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Android Application Development for Estimating Properties and Preliminary Stability of Rock Mass using Rock Mass Rating and Geological Strength Index

การพัฒนาโปรแกรมประยุกต์แอนดรอยด์สำหรับประเมินสมบัติและเสถียรภาพเบื้องต้นของมวลหินด้วยหลักการจำแนกมวลหินและดัชนีกำลังธรณี

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ABSTRACT

Rock mass stability is one of the key factors which influence mining and civil engineering operations. Rock mass rating (RMR) and geological strength index (GSI) are very useful classification theories for estimating preliminary rock mass properties and stability with discontinuities analysis. Engineers can plan their work properly and safely if they know the stability of the rock mass. Android smartphone are portable devices that have a microprocessor. PSU-RG Android application was developed for estimating the stability of rock mass using rock mass rating and geological strength index. The application allows users to evaluate rock mass stability instantly in the field. PSU-RG application was verified for reliable and accurate estimations. The application was tested with geological data from other researches (case studies), the results are satisfied.

บทคัดย่อ

เสถียรภาพมวลหินเป็นปัจจัยสำคัญประการหนึ่งที่มีอิทธิพลต่อการดำเนินงานทางวิศวกรรมเหมืองแร่และวิศวกรรมโยธา หลักการจำแนกมวลหิน เช่น การประเมินมวลหิน และดัชนีกำลังธรณี เป็นหลักการที่ทำให้ทราบถึงสมบัติและเสถียรภาพมวลหินเบื้องต้นได้จากการเก็บข้อมูลรอยไม่ต่อเนื่อง ซึ่งมีส่วนช่วยทำให้สามารถวางแผนดำเนินงานได้อย่างเหมาะสมและมีความปลอดภัย ในปัจจุบันสมาร์ตโฟนแอนดรอยด์เป็นอุปกรณ์พกพาที่มีประสิทธิภาพในการประมวลผลและได้รับความนิยม งานวิจัยนี้จึงทำการพัฒนาโปรแกรมประยุกต์ชื่อ PSU-RG สำหรับประเมินเสถียรภาพมวลหินด้วยหลักการประเมินมวลหินและดัชนีกำลังธรณี ช่วยให้ผู้ใช้สามารถประเมินมวลหินได้ทันทีบริเวณหน้างาน โปรแกรมประยุกต์ได้ถูกตรวจสอบเบื้องต้นแล้วว่ามีผลการประเมินที่ถูกต้องเชื่อถือได้ และเมื่อทำกรณีศึกษาร่วมกับข้อมูลจากงานวิจัยในอดีตพบว่าได้ผลลัพธ์ที่น่าพึงพอใจ

Keywords: Android application, Rock Mass Rating (RMR), Geological Strength Index (GSI)
คำสำคัญ: โปรแกรมประยุกต์แอนดรอยด์ การประเมินมวลหิน ดัชนีกำลังธรณี

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Introduction

Rock mass stability is one of the most important factors in mining and civil engineering operations. The stability affects safety, cost and operation progress. Information of the stability of rock mass helps engineers plan their work safely. The rock mass data can be applied to a wide range of planning and design. Engineering rock mass classification called Rock Mass Rating (RMR) and Geological Strength Index (GSI) are basic principles for evaluating preliminary rock mass stability. Rock mass estimations with these principles is based on visual inspection of geological conditions, compass is required in some cases. In this way, the experts can know the stability of rock mass without any equipment. These principles are widely accepted and attracted, both in the development of principles to use for specialized purposes such as tunnel excavation with TBM and rock bolting [1-4], combination with technology such as image processing [5], and practical applications such as tunneling and quarrying on the Earth [6-7], including concepts to be used on the Mars [8]. Rock mass classifications are not complicated calculation but classifications are principles that encompass many conditions and possibilities. It is difficult for a person to remember the combination of many conditions and it hard to review the theories during site investigation. Microprocessors can solve this problem. Desktop and laptop are useful devices for computation and logical processing, but these devices are suitable for indoor use. These things are large and requires a lot of electricity, so it is not easy to use outdoor, such as mine or geological field. The smartphone is more attractive choice in a situation like this. From many smartphone systems, Android is the most popular system in the world [9]. Android operating system is open source and free, developers can develop the application freely.

Android smartphone was selected in this research. We plan to develop an application for estimating preliminary rock mass properties and stability using rock mass rating and geological strength index. At present, there are many commercial applications that applied with rock mass rating from Google Play Store [10-13] and applications with research purposes [14-15], but there is only one application that applied to geological strength index [16]. The applications mentioned earlier, there have no applications that can estimate in detail and save the results. Some applications from Google Play Store are expensive. This research is an alternative rock mass classification application which can assist geologists and students in the field. Whenever android smartphone is available, the application allows users to estimate initial rock mass stability.

Background theories

The principles used for this research are rock mass rating (RMR) and geological strength index (GSI). These principles are summarized in the following.

Rock mass rating

Geomechanics classification, also known as Bieniawski's Rock Mass Rating, developed from practical knowledge of tunneling in sedimentary rocks [17]. This theory consists of six important parameters used in the assessment of rock mass stability. The rock mass rating is suitable for tunnel and dam foundation design. First parameter is the strength of intact rock measured from uniaxial compressive strength (UCS) or point load strength

index (PLSI) in the same conditions as the original [18-19]. Normally, this value is already known from the exploration phase. If the engineer does not want to test the rock samples, strength of rock can be indirect evaluated from average uniaxial compressive strength of rock from previous research [20]. The schmidt rebound hardness test is another way that researchers try to determine the strength of rock mass [21], but this method is infrequent. Experienced geologists and engineers can measure the strength of rock from geological hammer's reaction force [8], this method requires a lot of experience, it is not recommended. Indirect estimation may fail in some cases, these methods should not be used if it is not necessary. Second parameter is the rock quality designation (RQD) which determined from the percentage of 100 millimeters and longer core pieces per 1-meter core length [22]. The volumetric joint count is another way to evaluate RQD that does not require core sampling, it is the ratio of the number of main joints that appear on the rock mass to the total distance [23]. Third parameter is spacing of discontinuities. Discontinuities including joints, faults, beddings, shear zones, and weakness planes. Rock mass assessors must be able to distinguish the type of discontinuities before measuring its spacing. Forth parameter is discontinuities conditions consists of roughness, aperture, persistence, weathering and gouge materials [24]. Rock mass conditions of each are unique, especially the roughness and weathering which requires the experience of assessors. Significant conditions from experienced assessors are necessary. The fifth parameter is groundwater condition, measured by the flow rate of groundwater around the rock mass, or described in simple; dry, damp, wet, dripping, flowing. For tunneling project, this parameter can be measured from the ratio of seepage pressure per major principle stress [25]. The last parameter is the orientation of discontinuities, relation between rock mass face and discontinuities, both dip directions and dip angles. Orientation has a significant effect on the failure mechanism of natural rock and project appropriateness. Finally, RMR value can be calculated from the sum of six values, each parameter can be converted from the conditions into a value by Bieniawski's principle. Rock mass rating value can indicate the stability of rock mass in the form of tunnel stand up time, rock cohesion, internal friction angle, allowable bearing pressure [26] and safe cut slope [27]. The principle mentioned above is compatible with dam and tunnel.

Geological strength index

Geological strength index is the rock mass classification which based on visual inspection. The original GSI is the comparison between discovering rock mass conditions and geological quantitative chart [28]. This principle is more suitable to field application than rock mass rating but difficult to convert into the application. Over two centuries, researchers try to convert the geological quantitative chart into an equation. This research uses GSI calculation techniques of Cai and Kaiser [29] as following equation,

$$GSI = \frac{26.5+8.79 \ln Jc + 0.9 \ln V_b}{1+0.0151 \ln J_c - 0.0253 \ln V_b} \quad (1)$$

$$J_c = \frac{J_W J_S}{J_A} \quad (2)$$

where J_c is joint conditions factor, V_b is block volume in cm^3, J_w is large scale waviness of discontinuities factor, J_s is small scale smoothness factor and J_A is joint alteration factor [30-31]. Each factor is converted from the conditions into a value with rating table. Waviness is the undulation percentage of discontinuities or amplitude of rock surface per length of full cycle in large scale. This factor indicates the overall strength of the discontinuities structure. Smoothness is small scale surface roughness examine by touch and sight. Alteration is governed by the laws of thermodynamics related to environmental conditions, consists of joint conditions and coating materials. Smoothness and alteration indicate the strength of discontinuities surface includes the friction of joints. Block of rock, caused by multiple joint sets, indicates the frequency of discontinuities that appear on rock mass. Rock materials constant (m_r) is another factor that depends on the type of rock [32], this constant assume that rock mass is isotropic and do not disturbed by heavy breakage activities such as blasting. When plotting m_r constant against GSI value in the results graph, you can estimate the ratio of rock mass cohesive strength per uniaxial compressive strength and internal friction angle [28]. Cohesive strength and internal friction angle are important parameters in the assessment of rock mass stability, the values derived from this principle are only approximations.

Internal friction angle and cohesion

Angle of internal friction and cohesion are the values that indicate some properties of rock mass, especially related to stability. These two values are the components of rock shear strength. In the laboratory, relationships between normal stress and shear strength can be estimated by triaxial compressive strength test with Mohr-Coulomb criteria or direct shear test. This failure envelope is divided into two types: peak shear strength and residual shear strength. Peak type is the maximum shear strength of rock mass before collapse and residual type is the maximum shear strength of rock mass after collapse. Residual strength is commonly used in rock mass stability assessment. Many rock slope stability estimations, such as the factor of safety calculation by limit equilibrium analysis and stereographic projection, are required cohesion and friction angle.

Methodology

The research is divided into two parts; application development and application verification with the case studies.

Application development

Android Studio 2.2.2, official integrated development environment program, was used to develop this application [33]. Java language, Extensible Markup Language (XML), and Standard Query Language (SQL) has been coded together to create calculation logic, user interface, and database, respectively. Android 4.1 (Jelly Beans) has been selected as minimum requirement and Android 6.0 (Marshmallow) is target operation. Quad-core 1.3 GHz Cortex-A7 with 512 MB random access memory on 4 inches screen (resolution 480x800) was used as a real tester during application development.

Verification

After the development ended, application was verified by comparing the results between the application's display and Microsoft Excel calculation. Random rock mass conditions are generated to cover all parameters. The

results have been compared case by case to ensure that no extra errors are made from the application. Finally, put the real rock mass conditions from previous researches into the application to illustrate the actual use.

Results

PSU-RG is the name of this application. Developers want the application to suit everyone. The most important part of the application is the correct calculation and user friendliness. Simple usage reduces the complexity of the rock mass theory. However, users have to know basic geological structure of rock mass. This application is divided into three parts; rock mass rating module, geological strength index module, and data manager module. Each module is clearly separated and designed to prevent duplicate rock mass conditions entry. This application requires a geological compass to measure the discontinuities orientation. Simple guideline was attached in this application to help users understand the basic geological factors.

Rock mass rating module

Preliminary rock mass stability estimation is one of the first steps that geologists should do. This may help to make the work decision more confident, safety is the most important factor. Just entering a few basic values of rock mass as mentioned above, the application calculates immediately. This module was programmed to cover all 41,015,625 possible cases. The simplest factors set is rock type, joint counting, spacing, rock conditions, water condition and activity of the rock mass. Each parameter was separated clearly and sequentially. Users do not need to enter values in sequence, they can design their own input sequences. The display of this module is shown in figure 1. The forth parameter part is divided into two modes; simplicity and detail. Simple mode is a set of rock mass conditions created by the application, suitable for initial assessment. Detail mode allows the users to enter detailed condition values, suitable for re-assessment to improve the stability as shown in figure 2. The results of this module consist of rock mass properties, cohesion and friction angle of rock mass, safety suggestion, tunnel stand up time, safe cut slope angle and support suggestion as shown in figure 3. The results of rock mass can be saved in data manager module for future use.

Geological strength index module

This module is suitable for assessing of the stability of rock mass at inaccessible points. Only data from visual inspection can be used to evaluate the stability of rock mass. Although detailed gathering is better but sometimes it may be risky. Geological strength index allows users to evaluate the rock mass stability from a distance. This module was programmed to cover all 140,400 possible cases. Figure 4 is the user interface of this module, conditions are categorized easily but still computable like original theory. This module is applicable to rock masses that partly flooded, blocked, or located in a risk area. The results of this module is only simple rock mass properties, cohesion to uniaxial compressive strength ratio and friction angle as shown in figure 5. These values are important properties of rock mass as mentioned above. The user interface design of this module is similar to previous module.

Data manager module

This module is a useful add-on for saving data. The database is created in the form of SQL table and designed to save memory space of smartphone. The data manager module allows users to save the estimated results from rock mass rating module. The saved results are sorted by chronological sequence with data names and time stamps as shown in figure 6. Users can name the data in rock mass rating module before saving to the database. The database of this module is private, for the privacy of users. Sometimes the rock mass covers a large area, this module can be divided into smaller sections. Users will be able to gather more details if they work in small areas, the results are more accurate. Segmentation allows users to estimate the rock mass in different cases. The saved results in this module are the same as the rock mass rating module as shown in figure 7. This module eliminates mistakes from handwriting, reduce the error caused by the large amount of data. The application has a simple geological guide for beginners in this module.

Calculation verification

Random rock conditions were generated to verify the calculation of rock mass rating module and geological strength index module. This is a very important step to make sure that the application is reliable. The generated conditions were calculated for the RMR value and GSI value by Microsoft Excel. These results were compared with calculations by the application. Some comparison results of RMR and GSI are shown in table 1 and table 2, respectively. All comparisons reveal that the calculation of the application are the same as Microsoft Excel calculations. Now the application is ready to use in the field.

Application of PSU-RG with case studies

The application was tested with real rock mass conditions from previous research as using example. Carbonate rock quarry case in Phang Nga province of Thailand [7] was selected this time. This rock mass was excavated to be slope face in open pit mining. The nature of rock in this area is light-dark grey and brownish-reddish grey limestone with calcite vein and brownish grey calcitic dolomite, known as Ratburi Group in Permian period. Point load strength of rock sample is 3.52 MPa, uniaxial compressive strength is 66 MPa, and rock quality designation from the volumetric joint count calculation is 70%. Spacings are between 0.1 and 0.8 meters without trace of groundwater. Discontinuities surfaces are slickensides with thick infilling and highly weathered. The aperture of joints is between 5 and 10 millimeters. Slope face is oriented at 64°/073° (dip angle/ dip directions) with 15 meters in height and 10 meters in width. Two joint sets and one bedding were found on this slope at 62°/305°, 40°/130°, and 14°/296°, respectively. The RMR result of this rock mass is 60 classifieds in class III (Fair), a little bit less than the previous research (63). The GSI value and m_r value are 54.5 and 8, respectively.

Another case study is excavated sandstone slope, we used the conditions of jointed sandstone intercalated shale, the cut slope at rear PSU Wittayanusorn School in Songkhla province of Thailand [14]. The height of slope is 12 meters, the width is 6 meters. There are 41 discontinuities divided into 36 joints and 5 beddings plane. The direction of these joints is between 336° and 352°, the dips are between 72° and 90°. Joints surface is weathered, completely dry and slightly rough. The average aperture is 1 millimeter and the spacings are between 0.2 and 0.6 meters. Slope face is oriented at 78°/215°. The average point load strength of rock samples is 5.18 MPa, equal to 113 MPa of

uniaxial compressive strength. The RMR result is 65 classified in class II (Good), the same as previous research (65). The GSI value and m_r value are 40.5 and 19, respectively.

The results of these two case studies using PSU-RG are summarized in table 3. In both cases, the RMR value is close to the previous research. Some value is not equal because of the rock mass conditions details. The Phang Nga case study may have some details that we do not know. However, significant stability was assessed. The GSI values of both cases give the same friction angle as RMR classification. The calculated cohesion from GSI value is about 10 times higher than the RMR estimation. These case studies show that PSU-RG can be used to estimate the preliminary rock mass stability in the field. The application saves time in assessing rock mass stability and provide useful details to increase stability. The results of PSU-RG are only preliminary assessments, it has theoretical inconsistencies in some case. However, the multi-theories application will bring more choices to engineers.

Discussion and conclusions

PSU-RG is a useful tool for estimating preliminary rock mass properties and stability. This application is exclusively for Android phone users. The rock mass rating is used to estimate the stability and properties of rock mass that can be directly gathered. The application consists of several theories that give users a variety of assessment approaches. Stability recommendations from this module are the guideline for increasing the stability of rock mass in the future. The geological strength index can assess the rock mass properties by visual inspection, suitable for partly flooded, blocked, or located in a risk area. Estimated results can be saved in data manager module, use a little memory space by using SQL database. The application respects the privacy of users, so it can be used by private parties. The application has been verified that the estimation is correct and reliable. The simple rock structure guide is included in PSU-RG, students can learn how to use the application by themselves. The case studies show that the application actually works, although Phang Nga case study (limestone) is slightly different. Detailed inputs are important to make accurate calculations as found in the Songkhla case study (sandstone). Rock mass classification in this research is only preliminary assessment. Users should be aware if the assessment results are not consistent with reality in special case. Cohesion and friction angle results can be applied to more complex stability assessments such as safety factor calculation by limit equilibrium analysis and stereographic projection. The application saves time in estimating rock mass stability, makes you have more time to do other works. Sometimes, the application requires a geological compass. If you do not have a compass, you can use a digital compass application from both Google Play Store or digital compass application for research [34]. However, users should use the digital compass carefully because some research has shown that digital compass is inaccurate [35-36]. This application is not recommended as the primary rock mass stability estimation, long-term stability studies are needed. In future, this application will add other stability estimation theories to serve a variety of purposes. If you want to save your working hours on preliminary rock mass study, you can download PSU-RG from QR code as shown in figure 8.

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Table 1 Comparison results of RMR between Microsoft Excel calculation and PSU-RG application.

Rock Mass Conditions						Excel	PSU-RG
UCS (MPa)	RQD (%)	Spacing (m)	Joints Conditions	Inflow (L/min)	Orientation	RMR	RMR
<1	<25	0.06-0.2	Tight, discontinuous, rough	10-25	Fair	36	36
>250	90-100	<0.06	Slickensided, continuous	<10	Fair	55	55
1-5	75-90	0.2-0.6	>5 mm wide continuous	<10	V.favorable	38	38
25-50	25-50	0.6-2	<1 mm highly weathered	-	Fair	50	50
>250	50-75	<0.06	Rough, slightly weathered	>125	Fair	53	53
25-50	90-100	>3	Slightly rough, <1 mm	25-125	Favorable	66	66
100-250	<25	0.6-2	Very rough, no separation	10-25	Fair	62	62
<1	25-50	0.06-0.2	Rough, separation <1 mm	-	Unfavorable	46	46
5-25	50-75	>2	Slightly rough, weathered	>125	Fair	50	50
50-100	75-90	0.2-0.6	Soft gouge, continuous	25-125	V.unfavorable	26	26

Table 2 Comparison results of GSI between Microsoft Excel calculation and PSU-RG application.

Rock Mass Conditions					Excel		PSU-RG	
Waviness	Smoothness	Alteration	Rock Type	Block V. (cm^3)	GSI	m_r	GSI	m_r
Interlocking	Slickensided	Swelling clay	Conglomerate	1	16.6	22	16.6	22
Stepped	Polished	Soft clay	Sandstone	5	16.2	19	16.2	19
>3%	Smooth	Compacted clay	Siltstone	10	20.5	9	20.5	9
0.3-3%	Slightly rough	Sand filling	Anhydrite	50	28.0	13	28.0	13
<0.3%	Rough	Clay coating	Quartzite	100	28.1	24	28.1	24
Interlocking	Very rough	Sand coating	Mylonite	1000	50.3	6	50.3	6
Stepped	Slickensided	High weathered	Schist	10000	40.9	6	40.9	6
>3%	Polished	Low weathered	Slate	100000	52.0	9	52.0	9
0.3-3%	Smooth	Fresh rock	Granite	500000	70.1	33	70.1	33
<0.3%	Slightly rough	Unweathered	Tuff	1000000	68.1	15	68.1	15

Table 3 Estimated rock mass properties of Phang Nga limestone quarry and Songkhla sandstone slope by PSU-RG.

Case Study	Rock Mass Rating			Geological Strength Index		
	RMR	Friction Angle	Cohesion	GSI	Friction Angle	Cohesion
Phang Nga limestone	60 (III, Fair)	25-35°	0.2-0.3 MPa	54.5	30°	2.97 MPa
Songkhla sandstone	65 (II, Good)	35-45°	0.3-0.4 MPa	40.5	35°	4.75 MPa

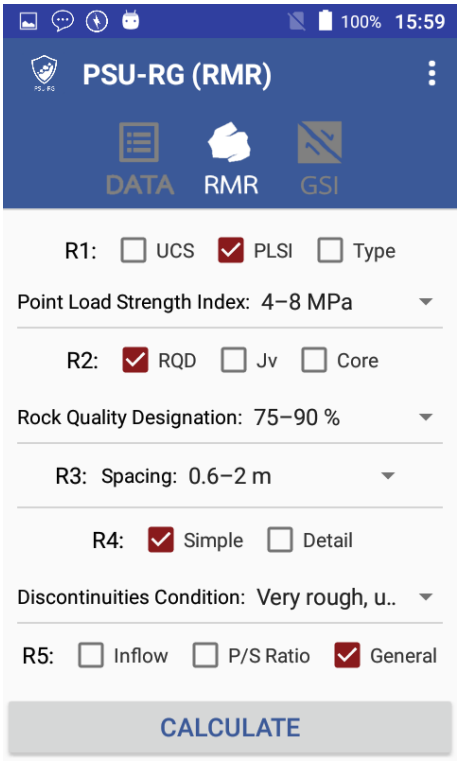

Figure 1 User interface of rock mass rating module.

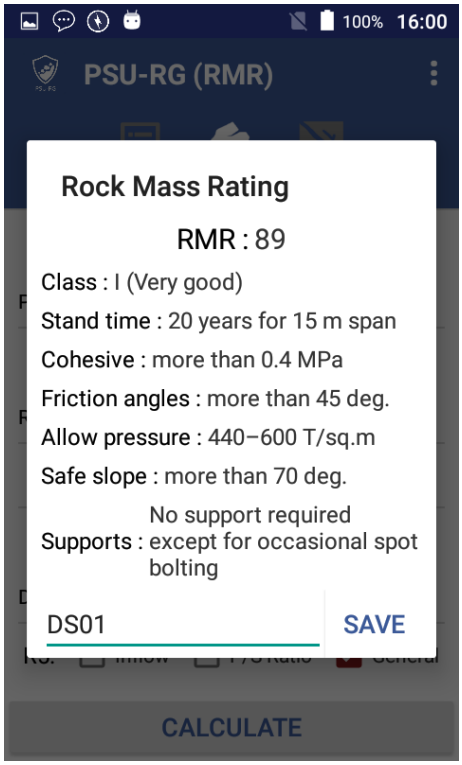

Figure 3 Estimation results from rock mass rating module.

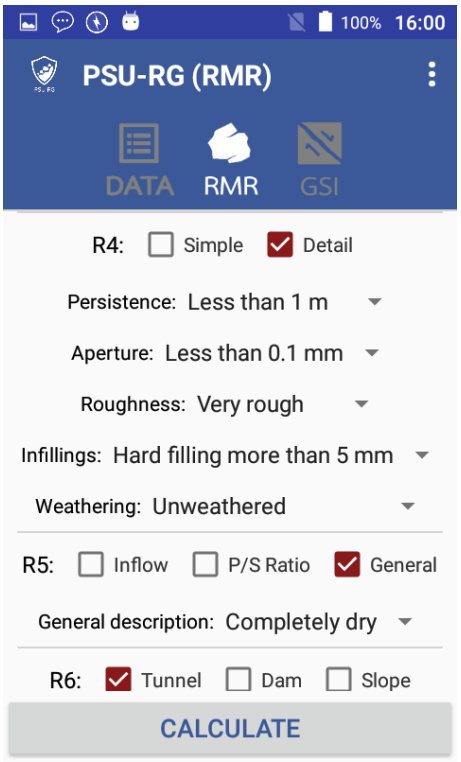

Figure 2 Detail mode of the forth parameters in rock mass rating module.

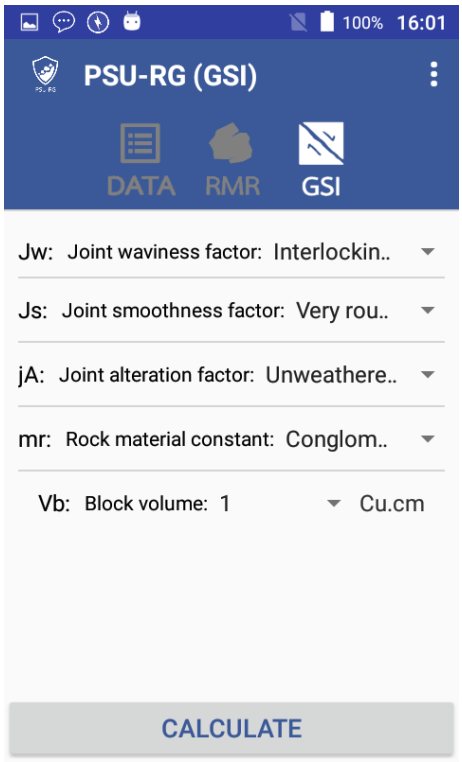

Figure 4 User interface of geological strength index module.

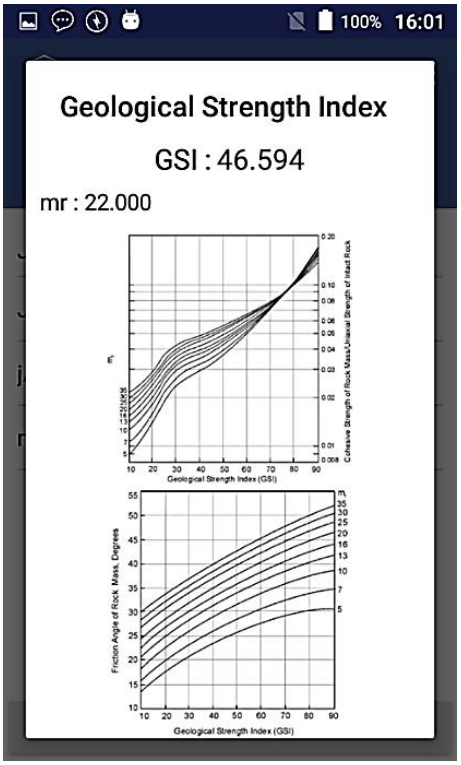

Figure 5 Estimation results from geological strength index module.

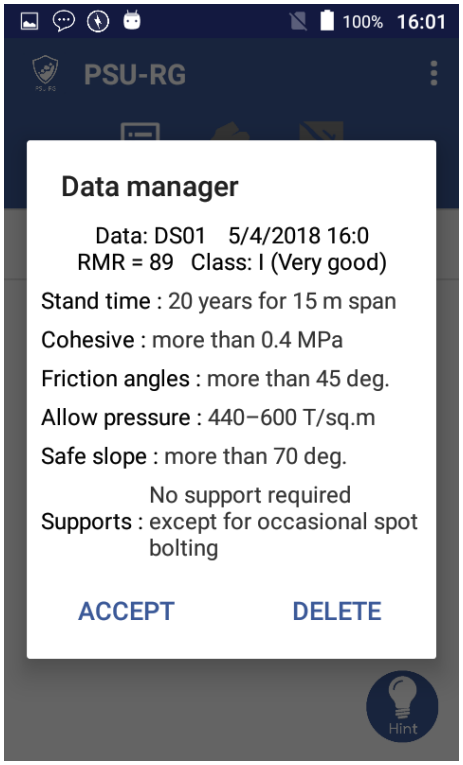

Figure 7 Details of estimated RMR results.

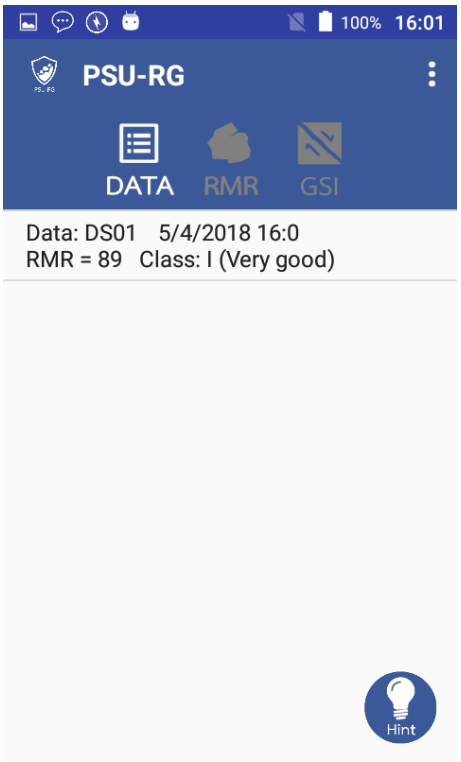

Figure 6 List of saved results in data manager module.

Figure 8 Android package download link of PSU-RG.