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THE EFFECTIVENESS OF CEMENT STABILIZATION FOR PREVENTING LIQUEFACTION OF SATURATED SANDY SOILS

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ABSTRACT

Cement stabilization is considered to be a useful method for preventing the liquefaction of saturated sandy deposits. However, there has been no information on how grain size of soil affects its validity, up till now. In this paper, liquefaction tests on six kinds of soils which was mixed with OPC(ordinary portland cement) or UKC-H(OPC with a little gypsum) at cement content(C)=1, 2 and 5% are performed in order to clarify the relationship between the increase of liquefaction resistance induced by the addition of cement and the characteristics of grain size of soil. Furthermore, the relationship between the liquefaction resistance of treated soils and the unconfined compressive strengh is obtained.

KEYWORDS

Cement stabilization; liquefaction of sandy soils; pH of pore water; soil grain; unconfined compressive strength

INTRODUCTION

Recently, in order to develop and utilize the cement stabilization method for preventing the liquefaction of saturated sandy soils, many experiments were performed to examine the effect of the kind of cement and the addition of cement used, and consolidation time on the liquefaction resistance of specific sands(Saxena *et al.*, 1988, Clough *et al.*, 1989, Watanabe *et al.*, 1992, Okumura *et al.*, 1989, Yasuda *et al.*, 1991, Yamamoto et al., 1993, Editor committee of JSSMFE, 1993, Zen *et al.*, 1990). More recently, shaking table tests were performed to use this method as a measure of liquefaction of sandy soils such as back-fill ground behind a quay wall or reclaimed ground(Zen *et al.*, 1994). However, no available information has been obtained on the validity of this method in relation to the characteristics of grain size of soil.

In this paper, liquefaction tests on six kinds of soils mixed with OPC or UKC-H are performed in order to clarify the relationship between the ratio of the increase of liquefaction resistance induced by addition of cement, RL(Eq.1) and the grain size of soil. The effects of the kind and content of cement, and the pH of pore water on the RL are also investigated. Furthermore, the relationship between the liquefaction resistance and the unconfined compressive strength of treated soils is obtained.

Table 1. Physical properties of soils.

	Shingu sand	Toyoura sand	Silt	Ubemisaki silty sand	Ubenishioki clayey soil	Ube decomposed granite soil
G_s	2.640	2.642	2.643	2.665	2.430	2.635
U_c	1.69	1.71	1.90	3.46	17.2	55.0
D_{10} (mm)	0.45	0.12	0.035	0.052	0.005	0.02
D_{50} (mm)	0.81	0.21	0.066	0.15	0.074	0.775
D_{max}(mm)	2.00	0.84	0.106	2.00	2.00	4.75
w_L (%)	NP	NP	35.8	NP	29.2	28.8
w_P (%)	NP	NP	NP	NP	26.5	NP
I_P	NP	NP	NP	NP	2.7	NP
e_{max}	0.851	0.941	1.261	1.027	1.518	0.950
e_{min}	0.624	0.643	0.722	0.658	0.852	0.673
F_{clay}(%)	0.0	0.0	0.0	0.0	9.0	5.0
FC (%)	0.0	0.0	62.5	13.3	51.7	16.4
	SP	SP	ML	SM	CL	SM

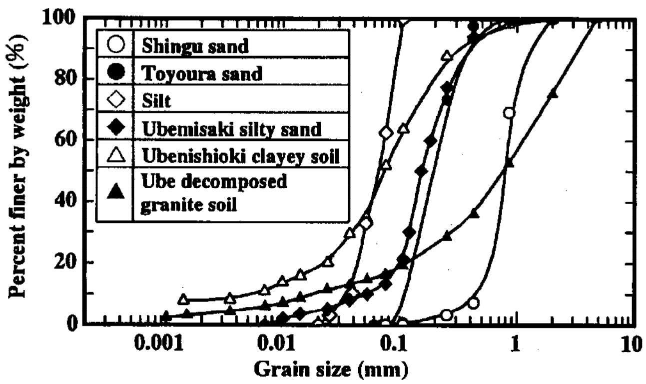

Fig.1. Grading curves of soils.

SAMPLES AND TEST PROCEDURES

Soils and cement used

Six kinds of soils ranging from sand to cohesive soil were used in this study. Their physical properties and grading curves are given in Table 1 and Fig.1, respectively. Silt was prepared by crushing Toyoura sand. Ubemisaki silty sand was obtained from the shallow portions of a sea bed. Although the pH value of pore water of this soil is 3.2, others ranged from about 6 to 7. The ordinary portland cement(OPC) and UKC-H (OPC with a little gypsum) were used as a cement fixing agent. The latter cement has mainly been developed for soil improvement of soft grounds.

Test procedures

Cyclic triaxial test apparatus was used. The detail of this apparatus is mentioned in our previous paper(Ōhara *et al.*, 1991).

Liquefaction tests on each soil mixed with OPC or UKC-H were performed as follows. First, saturated soil specimens mixed with cement of C=0%, 1%, 2% and 5% were prepared in a triaxial cell. The specimen was 5cm in diameter and about 12cm in height. The C was defined as the ratio of cement to the dry weight of soil.

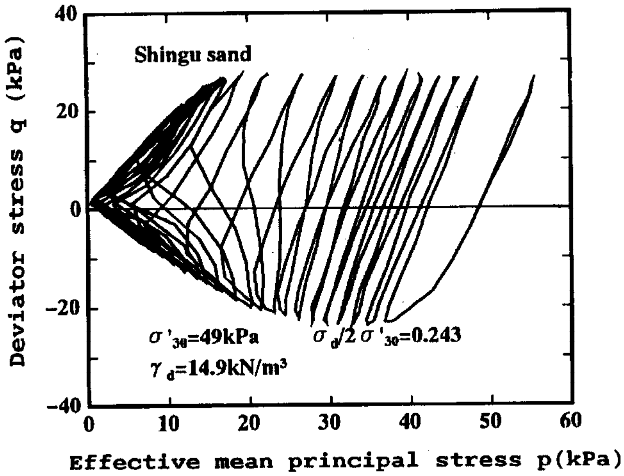

Fig. 2. (a). Effctive stress path (Shingu sand).

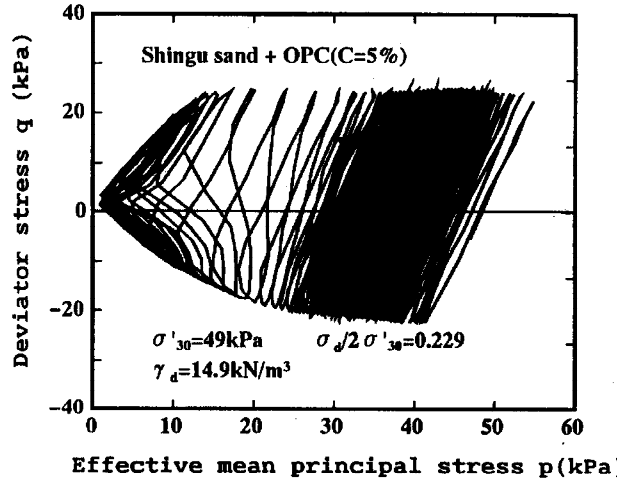

Fig. 2. (b). Effctive stress path (Shingu sand+OPC(C=5%)).

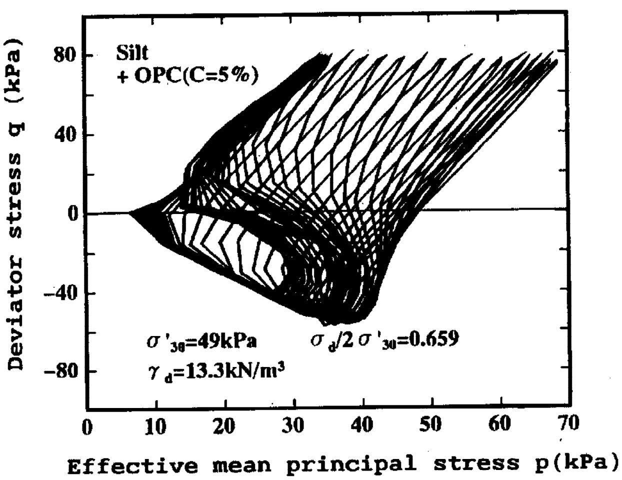

Fig. 3. (a). Effctive stress path(silt).

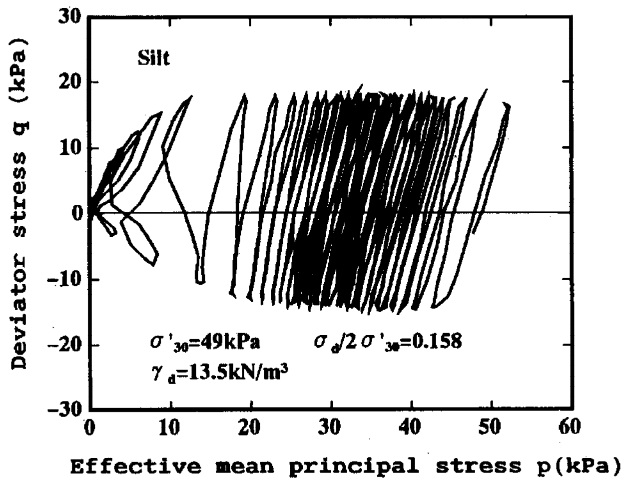

Fig. 3. (b). Effctive stress path (silt+OPC(C=5%)).

The specimen was then consolidated at a confining pressure σ'_{30} =49kPa for 1 day. Thereafter, cyclic deviatoric stress σ_d with a period of 2.0sec and a constant amplitude was applied to the specimen under undrained conditions. During the tests the pore water pressure in the specimen, the axial displacement of the specimen and the cyclic deviatoric stress were measured. In this paper the occurrence of liquefaction was defined when the double amplitude axial strain of the specimen reached 5%.

TEST RESULTS AND DISCUSSIONS

Typical liquefaction resistance curves for treated soils

Figs.2(a) and (b) show the typical effective stress paths for untreated and treated Shingu sand mixed without and with OPC(C=2%), respectively. Also, Figs.3(a) and (b) show the similar results for untreated and treated silt, respectively. As mentioned below, Shingu sand and silt have the smallest and the largest increases of liquefaction resistance induced by the addition of cement. As can be seen in Figs.2 and 3, although the effective stress p of the treated Shingu sand becomes zero similar as that of untreated one, the p of the treated silt never disappear.

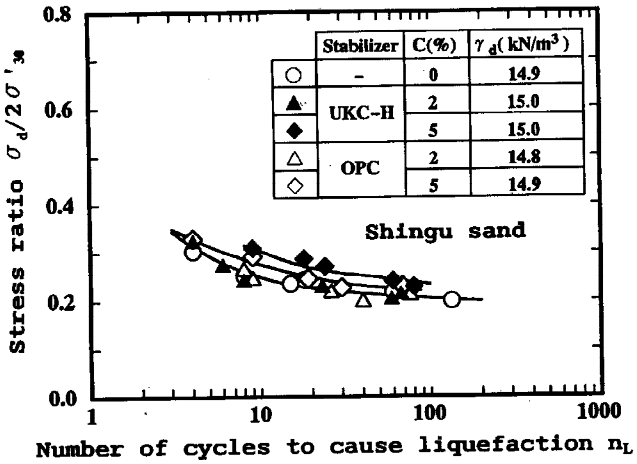

Fig. 4. (a). Liquefaction resistance of treated Shingu sand.

It was seen from the scanning electron micrographs for untreated and treated soils that although in the case of Shingu sand the bonding between soil particles with the addition of OPC did not occur, in the case of silt the bonding between smaller soil particles clearly occurred. Shingu sand consists of relatively larger and uniform soil particles. On the contrary, silt consists of relatively smaller and very fresh soil particles. Therefore it is thought that, due to the difference between grain size of both soils, different soil skeltons which affect the undrained stress paths of treated soils are induced.

Figs. 4(a), (b) and (c) show the relations between the stress ratio $\sigma_d/2\sigma'_{30}$ and the number of cycles to cause liquefaction n_L (liquefaction resistance curves) for treated Shingu sand, silt, and Ubemisaki silty sand, respectively. It may be noted that the liquefaction resistance curves for treated Shingu sand with cement of C=5% is almost the same as that of untreated Shingu sand. On the other hand, the curve fortreated silt with only cement of C =2% is considerably above that of untreated silt. No increase of liquefaction resistance of Ubemisaki silty sand by the addition of cement was obtained in the case of pH=3.2. This result is in agreement with the expectation that the static strength of acid soil would not increase through the addition of cement.

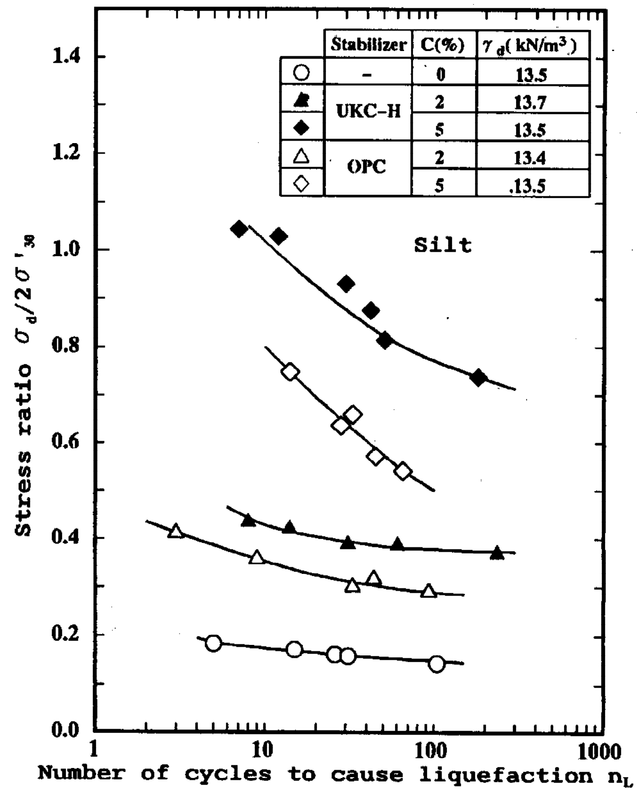

Fig. 4. (b). Liquefaction resistance of treated silt.

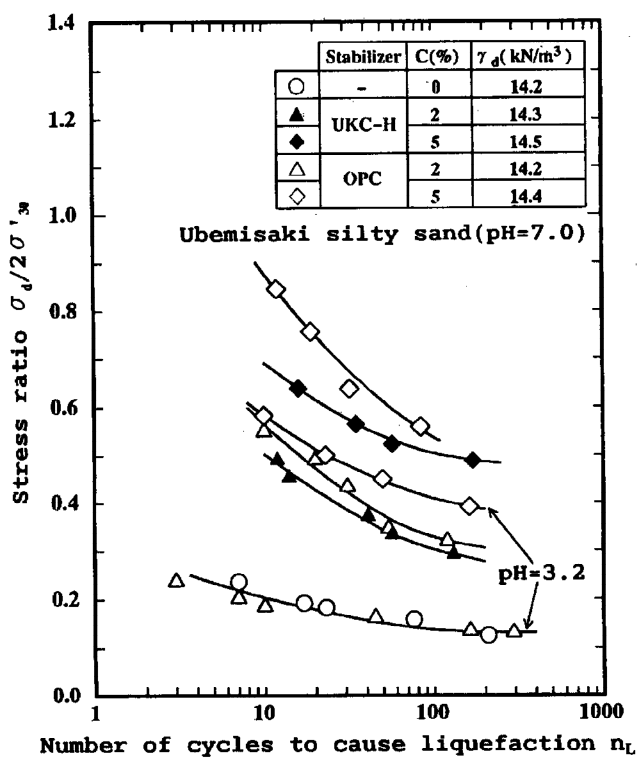

Fig. 4. (c). Liquefaction resistance of treated Ubemisaki silty sand.

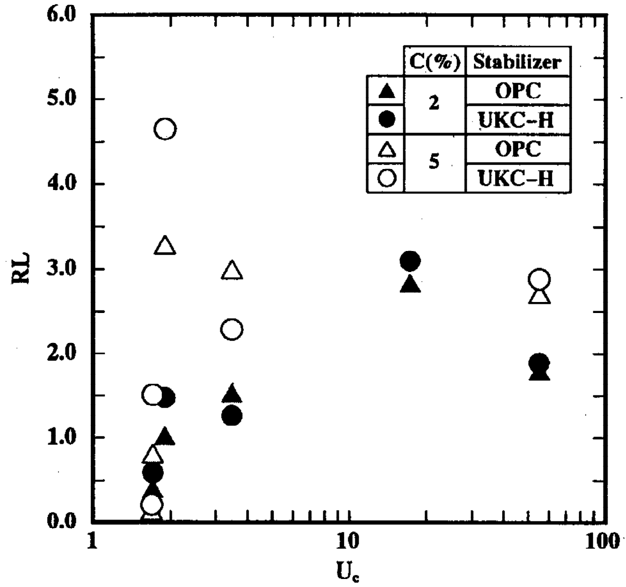

Fig.5. Relation between RL and U_c.

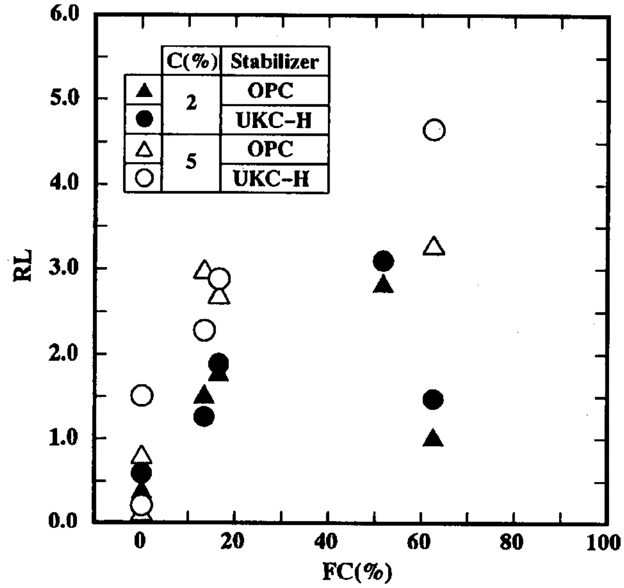

Fig.6. Relation between RL and FC.

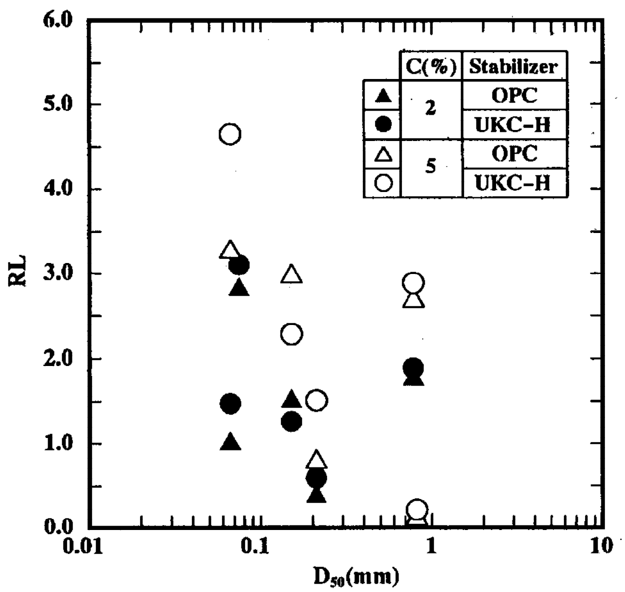

Fig.7. Relation between RL and D_{50}.

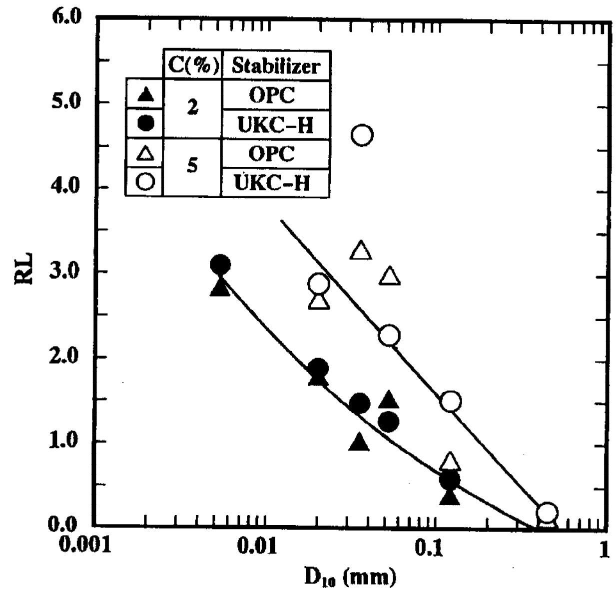

Fig.8. Relation between RL and D_{10}.

Effect of grain size on RL of treated soils

We defined RL (Eq.1) as an index representing the increase of liquefaction resistance of soils induced by the addition of cement.

$$RL = \{(R_{20})_c - (R_{20})_{c=0}\} / (R_{20})_{c=0} \qquad (1)$$

where $(R_{20})_c$ and $(R_{20})_{c=0}$ are the liquefaction resistance of treated and untreated soils, respectively.

The RL obtained for each soil are plotted with U_c, FC, D_{50} and D_{10} as shown in Figs.5 ~8, respectively. It is found from these figures that although the RL has no good correlations with U_c, FC and D_{50}, it has a good correlation with D_{10} for C=2% and 5% irrespective of the kind of cement. Namely, the RL increases with decreasing D_{10}. The

Table 2. Test conditions of other studies.

	Soil	Stabilizer	σ'_{30} (kPa)	t (days)	Researcher	
(a)	Niigata EP sand	PBSC typeB	?	34	Zen et al.	(1993)
(b)	Toyoura sand	OPC	98	2	Watanabe et al.	(1992)
(c)	Monterey No. 0/30	PCtype II	?	14	Clough et al.	(1989)
(d)	Monterey No. 0	PCtype I	98	15	Saxena et al.	(1988)
(e)	Toyoura sand	OPC	49	1	Yasuda et al.	(1991)
(f)	Toyoura sand	OPC	49	7	Yasuda et al.	(1991)
(g)	Toyoura sand	OPC	49	28	Yasuda et al.	(1991)
(h)	Toyoura sand	Sorstar	49	1	Yasuda et al.	(1991)
(i)	Toyoura sand	Sorstar	49	7	Yasuda et al.	(1991)
(j)	Toyoura sand	Sorstar	49	28	Yasuda et al.	(1991)
(k)	Chiba Mt. sand	OPC	49	7	Yasuda et al.	(1991)
(l)	Chiba Mt. sand	Sorstar	49	7	Yasuda et al.	(1991)
(m)	Decomposed granite	OPC	49	7	Yasuda et al.	(1991)
(n)	Decomposed granite	Sorstar	49	7	Yasuda et al.	(1991)

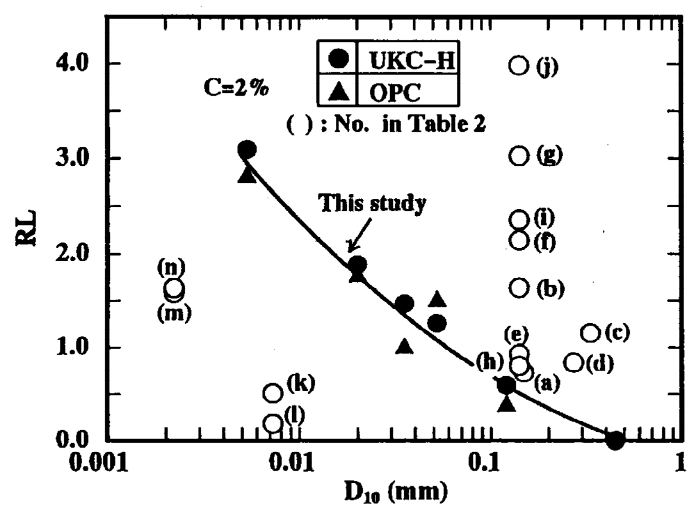

Fig. 9. Relation between RL and D_{10} obtained from other studies.

reason for this interesting experimental result is explained as follows. As mentioned before, the bonding between soil particles by the addition of cement were mainly brought about by smaller soil particles. Therefore RL has a unique correlation with D_{10} representing the size of the smallest soil particle of all indexes of soil grain.

The relation between the RL and D_{10} for treated soils with C=2% obtained by other researchers are shown in Fig. 9. Each test conditions are given in Table 2. It can be seen from this figure that contrary to our expectation, no good correlation was obtained between the both relations except for data (a), (e) and (h). The latter two data are of Toyoura sand and were obtained by almost the same test as ours. Therefore, the differrences in the relation between the RL and D_{10} obtained in our study and in others may be due mainly to the difference of a consolidation or curing method.

<u>Relationship between $(R_{20})_c$ and q_u for treated soils</u>

Uniaxial compression tests were performed on treated soils prepared by the consolidation in a triaxial cell. Fig. 10 shows the relationship between unconfined

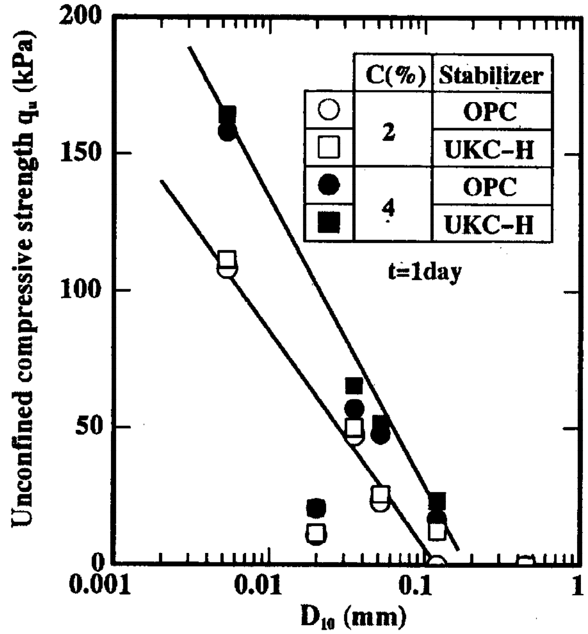

Fig. 10. Relation between q_u and D_{10}.

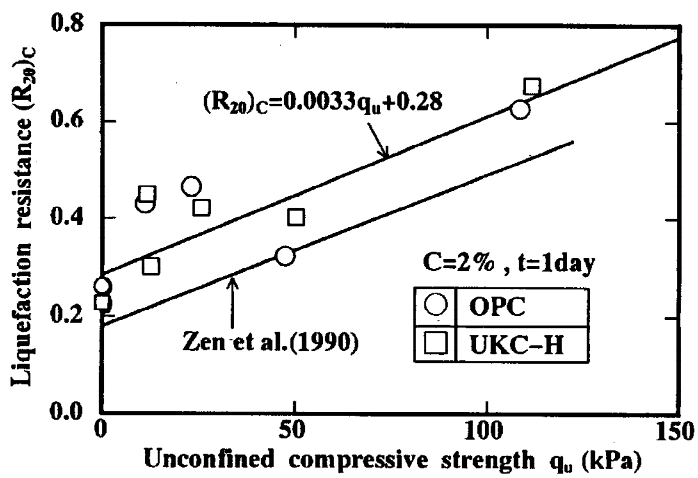

Fig. 11. Relation between $(R_{20})_C$ ' and q_u.

compressive strength q_u and D_{10} for treated soils with cement of C= 2% and 4%, respectively. It is interesting that in this figure that q_u linealy increases with the logarithm of D_{10} for C=2% and 4% irrespective of the kind of cement.

Fig. 11 represents the relation between $(R_{20})_c$ and q_u for treated soils with OPC and UKC-H of C=2%. Except for a fewscatters in small measured values, $(R_{20})_c \sim q_u$ relation may be given by a straight line(Eq. 2).

$$(R_{20})_c=0.0031q_u+0.30 (C=2\%,\ q_u:kPa) \quad (2)$$

Almost the same inclination as that of Eq. 2 was obtained previously(Zen et al., 1990).

CONCLUSIONS

Cyclic triaxial tests on six soils ranging from sand to cohesive soil mixed with OPC or UKC-H are performed mainly in order to clarify the effect of grain size on the validity of the cement agent method for preventing the liquefaction of sandy soils. The following conclusions were obtained from the tests.

1) The RL defined as an index representing the increase of liquefaction resistance by the addition of cement increases with decreasing D_{10} and has no correlation with other indexes of grain size.
2) Although effectiveness is not expected by the addition of cement, even in the case of C=5% for Shingu sand, which consists of larger grain particles and bad grain size. On the contrary, it is adequately expected only in the case of C=2% for silt, which consists of smaller and fresh grain particles.
3) Liquefaction resistance of Ubemisaki silty sand with pH=3.2 never increases by the addition of cement.
4) Liquefactin resistance of treated soils $(R_{20})c$ has a linear relation with q_u irrespective of the kind of soil. Namely, $(R_{20})_c=0.0033q_u + 0.28$ (C=2%, q_u:kPa).

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REFERENCES

Clough, G.W., J. Iwabuchi and T. Kuppusamy (1898). Influence of cementation on liquefaction of sands. *Journal of Geotechnical Engineering Division, ASCE*, **115**, **8**, 1102-1117.

Editor committee of JSSMFE (1993). Survey・design to construction for measure of liquefaction, *JSSMFE*(in Japanese)

Ōhara, S. and T.Yamamoto(1991). A practical method for obtaining correction factor of liquefaction resistance for membrane penetration. *Soils and Foundations*, **31**, **2**, 188-196(in Japanese).

Okumura, T., K. Narita and Y. Ohne (1989). Undrained cyclic shear strength of artificially cemented sands. *Soils and Foundations*, **29**, **2**, 169-180 (in Japanese).

Watanabe, N., T. Mori and H. Hamada(1992). Shaking table tests for the liquefaction countermeasure using cement suspension. *Proc. of the 27th Japan National Conference on Soil Mechanics and Foundations Engineering*, 1157-1158(in Japanese).

Saxena, S. K., K. R. Reddy and A.S. Avramidis (1988). Liquefaction resistance of artificially cemented sand. *Journal of Geotechnical Engineering Division, ASCE*, **114**, **12**, 1395-1413.

Yamamoto, T., S. Ōhara, K. Horibuchi and T. Suzukawa(1993). Cement fixing method for preventing liquefaction of saturated silty sand deposit. *Ground Engineering*, **11**, **1**, 83-88(in Japanese).

Yasuda, S., H. Nagase, K. Koseki, H. Shima and H. Matsueda (1991). Undrained cyclic shear strength of soils with lime or cement. *Proc. of the 26th Japan National Conference on Soil Mechanics and Foundations Engineering*, 853-854(in Japanese).

Zen, K., H. Yamazaki and Y. Sato(1990). Strength and deformation characteristics of cement treated sands used for premixing method. *Report of the Port and Harbour Research Institute*, **29**, **2**, 85-118(in Japanese).

Zen, K., T.Tateshita,A. Sawatari and S.Nagai(1993). Static and dynamic characteristics of treated grounds at in-situ tests of premixing method, *Proc. of the 48th Annual Meeting of JSCE*, 500-501(in Japanese).

Zen, K.(1994). Remedial measures for reclaimed land by premixing method. *Tsuchi-to-Kiso, JSSMFE*, **42**, **2**, 37-42(in Japanese).