THE BEHAVIOR OF RESIDUAL SHEAR STRENGTH OF LATERITE SOIL DUE TO THE ADDITION OF COARSE SAND AND LOW PLASTICITY CLAY FRACTIONS

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THE BEHAVIOR OF RESIDUAL SHEAR STRENGTH OF LATERITE SOIL DUE TO THE ADDITION OF COARSE SAND AND LOW PLASTICITY CLAY FRACTIONS

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ABSTRACT: Residual shear strength plays a very significant role in geotechnical engineering. This concept has contributed extensively to diverse studies on soil behaviors under the influence of shear failure, both in drained and saturated conditions. In terms of landslides, the assessment of the residual shear strength after an occurrence and the progressive failure risk of slope stability has been very useful. However, information on this shear property in laterite soil appears relatively minimal. This soil type is the most frequently applied embankment for road construction in every Kalimantan region. Therefore, the purpose of this research is to determine the behavior of residual shear strength in laterite soil and the effects of adding coarse sand and clay fractions, using direct shear analysis. Subsequently, the specimens were prepared by compaction tests to obtain the optimum moisture content and uniform density, using coarse sand of varying proportions, termed 5, 10, 15, 20 and 25%, while the shear strength treatment with wetting and drying cycle conditions was conducted under 2, 4, 6, 8 and 10 days, respectively. The results showed that the addition of the coarse sand and clay (CL) portions was able to increase the residual shear strength parameters (cohesion and internal friction angle) by 4-6%, compared to the pure state. Therefore, the introduction of clay (CL) materials ranging from 20-25% appears suitable in enhancing the residual shear strength of laterite soil. However, the extensive wetting-drying cycle tends to reduce the peak and residual shear strength.

Keywords: Shear strength, Residual shear strength, Laterite soil, Coarse sand, Low plasticity clay

1. INTRODUCTION

Laterite soil is a fairly hard and red surface residue originating from tropical deposits. The sample is generally a result of final weathering from disintegration and decomposition activities. This soil type is due to the chemical transfer of silica from the slump, with relatively increasing *Fe* and *Al* concentrations. The process is formed in the tropics where the rainfall intensity and temperatures are higher, causing the Si content to easily dissolve and form oxysols, comprised of laterite and latosol.

Laterites occur in the tropical regions, including Indonesia, with an extension over the Sumatra, Java, Kalimantan, Sulawesi, and Papua islands. This soil is commonly employed as an embankment material for road construction and shoulders, as well as expansion. The sample from South Kalimantan province varies in grain size distribution, comprising gravel, sand, silt and clay fractions. Meanwhile, the clay fragment shows a relatively significant percentage above 20%, leading to a high plasticity index. As a result of the superior value, the road embankment stability factor is relatively minimal, with certain limitations, including the easy occurrence of massive compressions on the main road from the embankment materials, as well as simple surface erosion due to the rain, with the tendency to instigate landslides.

Slope slides from embankments are common in Kalimantan, ranging from small to large scale, with the tendency to hinder traffic lanes. As a consequence, studies on residual shear strength in soils appear necessary to determine the possibility of using areas adjacent to the landslide as traffic access or total road closures. These actions are essential to avoid the potential threat to public safety, although the implementations are relatively time-consuming.

Residual shear strength is very significant in geotechnical engineering and has also contributed immensely to the research on the soil behavior of soil under failure events, both in drained and saturated conditions. This concept plays an essential role in landslide properties, particularly in the assessment of the residual shear strength after an occurrence and progressive failure risk of slope stability. Furthermore, the residual shear strength of the over-consolidated (OC) soil was analyzed in two stages. The first attempt was conducted at a peak state, followed by a gradual decrease to a critical condition value due to improved moisture content. Meanwhile, in the second stage, the shear strength declined under an extensive deformation, as a result of the re-orientation of the soil particles parallel to the shift direction. Under this circumstance, the shear strength becomes minimal and is called the residual shear strength.

However, information on residual shear strength of laterite soil after landslide appears relatively insignificant. This is related to the behavior of the residual shear strength of the embankment with laterite soil that shows the most frequently used for road construction in virtually every Kalimantan region in Indonesia.

Several studies on the residual strength of non-laterite clays have also been conducted since the late 1930s, including by scientists [1-3]. Furthermore, Skempton [4] reported the residual shear strength of the soil using a conceptual model, based on experimental data. This attempt was successively followed by scientists [5-8], where the results of Skempton [4] were refined over time.

The residual shear strength forms a key parameter required for the analysis and design of slopes, retaining walls and fine-grained soil foundations under relatively massive deformations [9]. This property is mainly applied for two purposes. The first effort involves calculating the extent of slope decrease in an earthquake [10], followed by evaluating the previous slope stability [11].

Residual shear strength is important in comprehending the stability of past landslides, assessment of engineering properties of soil deposits, comprising pre-existing shear surfaces and the progressive failure risk on new and current slopes [11-13]. The variable also plays a significant role in the design of corrective action [14] and understanding its position under initial failure conditions [15].

Several studies on soil parameters, termed Atterberg limit, clay fraction, friction angle, and so on, to determine residual strength have also been previously investigated, including scientists [16-20]. This research intends to contribute to the development of subsequent slope stability analysis [21]. The residual strength is commonly defined as the minimum and constant drained shear strength needed for the soil to undergoes an extensive shear shift under normal stress [21], as represented in Fig. 1.

Fig. 1 shows that the residual shear strength of soil is never zero [22]. This factor depends not only on soil type, termed material, particle size and shape, surface roughness, and so, but also on soil situations, in terms of density, moisture content, frame structure, and test conditions, including the selection of shear testing equipment, normal stress, over-consolidation ratio, shear rate, acceleration, and so on [23].

Several previous attempts have been recorded relating the friction angle of the residual soil and its index properties, including Atterberg limit as well as clay fraction [24] and friction angle in residual clay fraction [4], by performing a series of controlled direct shear tests in certain mixtures of bentonite, kaolin and sand. In the two investigations, the shear rate varied between 0.0001-100 mm/min. This observation concluded that a positive relationship between the shear transfer rate and the clay's residual strength was observed, with higher fractions and displacement above 50% and 1 mm/min, respectively. Additionally, the shear test has also been conducted on a mixture of soil and sodium chloride to examine the salt concentration effects. The results showed that the positive impact becomes more intense with increasing salt concentration. This increment is possibly comprehended by the decrease in the void ratio and the increase in contact solid particles due to the concentration of the mixture [25, 26].

Based on the description above, there are no known reports on the behavior of the residual shear strength of laterite soil due to the addition of coarse sand fraction and low plasticity clay fraction. Previous studies were limited to the residual shear strength behavior of pure clay, bentonite mixed clay, kaolinite mixed clay, and sand mixed clay. Furthermore, these studies examined the relationship between the residual shear strength of clays besides laterite soil types, and Atterberg limit parameters, clay fraction parameters, internal friction angle parameters, soil particle behavior, as well as porosity.

Therefore, studies on the residual shear strength behavior of laterite soil are required because the theory of laterite soils, especially regarding residual shear strength, has not been widely developed. This research is a suitable preliminary for further theory development on this topic, and the findings from this study are bound to provide more insight. Furthermore, it examines the shear strength behavior of the residual laterite soil after a mixture of coarse sand and low plasticity clay (CL) fractions have been added, as well as the effect of wetting and drying cycle conditions as in the rainy and dry season conditions in Indonesia, as these tend to reduce the peak shear strength and residual shear strength of laterite soils. In Indonesia, laterite soil is often used as embankment material for road bodies under the road foundation layer material, and the conditions of these soils exhibits weaknesses in several properties, while commonly causing problems, including low peak and residual shear strengths, due to the dominant plastic nature. This has the potential to easily cause landslides on the laterite soil slopes of the road embankment.

This research's findings are also a suitable material for the development of laterite soil theory, particularly the theory of residual shear strength behavior, and bound to play a significant role in the stability of laterite soil embankment slopes.

Furthermore, the findings also provide the groundwork for further explorations, for instance, studies on how the behavior of soil particles and porosity influence the residual shear strength of laterite soils, as well as how the magnitude and velocity of residual shear strength affect the slope stability behavior of laterite soils. This research is also useful for local government policymakers and engineering consultants in considering the use of laterite soil mixed with coarse sand and low plasticity clay fractions as a road embankment material, as this is technically better, compared to laterite soil alone.

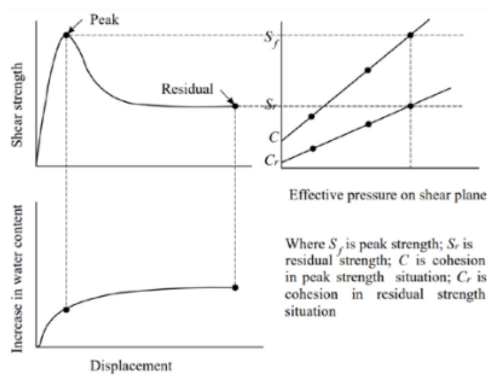

Fig. 1 Consept of residual strength in shear characteristics

2. RESEARCH METHODS

2.1 Material

The sample of laterite soil on this research is taken from a quarry in Cempaka, Banjarbaru city, South Kalimantan province, Indonesia. This soil is commonly applied as an embankment material in road construction across the Kalimantan island. The samples of coarse sand and clay fraction which have 6% of Plasticity Index as the additional material in the mixture is taken from the Barito River, Barito Kuala Regency. This value is classified by the USCS standard as CL (low plasticity clay).

Table 1 shows the physical and mechanical characteristics of laterite soil, with a classification of CH (high plasticity soil) and a relatively high PI of 34.51%.

Based on the grain size distribution test results, the fine-grained soil showed a percentage above 50%. This outcome is also reviewed on the basis of the moderately high liquid limit (LL) and compressibility index (Cc) values. Therefore, the selected laterite soil is plastic in nature, and is easily compressed, but appears less profitable in constructing road embankments.

Table 1. Characteristics of Laterite Soil

Properties	Value
- Volumetric weight, γ (kN/m^3)	17.38
- Water content, Wn (%)	40.636
- Specific Gravity, Gs	2.65
- Liquid limit, LL (%)	62.91
- Plastic limit, PL (%)	28.40
- Plastic Index, PI (%)	34.51
- Cohesion, C (kPa)	26
- Internal angle, (°)	22.61
- Compressibility index, Cc	0.51
- Swelling Index, Cs	0.07
- Grained of Distributions	
- Gravel (>2mm), %	16.99
- Coarse sand (0.6-2mm), %	7.85
- Medium sand (0.2-0.6mm), %	7.21
- Fine sand (0.05-0.2mm), %	6.42
- Silt-clay (0.002-0.05mm), %	24.79
- Clay (<0.002mm), %	36.74
- Sensitivity	1.1
- USCS classification	CH

2.2 Testing procedure

The laboratory research activities involved evaluating the physical and mechanical properties, including the shear strength, with the addition of sand and clay fractions at 5, 10, 15, 20 and 25% respectively. Soil specimens for the shear strength test were obtained from the standard compaction results, with 80-90% maximum density. This assessment was conducted for each variation, without the addition of mixing material in wetting and drying cycles, but at the peak and residual shear strength for 2, 4, 6, 8, and 10 days.

Figure 2 represents the main direct shear test tool in the present research. This also refers to the test method conducted by So and Okada [27].

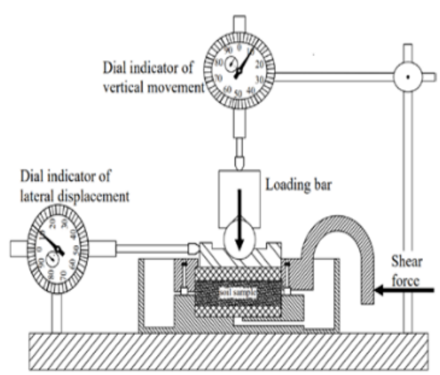

Fig. 2 Scheme for the Direct Shear Test Tool

3. RESULTS

3.1 Grain size distribution of Laterite soil mixture

Figure 3 shows the grain size distribution curve for each mixture. The shape of the curve for laterite soil and clay components rests on the upper side of the laterite soil and coarse sand blend, particularly the curve line on the fine-grained soil fraction, including silt and coarse sand.

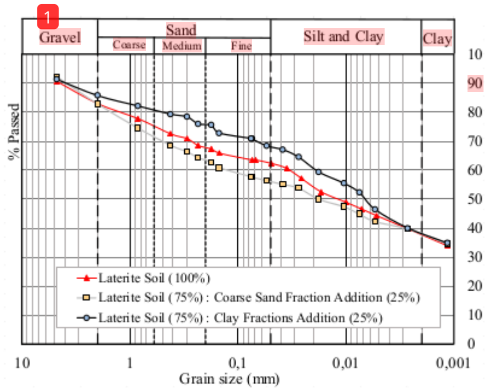

Fig. 3 Grain Size Distribution Curve

3.2 Effect of the addition sand and clay fraction on the cohesion value of Laterite soil at peak and residual conditions

Figure 4 shows the effects of adding sand and clay fractions on the soil cohesion value at peak and residual conditions. Based on the graph, the soil cohesion value at peak state generally appears greater, compared to the residual position. This statement applies to both added soil types, including coarse sand and clay fractions. Also, the residual cohesion values decreased towards the peak condition in the sand and clay materials by an average of 17 and 13%, respectively. This outcome indicates a cohesion value of the residual soil in the coarse sand and clay fractions at 83 and 87%, correspondingly, after the added materials. However, compared to the cohesion of plain laterite soil, the value was 4% lower than the added material of 20-25% clay fraction.

Figure 4, also shows an increase in the residual cohesion along with the percentage of added clay fractions, but contrary to the sand components. Theoretically, the addition of clay fractions was believed to enhance the soil friction, leading to an increased bond between the grains. Also, the cohesion among soil grains contained in the mixture was known to decline, due to additional coarse sand.

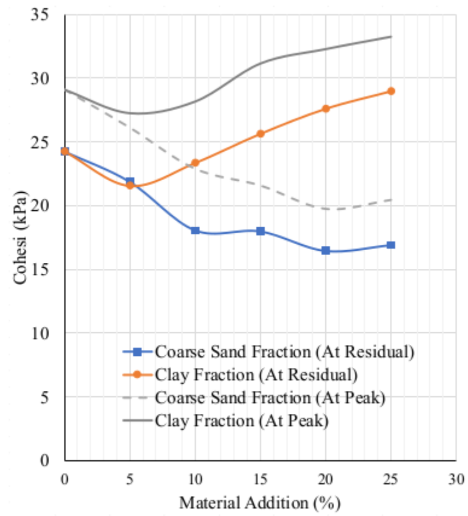

Fig. 4 The Relationship between the Added Materials and Soil Cohesion at Peak and Residual Conditions.

3.3 Effect of the addition of sand and clay fractions on friction angle in laterite soil at peak and residual conditions

Figure 5 shows the effect of adding sand and clay fractions on the friction angle in laterite soil at both peak and residual conditions. Based on the graph, the internal friction angle at peak position was greater, compared to the residual state. This statement applies to the two added materials, termed sand and clay.

The comparison shows that the internal friction angle at the residual conditions decreased by 12 and 23% in the coarse sand and clay fractions, respectively, at peak conditions. In addition, the relationship curve indicates that the residual state of added sand particles generated the maximum friction angle, compared to clay. This outcome also recorded a residual shear strength of 88 and 77% in coarse sand and clay fractions, respectively, after the added soil materials. Consequently, the internal friction angle in the residual condition for the plain sample was 6% lower than the added materials with a 20-25% clay fraction.

Therefore, the addition of coarse sand significantly enhanced the shear angle, compared to the original soil. Increasing the sand in the mixture cause the interconnected grains to strongly attract each other. Under the prevalent circumstance, the voids between the soil particles tend to reduce, although the friction between the sand fraction and the original soil becomes more extensive. This conclusion is also related to the previous studies by

Heidemann *et al*. [28], where the shear strain instigated a minimal decline in the friction angle, compared to the saturated peak condition (critical value). However, the displacement required to achieve this equilibrium appeared very significant.

This statement also relates to the shape of the particle size distribution curve obtained before and after the shear test. Therefore, most of the soil clusters disintegrated during sample preparation. Direct shear assessments showed that the normal effective stress greatly influenced the particle deformation mechanism. This situation results to the reduction in the friction angle at increasing normal effective stress, under residual conditions [28].

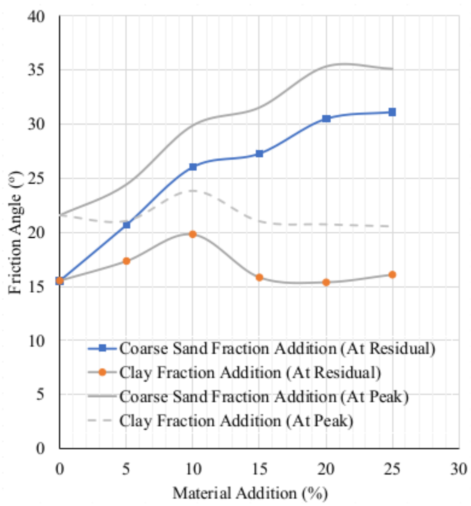

Fig. 5 The Relationship of Material Addition and Friction Angle at Peak and Residual Conditions.

3.4 Effect of plastic index on shear strength at peak and residual conditions

Figure 6 shows the effects of plasticity index on shear strength, with added coarse sand, at peak and residual conditions. Based on the graph, the shear strength significantly decreased as plastic index becomes intense. However, with a constant plasticity index, the residual shear strength appeared slightly minimal, compared to the peak positions.

Also, the reduction in plasticity index corresponded to the percentage increment in the added coarse sand that tends to disintegrate the grain adhesion. This inclusion was aimed at declining the soil mineral, cohesion value and plasticity index. However, the friction was due the involvement of the coarse sand fractions that tends to reduce the cavities between soil grains.

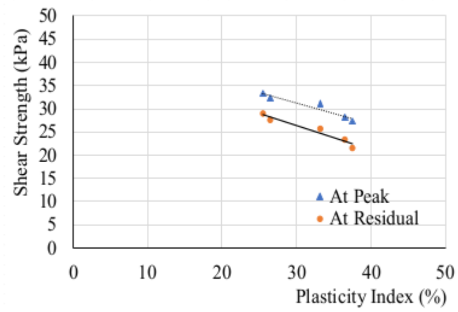

Fig. 6 The Relationship between Plasticity Index and Shear Strength at Peak and Residual Conditions.

3.5 Effect of the addition of sand and clay fractions on the shear strength of laterite soil at peak and residual conditions

Figure 7 represents the relationship between the added material and shear strength at both peak and residual conditions. Under these circumstances, the addition of coarse sand and clay fractions significantly influenced the shear strength. However, the soil retains the minimal residual shear strength after experiencing peak conditions. This observation corresponded to previous research [21], where the soil's residual shear strength was not zero.

Figure 7 also shows that the addition of the clay fractions instigated a higher residual shear strength than the pure sample, based on a constant percentage of added materials. According to the percentage ratio, the resulting graph and the comparison indicated a decline in the residual shear strength by average values of 17.4 and 16.6% in coarse sand and clay components, respectively. This peak outcome also observed the residual shear strength of 82.6 and 83.4% for coarse sand and clay samples after the added materials.

Furthermore, the soil mixture with 20-25% clay fractions tends to generate a minimal residual shear strength, compared to the added sand fractions. However, by comparing previous research [11], the residual strength was mainly influenced by the sand and silt fractions, with clay samples below 25%. Meanwhile, beyond 50%, the residual strength is almost entirely impacted, although further increase in the clay fraction reported insignificant effects. Also, between 25-50%, a 'transition' type of behavior occurred, where the residual strength was influenced by the proportion of clay particles and the properties.

In other research results, the clay content generated very minimal residual shear strength. This condition was due to the alignment of particles parallel to the shear surface and the disintegration of certain soil groups rather than the damage to individual soil particles. Conversely, the existence of various soil types or groupings described the significant difference between peak and residual conditions in direct shear tests [28].

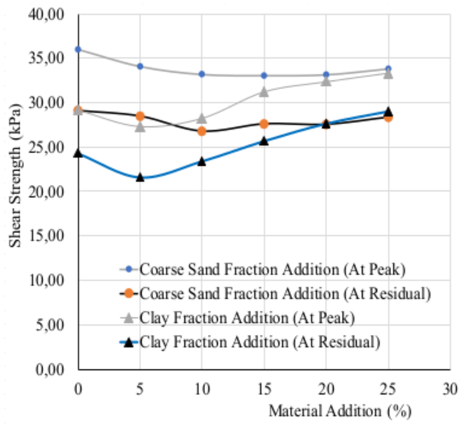

Fig. 7 The Relationship of Material Addition and Soil Shear Strength at Peak and Residual Conditions.

3.6 Effect of wet-dry conditions on laterite soil shear strength at peak and residual conditions

Figure 8 shows the relationship between wetting and drying cycles. Extensive periods tend to reduce the shear strength at normal and residual conditions. This decline generated average values of 5.11 and 4.92% for normal and residual conditions respectively. Consequently, the graph confirmed a decrease in the residual shear strength by an average of 26.42% against the normal conditions, under constant wetting and drying cycles.

Figure 8 also indicates an increased shear strength dues to the changes from wetting to drying phases, although not very significantly. Conversely, the transition from drying to wetting phase decreased the shear strength by an average of 4.5%. Under the 10-day drying interval, the shear strength under normal appeared more substantial, compared to the residual conditions.

Based on the shape of the curve shown in Figure 8, it can also be stated that the ratio of the peak shear strength value on the condition of the wetting and drying cycle on day 10 was 17% greater than on the previous days, which was only 5.8%. In addition, the comparison of the peak shear strength and residual shear strength on the 8th to the 10th day is relatively small, namely 27% compared to the 2nd day to the 6th day which is 34.4%.

In addition, a loss in suction power was known to reduce the shear strength of the residual unsaturated soil [9]. Also, the contribution of matric suction to residual shear strength decreased significantly with increasing matric suction, although the influence was drastically displaced with extensive normal stress. This behavior is caused by a reduction in the area of the water menisci in contact with the aggregate.

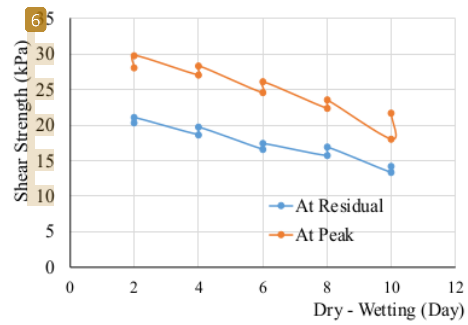

Fig. 8 The Relationship between Wet-Dry Laterite Soil Conditions on Shear Strength at Peak and Residual Conditions.

4. CONCLUSION

Based on the analysis results and discussion, certain deductions were generated, including:

1. The addition of the coarse sand and clay (CL) fractions in laterite soil increased the residual shear strength parameters.
2. The residual shear strength of the laterite soil mixed with the low plasticity clay fraction (CL) was higher than the pure state.
3. Additional clay materials, with a percentage between 20-25%, were applied to improve the residual shear strength of the laterite soil, must be improved as soil.
4. Extensive wetting-drying cycles tend to lower the peak and residual shear strength.
5. During the change from wet to dry phase, the shear strength increased in both peak and residual conditions, although not very significant.
6. Under a similar interval, the residual shear strength appeared minimal in wet conditions, compared to the dry state.

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] Hvorslev M.J., Conditions of Failure for Remoulded Cohesive Soil, Proceedings of the 1st International Conference on Soil Mechanics and Foundation Engineering, Cambridge, 22-26 June 1936, pp. 51-53.

[2] Hvorslev M.J., Torsion shear tests and their place in the determination of the shearing resistance of soils, Proc. Am. Soc. Mater. Issue 39, 1939, pp. 999–1022.

[3] Haefeli R., Investigation and measurements of the shear strength of saturated cohesive soils, Geotechnique, London, England, Issue 2(3), 1951, pp. 186-207.

[4] Skempton A.W., The long term stability of clay slopes, Geotechnique 14, 1964, pp. 77-101.

[5] Borowicka H., The influence of the colloidal content on the shear strength of clay, Proceedings Sixth International Conference Soil Mechanics, Montreal, Canada, Vol. 1, 1965, pp. 175-178.

[6] Chandler R.J., The measurement of residual strengths in triaxial compression, Geotechnique, Vol.16, 1966, pp. 181-186.

[7] Chandler R.J., The effect of weathering on the shear strength properties of Keuper Marl., Géotechnique, Issue 19(3), 1969, pp. 321–334.

[8] Kenney T.C., The influence of mineral composition on the residual strength of natural soils, Proceedings Geotechnical Conference on Shear Properties of Natural Soils and Rocks, Vol. l, 1967, pp. 123-129.

[9] Xiuhan Y. and Vanapalli S., Residual Shear Strength of Unsaturated Soils, Conference: GeoOttawa, 70th Canadian Geotechnical Conference, (researchgate.net), 2017.

[10] Newmark N.M., Effects of earthquakes on dams and embankments, Geotechnique, 1965, Issue 15 (2), pp. 137–160.

[11] Skempton A.W., Residual strength of clays in landslides, folded strata and the laboratory, Géotechnique, Issue 35(1), 1985, pp. 3-18.

[12] Lupini J.F., Skinner A.E. and Vaughan P.R., The drained residual strength of cohesive soils, Géotechnique, Issue 31(2), 1981, pp. 181-213.

[13] Skempton A.W. and Petley D.J., The strength along structural discontinuities in stiff clays, Proceedings Geotechnical Conference on Shear Strength Properties of Natural Soils and Rock, NGI, Oslo, 1967, pp. 29-46.

[14] Stark T.D. and Eid H.T., Drained residual strength of cohesive soils, Journal of Geotechnical Engineering, Volume 120, Issue 5, 1994, pp. 856-871.

[15] Mesri G. and Shahien M., Residual shear strength mobilized in first-time slope failures, Journal of Geotechnical and Geoenvironmental Engineering, Volume 129, Issue 1, January 2003, pp. 12-31.

[16] Wen B.P., Aydin A., Duzgoren N.S-Aydin, Li Y.R., Chen H.Y. and Xiao S.D., Residual strength of slip zones of large landslides in the Three Gorges area, China, Engineering Geology, Vol. 93, No. 3-4, 2007, pp. 82–98.

[17] Fang, Chen and Shimizu, Hideyoshi and Nishimura, Shinichi and Hiramatsu, Ken and Onishi, Takeo and Nishiyama, Tatsuro, Seismic risk evaluation of irrigation tanks: A case study in Ibigawa-Cho, Gifu Prefecture, Japan, International Journal of GEOMATE, Issue 14 (41), 2018, pp. 1–6.

[18] Voight B., Correlation between Atterberg plasticity limits and residual shear strength of natural soil, Géotechnique, Vol. 23, Issue 2, 1973, pp. 265–267.

[19] De P.K. and Furdas B., Discussion – Correlation between Atterberg plasticity limits and residual shear strength of natural soils, Géotechnique, Vol. 23, Issue 4, 1973, pp. 600–601.

[20] WESLEY L.D., Residual strength of clay and correlations using Atterberg limits, Géotechnique, Vol. 53, Issue 7, 2003, pp. 669–672.

[21] Fang C., Shimizu H, Nishiyama T. and Shin-Ichi Nishimura., Determination of Residual Strength of Soils for Slope Stability Analysis: State of the Art Review, J-STAGE, Volume 8, April 30, 2020, pp. 46-57 https://doi.org/10.7831/ras.8.0_46.

[22] Qijun Hu, Qijie Cai, Leping He, Xiaoqiang Yang, Tao Ye, and Rendan Shi., Determination of the Peak and Residual Shear Strengths of the Sandwich Material in Slopes, Advances in Materials Science and Engineering, Volume 2017, Article ID 9641258, 15 pages https://doi.org/10.1155/2017/9641258.

[23] Suzuki M., Basic study on residual strength of soil by ring shear test. Ph.D. Thesis, Shinshu Univ. (in Japanese), 1998.

[24] Khan S.Z., Shakti Suman, Pavani M., Das S.K., Prediction of the residual strength of clay using functional networks, Geoscience Frontiers, Volume 7, Issue 1, 2016, Pages 67-74, ISSN1674-9871, https://doi.org/10.1016/j.gsf.2014.12.008. (https://www.sciencedirect.com/science/article/pii/S1674987115000031).

[25] Scaringi G. and Di Maio C., Influence of displacement rate on residual shear strength of clays, Procedia Earth and Planetary Science, Vol.16, 2016, pp. 137–145. DOI: https://doi.org/10.1016/j.proeps.2016.10.015.
[26] Farzad Habibbeygi and Hamid Nikraz., Effect of shear rate on the residual shear strength of pre-sheared clays, Cogent Geoscience, Issue 4:1, 2018, DOI: 10.1080/23312041.2018.1453989.
[27] So E.K. and Okada F., Some factors influencing the residual strength of remoulded clays., Soils and Foundations., Volume 18, Issue 4, 1978, pp. 107–118 (in Japanese).
[28] Heidemann M., Bressani L.A. and Flores J.A., Residual Shear Strength of a Residual Soil of Granulite. Soils and Rocks, Issue 43. 2020, pp. 31-41. DOI:10.28927/SR.431031.

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