The Effect of Particulate Grouting With Bentonite in Wellingdon Island Soil Under Cyclic Triaxial Load along with SEM

Dipty Sarin Jacob[1], Anilkumar P S[2], Jain Suzan Zachariah[3]

[1]Assistant Professor, Department of Civil Engineering, SAINTGITS College of Engineering, Kerala, India
[2] Associate Professor, Department of Civil Engineering, Government Engineering College, Thrissur , Kerala, India
[3]PG student, Department of Civil Engineering, SAINTGITS College of Engineering, Kerala, India

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Abstract - *The Project mainly aimed at conducting an experimental study for improving the resistance offered by Wellingdon Island soil against possible threat of liquefaction, as Wellingdon Island in Cochin is the centre point of major offshore constructions and trade in Kerala, South India. For the same, undisturbed samples were collected from a site at Cochin, in Wellington Island near Lakshadweep Development Corporation limited, an area under the Cochin Shipyard limited, which has gained environmental clearance for an upcoming project worth Rs.1.5 crores . The experimental program mainly constitutes cyclic triaxial tests along with the determination of plasticity index and SEM analysis. The undisturbed marine soil samples, with increasing proportion of the particulate grouting material, Bentonite, have been obtained by pumping the Bentonite of appropriate consistency after conducting the Marsh funnel test, over the samples under pressure as per IS specifications. The experimental study proved to be appreciable in improving the resistance of the Wellington Island soil with increasing Bentonite concentration in the samples. The results from cyclic triaxial tests point towards better resistance to liquefaction; when samples were loaded at a frequency of 1 Hz (considering earthquake) upto about 100 cycles at selected confining pressures.*

Key Words: Liquefaction, cyclic triaxial test, particulate grouting, plasticity index, Marsh funnel test.

1.INTRODUCTION

Liquefaction is one of the most important, interesting, complex and controversial topics in geotechnical engineering. It`s devastating effects sprang to the attention engineers in a three month period in 1964 when the Good Friday earthquake (Mw = 9.2) in Alaska was followed by the Niigata earthquake (Ms = 7.5) in Japan. Both earthquakes produced spectacular examples of liquefaction - induced damage including slope failures, bridge and building foundation failures and flotation of buried structures. There have been many major earthquakes till date, and we have learned a lot from post-earthquake studies coupled with field investigations, laboratory testing and physical and numerical modelling. Although many performance patterns and observations tend to repeat from one earthquake to another, there is invariably something unique about each earthquake.

The totality of observations and the valuable lessons learned from post- earthquake studies and associated activities over the past 50+ years have improved our state of knowledge, state of art and state of practice in all earthquake related engineering fields and especially in geotechnical earthquake engineering.

There are two aspects to geotechnical engineering. One pertains to the effects of earthquakes on soils and soil structures (e.g., embankment dams), which may result in loss of strength and limited or uncontrolled deformations. The other aspect is the effects of local subsurface (or local site) conditions on the transient earthquake ground motions. In this project we mainly consider the first aspect and observations related to the improvement of soil.

The study mainly point towards the importance of the improvement of W.I soil near Cochin port, by conducting an experimental strategy for improving the resistance of Wellingdon Island against possible threat of liquefaction. As per the analysis report of Development Plan for Kochi City Region 2031, moderate earthquakes of Magnitude 6 are a possibility both on land as well as offshore sources. (Area falling within zone III of seismic zonation map). The importance of the area under consideration is also not less; Cochin is the centre point of major offshore constructions and trade in Kerala comprising major industries; like Malabar Cements Limited, Ambuja Cements Ltd., Ultratech Cements Ltd., Zuari Cements Ltd. , etc.

For the conduction of tests, undisturbed samples were collected from a site at Cochin, in Wellington Island near Lakshadweep Development Corporation limited, an area under the Cochin Shipyard limited, which has gained environmental clearance for an upcoming project worth Rs.1.5 crores. The main experimental program constitutes cyclic triaxial tests. The undisturbed W.I soil samples, with increasing proportion of the particulate grouting material, Bentonite, have been obtained by pumping Bentonite of appropriate consistency after conducting the Marsh funnel test [1], over the samples under pressure as per IS specification[2].

3. SOIL CONSTITUENTS SELECTED

Wellingdon Island (W.I) soil and Bentonite are considered for the experimental program. The classification tests conducted on both the specimens are summarized in **Table 1** and **Table 2.** The grain size analysis of both are shown in **Figure 1** and **Figure 2.**

Table 1 : Properties of Bentonite

Sl. No.	Particulars	Values	IS code provision
1	pH	9.1	8.0 -10.5
2	Liquid limit	500% (for 25 blows)	> 300 %
3	Plastic limit	80.52 %	
4	Plasticity index	419.48 %	
5	Free swell index	1060 (10.6 times)	10 - 12 Times Original Volume
6.	Shrinkage	Very high	
7.	Cumulative % by weight of all particles finer than size stated below:		
	0.002 mm	85%	> 85%
	0.2 mm	100%	> 99.9%
	2.0 mm	100%	100 %
8.	Initial water content	14.1 %	
9.	Specific gravity	2.5	
10.	Activity	5.0 (highly active)	

After conducting the initial classification tests the Bentonite is found to be High grade (HG) which is Sodium based, according to IS 12584:1989 [3] and highly compressible clay, (CH). Marine soil is found to be well graded sand, (SW).

Table 2 Properties of Welligdon Island Soil

Sl. No.	Particulars/Properties	Values
1	Initial water content	31.612 %
2	Specific gravity	2.63
3	pH	8
4	Plasticity Index	Non plastic
5	Field density	16.2 kN/m^3
6	Permeability coefficient	5.562 $x10^{-2}$ mm/s (Fair drainage , fine sands / loose silt)
7.	Cc	1.8
8.	Cu	6.4
9	Clay	1.5 %
10	Silt	9.7 %
11	Sand (Medium to fine)	88.8 %

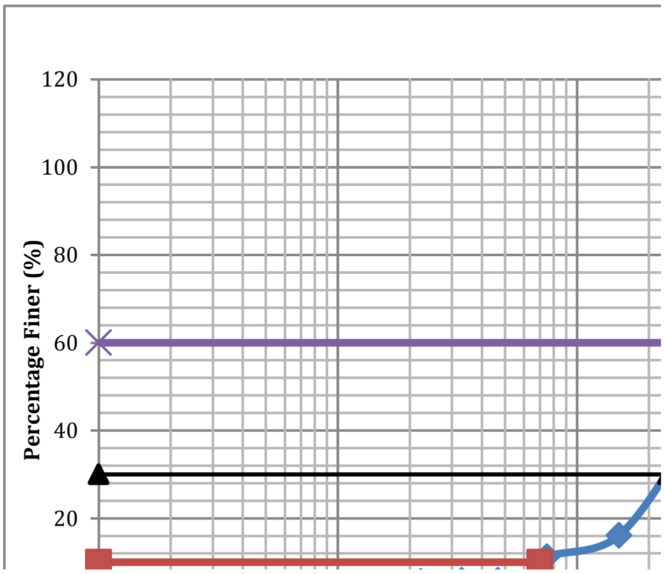

Figure 1 Wellingdon Island soil - Grain size analysis

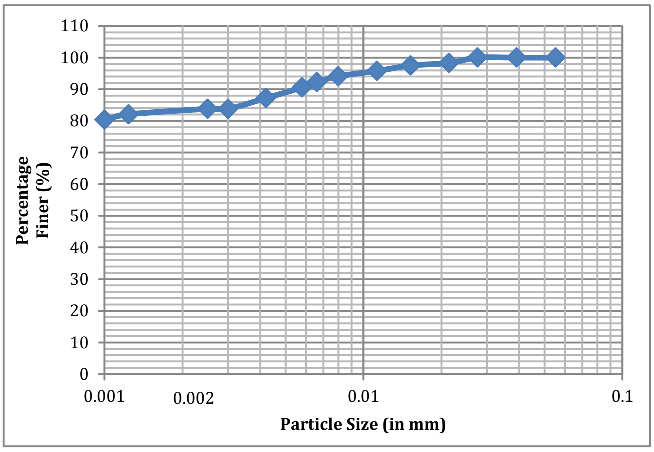

Figure 2 Bentonite - Grain size analysis

4. SAMPLE PREPARATION

The undisturbed samples required for the experiment was collected in tube samplers of 8cm and 9cm diameters; and sealed with microcrystalline wax and stored until testing. The samples of diameter 5 cm and length 10 cm was considered for the tests. The samples of appropriate dimensions are taken out from samplers and tested.

For those samples to be densified with Bentonite , samples of required dimensions are taken out from large samplers and kept in PVC moulds of same dimensions prior to adding Bentonite, and stored in dessicator, After that Bentonite of flowing consistency having Marsh funnel value of 31 seconds was prepared and sprayed into the sample at about five times the overburden pressure [2] using the apparatus setup shown in Figure 3.

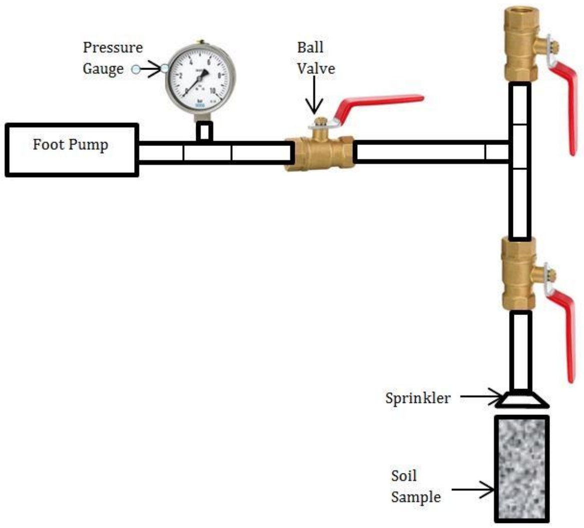

Figure 3 Experimental set up

The samples constitute mainly of 3 types:

- Pure W.I sand samples
- W.I Sand with Bentonite 5% volume of sample
- W.I sand with Bentonite 10% volume of sample.

Plasticity index of the combination are shown in Table 3.

Table 3 Plasticity Index of W.I soil- Bentonite combinations

Sl. No.	% Bentonite by volume of sample	LL (in %)	PL (in %)	PI (in %)
1.	0	NP	NP	-
2.	5	23.41	NP	-
3.	10	32.90	19.20	13.70

5. TEST PROGRAM

Cyclic triaxial test was conducted on the prepared samples at 1 Hz for 100 uniform cycles for 5% double amplitude. The specimens were represented by 0B for pure W.I soil, 5B for 5% Bentonite by volume of the specimen added to samples and similarly with 10B.

Table 4 Testing Criteria

Sl. No.	Sample Type	σ_c (kg/cm²)	Density x 10^{-2} (kg/cm³)	$B=\Delta u/\Delta \sigma_c$
1	0B	0.5	1.73	0.96
2	0B	0.5	1.71	0.98
3	5B	1	1.78	0.96
4	5B	1	1.77	0.95
5	10B	1	1.81	0.95
6	10B	1	1.83	0.96

6. RESULTS AND DISCUSSIONS

ASTM D5311 software has been used to obtain the following plots:

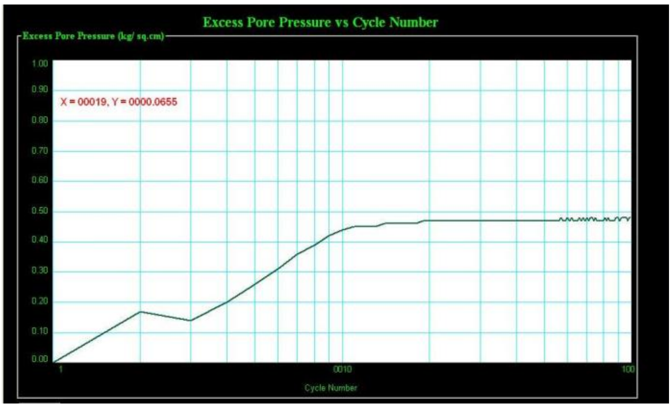

Figure 4 Excess pore water pressure vs cycles for 0B

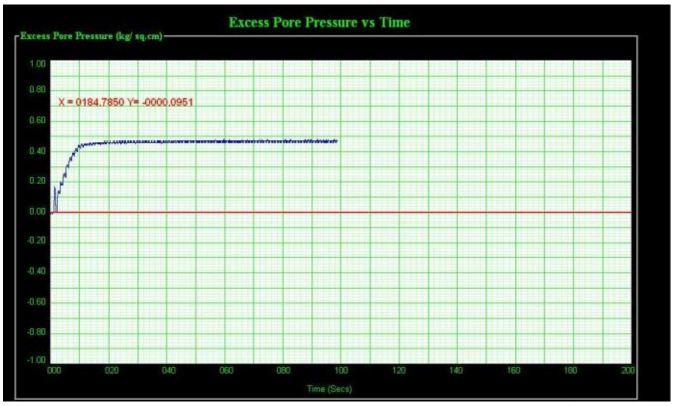

Figure 5 Excess pore water pressure vs Time for 0B

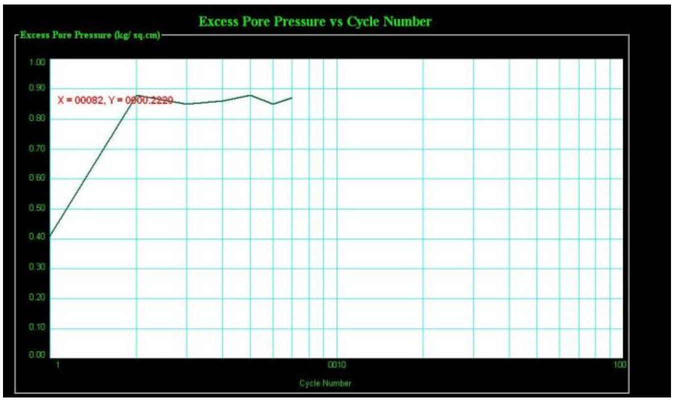

Figure 6 Excess pore water pressure vs Cycles for 5B

From Figure 4 and Figure 5 for 0B we could see that flow liquefaction occurred to the W.I soil at the 11th cycle. When the percentage of Bentonite was increased in the soil, the W.I soil - bentonite mixture showed a pattern of failure similar to cyclic mobility as shown in Figure 6 and Figure 7. For 10B as shown in Figure 8 and Figure 10 considerable resistance to liquefaction was shown by the soil mixture and the excess pore water was not increased to the applied confining pressure, details mentioned in Table 4.

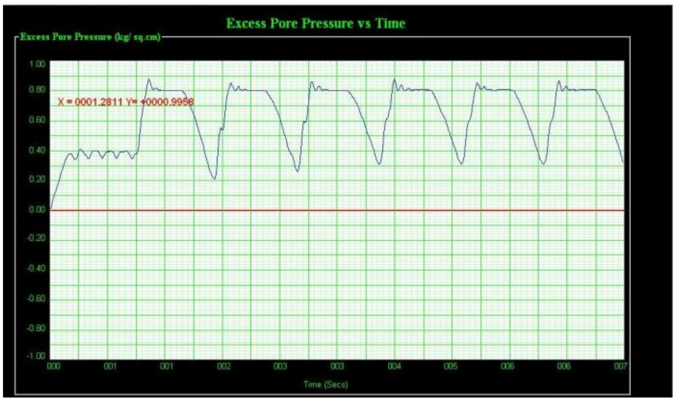

Figure 7 Excess pore water pressure vs time for 5B

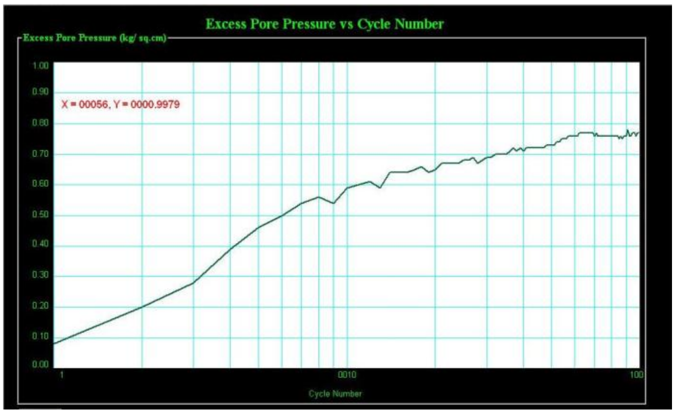

Figure 8 Excess pore water vs cycles for 10B

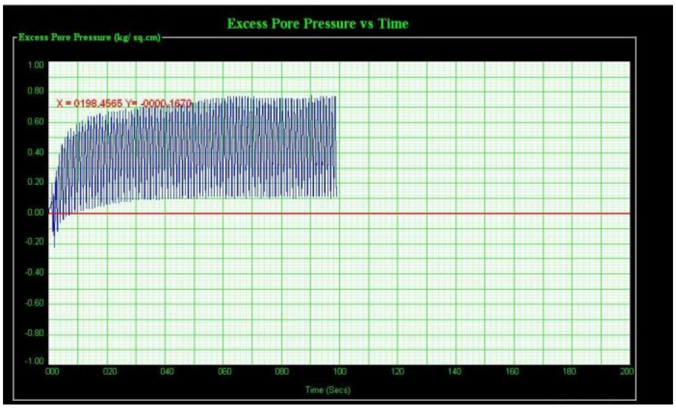

Figure 10 Excess pore water pressure vs Time for 10B

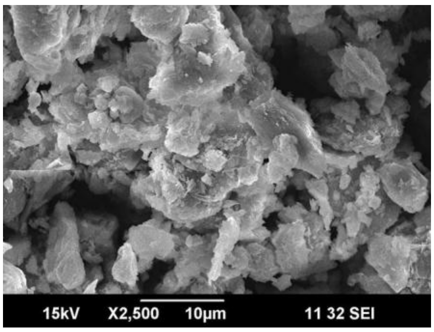

Figure 9 SEM image of Wellingdon Island soil

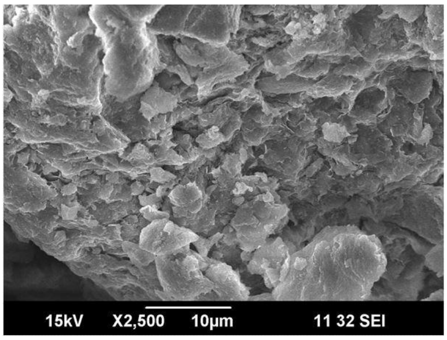

Figure 11 SEM image of Bentonite clay

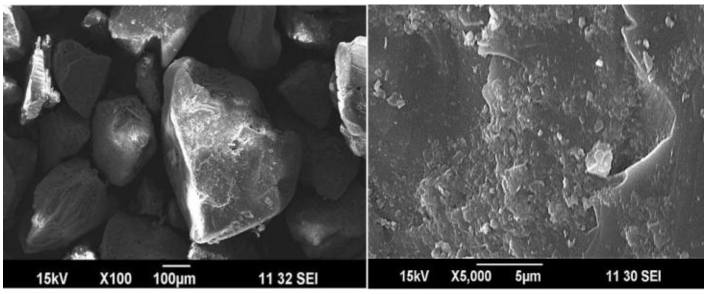

Figure 12 SEM image of 10B

Figure 11 and Figure 9 shows the SEM images of Bentonite clay and Wellingdon Island soil. Figure 12 shows the SEM image of 10B, where we could see that sand particles are covered with Bentonite, forming a Bentonite matrix.

7. CONCLUSION

The experimental strategy proved to be effective in increasing the resistance of W.I soil against possible threat of liquefaction by the pumping of Bentonite in the soil. Eventhough, initial addition of Bentonite into the soil sample (5B) lead to cyclic mobility, 10B considerably resisted the cyclic loading to 100 cycles which has a pronounced plasticity index; where Bentonite covers the sand particles, evident from the SEM image. Thus the experimental strategy proved to be effective in increasing the resistance of the saturated W.I sand against liquefaction.

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