Considerations for Judging the Suitability Filling Materials for SCP

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INTRODUCTION

The sand compaction pile (SCP) method has been widely used as ground improvement method in Japan. It conforms to fundamental principles of compaction and consolidation drainage. As a result, it has been used successfully on many occasions for the improvement of all types of soft grounds (ranging from sandy to clayey ground), using natural clean sands as filling material.

In order to lessen the environmental impact through efficient recycling of construction surplus soils and by reduced use of natural sands an improved SCP method was developed, in which construction surplus soils and coal ashes are used as a substitute for sands used as filling material in conventional SCP methods so as not to exhaust sand resources. Originally, the method have been developed for clayey ground, and in the design the strength increase of soft clay due to dissipation of excess pore water pressure generated through installation of sand compaction piles was newly considered. As for sandy ground, as the compaction effect is not significantly affected by filling material, this method has been acknowledged to be effective against liquefaction.

However, as this filling material have different properties from clean sands, it is very important to clarify the material properties for compaction pile methods. In this paper, the authors have examined the applicability of filling materials for compaction pile to improve soft ground through laboratory tests (Tsuboi et al. 2000) and field site tests (Tsuboi et al. 2001). As available high quality sand for filling material has been reduced year by year, and it may be extremely difficult to secure an adequate supply in the future. Construction surplus soil, slag, coal ash and other similar materials would therefore become potential substitutes for the filling material. The effective use of those materials would thus contribute to reducing the environmental load.

Based on the above-mentioned background, a

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ground improvement method using construction surplus soils has been developed and modified for implementation (Matsuo et al. 1997). Furthermore, in order to eliminate the vibration and noise generated by vibro-hammers in vibratory SCP methods, a non-vibratory SCP method has been developed and implemented for many practical cases (Tsuboi et al. 1998).

In this paper, the authors present a simplified design flow to judge whether or not filling materials can be applied to compaction pile methods through simple laboratory tests data. This study is based on the findings from the available data of laboratory and field site tests of filling materials in the vibratory and non-vibratory SCP methods.

FINDINGS FROM AVAILABLE TESTS DATA ON FILLING MATERIALS

Required filling materials performance

The implementation procedures for the vibratory and non-vibratory SCP methods are shown in Fig. 1. The former uses the vibrator and the latter uses the forced lifting/driving device. However there is no great difference in procedure between the two. Filling material (normally sand) is brought in with a wheel loader into a bucket, from which it passes through a hopper to fall into the casing pipe (f400-500mm). Then, through a process of raising and redriving the casing pipe, a compacted sand pile is formed in the ground.

Fig.2 lists factors to be considered for both design and implementation. For clayey ground, a composite ground containing well-compacted sand piles is formed, and for the case, shear strength and permeability tests for the SCP should be carried out in order to confirm their characteristics. For sandy ground, SCP is often used to increase the density of ground as a countermeasure against liquefaction, and so the sand pile is required to have sufficient strength and diameter. Thus for the design, the data of shear strength tests in a dense state is required. For the implementation, clean sand is desirable, as the materials with high fines content lead to clogging.

Fig. 3 shows the states of filling material at the different stages of pile installation: stock (r) sliding (r) raising of casing pipe (material discharge) (r) redriving of casing pipe (material compaction). The figure also shows the required material characteristics and laboratory tests at each stage. As for the stock, lower water content of filling material facilitates the implementation. As for the sliding of filling material passing through hopper, if the water content is below 25%, there is little adhesion and the sliding is possible (Matsuo et al. 1997). Thus, the water content tests can determine whether or not the material will pass through hopper to the casing pipe. As for the material discharge, a loosely compacted material can be discharged, if it has moderate to low plasticity and a permeability coefficient lower than about 10-4 cm/sec (Tsuboi et al. 2000). As for the easiness of compaction, the amounts of silt and clay in the material are the prevailing factor (Tsuboi et al. 2000). Thus the compaction characteristics can be determined by grain size analysis.

Findings from laboratory tests

To evaluate the suitability of filling materials for compaction pile methods, a series of laboratory tests was carried out on a variety of artificial specimens with construction surplus soils (sandy, intermediate, clayey). The relationship between their gradation and plasticity index was examined as a factor influencing their compaction shear strength and permeability characteristics. The states of passage, discharge and compaction during the implementation process were estimated through those results.

State during passage

The state during passage was simulated in steel sheet sliding tests and the findings are as follows:

1) When the sliding angle is plotted against the plasticity index of the materials at water content w=25%, the adhesion increases as the plasticity index increases.
2) The inclination of hopper wall is usually 45°-60° (normally 45°). If this angle is taken as a yardstick for the passage, its limiting value for plasticity index is 20-25 (see Fig. 4).

State at discharge

The state at discharge was studied through the data of permeability tests on the materials in loosely compacted state, and the findings are

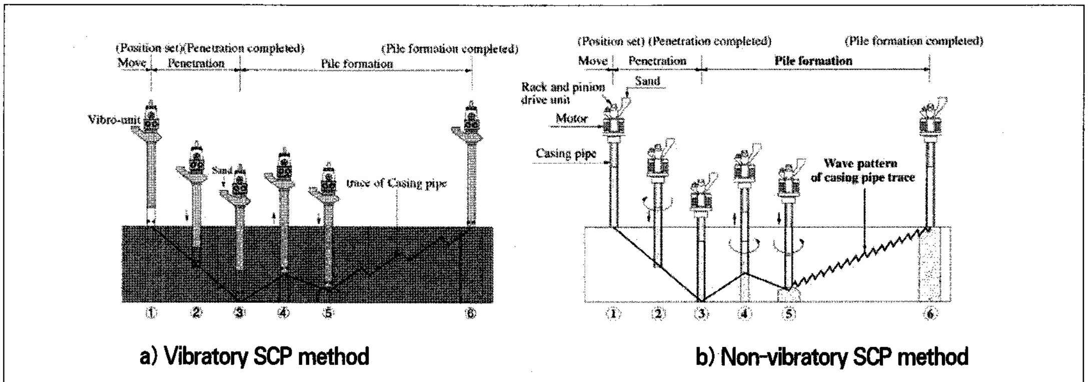

Fig 1. Implementation procedures for vibratory and non-vibratory SCP methods

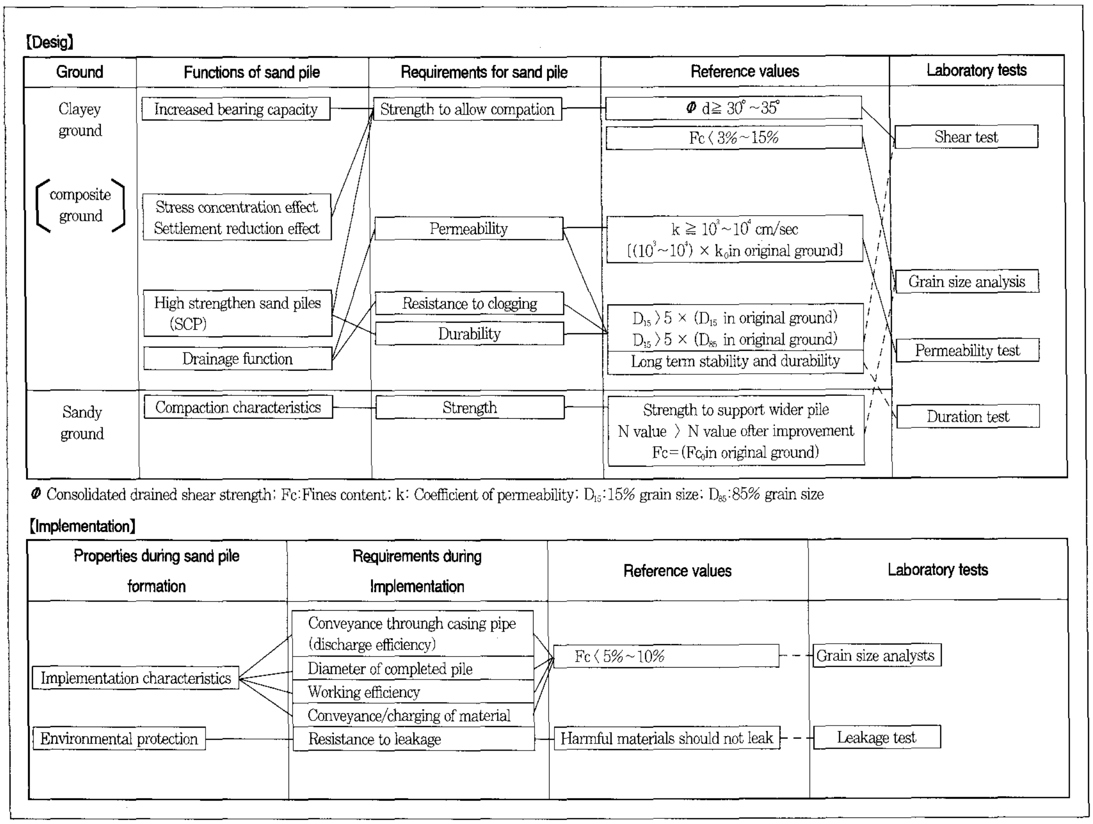

Fig 2. Factors to be considered for both design and implementation

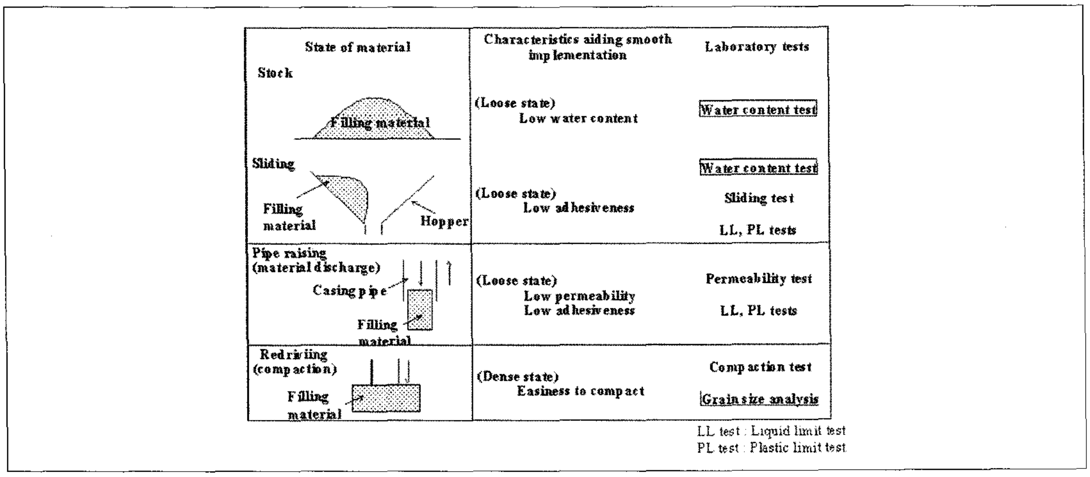

Fig 3. States of filling material and requirements for implementation

summarized as follows:

1) The higher the fines content and plasticity index of the soil specimen, the lower the permeability coefficient. In contrast, the shear strength was constant irrespective of the specimen being densely or loosely compacted.
2) By keeping a coefficient of permeability higher than about 10-4 cm/sec in loosely compacted material, which is the minimum requirement for discharging the material from the casing pipe into the ground, discharge becomes possible for moderate or low plastic materials with a plasticity index of lower than 20-25 (see Fig. 5).

State at compaction

The state at compaction seems to be controlled by the shear strength and coefficient of permeability, and the findings are as follows:

1) As for compaction characteristics, materials with a gradation ratio (M/C) between silt (M) and clay (C) being higher than about 2 are easy to compact (see Fig. 6).
2) As for the design of the pile compaction by repeated redriving of the casing pipe, well compacted low plasticity substitute materials, even those with a higher fines content, have relatively higher shear strength like a compacted sand (see Fig. 7) But as for permeability, as can be seen for densely compacted material in Fig. 5, it is difficult to secure a level above 10-3 cm/sec

Findings from field site tests

Table 1 shows ground improvement and implementation data for test sites, in which filling materials with high fines contents were used. Ground improvement data (pile diameter, pile length, improvement area ratio), ground characteristics (soil type, fines content, strength by N values etc.), properties of filling material (water content, fines content, plasticity index) and implementation data for filed site tests (improvement effect, material properties test, implementation efficiency), are given for previously reported vibratory SCP test sites (Tsuboi et al. 2000), and non-vibratory SCP implementation. At sites TS and TA, the tests were focused on checking the implementation efficiency, and the improvement effect was not confirmed. Grain size distribution curves and triangular soil chart for the materials used at each site are shown in Figs. 8 and 9.

Vibratory SCP method

The findings from field site tests using vibratory SCP method are as follows:

1) Among the various improvement effects, the effect against possible liquefaction through the compaction of the surrounding ground was almost the same as

improvement using sand.

2) As for shear strength and permeability of the pile, plasticity index affects both the shear strength and permeability characteristics, each of which tends to decrease with a higher plasticity index (see Figs. 5 and 7).

3) As for easiness of implementation, the lower the fines content, the easier it becomes. For the same fines content, the lower the plasticity index, the easier it becomes.

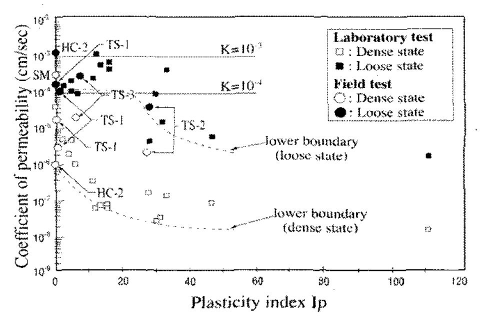

Fig 5. Relationship between coefficient of permeability and plasticity index

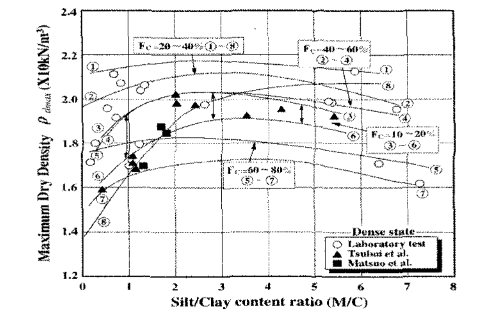

Fig 6. Relationship between maximum dry density and silt/clay(M/C) content Ratio

Non-vibratory SCP method

In tests at site TA using a non-vibratory SCP method, quick lime of about 100kg/m3 was mixed into dredged clay to improve its handling, and additionally a 65% of sand by weight was further mixed in. Its water content was lowered below 25% in this way, and this mixed material was used for pile installation in the non-vibratory SCP method. Fig.10 shows the

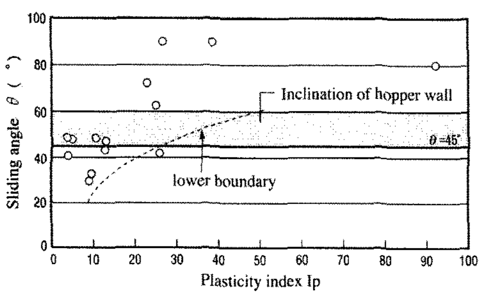

Fig 4. Relationship between sliding angle and plasticity index

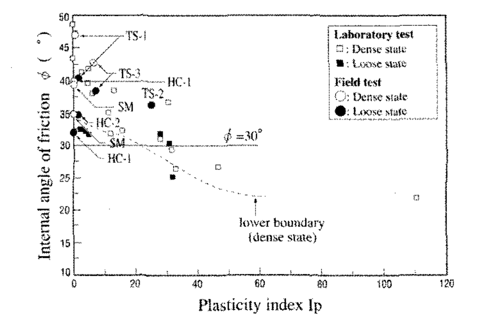

Fig 7. Relationship between of frictional angle and plasticity index of substitute materials

Table 1. Ground improvement and implementation data for test sites

Site name(Material name)		SM		HC		HT	TS			TA
				HC-1	HC-2		TS-1	TS-2	TS-3	
SCP type		Vibratory SCP								Non-vibratory SCP
Specifications of ground improvement	Pile diameter(mm)	Φ 700		Φ 700		Φ 700	Φ 700			Φ 700
	Pile length(m)	15.5		9.0		12.0	10.0			10.0
	Improvement area ratio(%)	13.0		15.0		9.6	9.6			-
Ground	Soil type	Clayey	Sand	Coal ash landfill		Silty sand	Clay			Silty sand
	Fines content(%)	60~80	30~40	75~95		10~30	70~90			30~40
	N value, etc.	Av. UCS =40kN/m²	2-7	Av. e=1.3		5-20	Av. UCS =49kL/m2			2~4
Filling material	Water content(%)	15		12	81	51	52	81	9	23
	Water content(%)	24		89	27	18	16	34	20	32
	Plasticity index	NP		NP	NP	NP	1	24	6	20
Check of improvement effect(before/after)		SPT				SPT	-	-	-	-
Material properties test at pile center		SPT TT(CD) PT		TT(CD) PT	TT(CD) PT	-	DT TT(CD) PT	TT(CD) PT	DT TT(CD) PT	SPT
Implementation efficiency		O		O	O	O	O	-	O	O

e : *Void ratio*
UCS : Uncomfined compressive strength test
SPT : Standard ptenteration test
TT : Traixial test(CD)
CD : Consolidated drain condition
PT : Permeability test
DT : Density test

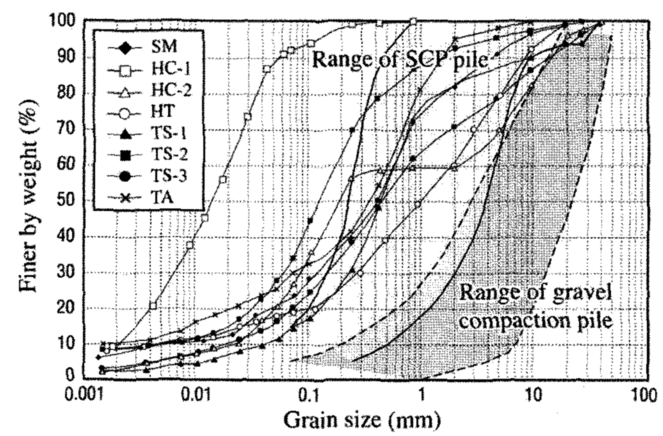

Fig. 8 Grain size distribution curves for filling materials in site tests

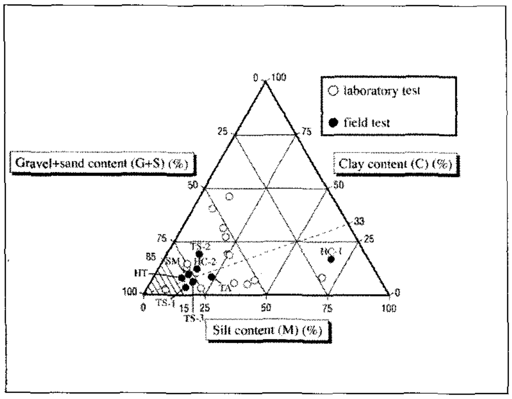

Fig 9. Triangular soil chart of gradation for used materials

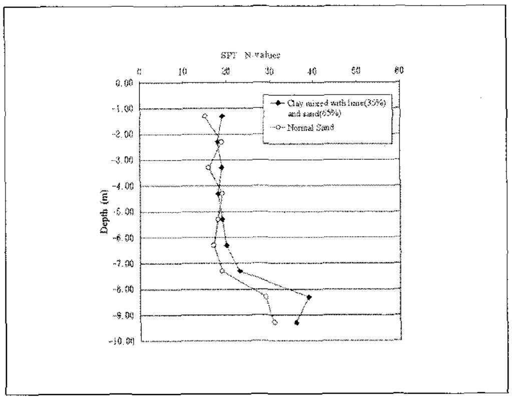

Fig 10. Comparison of SPT N-values for different filling materials

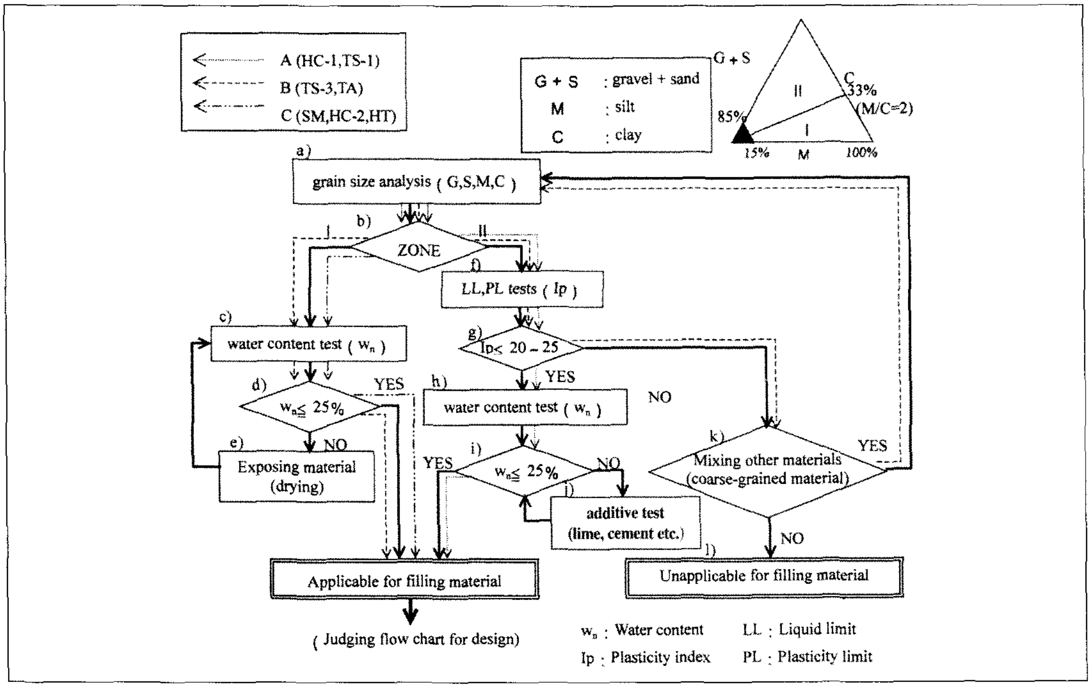

Fig 11. Flow chart for evaluating pile formation

distribution of SPT N-value at the mixed pile center with depth. It is seen from this figure that the mixed material has almost equal strength to the normal sand. As to the implementation efficiency, the implementation cycle (time) was slightly longer than regular

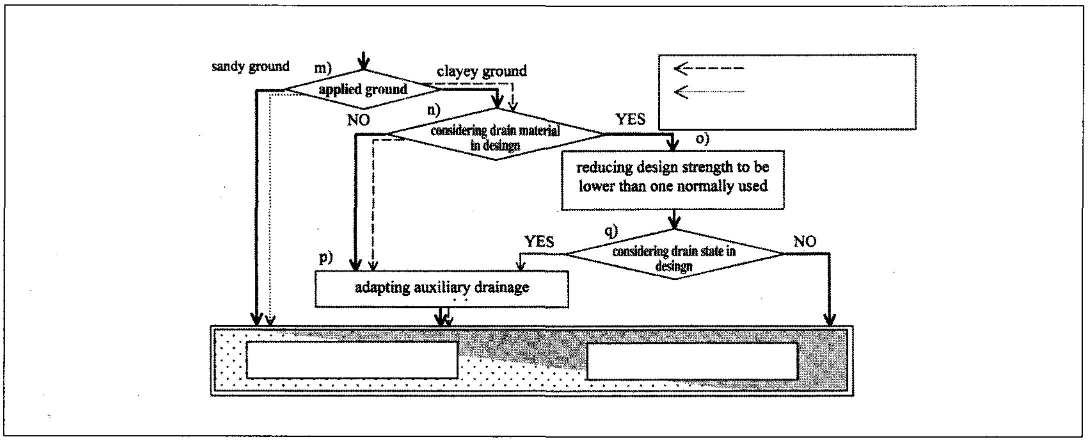

Fig 12. Design flow charts for evaluating pile formation

sand, but the overall implementation proceeded without any troubles.

Outline of flow charts

Based on the above mentioned findings, the following two design flow charts can be drawn up for evaluating pile formation and for selecting pile installation type, based on simple physical properties tests such as grain size analysis, water content test, and liquid/plastic limit tests. The one of design flow charts is to determine whether the material can be compacted in the ground to form a continuous pile, and the other is to indicate whether the material is appropriate for selecting pile installation type (see Figs. 11 and 12).

Flow chart for evaluating pile formation

The design steps for evaluating pile formation are as follows:

a) Conduct grain size analysis to obtain gradation.
b) Plot triangular soil chart of gradation and identify the soil type (zone).
c) Conduct water content test.
d) If water content is lower than 25%, the material can be used. If higher, proceed to step e).
e) Expose material to the air for drying to be lower than 25% of water content.
f) Conduct water content test and liquid/plastic limits tests.
g) If plasticity index is lower than 20-25%, proceed to step h). If higher, proceed to step k).
h) Conduct water content test.
i) If water content is lower than 25%, the material can be used. If higher, proceed to step j).

j) From additive tests with quick lime or cement, determine the quantity of additive required to bring the water content below 25% in the required number of days. If the water content is not so high, expose the material to the air for drying, to reduce the water content to be lower than 25%.

k) In case of mixed material with other coarse-grained material to modify grain size, return to step a). If a suitable coarse-grained material is not available, proceed to step l).

l) Such material as in l) cannot be used as a filling material.

Flow chart for selecting the installation type

The design steps are as follows:

m) If pile strength has no significance to pile design, any substitute filling material is applicable. If it has, proceed to step n).

n) If the material should be considered as drainage in pile design, proceed to step o). If not, proceed to step p).

o) Reduce the design strength to be lower than one normally used.

p) If the material should be considered as drainage in pile design, proceed to step q). Otherwise, it is suitable for medium or high displacement.

q) Examine an auxiliary drainage material (such as plastic board drain).

Case studies of proposed design flow chart

The flow charts in Figs. 11 and 12 are verified for the 8 materials listed in Table 1.

As for evaluating pile formation, materials HC-1 and TS-1, used in the vibratory SCP method, belong to the zone I of the triangular soil chart shown in Fig. 11, indicating by arrow A in the figure. As their water content is low, the materials can be used for filling materials. Material TS-3 in the vibratory SCP method and material TA in the non-vibratory SCP method, were prepared using material TS-2 mixed with high quality materials (the former with material TS-1, the latter with high quality sand), because material TS-2 of dredged clays cannot be implemented because of high water content and high plasticity. Their grain size distribution and plasticity index can be lowered to improve handling. Thus, following the arrow B in the figure, they can be applicable for filling material. The other materials were all of low plasticity or non-plastic, so they can be applicable following the arrow C in the figure if the water is lower than 25%.

As for selecting pile installation type, material SM was implemented in a ground alternating clay and sand layers with plastic board drains to boost the drainage function (Matsuo et al. 1997). Thus the SM (clay) material follows the arrow D in the figure. The materials of SM (sand), HC, HT-1 and HT-2 follow the arrow E in the figure, because they were used as a countermeasure against possible liquefaction.

Following the design flow charts in Figs. 11 and 12, it was possible to judge the suitability of filling materials for evaluating pile formation and for selecting pile installation type in compaction pile method, merely by conducting simple laboratory tests.

CONCLUSION

This paper proposes a design flow chart to assess the applicability of substitute filling materials for compaction pile methods, based on the findings from available laboratory and field site tests data.

Using the proposed flow charts in this paper, the suitability can be judged easily in a wide range of substitute filling materials for compaction pile method, based on a series of simple laboratory tests data.

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