N-VALUE DISTRIBUTION PATTERN WITH DEPTH OF ALLUVIAL SOIL DEPOSITS

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ABSTRACT: The paper focuses on two important inherent characteristics of N-values. The first being increase in N-value with depth caused by overburden pressure. It is proposed that this property of N-value may be approximately related to a root power law of confining pressure and this is specifically explained by a cavity theory in this paper. The second inherent characteristics is the change in pattern of N-value distribution with depth depending on geological age of alluvial soil deposits. Here an alluvial deposit in Busan is compared with the geological profile of Tokyo lowland area and Osaka bay. In these regions, upper parts of soft alluvial clay layer often has zero N-values indicating N-values of less than 1. This is generally followed by lower layers with large N-values. A comparative study of geological sediments shows a clear resemblance between lower parts of alluvial deposits in Busan and that of Tokyo lowland deposits of Nanagochi-so.

Keywords: N-value, overburden pressure, geological profile, alluvial clay

INTRODUCTION

N-value has an inherent property of increasing with depth governed by an over burden pressure. However, soft alluvial clay layer often has a specific pattern giving a part of N-value with zero indicating less than 1, which is connected to the thin layer with large N-value. This sequence of N-value pattern with depth provides useful information for indicating the geological date of sedimentation in natural environment. Predicting geological age of deposit is useful in understanding soil properties. In this paper, sedimentation property of alluvial clay layer in Busan offshore is analyzed whose upper clay layer of N-value of zero and the lower clay layer of N-value of more than 10. Clear differentiation in their properties is found at the boundary of both layers. This difference is the key to analyze the lower sub layer with stiff clay that remains as a problem of sedimentation condition - whether it was deposited in the Pleistocene epoch or it was done so in the Holocene epoch. In order to identify the geological sedimentation period of the lower stiff clay encountered in Busan offshore, alluvial layers in Osaka bay, Tokyo lowland, and Busan offshore area in Korea are compared.

Focal point is the N-value change properties governed by overburden pressure. The tendency of N-value helps us for dividing soil layers. An experimental finding gave a 0.5 power law of over burden pressure. This formulation appears also in deferent field of shear wave velocity, e-log p relation with consolidation behavior, and so on. In general, deformation and density is reasoned with overburden pressure. However, it is not clear why the 0.5 power law of overburden pressure governs. In this study, a cavity theory, provided by Yamaguchi (1973), is used for predicting N-value pattern with depth. Efficiency of this theory for understanding the profile of N-value with depth is proved comparing experimental findings, and by comparison of pattern with large manmade island.

DEPENDENCE OF N-VALUE ON CONFINING PRESSURE

N-value tends to increase as confining pressure increases. It derives a trend of N-value increasing as the overburden pressure increases, and helps us classifying deposit of sedimentation. This trend can be proved in field embankment data as fitted by the cavity theory.

The basic equations governing the N-value increase with depth are drown (Fukuda 2003):

\[ q_d = \sigma_m' F_q \]

\[ F_q = \frac{3(1 + \sin \phi)}{3 - \sin \phi} \left[ \frac{(3 - \sin \phi)E_s}{6\sigma_m'(1 + \nu)\sin \phi} \right]^{\frac{1}{2}} \]

where \( q_d \) is bearing capacity, \( \sigma_m' \) confining pressure, \( F_q \) bearing capacity factor, \( \phi \) internal friction angle, \( E_s \) coefficient of deformation, and \( \nu \) Poisson ratio are corresponded.

Further, it is added that relation of N-value and cone penetration are strictly concerned as following:

\[ q_d = q_t = n \times N \]
Approximated condition
Osaki \( n=6, E_s=400\text{kgf/cm}^2 \)
Hatanaka \( n=6, E_s=270\text{kgf/cm}^2 \)
Aoki \( n=10, E_s=1200\text{kgf/cm}^2 \)

Sold line is the predicted by cavity theory.

Fig. 1 Comparison of experimental findings and the predicted by cavity theory

The above equation is obtained by comparing with the experimental equations proposed by Hatanaka et al. (1996) and Aoki (1985) \( n=6, E_s=27\text{MN/m}^2 \) are obtained for Hatanaka’s equation but restricted within N-value more than 15 and when standardizing at the pressure condition of \( \sigma_{v'}=100\text{kN/m}^2 \). Under the same condition, \( n=10, E_s=120\text{MN/m}^2 \) are derived for Aoki’ equation.

Significance of the basic equations is further exemplified when the N-value profile is compared with the profile of N-value of fills located in Osaka bay area that filled using the Masa soil (Suwa et al. 2003). Figs. 2-5 show the N-value distribution with depth and predicted curves in relative to the overburden pressure. Figures are described by the parameters presented in Table 1. Coefficient of rigidity of soil is taken by the equation \( E_s=28N \) using a mean N-value at a site. Figures show the large scatter of N-value distribution with depth, however, the predicted curves are drawn through the structural part of N-value data.

Also from the figures, though the data is scattered, the inherent trend runs through the scattering data at each sites applied for, if except of data taken at the test site A. The inherent curve changes depending on the overburden pressure. Further, even focusing on the trend with the site A, the governing trend by the overburden pressure can be traced over the weak points.

OVERBURDEN AND EXISTING FUNCTIONS

<table>
<thead>
<tr>
<th>Mannmade island</th>
<th>Average N-value</th>
<th>( E_s ) (MN/m²)</th>
<th>Ground water (GL-m)</th>
<th>Wet density kN/m³</th>
<th>( n )</th>
<th>Internal friction angle ( \phi ) (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20</td>
<td>56</td>
<td>3</td>
<td>21</td>
<td>6</td>
<td>45</td>
</tr>
<tr>
<td>B</td>
<td>15</td>
<td>42</td>
<td>3</td>
<td>21</td>
<td>6</td>
<td>35</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>28</td>
<td>3</td>
<td>21</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>D</td>
<td>15</td>
<td>42</td>
<td>3</td>
<td>21</td>
<td>6</td>
<td>40</td>
</tr>
</tbody>
</table>

Fig. 3 Measured and estimated N-value (Manmade bank-site B)

Fig. 4 Measured and estimated N-value (Manmade bank-site C)
The trend of N-value dependence on the overburden pressure has been described by Liao-Whiteman (Fujita, 1997; 2003). The equation (4) draws the relationship of this trend.

Corrected N-value = measured N-value×\sqrt{\frac{0.8}{\sigma_v'}} \tag{4}

where \(\sigma_v'\) is the effective overburden pressure. This equation explains the relationship that measured N-value is proportional to the square of effective overburden pressure \(\sigma_v'^{0.5}\). The same idea was confirmed in the famous equation, Eq. (5) in the world presented by Meyerhof that defines a relative density. However, this equation means that N-value is proportional to the overburden pressure if a constant of relative density is assumed.

\[ Dr = 21 \frac{N}{\sigma_v' + 0.7} \tag{5} \]

where \(Dr\) is the relative density.

And Akai (1996) gave the equation (6) that relates the wave velocity to the depth.

\[ V_s = 30Z^{0.5} \tag{6} \]

where \(V_s\) is the velocity of shear wave (m/s), \(Z\) the depth from the surface of the sea bed (m). Since the relationship of \(\sigma_v' \propto \rho'\) \(Z\) is allowed in general, Eq. (6) leads that the shear velocity \(V_s\) is proportional to \(\sigma_v'^{0.5}\).

Many researchers proposed the same idea concerning with the dynamic behavior of ground as functioned by Eq. (7). They confirmed the dependence of shear rigidity on the confining pressure, 0.6 for sand, 0.65 for clay.

\[ G_0 = A(t) \cdot (OCR)^k \cdot F(e) \cdot (\sigma_m)^n \tag{7} \]

Fukuda et al. (1994) presented Eqs. (8) and (9) that describe the relation between void ratio (\(e\)) and temporary coefficient of compression (\(C_c\)) as shown in Fig. 6. This characteristic straight line is extended to the trend of relationship governed by the 0.5 powers of pressure.

\[ C_c = 1.125(e-0.322) \tag{8} \]

\[ \left( \frac{p_0}{p} \right)^{0.5} = \frac{e - 0.322}{e_0 - 0.322} \tag{9} \]

The similarity of the dependency on the overburden pressure with density, deformability and consolidation can be confirmed over the presented cavity theory. It is drawn in Eqs. (10) and (11).

\[ q_d \propto (\sigma_m)^{1-\frac{4\sin \phi'}{3(1+\sin \phi')}} \tag{10} \]

\[ A = 1 - \frac{4\sin \phi'}{3(1+\sin \phi')} \tag{11} \]

DISTRIBUTION OF N-VALUE OF ALLUVIAL CLAY IN BUSAN OFFSHORE, KOREA

Fig. 8 shows the represent geological section in Busan offshore district. And Fig. 9 also shows the compatible example of N-value distribution with depth. From the figures, the deposit over the weathered rock is classified wholly into two parts, of which the upper clay layer has N-value of around 0 to 1, and the lower clay layer that directly contacts with the upper clay layer has the higher N-value of 5 to 10. The lower part is identified as the stiff clay. At the connecting boundary of both layers is found a jump of N-value and sharp discrete distribution patterns of N-value contact. Considering the geological age, the upper clay layer is clearly concluded.
This geological dating of both layers explains the expectation of scraping a surface of the lower clay layer in process of sea waters transgression and regression. This idea seems easily reasonable, however, sedimentation area of the stiff clay is so localized that it makes us to conclude existence of sites where the stiff clay itself is completely scraped away.

The trend of giving the dependence of $N$-value on the overburden pressure is added in the Figure. The existence of discrepancy between the upper part and the lower is evidently found as comparing with the predicted line of $N$-value with depth. This curve is drawn by approximately fitting $N$-value data with the depth of the lower clay. Whether the lower stiff clay belongs to the alluvial clay or to the Pleistocene clay takes an important role on the engineering judge with soil properties. Because reliability of soil test results depends on the geological ages when deposited.

Fig. 10 shows the liquid limit distribution. The surface deposit over the bed rock is divided into 6 layers containing the stiff clay deposited at the lowest. It is found that the liquid limit property of the stiff clay has similar with the layer 3 and 4 of alluvial clay.
Accordingly, it encounters us to know the sequent relationship of both parts and why the strict boundary exists on the sea water changing.

Fig. 11 shows the locations of borings contained in the data base relating to the Busan offshore area. Regional grouping is executed into 9 districts. And Fig. 12 shows the distribution of N-value with depth compatible with the grouped districts. It is easy to find that there is localized and thin layer corresponding to the location of stiff clay layer with high N-value which connecting the upper layer with the lower or zero of N-value. The geological section and N-value mentioned above is the soil profile of the E zone. It is derived from the regional study on sedimentation environment that the stiff clay is partly deposited and like the buried valley. This sedimentary condition is similar to Nanagochi-so in Tokyo lowland soil profile shown later.

PATTERN OF N-VALUE DISTRIBUTION OF ALLUVIAL CLAY IN JAPAN OFFSHORE

Two representative soil profiles in Japan are prepared for conducting the comparative study of deposit of alluvial clay. Figs. 13 and 14 show N-value distribution taken in Osaka bay and Tokyo lowland area. The later data is derived from the reference by Yamaguchi (2005). Table 2 a geological legend proposed for Osaka bay surface layers and Table 3 is summarized the characteristics regarding with 3 districts.

The similarity of N-value distribution with depth is found in both sites, taken from Busan and Tokyo. Strict jump of N-value distribution with deep in Tokyo lowland is clear at the boundary between Yurakucho-so and Nanagochi-so. And the location of Nanagochi-so is found to be partially located as if it is buried valley. This pattern is like the stiff clay in Busan.
On the other hand, underneath the alluvial clay is the sandy layer having difference of distribution pattern of $N$-value. Silty and sandy layer named Namko-so in Table 2 has a little higher of $N$-value comparing to that of alluvial clay. Hence, the existence of stiff clay attached in Busan offshore is similar to the Nanagochi-so in Tokyo not in Osaka offshore alluvial clay profile.

MECHANICAL PROPERTIES OF CLAY IN BUSAN

Fig. 15 shows the distribution of strength with depth in relation to the Busan offshore. The discrepancy is observed at the boundary of the upper clay and the lower clay. This explains why the great difference generated between the upper layer and the lower layer. In the meanwhile, the strength of the upper layer could contain ambiguous data due to the disturbance during testing. However, the high strength and discrepancy between the upper layer and lower is common at least in Busan and Tokyo, leads to the similarity.

CONCLUSIONS

The following conclusions can be derived.

1) $N$-value depends on the overburden pressure and it can be taken account by the cavity theory.
2) The pattern of $N$-value distribution in depth of surface layers in Busan offshore is fully classified into two parts.
3) The stiff clay detected in Busan district deposited as the lower parts is similar with Nanagochi-so in Tokyo.

Lower clay is predicted as the deposit in the beginning ages of Holocene and in the end of Pleistocene.

REFERENCES