Some basic engineering properties of halloysite and allophane clays in Java, Indonesia

WESLEY, L. D. (1973). *Géotechnique* 23, No. 4, 471–494.

D. Hill, Van Houten Associates, New York, A. Stamatopoulos and P. Kotzias, Kotzias-Stamatopoulos, Athens, Greece

Wesley has presented an excellent study of some basic properties of latosol and andosol soils of Indonesia.

We have encountered soils very similar to latosols described in Wesley's Paper; they were observed during a site investigation for foundations of heavy structures on the southern shore of Sumatra. Investigation was performed on land and off-shore. The project site is in Semangka Bay about 100 km northwest of Krakatoa volcano and about 60 km west of Teluk-Betung. Although Wesley states that the dividing line between andosols and latosols on pedological maps for Java and Sumatra appears to be drawn rather arbitrarily along the 1000 m contour the colour of the fine-grained soils obtained at depths as deep as 60 m below sea level showed the grey and yellowish-brown colours described as typical of andosols. Based on the liquid limit and the plasticity index the Semangka soils fall in the middle of the latosols shown in Wesley's investigations. Teluk-Betung was covered in August 1883 by a wave 30 m high, following the catastrophic eruption of Krakatoa. We were impressed with the unusually high water content and liquid limit and the low dry density of the soils, which appeared at variance with their favourable compressibility and strength characteristics.

The predominant formation on shore is a product of in situ weathering of tuff-breccia and andesite, both of which were identified at lower elevations by borings. The thickness of the residual material is erratic, varying from as little as 3 m to as much as 40 m, within relatively short distances. Ground surface is only a few metres above sea level. Wesley states that the water table in latosol and andosol areas is very deep, a requirement for the formation of these soils but in fact the water table at Semangka Bay is at a shallow depth. The colour of the weathered material is variable. Brown-yellow or green-blue colour is common even within the same sample; moreover, soils coloured grey-brown mottled with white were observed. Mottles reacted strongly to hydrochloric acid. Variations in colour could not be correlated to either index values or depth and probably reflect the colour of the parent rock.

The same type of soil was also found up to 700 m off-shore, to a maximum water depth of 40 m. It is underlain by boulders which were not penetrated more than 3 m. It cannot be stated with certainty whether they are parent rock blocks, pyroclastic material, or soil transported by streams from the land. The compressibility, shear strength and resistance to standard penetration are similar in both sea and land material. The main difference between the two materials is that a higher proportion of sand and gravel and occasional non-plastic silts were found in the sea. Probably the sea deposit is also residual but of less mature weathering. The possibility of the sea material having been transported from the nearby land cannot be excluded but is considered remote. Classification and identification properties are given separately for land and sea materials in Tables 1 and 2. The remaining characteristics are discussed jointly.

VARIATION OF PROPERTIES WITH DEPTH

The variation of properties with depth for a typical boring is shown in Fig. 1. The latosol layer was always associated with unusual colour and a jump in natural water content. Natural water content was consistently higher than the plastic limit, contrary to Wesley's Fig. 13. Typically there is a large scatter of results with depth, and high resistance to standard penetration, despite the very high natural water content.

ATTERBERG LIMITS—GRADATION—ORGANIC CONTENT

Atterberg limits fall mostly below and occasionally on or above the A-line in Casagrande's Chart. They cover the same wide spectrum as indicated by Wesley's Figs 5(b) and 5(c). Statistical parameters for these soils are summarized in Tables 1 and 2. Extreme values as high as 218 for the liquid limit and 158 for the plasticity index are noted (Table 1).

Table 1. Land residual soil: classification and identification characteristics

Soil characteristic	Mean value	Standard deviation	Maximum value	Minimum value	Number of test results
Natural water content	59	26	180	23	193
Dry unit weight, t/m ³	0.952	0.211	1.26	0.73	16
Liquid limit	80	27	218	32	189
Plasticity index	39	21	158	3	192
Fines (<0.074 mm), %	70	24	99	17	190
Clay fraction (<0.002 mm), %	32	16	10	80	20
Specific gravity	2.62	0.05	2.70	2.54	72
Organic content	6	1.3	8.9	2.7	20
Resistance to penetration	29	22	100	3	258

Table 2. Sea residual soil: classification and identification characteristics

Soil characteristic	Mean value	Standard deviation	Maximum value	Minimum value	Number of test results
Natural water content	43	18	95	10	56
Liquid limit	57	38	176	8	52
Plasticity index	27	23	116	0	52
Fines, %	58	32	100	7	58
Resistance to penetration	26	21	100	2	79

Fig. 1. Variation of properties with depth (typical land boring)

Fig. 2. Frequency diagrams for natural water content and specific gravity

On the average, 70% of the grains pass sieve No. 200 (0.074 mm), the remainder being sand. Clay fractions (less than 0.002 mm), obtained with sodium metaphosphate solution as the dispersing agent, vary between 20% and 50% and these results differ from those given by Wesley. The difference might be attributed to the larger numbers of results encompassing a range wider than that by Wesley. The organic content is generally low (Table 1).

NATURAL WATER CONTENT—DRY UNIT WEIGHT—SPECIFIC GRAVITY

The variation in water content of land latosols is indicated in the frequency diagram of Fig. 2(a). Statistical parameters are given in Tables 1 and 2. Water content varies between wide limits, being usually high. Dry unit weight is low, averaging 0.95 t/m³.

Fig. 3. Results of compaction tests on Harvard miniature device

The specific gravity of grains was found to be lower than indicated in Wesley’s Paper. In Fig. 2(b) the frequency diagram is given for 72 results. 70% of results fall below 2.66. The specific gravity appears to be independent of depth, natural water content, percent fines and Atterberg limits.

COMPACTION

Two compaction test results performed with the Harvard miniature device (Wilson, 1964) are shown in Fig. 3. Optimum water content is equal to the plastic limit; maximum dry density is about 1.13 t/m³, close to the value reported in Wesley’s Table 2.

COMPRESSIBILITY—CONSOLIDATION—SECONDARY COMPRESSION

Figure 4 shows a characteristic pressure–void ratio curve and its corresponding pressure–constrained modulus curve (Stamatopoulos and Kotzias, 1973). The initial void ratio is 2.219, natural water content and liquid limit are 73 and 75 respectively. In spite of these high values, a low compressibility is observed. Graphically estimated preconsolidation pressure was always between 2 and 3.5 kg/cm² and consistently much higher than the natural overburden pressure. The specific constrained modulus (Stamatopoulos and Kotzias, 1973)

Table 3. Statistical parameters

Parameter	Mean value	Standard deviation	Maximum value	Minimum value	Number of test results
Specific constrained modulus	84	50	25	225	21
Coefficient of consolidation cm²/s × 10 ⁻⁴	29	22	6	75	18
Primary compression	0.52	0.12	0.3	0.75	18

Fig. 4. Typical compression curve

Fig. 5. Secondary compression curves under pressure of 12 kg/cm²

Fig. 6. Correlation of unconsolidated undrained compressive strength and resistance to standard penetration

is on the average 84 kg/cm^2 . Coefficient of consolidation and primary compression ratio (Taylor, 1955) are on the average $7 \times 10^{-4} \text{ cm}^2/\text{s}$ and 0.6 respectively. Statistical parameters for these values are given in Table 3.

Figure 5 shows the rate of secondary compression under a pressure of 12 kg/cm^2 . Although pressure was applied in the virgin compression range, and the soils have a high liquid limit and initial water content, the rate of secondary compression appears to be of moderate magnitude.

STRENGTH—SENSITIVITY

Resistance to standard penetration is generally high (Tables 1 and 2); sensitivity is normal to low. Consolidated drained triaxial compression tests, performed under ambient pressures of $1.5\text{--}4.0 \text{ kg/cm}^2$, indicated an angle of intergranular friction having a mean value of 30.5° and standard deviation of 3.3° (25 tests).

Unconsolidated undrained triaxial compression tests performed under ambient pressures of $0.5\text{--}4.7 \text{ kg/cm}^2$ indicated variable strength values. In order to reduce the effect of selective sampling, which was inevitable in this investigation (the frequency of undisturbed sampling in the softer soils was higher, because undisturbed samples of harder soils were obtained with greater difficulty), an attempt was made to correlate the unconsolidated undrained strength with a soil property measured on samples taken more nearly at random. By succeeding in establishing such a correlation, strength values to be used for design can be estimated from the combination of the results of the more random variable and of the correlation between the strength and this random variable.

The correlations of unconsolidated undrained strength with natural water content, liquid limit and consistency, gave weak coefficients of correlation (between 0.20 and 0.31). However, the correlation with standard penetration resistance indicated a coefficient of correlation of 0.72 (Fig. 6). The unconsolidated undrained strength did not increase substantially with increasing ambient pressure.

ACKNOWLEDGEMENT

We are indebted to Indonesian Tanker Terminals SA for granting permission to publish these results.

Author's reply to Hill, Stamatopoulos and Kotzias

The contribution is a valuable one in that it is a further illustration of the fact that residual soils of this group may possess good engineering properties despite high water contents and Atterberg limits. The range of water contents and Atterberg limits quoted by Hill *et al.* is certainly very similar to that normally found in Indonesian latosols and the ϕ values of around 30° are also normal. No specific data on shear strength or compressibility were included in my Paper but ϕ values were found to range from about 30° to 40° with the lower values surprisingly occurring in the latosols and the higher values in the andosols.

However the information given by Hill *et al.* on the environment in which the soil occurs and the reported colour variations raises some interesting questions in relation to its mode of formation and in particular as to whether the soil actually belongs to the latosol group. The present on-shore environment, with its shallow water table would not be conducive to the formation of a latosol, and the off-shore deposit, if a residual soil, could clearly not have been formed in its present environment. It seems likely therefore that the land surface here has at some time been considerably higher in relation to the sea level than it is at present. This is not improbable in view of the very active geological history of the area generally.

It should perhaps have been emphasized in my original Paper that geological factors can easily give rise to situations in which the present environment of the soil is not that in which it was formed and the pattern of occurrence of the soils described in my Paper no longer applies.

It is thus not possible to say with any certainty whether or not the soils described by Hill *et al.* are latosols and in any case this is only of secondary importance. The engineer is interested in the engineering properties and in methods of assessing these. A general observation with respect to residual clays in Indonesia is that those whose Atterberg limits plot below the A-line on the plasticity chart are generally formed in well drained environments and possess good engineering properties, while those whose Atterberg limits plot above the A-line are formed in poorly drained areas and tend to possess poor engineering properties.

REFERENCES

- Stamatopoulos, A. C. & Kotzias, P. C. (1973). The specific constrained modulus. *Proc. Eighth International Conf. Soil Mech. Fdn Engrs, Moscow*, 1–61.
Taylor, D. W. (1955). *Fundamentals of soil mechanics*, 240. New York: John Wiley.
Wilson, S. D. (1964). Suggested method of test for moisture–density relation of soils using Harvard compression apparatus. *ASTM Committee D-18*, fourth edition.

Fabric changes in consolidated kaolin

- McCONNACHIE, I. (1974). *Géotechnique* **24**, No. 2, 207–222.
Discussion by Foster (1974). *Géotechnique* **25**, No. 1, 153–154.

Author's reply to Foster

I should like to provide the following detailed information in amplification of the points which Foster has raised.

With regard to the occurrence of single particles, my findings were that when domains had been outlined on the studied micrographs the structural elements which remained, i.e. single particles, were comparatively few in number and were therefore considered to be unimportant. Any links which they did form would be weak.