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Numerical evaluation of the effect of soil type on the behavior of underground structures against explosion

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Abstract—This paper presents a 3D numerical investigation on explosion response of underground structures. Analysis of the behavior of structures against explosion is very essential. Design philosophy of protective structures against explosion is minimizing possible damages. Exploitation underground structures is one of the popular method to preserve strategic structures, so that understanding the behavior of soil under blast loading is very important to engineers in tunneling and military construction. In this study, a two-story structure with reinforced concrete walls and slabs that constructed underground has been studied. The soil using as an absorber to improve the performance of structures against explosive load by absorbing the released energy from explosion. Considered structure has been modeled by finite element software (ABAQUS). In numerical simulation different amounts of explosive charges and different locations have been considered. Two types of soil including clay and sandy soil have been used. The results revealed that the sandy soil has greater ability to dissipate energy of explosion in comparison with clay. The strain and displacement response have been compared and depicted that the sand-underground structure has better behavior than the clay-underground structure and has less displacement. Also the results revealed the stresses of sand-underground structure are less than stresses of the clay-underground structure.

Index Terms— Explosion, Underground Structures, Explosive energy, Reinforced Concrete Structures, Numerical Simulation.

1 Introduction

During the last decades, research activity related to underground structures and the effect of explosion on them have progressively increased. The correct evaluation of the effect of explosion is very important for the design of protection structures. The action of explosions on soils and the resulting effect on structures is a strongly complex physical problem. Loads resulting from the explosion can cause severe damage to civil engineering structures. In comparison with other threats such as earthquakes and hurricanes, explosions has a different effect on the structures [1, 2]. Due to the effects of explosion loads is destructive, the design of structures against explosions is impractical. Often the designers try to reduce the damages caused by the explosion with different ways. Among these solutions, using the underground structures can be a good choice, but the influence of that dependent on many parameters that include the weight of explosive charge, the explosion depth, soil type and properties, among others. The structural system used for the underground structures is very important. One of the most popular system for this purpose is the reinforced concrete structures. The system of reinforced concrete structures due to high resistance to corrosion can be a suitable option. Underground reinforced concrete structures are used for essential installations protected against the effects of conventional weapons. Owning the low tensile strength and low flexibility can be one of important disadvantages of reinforced concrete system. The effects of changing the strain rate increased the tensile and compressive strength in concrete and for this reason the initial stiffness increased. Because of this fact, the concrete response to the explosion and impact loading differs from the static load [3].

In recent years a lot of researches about the behavior of underground structures against blast and blast effects on them have done. In 2005, Lu et al. proposed a fully coupled numerical model is used to simulate the response of underground concrete structure under subsurface blast, with emphasis on the comparative performance of 2D and 3D modeling schemes [4]. Nagy et al. proposed a numerical model to investigate the influence of surface explosion on the underground structures [5]. Another investigation is focused on soil–structure interaction and multiple blasts which are the realistic scenarios. The finite element analysis is carried out using ABAQUS. Results indicate that the buried depth of structure, soil–structure interaction and strain rate governs the dynamic behavior of the structure. Besides, in this work concluded that blast design of structure is governed by the time interval between successive blasts, and not merely by single blast of the given amount of explosive [6]. In 2012, De proposed a numerical modeling of the effects of explosions relies on suitable material models appropriate for large deformation problems. A fully-coupled Euler-Lagrange Interaction was utilized to correctly model pressures created by the explosion simultaneously with the large deformations in the soil. The model was used to study two cases-the first with a 2D axisymmetric case of crater formation; and the second with a 3D case of surface explosion above an underground tunnel. The results of numerical analyses were found to closely match those from other analyses, field tests [7].

Numerical simulation is one of the useful method for studying the structures behavior against explosion loads. Recent advances in numerical simulation have allowed the modeling of underground structures and evaluating the behavior of them under explosion loads with acceptable accuracy. The effect of explosions on underground structures under soil surface is numerically studied in this paper. In this study, using the finite element software ABAQUS to study the effect of explosions on underground structures [8]. Both clay and sandy

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soil considered to evaluate the effects of soil type on the behavior of the structure. Structure and soil in the application model and under different amounts of explosives and the blast site has been different distances.

2 Modeling

Underground structure is a two-story structure with reinforced concrete slabs and walls, which in Figure 1 is shown. Structures with spans of 9 m and 7.25 m in the x-direction and in the z direction has a spans of 5.5 m and 7.5 m. First and second floors height are 1.9 m and 3.7 m, respectively. Thickness of slabs and walls is 30 cm and the diameter of the longitudinal reinforcement bars are 20 and 16 mm.

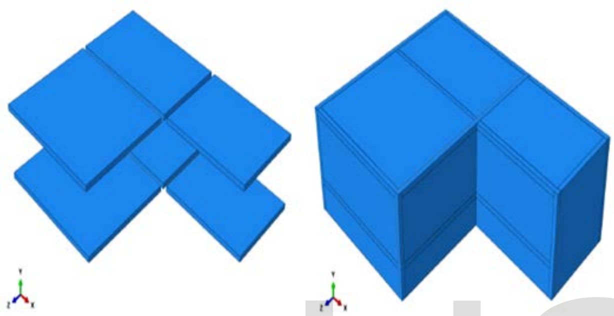

Fig. 1. Underground structure

Slabs and walls connection is considered completely fixed. The depth of the top level of structures is 2 m from the ground level. In Figure 2 the soil model is shown. Soil and structure interaction defined by Penalty function in software. Perpendicular and tangent behavior of soil defined as Hard Contact and Penalty, respectively and the coefficient of friction is considered 0.345.

3 Material properties

The density of concrete, Young's modulus of concrete and Poisson's ratio are considered 2500 kg/m^3, 2.4*10^5 kg/cm^2 and 0.2, respectively. A constitutive model called concrete damage plasticity model based on models proposed by Lubliner et al. (1989) and Lee (1998) in ABAQUS is considered to account for the inelastic mechanical properties and to model the behavior of concrete under shock loading. This model is based on the assumption of scalar damage in which the degradation of elastic stiffness induced by plastic straining both in tension and compression are considered. The compression yield stress is considered 250 kg/cm^2 and the tension yield stress is considered 25 kg/cm^2. The stress- strain behavior of concrete in uniaxial loading used in the study are given in Figure 3.

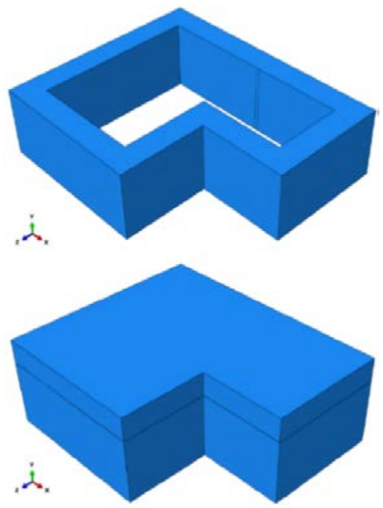

Fig. 2. Soil modeling

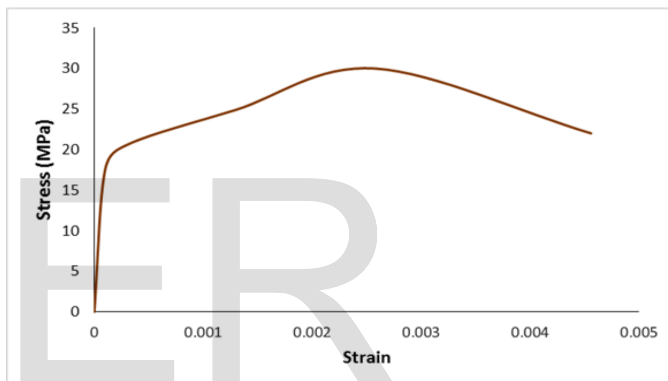

Fig. 3. Stress-strain behavior of concrete

The density of steel, Young's modulus of steel and Poisson's ratio are considered 7850 kg/m^3, 2*10^6 kg/cm^2 and 0.3, respectively. The yield strength of steel, 4200 kg/cm^2 is considered. The stress-strain behavior of steel in uniaxial loading used in the study are given in Figure 4.

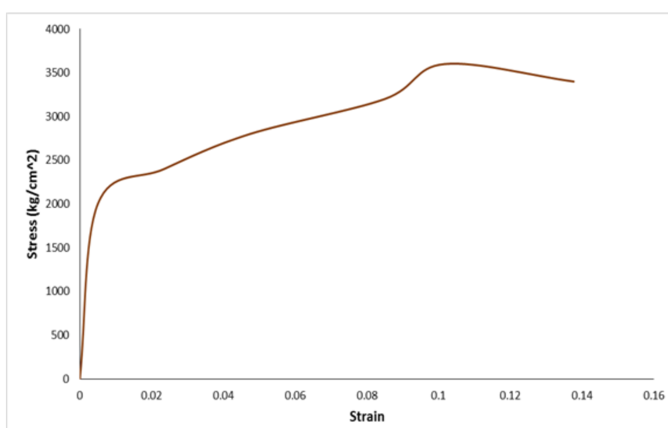

Fig. 4. Stress-strain behavior of steel

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4 Explosion MODELING

An explosion is defined as a large-scale, rapid and sudden release of energy. Explosions can be categorized on the basis of their nature as physical, nuclear or chemical events. In physical explosions, energy may be released from the catastrophic failure of a cylinder of compressed gas or even mixing of two liquids at different temperatures [9]. Explosive materials can be classified according to their physical state as solids, liquids or gases. Solid explosives are mainly high explosives for which blast effects are best known. They can also be classified on the basis of their sensitivity to ignition as secondary or primary explosive. The latter is one that can be easily detonated by simple ignition from a spark, flame or impact. Materials such as mercury fulminate and lead azide are primary explosives. Secondary explosives when detonated create blast (shock) waves which can result in widespread damage to the surroundings. Examples include trinitrotoluene (TNT) and ANFO. The detonation of a condensed high explosive generates hot gases under pressure up to 300 kilo bar and a temperature of about 3000-4000C°. The hot gas expands forcing out the volume it occupies. As a consequence, a layer of compressed air (blast wave) forms in front of this gas volume containing most of the energy released by the explosion. Blast wave instantaneously increases to a value of pressure above the ambient atmospheric pressure. This is referred to as the side-on overpressure that decays as the shock wave expands outward from the explosion source. After a short time, the pressure behind the front may drop below the ambient pressure (Figure 5). During such a negative phase, a partial vacuum is created and air is sucked in.

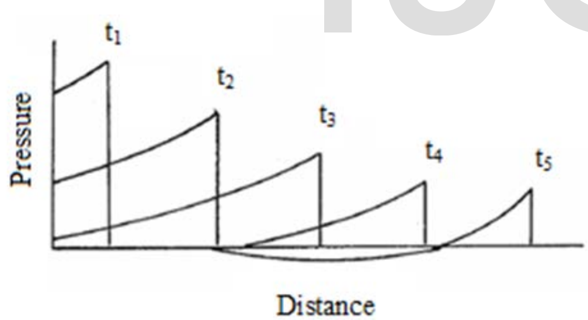

Fig. 5. Explosion pressure reduction

In this study the underground structure is considered for the analysis and design against the air blast equivalent TNT at different distances. Varying charge weights ranging from 10 kg, 30 kg and 50 kg TNT have been used. The explosive loading generated due to an air blast (equivalent of TNT) at distances of 0.5, 1 and 2 m from the soil surface. The depth of the top level of structures is 2 m from the ground level. In addition the gravity loads are applied to the structures.

5 SIMULATION RESULTS

Numerical simulations of explosive load applied on existing structural finite element model. As a general concluding, due to the location of explosion and according to the Figure 6 can be observed, the stresses of slabs are much more than stresses of walls.

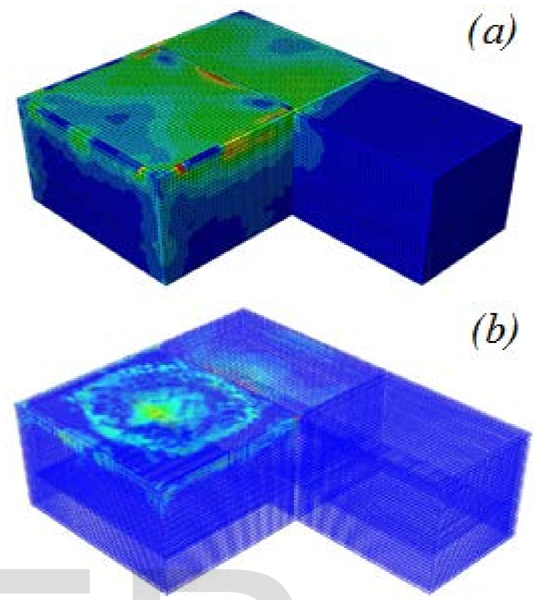

Fig. 6. (a) Stress distribution in concrete, (b) Stress distribution in steel

The improvement performance of the underground structures is due to dissipating and absorbing the explosion's energy by the around soil. The around soil absorb the entrance explosive energy as an absorber. In an evaluation found out that the soil type can be an important parameter in absorbing the energy. In this study, as in Figure 7 depicted the sandy soil in absorbing the energy of the explosion is better than clay. Figure 7 compares the energy dissipation by the soil for various explosive charge weights.

For more investigating and better understanding it is interested in comparing the time history displacement response of the top floor slab. It should be noted that the displacement has two reason, first caused by explosive load and second caused by gravity loads. By noting the density of clay and sandy soil it can be concluded the displacement that caused by gravity loads in sandy soil is larger than clay. Figures 8 to 10 compared the response of structure in various considerations. It can be seen that the displacement response of underground structure caused by explosion in sandy soil is less than the displacement response of underground structure in clay. As another concluding remarks, it is realized that the plastic strain for 10 kg and 30 kg explosive loads is almost zero, but for 50kg explosive load the plastic strain is considerable. This fact depicted in Figure 10 that the permanent deformation is also visible at the end of the loading period.

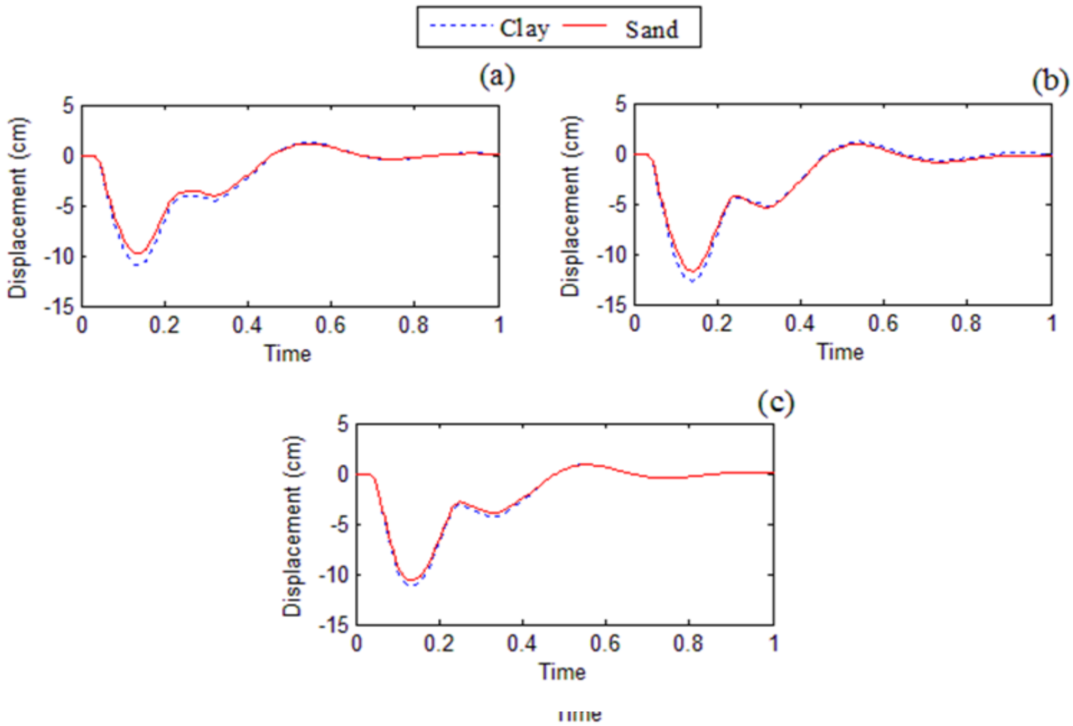

Fig. 7. Dissipated energy by soil; (a) 10 kg TNT, (b) 30 kg TNT, (c) 50 kg TNT

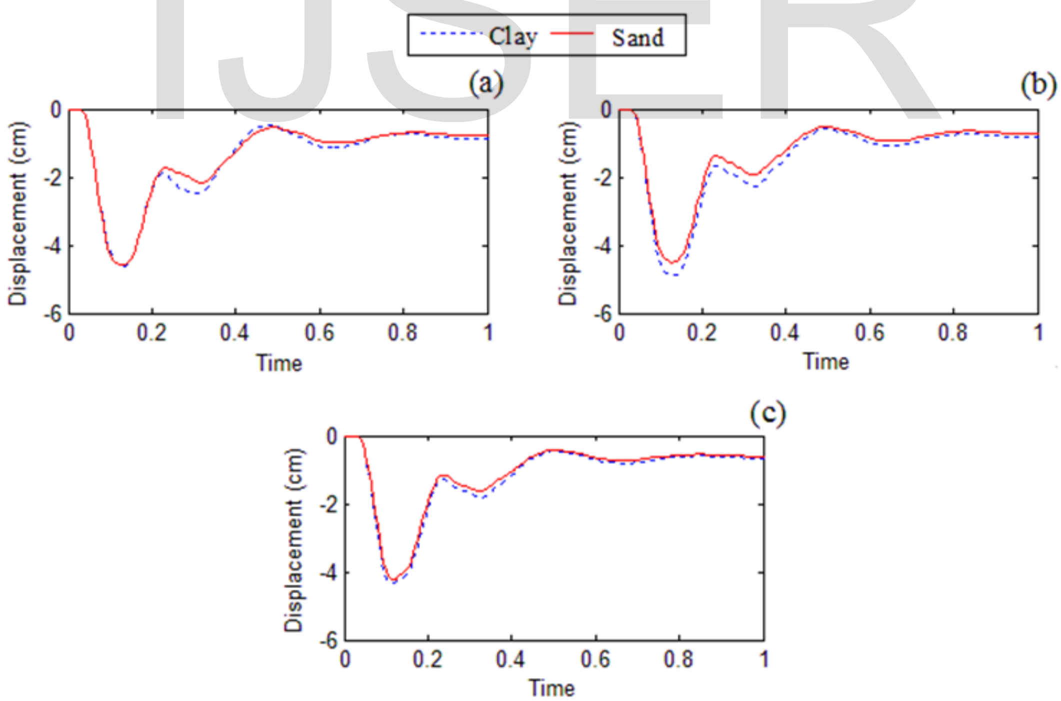

Fig. 8. Time history displacement response for blast load of 10 kg TNT with different distances; (a) 0.5 m, (b) 1 m, (c) 2 m

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Fig. 9. Time history displacement response for blast load of 30 kg TNT with different distances; (a) 0.5 m, (b) 1 m, (c) 2 m

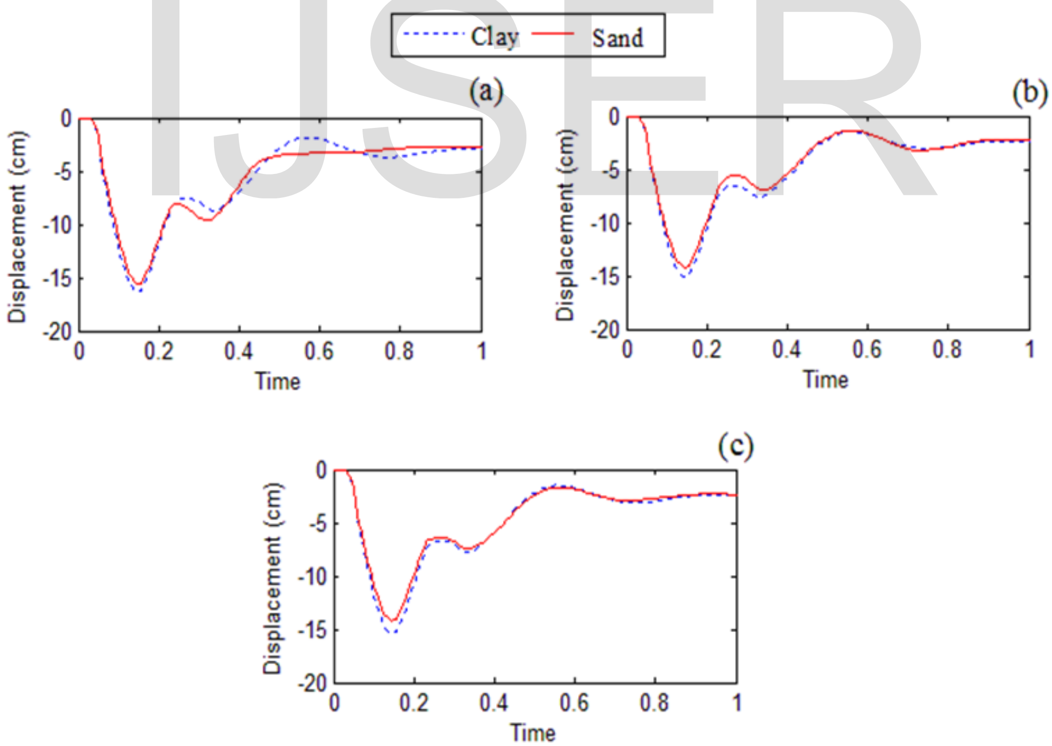

Fig. 10. Time history displacement response for blast load of 50 kg TNT with different distances; (a) 0.5 m (b) 1 m (c) 2 m

Comparing the stresses in concrete slabs and reinforcement bars give an opportunity to better understand the performance of two considered soil type. The maximum stress in concrete and steel tabulated in tables 1 and 2. From comparison results shown the sandy soil in reducing the stresses has better performance than clay.

Table 1. Maximum stress in concrete (MPa**)**

Soil type	Sand			Clay		
	0.5 m	1 m	2 m	0.5 m	1 m	2 m
10 kg	2.60	2.10	2.08	2.68	2.65	2.31
30 kg	5.98	6.55	5.62	6.33	6.58	5.74
50 kg	8.10	6.81	6.27	8.63	6.92	6.55

Table 2. Maximum stress in steel (MPa)

Soil type	Sand			Clay		
	0.5 m	1 m	2 m	0.5 m	1 m	2 m
10 kg	129.70	137.20	119.60	154.90	158.60	124.30
30 kg	389.70	400.30	401.50	400.10	403.70	403.30
50 kg	402.20	400.70	393.80	402.30	404.10	401.80

5 Conclusion

Designing structures resistant to explosions is impractical and impossible, which is why in designing of safe structures attempts to minimize the damage caused by the explosive loads. Using the underground structures, which is one of the most useful ways to protect structures against explosions, can be considered. The underground structures by using the soil to absorb and to dissipate the energy of explosions, reduced the potential damages caused by the explosion. A 3D finite element model for underground structure is developed using the commercial software ABAQUS. In this study, the soil type compared to improve the behavior and performance of the underground structures. Two types of clay and sandy soil was considered. The results of numerical simulations revealed that in improvement of the performance of the considered structure, the sandy soil is better than the clay. Besides, by comparing the ability of soil type to absorb the energy of the explosion, it is depicted the sandy soil is more capable than the clay. Comparing results revealed the response displacement, strain and stress of the sand-underground structure are less than the clay-underground structure.

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References

[1] M.Y.H. Bangash, *Shock, Impact and Explosion Structural Analysis and Design*. Germany: Springer Heidelberg, 2009.

[2] W.E. Baker, P.A. Cox, P.S. Westine, J.J. Kulesz, R.A. Strehlow, *Explosion hazards and evaluation*. New York: Elsevier Scientific Publishing Company, 1983.

[3] Robert J.f. Goodfellow, *Concrete for Underground Structures*. USA: SME, 2011.

[4] Y. Lu, Z. Wang, K. Chong, "A Comparative Study of Buried Structure in Soil Subjected to Blast Load Using 2D and 3D Numerical Simulations", *Soil Dynamics and Earthquake Engineering*. 2005, 25, 275-288.

[5] N. Nagy, M. Mohamed, J.C. Boot, "Nonlinear Numerical Modeling for the Effects of Surface Explosions on Buried Reinforced Concrete Structures", *Geomechanics and Engineering*; 2010, 2, 1-18.

[6] M. Kumar, M.D. Goel, V.A. Matsagar, K.S. Rao, "Response of Semi-Buried Structures Subjected to Multiple Blast Loading Considering Soil–Structure Interaction", *Indian Geotechnical Journal*. 2015, 45, 243-253.

[7] A. De, "Numerical simulation of surface explosions over dry, cohesionless soil", *Computers and Geotechnics*. 2012, 43, 72-79.

[8] ABAQUS user's manual. Hibbit, Karlsson, Sorensen. Inc; 2010.

[9] C.W. Silva, *Vibration Monitoring, Testing, and Instrumentation*; Boca Raton: CRC press, 2007.