

## SEISMIC PERFORMANCE OF TANK FOUNDATIONS IMPROVED WITH STONE COLUMNS

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### ABSTRACT

Natural soil in engineering practices is not always considered to bear loads of above structures. In such a way, it is necessary to improve the quality of the soil before any constructions. Tanks are the structures that apply significant load to the beneath soil and they are usually constructed with circular foundations in shape. Seismic loads can apply irremediable damages to the structures and sometimes tanks are the highly important infrastructures during earthquakes. One of the most techniques that has been recently widely used on soft deposits and loose fine-grained soils is stone columns or singular piles. The stone columns increase the strength of loose soils and also decrease settlements induced by applying the loads. In this study, a linear numerical model of the structure-foundation-soil-stone column was simulated using the ABAQUS. Results show that with the increase of the length of stone columns a decrease in settlement occurred, while the increase of length more than a specific threshold had no significant effect to decrease the uplift and settlement.

### KEYWORDS

Circular foundation, Acceleration, Stone column, Settlement, Uplift

### INTRODUCTION

One of the existing structures in oil and petrochemical industries that can have economic and environmental catastrophes is steel tanks. Increasing use of firing, toxic and dangerous materials which cause the environment pollution and also waste resources is an example of unreplaceable and destruction of structures. Steel tanks located on soils can be constructed in two ways of braced and unbraced. The braced tanks are linked to their foundation using piles and anchors. In unbraced tanks, there is no linkage between the tank wall and its foundation. [1]

Primary seismic analysis investigations were introduced by Sivý et al. They proposed that foundation and tank wall are rigid [2]. During a drastic earthquake in Alaska in 1964, extreme damages to fluid tanks occurred. These damages were arising from lack of consideration of any flexibility for the tank wall in the design process. Ozdemir et al. analysed the problem of fluid-structure interaction by numerical methods and finally introduced a simple model in which the effect of flexibility of tank wall had considered [3]. Estekanchi and Alembagheri published an article in which the effect of higher turbulence mode contributions had been considered [4].

Ormeño et al. studied static uplift of steel tanks and concluded that the important resistant element against uplift is tank under sheet [5].

Malhorta et al. analysed the resistance of semi-infinite beam on a rigid bed against uplift [6].

Brown and Mikle also introduced a method of quasi-static simulation on nonlinear uplift of unbraced tank sheet based on results of the tank sheet uplift model. A simple method for analysing of cylindrical unbraced tanks' uplift was also developed [7].

One of the most techniques that has been recently widely used on soft deposits and loose fine-grained soils is stone columns or singular piles. These stone columns cause an increase in strength of loose soils and also decrease settlements induced by loadings [8].

Nowadays, stone columns are widely used to decrease the settlements of tanks. Stone columns were first used in 1830 in France and after 1950 they are widely used in many other countries [9].

In Iran, stone columns were used firstly with compaction method and since 1383 (Persian Calendar) vibrating methods were imported to create this kind of soil improvement technique. Laboratory investigations have been conducted on the use of lime and fly ash columns to increase the bearing capacity and also decrease settlements of clays [10].

Laboratory results showed that singular stone columns failed at top parts of the column due to bulging phenomenon. Based on the test results of single stone columns, it was concluded that every single column in columns group can deform independently and then failure. In other words, in this method, the effect of columns on adjacent ones is not considered [11]. Many laboratory and numerical investigations showed that it is not true to design and analysis of group stone columns without considering the effect of adjacent columns on each other [12-15]. In this research, numerical simulation is run to evaluate the effects of length and diameter of stone columns and settlement. Moreover, the sliding of the tank in different modes has been considered.

## METHODS

The simulated geometry of the tank and its beneath soil using ABAQUS has been shown in Figure 1. The simulated geometry dimensions are 100 m of width, 100 m of length and 30 m of depth. Figure 2 shows the applied acceleration within the soil. The maximum acceleration of the applied earthquake occurs in the first 10 seconds. Soil strength parameters and steel tank dimensions are presented in Table 1. Table 2 presents the linear constitutive properties of material of the cylindrical steel tank. The thickness of the steel tank wall,  $t = 0.004 \times R$  is performed as suggested by Jadhav and Jangid [16]. The dimensions of the circular footing of steel tank were selected with a height/radius ratio of 0.66 ( $H/R=0.66$ ) that settled on the soil. In this study, the height and radius of the cylindrical tank footing were selected as 2 m and 3 m, respectively. Relatively fine mesh is used near the surface while a coarser mesh grid was used for farther distance from the centre of the foundation. Stone column and soil were modelled as the perfectly-elastic plastic using the Drucker-Prager model. The boundary conditions were chosen such that the horizontal displacement of the boundary is restricted in all directions, while vertical boundaries are restricted horizontally and free to move in the vertical direction. The acceleration boundary condition is applied at the bottom of the model. The acceleration time history of the earthquake is applied as a base excitation input to the steel tank along x- and y-axis. The base is fixed to a rigid foundation and is assumed to be excited by ground acceleration. The tank wall is modelled using three-node triangular and four-node quadrilateral shell elements, S3R and S4R, respectively. The analysis was performed under displacement controlled method. The model with boundary is used to include deformable foundation effects as a linear elastic soil medium. The Newmark's step-by-step method [17] assuming linear variation of acceleration over a small time interval is chosen for evaluating the response of the system. The tank and stone columns materials are assumed to be linear elastic. The soil medium is modelled as an isotropic elastic space. Provided the assumption is made that the base of the tank is rigidly attached to the foundation thereby linear elastic behaviour was carried out to determine its response.

The applied acceleration record below the tank is one of the El Centro earthquake data recorded in 1940 with a maximum peak of 0.5g. A surcharge (75 kPa) pressure was applied on the soil to simulate the loads from the steel tank. Additionally, analyses were carried out under static

loading in order to evaluate the effects of the stone column on settlements of stone column subjected to such loading.

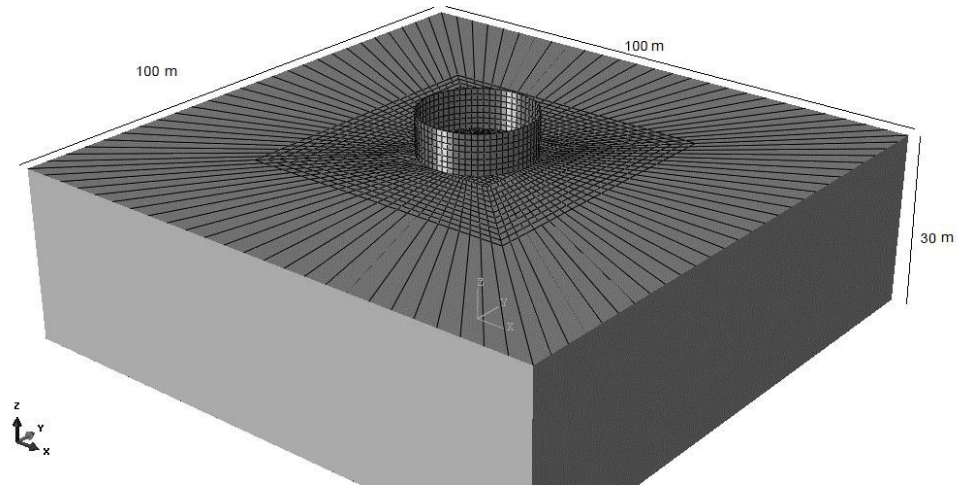


Fig. 1 - Simulated soil and tank

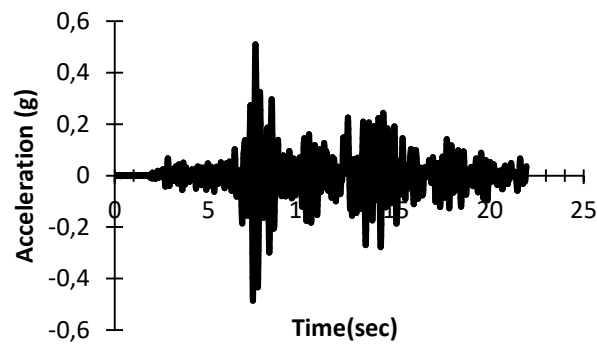


Fig. 2 - Applied earthquake acceleration beneath of the tank

Tab. 1 - Properties of soil

	Module of elasticity (E) (kPa)	Poisson's ratio ( $\nu$ )	Unit weight ( $\gamma$ ) (kg/m <sup>3</sup> )	Friction angle ( $\phi$ )	Cohesion (kpa)	Dilatancy angle ( $\psi$ )
Moderate compacted sand	7e6	0.35	1800	35	0	2
Stone column	20e6	0.25	2000	47	0	4

Tab. 2 - Parameters of cylindrical tank

	Material	Module of elasticity (E) (kPa)	Poisson's ratio ( $\nu$ )	Unit weight ( $\gamma$ ) (kg/m <sup>3</sup> )	Height (m)	Radius (m)	Wall thickness (m)
Cylindrical tank	Steel	2e8	0.3	7900	21	14	0.056

## RESULTS

As shown in Figure 3, in the beginning, the tank was located on the soil with no stone column and also the amounts of uplift, settlement, slide and recorded accelerate is impressible for the tank on the soil without any improvement. After evaluation of the improved soil with the tank, it was observed that the vertical settlement of soil decreased due to the reinforcing effect of stone columns. Figures 4, 5 and 6 are related to settlement and uplift of the tank foundation and stone columns with the lengths of 8, 10 and 12 m and diameters of 0.4, 0.8 and 1.2 m. With the increase of the column's length, the more area of the soil was affected and simultaneously the improved soil showed more strength to the applied stress during the loading process.

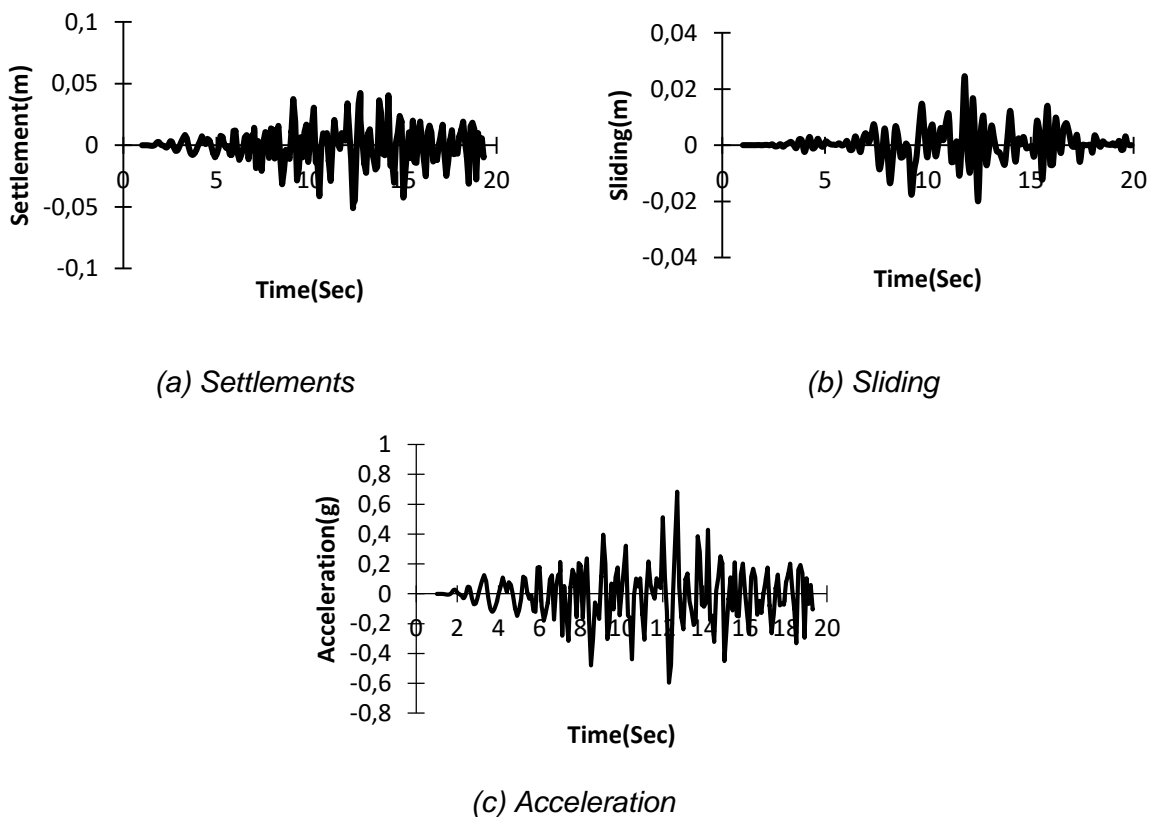
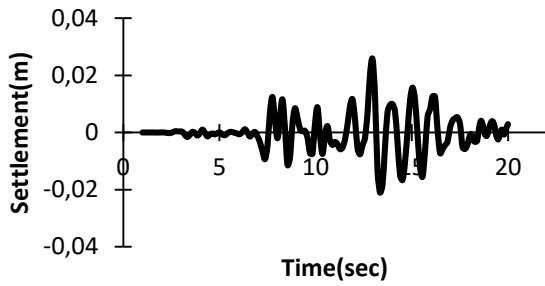
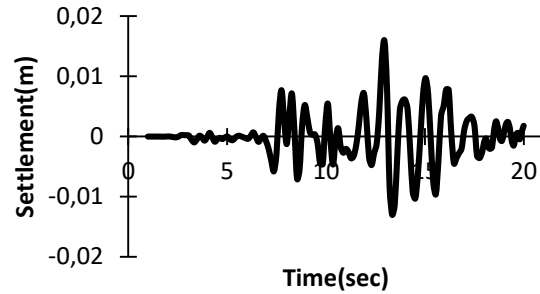


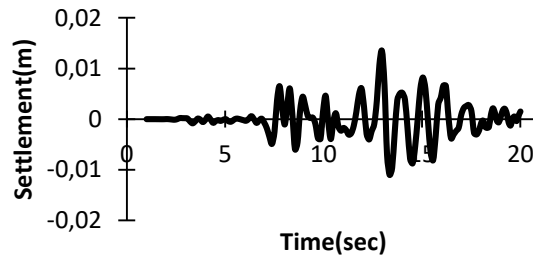
Fig. 3 - Settlement (a), Sliding (b) and acceleration (c) of the tank without stone column



(a) 0.4 m

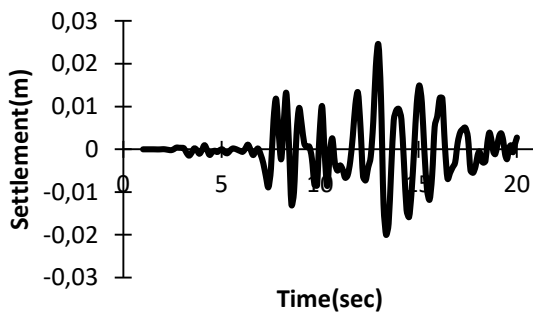


(b) 0.8 m

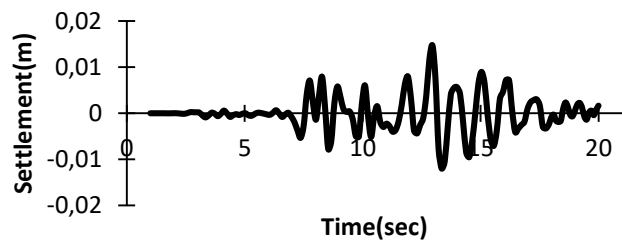


(c) 1.2 m

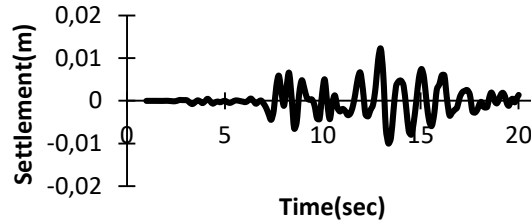
Fig. 4 - Settlements of 8 m length column with varying diameters



(a) 0.4 m



(b) 0.8 m



(c) 1.2 m

Fig. 5 - Settlement of 10 m length column with varying diameters

It is noticeable that in the present study, the centre to centre distance between all columns is 2 meters and also as it can be noticed that with the increase of the column's length, the settlement and uplift decrease. For instance, in a column with a diameter of 0.8 m and centre-to-centre distance of 2 m, with the increase of the column's length from 8 m to 10 m and then 12 m, the induced settlements decrease of about 7.7 % and 8.3 %, respectively. It is considered that with a constant diameter and centre-to-centre length, the further increase of the length after 8 m, would not have any significant effect on the settlement. Thus, the effect of centre-to-centre and the column's diameter up to a threshold length is more important.

As it can arise from the charts, the amounts of uplift and settlement significantly decreased with the improvement of the soil beneath the tank using stone columns. Furthermore, with the increase of the diameter of the columns from 0.4 m to 0.8 m, there is a significant decrease in uplift and settlement. Also, with the increase of the diameter of the columns from 0.8 m to 1.2 m, the amounts of uplift and settlement decreased but these decreases were more when the diameter was changed from 0.8 m to 1.2 m. Hence, the use of stone columns with 1.2 m in diameter does not seem to cost economically.

In terms of settlements, the use of stone columns has a significant effect on the decrease of the settlements of the tank. As shown in Figure 6, in the exact location of the tank, there are fewer settlements than other areas. This can be justified that by using the stone columns the settlements decreased.

According to uplift results from Figure 7, the settlements of the tank decreased using stone columns. Thus, it is the best way to reduce damages from earthquakes by using improvement techniques.

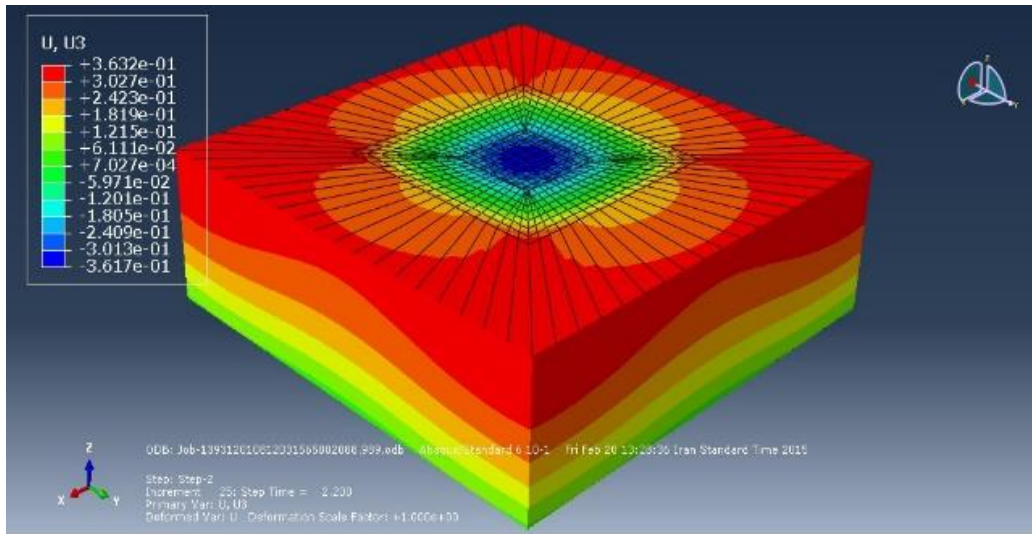


Fig. 6 - Vertical displacements of the foundation of tank using stone columns

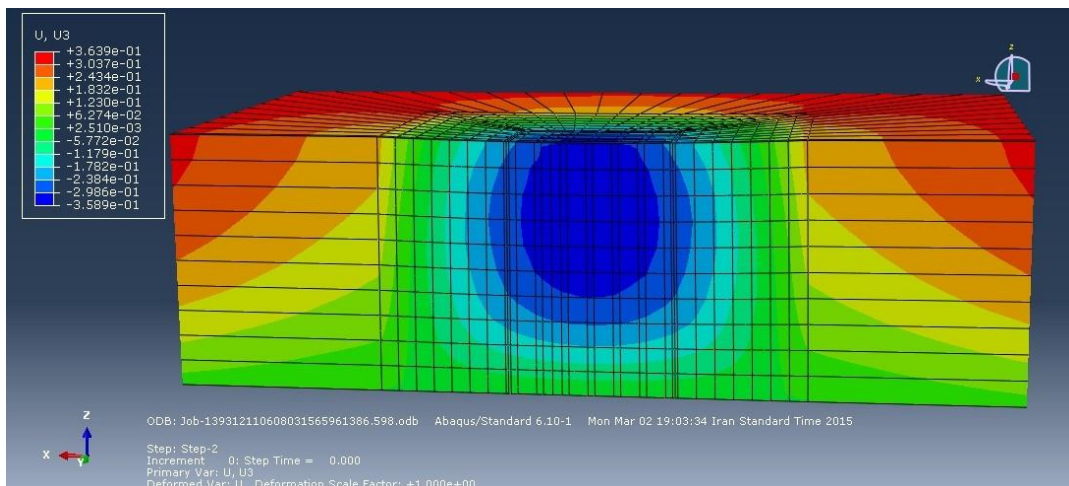


Fig. 7 - settlements of the foundation of tank using stone columns

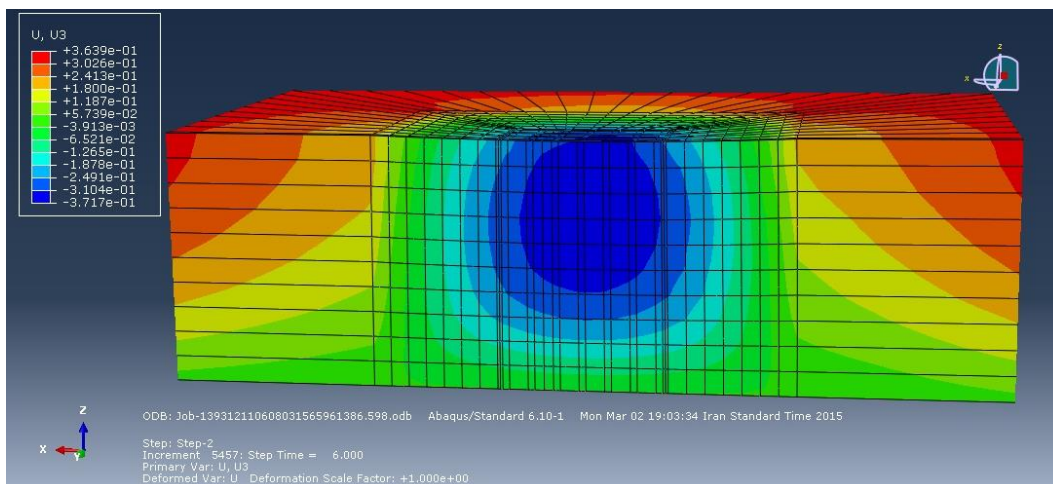


Fig. 8 - Settlements of the foundation of tank without using stone columns

## CONCLUSION

The following results are derived from the numerical simulation of the tanks with and without stone columns to decrease the amounts of uplift, settlement and in consequence increase in bearing capacity of them:

- Increase of the length of the columns caused a reduction of settlement. This conclusion is obviously clear in the presented results. In a model with a stone column that has 0.8 m diameter and 2 m centre-to-centre distance, there was a 46% reduction in settlement compared with the model without any stone column. With the increase of the length of the columns from 8 m to 10 m and 12 m, a reduction of 62% and 64% was observed, respectively.
- The study of the diameter of the columns in settlement of the tank is an item which was evaluated in the present study. In soil with a stone column with a diameter of 0.8 m, the increase of the column's length from 0.4 m to 0.8 m, caused a 38% reduction in settlement and with the more increase of the diameter from 0.8 m to 1.2 m, only a 15% reduction were observed. The rate of this reduction with the increase of the diameter from 0.8 m to 1.2 m was less significant.

## ACKNOWLEDGEMENTS

The author states that there is no conflict of interest.

## REFERENCES

- [1] American Petroleum Institute (API), (1998) "Welded Storage Tanks for Oil Storage," API 650, American Petroleum Institute Standard, Washington D.C.
- [2] Sivý M., Musil M. (2017) Procedure for Seismic Analysis of Liquid Storage Tanks Using FEM Approach and Analytical Models. In: Beran J., Bílek M., Žabka P. (eds) *Advances in Mechanism Design II. Mechanisms and Machine Science*, vol 44. Springer, Cham. [https://doi.org/10.1007/978-3-319-44087-3\\_28](https://doi.org/10.1007/978-3-319-44087-3_28)
- [3] Ozdemir, Z., Souli, M., & Fahjan, Y. M. (2010). Application of nonlinear fluid–structure interaction methods to seismic analysis of anchored and unanchored tanks. *Engineering Structures*, 32(2), 409-423.
- [4] Estekanchi, H. E., & Alembagheri, M. (2012). Seismic analysis of steel liquid storage tanks by Endurance Time method. *Thin-Walled Structures*, 50(1), 14-23.
- [5] Ormeño, M., Larkin, T., & Chouw, N. (2015). The effect of seismic uplift on the shell stresses of liquid- storage tanks. *Earthquake Engineering & Structural Dynamics*, 44(12), 1979-1996.
- [6] Malhotra, P. K., Wenk, T. and Wieland, M, (2000) "Simple Procedures for Seismic Analysis of Liquid Storage Tanks", *Structural Engineering International, IABSE*, Vol. 10, No. 3, pp 197-201.
- [7] Brown, S.; Mickle, G.N, (2010), Analysis of stone column reinforced foundations. *Int. J. Numer. Analyt. Methods Geomech.* 22, 1001–1020. [https://doi.org/10.1002/\(SICI\)1096-9853\(199812\)22:12<1001::AID-NAG955>3.0.CO;2-I](https://doi.org/10.1002/(SICI)1096-9853(199812)22:12<1001::AID-NAG955>3.0.CO;2-I)
- [8] Wood, D.M.; Hu, W.; Nash, F.T.: Group effects in stone column foundation: model tests. *Geotechnique* 50(6), 689–698 (2005).
- [9] Malarvizhi, S. N. (2007). Comparative study on the behavior of encased stone column and conventional stone column. *Soils and Foundations*, 47(5), 873-885.
- [10] Bowles, Joseph E. 1988. *Foundation analysis and design*. New York: McGraw-Hill.
- [11] Ngo, N. T., Indraratna, B., & Rujikiatkamjorn, C. (2016). Load-deformation behavior of a stone column using the coupled DEM-FDM method. In *Geotechnical and Structural Engineering Congress 2016* (pp. 1618-1626).
- [12] Deb, K., Samadhiya, N. K., & Namdeo, J. B. (2011). Laboratory model studies on unreinforced and geogrid-reinforced sand bed over stone column-improved soft clay. *Geotextiles and Geomembranes*, 29(2), 190-196. <https://doi.org/10.1016/j.geotexmem.2010.06.004>
- [13] Elsayy, M. B. D. (2013). Behaviour of soft ground improved by conventional and geogrid-encased stone columns, based on FEM study. *Geosynthetics International*, 20(4), 276-285.



- [14] Jaiswal, O. R., Rai, D. C., & Jain, S. K. (2007). Review of seismic codes on liquid-containing tanks. *Earthquake Spectra*, 23(1), 239-260.
- [15] Papadrakakis, M., & Fragiadakis, M. (2017). EVALUATION OF CODE PROVISIONS FOR SEISMIC PERFORMANCE OF UNACHORED LIQUID STORAGE TANKS.
- [16] Jadhav, M. B. and Jangid, R. S., "Response 26. of base-isolated liquid storage tanks", *Shock and Vibration*, Vol. 11, 2004, pp 33–45. DOI :10.1155/2004/276030
- [17] Rosenblueth, E. and Newmark, N.M. (1971). "Fundamentals of Earthquake Engineering", Prentice-Hall, N.J.