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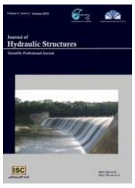

Effect of Strength Parameters on Seismic Performance of Elevated Tanks by Probabilistic Analysis

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Abstract

Considering the importance of the effect of elevated tank body strength on the seismic performance of model during an earthquake, this research evaluated the effect of Young Modulus of body concrete and foundation as strength parameters on seismic performance of elevated tanks and examines the responses to achieve the optimal body stiffness using probabilistic analysis as an effective method to know the effect of different parameters on the output responses. The system is modeled and analyzed by ANSYS software based on the finite element method. The applied approaches included the Newark method for time integration of the dynamic analysis and the probabilistic analysis using the Latin Hypercube sampling method (LHS). Accordingly, first, the modulus of the elasticity of the tank body and foundation were considered as the input parameters. Seismic responses of the model due to Manjil earthquake ground motions are compared with each other. Obtained results illustrated the capability of presented finite element model.

The obtained results of the probabilistic analysis indicate the sensitivity of responses to the variation of the flexibility of the tank foundation. Increasing the modulus of elasticity of concrete enhances the principle stresses on tank body and decreases tank displacement. According to the diagrams, changes in the modulus of the elasticity of the tank have a significant effect on the response values, and the percentage of response variations is high. However, the variations in modulus of the elasticity have little effect on the values of the output responses.

Keywords: Elevated tank, LHS simulation, Modulus of elasticity, Seismic Performance.

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1. Introduction

Water tanks are one of the components of water supply networks required to store, maintain, and supply pressure. The importance of these structures and their proper functioning during and especially after the earthquake is in meeting the needs of citizens, avoiding fire, and causing environmental damage. Several cases of damage to these types of structures have been reported in various countries, including Chile, California and Sanchuan earthquakes.

Haroun and Ellaithy provided a model for analyzing different numbers of rigid elevated tanks under displacement and rotation. In this study, the effects of turbulence moods are studied, and the effect of tank wall flexibility is estimated on the seismic response of the elevated tanks [1]. Marashi and Shakib conducted ambient vibration tests to assess the dynamic properties of the elevated tanks [2]. Haroun and Termaz have analyzed two-dimensional cross-braced elevated tanks supported by isolated foundation to study the effects of dynamic interaction between the tank and foundation-soil support system. In this study, the effects of turbulence are ignored [3]. Shrimali and Jangid investigated the seismic response of elevated tanks containing fluid separated by a lead rubber-bearing separator. In this study, the separators were placed once under the base and once on it. In this study, the seismic response of the elevated tanks has been effectively reduced [4]. Dutta et al. showed that soil-structure interaction might increase the base shear, especially in elevated tanks with low structural periods. Also, the results indicate that ignoring the soil-structure interaction may result in significant potential tensile forces in some columns due to seismic load [5]. Jadhav and Jangid investigated the effects of near-fault pulses on the response of fluid storage tanks using the mentioned mass and spring model. In this study, friction separators were also used under the tank, and it was concluded that the seismic response of fluid storage tanks to the maps, which includes long pulses, can be controlled by the separators. Several other investigations have been carried out on tanks equipped with seismic separators that are not mentioned in this article [6]. Chen and Kianousgh proposed an analytical method called the "repeated" method for analyzing the dynamic response of concrete tanks. In this method, they modeled the fluid inside the tank as multiple nodes. This method is based on the step-wise "integration" method, considering the flexibility of the walls under horizontal and vertical components [7 and 8]. Sweedan used an equivalent mechanical method to model the dynamic behavior of the elevated tanks. In the studies, the effect of the vertical component of the earthquake on the hydrodynamic pressure was undeniable [9]. Livaoglu examined the dynamical behavior of a rectangular tank concerning fluid-structure and soil-foundation interactions, using the changes in soil-foundation conditions and concluded that displacements and the base shear forces of the tank are affected by the soil hardness [10]. Shekari et al studied the performance of the elevated tank for storing cylindrical steel fluids considering the fluid-structure interaction and interactive solution of limited and cylinder components with a flexible wall, under the horizontal component of the earthquake record. In this study, the effects of fluid-structure interaction are considered. The results showed that the seismic response of the isolated tanks in the base could have a significant decrease compared to the tanks with fixed bases. The seismic separator in slender tanks is more effective than broader tanks, and the separation efficiency in rigid tanks is more appropriate [11]. Ghaemmaghami and Kianoush investigated the dynamic behavior of concrete rectangular above-ground tanks by the finite element method in 2D and 3D modes. In this research, the dynamic analysis of concrete water tanks was carried out using the finite element method with modal and time history analyses, and the effect of different elements was investigated on dynamic responses [12]. Moslemi and Kianoush addressed the dynamic behavior of cylindrical above-ground water tanks. The focus of this study was to identify the main parameters affecting the dynamic response of the structures and counteracting the interaction between these parameters. The results show that the design methods are too conservative in estimating hydrodynamic pressure [13]. Panchal and Jangid used FPS and VCFPS separators to control slender elevated fluid storage tanks. The result of the study has shown that VCFPS separators have a better performance in reducing convective mass displacement and impact [14]. Gazi et al. analyzed the nonlinear fluid tanks with nonlinear viscous dampers in near and far zones [15]. Moslemi and Kianoush investigated the application of effective seismic control using lead rubber and elastomeric bearings for almost full cone-shaped tanks. In this research, the dynamic response was obtained by time history analysis and finite element modeling is used for models of base tanks, and the effect of different parameters such as lateral versus vertical isolation, location of isolators, hardness of the shaft, ratio of the tank dimensions, and the yield stress of the isolators is studied on the isolating system. The results show that the use of useful control devices for elevated cone-shaped water tanks can provide an effective way to reduce responses in such structures. Also, the results of further studies showed that the size and distribution of forces, time and displacement caused by the earthquake can be controlled by selecting devices with special characteristics, isolators' locations, and geometric and structural tank characteristics [16]. Paolacci analyzed the effect of two separator systems for seismic protection of elevated steel storage tanks especially high damping rubber bearing (HDRB) and friction pendulum isolators (FPS) [17]. Safari and Tarinejad studied the parameters of seismic responses of tanks in two near and far-field zones [18]. Phan et al. addressed the seismic performance of elevated storage tanks with reinforced concrete columns through probabilistic seismic assessment. This research considered an elevated steel storage tank under the influence of Kocaeli earthquake in Turkey in 1999, and by 3D modeling using the finite element method and seismic analysis of the model with the time history method in terms of nonlinear behavior of materials. They observed that the highest response of the structure occurs at the time of the earthquake peak [19]. The theory of probabilities is a mathematical framework for quantifying the uncertainties in decision-making. Almost all of the parameters needed to design a structure, such as mass, damping, material properties, boundary conditions, and ground motion, are uncertain. Uncertainties should be identified to design a safe structure. Safe structures function without damage for many years, and the builder is responsible to construct the structures in such a way that failure does not occur in them [20]. Several studies have focused on the validity of this analysis on various structures, but little research has been done on the elevated tanks. Altarejos-Garcia et al. estimated the probability of concrete gravity dam break for sliding failure under hydraulic loading as a case study [21]. Pasbani Khiavi, in the field of probabilistic and sensitivity analysis, studied the effect of the bedrock specification earthquake analysis of concrete dam using Monte Carlo simulation. The obtained results indicate the capability of probabilistic analysis in analyzing the seismic sensitivity of concrete dams to the bottom absorption effects [22]. The Monte Carlo method is a simulation method, one of the common goals of which is to estimate the specific parameters and probability distributions of random variables. One of the most commonly used methods for solving complex problems is probability analysis [23].

Pasbani Khiavi et al. also used the Monte Carlo probabilistic analysis capability to investigate the effect of the reservoir length on the seismic performance of concrete gravity dam and examined the trend of changes in responses according to the effects of reservoir length [24]. Following the investigation, Pasbani Khiavi et al. used the Monte Carlo probabilistic method with Latin Hypercube Sampling method for seismic optimization of the concrete gravity dam using an upstream rubber damper. Using sensitivity and uncertainty analysis, they obtained the optimal dimensions of the rubber damper to control the hydrodynamic pressure due to the interaction between the dam and reservoir [25].

The Monte Carlo method is divided into two methods of Direct Sampling and Latin Hypercube Sampling. The LHS method is a more advanced and appropriate form of Monte Carlo simulation. It performs 20 to 40 percent fewer simulation loops to obtain the results similar to Direct Sampling. In this research, the Latin Hypercube Sampling method is used for Monte Carlo analysis.

2. LHS method

The main procedure of performing calculations by simulating the LHS algorithm for any simple or complex process is presented with examples more or less. Figure (1) shows the LHS simulation flow diagram. First, a random number is determined, and then the likelihood of an event is compared with the randomly generated number. In the case where the generated number meets the probability criterion, a process or set of processes or developments occurs in the next section. This procedure can be repeated several times, and a measurable output can be generated for each repetition. In the final section, the set of experiments or outcomes are processes statistically, and an understandable and interpretable quantity is reported. The process part with events can be simple or very complex and may contain many loops and algorithms and even multiple random generators. Besides, it is possible to extract quantitative data from any point of the algorithm and analyze them as output variables. Monte Carlo simulation methods can be used in all fields of science and engineering to predict the real and virtual behavior of systems and define different scenarios [26].

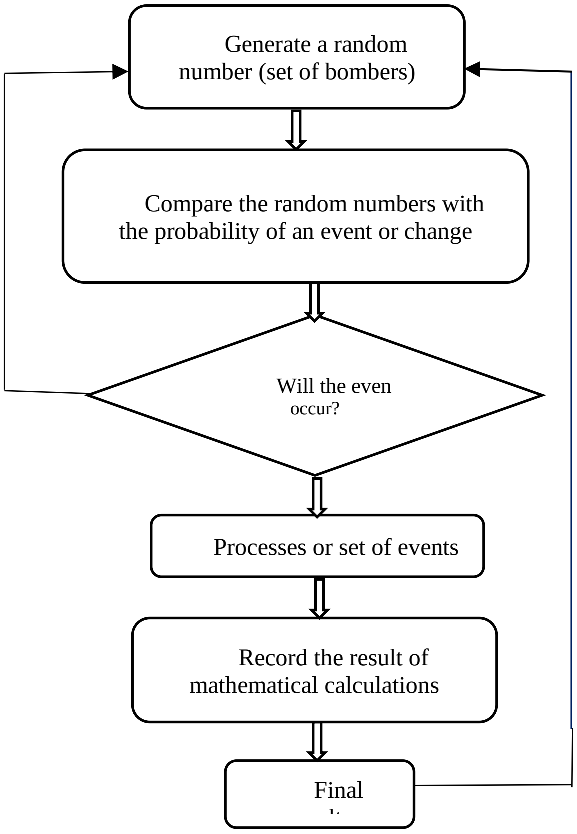

Figure 1. the calculation process in a probabilistic simulation using LHS

The following assumptions are considered in the tank [27]:

- The elevated concrete tank materials have homogenous and isotropic behavior.
- The fluid or tank water is a homogeneous, isotropic, non-stationary, non-rotating and with the small displacement medium.
- The Newmark method is used to perform seismic analysis.
- The effect of the surface water waves is neglected, and pressure is considered zero in the free surface.
- Considering the conditions governing the elevated tank behavior and the geometric shape of it, the problem is considered as a three dimensional.

The massless foundation model has been used. The mass-less foundation model is the best model for expressing the foundation behavior in interaction issues according to previous studies. The flexibility of the foundation is considered in the simple massless model, while the effects of inertia and damping are eliminated. The size of the massless foundation model does not have to be very large and only provides an acceptable estimate for the flexibility of the foundation.

This paper investigated the seismic sensitivity of the elevated tank to changes in the modulus of elasticity of the body concrete using ANSYS software and Monte Carlo probabilistic analysis as a suitable optimization method. The ANSYS software, based on the finite element method is capable of seismic analysis and Monte Carlo probabilistic modeling. The Latin Hypercube Sampling (LHS) method is used in Monte Carlo probabilistic analysis. The outstanding features of the software are as follows:

- Programming capability and the potential to develop
- Ability to investigate the fluid and structure interaction fully and comprehensively and optimize the designed models
- High capability of ANSYS software in seismic analysis and application of earthquake load in the form of time history analysis using programming in the software environment

3. The governing equations

In this part, the solid and fluid domain formula are presented while the water inside the tank is assumed to be inviscid, incompressible, and with small displacements. Considering that the main purpose of the research is to show the probabilistic model application in investigating the seismic behavior of the model, analyzing the sensitivity of the parameters, and presenting the optimal model, and due to the high computational effort in this field, the tank is considered solid elastic with a linear behavior of materials [28, 29]. However, the results can be generalized to nonlinear behavior after selecting the optimal mode.

3.1. Modeling of the tank structure

The governing equation of the dam behavior is the equation of motion. However, for the consideration and comprehensive definition of the interaction between the fluid, and the structure, the load applied due to the hydrodynamic pressure of the fluid at the contact point between the structure and fluid must be added to the equations of structure:

$$\mathrm{M}\ddot{\mathrm{u}} + \mathrm{C}\dot{\mathrm{u}} + \mathrm{K}\mathrm{u} = \mathrm{M}\ddot{\mathrm{u}}_{\mathrm{g}} + \mathrm{F}^{\mathrm{Pr}} \tag{1}$$

In Eq. (1), *M*, *C*, and *K* represent mass, damping, and stiffness matrices, respectively. *u* shows the relative movement vector, $\ddot{u}_g$ refers to the ground acceleration vector. F^{Pr} is the hydrodynamic force pressure vector at the contact point [30 and 31].

3.2. Modeling the reservoir

The equation for the dynamics of the structure should be considered with Navier-Stokes, momentum, and fluid continuity equations with problems related to the acoustic interaction between the structural and fluid. Given that the water inside the tank is inviscid, incompressible with small displacement, the equations of continuity and momentum are summed up to the wave equation. Also, the pressure applied to the structure by the fluid at the contact point is considered to form the interaction matrix [29].

$$\frac{1}{C^2}\frac{\partial^2 P}{\partial t^2} - \nabla^2 P = 0 \tag{2}$$

Where C is the velocity of the acoustic waves in the fluid. Equation (2) is the basis of acoustic issues and is known as the Helmholtz Equation, which is derived from hydrodynamic pressure.

3.3. Formulation of the finite elements of the governing equations

The equations governing the system are expanded using a finite element method in a matrix form. The structural elements are used to formulate the discretized dynamic equations of the dam system. To apply the interaction effects, the compressive load is added on the structure by the fluid and sediment. The matrixes of the tank elements are also extracted by discretizing the wave equation. The velocities and accelerations are expanded as first and second-order derivatives of displacements in the extraction of matrices.

3.3.1 The finite element equation of the tank

The finite element equation of the tank is as follows:

$$[M_e]\{\ddot{u}_e\} + [C_e]\{\dot{u}_e\} + [K_e]\{u_e\} = \{F_e\} + \{F_e^{Pr}\} \tag{3}$$

In which the fluid's compressive load vector $\{\mathrm{F}_\mathrm{e}^\mathrm{Pr}\}$ at the contact point is obtained with vector integration:

$$\{F_e^{Pr}\} = \int_s \{N^{'}\} P\{n\} ds \tag{4}$$

Where $\{\mathrm{N}^{'}\}$ is the interpolation function used to discretize displacement components and $\{\mathrm{n}\}$ is the normal vector at the contact point.

$$\{F_e^{Pr}\} = \int_s \{N^{'}\}\{N\}^T\{n\} ds \, \{P_e\} \tag{5}$$

Or

$$\{F_e^{Pr}\} = [Re]\{P_e\} \tag{6}$$

Where $[Re]^T = \int_s \{N^{'}\}\{N\}^T\{n\} ds.$

Replacing equation (6) in (3) results in the dynamic finite element equation of the structure as follows:

$$[M_e]\{\ddot{u}_e\} + [C_e]\{\dot{u}_e\} + [K_e]\{u_e\} - [Re]\{P_e\} = \{F_e\} \quad (7)$$

4. Case Study

As a case study, the three-dimensional model of the Rasht tank in Iran has been selected. System specifications are summarized as follows: Specific weight and Poisson's ratio of tank concrete are assumed 2400 kg/m^3 and 0.2; the modulus of elasticity of tank (E) is 28Mpa. For foundation, Poisson's ratio is 0.22, density is 2400 kg. For water, density is 1000 kg/m3 and acoustic waves speed in water is 1440 m/s^2. The height of the water is 8 meter, and the radius is 10 meter. The water level in the studied tank is considered full in the critical state. Figure 2 shows the dimensions of the elevated tank and its geometry.

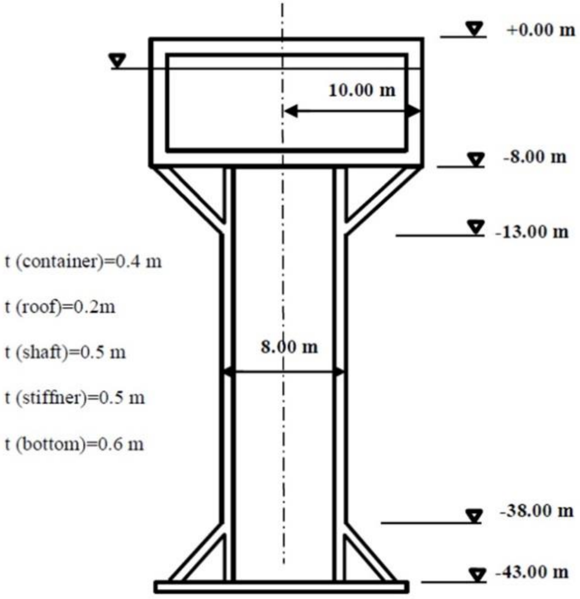

Figure 2. Model geometry

Therefore, after building the geometry of the models, 0.7 meters of mesh segments of the introduced elements are applied to the foundation base, tank, and water inside the tank. With this meshing, the numerical computations are performed by the finite element method by the software program.

In this research the necessary studies and sensitivity analysis have been done regarding the determination of the applied element size. In this way, when the size of the element was considered lower, the time of analysis was very high, and if the size of the elements were chosen more than the mentioned number, the accuracy of the calculations was less. The most appropriate mesh size is determined by the finite element model and the tank finite element model is shown in Figure 3. For these cases, the maximum horizontal displacement at the tank crest (No.1), 1st principle stress (N0.2), 3rd principle stress at the bottom of column and where the column junctions to the foundation were selected as the output parameters (No.3).

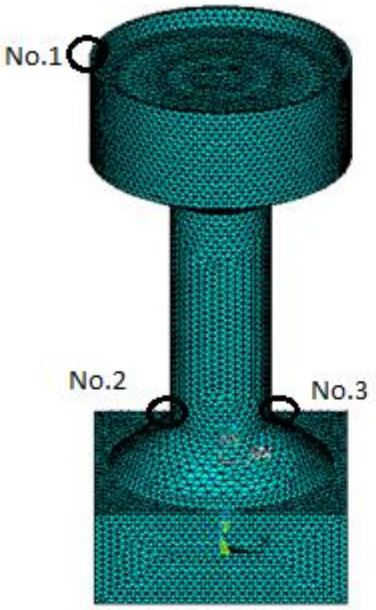

Figure 3. Finite element model of the tank

The numerical integration methods can be divided into explicit and implicit methods. Newmark method is an implicit method. Generally, the explicit methods are conditionally stable, and if a small time step is not chosen, the responses will diverge. However, in implicit methods, the relevant parameters are unconditionally stable with an appropriate selection. β and γ are parameters that can be determined to obtain the accuracy of integration and stability of the method. Given β=0.25 and γ=0.5, the accuracy of integration and stability of the method are in the optimal status [30]. In this study, the Solid185 element is used for 3D modeling of the solid part of the structure, and the 3D Acoustic30 element, which displays the behavior of fluid density, is used to create the fluid. The time step was selected as 0.02 sec

Also, according to Figure 4, the Solid185 element is used for 3D modeling of the solid part of the structure. As shown in Figure 5 the 3D Acoustic30 element which displays the behavior of fluid density is used to create the fluid. Moreover, the rigid connection foundation in all directions, water level in the tank with zero pressure and the water- structure interaction are considered for the contact location of water and tank wall and bed.

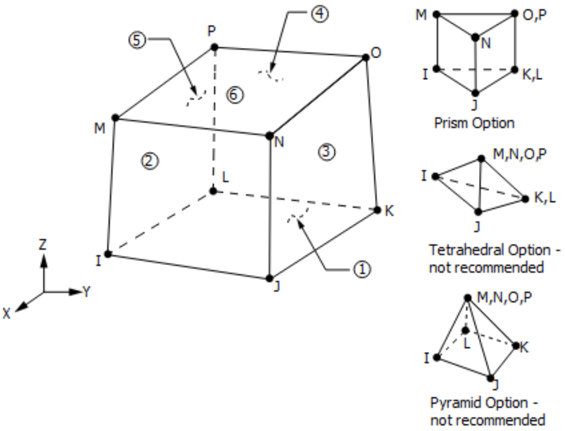

Figure 4. Geometric properties of Solid185 element

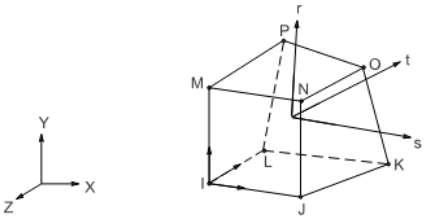

Figure 5. Geometric properties of Fluid30 element

5. Finite element model validation

At first, the finite element model is validated considering the hydrostatic pressure parameter on the tank bottom by in terms of the boundary conditions obtained from analytical method. By performing static analysis of the model under gravity acceleration, the result has been obtained. Obtained result was compared with the result of analytical values to check the validity of the model. The hydrostatic pressure contour of the water inside the tank obtained from the model has been shown in Figure 6.

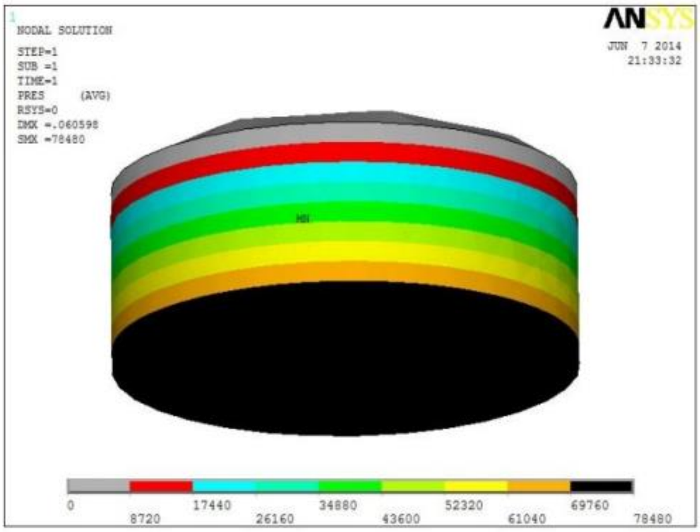

Figure 6. Hydrostatic pressure distribution of water inside the tank

The maximum value of hydrostatic pressure in the tank bottom is obtained according to the governing equation (8):

$$P = \rho g h = 1000 * 9.81 * 8 = 78480\ Pa \tag{8}$$

In which, P is the hydrostatic pressure (Pa), ρ is the water density (kg/m^3), and h is the height of the tank water in meter. The comparison of the obtained results shows that the value obtained from the static analysis of the model did not differ much from the calculation of equation (8), so the finite element model has the appropriate accuracy.

6. Seismic performance and Sensitivity Analysis

The horizontal and vertical components of Manjil earthquake that occurred in 1990 in Manjil region of Iran are applied to the entire body of the system along the reservoir and and in the vertical direction to perform seismic performance of the studied system according to the ANSYS software capabilities. Figures 7 to 9 show components of the Manjil earthquake.

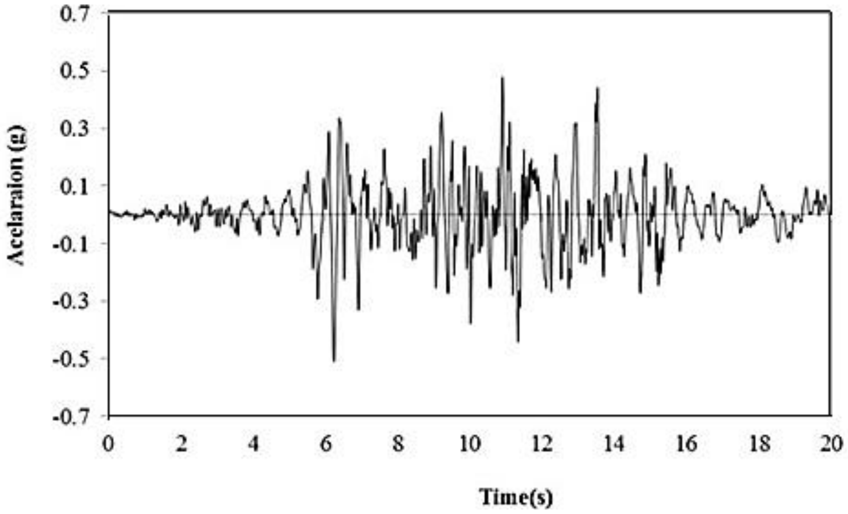

Figure 7. North-south Component of the Manjil Earthquake

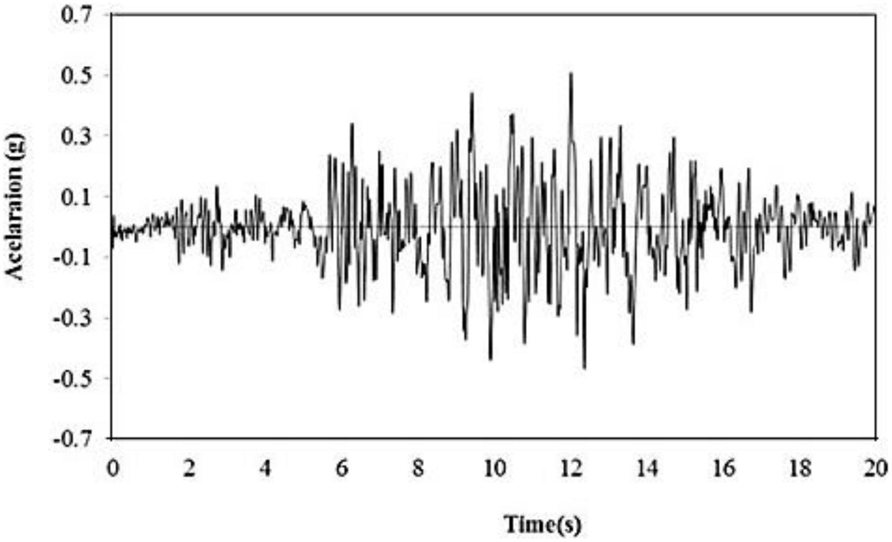

Figure 8. East-West Component of the Manjil Earthquake

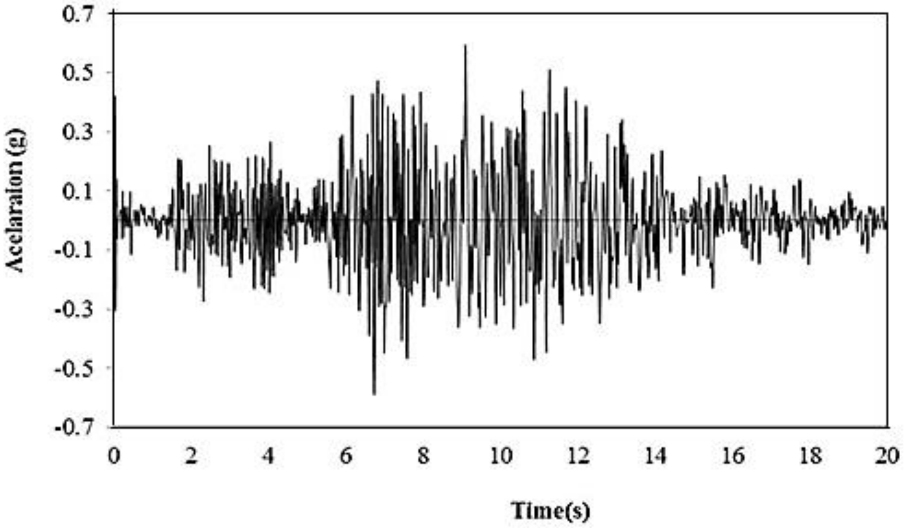

Figure 9. Vertical Component of the Manjil Earthquake

The ACI-318 instruction provides the relationship between the modulus of elasticity of concrete and cylindrical compressive strength to calculate flexural deformation in the form of relation (9):

$$E_C = 5000 f_C'^{\frac{1}{2}} MPa \tag{9}$$

Where E_c is the modulus of elasticity and f'_c is the compressive strength of the concrete sample. Many researchers have presented a variety of methods for determining the tensile strength of concrete. Raphael experimented 1200 typical samples with typical dimensions to determine the tensile strength of concrete. In the end, with the fitting of the curves and the results of experiments, Raphael presented equation (10) for concrete tensile strength [32]:

$$\sigma_t = 2.6 f_C'^{\frac{2}{3}} \tag{10}$$

Where σ_t is the tensile strength and f_C' is the compressive strength in Psi.
In the present study, the allowed compressive and the permissible tensile strengths are 31.36 and 4.65 MPa, respectively.

7. Results and Discussion

At first, the model is analyzed to study the critical points of the structure with Manjil ground motion as a time history. The contour distribution of the structure response is plotted for three important and influential responses in the design including displacement, first principal stress, and third principal stress in the most critical mode and presented in Figures 10 to 12.

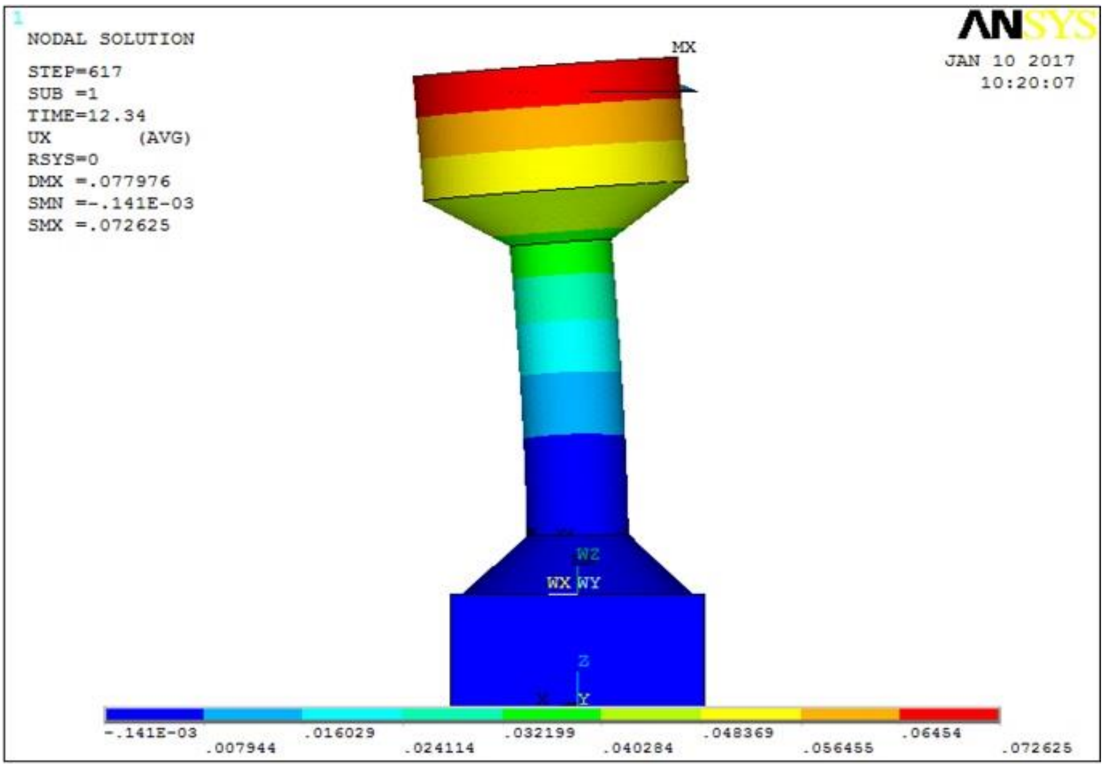

Figure 10. Distribution contour of displacement at the critical time

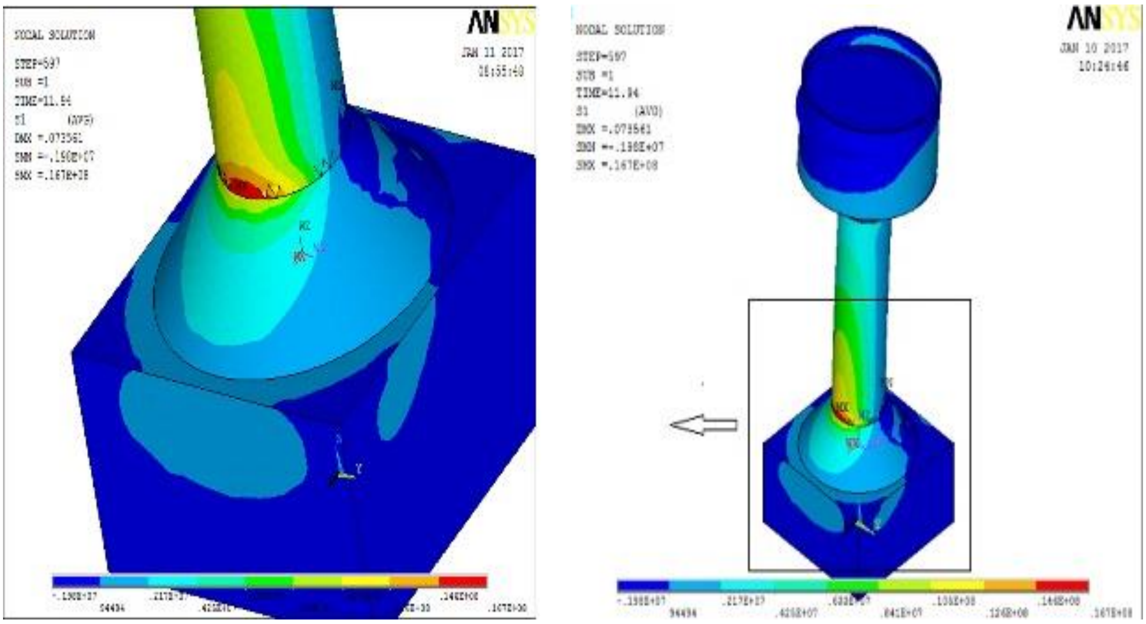

Figure 11. Distribution contour of the first principal stress at the critical time

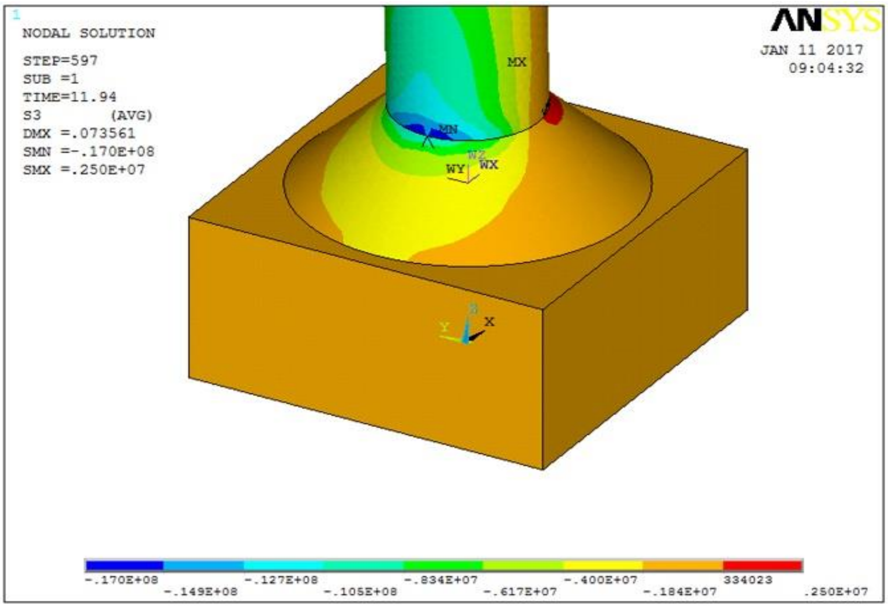

Figure 12. Distribution contour of the third principal stress at the critical time

Considering the contour of the critical responses, the most significant displacement occurs at the tank crest and the highest tensile and compressive stresses occur at the lower conical part attached to the base. Therefore, these points are considered critical points, and they are analyzed. The Gaus distribution has been selected for description of the scatter of the data, which is very effective for the problems with a large number of uncertainty and two or more random effects. At first, the Young modulus of concrete is selected equal to 20 GPa for the base-case model. The model is analyzed using ANSYS software. Afterward, LHS simulation is done for the sensitivity analysis to show the response sensitivity to variation of the Young modulus of concrete as random input parameter.

For probabilistic analysis, 20 samples of input parameters with GAUS (normal) distribution and standard deviation of 0.4 were generated and assigned to the modulus of elasticity. The most basic form of post-processing of results is direct observation of the results of the simulation loops as a function of the number of loops. In this section, variations in the average value of the input parameters are investigated in terms of the number of samples. Figures 13 to 15 show the average variation in output parameters in terms of sample size. According to Figures 13 to 15, it is seen that in order to modify the average value of the output parameters, the number of loops implemented for convergence is sufficient. The end parts of presented curves are almost horizontal which confirms the adequacy sample number in the probabilistic analysis.

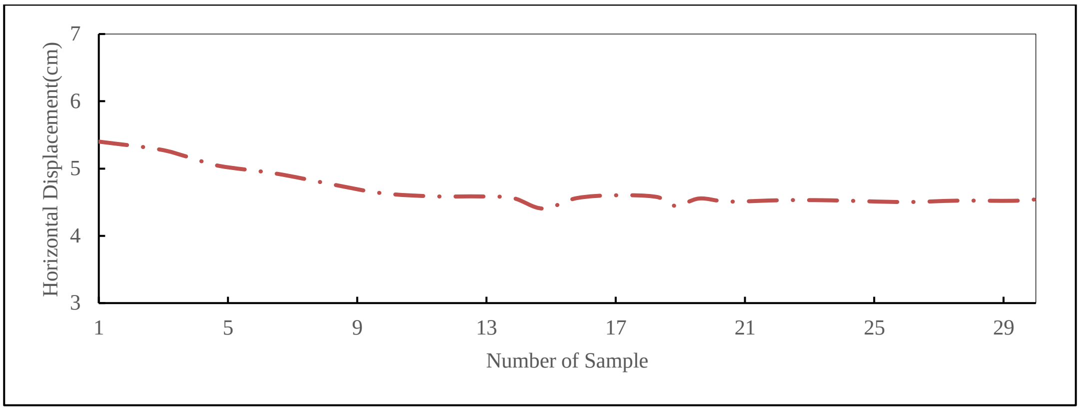

Figure 13. Variation of the mean value of displacement of the tank crest under the influence of Manjil earthquakes

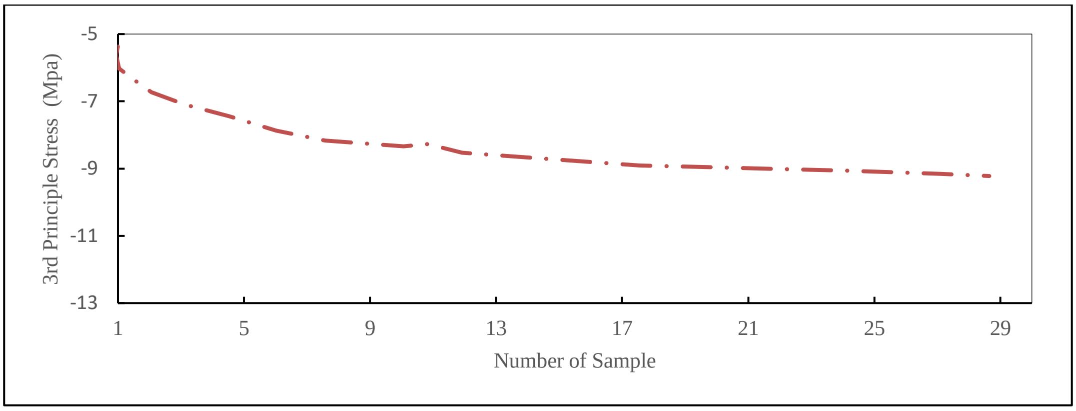

Figure 14. Variation of the mean value of the 1st principle stress under the Manjil earthquakes

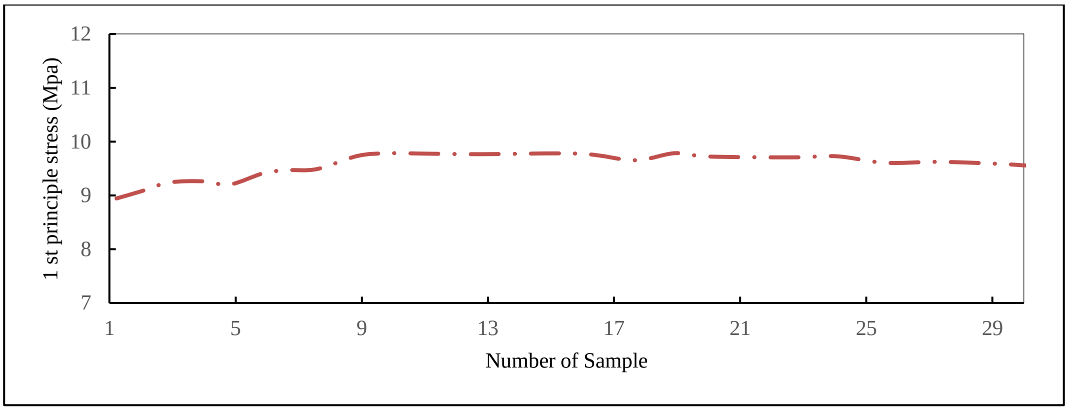

Figure 15. Variation of the mean value of the 3rd principle stress under the Manjil earthquakes

7.1. Cumulative Distribution Function

In this section, Cumulative Distribution Functions (CDF) for the output parameters are presented. CDF explains the probability in which the value of the random parameter has a value less than or equal to a specific value [33]. Figures 16 to 18 show the cumulative distribution of the input parameter for two modes of variation in the modulus of elasticity of the tank body and foundation.

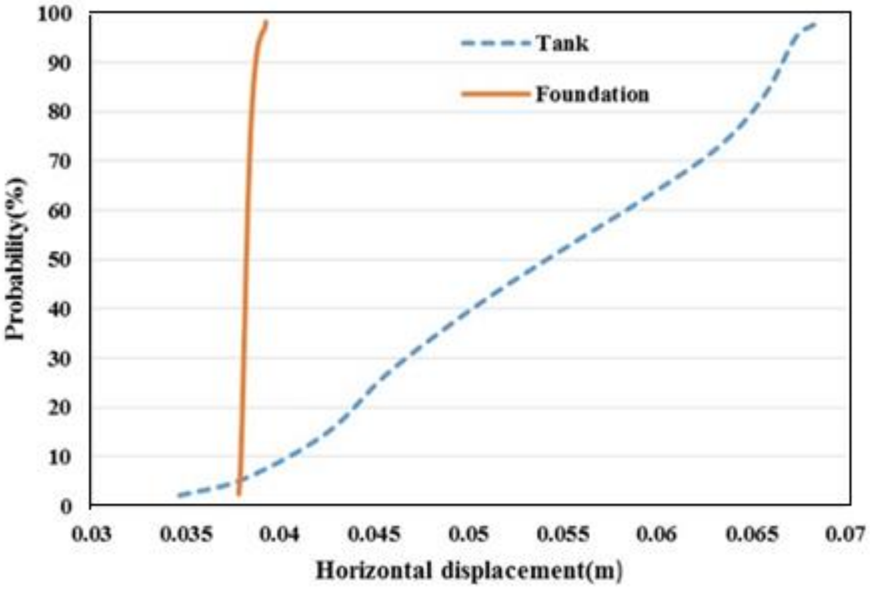

Figure 16. Cumulative distribution of maximum horizontal displacement in the critical area in terms of increasing the modulus of elasticity of the tank body and foundation

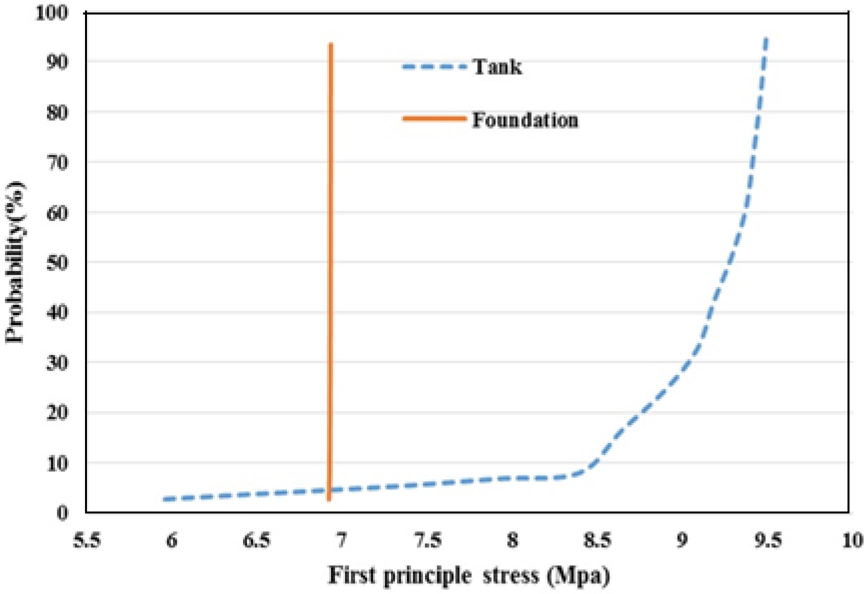

Figure 17. Cumulative distribution of first principle stress (tensile stress) in the critical area relative to the increase in modulus of elasticity of the tank body and foundation

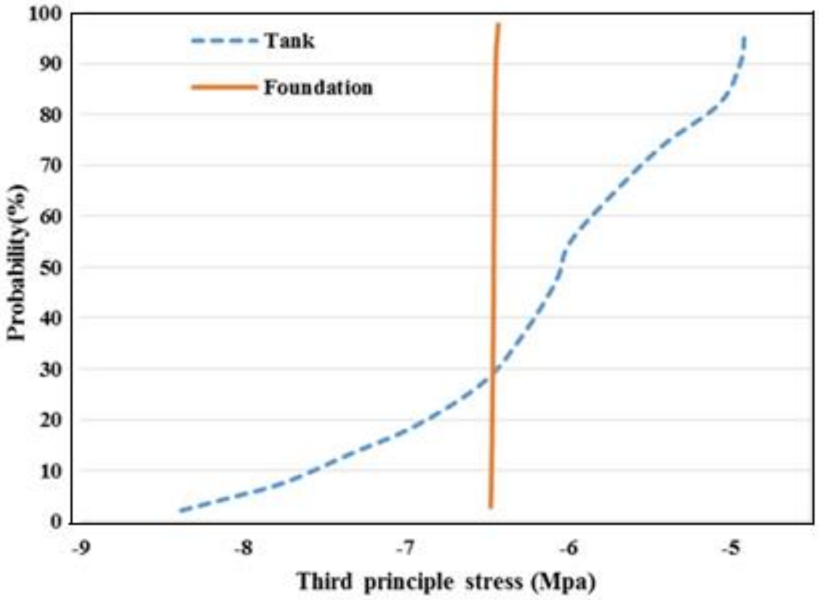

Figure 18. Cumulative distribution of third principle stress (tensile stress) in the critical area relative to the increase in modulus of elasticity of the tank body and foundation

According to Figures 16 to 18, while the modulus of elasticity of the body is considered as the input parameter (modulus of elasticity of the tank increases), the probability that the critical area displacement is less than 51cm is 41%. The results also show that the 1st principle stress is undoubtedly less than 4.65, and the 3rd principle stress will be more than 31.36 MPa. If the modulus of elasticity of the foundation is considered as an input parameter (the modulus of elasticity of the foundation increases), the probability of displacement about 3.8 cm, first principle stress of 6.9 MPa and third principal stress of 6.5 MPa in the critical area will be 100%. The effect of tank and foundation modulus of elasticity as random input variables on the output responses is presented in Figures 19 to 21. Also, in Table 1, the critical response values for the change in tank and foundation modulus of elasticity are compared.

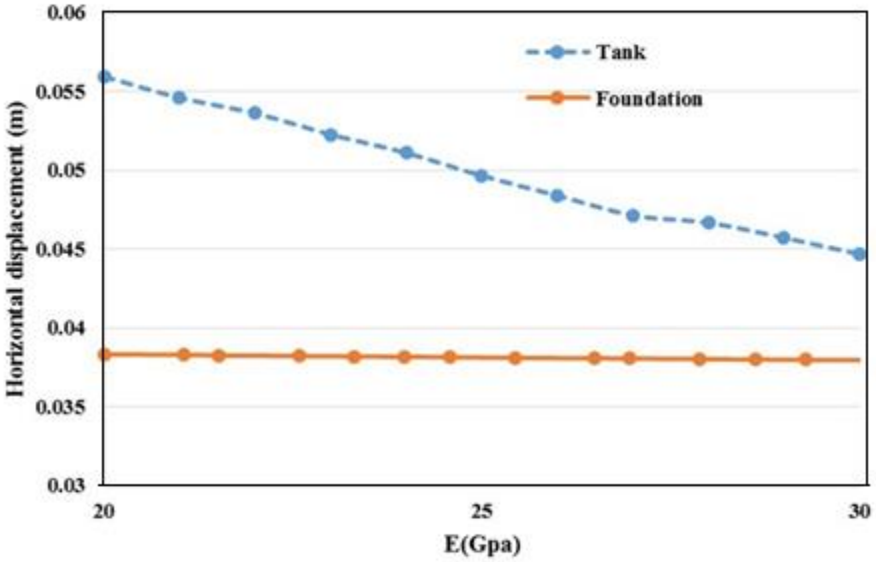

Figure 19. Critical displacement variations vs. tank and foundation modulus of elasticity variations

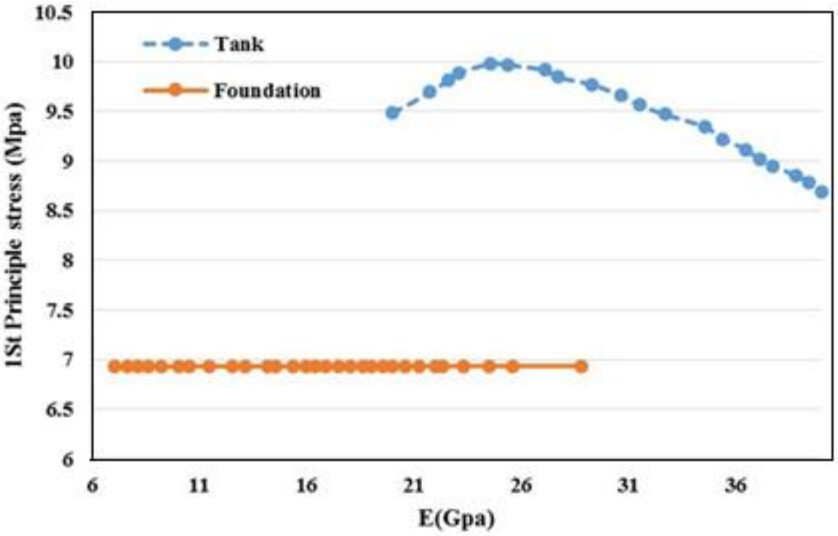

Figure 20. First principle stress variations vs. tank and foundation modulus of elasticity variations

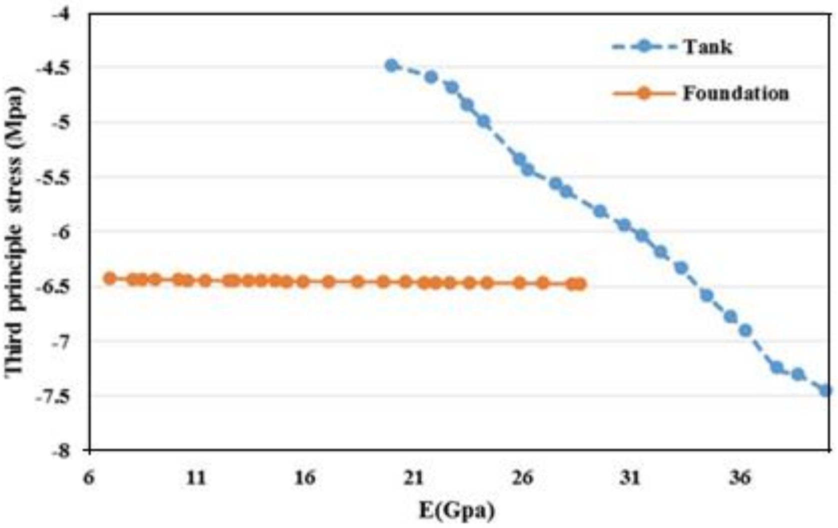

Figure 21. Third principle stress variations vs. tank and foundation modulus of elasticity variations

Table 1: Critical response values for tank and foundation modulus of elasticity variations.

Modulus of elasticity	**Horizontal displacement**			**1st principle stress (Tensile stress)**			**3rd principle stress (Compressive stress)**		
	Max	Min	Percentage of response variations	Max	Min	Percentage of response variations	Max	Min	Percentage of response variations
Tank	0.055	0.036	-35.64	9.48	8.68	-8.37	-7.44	-4.48	66.07
Foundation	0.039	0.037	-3.83	6.93	6.92	0.11	-6.47	-6.42	0.73

The results of Figures 19 to 21 show that, due to tank modulus of elasticity variations, the horizontal displacement curve of the critical area is descending with a variable rate of 35.64%. Moreover, in the first principle stress curve (tensile stress), the variation process is first ascending, and then descending and the response rate variation is 8.37%. However, in the third principle stress curve (compressive stress), the variation process is ascending with a relatively high rate of about 66%. If the modulus of elasticity variations is applied on the foundation, the response variations are negligible, and the chart is almost horizontal.

8. Conclusions

In this research, the seismic performance of elevated tanks is discussed with probabilistic analysis. The ANSYS software, which is based on the finite element method, is used for analysis and modeling. In this study, modeling is done on one of the elevated tanks in Iran. Accordingly, the effect of interactions between the system's amplitudes is considered, and according to the conditions governing the elements and geometry of the tank, the three-dimensional modeling has been done. The foundation is modeled as massless and tank water is assumed as an isotropic, inviscid, irrotational, and with small displacement medium. The Newmark numerical method has been used for numerical integration, and the Monte Carlo simulator using the Latin Hypercube Sampling method is applied for the probabilistic analysis. The tank body and foundation modulus of elasticity are applied to the model as an input parameter separately and system responses are compared for both cases. According to the results, the tank modulus of elasticity variations had a significant effect on the response values, and the response variations were high. Therefore, the maximum percentage of response variations (66%) was related to the third principal stress (compressive stress) for the modulus of elasticity variation. The minimum percentage of response variations was related to the 1st (tensile stress) for the modulus of elasticity variation of foundation. Therefore, the foundation modulus of elasticity variations has little effect on the output response values. Accordingly, the foundation concrete could be chosen with lower sensitivity in the design of the elevated tanks so that it is economically feasible. However, both performance and economic issues should be considered in choosing the type of tank concrete.

According to the design criteria, it is possible to investigate the safety status of the system and select the optimal state in terms of structural strength for the model.

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