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Technical Report No1

MODIFIED DESIGN PROCEDURE OF SAND COMPACTION PILE (SCP) METHOD FOR LIQUEFACTION MITIGATION CONSIDERING ARTIFICIALLY UNSATURATED GROUND CONDITION

ABSTRACT

Sand Compaction Pile (SCP) method has been widely used to mitigate liquefaction in Japan since 1950's and had great effects even though huge earthquakes attacked so far. It can create compacted and expanded sand piles in the ground by using 'Bottom feed sand supply system' with up-and-down sequence together with the aid of compressed air. According to the recent research program, unsaturated ground condition has been observed in the frozen soil samples from SCP improved ground that have been extracted 26 years after the SCP work (Okamura, 2003, 2004). The compressed air that had been ejected during SCP operation has remained into the void between soil particles and not dissipated even such long periods. And this unsaturated condition of the ground increases resistance against liquefaction significantly and consequently prevents serious ground settlement during seismic event. In this report, by utilizing this unique effect, new SCP design procedure was proposed to reduce the spacing of SCP without compromising liquefaction mitigation effect.

Keywords, Liquefaction mitigation, Sand compaction pile, design, Unsaturated soil condition

INTRODUCTION

The typical procedure of SCP is shown in Figure 1. In this report, first the records of unsaturation in the ground due to SCP installation are introduced. Then new design procedure is proposed and verified with using actual data in the SCP improved site in Urayasu city where serious settlement damages were observed at the Tohoku earthquake in 2011.

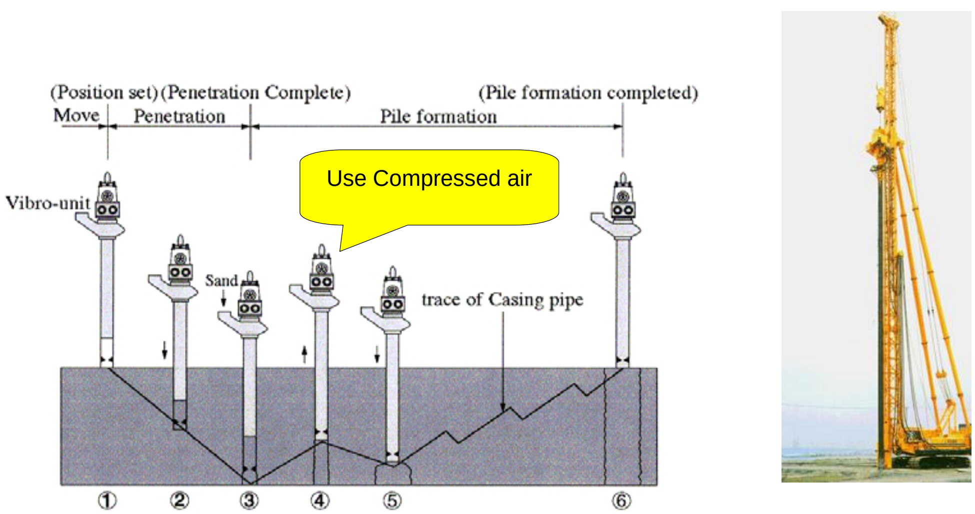
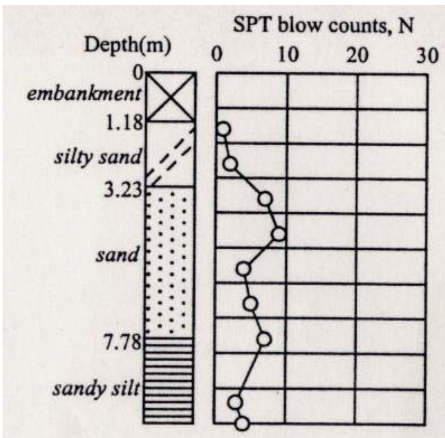


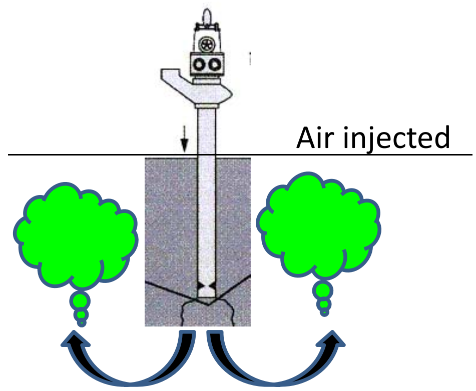
Figure-1 Work Sequence of Sand Compaction Pile

CASE HISTORIES OF UNSATURATED CONDITION AT IMPROVED GROUND BY SCP

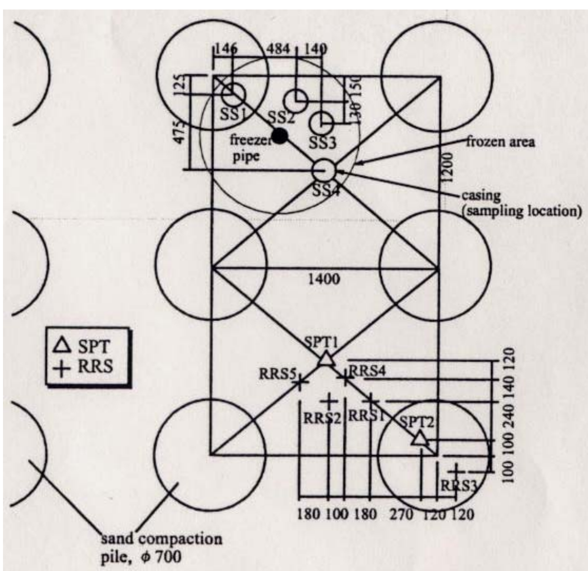
Public works research institute (PWRI) in Japan has started soil investigation and extraction of subsurface soil samples with accurate frozen sampling and performed saturation test of the samples at more than 10 SCP improved sites since 2002, and reported that even 26 years after the SCP installation, unsaturated condition of the ground is still remained. (Okamura et.al., 2003(1), Okamura et.al., 2003(2), Okamura et. Al., 2004, Soga., et. Al., 2005)



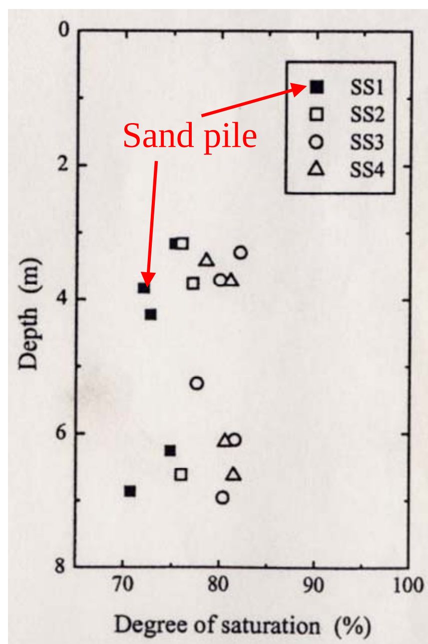
(a) SPT data before SCP improvement



(b) Air injection into the sand layer



(c) Sampling location



(d) Results of unsaturated condition

Figure 2 Results of unsaturated condition after SCP installation (Okamura et.al., 2003(1))

3. New design procedure of SCP by considering unsaturated condition

Figure-2 shows degree of saturation of samples together with other indexes such as void ratio, fines content and 5% particle size. There is correlation between fines content and degree of saturation as the red curve on the graph. This correlation is summarized in Table-1.

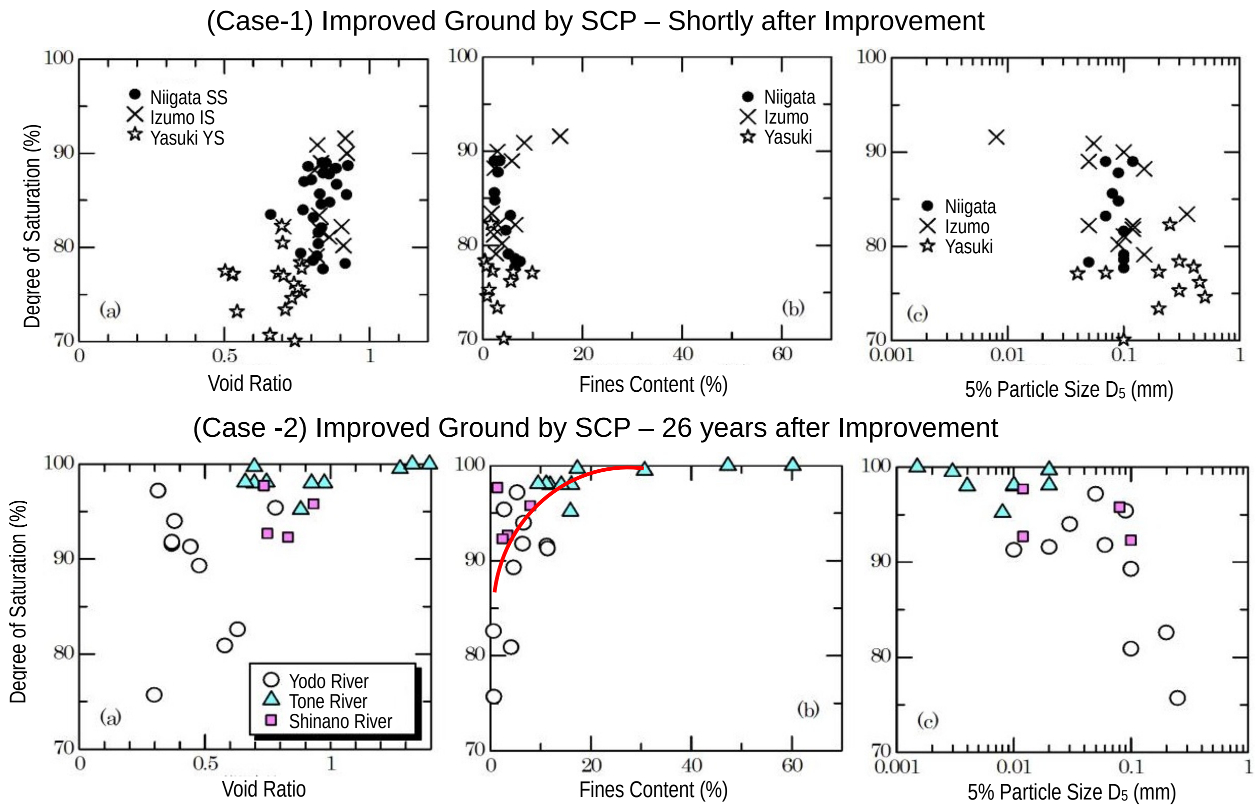


Figure-2 Soil profile and saturation degree at SCP improved ground (Okamura et.al., 2004, red line is making by Fudo)

Table-1 Fines Content (Fc) and Degree of Saturation (Sr)

Fc (%)	Sr (%)
5	90
10	95
15	97
20	98
25	99
30	100
>35	100

Figure-3 is the results of laboratory testing by Okamura et al. (2005). This graph shows the increase of liquefaction strength with unsaturated condition. Depending on this graph, we have estimated the increase rate of liquefaction resistance (Rscp) by degree of saturation as Table-2.

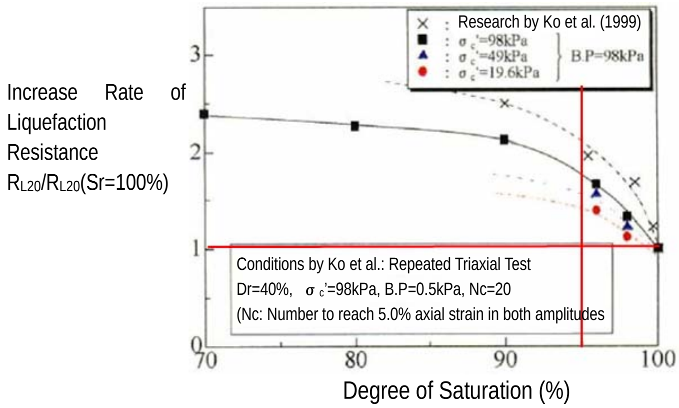


Figure-3 Increase Rate of Liquefaction Resistance by Degree of Saturation (Soga, et. al., 2005)

Table-2 Fc, Sr and Increase Rate of Liquefaction Resistance

Fc (%)	Sr (%)	Increase Rate (Rscp)		
		Depth (m)		
		0-5m	5-10m	>10m
5	90	1.5	1.7	2.2
10	95	1.4	1.6	1.7
15	97	1.3	1.4	1.5
20	98	1.1	1.2	1.3
25	99	1.0	1.1	1.2
30	100	1.0	1.0	1.1
>35	100	1.0	1.0	1.0

By considering the increase rate of liquefaction resistance, we propose the following new design flow to mitigate liquefaction of the ground by using SCP. This new design is expected to realize more economical design of SCP such as smaller diameter of sand/stone piles and wider spacing between piles.

(1) Estimate degree of saturation from Soil profile

↓

(2) Estimate increase rate of liquefaction resistance from estimated degree of saturation

↓

(3) Use the increased liquefaction resistance (Rscp) at usual SCP/Stone Column design

Figure-4 New SCP Design Flow

4. Trial design calculation

By using the new design procedure as shown in Figure-4, we have conducted trial design calculation based on the following conditions:

(1) PGA=0.31
(2) Underground water level: GL.-1.0m
(3) Fines content of soil to be treated: Fc=5% → Increase rate (Rscp): See Table 3
(4) Thickness of liquefable layer: 15m
(5) SPT N-Value of liquefable layer: 3-7

According to the calculation, the required improvement ratios by SCP in the case of both considering and not considering unsaturated condition are presented in Table-3. Significant decrease of improvement ratio is achieved by considering unsaturated condition.

Table-3 Required Improvement Ratio by SCP

	Considering Unsaturated Condition	Not Considering Unsaturated Condition	Rate
Fine Content 5%	10%	16%	0.63
10%	13%	18.5%	0.70
20%	18%	22%	0.85
30%	24%	24%	1.0

5. Verification Procedure of Unsaturated Condition

For the verification of densification, P-wave velocity testing together with SPT (or CPT) and it is cost effective as shown in Appendix-1 and Appendix-2. In general, P-wave velocity of saturated ground is approximately 1500m/sec; however, after compressed air is injected into the ground, the velocity is significantly reduced to less than 500m/sec.

Although the new design procedure realizes drastic reduction of improvement ratio by SCP, the maximum spacing between each sand pile should be less than 2.3m according to our past experience.

Reference

Harada, K, Nozu, M, Matsushita, K, and Sakakibara, M, 2015, Consideration on Liquefaction Resistance of Ground Improvement by the Sand Compaction Pile Method, DFI Annual Conference

Okamura et.al, 2003, Liquefaction resistance of sand deposited improved with sand compaction piles, Soils and Foundations, Vol. 43, No.5, 175-187, Japanese Geotechnical Society

Okamura, M, Ishihara, M, Tamura, K: Degree of saturation of sand improved with SCP 27 years ago, Proceedings of JGS annual symposium, 2003.

Okamura et.al, On liquefaction resistance and degree of saturation of sand improved with SCP, Proceedings of 38th JGS annual symposium, 2003.

Okamura, M, Ishihara, M, Tamura K, 2004, Investigation of saturation degree at SCP improved ground, Proceedings of 39th JGS annual symposium (in Japanese).

Soga, Y., Okamura, M, Yatabe, R, 2005, Liquefaction resistance of a Partially Saturated Sand with reference to Air Compressibility, Proceedings of 40th JGS annual symposium. (in Japanese)

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Appendix-1 P-wave Velocity Testing at SCP Improved Ground #1

P-wave velocity (Vp) testing was performed at SCP improved site. Vp of improved soils by SCP was measured less than 500m/sec that was much lower than that of usual saturated ground (1500m/sec).

* *Okamura, M, Ishihara, M, Tamura, K: Degree of saturation of sand improved with SCP 27 years ago, Proceedings of 38th JGS annual symposium, 2003.*

Figure-A1 P-wave & SPT Test Location

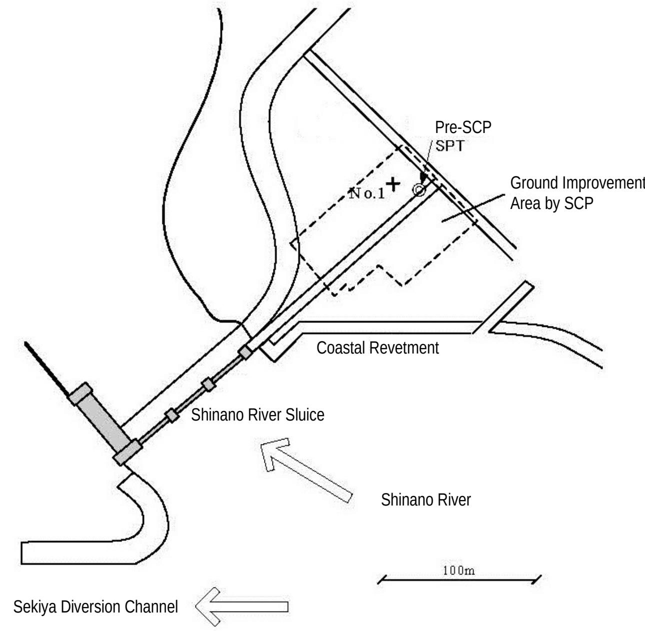
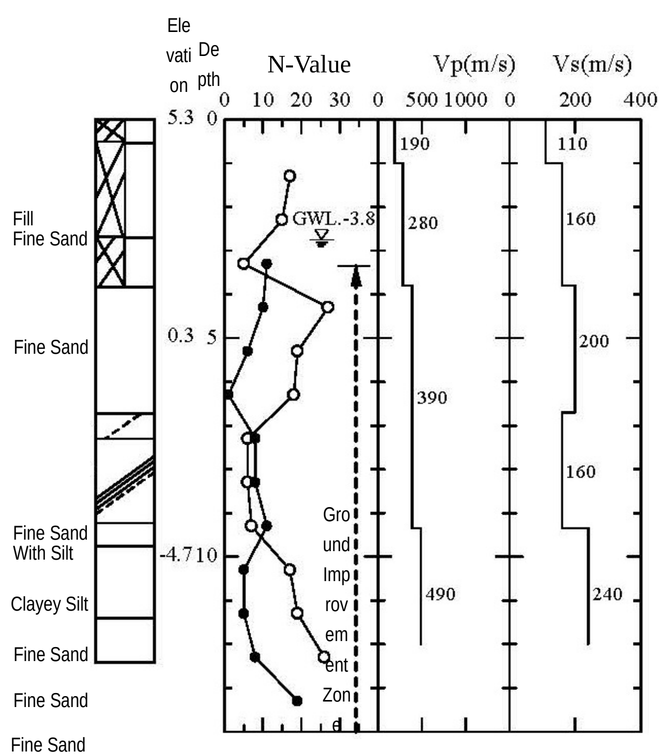


Figure-A2 Test Results at No.1 Test Location



Appendix-2 P-wave Velocity Testing at SCP Improved Ground #2

P-wave velocity (Vp) testing was performed at SCP improved yard. Vp was observed at very low value such as less than 500m/sec although it should be 1500m/sec in usual saturated ground.

** Aochi, K, Uchida, A, Hayashi, K.: Measurement of sand-compaction pile related velocity change using seismic exploration methods, Proceedings of 40th JGS annual symposium, 2005.*

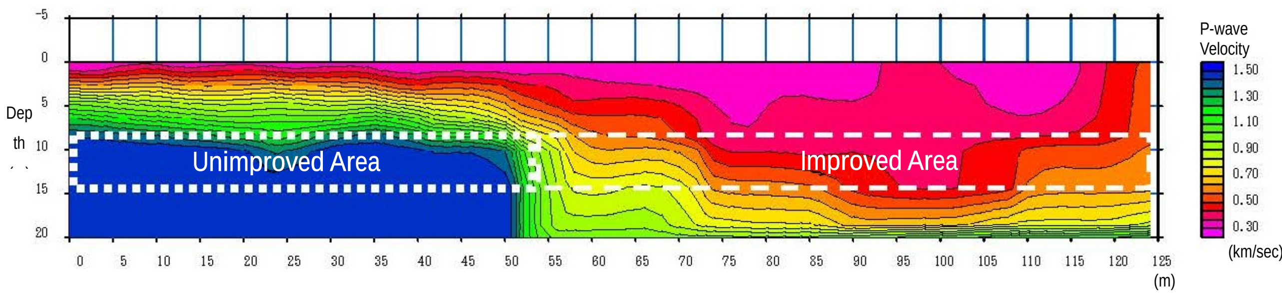


Figure-A3 P-wave Velocity Section

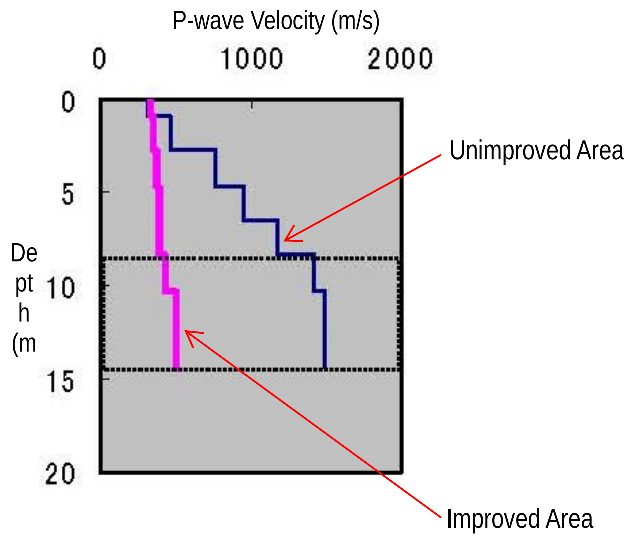


Figure-A4 P-wave Velocity by Depth