MAJOR TYPES OF SOIL DEPOSITS IN URBAN AREAS IN JAPAN

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ABSTRACT

By taking into account the geological processes of formation of alluvial and diluvial soil deposits, it has been found that the soil deposits are classified into six major types in urban areas in Japan situated on alluvial plains. The same result has been reached by applying a computer technique, which has been developed to simplify an original, complicated boring record in the form of a refined soil profile, to the numerous boring data obtained in city areas which consist of a wide variety of soil conditions. Statistics on thicknesses and N -values are also given for sublayers of soil deposits belonging to each major type and, furthermore, the ranges of predominant periods for strain levels of microtremors and strong-motion earthquakes are evaluated with respect to each type of soil deposits.

Key words: alluvial deposit, classification, computer application, diluvial deposit, dynamic, geology, layered system, natural ground, penetration test, statistical analysis

IGC: D1/B1/E8

INTRODUCTION

It is true that, as a rule, boring records at a site for a proposed structure should be as detailed as possible, and such are generally accepted as desirable. As a result, our impression is that soil deposits are of extreme complexity and in countless varieties. On the other hand, however, too detailed records sometimes mislead an engineer in his judgement on true soil conditions, while experienced engineers simplify by intuition the original boring records adequately so as to grasp a general view of soil conditions according to their purposes such as the evaluation of bearing capacity, the settlement estimation, or the response analysis during an earthquake. Knowledge of the so-called shallow geology, which primarily deals with Quarternary deposits, is quite useful for such treatments (Twenhofel, 1950; Krumbein & Sloss, 1958; Ikeda, 1966).

If the process of formation of soil deposits is taken into account macroscopically, an idea is shaped that they may be classified into a limited number of major types however varied and complicated individual profiles may appear. In this paper, two approaches are presented to formulate this idea; one is from the viewpoint of the shallow geology and the other is rather mechanical or automatic resorting to computer techniques instead of the intuitive simplification of original boring records.

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As a result of both approaches, it has been found that there are six major types of soil deposits in alluvial plains in the urban areas of this country. In addition, the soil deposits in diluvial areas are classified into five types, and Tertiary rock or rock-like deposits are simply divided into two types according to whether their top portion is weathered or not. Based on analyses of boring records, statistics are also given with respect to thicknesses and N -values of the standard penetration test for sublayers of soil deposits belonging to each major type mentioned above. Furthermore, the predominant period of vibration of each soil deposit in strain levels for microtremors and strong motion earthquakes is discussed at the last part of this paper.

FORMATION OF SOIL DEPOSITS

In the field of foundation engineering, where problems on bearing capacities or settlements evaluation, dynamic response due to earthquake excitation and so forth are primarily dealt with, most frequently encountered soil deposits are what have been formed in Quarternary period, i.e., in Alluvium and Diluvium. Alluvial formations in the urban areas in this country are in most cases an estuary or marine deposit of materials transported by the fluvial flow. In some cases, lacustrine and flood-plain deposits are also encountered. Topographically, they form most of coastal plains, basins and river plains in this country. Diluvial formations are also primarily of fluvial deposits; in addition, aeolian deposits of volcanogenic materials are distributed in considerably wide areas. The latter soil topographically forms hills, plateaus or terraces, and is on rare occasions overlain by alluvial deposits.

With the decrease of water velocity, coarse sand is first dropped during the fluvial transportation and, in the vicinity of a mouth of river, finer sand is deposited. Then, toward offshore, silt and clay are sedimented in this sequence. As a rule, the shoreline tends to advance gradually toward the sea with the development of an estuary deposition and, therefore, the typical formation of soil deposits would be as schematically shown in Fig. 1, if there were no change of the sea level and the river flow were completely steady. This is known as the process of a delta-deposits formation, and in this case the downward sequence of soil layers is S-C, where the symbols S and C denote coarse-grained, cohesionless (sandy) soils and fine-grained, cohesive (clayey) soils, respectively.

As a matter of fact, however, there are extensive evidences that a marked rise of the sea level or a marine transgression took place from the end of Diluvium through the middle of Alluvium period due to the world-wide warm climate and, recently, the

Fig. 1. Soil deposits at delta

sea level is lowering again. Therefore, the once formed delta was submerged under the sea level and overlain by a newly formed delta deposits of Fig. 1, resulting in a sequence S-C-S-C. The soil deposits of such an origin having the S-C-S-C formation are frequently encountered even at inland areas far from the present shoreline because of the recent marine regression.

Along a river flowing through a flood plain, a natural levee and a backmarsh are developed as shown in Fig. 2. Coarse grains are concentrated at the levee during an overflow and, as a result, only fine-grained materials stagnate and are deposited at the backmarsh, forming a soft, clayey surface layer. Such a type of soil deposits is frequently encountered at inland areas.

Fig. 2. Soil deposits by flood water

In general, it is a characteristic feature of alluvial soil layers that they lie almost horizontally without any appreciable inclination except local lens-like deposits.

On the other hand, the process of deposition of diluvial soil layers may be similar to that of alluvial deposits, whereas their present situations are far more complex since they were exposed to repeated transgression and regression of the sea water, eroded by river flows, and inclined by the effect of crustal movements during a far longer period of presence than alluvial deposits. Aeolian deposits in Diluvium, such as Kanto-Loam layer widely spread in and around the city of Tokyo, are deposited in most cases preserving the undulation of the original ground surface.

TYPE CLASSIFICATION OF SOIL DEPOSITS

Stratigraphy of Alluvial Deposits

As has been illustrated in the previous section, an alluvial deposit consists in principle of the alternation of sandy and clayey soil layers and, in view of the fact that the change of the sea level has been only one cycle in the Alluvium (Ikeda, 1954; Takenaka, 1962; Ichikawa et al., 1970), the total number of layers may be considered stratigraphically not to exceed 4. Hence, as the sequence of S-C alternations, no other combinations can be conceived than are shown in Table 1 or Fig. 3.

Table 1. Sequences of S-C alternations

System	Sequence	Number of cases
1-layer	S or C	2
2-layers	S-C or C-S	2
3-layers	S-C-S or C-S-C	2
4-layers	S-C-S-C or C-S-C-S	2
	Total	8

Fig. 3. Stratigraphies of alluvial deposits

Theoretically, a sequence C-S-C-S-C, i.e., an S-C-S-C system overlain by a clayey backmarsh deposit, is conceivable; in reality, however, such a formation is seldom encountered in this country.

Stratigraphy of Diluvial Deposits

Similar to the stratigraphy of alluvial deposits, diluvial deposits consist in general of alternations of S and C layers. In contrast with the alluvial deposits, however, they are of far larger strength and usually overconsolidated; in particular, the diluvial deposits at a large depth are so hard that they are not taken into consideration in usual cases from the viewpoint of foundation engineering. Therefore, if only the uppermost sandy layer is considered, all possible combinations of S and C layers are as shown in Fig. 4.

Fig. 4. Stratigraphies of diluvial deposits

Major Types of Soil Deposits in Alluvial Plains

In most alluvial plains in this country, alluvial deposits are underlain by diluvial deposits; it is quite difficult to find an alluvial deposit directly overlying a rock or rock-like layer older than Tertiary. Therefore, if all cases are considered in which the types of alluvial deposits in Fig. 3 are underlain by the types of diluvial deposits in Fig. 4, the total number of possible combinations amounts to $8 \times 5 = 40$.

On the other hand, keeping all of these combinations in mind, the writers have examined about 30,000 available boring records (Ministry of Construction, 1960~1969) which were collected from 20 major cities and industrial districts in this country. The result is as shown in Fig. 5, in which frequencies of each stratigraphic combination of overlying alluvial and underlying diluvial deposits are indicated. The total frequency of appearances for the category 'frequent' amounts to approximately 70% of the total boring records, and the total frequency for 'rare' is approximately 25%. The combinations belonging to 'frequent' are designated as Type A-1 through A-6 as shown in Fig. 5, and they are also depicted in Fig. 6. Usually, those soil deposits are covered by a top soil consisted of artificially filled soils and miscellaneous soils of geologically unidentified origin. The thickness of top soils is not large and it is quite rare to exceed 2.5 meters.

It is not so easy to distinguish a deep-seated alluvial layer from a diluvial one and, when a questionable layer has been encountered in examining boring records to construct Fig. 5, the hardness and overconsolidation of the layer have primarily been considered. Nevertheless, it should be noted that, in Types A-4, 5, and 6 in Fig. 6, some confusion may be present in the geological interpretation of the second and third layers; but it is not a serious problem from the engineering viewpoint.

		DILUVIAL DEPOSITS				
		d-1	d-2	d-3	d-4	d-5
ALLUVIAL DEPOSITS	a-1	A-1				
	a-2	A-2				
	a-3	A-3				
	a-4				A-5	
	a-5	A-4			A-6	
	a-6					
	a-7					
	a-8					

LEGEND :

FREQUENT
 RARE
 VERY RARE

Fig. 5. Frequencies of alluvial-diluvial combinations

Fig. 6. Major types of soil deposits in alluvial plain

Types in Diluvial and Tertiary Areas

Since the number of available boring data in urban areas is not sufficient to statistically treat them where the top soil is directly underlain by diluvial soil deposits, Types D-1 through D-5 are proposed in Fig. 7 independently of Fig. 4. It has been confirmed, however, that the second and deeper layers are in most cases so firm that they can be

Fig. 7. Types of diluvial soil deposits

Fig. 8. Types of tertiary rock

considered as a rock-like base layer for the purpose of foundation engineering provided that they are sandy.

Tertiary rocks, which seldom appear in urban areas, are simply classified into two types, T-1 and T-2, as shown in Fig. 8 according to the presence of distinctly weathered zone at a shallow depth from the ground surface.

SIMPLIFICATION OF BORING RECORDS

Simplification by Soil Types

The objective in this section is a reasonable simplification of original, detailed boring records by taking into consideration the change of soil types between two individual layers which vertically adjoin each other. For example, if the upper layer is sandy clay and the lower layer is clayey sand, it may be permitted or frequently rather pertinent to consider that the two layers constitute a single layer of sand-clay mixture, whereas if the two adjoining layers are pure sand and pure clay the boundary between those two can not be removed. Such a judgement is usually exercised intuitively.

To use a computer by which such judgement is made automatically, it is necessary to assign a numerical value to each soil type. For this purpose, the concept of soil-type factor has been developed, which means a digitization of the nature of a soil layer. For the time being, Table 2 is proposed in this paper although it has no rigorous, theoretical background but has been determined after repeated trials so that a good agreement can be obtained between intuitive and automatic simplifications of the same original boring record.

Table 2. Soil-type factor

Soil type	Symbol	Soil-type factors	
		Representative values	Boundary values
Sand	SS	1	5/6
Clayey sand	CS	2/3	
Sandy clay	SC	1/3	1/2
Clay	CC	0	1/6

Furthermore, for the time being, silt is included in the category of clay; thus, for example, silty sand and clayey silt are expressed as CS and CC, respectively. Gravel is categorized as sand, and Kanto-Loam, which is an aeolian deposit of volcanic ash from Mt. Fuji, is regarded as clay in consideration of its highly cohesive characteristics.

An example of the original boring record is shown in Fig. 9, where depths of boundaries and descriptions for encountered sublayers are represented together with the number of blows per foot in the standard penetration test.

Fig. 10 shows an example of the process of simplification by soil types. The column (1) in Fig. 10 represents the thickness of each sublayer, and in the column (2) a symbol prescribed in Table 2 is assigned to each sublayer based on the description in the original record shown in Fig. 9. The soil-type factors in the column (3) are assigned correspondingly on reference to Table 2.

Now, examining the changes of soil-type factors between two adjacently lying sublayers, boundaries are laid if the difference in the factors is larger than a threshold $2/3=0.666$; otherwise, adjacent sublayers are regarded as a single layer. In the column (3), the sublayers bracketed by parentheses are what can be unified in this sense. Thus, the original soil profile is simplified to a four-layered system as shown in the column

Fig. 9. An example of original boring record

(4) in Fig. 10.

Simplification by N-Values

The second process is on the basis of N -values in the standard penetration test. The principle of simplification is to lay a boundary where a significant change between two successive N -values is encountered. The threshold for laying boundaries is determined in consideration of overall scattering of observed N -values and, at the same time, there is an option to adjust the threshold value so that any degree of simplification may be attained in accordance with the purpose of using the resulted, simplified soil profile.

Fig. 11 (1) is a re-representation of observed N -values shown in Fig. 9, and the differences of successive N -values, ΔN , are represented in Fig. 11 (2). The total number of ΔN 's in this example is 16. ΔN 's of extremely large values are excluded, the number of which may be assumed in general approximately equal to one-tenth of the total number, i.e., $16 \times 1/10 \approx 2$ in this example. Then, with respect to remaining fourteen ΔN 's, the mean value and the standard deviation

Fig. 10. An example of simplification by soil types

mean value $\overline{\Delta N} = 8.36$

standard deviation $\sigma = 5.35$

are computed. Based on these two statistic values the threshold

$$\Delta N^* = \overline{\Delta N} + C\sigma \quad (1)$$

is determined, where C is optional and is referred to as the 'coefficient of simplification' in this paper.

Finally, at an intermediate point of two N -values, whose difference exceeds ΔN^* , a boundary is defined. In Fig. 11 (2), a threshold line is drawn for the coefficient of simplification $C=2$, for example, and it will immediately be seen that the boundaries are to be laid at the depths 12.40 m and 18.50 m as shown in Fig. 11 (3).

Fig. 11. An example of simplification by N -values

Simplified Soil Profile

Now, the final boundaries are determined in view of both the simplification by soil types and the simplification by N -values, that is, Fig. 10(4) and Fig. 11(3) are superposed, resulting in a simplified soil profile as shown in Fig. 12. Individual sublayers in the original record, which are within thus determined boundaries, are unified into a single layer. With respect to each unified layer, the weighted average of soil-type factors with the thickness of each sublayer as a weight, and the average of N -values are computed as shown in Fig. 12. Referring again to the boundary values in Table 2 a new symbol may be assigned, if necessary, to each unified layer according to the averaged soil-type factor as also shown in Fig. 12.

The coefficient of simplification, C , in Eq. (1) has an effect of controlling the degree of simplification, and an example is represented in Fig. 13 to illustrate how an original boring record is simplified according to different values of the coefficient.

From repeated experiences of applying the programed process to actual boring records in a wide variety of soil conditions, it is interesting to note that, as a rule, the simplified soil profiles for $C=0$, 1, and 2 are useful for the purposes of design of spread or pile foundations, dynamic response analysis, and stratigraphic correlation, respectively. Another important result to be pointed out here is that, among about 840 cases of application, almost all simplified profiles have been reduced to some one of the major

types already represented in Fig. 6 when the coefficient $C=2\sim 2.5$ has been applied.

Of course, it is at one's disposal to make a manual modification to the computer output, i.e., to add or delete boundaries when such are considered necessary.

PROPERTIES OF SUBLAYERS

Based on the analyses of over 800 boring records in alluvial plains, the averages and the standard deviations have been evaluated with respect to thicknesses and N -values for sublayers of soil deposits belonging to each type shown in Fig. 6. The results are shown in Table 3. Upon somewhat rounding the numerals in Table 3, they are also represented in Fig. 14, which is drawn to the scale proportional to average values of both thicknesses and N -values. The expression 7.0 ± 4.5 in Fig. 14, for instance, means that the average is 7.0 and the standard deviation is 4.5.

PREDOMINANT PERIODS OF VIBRATION

With respect to six major types of soil deposits shown in Fig. 14, predominant periods or fundamental periods of free vibration will be estimated in this section.

As the relation between an N -value of the standard penetration test and the shear

Fig. 12. Simplified soil profile

Table 3. Thicknesses and N -values of layers for major types of soil deposits

Type	No. of layer	Soil type	Thickness (m)		N-Value		Number of samples
			Average	Standard deviation	Average	Standard deviation	
A-1	1	Sandy	6.92	4.40	10.0	5.4	206
	2	Base	—	—	40.4	15.0	
A-2	1	Clayey	9.51	7.08	1.5	1.0	174
	2	Base	—	—	41.4	14.4	
A-3	1	Sandy	5.60	3.36	12.0	7.9	148
	2	Clayey	11.28	7.39	2.5	0.4	
	3	Base	—	—	45.7	11.8	
A-4	1	Sandy	4.45	2.97	12.2	7.5	89
	2	Clayey	10.06	5.77	1.8	1.2	
	3	Sandy	6.52	5.10	14.8	5.0	
	4	Base	—	—	49.1	11.3	
A-5	1	Clayey	8.50	5.02	1.7	1.1	154
	2	Sandy	7.44	4.41	19.5	10.2	
	3	Clayey	6.22	4.18	9.6	4.5	
	4	Base	—	—	45.1	13.1	
A-6	1	Sandy	5.56	3.18	12.4	7.8	72
	2	Clayey	10.28	6.67	1.7	1.2	
	3	Sandy	4.51	2.45	26.5	11.5	
	4	Clayey	6.18	4.41	10.1	4.8	
	5	Base	—	—	50.4	10.4	

Total 843

Fig. 13. Coefficient, C , and degree of simplification Fig. 14. Thicknesses and N -values of layers for major types of soil deposits in alluvial plains

Fig. 15. Limiting profiles of each type of soil deposits

modulus in tons/qs. meter, an expression

$$G=1200N^{0.8} \quad (2)$$

is employed for shear strain levels $10^{-5} \sim 10^{-4}$ percent, which approximately correspond to amplitudes of microtremors, regardless of effective overburden pressure and whether soils are sandy or clayey (Ohsaki and Iwasaki, 1973). For strain levels $10^{-1} \sim 1$ percent corresponding to strong motion earthquakes, the shear modulus in Eq. (2) is reduced to about 1/10 and 1/4 for sandy and clayey layers, respectively. Unit weights of sandy and clayey soils are assumed to be 1.85 and 1.50 tons/cu. meter, respectively.

Furthermore, for each type of soil deposits shown in Fig. 14 two extreme cases have been considered, i.e., for Type A-1, for instance, plus and minus signs are so chosen that

case (1) thickness = $7.0 - 4.5 = 2.5$ m

$N\text{-value} = 10 + 5 = 15$

and

case (2) thickness = $7.0 + 4.5 = 11.5$ m

$N\text{-value} = 10 - 5 = 5$

and they are called Type A-1(1) and Type A-1(2), respectively. It is readily apparent that Type A-1(1) represents extremely stiff soil deposits among what belong to Type A-1, and Type A-1(2) represents extremely flexible one. Since the probability that random cases lie below or above the $\pm$ one-sigma range is 15.87%, the presence of soil deposits lying outside the bounds of case (1) and (2) may be quite rare having the probability approximately equal to $2 \times (0.1587)^2 \approx 0.05$. In a similar way, two extreme cases have been drawn in Fig. 15 for each type of soil deposits and, with respect to them, the predominant periods, i.e., the periods of undamped free vibration for the first mode have been evaluated by assuming lumped mass models and by means of a computer program. In modelling a lumped mass system, the number of subdivision for each layer has been determined according to Fig. 16, which was drawn so that errors in frequencies were approximately equal to 5% and never exceeded 10%, at the most, when compared

Fig. 16. Fundamental period of a layer and number of subdivision

with the exact solution for a continuous model.

From the previous probabilistic consideration, it may be assumed that almost all Quarternary soil deposits in the Japanese city areas are 'enveloped' by soil profiles represented in Fig. 15. In Fig. 15, shear moduli in tons/sq. meter computed by Eq. (2) are also shown; numerals without and with parentheses represent the moduli for micro-tremors and strong motion earthquakes, respectively. The presence of top layers is ignored in the period evaluation for every soil deposits.

The results of predominant periods' evaluation are shown in Table 4. If the results

Table 4. Predominant periods in sec of major types of soil deposits

Type of soil deposits	Strain levels	
	Microtremors	Strong-motion earthquakes
A-1 (1) (2)	0.047 0.311	0.149 0.966
A-2 (1) (2)	0.081 0.748	0.162 1.492
A-3 (1) (2)	0.177 1.300	0.341 2.640
A-4 (1) (2)	0.188 1.200	0.390 2.690
A-5 (1) (2)	0.142 0.899	0.329 2.053
A-6 (1) (2)	0.210 1.372	0.441 2.884

Fig. 17. Ranges of predominant periods

are plotted as shown in Fig. 17, it will be seen that almost all of the predominant periods of soil deposits in the Japanese city areas situated on the alluvial plain lie within enclosed ranges in the figure for strain levels of microtremors and strong-motion earthquakes, respectively. Occasionally, microtremors or minor earthquakes are observed having a longer period than are shown in Fig. 17. The cause developing such a period is still not clear, but may be attributed to effects of the layers which are at deeper levels than what are regarded as the base layers in Fig. 14.

CONCLUSIONS

1) By taking into account geological processes of formation of alluvial soil deposits, the deposits in alluvial plains are classified into eight types. Similarly, diluvial soil deposits are classifiable into five types if their upper portions solely are considered.

2) Among all combinations of such types of alluvial and diluvial soil deposits, six are actually encountered most frequently in the urban areas in this country; thus, the six are regarded as the representative types of soil deposits in our cities.

3) Usually, detailed and complex boring records are adequately simplified by intuition or by judgement according to the purposes, for which the simplified profiles are employed in practice. To replace such an intuitive judgement, a computer technique has been developed which automatically simplifies original boring records to a desired degree of simplification. As one of the means for such an automatic process of simplification, a concept of soil type factor is introduced to digitize the soil types, although values of the factor in this paper are only a tentative and crude approximation.

4) It is interesting to note that almost all the results of simplification of boring records in the city areas in this country coincide with the six major types which have been classified in the above on the basis of geological considerations.

5) Properties of sublayers in each major type of soil deposits are statistically represented, and its predominant periods of vibration are evaluated both for strain levels of microtremors and strong-motion earthquakes.

NOTATION

N = N -value of the standard penetration test

$\overline{\Delta N}$ = average of the differences of successive N -values

σ = standard deviation of the differences of successive N -values

ΔN^* = threshold for defining a boundary

G = shear modulus in tons/sq. meter

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