# A Study on the Bearing Capacity Alteration of Shallow Foundation Resting on Anzali Sand after Applied Cyclic Loading

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## Abstract

Laboratory cyclic loading tests have been employed as a basis to understand the post shaking bearingcapacity of Anzali Sand.Bearing capacity of foundations has been always one of the most challenging research subjects in the field of geotechnical engineering. In this paper, the experimental investigation is aimed to obtain a better understanding of the post liquefied behavior of Anzali Sand and alterationof the bearing capacity of shallow foundations on resting on it. For this purpose, two series of testswere carried out before and after the event of cyclic loading to simulate this phenomenon.Samples of sand tested in this study were collected and transferred from AnzaliPort which is located in an area potentially prone to moderate to intensive seismic risk. Liquefaction or limited liquefaction was modeled in a glass tank at the University of Guilan soil laboratory. Cyclic loading tests were performed under different conditions, i.e. relative varying densities, duration of shaking and frequency of cyclic loads. A series of bearing capacity tests of centrally loaded model footings at circular and strip foundation were performed. Reduction or increase in the volume of the specimens with the dissipation of the excess pore water pressure thus built-up and alternation of the bearing capacity of shallow foundationswith respect to the initial (reference) condition, were studied.Results indicate a relationship between the bearing capacities corresponding to the initial state of the soil from which, the cyclic loading starts.

**Keywords:** Anzali Sand, Strip Foundation, Frequency, Shaking Test.

## 1. Introduction

Loose deposits of saturated sand, may be prone to complete or partial loss of shear strength if it is subjected to the cyclic or seismic loads, mainly due to the built-up of the excess pore water pressure. Thedecreasein the shear strength can be related to the redistribution of the water content throughout the medium corresponding to the void spaces as it is subjected to shaking. However, in dense sands, a reversed mechanism would happen, that is, dilation may occur which causes the soil density to increase and as a consequence, a higher strength to be mobilized. Therefore, whatever the initial state of the sand is, it will be changed after it is subjected to shakings due to seismic or cyclic loadings (Seed and Idriss, 1982). Laboratory cyclic loading tests have been broadly applied by different researchers to investigate the behavior of the sand under seismic loads. There are several studies and explanations on the behavior of the sand under monotonic, cyclic or dynamic loads to better comprehend the mechanism of deformations and the development of the excess pore water pressure in such scenarios (for example, Castro, 1975; Ishihara, 1993). In the past decade, small scale laboratory shaking table tests have become traditional in further studying the behavior of sand and other deposits during and after dynamic loading. In such tests, the post-shaking behavior, in terms of deformations and settlements has been investigated by different researchers (Hushmand*et al.*, 1988; Chen, 2007; Ueng*et al.*, 2010). Based on such tests, the initial state of the sand has been known as one of the important causes of the post-shaking volume of the sand in cyclic and seismic loading (Tokimatsu and Seed, 1987). It has been observed and reported that in liquefied sands, the post-shaking deformations increase as the duration of the shaking increases (Seed and Idriss, 1982). Besides, surface deformations are quite small in those cases where the liquefaction does not occur in comparison to cases where it occurs (Tokimatsu and Seed, 1987).

In 1989, Dobryreported an expected range for the volumetric strain in liquefied soils which between 1.5% and 5% in loose sand and around 0.2% in dense deposits. These ranges indicate that dense sands undergo less deformation during the shaking tests. Whereas the post-shaking deformations are very important, the post-shaking bearing capacity of shallow foundations is important as well. The bearing capacity of shallow foundations has been both theoretically and experimentally studied by many researchers (Terzaghi, 1943; Meyerhof, 1963 among many). Sincethe post-shaking behavior of soils can alter their properties, the post-shaking bearing capacityof soils, beside the settlement and other issues, can be of particular interest.

In the present study, an experimental program is conducted to study the post-shaking bearing capacity of Anzali Sand. In order to accomplish this task, a series of shaking table tests along with initial and post-shaking model footing load tests have been performed on this sand under different conditions. The effect of different factors, such as duration of loading, frequency and the initial state has been considered.

## 2. Properties of the Investigated Soil

TheAnzali, as the main material of this study, was collected fromAnzalishorelinesin the south west of the Caspian Sea located in northern Guilan Province, Iran, I.R.. The aggregation curve of Anzali Sandexhibits a relativelyuniform sand,reasonably dropped into a poorly graded sand (SP) class, based on the USCS. The maximum and minimum void ratios($e_{\max}$ and $e_{\min}$) of the Anzali Sandwere found experimentally (in accordance with ASTM D4253 and ASTM D4254) as 0.89 and 0.52 consequently. The index properties of the Anzali Sand are summarized in Table 1.

| **Property** | ***c*** **(kPa)** | $G_s$ | $e_{max}$ | $e_{min}$ | $D_{60}$ **(mm)** | $D_{50}$ **(mm)** | $D_{30}$ **(mm)** | $D_{10}$ **(mm)** | **Coefficient of uniformity,** $C_u$ | **Coefficient of curvature,** $C_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Value | 0.00 | 2.65 | 0.89 | 0.52 | 0.22 | 0.20 | 0.18 | 0.13 | 1.80 | 1.08 |

**Table 1Index Properties of Anzali Sand used for the current study**

## 3. TestApparatuses and Specimens Preparation

### Apparatus and Foundation Models

The device employed for footing load testswere composed of a frame, a rigid platen over which the glass tank containing the soil is placed, a loading ram (a jack) which works under displacement controlled condition and a measurement device along with some instrumentation to record the footing displacements as the ram applies the load on the model footing. A horizontal sliding steel beam rest above the soil sample, but restrained to displace only in the vertical direction by means of two adjustment bolts. The test speed is in a range which simulates the static loading condition, i.e. it is assumed that the load increases gradually up to the failure at a loading rate slow enough so that no inertia or viscosity effects can affect the result. The rate of application of the load was about 0.5mm per minute. In this research, four different density indices ($D_r$), i.e. 30%,corresponding to a relatively loose, 50%,corresponding to a medium dense, 70%,corresponding to a relatively dense, and finally 90%,corresponding to a very dense sand were chosen.Model footings were both circular and strip rigid steel footings which were set on the surface of the soil of different density indices used for shaking table tests.Circular footings are 58mm in diameter and 3mm in thickness and strip footings are 200mm in length and 40mm in width with 2mm thickness. Model footings were loaded concentrically up to the ultimate capacityand vertical displacements were measured by highly sensitive (0.01mm precision) displacement gauges.

With the density index-bearing capacity relationship assumed to be pre-determined, it is possible to directly relate the initial and final states of the sand achieved in the shaking table tests to the bearing capacity. The bearing capacity tests are presented first and the bearing capacity change in the shaking table tests are presented afterwards which are based on the results already obtained by the bearing capacity tests. These results will be then inserted in the following parts of this research.

## Shaking Table Tests and Sample Preparation

Anumber of shaking table tests in a glass tank followed by a series of footing load tests were scheduled to be performed in the advanced soil mechanics laboratory of the University of Guilan.The experimental setup includes a shaking table hold in a fixed steel frame over which, a twin-wall glass tank is placed upon and fixed. The box material is plexiglass with a negligible (but not zero) flexibility. A multistage frame was provided to fill the tank with the sand fall method and to prepare uniform samples of different density indices as the elevation of the sand fall is changed. The excess pore water pressure (EPWP) developed during the test and its dissipation is measured by the pressure transducers and three standpipe piezometers are used only for calibration purpose. A data acquisition system is also attached to the tank which records the variation of the excess pore water pressure and the displacement time history of the shaking table at prescribed time intervals (usually 0.02 seconds).The water sedimentation method (pouring dry sand into water) was used for sample preparation.

A total number of sixtyshaking table tests were carried outat 5 different density indices. Harmonic loading was applied at a constant displacement amplitude (11mm) in a different durations (15sec., 30sec., 45sec. and 60sec.) and frequencies (1.8Hz, 2.7Hz and 3.6Hz) corresponding to different acceleration amplitudes (0.14g, 0.32g and 0.56g). These values of acceleration cover the range of all moderate and strong earthquakes. It should be noted that unlike real seismic events, the shaking imparted in shaking table tests is a harmonic loading with a constant amplitude; but it has been experimentally found to be more convenient and become common to simulate the effect of earthquake loads by cyclic loads (Ishihara, 1985; Kramer, 1996).

## 4. DataAnalysis and Interpretation

### Model Footing Load Test Results

In the previous step, for each test the load-displacement curveswere plotted and the bearing capacity corresponding to the apparent peak of the curves was extracted. It is of particular interest that in most cases the bearing capacity mode was a general shear failure and hence, an apparent peak was obvious.In this section, the details of experimental program are described for bothtypes of footings to determine the bearing capacity of concentrically loaded footings on Anzali Sand.Variation of the bearing capacity with the density index is presented in Figure 1 for both circular and strip footings with a best-fitted trend

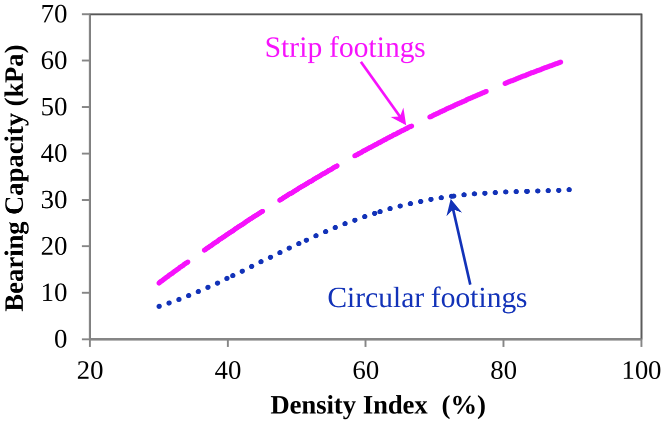

**Figure 1variation of the bearing capacity of strip and circular footings on sand with density index**

As it is visible from the plots, the bearing capacity does not increase with the density index unboundedly; the rate of increase decreases as the density index increases. It can be simply stated that as the density index increases, the maximum dilation angle increases as well and hence, the maximum friction angle. However, as the maximum friction angle increases, the effect of dilatancy in a plastically deforming material will be more effective on the bearing capacity in comparison to lower friction angles. Therefore, although the maximum friction angle increases, the rate of increases in the bearing capacity decreases and the bearing capacity of footings on very dense sand reach a rather constant value with further increase in the density index. This phenomenon which is still a direct result of the stress level effect on the bearing capacity has been presented by Jahanandish*et al.* (2010) and Veiskarami*et al.* (2012). Due to the obtained results in this program, it can be concluded that non-associativityinducesan approximately constant bearing capacity in high density indices (i.e., $D_r$>70%).

Figure2, shows a comparison between the results found by the developed design charts and those obtained experimentally for a few cases with similar properties corresponding to design charts. It is evident that if the graphs are used in a proper manner, i.e. selected in accordance with the density index of the sand, footing roughness and shape, estimation of the bearing capacity will be reasonably accurate.

### Approaches of Analyzing the Results

In the followingsection, variation of the bearing capacity ratio with cyclic load parameters, i.e. the duration of the cyclic loading and the frequency are presented through some graphs. These graphs have been obtained based on different tests conducted on samples of different initial density index under various combinations of cyclic loading parameters. It is noticeable that the bearing capacity ratio is the ratio of the final to the initial bearing capacities.

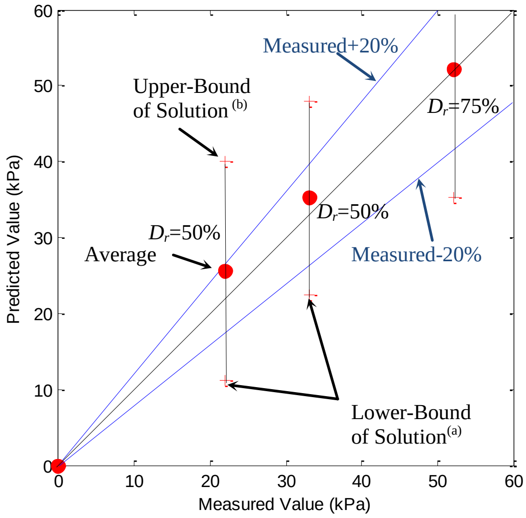

**Figure 2 Measured vs. predicted values by:**
**(a) Jahanandishet *al.*(2010) developed for $\phi_{c.s.}$=30° and *B*=0.1m, strip foundations and**
**(b) Veiskaramiet *al.*(2012) developed for $\phi_{c.s.}$=30° and *B*=0.1m, circular foundations**

## Bearing Capacity Ratio alternation in varying Frequency

Figure 3illustrates the variation of the bearing capacity ratio of sand at different density indices for durations of 15, 30, 45 and 60s at a fixed frequency of 1.8Hz. It is noticeable that for a better visualization of the results, the graph corresponding to $D_r$=30% was omitted in part (b) of this figure.

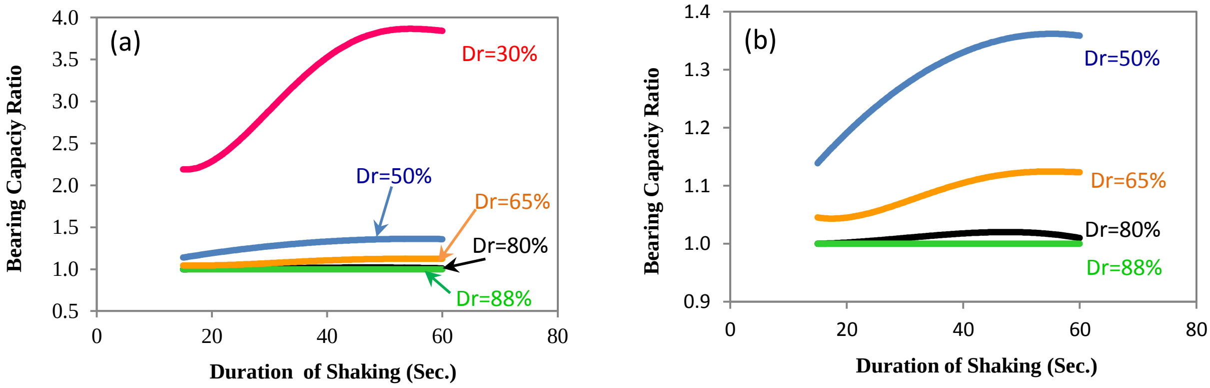

**Figure 3 Variations of the bearing capacity ratio with the durations of shaking at the frequency of 1.8Hz (a) All results and (b) Results with $D_r$=30% excluded**

Observationsrevealed that an increase in the duration of the shaking leads to an increase in the bearing capacity ratio, but the change will be insignificant for durations exceeding 45sec. It can be observed that all results obey almost the same trend regardless of the frequency. In all cases the bearing capacity ratio rises to a peak value under a certain frequency and reaches a constant value thereafter. The same results hold for frequencies of 2.7Hz and 3.6Hz. Due to similarities between the results, plotscorresponding to frequencies of 2.7Hz and 3.6Hz were omitted.

## Effects of Frequency on Bearing Capacity Ratio

Figure 3 shows the change in bearing capacity ratio of the Anzali Sand at different density indices as the frequency of shaking is changed while the duration is held constant (15sec.). Again, part (b) of this, for the sake of better representation of the results, the case corresponding to $D_r$=30% was excluded. It can be observed that as the frequency generally increases the bearing capacity ratio increases. However, for density index exceeding 80%, a decrease in the bearing capacity can be observed. An insight in the results indicates that the bearing capacity of sands with density indices exceeding 88% decreases as the frequency of shaking increases. This effect, i.e. the decrease in the bearing capacity ratio can be related to the dilative nature of the sand at its dense to very dense states.

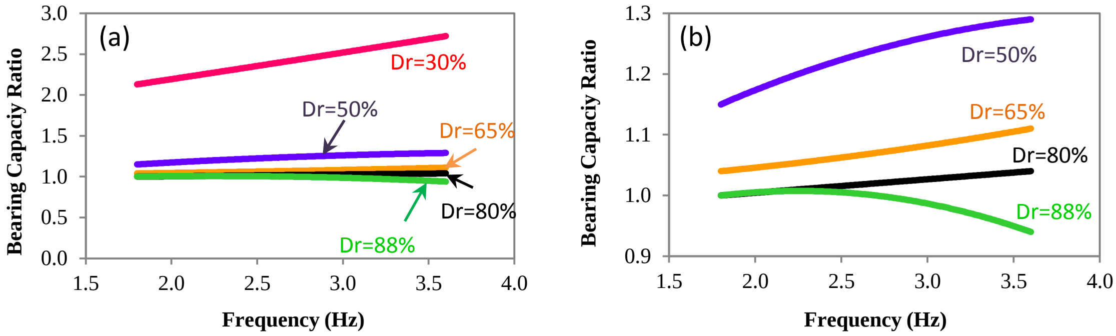

**Figure 4 Variations of the bearing capacity ratio with the frequency of shaking for a constant duration of shaking, 15sec. (a) All results and (b) Results with $D_r$=30% excluded**

Figures 5(a) and 5(b)illustrate variations of the bearing capacity with frequency for time duration of 45s. Based on experimental observations, it was found that the increase in the frequency causes an increase in the bearing capacity ratio for loading durations of 15s and 30s inall samples. However, beyond 45s duration, different behaviors were observed for samples initially at different density indices: (i) The bearing capacity ratio in samples of medium sand increases ($D_r$=50% and 65%); (ii) There is no change in the bearing capacity ratio of initially loose samples ($D_r$=30%); (iii) In initially very dense samples on the other hand, there is no increase in the bearing capacity ratio; such samples exhibit a dilative behavior and hence, the bearing capacity ratio decreases with increasing the frequency. ($D_r$=88%) and (iv) The bearing capacity ratio in dense samples increases with frequency up to 2.8Hz and it decreases as the frequency goes beyond 2.7Hz. Therefore, there is a peak in the bearing capacity ratio with frequency which occurs at a frequency roughly between 2.5 to 3.0Hz. This range can be regarded as a range of *critical frequencies* ($D_r$=80%). It is mentionable that the rate of change in the bearing capacity is much significant for samples which are initially loose to medium dense, i.e. $D_r$<80%. Therefore, the change in the bearing capacity of dense to very dense samples can be regarded as insignificant in most practical cases.

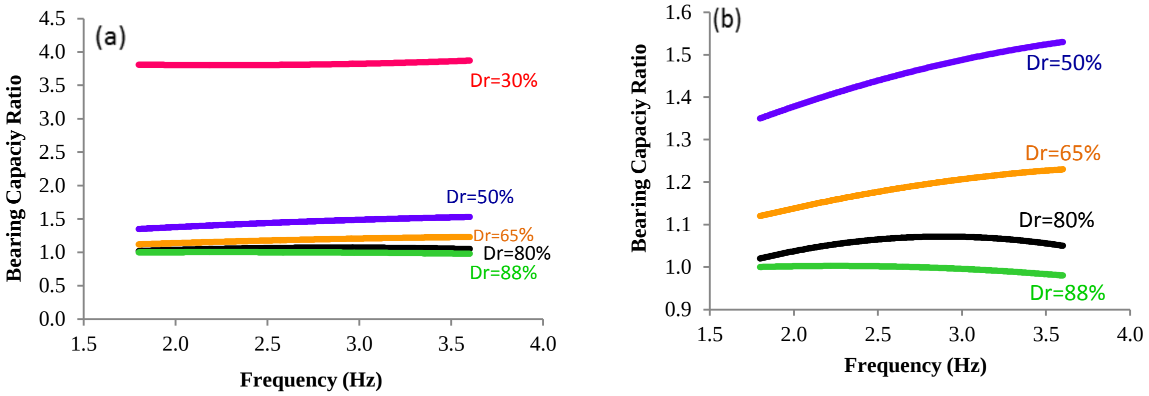

**Figure 5 Relations between bearing capacity ratio and frequency (a) at 45s shaking duration and (b)at 45s shaking duration except for $D_r$=30%**

## Effect of Density Index on the Bearing Capacity Ratio

Cyclic loading tests were performed at five different density indices. For each density index, the bearing capacity ratio was calculated in order to find the bearing capacity ratio – density index relationship. Figure 6shows this relationship for three sets of tests at different frequencies. It is evident that the influence of frequency is quite insignificant in particular for medium to medium dense sands ($D_r$>50%). Moreover in all frequencies, as the density index increases, the change in the bearing capacity ratio decreases and all curves follow the same trend.

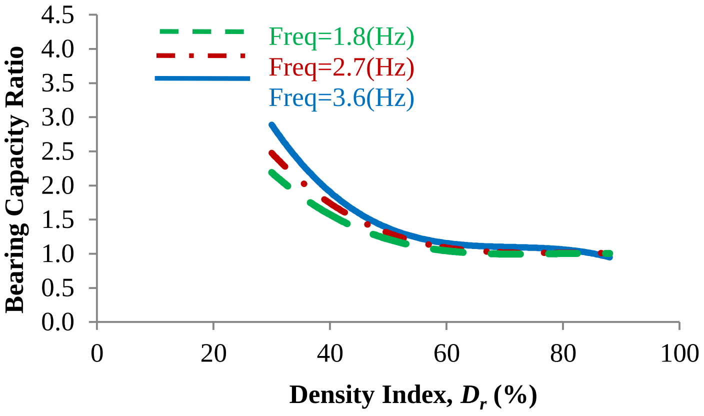

**Figure 6 The effect of density index,$D_r$ on the bearing capacity ratio at different frequencies**

## 5. Discussion and Conclusions

The post-shaking bearing capacity of Anzali Sand was intended to be studied. In order to do it, shaking table and bearing capacity tests have been conducted in conjunction of each other on saturated samples of Anzali Sand. The bearing capacity tests were carried out before and after application of the cyclic loading under different frequency and duration of loading. The initial stateof the sand, beside many factors, such as the frequency and the duration of shaking, was found to be the most crucial parameter which controls the post-shaking behavior of the sand. The initial and the post-shaking bearing capacities were found by laboratory model footing tests at different densities corresponding to different void ratios.

While the sand at loose to medium dense states (i.e. for $D_r$<80%), exhibited a contractive behavior, for the initially dense sand (with $D_r$>80%) a dilative behavior was observed. As a result, it was expected that the bearing capacity, depending on the initial state, can either increase or decrease. The frequency and the duration of shaking, although were found to be important, showed a rather slight effect on the bearing capacity change for initially dense sand. For loose to medium dense sand, it was observed that the higher the frequency the higher in the alteration of the bearing capacity; however, the bearing capacity alteration decreases as the density index increases. The duration of shaking has almost the same effect on the change in the bearing capacity, i.e. as the duration increases the bearing capacity ratio increases as well; but again, for initially dense state, this effect is less important. In general, it can be concluded that: i) the effect of duration is more crucial than that of frequency and ii) both the frequency and the duration of shaking have the most significant influence on initially loose to medium dense states.

## 6. References

Chen Y. C., 2007, Shaking Table Test on Large Saturated Mailiao Sand Specimens, M.Sc. Thesis, Department of Civil Engineering, National Taiwan University, Taipei, Taiwan. (in Chinese)

Dobry, R., 1989, Some Basic Aspects of Soil Liquefaction During Earthquakes, in K. H., and Turkstra, Carl J. Jacob, Earthquake Hazards and the Design of Constructed Facilities in the Eastern United States, New York Academy of Sciences 558. 172-182.

Hushmand et al., 1988, Centrifuge Liquefaction Tests in a Laminar Box, Géotechnique, Vol. 38, No. 2, pp. 253–62.

Ishihara, K., 1993, Liquefaction and Flow Failure During Earthquakes, Géotechnique, Vol. 43, No. 3, London, England, pp. 351–415.

Ishihara, K., 1985, Stability of Natural Deposits During Earthquakes, In Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, San Francisco, U.S.A., pp. 321–376.

Jahanandishet al., 2010, Effect of Stress Level on the Bearing Capacity Factor, $N_\gamma$, by the ZEL Method, KSCE Journal of Civil Engineering, Springer, Vol.14, No.5, pp.709-723.

Meyerhof, G. G., 1963, Some Recent Research on the Bearing Capacity of Foundations, Can. Geotech. J., Vol. 1, pp. 16-26.

Seed, H. B. and Idriss, I. M., 1982, Ground Motion and Soil Liquefaction during Earthquakes, Monograph Series, Earthquake Engineering Research Institute, Berkeley, CA.

Terzaghi, K., 1943, Theoretical Soil Mechanics, John-Wiley and Sons Inc., NY, 1943

Tokimatsu, K. and Seed, H. B., 1987, Evaluation of Settlements in Sand due to Earthquake Shaking, Journal of Geotechnical Engineering Division, ASCE Vol. 113, No. 8, pp. 861-878.

Uenget al., 2010, Settlements of Saturated Clean Sand Deposits in Shaking Table Tests, Soil Dynamics and Earthquake Engineering, Vol. 30, No. 1-2, pp. 50-60.

Veiskaramiet al., 2012, Stress Level Based Bearing Capacity of Foundations: Verification of Results with 131 Case Studies, KSCE Journal of Civil Engineering, Springer, .16 (**5**): 723-732.