ORIGINAL RESEARCH

The Sensitivity Analysis of the Distance Effect and Explosive Load on Concrete Structures, Considering the Soil-Structure Interaction Effects

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Abstract:

The undeniable impact of soil-structure interaction on the behavior of structures, coupled with the increased importance of explosive loads in current global security and social conditions, has led to the modeling and sensitivity analysis of the distance effect and explosive load on concrete structures, taking into account the effects of soil-structure interaction. Three types of structures with 3, 7, and 15 floors were modeled for this investigation, and the results were evaluated. The software tools ETABS and ABAQUS were utilized, with ETABS for structural element design and ABAQUS for examining the effects of soil-structure interaction. The input energy and induced displacements in the structures have a meaningful relationship with the explosion force. In all three structures (3, 7, and 15 floors), the energy and displacements created vary proportionally with the explosion distance or the reduction in explosive material weight. The plasticity rate reflects a substantial reduction in damage with an increasing explosion distance from the structure. Additionally, according to the research results, an increase in the number of floors undoubtedly leads to more noticeable displacements. Therefore, these displacements and energy absorption in the 15-floor structure exceed those in other structures. The failure zone in the 3-floor structure is mostly in the last floor, in the 7-floor structures in the middle floors, and in the 15-floor structures in the initial floors. Displacement in the 3-floor structure is at the upper levels, in the middle of the 7-floor structure, and at the lower levels of the 15-floor structure.

Keywords:
Nonlinear dynamic analysis, soil and structure interaction, explosive load, sensitivity analysis, distance effect.

1. Introduction

During the occurrence of explosion loading, the behavior of the soil beneath the structure plays a crucial role in the structure's response. In many cases, the soil is not modeled, and its significant effects are neglected. Due to the unbounded nature of the soil environment, modeling it is more complex compared to structural modeling. In structures subjected to dynamic forces over time, such as explosion forces, the interaction between soil and structure, including soil parameters, becomes indispensable, significantly influencing the system's behavior. Studies by various researchers and documented observations from different construction sites indicate that the nonlinear behavior of the soil foundation and the soil-structure interaction phenomenon can lead to an increase in structural response, despite an increase in damping, resulting in elevated dynamic forces on the structure. Based on the aforementioned studies, it is necessary to quantitatively estimate the effects of nonlinear soil behavior on structural response. In the mixed method, the problem domain is divided into two substructures: the near field, which includes the structure and a defined region of the surrounding soil, and the far field, which encompasses the remaining semi-infinite soil environment. In this approach, stress and displacement values are first calculated at the interface position in the far field, and then they are applied as forces in .the finite element analysis of the near-field

In the year 2001, Yerli and Tanrikulu

presented a mixed finite element and boundary element method, along with unlimited elements, which has been employed in this study to assess the accuracy of the proposed soil model. In 2004, Wolf utilized a cone model to simulate the soil beneath the structure, and in this investigation, it was used to evaluate the accuracy of the soil model along with the structure. In 2007, Hong and colleagues extended research on finite element models to model the far-field soil region using viscoelastic elements, attempting to incorporate nonlinear soil characteristics into their model. Studies on boundary elements in finite element methods have garnered significant attention from researchers. Hekmati and his team in 2014 examined and evaluated tall structures on soft soil, considering soil-pile-structure interaction (SSPSI). This research aimed to investigate the dynamic response of 5, 10, and 15-story structures on a shake table, evaluating the effect of SSPSI. Rahgozar and his team in 2015 conducted a study on soil-structure interaction in adjacent tall structures. They examined the importance of soil-structure interaction on the dynamic response of 20 and 40-story structures, specifically designed as special steel moment frames on soft and hard soils. Soft soil had a dynamic period close to the 20-story structure, while hard soil had a dynamic period close to the dominant period of the bedrock. The distance between adjacent structures was considered one-tenth and one-fifth of the pile length. In 2018, Bahroozi and Babaali investigated the impact of carbon polymer fibers on the blast resistance of composite shear walls, considering both soil-structure interaction and non-interaction scenarios. This study emphasized the significance of non-structural components in the overall performance of a military blast-resistant system after an explosion event. In 2019, Kazemini and Ramazanpour conducted research to examine the effect of soil-structure interaction on the analysis of a concrete structure with a central core under explosive loads. The structure, designed with fifteen floors, was analyzed in three explosion scenarios using Abaqus software. The results showed a reduction in structural forces such as base shear and flexural anchor forces due to soil-structure interaction during explosion conditions. The study also compared the maximum displacements across different scenarios.

2. Research Fundamentals

In general, the deformations of a structure resulting from an earthquake are influenced by the interaction of three interconnected systems: the structure itself, the foundation, and the characteristics of the subsoil layers beneath and around the foundation. The analysis of soil-structure interaction (SSI) evaluates the response of these systems to ground motion in a free-field scenario. The mechanisms of interaction between the structure and soil include two main components: inertial interaction and kinematic interaction. The inertial effect in the structure, resulting from its own vibrations, induces shear forces and moments at the foundation. In other words, the vibrations of the structure and the inertial forces generated give rise to new movements in the foundation. Various methods exist for analyzing the soil-structure interaction, including finite element method, boundary element method, hybrid or coupling methods, and substructure method. The two mentioned methods are finite element method and substructure method. Generally, the analysis methods for soil-structure interaction can be classified into two main groups: direct methods and substructure methods. In the direct method, both the structure and the soil are modeled together, and the analysis is performed in a single step. Often, the soil is modeled with Solid elements, and the structure with Beam elements. Due to the absence of the assumption of force superposition in this case, real nonlinear analyses become feasible. However, nonlinear analyses may be sensitive to incomplete definition of soil model parameters, potentially leading to inaccurate results. Additionally, these analyses are computationally expensive. As a result, direct

SSI analyses are mostly conducted using linear methods, which approximate the nonlinear effects of the soil.

The main advantage of the substructure method lies in its flexibility, and due to the independence of each stage from others, the analysis can be focused on critical aspects of the problem. Inertial interaction analyses illustrate the difference in the participation factors and periods between the flexible base mode (comprising the flexibility of both the soil-foundation system) and the unrealistic fixed-base mode (including only the structure's flexibility) in the first mode of vibration. Modal parameters of the flexible base can be assessed using the response spectrum of shear forces on the structure's foundation design. Therefore, these analyses align with steps 2 and 3 of the substructure method. However, kinematic interaction analyses (step 1 of the substructure method) describe frequency-dependent transfer function domains, linking foundation movements and free-field motions. ATC and NEHRP regulations, encompassing seismic design codes, provide similar guidelines for SSI, addressing aspects of inertial interaction analysis stages. These codes tend to overlook kinematic effects, assuming the motions of the free field and the foundation input motion are identical. Due to the large amount of material that can be presented in this article, the theoretical foundations of the research have not been mentioned. In general, the modeling of the effect of soil and structure interaction has been done in a direct way using finite element theory, and explosive loading has also been presented in the research method section.

3. Methodology

In general, after performing nonlinear dynamic analyses on the structural model under consideration, the behavior of load-displacement, stress, locations of plastic hinges, and its energy absorption under the effects of blast loads are determined, and the impact of blast forces on the system's behavior is investigated. Various types of damages possible in this structure are also introduced, and finally, necessary recommendations for engineering design are provided. In summary, the research stages in this article consist of: 1- Modeling three-dimensional finite element concrete frame structures of low-rise (3 stories), mid-rise (7 stories), and high-rise (15 stories), 2- Static stability analysis of models under gravity loads, 3- Dynamic analysis of models under blast loads, presenting results related to the effect of influential parameters on structural stability, 4- Determination of different failure mechanisms including local and global failures, 5- Presentation of results related to tensile and compressive effects of blast loads on support reactions, and 6- Comparison of structure response considering soil-structure interaction effects. To find the maximum explosion load, the scaling parameter Z is also used, and after calculating Z, the maximum applied pressure is extracted from Figure (1), and Figure (2) is scaled to the obtained value, and applied to the structure face facing the explosion as a pressure spectrum.

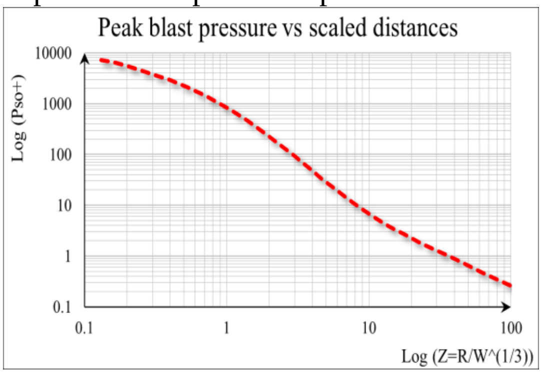

Fig. 1. Maximum burst pressure versus scaled distance

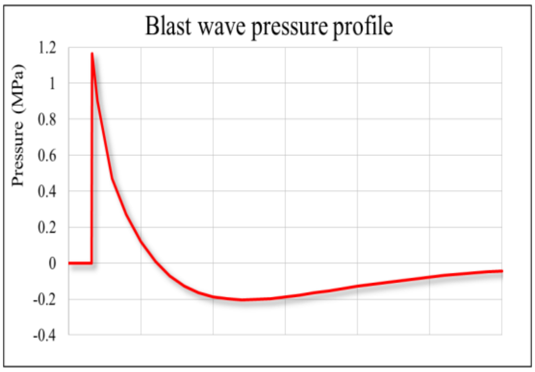

Fig. 2. Blast loading spectrum for Z=0.5 mode

The force spectrum presented in Figure (2) corresponds to a 100-kilogram TNT explosion at a distance of 2.35 meters from the structure. Therefore, by applying the above values in the equation $Z=R/\sqrt[3]{W}$, the equivalent distance value of Z will be equal to 0.5. The study population in the current research consists of the dynamic behavior of all reinforced concrete structures built on stiff soil when subjected to blast loads. Thus, the specimens examined in this study will include three reinforced concrete frame structures of low-rise (3 stories), mid-rise (7 stories), and high-rise (15 stories), considering various scenarios with and without soil-structure interaction. To investigate the effect of soil-structure interaction on the behavior of concrete frames according to seismic regulations, initially, three models are designed categorized into 3, 7, and 15-story structures. In each of these three groups, samples are analyzed and designed in three dimensions using ETABS software. Then, one frame from the designed models is simulated in ABAQUS software, and their performance is evaluated in two conditions with and without soil-structure interaction. Parameters such as maximum roof displacement, load-bearing capacity, and stress are compared among the models. For seismic analysis and loading, the models are based on the 4th edition of standard 2800 and ASCE/SEI 7-10 regulations. For structural design, the provisions of AISC 360-05 design code for structures analyzed with Iranian and American codes are utilized. To evaluate the seismic behavior of the models, the guidelines provided in publication 360, FEMAP695, and ASCE/SEI 41-13 regulations are employed.

3.1. Modelling in ETABS

The models are designed and analyzed in three dimensions using ETABS software. The models have five 5-meter spans in each direction. Additionally, a total height of 3 meters is chosen for all floors. According to Figure (3), a regular structural plan and moment-resisting connections are considered.

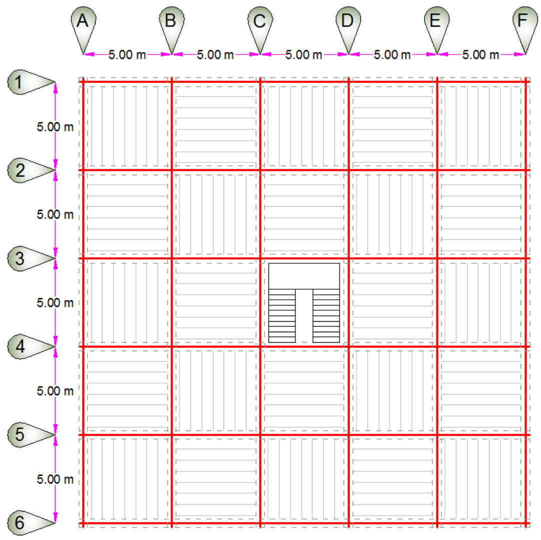

Fig. 3. The plan of the structures modeled in this research

The steel used in all models is of the common type St37 with a yield stress of 400 megapascals. The concrete strength is also set to 24 megapascals. Other material properties are standardized according to regulations. For linear analysis, the standard equivalent static analysis method of 2800 is employed. In this method, the base shear is equal to V=CW, where C is the seismic coefficient and W is the seismic weight of the structure based on the standard formula of 2800. The ASCE/SEI 7-10 code specifies seismic loads and design provisions under seismic design category (SDC), which is a function of design earthquake level (DE) and building occupancy classification. In this study, the models are loaded in a way that the life safety behavior assumes all structures in one of the occupancy categories 1 or 2, with a similar importance factor equal to unity. All three structures of 3, 7, and 15 stories are precisely designed according to the provided methods. The design details of these models are not presented in the article to avoid excessive content volume but can be provided as an appendix if needed. The results of modeling and final design of the structures will be similarly presented. As an example, figures of the preliminary and post-design stages of the 3, 7, and 15-story structures are provided. Figure (4) illustrates the modeling of the three-story structure, Figure (5) displays the stress ratio values for the 7-story structure, and Figure (6) depicts the stress ratio values for the 15-story structure.

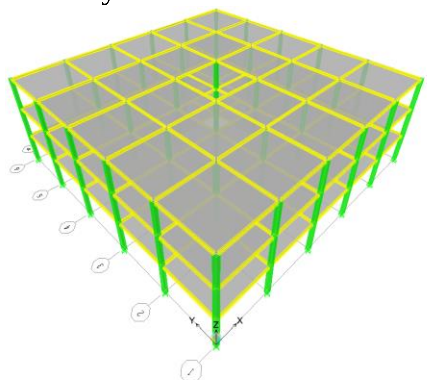

Fig. 4. Modeling the three-story structure in three-dimensional form

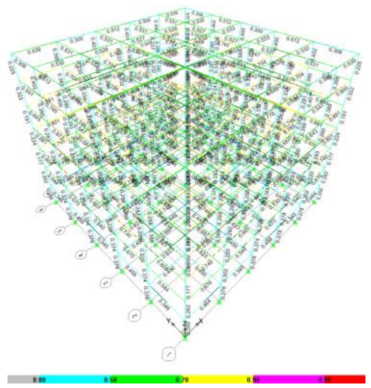

Fig. 5. Values of the stress ratio of the 7-story structure after design

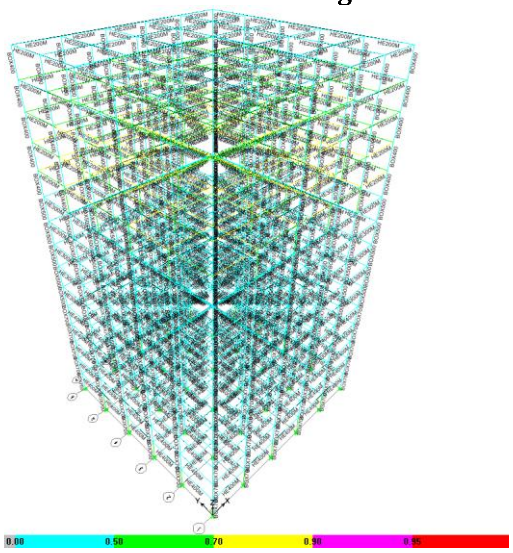

Fig. 6. Modeling and sections of the 15-story structure in three-dimensional form

3.2. Modelling in ABAQUS

The main objective of this article is to investigate the effects of soil-structure interaction on the behavior of concrete structures under blast loading. The ABAQUS software has been chosen due to its extensive capabilities in directly modeling soil-structure interaction effects and its ability to model blast loading. However, due to the high computational effort required in this software, three-dimensional modeling imposes significant time and cost burdens on users. Therefore, one frame from the 3, 7, and 15-story structures designed by ETABS, considering soil-structure interaction and in accordance with the models developed in the validation section, was simulated in ABAQUS software. Blast loads were applied to the lower, middle, and upper floors of each structure, and the results were extracted. It is worth mentioning that after the explosion occurs, a shock wave emanates from the explosion site and propagates outward. At each point in the surrounding environment of the structure reached by the blast wave, the pressure suddenly reaches its maximum value, denoted as Pm. The dynamic pressure due to the shock wave over time is represented by P(t). The relationship between pressure and time is typically as follows.

$$P(t) = P_m . e^{\left(\frac{-t}{\theta}\right)} \quad (1)$$

$$P_m = 52.16 \left(\frac{W^{\frac{1}{3}}}{S}\right)^{1.13} \quad (2)$$

$$\theta = 96.5 \left(W^{\frac{1}{3}}\right) \left(\frac{W^{\frac{1}{3}}}{S}\right)^{-0.22} \quad (3)$$

In Equation (1), Pm and θ are provided in Equations (2) and (3) respectively. W represents the weight of TNT material in kilograms, and S denotes the distance from the explosion site to the structure. According to previous studies, the blast load is estimated to be 39,872,000 Newtons for a constant weight of 100 kilograms of TNT and at a distance of 10 centimeters from the structure, based on Equation (3). As mentioned, the blast load was applied to the lower, middle, and upper floors of each structure. For naming the models in this section, first, the number of stories of the structure is presented with names like 3Story, 7Story, and 15Story. Then, the position of the blast load application on the structure is indicated. For this purpose, the letter B (abbreviated for Bottom) is chosen for the lower position, the letter M (abbreviated for Middle) for the middle position, and the letter T (abbreviated for Top) for the upper position. Subsequently, the models along with the results, including stress contours, time history plots of roof displacement, corner column stress, energy dissipation in the entire structure, and the equivalent plastic strain rate of the entire structure, are presented. Figures (6) and (7) show the position of blast loading on 3- and 7-story structures.

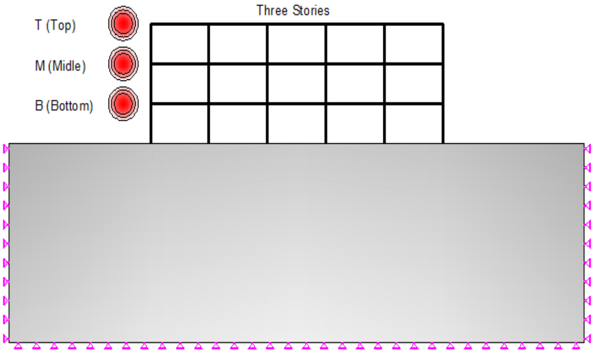

Fig. 7. The positions of the blast load in the three-story structure

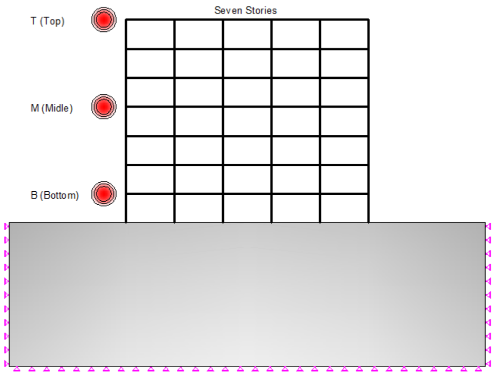

Fig. 8. The positions of the blast load in the seven-story structure

4. Analysis of modeling results

The main objective of the current article is to analyze the sensitivity of the distance and blast load on the behavior of reinforced concrete structures while considering soil-structure interaction effects. In this section, the effects of various explosion distances and blast loads are examined. Different explosion distances ranging from 10 centimeters to 10 meters are considered as variable parameters. The explosion distance parameter is denoted by the letter S. Additionally, the weight of the explosive material is simulated as a variable parameter ranging from 20 kilograms to 180 kilograms. The resulting blast force values at different distances from the structure are presented in Table (1). The models in which the explosion distance is considered as a variable are represented by S1 to S7.

Table 1. Values of the incoming force under the effect of different distances and for 100 kg of explosives

Model No.	S1	S2	S3	S4	S5	S6	S7
Distance (m)	0.10	0.25	0.50	1.00	2.00	5.00	10.00
Force (N)	39872000	14158000	6468900	2955700	1350500	479500	219100

To better understand the effect of distance on the applied force during the explosion on the structure, the force values against the model number are shown in the figure below.

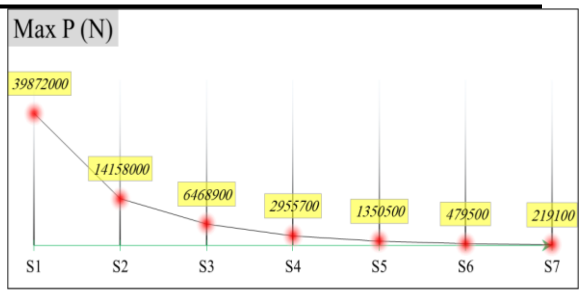

Fig. 9. The maximum amount of force applied at different distances

As evident from the figure, the explosion distance to the structure significantly affects the magnitude of the applied force, with the force decreasing substantially as the explosion distance increases. The table below indicates models S1 to S7 and the distance of occurrence of the explosion from the structure for a 100-kilogram explosive material.

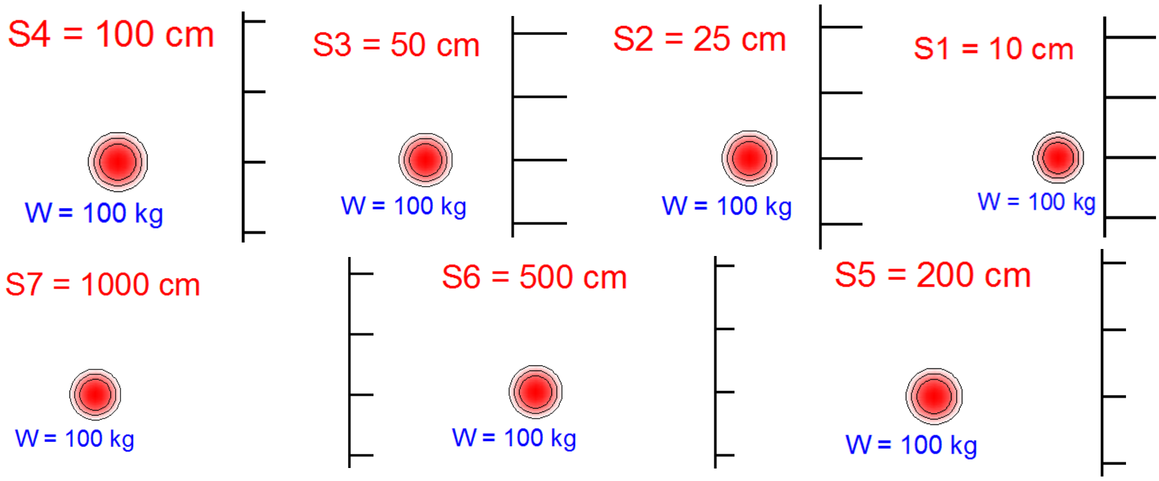

Fig. 10. Distance sensitivity analysis in models S1 to S7 and the place of explosion

Similarly, as mentioned, 20 different values for the weight of the explosive material ranging from 20 kilograms to 180 kilograms are simulated for the explosive material weight parameter, which are shown in Table (2).

Table 2. Values of the incoming force under the effect of different weights of TNT and for a distance of 10 cm

Model No.	W1	W2	W3	W4	W5
Weight (kg)	20	40	60	80	100
Force (N)	21747000	28235000	32893000	36658000	39872000

Model No.	W6	W7	W8	W9
Weight (kg)	120	140	160	180
Force (N)	42707000	45260000	47594000	49753000

To better understand the effect of the weight of the explosive material on the applied force during the explosion on the structure, the force values against the model number are shown in Figure (11).

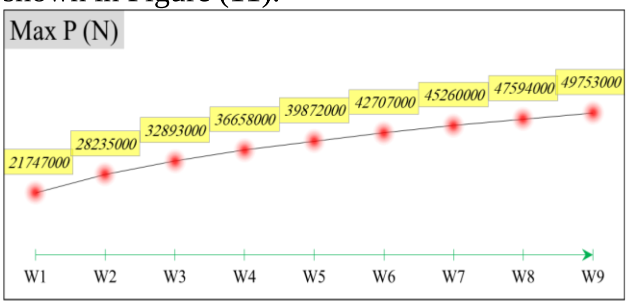

Fig. 11. The maximum amount of force applied at different distances

Thus, for the 7-story structure and in the case of explosion application at the center of the structure, 20 models are created. The reason for selecting the 7-story structure is that it can be a suitable representative for both 3 and 15-story structures. In this way, the effect of the explosion distance to the structure in seven models (S1 to S7), applied to the middle floor of the 7-story structure, is evaluated. Finally, the effect of the weight of the explosive material in nine models (W1 to W9) is examined. It is worth mentioning that for the application of the load, a loading spectrum with a maximum value of 1 is entered into the Abaqus software, and the force resulting from the explosion is applied as a coefficient of this spectrum at the desired location of the structure.

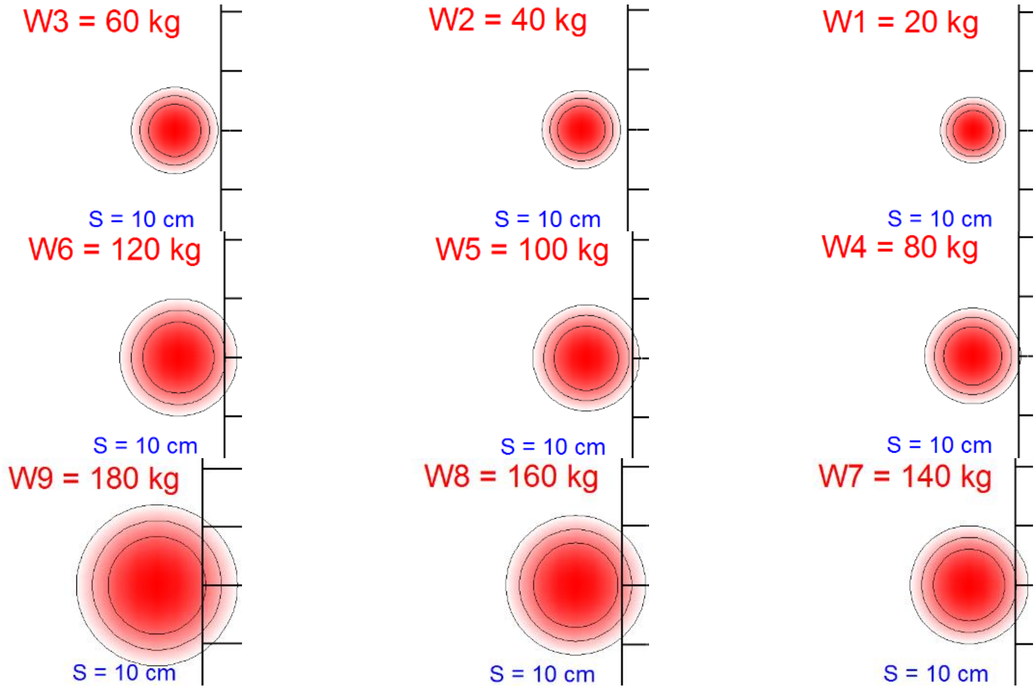

Fig. 12. Magnitude of the explosion due to different amounts of TNT weight

The results of the analysis of models S1 to S7 are presented below, and their discussion is provided. In these models, the effect of a 100-kilogram TNT explosion on the middle floor of the 7-story structure at different distances from the explosion center to the structure is applied. The modeling results mentioned above in the previous section are extracted similarly as Figure (13) for all the mentioned scenarios and summarized in Figures (14) and (15).

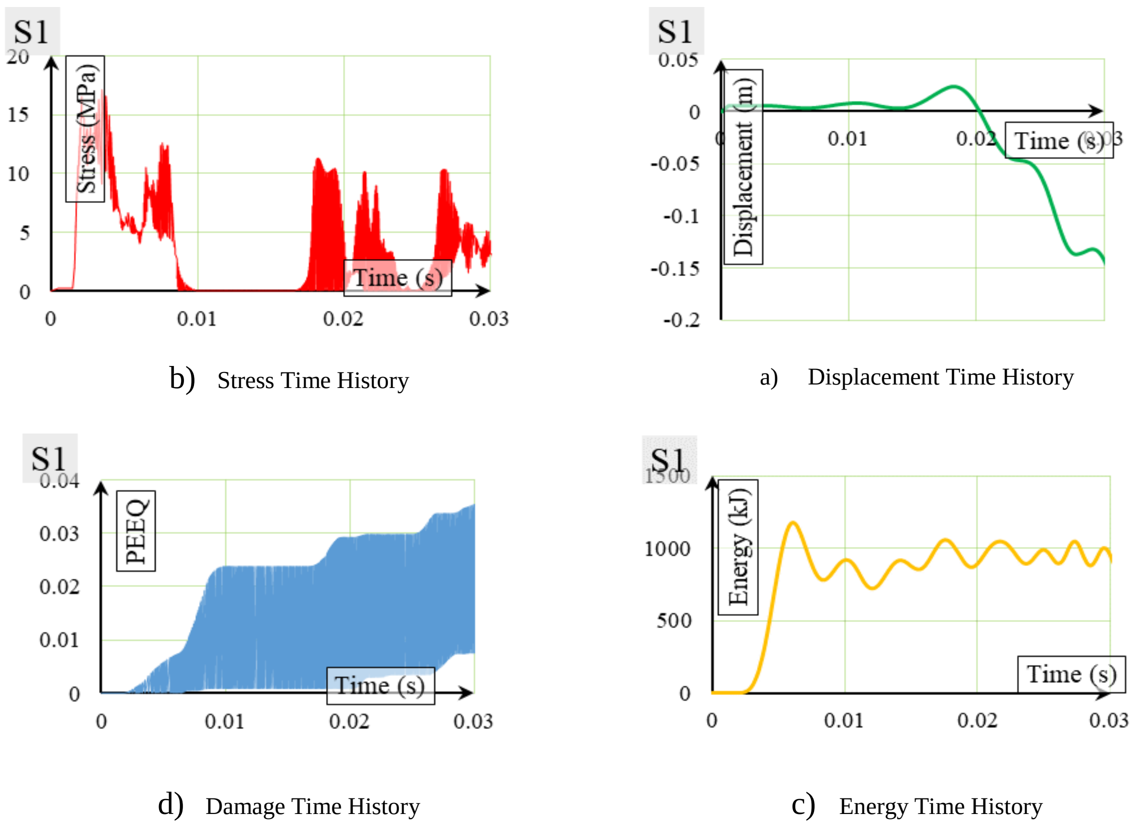

Fig. 13. The results of the analysis of model S1

According to the above table, it is evident that the maximum displacement value in this case is 0.938 meters, the maximum stress value applied to the frame is 13.53 MPa, the maximum energy applied to the structure during the explosion is 2589 kJ, and the maximum equivalent plasticity percentage is 0.0022. Similar figures are calculated for all scenarios and can be provided as attachments if needed. Various parameters presented in Figure (13) based on different sensitivity analysis scenarios are further depicted in Figures (14) to (17).

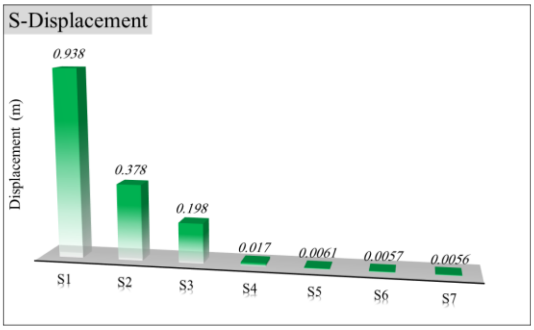

Fig. 14. The maximum amount of displacement created in the structure in the analysis of the effect of different explosion intervals

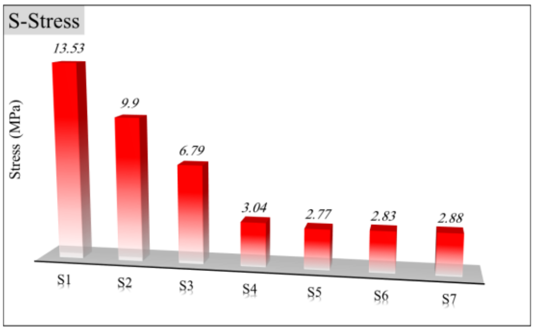

Fig. 15. The maximum amount of stress created in the structure in the analysis of the effect of different explosion intervals

It can be observed that increasing the distance of the explosion from the structure results in a decrease in the induced displacement, and this decrease is very significant. According to the above chart, increasing the distance of the explosion beyond 1-meter leads to a sharp decrease in the stress applied to the structure.

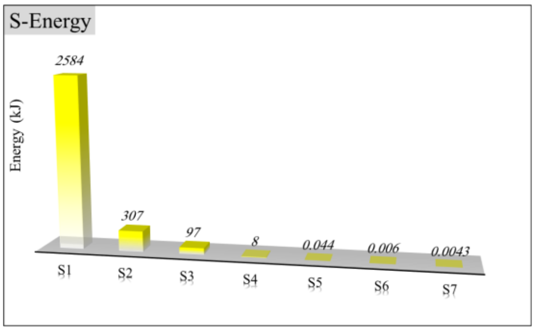

Fig. 16. The maximum amount of energy entering the structure in the analysis of the effect of different explosion intervals

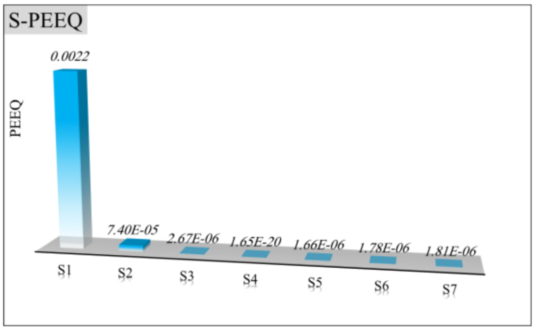

Fig. 17. The maximum amount of equivalent plasticity created in the structure in the analysis of the effect of different blast intervals

The occurrence of the explosion phenomenon at a distance of 10 centimeters from the structure imposes severe shock on the frame, and increasing the distance significantly reduces the energy applied to the structure. It is noticeable that the equivalent plasticity rate follows a trend consistent with the applied energy. Increasing the distance of the explosion significantly reduces the forces applied to the structure.

Similarly, similar calculations for the sensitivity analysis of the explosion load have been modeled and summarized, and the charts of Figure (13) have been extracted for this modeling, which can be provided if needed. Then, with consideration of the obtained charts, the conclusion graphs are presented in the form of Figures (18) to (21).

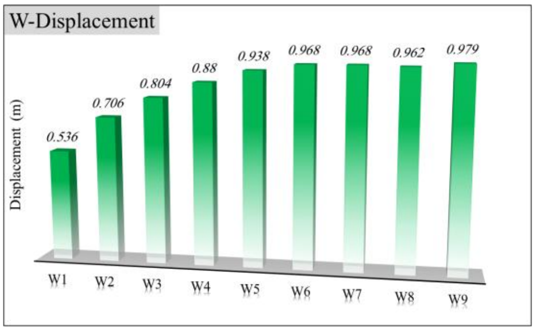

Fig. 18. The maximum amount of displacement created in the structure in the analysis of TNT weight effect

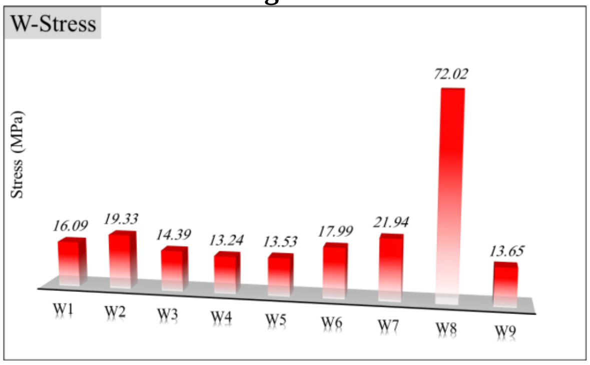

Fig. 19. The maximum amount of stress created in the structure in the analysis of TNT weight effect

The displacement induced in the structure has shown an increasing trend against various weights of TNT. The spectrum of this increase aligns with the calculated force in each case. The stress induced in the structure also has an almost random trend and may not explicitly present a meaningful relationship between the TNT weight and the induced stress.

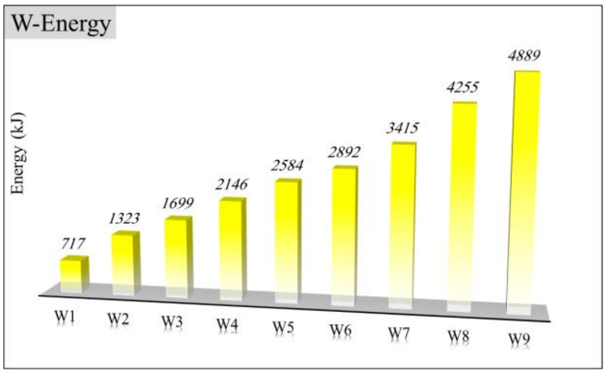

Fig. 20. The maximum amount of energy input to the structure in the analysis of TNT weight effect

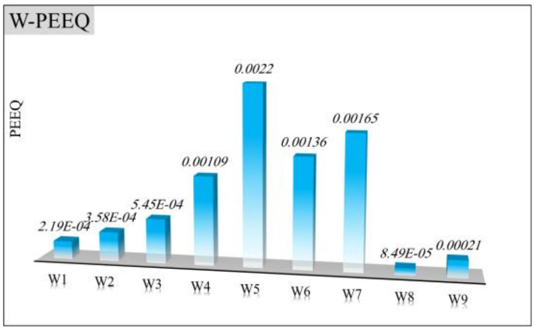

Fig. 21. The maximum value of failure rate caused in the structure in the analysis of TNT weight effect

The applied energy also increases with the increase in the weight of the explosive material, corresponding to the increase in the force magnitude. The equivalent failure rate will also increase with the increase in the weight of the explosive material, and this increase will occur exponentially. However, for values greater than 100 kilograms, the values are accompanied by noise.

5. Validation

For model validation, the study by Tarabi et al. (2014) on the dynamic interaction of soil-structure against earthquakes has been utilized. Tarabi and colleagues examined a highly simplified structure placed on soil, considering soil-structure interaction for validation. They applied the Northridge earthquake to the model and presented the structural response, including the time history plot of the acceleration generated in the structure.

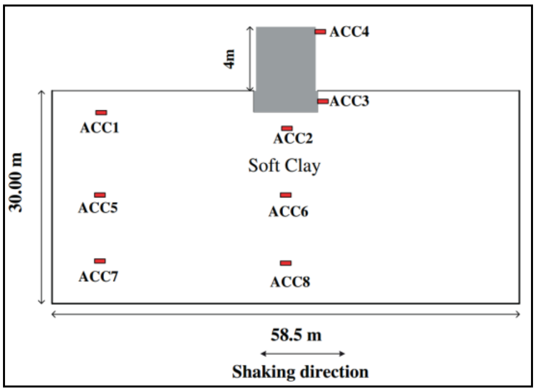

Fig. 22. Torabi research model along with the direction of the earthquake

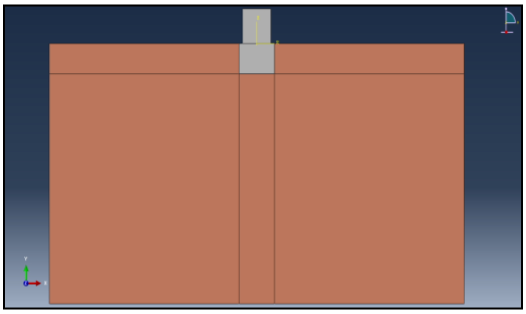

Fig. 23. Simulated model in Abaqus software according to Torabi research model

The model was simulated as a shell in the Abaqus software, and its geometry is shown in Figure (23). Overlaying the results obtained from Torabi's study and the current model, the plots in Figure (24) were generated.

The peak and descent trends obtained in Abaqus showed very close resemblance to the results obtained from Torabi's study. Additionally, the peak acceleration value generated in the structure in Torabi's study at 11.2 seconds was 0.21 g. In the finite element model, this acceleration value at 11.2 seconds was calculated to be 0.209 g with a negligible error of 0.47%. This indicates the accuracy and precision of the finite element model created. Similarly, using Abaqus, the experimental model in Zhang's doctoral dissertation was validated. In this study, composite steel-concrete CFDST columns with high-strength UHPC concrete were subjected to blast loading, as shown in Figure (25). It should be noted that only rectangular cross-sections will be used for validation in this study.

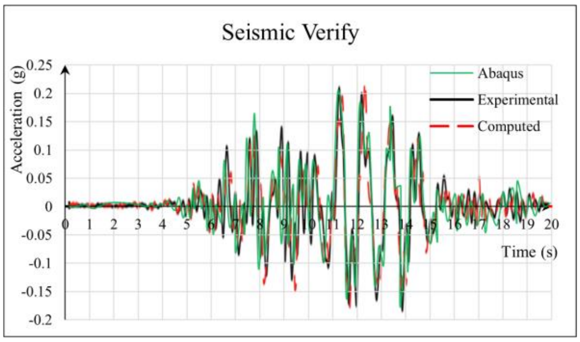

Fig. 24. The response of the tip of the end of the structure in the present study by Abaqus software and comparison with the results of Torabi

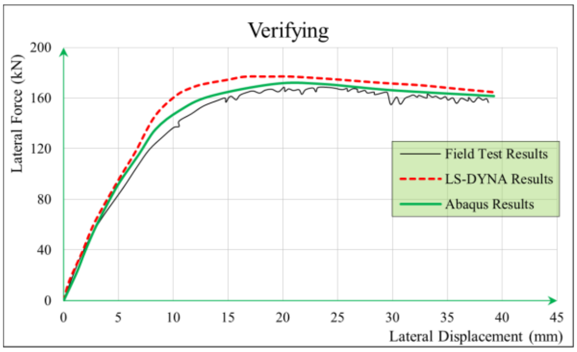

Fig. 25. Comparison of the response obtained from the finite elements and Zhang's numerical and field study results

It can be observed that in the model calibrated by Zhang, there is a 5% error between the maximum response value of the LS-DYNA software and the tested specimen. However, with a more accurate simulation in Abaqus, the error has been reduced to 1%.

6. Summary and Conclusion

Today, due to urban development, there is a rapidly growing need for construction. Factors such as urban space scarcity and high land prices drive housing designers and developers towards tall structures. Additionally, a significant portion of structures are built on hard soils. Moreover, considering Iran's strategic location in the region, it is essential to take all necessary precautions and examine possible scenarios thoroughly. Therefore, the first chapter of this thesis provides an introduction to the construction of reinforced concrete frames on hard soils and also discusses blast loading. The second chapter presents a historical overview of the conducted research and outlines the theoretical foundations of the existing methods for analyzing this system. Furthermore, the details of the finite element method and Abaqus software, along with the validation of the responses, are discussed in this chapter. The fourth chapter focuses on presenting the results of the design and finite element analysis of 3, 7, and 15-story structures against blast loading. The present chapter also offers general findings from this study and suggests areas for future research in this field. The overall results of this research can be summarized as follows:

1- The existing models in the Abaqus software toolbox are among the strongest and most accurate models available today in finite element analysis. This software has attracted a lot of attention from users and has made many designers interested in using it. In this study, by using appropriate material behavior models, very accurate responses have been obtained in the analysis of reinforced concrete frame structures. The close approximation of the numerical model results to the results of the studies by Terabian et al. in 2014 and Zhang in 2017 has validated the accuracy of the current numerical model. According to the validation results, the responses of the systems in the models created by Abaqus have differences of 0.47% and 1% compared to the desired models, respectively. Based on the accuracy obtained from the validated models and disregarding the mentioned errors, the intended model for 3, 7, and 15-story structures has been developed.

2- With the increase in the number of stories, the displacements created are undoubtedly more noticeable. Therefore, these displacements and energy absorption in the 15-story structure have been greater than in other structures.

3- A very important point in the behavior of structures, which is often overlooked in many studies, is the identification and prediction of the location of damage in the structure. In this study, based on the plasticity contours obtained from the analyses, it was observed that the damaged area in the 3-story structure was almost in the last story. With the increase in the number of stories and in the 7-story structure, it was observed that the created damaged area shifted to the middle stories of the structure, and most of the damage in the 7-story structure occurred in the middle stories. However, in the tall 15-story structure, the conditions were different. The lower stories of these structures were heavily damaged, and material plasticity occurred in these stories. Therefore, these positions in the mentioned story structures are prone to reinforcement and need to be carefully considered.

4- Another significant issue in the displacements created in the short 3-story structure was that significant displacement occurred in the upper stories of this structure. This is while in the large 7-story structure, significant displacement occurred in the middle stories of the structure. Also, in the tall 15-story structure, it is evident that the main displacement occurred in the lower stories of the structure.

5- The blast loading spectrum applies pressure and tension phases to the structure. Although the absolute value of the tensile force applied in the blast spectrum is much less than the force in the initial compression phase, it is observed that after the end of the compression phase, significant damage also occurs during the occurrence of the reverse pressure phenomenon in the explosion on the structure.

6- By considering interaction and boundary conditions exactly in accordance with a specific physical phenomenon such as reinforced concrete frame structures along with hard and semi-rocky soils, very appropriate responses can be obtained using Abaqus finite element software. However, this requires accurate parameters of the problem of interest, including geometric and mechanical properties of materials.

7- One of the significant effects of the explosion on structures is local destruction of the system and then total destruction of the structure. However, the ultimate resistance of the structure under changes in various parameters, including geometric dimensions, as well as the resistance of the structure to pressure, are factors that distinguish two different structures from each other and determine the preference of design. Therefore, in the present study, in addition to presenting stress, the amount of energy against the explosion has also been discussed.

8- The energy input and the displacements created in the structures have a significant relationship with the force generated by the explosion. Thus, in all three structures of 3, 7, and 15 stories, with increasing explosion distance or decreasing explosive material

weight, the energy and displacement created vary proportionally with the force.
9- The parameter of the created stress has been accompanied by very significant changes, and different modes of movement created in the structure may significantly change the maximum stresses.
10- The plasticity rate, which indicates the amount of damage from the occurrence to the ultimate resistance of the structure, also indicates that with an increase in the distance of the explosion from the structure, the damage decreases significantly. Therefore, based on this finding, it is suggested that in future studies, solutions for increasing the explosion distance be presented and discussed.

8. References

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