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MITIGATION OF SEISMIC LIQUEFACTION INDUCED DAMAGE OF EARTHEN EMBANKMENT BY PERMEATION CEMENT GROUTING

Md. Shohrab Hossain Pavel[*1], Md. Mahfujur Rahman[*2], Md. Abu Taiyeb[*3], Mohammad Irfanul Kabir[*4], Md. Shakhawat Hossain[*5], Md. Hakimuzzaman Shah[*6], Israfil[*7], Md. Rabiul Islam[*8]

[*1, 6, 8]Lecturer, Department of Civil Engineering, Dhaka International University, Dhaka, Bangladesh.

[*2]Assistant Professor, Department of Civil Engineering, Dhaka International University, Dhaka, Bangladesh.

[*3]Professor, Department of Civil Engineering, Dhaka University of Engineering & Technology (DUET), Gazipur, Bangladesh.

[*4]Ex-Shelter Project, Coordinator, Save the Children International, Rohingya Response, Dhaka, Bangladesh.

[*5, 7]U. G. student, Department of Civil Engineering, Dhaka University of Engineering & Technology (DUET), Gazipur, Bangladesh.

ABSTRACT

The application of the permeation grouting method against a liquefiable ground covered by existing structures is a great challenge to engineers. The earthen embankment is an important structure among many existing structures. This study aimed to observe the mechanism, effect, and damage due to liquefaction as well as the mitigation of seismic liquefaction induced damage of earthen embankment. This report includes details of the mechanism, damage, and the mitigation process of seismic liquefaction induced damage of earthen embankment by permeation of cement grout. In this method, the interstices of the sample (sand) are filled with cement. Then the cement binds the soil particles together and maintains it during seismic loading. Permeation grouting method was used under gravitational force only in this study. Four perforated pipes were used for grouting. Each of these pipes was drilled to maintain 40 holes of diameter 3mm each. The sample was improved sufficiently against liquefaction and settlement by this process. The application of seismic load with the aid of a shaking table confirmed this improvement.

Keywords: Liquefaction, sandy soil, soil improvement, cement grouting, displacement, mitigation, model test.

I. INTRODUCTION

Liquefaction may be a phenomenon during which the strength and stiffness of soil are reduced by earthquake shaking or other rapid loadings. When a fine or medium-fine, saturated, loose sand deposit is subjected to a sudden shock the mass will temporarily liquefy is termed liquefaction. These circumstances can be divided into two main categories: flow liquefaction and cyclic mobility. Liquefaction, caused by increased pore water pressure, is very pernicious for the existing earthen embankments. During an earthquake, increased pore pressure gradually causes a decrease in effective stress in the soil particles. Eventually, a stage of zero effective stress breaks out.

Densification, gravel drains, and compaction techniques are more economical for the countermeasure of liquefaction where no structure exists. But in the developed site, these methods cannot be applied easily. Permeation grouting method has been used in such a case. It is a technique for mitigating liquefaction. In this method, pore water is replaced with solvent-type silicate-based material. This material binds the particles of soil together. Controlled permeation of grouting method was used to improve Fukuoka International Airport's runway. Controlled curved drilling machines and silica-based grout were used there. Raman et al (2015) used chebulic myrobalan grout solution with cement as a replacement of water to increase the soil strength. They were successful to increase the soil strength. Dayakar et al (2012) used Portland pozzolana cement and local river sand followed by a plate load test performed with a triaxial loading frame. They were able to increase the

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bearing capacity of the soil. But for the case of the earthen embankment, this method has not been used significantly. In our study, the permeation grouting method was used for mitigating liquefaction under earthen embankments. The use of the permeation grouting method under gravity only without using heavy equipment's made our study a distinct one from others.

II. MATERIALS

Grouting is generally embarked on to reduce the permeability of the soil strata. Materials associated with the grouting procedure are soil and grout materials. In this study, the type of soil material is sandy soil which was collected from the local field of Gazipur city and grout material is the cement that was collected from the local market of Joydebpur.

Sandy soil

Grain size plays a crucial role in liquefaction. This test was performed to work out the share of various grain-size of sand. Sieve analysis was wont to determine the grain size distribution of sand.

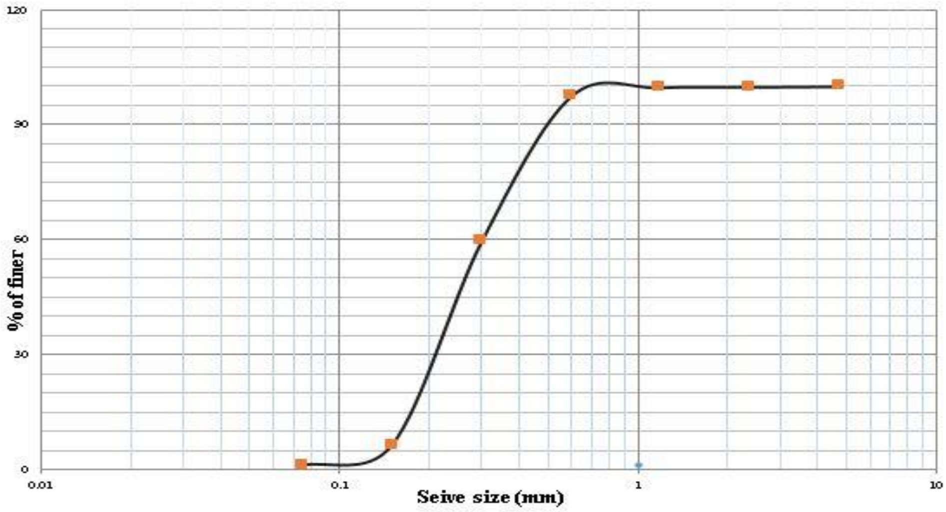


Fig.-1: Grain size distribution of soil

Table 1: Magnifies the properties of the soil sample after inferring with several tests on the soil samples which is utilized in the study. The tests are accomplished to determine the fundamental properties of the soil sample.

Properties	Values
Specific gravity (G_s)	2.722
Maximum unit weight (γ_{max})	1.69 gm/cc
Minimum unit weight (γ_{min})	1.35 gm/cc
Maximum void ratio (e_{max})	0.74
Minimum void ratio (e_{min})	0.59
Average void ratio (e_{avg})	0.67
Dry unit weight (γ_d)	1.62 gm/cc
F.M	1.36
D_{10}, mm	0.16
D_{30}, mm	0.19
D_{60}, mm	0.30

Coefficient of uniformity (C_u)	1.89
Coefficient of curvature (C_c)	0.76

Grout materials

Locally available hydraulic cement (OPC Type-I) as per ASTM C114 (2017) Type-1 was used as a cementing material during this research. Normal consistency and setting time were determined by using the Vicat apparatus and test methods conform to the quality requirements of ASTM specifications C187 (1998) and C191 (2001) respectively.

Normal consistency

A normal consistency test was wont to define the optimum ratio of the water content of cement grout. Generally, the range of normal consistency is 26% to 33% for ordinary hydraulic cement.

Setting time

Initial and final setting times were examined using the manually operated Vicat apparatus according to ASTM C191 (2001). These methods determine the time of setting of cement by means of the Vicat needle. A paste of cement was molded, placed, and allowed to start setting. Periodic penetration tests were accomplished on this paste by permitting a 1 mm Vicat needle to settle keen on this paste. The time of setting was measured as the difference between the time that a measurement of 25 mm penetration and the time of the initial contact between the cement and water. The final setting time is when the needle doesn't sink noticeably into the paste. This process was completed on pure cement paste. The test specimen was prepared and placed on the mold according to ASTM C187 (1998) and ASTM C191 (2001) respectively. The findings of an experimental analysis carried out in this path are present in the below table.

Table-2: Properties of cement

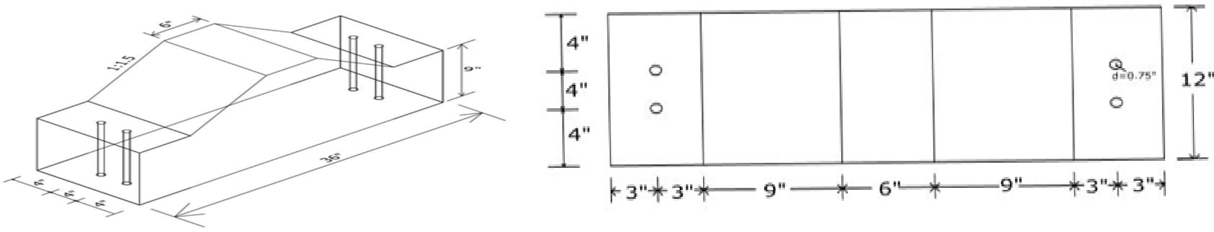
Properties	Values
Consistency, %	36.5
Initial Setting Time, min	155
Final Setting Time, min	375

III. METHODOLOGY

To facilitate the application of seismic load on the liquefiable sand a rigid frame 91.44cm×30.48cm×68.58cm was prepared with angles, plates, and channel section of mild steel. Sidewalls were made of transparent glass to achieve the facility of observation. Two expanded polystyrene sheets were set at the inner face of side walls along the width to absorb the wave propagated by the shaking table.

Fig.-2: Tank set up

Uniformity in compaction is necessary during the preparation of different samples. Each of these samples represents a foundation. So water sedimentation method was used to fill the tank with dry sand underwater up to a height of 23 cm. Excess water was discharged through the drainage path. An earthen embankment of height 13.5cm was prepared in three layers with approximately 50 blows in each layer using sand of average moisture content of 9.79%. A steel plate 10 cm x 10 cm having weight 693 gm. was used for exerting blows in each layer. The slope of the embankment was 2V:3H. The embankment was 15cm in top width and 55cm in bottom width. It was set along the width of the rigid frame having a length of 30 cm. Figure 4 represents the preparation of the model.



(a): 3-D view (b): Plan

Fig.-3: Sketch of sample

Fig.-4: Installation of perforated pipes in the tank for grouting

In the case of the 2nd, 3rd, and 6th test cement grout was used with a cement-water ratio of 1:7. Amongst many ratios, 1:7 was selected as an arbitrary value. During the 3rd test, 7.49 L of water and 0.94 Kg of cement were used for grouting to maintain a ratio of 1:7. Cement grout was applied with the aid of 4 perforated pipes each having 40 holes of diameter 3mm from a minimum height of 0.99 m under gravity. Grout was prepared in a container having four controlling valves. Perforated pipes were connected with the container with the aid of 4 flexible pipes. Grout was stirred in the container with a stick to prevent sedimentation during the application of grout.

To gain strength after entering the pores of sand, cement grout needs some time to gain strength. A 4-day curing period was used to see the effect after the application of grout during the 3rd and 4th tests. A 1-day curing period was used during the 6th test.

The seismic load was applied with the aid of a shaking table along the width of the embankment. The shaking table exerts seismic load with a motor running at a rate of 1500 revolutions per minute. This is a one-dimensional load. The effect of the earthquake was observed carefully.

IV. RESULTS AND DISCUSSION

The results of the series of shaking table model tests of the earthen embankment with and without cement grout for mitigation measures subjected to seismic load in detail. During the 1st, 4th, 5th, and 6th tests, excess pore water pressure developed. Excess pore water came out on the surface of the sample and the sample experienced liquefaction simultaneously. The 2nd and the 3rd tests, after the application of grout and 4-day curing, revealed how the samples became resistant to liquefaction.

Figure 5, Figure 8, and Figure 9 demonstrate the phenomena of liquefaction of the sample of 1st, 4th, and 5th tests without grout. In Figure 6 and Figure 7, the little settlement of the sample with cement grout (4-day curing) is shown during the 2nd and 3rd tests respectively. Figure 10 shows the liquefaction of the sample during the 6th test with cement grout (1-day curing).

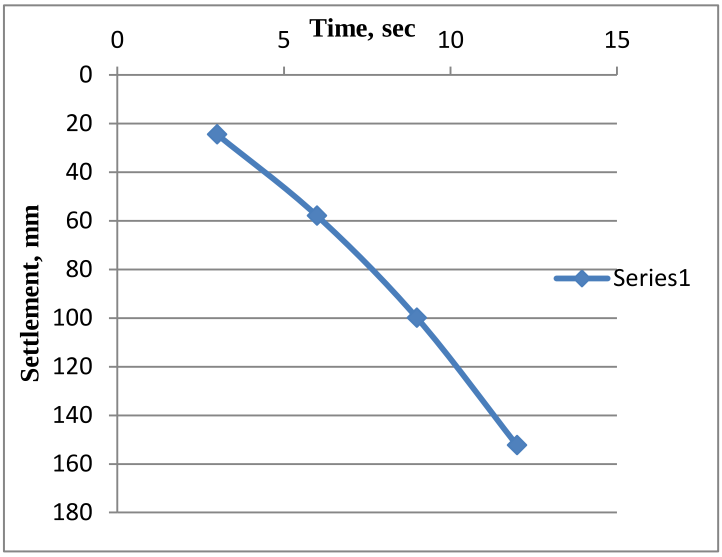


Fig.-5: The Relationship between settlement and time for model 1 without cement grout.

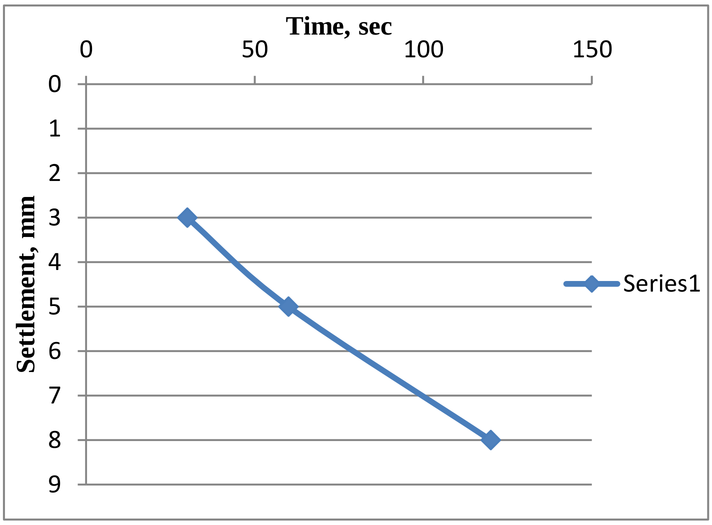


Fig.-6: Settlement versus time curve of soil sample (model 2) with grout (1:7) - 4 days curing.

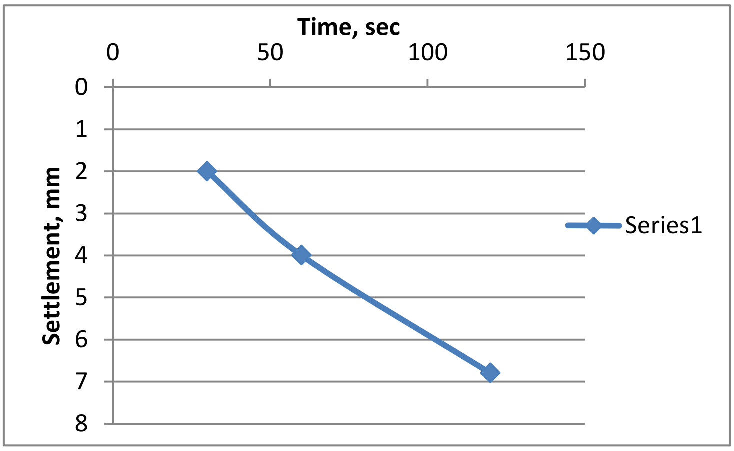


Fig.-7: Settlement versus time curve of soil sample (model 3) with grout (1:7) - 4 days curing.

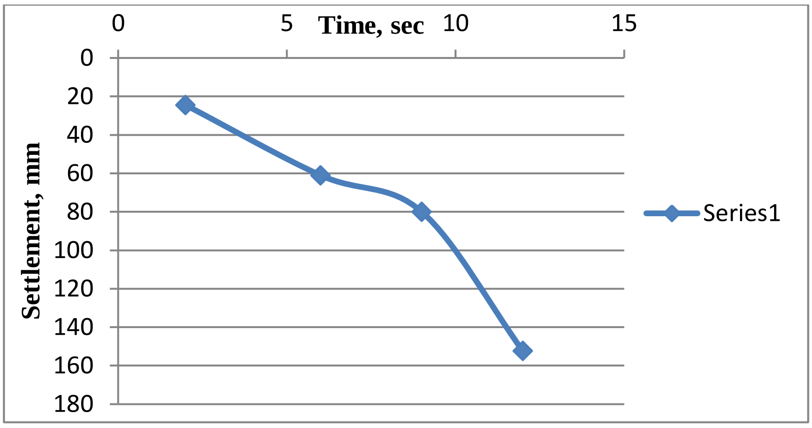


Fig.-8: Settlement verses time for soil sample (model 4) without cement grout.

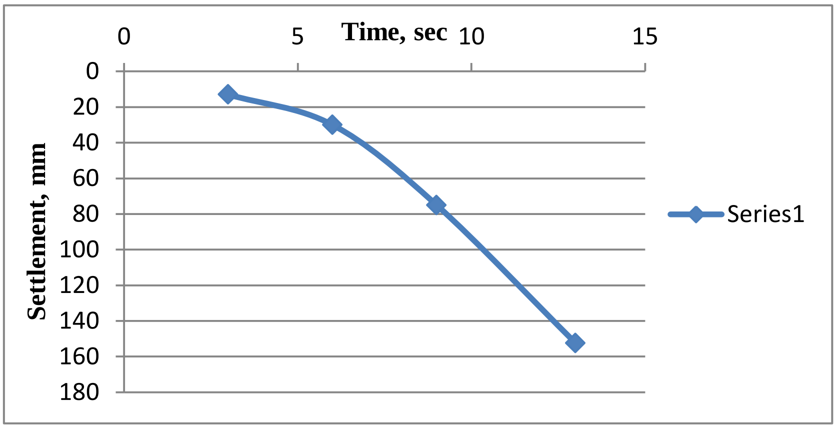


Fig.-9: Settlement verses time for soil sample (model 5) without cement grout.

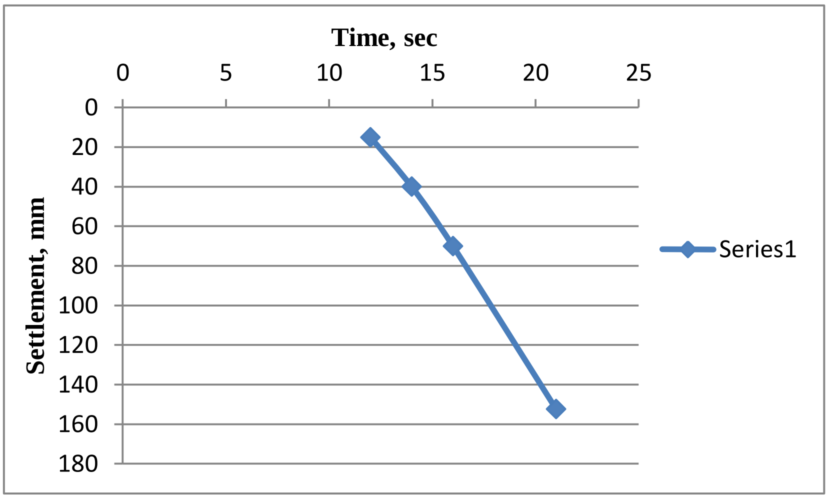


Fig.- 10: Settlement versus time curve of soil sample (model 6) with grout (1:7) - 1-day curing.

Table-3: Summary of experimental results

Test no	Grout ratio (cement : water)	Curing (days)	Result
01	without grouting	N/A	Embankment fully settled within 12 sec
02	1:7	4	Embankment settled 3 mm,5 mm, and 8 mm after 30 sec, 60 sec, and 120 sec respectively

03	1:7	4	Embankment settled 2 mm,4 mm, and 6.8 mm after 30 sec, 60 sec, and 120 sec respectively
04	without grouting	N/A	Embankment fully settled within 12 sec
05	without grouting	N/A	Embankment fully settled within 13 sec
06	1:7	1	Embankment fully settled within 21 sec

Mechanism of liquefaction was observed with the unaided eyes only. During the 1st test, quick liquefaction caused total settlement of embankment into the sample. No grout was used in this test. Development of excess pore water pressure was observed. The 2nd and the 3rd tests didn't experience liquefaction due to strong bonding by cement grout. The embankment fully settled quickly during the 4th and the 5th tests (without grout) due to liquefaction by increased pore water pressure. Cement grout caused a longer duration of the settlement of embankment during the 6th test. The embankment also settled fully in this test.

Liquefaction caused full settlement of the embankment into the sample during the 1st, 4th, 5th, and 6th tests. The 2nd and the 3rd sample were resistant against liquefaction. But the 2nd test and the 3rd test caused 8 mm and 6.8 mm settlement respectively.

The 1st test was carried out to justify whether the sand was liquefiable. This sample (sand) failed i.e. the embankment fully settled under seismic load within 12 seconds. The 2nd test was performed after a 4-day curing period. It showed a liquefaction resistance even after the application of a seismic load of two minutes with a settlement of 8 mm. The 3rd curing period was selected the same as that of its predecessor. The drainage valve was kept open for a long time before the application of seismic load and water was supplied to the sample (sand) through the bottom drainage path just before loading, during the 2nd test. For this reason, the sample was suspected not to be saturated fully. So the same curing period was selected again. At this time, the drainage valve was kept closed to confirm the saturation. The sample underwent a seismic load of more than two minutes during this test. The load caused no liquefaction but only a settlement of 6.8mm. 4th, 5th, and 6th tests were performed to crosscheck the phenomena of liquefaction. Because during the 2nd and 3rd tests the samples were fully resistant to liquefaction. During the 4th test, the sample was subjected to seismic load just after the preparation of the sample. This embankment settled within 12 seconds. The sample was first prepared during the 5th test. Then the sample was subjected to seismic load after 1-day. During this test, the embankment settled within 13 seconds showing nearly the same duration as those of the 1st and the 4th tests. The load was applied after 1-day curing, during the 6th test. This embankment experienced full settlement after 21 seconds. The duration of the 6th test is more than those of the 1st, 4th, and 5th tests. The longer duration of the 6th test indicates the improvement against liquefaction by cement grout. This sample failed due to the lack of the curing period.

V. CONCLUSION

A simple and cheap permeation grouting method was used for the mitigation of seismic liquefaction induced damage to existing earthen embankments. Subsequent decisions can be drawn from the experimental research:

- Permeation grouting method, acting under the gravitational force only, was successful to improve the liquefiable soil against liquefaction and settlement.
- Cement grout can be applied (after proper field test) in case of existing earthen embankments for the mitigation of liquefaction by permeation grouting with a minimum curing period of 4 days.

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