Review on current advances and consideration issues in preparing soil-rock mixture for laboratory testing

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Abstract. An extensive review of the soil-rock mixture strength measurement has been carried under various geomaterials and experimental methods. Primarily, the factors affecting the SRM mechanical behaviour and the testing methods discussed to further understand the importance of the sample preparation process before conducting laboratory testing. The soil-rock mixture is prepared in the laboratory using the test scheme proposed from very recent literature to perceive the dependence of the sample preparation procedure on the result of strength measurement. Then, a thorough literature review conducted to highlight the significant observations that are important in developing a systematic procedure for soil-rock mixture laboratory testing. Furthermore, the findings conclude that besides the soil-rock ratio, the moisture content, type of soil or finer grain component, and variation block strength or coarse grain component are essential factors that need to be determined while preparing soil-rock mixture samples before conducting the laboratory testing. Finally, for the future research direction of preparing a systematic standard for soil-rock mixture samples, several key points include the particle size, the range of soil-rock ratio, the geomaterials used, and the compaction degree proposed to be considered.

1. Introduction
Soil-rock mixture (SRM) is a significant geomaterial that is widely distributed and abundant in nature. SRM described as distinctively chaotic geomaterials composed of various block rocks of differing lithologies and sizes pervasively embedded within a weaker fine-grained matrix [1]. Indifference to block-in-matrix (bimrocks), a mixture of rocks composed of geotechnically significant blocks within a bonded matrix, the matrix of SRM is looser [2]. Soil-rock mixtures are usually heterogeneous, and their strength parameters correlated to structural components such as rock content, size, block shape, nature of the soil, and spatial distribution [3], [4]. Figure 1 shows an example of a soil-rock mixture in nature.

Due to the non-linearity of the parameters and deformation characteristics of SRM, its mechanical properties measurement is more complicated than other geomaterials [5]. At the same time, there is a complex interaction between soil and rock blocks [6]. In many construction projects such as tunnels, dams, and slopes, the soil-rock mixture is common, which leads to challenging instability problems and project delays during the design and construction process. Thus, identifying the strength parameters of this kind of anisotropy geomaterials is crucial in engineering work.
Currently, SRM is not separated from the traditional classification system of geotechnical materials. Even though researchers worldwide have conducted various experimental studies using SRM, a systematic standard of experimental or laboratory work is not well established. The sample preparation of the SRM used for laboratory work is complex due to the disturbance condition, sample size, and state. It is not easy to provide an identical sample between the specimens from the field and the fabricated or moulded sample, which usually used in laboratory testing.

To overcome these disadvantages, certain researchers have started to research the strength of the SRM using the numerical modelling method. Yet, most of the numerical modelling software requires the implementation of a specific constitutive model. This method can affect one’s judgment of the failure mechanism of soil-rock. Therefore, laboratory model experiments are still an efficient way to understand the properties of the SRM. Yet, there are a variety of methods used in preparing the SRM sample for laboratory testing. Thus, this paper aimed to review the significant work in SRM’s properties measurement using a physical model, highlight the fundamental factors that affect the SRM preparation process, and suggest a way forward to have a systematic standard on preparing the sample for laboratory work.

2. Soil-rock mixture strength measurement
Strength is among the key parameters to characterize geomaterial mechanical behaviour. Hence, various methodologies applied by researchers to measure the strength of the soil-rock mixture. Most of the studies recognized that the soil-rock ratio mainly influences the strength. Based on the popularity table constructed from the literature review (refer to Table 1), the soil-rock ratio is indeed the most popular factor studied, followed by the rock grain size. It is observed from the literature study that most works focus on the influences of gravel content and SRM’s failure mechanism [4], [7], [8], as well as the influence of gravel size and gravel shape [9]–[12]. Other factors such as rock-block shape, strength, and orientation not included here as the works are minimal.
Table 1. Popularity table on previous research regarding factors affecting the shear strength of soil-rock mixture.

| Paper                          | Soil-rock ratio | Particle size distribution | Moisture content | Rock grain size effect | Material composition |
|-------------------------------|-----------------|----------------------------|------------------|------------------------|----------------------|
| B. Li [9]                     | 1               | 1                          | 1                | 1                      | 1                    |
| Shaorui S. et al. [13]        | 1               | 1                          | 1                | 1                      | 1                    |
| Wang S, Ji T, Xue Q, et al. [8]| 1               | 1                          | 1                | 1                      | 1                    |
| Minghui R. et al. [10]        | 1               | 1                          | 1                | 1                      | 1                    |
| Yanxi Z. & Zhongzian L. [3]   | 1               | 1                          | 1                | 1                      | 1                    |
| Cen D et al [14]              | 1               | 1                          | 1                | 1                      | 1                    |
| Zong-Liang Z. et al. [15]     | 1               | 1                          | 1                | 1                      | 1                    |
| Hai-Yang Zhang et al. [7]     | 1               | 1                          | 1                | 1                      | 1                    |
| Xue et al. [16]               | 1               | 1                          | 1                | 1                      | 1                    |
| Gao W. et al. [17]            | 1               | 1                          | 1                | 1                      | 1                    |
| Shaorui Sun et al [18]        | 1               | 1                          | 1                | 1                      | 1                    |
| Linping Y. & Zhiyun W. [19]   | 1               | 1                          | 1                | 1                      | 1                    |
| Xu Wen-jie et al. [20]        | 1               | 1                          | 1                | 1                      | 1                    |
| Wickland BE et al. [21]       | 1               | 1                          | 1                | 1                      | 1                    |
| Vallejo LE [22]               | 1               | 1                          | 1                | 1                      | 1                    |

| Popularity | 8 | 3 | 2 | 5 | 4 |

The majority of studies measure the mechanical properties of SRM using large direct shear tests either in the field or laboratory [9], [10], [13], [16], [20], [23]–[25]. Though there are many limitations to direct shear testing, including the non-uniformity of the stresses and strains within the box, due to its simplicity and suitability for testing, the direct shear box is one of the most widely used equipments for obtaining shear strength parameters (cohesive force and internal friction angle) for geotechnical material. For instance, a shear test conducted using fabricated SRM made of breccia and subrounded gravels mixed with silty clay as fine soil [13]. The result shows that when the gravel proportion is too high (for example, 70%), the shear stress value depends on the gravel shape and the distribution in space and not completely on the gravel proportion. B. Li similarly uses a large-scale indoor shear test on SRM to investigate the effect on gradation and maximum particle size [9]. In his study, the SRM sample made of sandy gravel and quartzite. The result showed that the effect of gradation on τ, φ, and c is small. Meanwhile, as the maximum particle size increases, the τ, and φ of the SRM increase, while the c decreases.

The triaxial test is another typical method selected to study the strength of the soil-rock mixture. J. Yang et al. also used triaxial compression tests but using different moulded SRM samples made of cement sand-gravel [26]. Ren et al. also studied the specimen size effect on the mixture of clayey soil, gravel, and rock blocks [10]. They determined that the shear gap controls the shear behaviour of SRM. With the gap increment, the relationship between internal friction angle and cohesion is in negative correlation. Stable and realistic shear strength of SRM obtained in suitable gaps, and the specimen size effect also exists with the gap effect.

Other than the conventional testing method (shear and triaxial test) mentioned above, several attempts using different strategies and equipment to measure the strength of SRM presented here. For example, Lv and Zhou instead conducted a laboratory test using a modified borehole pressure shear test on the mixture of sand, calcium carbonate, gypsum [27]. They found that the strength parameters are slightly higher than the direct shear test, but this suggested alternative method considered efficient enough. Zhenping Z. et al. and Hai-Yang Z. et al. conducted a uniaxial compression test combined with computed tomography triaxial test, another different testing method of SRM sample from
colluvium slope [4],[7]. Their finding introduces another two controlling factors of soil-rock mixtures’ mechanical properties: interlocking and the breakage of the large rock blocks.

There are also several studies of SRM made using synthetic material. For instance, Ding et al. mould a transparent synthetic soil using a mixture of fused quartz sand with liquid paraffin and n-tridecane [23]. The results show that transparent soil can be used for similar simulation experiments of the soil-rock mixture since both of them have high similarity. Besides, Wang et al. analyze the shear properties of clayey soil with corundum ball using an electro-hydraulic servo and determined the axial and lateral deformations [28]. The experimental results define three failure patterns of SRM; spitting failure, shear failure, and conical failure at various strain rates. They also found that the interactions between the rock blocks and the soil matrix are the primary factor determining the dynamic response of SRM.

Rather than using testing equipment as mentioned above, there is also another study determined that the sand-gravel mixtures’ shear strength using empirical equation $S_c = S_m (1+2.5 C)$, which is developed by Vallejo et al. The equation used value from the shear strength of the sand matrix and the concentration by volume of the gravel in the mixtures. In this equation, $S_c$, $S_m$, and $C$ represent the shear strength of the sand-gravel mixture, the shear strength of the sand matrix alone, and the concentration by volume of the gravel in the mixture. However, the equation’s validity has not yet been determined to be general and has only applied to the type and size of the grain, stress conditions, and equipment used in the reported testing program [24].

To conclude, the strength properties of the soil-rock mixture depend not only on soil-rock proportion but also on other factors, such as the rock block size, texture, shape, moisture content and the experimental conditions. Concurrently, the documentation of the strength parameters for the SRM is necessary for engineering work and could be done by utilizing the results of the model experiments that consider many influencing factors [13].

3. Soil-rock mixture sample preparation method

Variety in soil-rock mixture testing influences the sample preparation method too. Generally, soil-rock mixture (SRM) preparation for laboratory testing divided into three-phase. The first phase starts with collecting and preparing the soil-rock mixture component. The type of materials used can be collected from natural sources or fabricated. Several types of geomaterials used to prepare the soil-rock mixture sample from previous studies, as presented in Table 2. It is essential to mention here that the works of literature presented in this section only involve SRM behaviour measurement using physical testing.

| Material list used in preparing soil-rock mixture from literature |
|---------------------------------------------------------------|
| Paper | Material |
|-------|----------|
| Lv & Zhou [27] | Sand, calcium carbonate, gypsum |
| Ren et al. [10] | Clayey matrix, gravel, and rock blocks |
| B. Li [9] | Sandy gravel and quartzite |
| Xue et al. [16] | Pebbles, silty clay, and water |
| Ding et al. [23] | Synthetic transparent soil |
| Wang et al. [28] | Clay soil and corundum ball |
| Sun et al. [13] | Silty soil and gravel |
| Zhang Z. et al. [4] | Colluvium |
| Zhang H. Y. et al. [7] | Colluvium |
| Xu et al. [20] | Clay, cobbles, and gravels from SRM slope |
| Zhao & Liu [3] | Clayey soil and artificial rock |
| Vallejo et al. [24] | Sand and gravel |
| Zhang Z. L. et al. [15] | Residual soil and granite |
| Younes Amini et al. [25] | Soil with fine sand and gravel |
| Hamidi et al. [29] | Sandy soil with gravel |
| Selvam & Chakravaty [30] | Sandy silt |
In the second phase, the procedure proceeds with designing the material composition or soil-rock ratio. A recent study conducted on the material composition effects on the mechanical properties of SRM, where the soil-rock material was separated into different size categories before tested using medium-scale shearing and triaxial experiments [3]. The relationships among macro deformation, strength, content, size, and random location of rocks observed where the stress-strain curve of soil-rock mixtures found as an approximately hyperbolic hardening curve. The SRM sample collected from the site undergoes a sieving process to separate the soil and rock particles. A study on the effect of SRM particle size on the shear strength found out that, when the Mohr-Coulomb criterion used to depict the curve under a shear strain of 0.15, cohesion first increased and decreased. It also determines that the elastic modulus increased with an increase in rock size, but Poisson’s ratio remained constant.

The third phase is the moulding process. Depending on the scale and testing equipment used, the sample prepared come in different form and size. Based on previous works included in this review, the sample is usually moulded into a core sample or compacted into the shear box. Large-scale equipment can run a test with a minimum square dimension of 10cmx10cm. Meanwhile, the core sample used in the triaxial or uniaxial compressive test is in cylinder form with a minimum dimension of 100cmx50cm. A standard dimension of the sample preparation is not fixed yet in any published work.

4. Perspective and Future Direction

Based on the discussion in the previous section, various methods are existing in testing and preparing the soil-rock mixture. In this study, a soil-rock mixture core sample had been prepared by following the test procedure present in previous work using natural samples collected at a construction site from Kinta Valley. After attempting to prepare the soil-rock mixture, there are several findings can be concluded. There are three significant factors observed through the process that is going to affect the sample preparation, which discussed as the following:

4.1. Moisture content

The moisture content affects the shear strength of the soil-rock mixture. A previous study shows that the shear strength of SRM reaches its peak when the moisture content is 10.5% [9]. Consequently, the moisture content needs to be determined before preparing the laboratory sample. The moisture content of the sample is also dependent on the type of soil present in the mixture. Sandy and silt soil hold moisture differently as they have more pores compared to clayey soil. In the water film theory, too high or too low moisture content is not conductive to closely arranged granular materials as the grain squeezes each other and adversely affects the mixture’s strength [34].

Besides, it is observed that the time gap between sample preparation and sample testing also affect the moisture content, consequently the testing result. The core samples are purposely left in the open air and closed box for different time ranges before running the uniaxial compressive test. The finding shows that the longer the sample kept before the testing, the lower the moisture content, the harder the sample becomes. Thus, a standard time gap needs to be established in the systematic procedure of soil-rock mixture testing to obtain more comparable data to be analyzed.

4.2. Type of soil

The soil in the soil-rock mixtures is a relative concept and different from the traditional notion of silt, clay, and other fine-grained soil. Since particle size varies from several millimetres to tens of centimetres, defining the soil and rock is vital in determining the rock content of this medium [3]. In the particle size distribution (PSD), the soil type classified as clayey, silty, or sandy. The SRM sample prepared in this study divided into two types according to the soil used. The first sample prepared...
using sandy soil, and the other is silty soil. The core using sandy soil is fragile compared to silty soil. Thus, the PSD analysis is a crucial procedure proposed to include in the systematic procedure of SRM laboratory testing.

4.3. Rock-block properties

The soil-rock mixture is a cohesive-frictional geomaterial subjected to impacts of composition and structure seriously [8]. The coarse-grained component, known as rock block in the soil-rock mixture, can be weathered, fabricated, or fresh. The texture of the rock block also affects the mechanical behaviour of SRM. For example, a recent study on soil-breccia mixture (a type of SRM) shows that, as the confining pressure increased, the shear strength of the soil-rock mixture increased. The amount of displacement of the upper breccias is the largest.

Usually, the sample is taken from the field and classified into a disturbed or undisturbed sample. The sample also could be made of synthetic or artificial material. Most researchers prepared the SRM sample by moulding them using either natural or synthetic material, as shown in Table 2. Some other researchers utilize sample that is undisturbed and taken from SRM slope, colluvium, or talus. Due to this variety of the SRM type, methodology, and laboratory sample preparation, a guideline in preparing the sample for laboratory-scale testing is helpful to related practitioners (i.e., geotechnical engineer, engineering geologist) to conduct their experiment and enhance the reliability of the measurement result. Thus, a systematic standard for the soil-rock mixture preparation proposed here shall at least considers and includes the following suggested items (refer to Table 3).

| No | Criteria | Description |
|----|----------|-------------|
| 1  | The particle size in the soil-rock mixture. | The sizing includes the minimum and maximum particle size used. |
| 2  | Range of acceptable soil-rock ratio that represents the soil-rock mixture. | The soil-rock ratio designed based on the limit on the percentage of soil and rock block. |
| 3  | Type of geomaterial used in forming soil-rock mixture. | Soil type based on particle size distribution. Rock block properties include its strength, texture, and shape. |
| 4  | Compaction degree. | The percentage of compaction degree must be consistent. |

5. Conclusion

Although researchers performed some efforts to assess the strength of SRM based on physical testing in-situ and in laboratory works, further studies to develop more efficient methods and a database for the strength of such materials are still needed. The variation in the soil composition and rock material to prepare the SRM sample allowed us to obtain more information and prepare a comprehensive reference from the various case study. This review conducted successfully enhance the understanding of the variation of sample preparation of SRM and its effect on the strength measurement. The findings in this study also suggest these fundamental factors; moisture content, type of soil, and rock block strength to be sensibly determined in the sample preparation process. The future study proposed considering this input in the development and improvement of a standard systematic procedure of SRM laboratory testing, which is beneficial to the related practitioner.

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