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Evaluation of densification of loose sand by SBP and DMT

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→ CONCLUSIONS

ABSTRUCT : For improvement of loose sand in reclamed land, three types of improvement method were applied to compare their densification effect. In the field to perform them, SBP, DMT and SPT were carried out to estimate and compare the densification effects by each imroving method. According to the result of these in-situ tests, two method were found effective to densify loose sand.

1 INTRODUCTION

In soft ground consisted of loose sand layers in Japan, so many case histories on tremendous disasters due to liquefaction by earthquake had been informed recently.

The main current measures to prevent foundation ground from liquefaction are applied on the basic concept of densification effect of loose sand : the sand compaction pile method (SCP method) and the vibrating rod method (VR method) which are characterized as the method, in which the specified soil material such as clean sand is nececcery to include.

New iprovement method for densification of loose sand with no specified soil was developed and comparative study of effectiveness of the new method with current methods was carried out, mainly using self-boring pressuremeter(SBP) and flat-dilatometer(DMT). Commonly, SBP testing is known to be more time-consumingand too-much expensive than any other in situ testing such as DMT and SPT and gives soil data on only one meter depth. But SBP is considered to have theoretical background of each soil properties, whereas interpretation of DMT are based on experimental correlation to each soil properties. To compare effectiveness of soil-densification by the new improving method with another current method, site invesigation using DMT and SBP were carried out in field. In this field, the result of SBP is considered to be as basic factors of soil property and results obtained from Marchetti-solution for DMT is to be interpolative data to give semi-continuous profile of ground conditions.

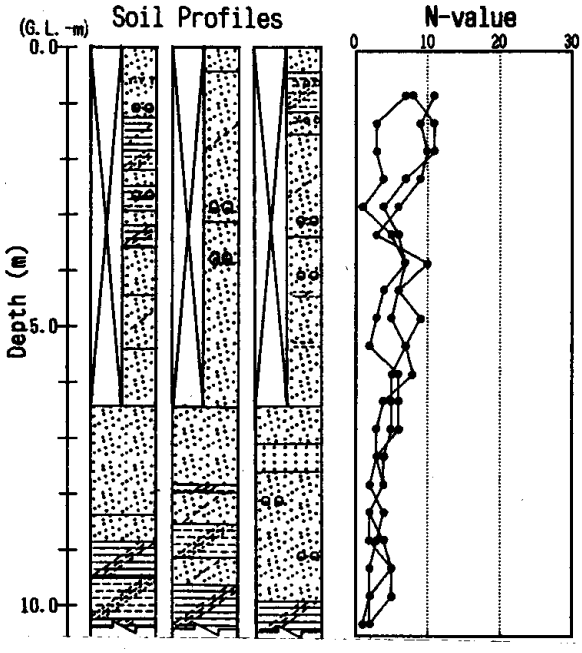

Fig.1 Soil profiles in the test site

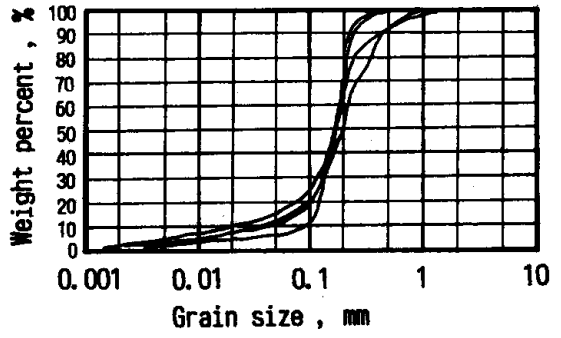

Fig.2 Main grain size distributions of reclaimed sandy soil in the test

2 GROUND CONDITIONS IN SITE

Field comparative study undergone is located in the reclaimed land near the Tokyo Bay. The soil profile and N-values by the standard penetration test(SPT) are shown in Fig.1.

Problematic soil in the field is the part of hydraulic fills which was constructed by dredging. The fills is mainly consisted of fine sand with shell fragments and interbedded with clayey-silty thin layer of 5-15 cm in thickness. And also, N-values of SPT in the fills are less than 10 blows that shows relatively loose sandy soils. This fills develop from the surface to about 6m in depth above natural loose sand layer underlying normal marine clay to 30m in depth. The main grain size distributions of the fills are shown in Fig.2.

According to both N-values and grain size distribution of fills,it is estimated that the fills have a great potential of liquefaction by earthquake. And also, N-value of SPT shows that improvement measures against liquefaction are necessary to undergo in the part of fills and natural loose sand layer developing from the surface to 10m in depth.

3 THREE TYPE OF IMPROVEMENT MEASURES APPLIED IN FIELD

Three type of improvement measures were undergone in the field to compare effectiveness of densification of each measure: Vibrating Rod method,Sand Compaction Pile method and Vibrating Rod with Suction method.

(1) Vibrating Rod method (VR)

VR method is th at densification of loose sandy soil are performed by vibro-penetrating 30 × 30 cm steel H pile, end of which has a special hinge-point being able to have it close during its penetrating and open during its pulling. This is one of the simplest procedure to make loose sand dense. (see Fig 3(a))

(2) Vibrating Rod with Suction method (VRS)

VR method,mentioned above,is supposed to have a weak point which the effective vibrating energy to promote densification of sand may decrease due to excess pore pressure around vibrating rod during its penetration. And then,in combination with well point - suction method to decrease excess pore pressure, effectiveness of densification by vibrating should increase.

As shown in Fig.3(b), VRS method is that well-point suction pipe is gone first before penetration of vibrating rod.

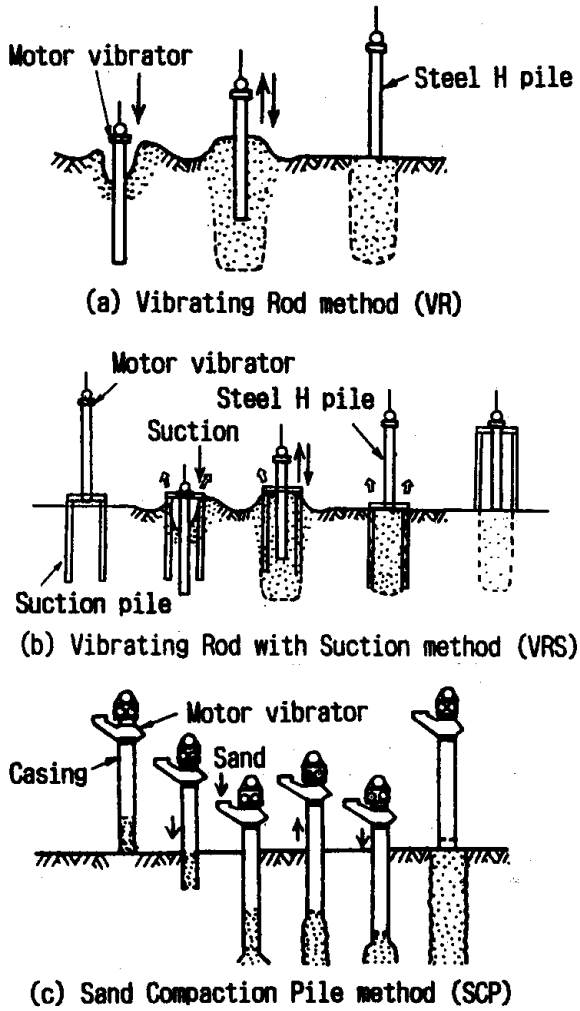

Fig.3 Improving method used in the field

(3) Sand Compaction Pile method (SCP)

SCP method is the most popular current method to measure ground against liquefaction by earthquake in Japan. First, steel casingpipe at end-closed state are penetrated into groundat a given depth,and clean sand is put into the casing pipe. At second,the casing is pulled up pressuring clean sand by repeating it to advance downward and upward. In such way as mentioned above,compacted sand pile may be constructed in ground and at the same time ground may be densified by the effect of sand pile displacement. (see Fig.3(c))

4 SITE INVESTIGATION IN FIELD

Before and after the execution of soil improvement was finished, in-situ tests including SBP and DMT was carried out in such arrangement as shown in Fig.4.

The SBP probe developed by Clarke et al (1989) was used in the site .(see Fig.5)

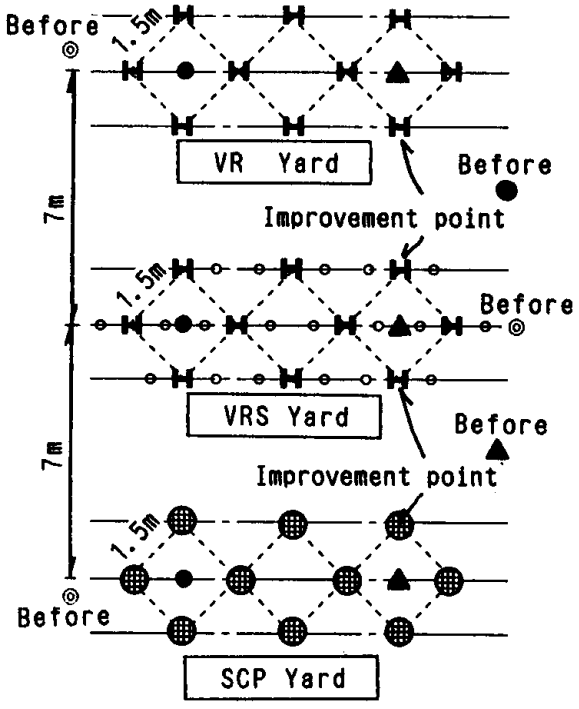

Fig.4 Arrangement of execution of improving methods and site investigations

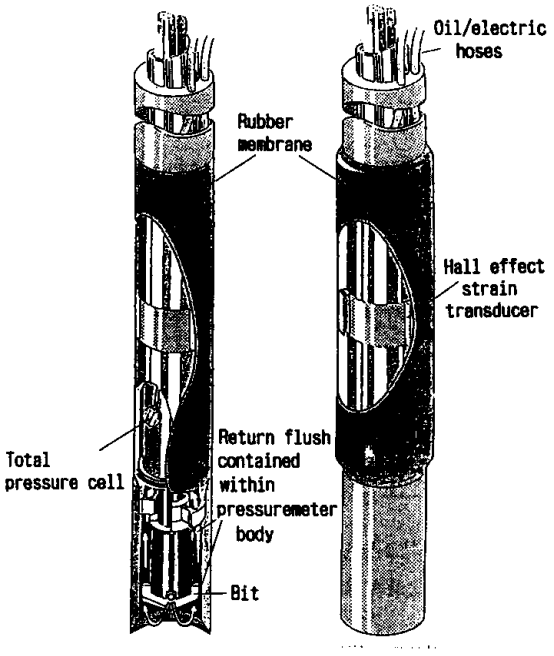

Fig.5 Selfboring pressuremeter used (after Clarke et al 1989)

The probe is 73.6mm in diameter and 450mm long,i.e.,the ratio of length to diameter is 6.1. The probe installs three displacement transducers located at 120 ° around the circumference,to measure the probe expansion with sensitivity of 0.001mm and a pressure transducer with maximum pressure of 5 MPa to measure inner pressure. The expansion of the membrane was stress-controlled and continued to over 10 % of radial strains. Before 5% of radial strain is over, several unload/reload cycles of different cavity strain amplitudes were included. Considering total investigation price economical,SBP testing was planned to perform at intervals of about 2 or 2.5m in depth of each boring hole. DMT was planned to use for making up data of SBP.

And it was performed using 1989-version equipment developed by Marchetti(1980).

The vertical depth increment used in DMT sounding is 20cm by advancing the blade using static push of boring rod.

5 CONPARISON OF EFFECTIVENESS ON EACH IMPROVING METHODS BY SBP TEST RESULTS

At first,to compare the effectiveness on each improving methods, typical SBP expansion curves of the ground before and after improved with three method at about 6m depth is shown in Fig.6. A group of each expansion curves on three localized displacement sensors are not always same, showing that their soil properties before and after improving work around the center point of probe is not necessarily uniform.

As no consensus exists on the method of avaraging, the arithmatical mean value of results interpreted from each expansion curve are mainly used to compare the rate of effectiveness of each improving works.

The mean lift-off pressures of three type of methods with depth are shown in Fig.7, which shows that densification by VR method is less effective than VRS- and SCP-method. Based on the analysis presented by Hughes et al(1977),the mobilised angle of friction ϕ' and the mobilised angle of dilation ψ are interpreted assuming the constant mobilised angle of friction ϕ' as 30°. The meanvalues of each depth on each ground on ϕ' and ψ are shown in Fig.8. From the concept that the more values of ϕ' and ψ show the more effectiveness by improving work, it is approximately judged on improved ground that the ground improved by VR-method came into looser state than that of pre-improved condition,and the grounds by VRS-and SCP- method were significantly changed into denser state. The increase of shear modulus may show the increase of

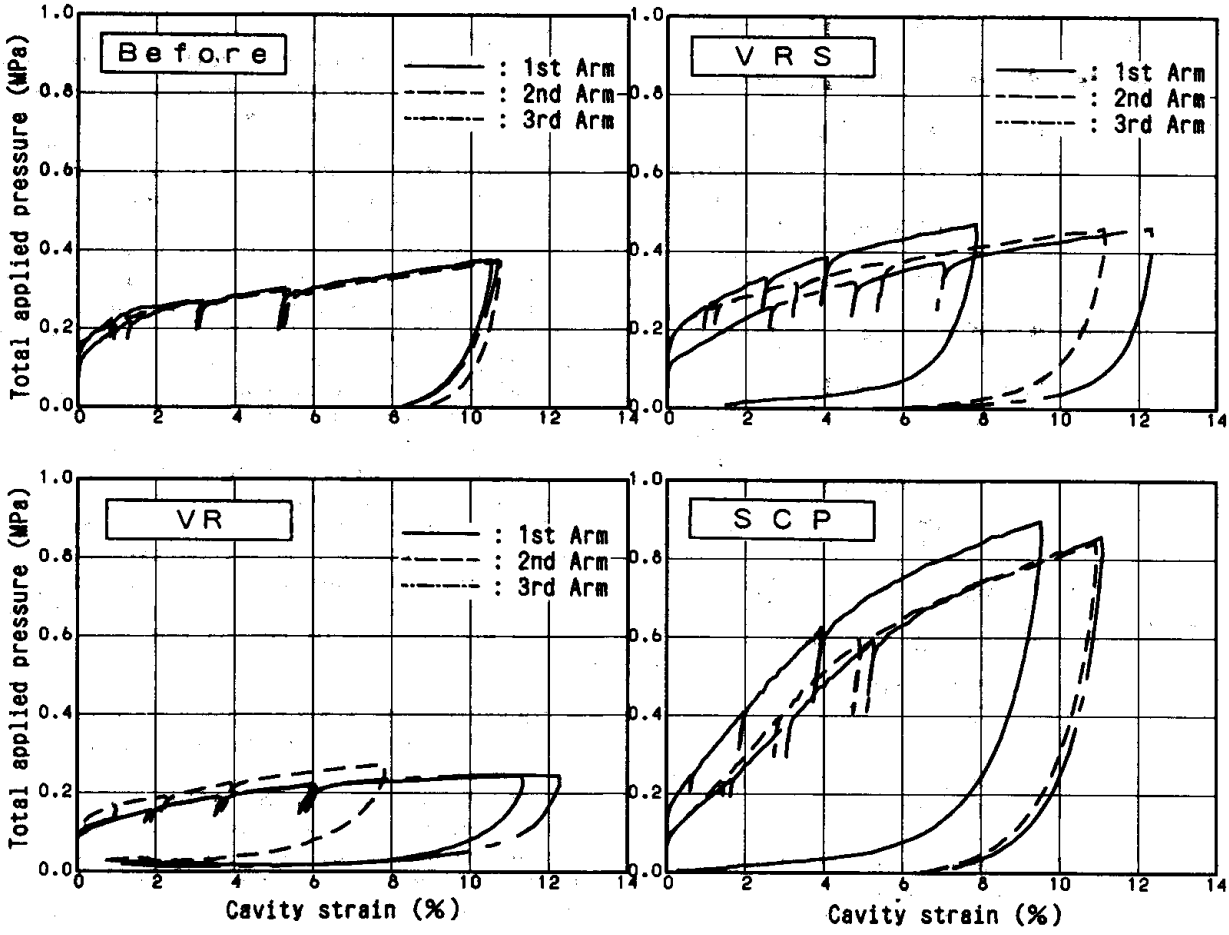

Fig.6 Typical expansion curves of SBP before and after improving works at the depth of about 6m

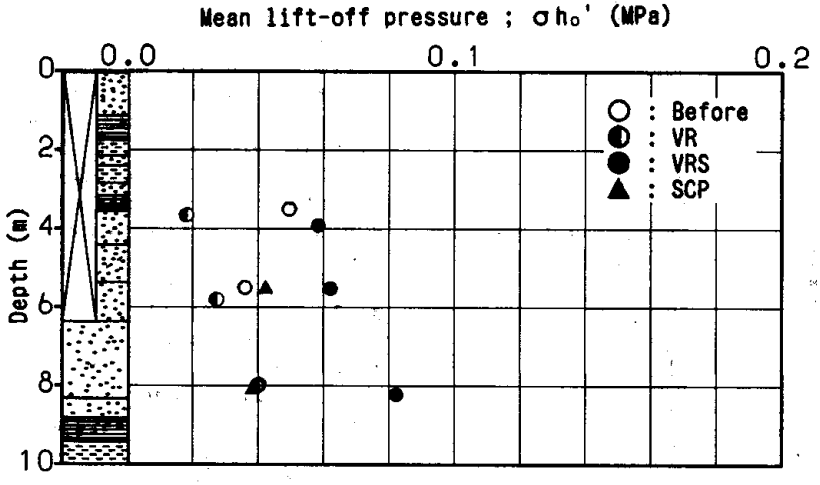

Fig.7 Mean lift-off pressure with depth

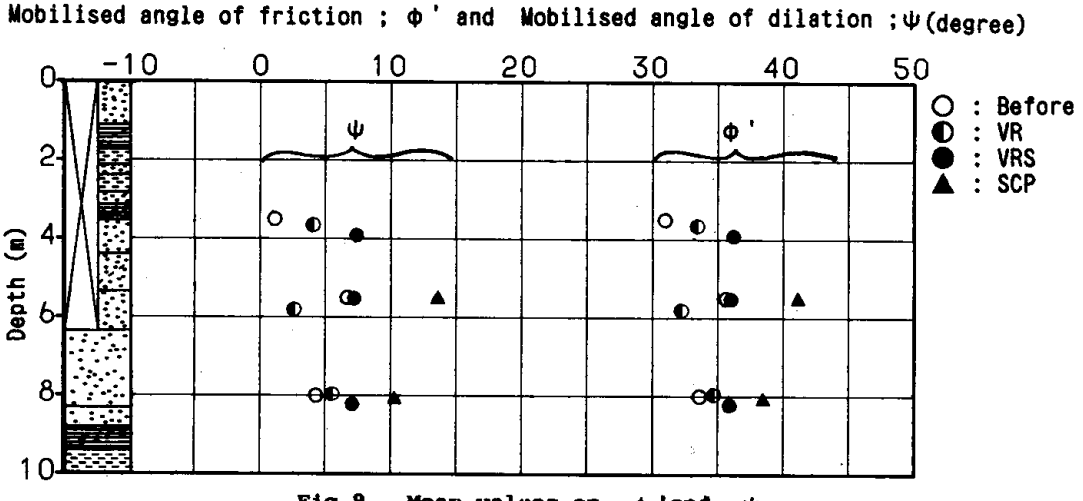

Fig.8 Mean values on ϕ 'and ψ

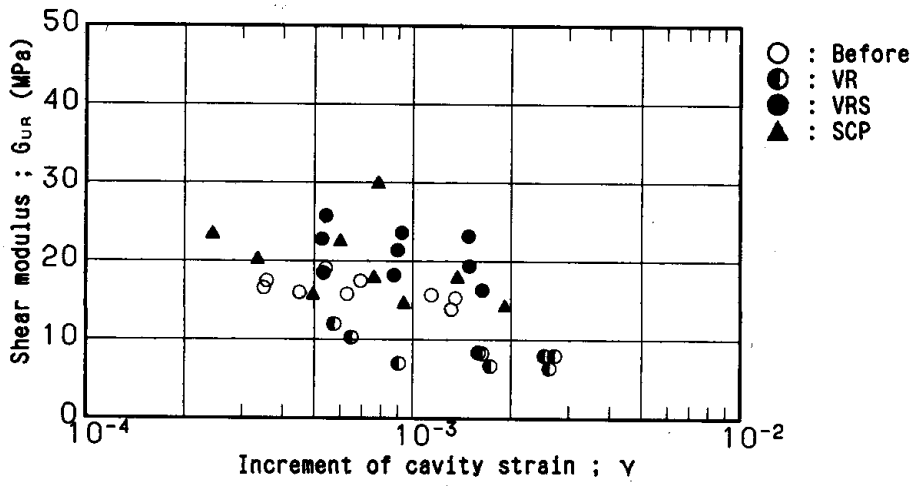

Fig.9 Shear moduli from unload -reload cycle of each displacement sensor against increment of cavity strain at the depth of about 6m.

densification by improving work. The shear moduli obtained from unload/reload cycle at the depth of about 6m with increment of cavity strain are shown in Fig.9.

All these shear moduli are values corrected on mean stress level as presented by Bellotti et al (1989).

Fig.9 shows that the effectiveness by various methods is concluded to be the same as mentioned in terms of ϕ ' and ψ .

6 INTERPOLATIVE INVESTIGATION USING DMT

Generally,the reclaimed ground is known to be not necessarily uniform. A few investigation data in complicated soil such condition may lead judgement to mistake. In order to confirm the validity of judgement according to the result of pressuremeter, results obtained from DMT were supplied.

Test result from DMT provides three indices denoted as:

$$\text{Marerial Index ; } I_D = \frac{p_1 - p_0}{p_0 - u_0}$$

$$\text{Horizontal Stress Index; } K_D = \frac{p_0 - u_0}{\sigma_{v0}'}$$

$$\text{Dilatometer Modulus; } E_D = 34.7\ (p_1 - p_0)$$

The use of these indices for predicting a variety of soil parameters was proposed by Marchetti(1980) who presented a series of empirical correlations based on more conventional laboratory and field test data.

The three indeces from DMT in the ground before and after the improving works is shown in Fig.10. Supposing the most affective factors due to densification are a coefficient of in situ horizontal stressat rest, K_0 and amobilized angle of

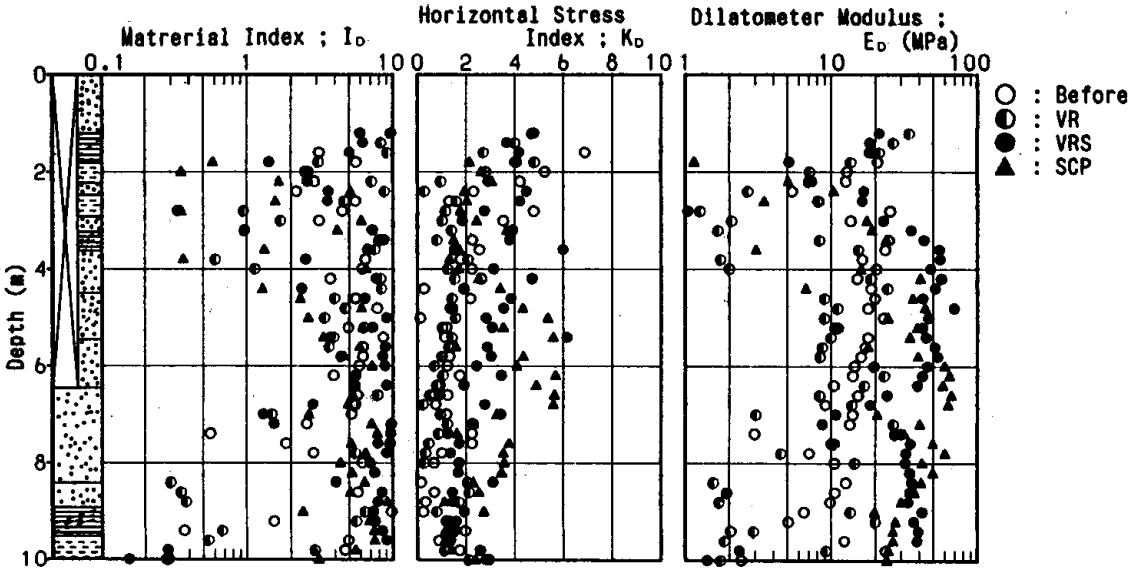

FIg.10 Indexes before and after improving works

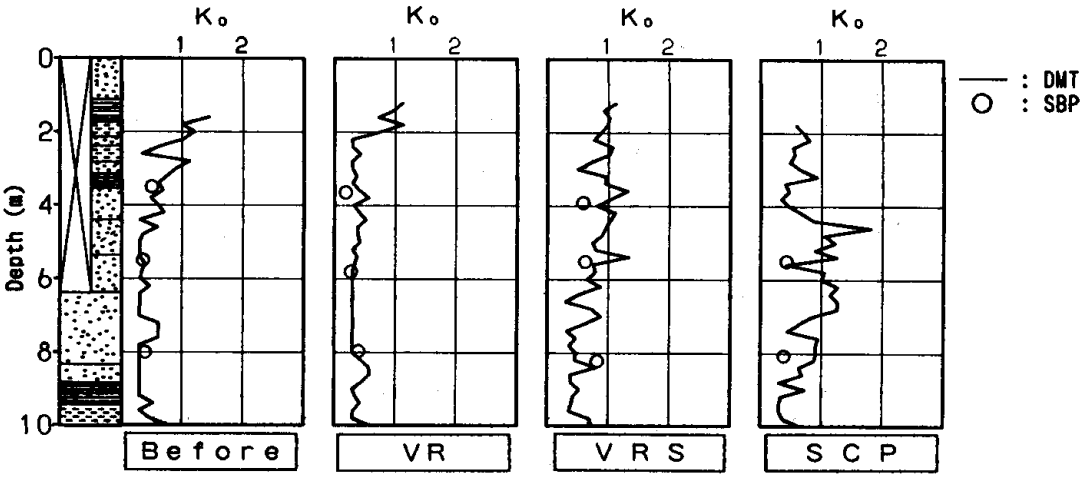

Fig.11 Horizontal stress at rest (K_o) interpreted from SBP and DMT

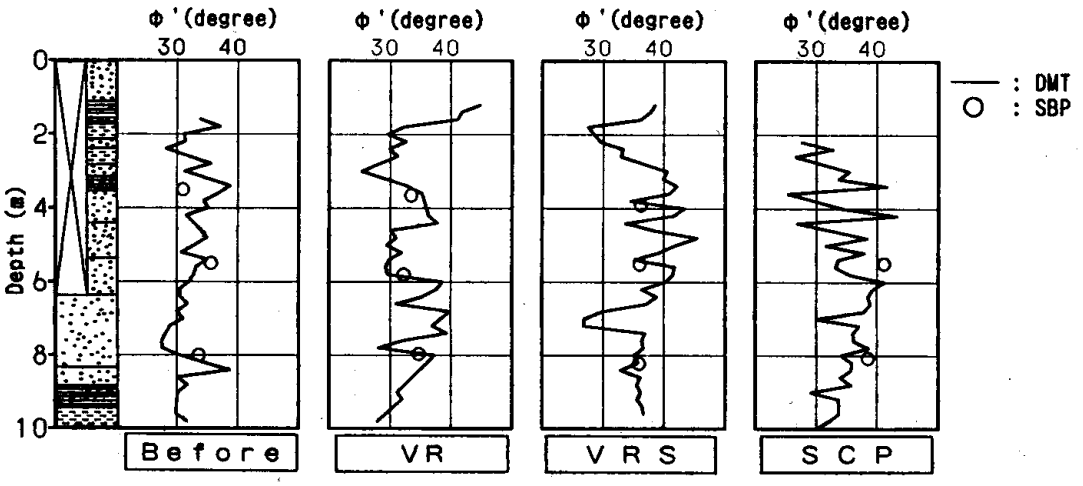

Fig.12 Mobilised angle of friction (ϕ ') interpreted from SBP and DMT

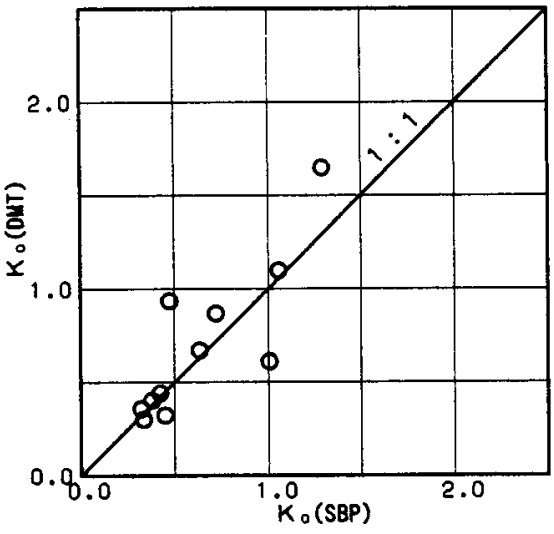

Fig.13(1) Correlation between K_o (SBP) and K_o DMT)

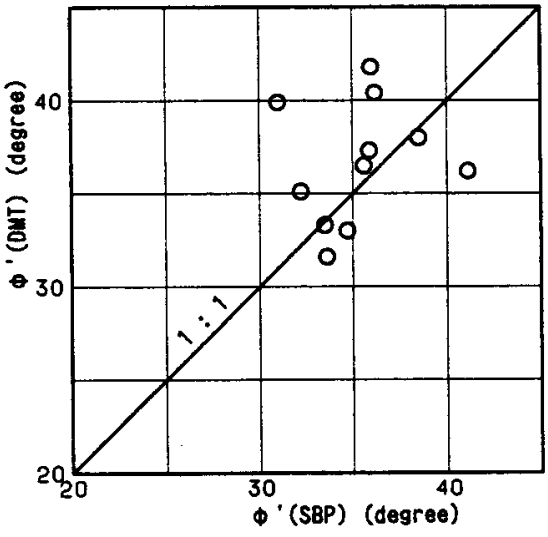

Fig.13(2) Correlation between ϕ' (SBP) and ϕ'(DMT)

friction, ϕ'.the variations of K_o and ϕ' with depth on each ground before and after improving work were shown in Fig.11 and Fig.12 to which the mean values interpreted from SPB data are added.From Fig.11 and Fig.12,it is judged that although the ground condition of site is not necessarily uniform, the effective grade of densificaion is almost the same between VRS-method and SCP-method, but VR-method makes clearly the foundation of ground looser.

7 RELATIONSHIP of K_o AND ϕ' OBTAINEDFROM TEST RESULTS BETWEEN SBP AND DMT

The mean values of K_o and ϕ'obtained from SBP test results are plotted with those from DMT of coresponding depth as shown in Fig.13.

Fig.13 indicates that each valuesof both SBP and DMT have some scatering relationship, but considering the foundation of ground to be not necessarily uniform, a relatively good agreement between both interpretated soil parameters should be estimated to be shown.

8 CONCLUSION

To compare the effectiveness of densification by three type of improving works, in-situ testing such as SBP and DMT was carried out in the field. Basically,SBP has theoretical background for deduced soil parameters, while DMT has only back ground from correlation of each soil parameters. Assuming the result from SBP as foundamental parametersand that of DMT as interpolative parameters, judgement on effectiveness of soil inproving method was started.

According to the results from those in-situ tests,it is concluded that VR method is not effective, rather to make ground looser,and VRS method is significantly effective as well as SCP method.

As SBP testing is much time-consuming and too much expensive, another in-situ test such as DMT should be used as interpolative test.

From this experience, SBP and DMT are very available means for estimating soil parameters on sandy soil.

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