Design concept for sand compaction pile method by considering ground information

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ABSTRACT

This paper describes that pre- and post- SPT *N*-values and data of physical properties of soil improved by sand compaction pile method were collected and analyzed in order to examine the effects of the soil's physical properties other than fines content, F_c, which is used in current design method on the increase in SPT *N*-value. Based on the results, it is suggested that the accuracy of the estimation of the predicted SPT *N*-value can be improved as compared with the current design method by correcting the predicted SPT *N*-value using the uniformity coefficient, U_c, when the value of F_c is small (< 35%), and using the plasticity index, I_p, when F_c is large (> 35%).

Keywords: sand compaction pile method, fines content, uniformity coefficient, coefficient of curvature, plasticity index

1 INTRODUCTION

Sand compaction pile method (herein referred to as SCP method) is a method for improving soft ground through the installation of well-compacted sand piles into the ground. It combines fundamental principles for ground improvement, such as "densification" and "drainage". It has been implemented on various ground types, such as sandy or clayey ground, using a single piece of equipment; therefore, it has been widely used to improve and strengthen soft grounds. SCP method has been adopted in many construction projects in Japan to improve the foundation ground for various structures, such as roads, harbours, and buildings. In particular, when applying the SCP method to sandy soils, it is widely used as a countermeasure against liquefaction, and its effectiveness in preventing the occurrence of liquefaction has been confirmed in many large-scale earthquakes in the past, making it the most reliable liquefaction countermeasure method in Japan (Harada and Ohbayashi 2017).

The principle of the SCP method is to install well-compacted sand piles into the sandy soil in order to reduce its void ratio, especially in the vicinity of the sand pile, and increase its density, producing ground with high bearing capacity and high liquefaction resistance. In terms of increase in density, it is considered that the primary properties of the soil, such as particle size distribution and consistency, as well as its secondary properties, such as density, moisture content and volume of voids, are the contributing factors. In this paper, attention is paid on the primary properties of soil and on their contribution to the increase in SPT *N*-value associated with the application of SCP method.

2 DATA ANALYSIS AND ARRANGEMENT OF RESULTS

2.1 Outline of data

Analysis of the effects of SCP method was performed by collecting and arranging data of pre- and post-SPT *N*-values as well as the physical properties of the soil. The collected in-situ data consisted of pre- and post-boring data and liquid limit/plastic limit tests on soils from 32 pre-improvement boring data and 39 post-improvement boring data from 13 sites (with improvement ratio, a_s = 6.2 to 19.6%) nationwide, totaling 71 boring data. When combining the pre- and post-improvement SPT *N*-values, those data with fines content, F_c, which differed by more than ±10% were excluded from the analyses.

2.2 Relation between fines content and various physical properties

From the collected data, the relations between the fines contents and various physical properties of the soils were examined. Figure 1 shows the relation between F_c and the average particle diameter, D_{50} with the vertical ordinary axis (a) and the vertical logarithmic axis (b). Although the correlation between the two parameters is high, D_{50} tends to decrease as F_c increases, and the data scatter becomes large when $F_c \leq$ 35%. Figure 2 shows the relation between F_c and the uniformity coefficient, U_c, where it can be seen that as F_c increases, U_c tends to increase, on average; however, at around F_c = 30%, U_c decreases slightly. The relation with the coefficient of curvature, U_c', shown in Figure 3, also shows the same tendency as that with U_c.

On the other hand, in terms of the relation of F_c to the plasticity index, I_p, which is shown in Fig. 4, most soils are non-plastic (I_p = 0) up to around F_c = 30%, and beyond this F_c value, I_p tends to increase. While many standards and guidelines indicate that the soils to be considered for liquefaction analysis are often those with $F_c \leq 35\%$, data for non-plastic soils with $F_c > 35\%$ are also found.

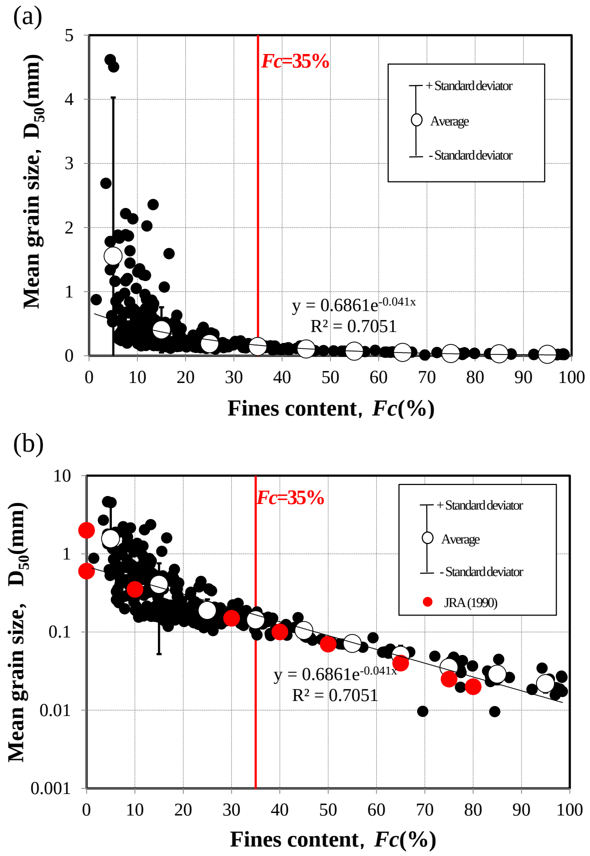

Fig. 1. Relation between F_c and D_{50}

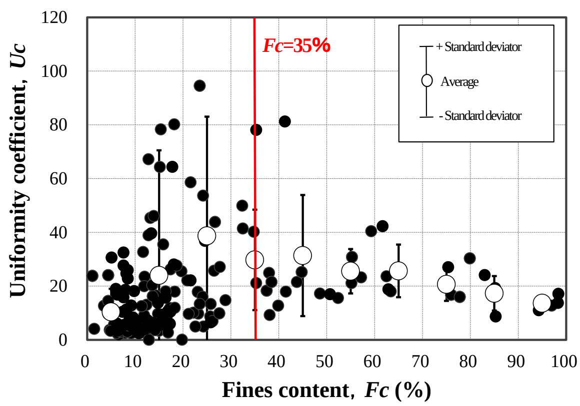

Fig. 2. Relation between F_c and U_c

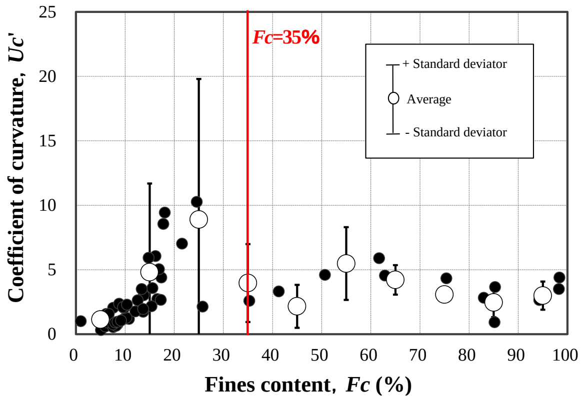

Fig. 3. Relation between F_c and U_c'

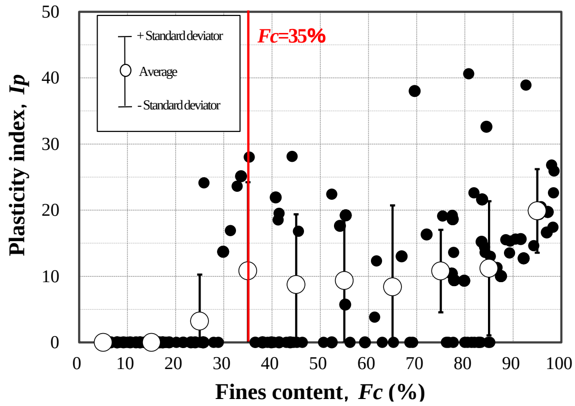

Fig. 4. Relation between F_c and I_p

3 EFFECT OF SOIL'S PRIMARY PROPERTIES ON ESTIMATION OF PREDICTED SPT *N*-VALUE

3.1 Influence of Fines Content on SPT *N*-Value

In the current SCP design method (JGS, 2009), among the primary properties of soil, only the fines content is used as the parameter with the highest rate of contribution to the improvement effect (i.e. improvement effect on SPT *N*-value). For this purpose, the effective compaction coefficient, R_c, which is a parameter representing the rate of change of the volume of the inserted sand, is used. As shown in Figure 5, R_c basically represents the reduction in the voids of the

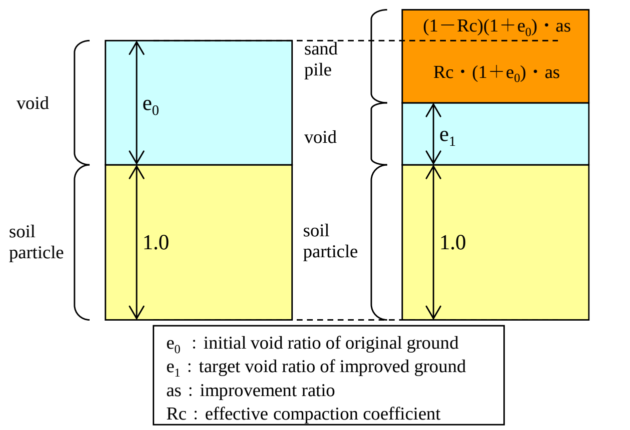

Fig. 5. Concept of effective compaction coefficient, R_c

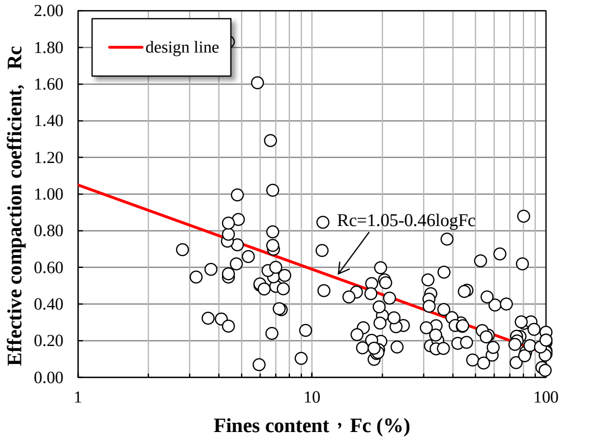

Fig. 6. Relation between F_c and R_c according to current design method

sand used for the sand piles, and its relation with F_c is provided by the approximate curve given by Equation (1) (see Figure 6).

$$R_c = 1.05 - 0.46 \log F_c \tag{1}$$

In the current design method using F_c, the relation between the estimated SPT N-value (N_{est}) obtained from Equation (1) and the measured SPT N-value (N_{mea}) is used as an index of prediction accuracy. Figure 7 shows the relationship between F_c and the ratio N_{mea}/N_{est} for the current data, where it could be seen that while the N_{mea}/N_{est} is about 1.0 on average, the rate of contribution of F_c is quite small and, as a whole, the data scatter is large.

Next, R_c can be back-calculated using Equation (2) from the measured SPT N-value (N_{pre}, N_{post}), the pre- and post-improvement void ratios (e_0, e_1), the pre- and post-improvement relative density (Dr_0, Dr_1), a_s, and F_c.

$$R_c = \frac{e_0 - e_1}{a_s(1+e_0)} \tag{2}$$

where

$$e_{0,1} = e_{\max} - \frac{Dr_{0,1}}{100}(e_{\max} - e_{\min}) \tag{3}$$

$$D_{r0,1} = 21\sqrt{\frac{N_{pre,post}}{0.7+\sigma_v'/98} + \frac{\Delta N_f}{1.7}} \tag{4}$$

In addition, σ_v' is the effective overburden pressure and ΔN_f is the increment in the corrected SPT N-value (related to F_c).

Figure 8 shows the current data (●) obtained from Equation (2) in combination with Equation (1) as well as the data with $I_p = 0$ (○) from the dataset. As shown in the figure, R_c of the data with $I_p = 0$ is clearly larger than those from the approximate expression derived from previously available data. Thus, it is conceivable that the variability of the SPT N-value when compared with the predicted value could be due to the physical properties of soil other than fines content, F_c.

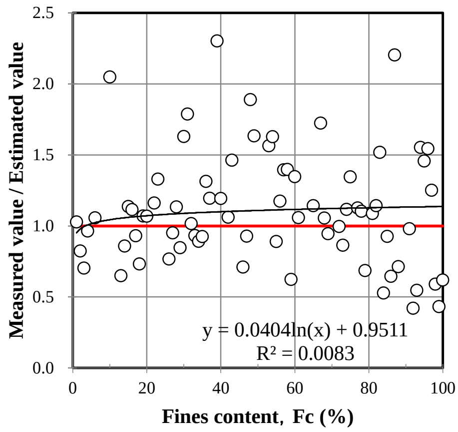

Fig. 7. Relation between F_c and N_{mea}/N_{est}

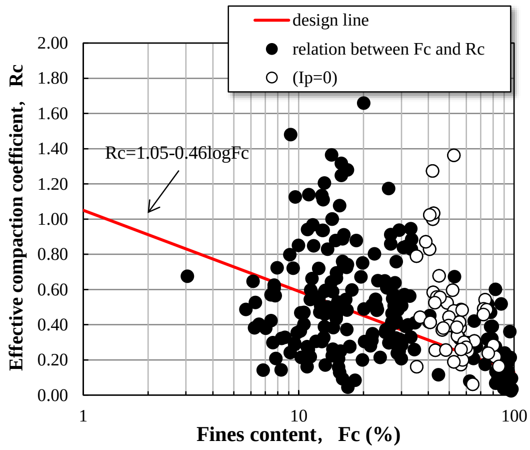

Fig. 8. Relation between F_c and R_c

3.2 Influence of physical properties of soil on the SPT *N*-value

From Figures 1 to 4, it is observed that when $F_c \leq$ 30%, there is vast variation in the values of U_c and U_c', there is large data scatter in D_{50} and I_p indicates that most soils are non-plastic. Therefore, the influence of the soil's physical properties on the increase in SPT N-value was examined by dividing the data into those with F_c values larger and smaller than 35%, which is the threshold value used for liquefaction judgment.

Figure 9 shows the relationship between D_{50} and N_{mea}/N_{est} for data with F_c < 35%. In the figure, the approximate curve and the rate of contribution are shown together, where it is seen that, while on average, the value of N_{mea}/N_{est} is about 1.0, the data scatter is large and the rate of contribution is small. This is due to the strong correlation between F_c and D_{50}, as shown in Figure 1. Next, Figure 10 shows the relationship between U_c and N_{mea}/N_{est}. For those data with low U_c (indicating poor particle size distribution), the value of N_{mea}/N_{est} is smaller than 1.0 indicating that the measured SPT N-value is smaller than the predicted SPT N-value; but as U_c increases, the value of N_{mea}/N_{est} tends to exceed 1.0, suggesting that soil with large U_c and good particle size distribution tends to be easily compactable and the SPT N-value tends to be large. In addition, the rate of contribution of U_c' is relatively high as shown in Figure 11 because the case of $1 < U_c' < 3$ is considered to have a good particle size distribution; and as U_c' increases, N_{mea}/N_{est} tends to be larger than 1.0.

On the other hand, for data with $F_c \geq 35\%$ as plotted in Figure 12 using I_p, the value of N_{mea}/N_{est} tends to decrease as I_p increases. For low-plasticity silt layer with $I_p \leq 15$, the value of $N_{mea}/N_{est} > 1.0$, indicating that there is a possibility that the current design method may underestimate the improvement effect.

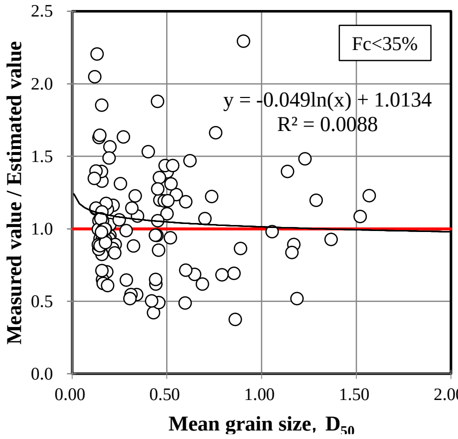

Fig. 9. Relation between D_{50} and N_{mea}/N_{est}

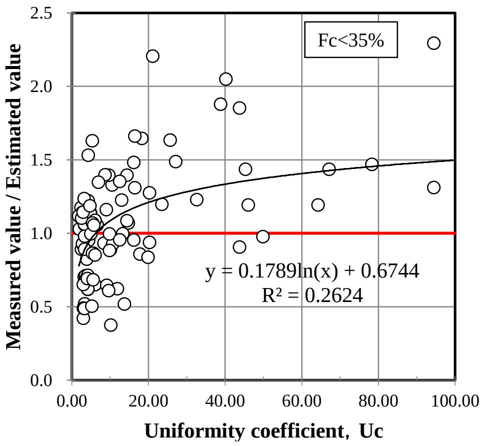

Fig. 10. Relation between U_c and N_{mea}/N_{est}

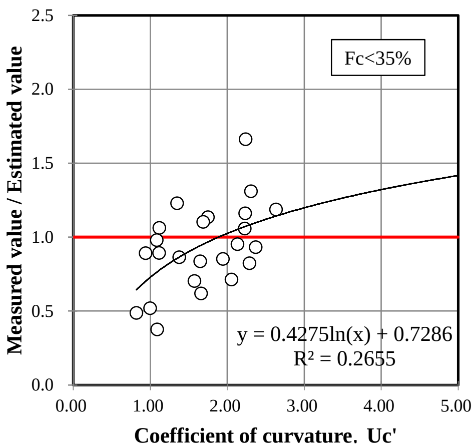

Fig. 11. Relation between U_c' and N_{mea}/N_{est}

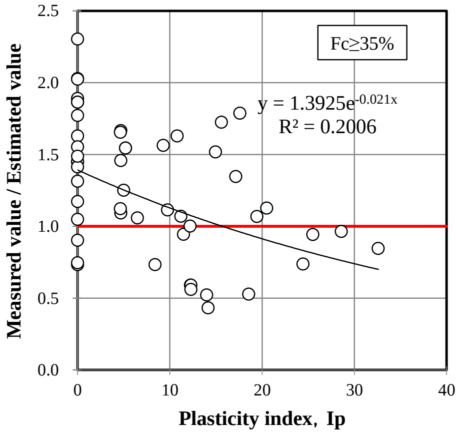

Fig. 12. Relation between I_p and N_{mea}/N_{est}

4 CONCLUDING REMARKS

In this paper, we collected and analyzed pre- and post- SPT N-values and data of physical properties of soil improved by sand compaction pile method in order to examine the effects of the soil's physical properties on the increase in SPT N-value. Based on the results, it is suggested that the accuracy of the estimation of the predicted SPT N-value can be improved as compared with the current design method by correcting the predicted SPT N-value using the uniformity coefficient, U_c, when the value of F_c is small (< 35%), and using the plasticity index, I_p, when F_c is large (> 35%).

In the future, it is planned to examine the design method considering physical properties of soil other than F_c, which is used in the current design method.

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