Shaking table tests on liquefiable sand deposits treated with sand compaction piles

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Abstract. Soil liquefaction and its associated ground failures during earthquake is one of the major hazards causing risk to life and infra-structures. Even though several literatures available using Sand Compaction Pile (SCP) technique, investigations under sequential acceleration conditions for SCP treated soil deposits were limited. Hence in this study, liquefaction resistance of sand treated with sand compaction pile under sequential acceleration conditions was performed and reported. For experimental studies, an acrylic tank having dimensions of 1.4m × 1m × 1m was selected and mounted on Uni-axial shaking table. Soil deposits having 600 mm depth was prepared with 40% and 60% relative density using sand pluviation method. For soil reinforcement, SCP having diameter 110 mm and 600 mm length was installed inside the soil deposit. Then, shaking table experiments were performed with and without improvement technique under sequential accelerations. For sequential acceleration, the selected accelerations are 0.1g, 0.2g, 0.3g and 0.4g with 5 Hz frequency. Initially, the sand deposit was subjected to 0.1g acceleration amplitude and generation of excess pore water pressure with time was continuously monitored and recorded. After 0.1g loading, the tank was left undisturbed for 24 hours or until complete dissipation of generated pore-water pressure whichever earlier. Then next sequential loading of 0.2g acceleration amplitude was applied and the same procedure was repeated up to 0.3g and 0.4g testing conditions. The influence of various parameters affecting the performance of SCP improvement technique under sequential loading was compared and reported.

Keywords: Liquefaction, Nepal earthquake, Uni – axial shaking table.

1 Introduction

Soil liquefaction and its associated ground failures during earthquake is one of the major hazards in recent years. Soil liquefaction is highly susceptible in case of loose and saturated sandy soil conditions, though sandy soil has relative preferable properties for compressibility. The strong seismic or earthquake shaking will generates excess pore water pressure in the gently sloped or horizontal layer of loose saturated sand deposits; thus reduces the effective stresses and strength of the sand deposits [1]. The catastrophic nature of this type of failure always invites attention of researchers across the world and so far significant work has been reported to evaluate the susceptibility of liquefaction [2] and [3]. To improve liquefaction resistance, ground improvement techniques such as stone columns, sand compaction piles, prefabricated vertical drains and permeation grouting have been used successfully and reported. Among them, installation of Sand Compaction Pile (SCP) is a classical method developed in the year 1956 for mitigating liquefaction in Japan. The concept behind the SCP is to improve the density of the ground by feeding the sand and compact it to the desired relative density [4]. SCP was found to be very effective in mitigating the liquefaction and its associated ground failures. The method came into limelight during the Miyagi – ken Oki earthquake at Japan in the year 1978. Since then the method was successfully adopted for many earthquake induced liquefaction hazards [5].

The installation of SCP involves penetration of a casing pipe vertically in to the ground. The verticality of the casing pipe should be ensured with respect to depth. Dynamic impact or static excitation was provided at the top of the casing pipe to construct the compacted sand pile in the ground. The casing pipe was then withdrawn from the ground after reaching the desired depth. During the withdrawal process, sand was fed into a ground through a casing pipe [5] and [6].

Several researchers successfully investigated the liquefaction potential of sands with and without sand compaction pile through reduced scale models in centrifuge modeling and 1-g shaking table tests [3], [7], [8], [9], [10], [11], [12], [13] and [14]. The liquefaction studies on a shaking table tests using large saturated samples offer many advantages when compared to other small scale laboratory experiments and highly helpful for evaluating liquefaction potential of sands. Additionally the effect of drainage conditions on the liquefaction induced deformations was studied using the shaking table tests [15].

Even though detailed experimental studies has been carried out in liquefaction and its associated deformations through sand compaction pile, still there are research gaps in understanding liquefaction mitigation mechanism. Also, earthquakes are too complex in nature; the frequency and return period of earthquake occurrence cannot be predicted accurately. The recent observed continuous ground shaking events due to earthquake and its associated aftershock movements in Nepal suggested that, still there is a possibility for multiple dynamic events can happen at particular location (Example: Date: 25thApril, 6.11 AM, Magnitude: 7.8, and aftershocks of magnitude 6.6 at 12.30 PM and then 6.7 at 24-hour difference, and again on 12th May with 7.3 magnitude, Place: Kathmandu, Nepal [16]. Even though, installation of SCP improves liquefaction resistance reasonably, studies relating to their performance evaluation under sequential acceleration conditions (i.e. same ground subjected to continuous acceleration of higher intensity or lower within limited time) are limited.

The objective of this study is to study the performance of sand compaction pile for mitigating the liquefaction behavior of solani sand under sequential incremental acceleration conditions through uni-axial shaking table testing. For experimental studies, the ground model was prepared with 40% and 60% relative density and subjected to series of sequential acceleration amplitudes such as 0.1g, 0.2g, 0.3g and 0.4g at 5 Hz frequency simulating medium to very high earthquake magnitude. The maximum generated pore water pressure, soil displacement and settlement, change in relative density under sequential loading were monitored continuously. Finally, the study presents the efficiency of SCP reinforced ground subjected to sequential acceleration conditions.

2 Motivation and Objective

There are reported case studies available regarding reoccurrence of earthquake in particular regions. Also, earthquakes are too complex in nature. The frequency and return period of the earthquake cannot be predicted. Hence, the effect of continuous reoccurrence earthquake intensity and its impact on soil density was attempted in this study. To validate this objective, sequential incremental accelerations conditions were selected and test edin liquefiable soil using 1-g shaking table tests. Additionally, ground improvement using Sand compaction pile on repeated acceleration conditions also evaluated and assessed. .

The shaking table tests are performed on poorly graded sand collected from solani river bed, near roorkee. The index properties of the sand are given in table 1.

Table 1: Index properties of the Solani sand

Serial number	Property/Characteristic		Value
1.	Soil type (SP)		Poorly graded sand
2.	Specific Gravity of grains (G)		2.67
3.	Uniformity coefficient (C_u)		2.63
4.	Coefficient of curvature (C_c)		1.14
5.	Grain size	D_{50}	0.23 mm
		D_{10}	0.09 mm
6.	Maximum void ratio (e_{max})		0.87
7.	Minimum void ratio (e_{min})		0.64
8.	Relative density considered (D_r)		40%
			60%
9.	Void ratio (e) for	D_r = 40%	0.80

10.	Dry unit weight for D_r = 40%	14.5 kN/m^3
11.	Void ratio (e) for D_r = 60%	0.76
12.	Dry unit weight for D_r = 60%	14.88 kN/m^3

3 Experimental Setup

The liquefaction experiments are carried out on a uni-axial shaking table available at CSIR – CBRI, Roorkee having a pay load capacity of 3T. The uni-shaking table can works with an operating frequency ranging from 1 to 50 Hz and can able to accept acceleration amplitude from 0.05g to 1g. For experimental study, a transparent acrylic model container of size 1400 × 1000 ×1000 mm was used. The tank was mounted over the shaking table and sample preparation was carried out. For sample preparation wet pluviation method was adopted. To assess liquefaction resistance sand under repeated acceleration conditions, the 600 mm thick ground was prepared with 40% and 60% density. The required quantity of sand and water required to achieve the density was calculated. To achieve maximum uniformity in sample preparation the total depth was prepared in three layers. For monitoring pore water pressure generated during shaking, piezometers were connected to the side of the tank at 0.2m, 0.4 m from bottom of the tank. At one end, the tube was designed with a provision for placing porous stone which was further connected to piezometer. The other end was connected to graduated glass stand pipes. The rise in water level during shaking was monitored through glass standpipe and corresponding pore water pressure was estimated. The schematic diagram of the experimental setup was shown in figure 1.

For ground improvement, Sand compaction piles (SCP), having diameter 110 mm and 600 mm length at 450 mm c/c spacing was installed in the soil deposit. The SCP was constructed with an estimated area replacement ratio of 3% [17]. Methodology of installation involves (a) pushing PVC casing pipe having outer diameter equivalent to SCP diameter into the selected locations (Fig.2) (b) removal of soil inside the PVC pipe (c) Filling the hole with sand and removal of casing pipe at equal intervals. Compacting the poured sand using a tamping ratio achieve 85% density. The procedure was repeated for installation of all sand compaction piles.

After sample preparation under unreinforced and reinforced conditions, application of incremental sequential acceleration loading in sinusoidal wave form having acceleration 0.1g, 0.2g, 0.3g and 0.4g at 5 Hz constant frequency was applied through shaking table. The procedure adopted for application of sequential acceleration involves the following; initially 0.1g at 5 Hz frequency was applied to the ground bed. The rise in pore water pressure was then monitored. Then the bed was undisturbed for 24 hours until the generated pore water pressures completely dissipates. Then procedure is repeated following the same procedure up to 0.2g, 0.3g and 0.4g acceleration loading

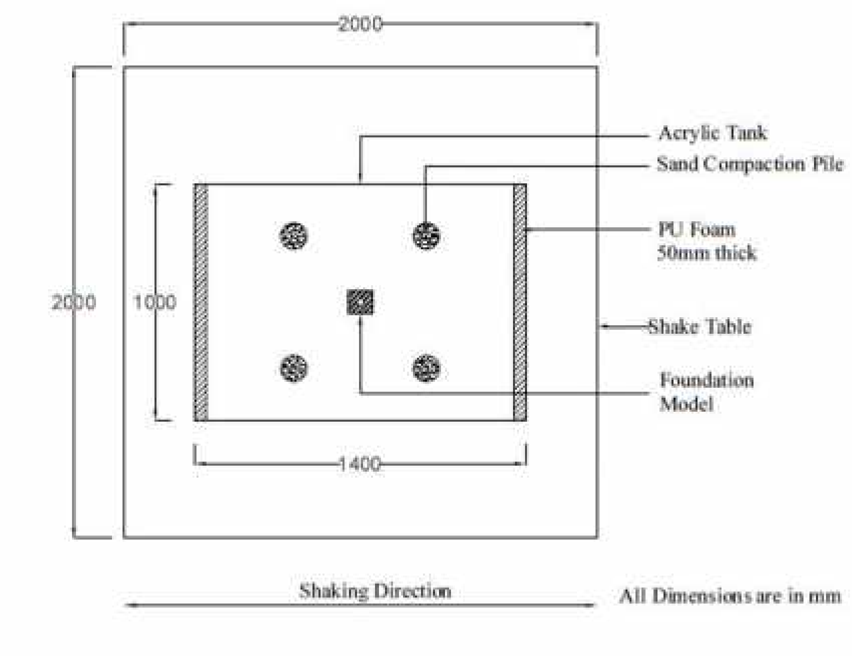

Fig.1. Prepared sand bed of required depth for desired relative density

Fig.2a. Prepared sand bed of required depth for desired relative density

Fig. 2b. Construction of Sand Compaction Piles by inserting casing pipe vertically into the prepared ground

Fig. 2c. Sand Compaction Piles of required dimensions installed in the prepared ground in square pattern

4 Results and Discussions

4.1 Effect of Pore water pressure

In this section, effect of pore water pressure and pore pressure ratio generated under sequential incremental loading was discussed. As mentioned earlier section, the sequential acceleration loading was applied to the prepared soil bed incrementally i.e. 0.1g, 0.2g, 0.3g and 0.4g at 5Hz frequency only after achieving complete dissipation of generated excess pore water pressure from previous loading. The variation of excess pore water pressure with time for 40% and 60% density of soil bed under sequential incremental loading is shown in Fig. 3 – 8. It can be observed that, generation of excess pore water pressure was maximum at bottom piezometer than at top under repeated testing conditions. This suggesting that, the initial mean effective stress and overburden pressure at bottom is higher than effective vertical stress at top. The reinforcing effect of sand compaction piles under sequential acceleration conditions also plotted in the same figures. Comparatively, SCP performs exceptionally well in 0.1g acceleration conditions and no pore water pressure was developed when ground was installed with SCP. Hence for comparative analyses, generation of pore water pressure at acceleration intensity 0.2g, 0.3g and 0.4g was presented in Fig 3 - 8.

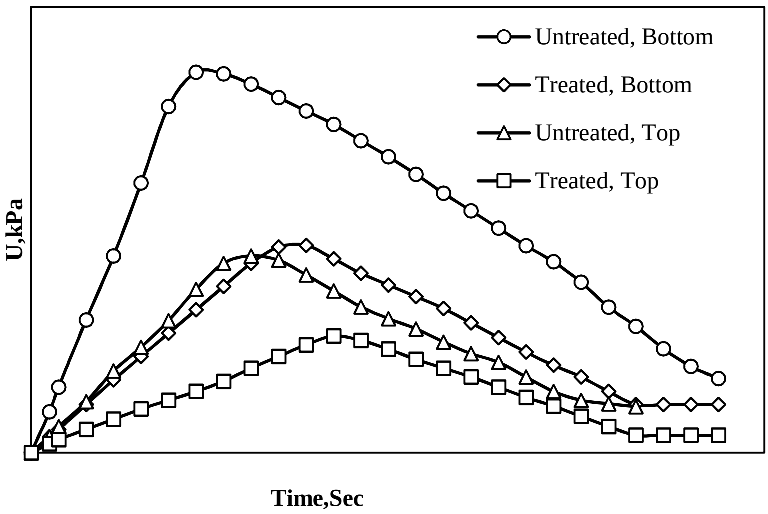

Fig.3. Variation of Pore pressure with time for 0.2g acceleration for 40% Relative Density for both treated and untreated conditions

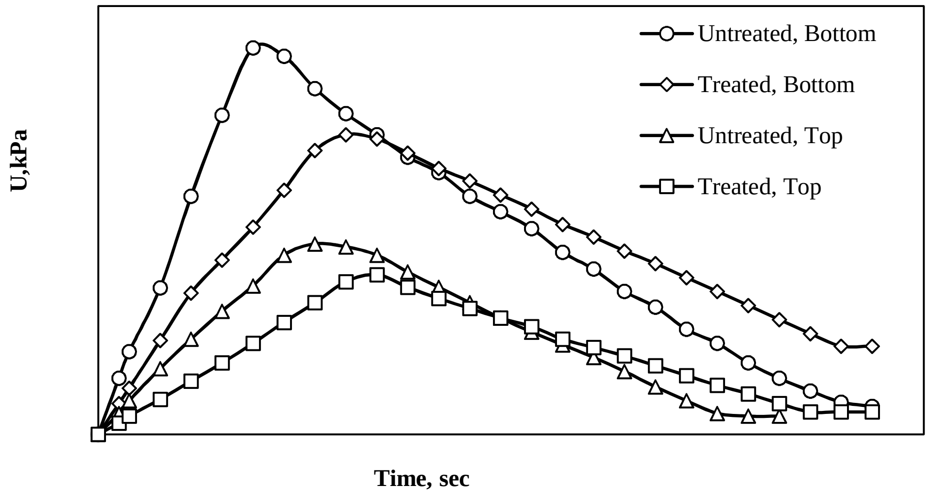

Fig.4. Variation of Pore pressure with time for 0.3g acceleration for 40% Relative Density for both treated and untreated conditions

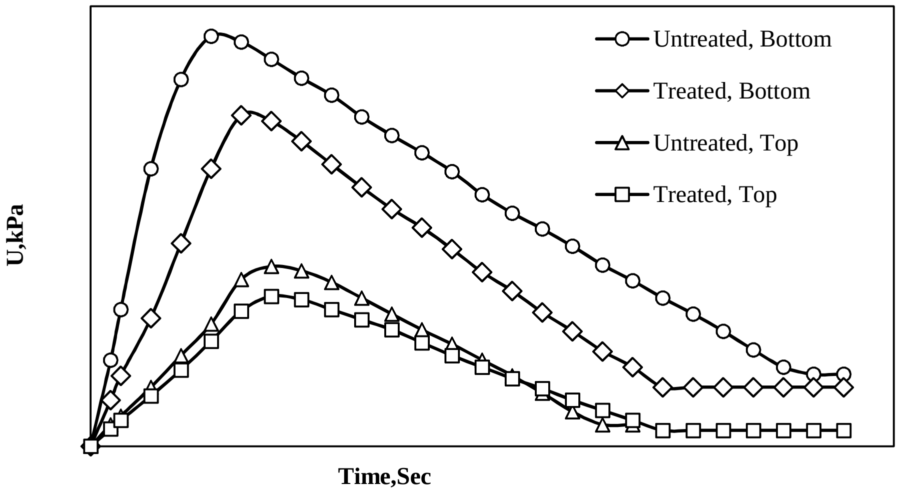

Fig.5. Variation of Pore pressure with time for 0.4g acceleration for 40% Relative Density for both treated and untreated conditions

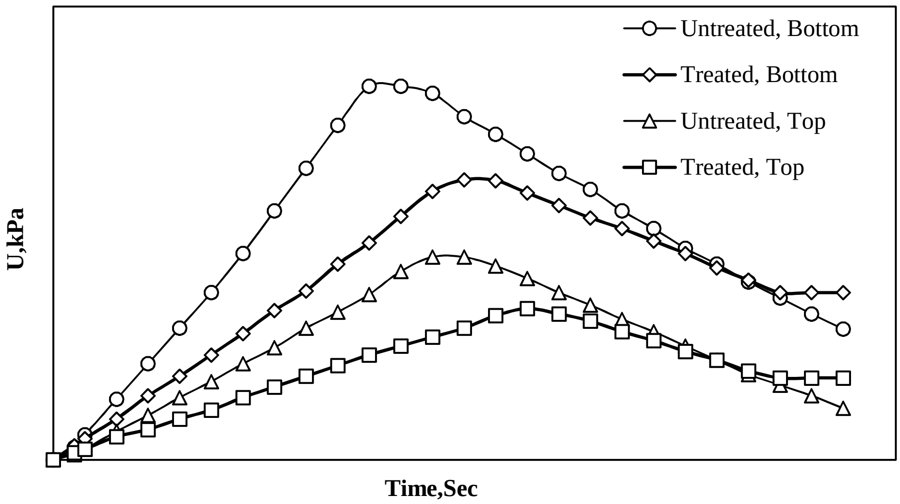

Fig.6. Variation of Pore pressure with time for 0.2g acceleration for 60% Relative Density for both treated and untreated conditions

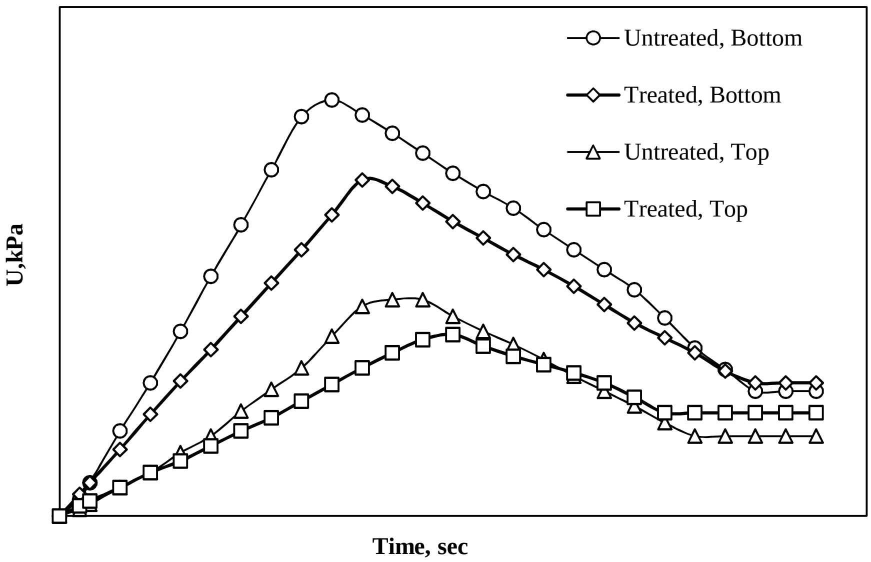

Fig.7. Variation of Pore pressure with time for 0.3g acceleration for 60% Relative Density for both treated and untreated conditions

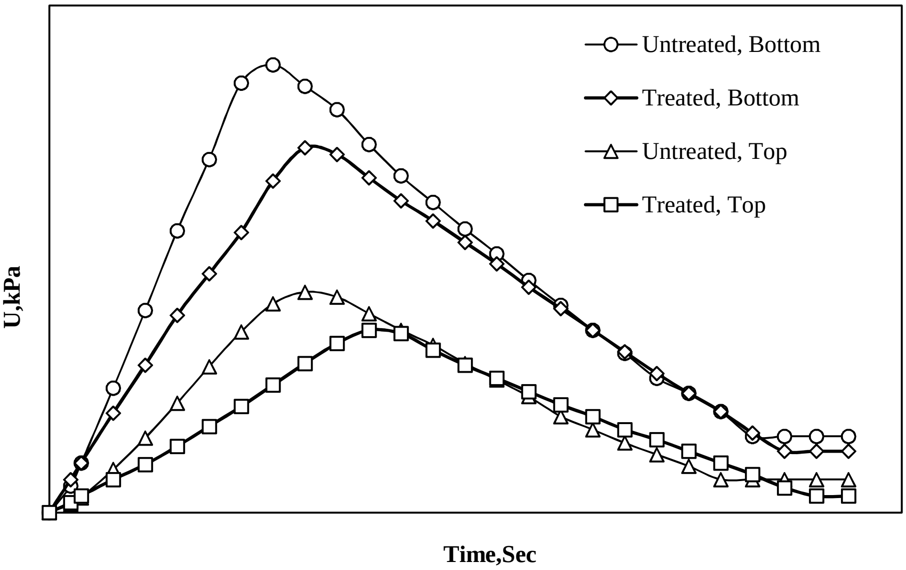

Fig.8. Variation of Pore pressure with time for 0.4g acceleration for 60% Relative Density for both treated and untreated conditions

From all the Figure it was observed that, Sand Compaction piles perform much better than untreated ground in resisting liquefaction both at 40% and 60% density. Installation of SCP, improves the density of the ground, minimizes pore water generation and improves liquefaction resistance. As in case of sequential acceleration amplitude, density of surrounding soil also increases but still liquefaction occurs under higher acceleration amplitude. Similar observations were observed for 60% density ground. The test results suggesting that, improving density of liquefiable soil will not helpful in improving liquefaction resistance. Providing proper drainage system additionally improves the resistance. The same was clearly observed from experimental test results, when the ground was installed with SCP; both density of the ground improves and delays generation of pore water pressure during shaking. No rise in pore water pressure was observed in case of tested under 0.1g conditions whereas comparatively less pore water pressure developed at higher amplitudes. However, installation of SCP delays generation of pore water pressure and subsequently minimizes liquefaction time. Hence when selecting ground improvement techniques selected for improving liquefaction resistance, the technique should incorporates provision of drainage and should tested for repeated acceleration conditions for achieving effective improvement in liquefaction resistance.

5 Conclusions

1. Liquefaction potential of sand deposits increases with increase in accelerations.

2. Under sequential accleration amplitude, density of sand deposit increases but still soil liquefied under higher acceleration amplitudes. This suggests that, increasing density alone not improving the liquefaction resistance of sand deposits.
3. Performance evaluation of sand compaction piles subjected repeated accleration amplitude was attempted in this study and it was found that, sand compaction piles performing exceptionally well under repeated accleration amplitude and improves the liquefaction resistance of sand deposits.
4. For liquefaction mitigation, the selected ground improvement should contain proper drainage system so that both density and drainage characteristics can be improved which makes the techniqe perform better during earthquake.

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