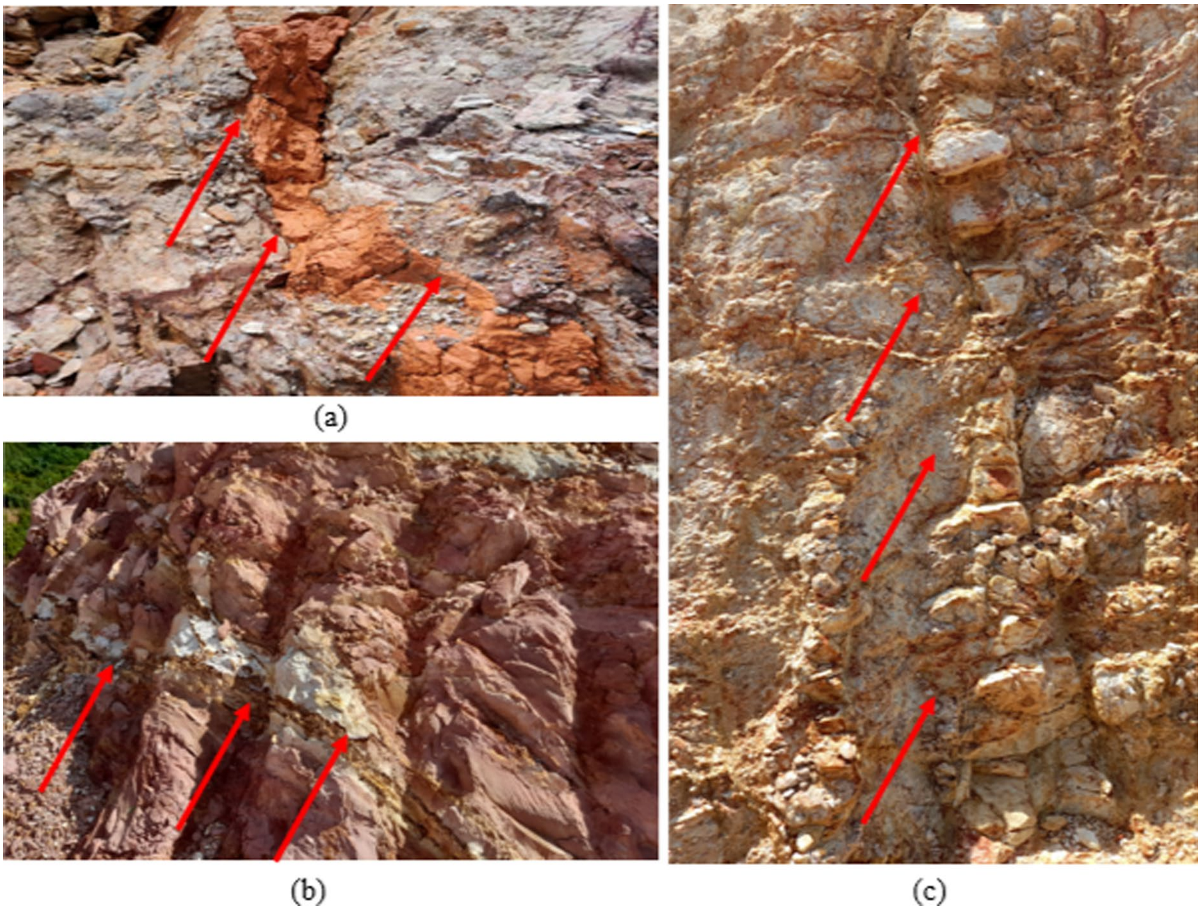

Fig. 6 Presence of iron pan at site studies **a** rhyolite tuff **b** sandstone **c** quartz ridges

elements into the excavatability classification system offers numerous advantages, such as the establishment of standard evaluation criteria, enhanced safety protocols, and more accurate cost predictions. Engineers and project managers can enhance project outcomes and ensure the successful implementation of excavation projects by carefully analyzing elements that impact excavatability. Excavatability classification systems offer a standardized framework for assessing geological and geotechnical factors associated with excavation. They help in allocating resources efficiently, planning projects, and carrying out construction work. Furthermore, the creation of an excavatability classification system specifically designed for tropical regions enhances understanding in the domains of engineering geology, geotechnical engineering, and project management from a research standpoint. Academic endeavors focused on comprehending the distinct difficulties presented by tropical environments and formulating suitable categorization algorithms have a wider impact on the issue and foster collaboration among stakeholders.

6 Challenges and future works

The preceding explanation indicates that studying climate in tropical regions necessitates a more focused observation, technique, and comprehension to accommodate the more demanding and distinctive environmental conditions. Various superior research and management solutions exist to address the difficulties presented by tropical regions. Both types of rocks pose unique obstacles and difficulties while doing surface excavation work in earthworks. Variations in rock types and the existence of soil-like or hard material cause disputes and ultimately result in high variation order and increase the earthwork cost. Field test methods play a crucial role in achieving accurate results in geotechnical investigations when determining rock parameters (Kuvik Marian et al. 2018). It is important to establish this to prevent conducting unnecessary laboratory tests and so compromising the accuracy of data needed to choose the most suitable excavation method. This issue often arises in disputes between contractors and owners, involving many arbitrary matters. Gaining a comprehensive understanding of the engineering qualities that differ among different types of rocks and their presence can greatly enhance the knowledge base on difficulties specific to tropical regions. However, the complexity of the nature of rock masses somehow makes it difficult and be accepted.

In addition, the completely homogeneous granite results in the formation of irregularly shaped fragments during the process of excavation. Therefore, blasting can be employed to manage and reduce breakage. Excavating in regions with weathered granite and large boulders can be a laborious and expensive process due to the extra exertion needed to break and relocate the rock. Boulders are primarily located in areas of tropical weathered granite that have undergone moderate to complete weathering. These boulders pose obstacles and challenges in underground excavations and construction projects (Mohd Firdaus Md Dan et al. 2016a, b). For this weathered granite excavation task, specific equipment, excavation techniques, and safety precautions are required. This includes the utilization of hydraulic breakers and rock crushers to fragment the rock into smaller pieces. In addition, issues arise while dealing with and moving rock fragments, necessitating the use of a more powerful excavator.

The issue of surface excavation arises from the varying strengths within a weathered bedded rock mass structure. The primary challenge associated with excavation work in this stratified region is the presence of folded and strongly affected geological formations. Sedimentary rocks often display a stratified microstructure with clear bedding lines that might create areas of vulnerability (Methods et al. 2020). Sandstone rocks exhibit intricate structural patterns characterized by the presence of folds, faults, and fractures, which have a significant impact on the stability of the rock mass. When dealing with shale and sandstone rocks that are layered together, it is important to use more appropriate excavation methods for the tougher sandstone layers. In contrast, shale rocks with a lower hardness are more prone to fracturing and can be excavated with relative ease. This circumstance has an impact on the utilization of excavation machinery.

In addition to variations in strength, it also imparts differences in the rock's hardness. This variance can impact the uneven fragmentation, namely causing harder layers to result in larger fragments. In addition to that, it impacts various excavation speeds. The presence of a harder layer will result in a reduced rate of production due to the increased time and effort required to excavate the rock, in contrast to a softer layer. The current methods used to assess the excavatability of tropically weathered rock are not very trustworthy since they have limitations and are subjective, particularly in places where there are layers of different rock types and natural variations in strength and directionality (Liang et al. 2017). The excavatability classification system for weathered sedimentary rock incorporates many that are directly related to excavation productivity (Liang et al. 2015a, b).

To address the difficulties encountered in excavating in both bedded and non-bedded rock formations, it is essential to engage in meticulous planning, which involves conducting thorough site investigations and choosing appropriate excavation techniques and equipment. To enhance efficiency and preserve best practices in sustainable surface excavation for future projects, it is essential to address the challenges associated with weathered rock. Hence, certain advanced technologies have been discovered to possess the capability to be utilized in surface excavation operations for weathered rock. Compared to simulation-based methods, the established methodology, which combines GPS data, fuzzy set theory, and Google Earth, offers more precise and straightforward estimates of worksite productivity in urban buildings (Alshibani 2018). Using excavation volume estimation, obstruction region detection, and 5D mapping, this research introduces an efficient excavation progress monitoring system that provides expanded ground information for autonomous excavation (Rasul et al. 2021). Regarding the blasting work, the blasting parameters can be optimized in the blasting design to accomplish rock fragmentation with little harm to the environment and reduced safety hazards.

Controlled blasting and the use of expansive mortars are techniques employed to extract solid rock in metropolitan locations to facilitate the whole construction of buildings (Milanović et al. 2023). Optimized parameters for sequential controlled pre-splitting blasting can minimize explosive consumption, lessen drilling workload, and enhance rock protection (He et al. 2022). The challenges of digging weathered granitic rocks in tropical climates include increased maintenance expenses, more frequent weathering that accelerates physical–mechanical degradation and more (dos Santos et al. 2021). Innovative approaches and various advanced technologies are being actively explored to address these challenges and achieve optimal excavation operations in tropical environments. Nevertheless, researchers must persist in their research and development endeavors to enhance the efficacy and implementation of this effort in the future.

7 Conclusion

Several parameters of rock properties and rock mass have been identified influencing surface excavation of rock mass, which need to be studied in detail for bedded and non-bedded rock mass. Generally, an evaluation of the rock masses' excavatability considers numerous essential parameters such as the UCS, $Is_{(50)}$, blockiness index, moisture content, seismic velocity, rock structure properties, and others. It is believed that these parameters are essential and significant to take into account in weathering classification for geotechnical and geological engineering designs in a tropical region. However, the complexity of the nature of rock masses somehow makes it difficult and be accepted. Therefore, a classification system for relevant rock mass and material properties in tropically weathered rock is highly needed for engineering purposes in this country. The issues raised are unclear zones of common, hard mass, and rock mass excavation. This issue is more complicated and complex when dealing with bedded and non-bedded rock. The current classification system does not consider the type of bedded and non-bedded. At the same time, many features need to be taken into account among these types of rocks in determining the excavatability of rock excavation.

To improve the classification system for weathered rock, a quantitative approach is employed that integrates rock mass and rock properties. The rating system relies on physical and geomechanical factors that are significantly influenced by weathering and excavatability. A grading system is employed to assign a score or grade to the weathering of rock materials, dependent upon the significance of their engineering characteristics. This literature discusses the development of weathering and excavatability class models and classifications in the field of engineering geology. There is an urgent necessity for researchers to persist in developing a flexible and precise model for assessing rock excavatability. This study seeks to address the gap by presenting a precise classification system utilizing the most significant rock mass and rock properties. This study aims to correlate the impact of weathering on excavatability. This research innovates by offering a more thorough classification for predictive models of non-bedded rock by the application of statistical methods, specifically multiple linear regression (MLR). This study will identify relevant parameters and build Weathering Index (WI) models by statistical analysis. The derived model is employed, and its efficacy is evaluated by statistical techniques like the coefficient of correlation (R^2), Root Mean Square Error (RMSE), Variance Accounted For (VAF), and Performance Index (PI). Subsequently, it assessed the approaches by conducting a comparative analysis against one another and prior studies.

In rock engineering, rock's physical and mechanical properties are essential in rock mass characterization and classification. Given the rock mass properties, including rock type, weathering states, rock structure (i.e. orientation, spacing, discontinuity, gouge), and relevant rock properties of different rock types is crucial in the feasibility study of surface excavation. A comprehensive understanding of weathering profiles is important in a tropical country like Malaysia. The resultant material may have relatively different characteristics from the parent rock, depending on the grade or degree of weathering. Many studies have begun to examine these essential parameters in countries, not yet in tropically weathered rock. The occurrence of inaccurate assessment and wrong excavation methods often being selected and adverse construction conditions on sedimentary rock masses urge this research. A systematic evaluation of the rock structure and materials characteristics can help establish the relevance of these properties in verifying the excavatability of some sedimentary rocks, which has not been clearly defined in existing earthwork specifications. The classification system created in this work was intended to be useful in the geotechnical and geological domains concerning surface excavation in a distinct type of tropically weathered rock. It is also predicted to make a significant contribution to the field of tropical rock engineering's advancement and understanding.

To ascertain the optimal method for carrying out excavation work based on rock properties and rock mass, numerous classification systems for excavation have been presented. These classifications are highly associated with equipment and machinery usage. It is crucial to take into account not only the expenses involved but also the utilization of state-of-the-art technologies and excavation criteria. Determining the methods used for excavation work based on rock types is a key objective for developing excavation classification systems. These are the significant factors that have a strong impact on work efficiency, planning, and operational costs. The graphical method merely serves as a reference and should be compared with fieldwork findings to determine the machine's ability and excavatability of rocks. Nonetheless, because excavation technology is developing so rapidly, these techniques should be periodically examined and updated.

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Declarations

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