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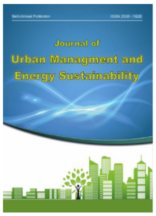

CASE STUDY RESEARCH PAPER

Investigation of the effect of SMA SMArt materials for the construction of concrete tanks under finite element analysis

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ABSTRACT

Shape memory alloys are designed to revert to their original state due to stress and heat, as well as to enhance ductility, energy absorption, and damping capabilities for significant deformations. Fatigue caused by cyclic loading with high frequency is of paramount importance for controlling deformation, drift, and the initial state of the material, as well as structural stability. Therefore, studying their behavior under loading cycles and qualitatively and quantitatively assessing their effectiveness in reducing deformations and parameterizing this effect becomes essential for optimizing structural behavior using Shape Memory Alloys. Given the significance of these materials in the construction of concrete tanks, this research focuses on analyzing Shape Memory Alloys components, specifically investigating the effects of SMArt materials. The scope of the Shape Memory Alloys is limited, and consequently, this study examines a concrete tank model utilizing SMArt materials aimed at enhancing Shape Memory Alloys performance. The conclusion of this research indicates that the use of SMArt materials will positively affect the structural behavior.

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INTRODUCTION

Fluid storage tanks are integral components across various industries, playing a crucial role in managing and containing fluids necessary for operations. Particularly in the petrochemical sector, these tanks facilitate the safe storage of hazardous materials, ensuring that environments remain secure and operational efficiency is maintained. Furthermore, these tanks serve essential functions in the supply of potable water to urban populations, underscoring their significance in public health and safety. However, the structural integrity of fluid storage tanks can be compromised due to natural disasters, manufacturing defects, or wear and tear, leading to potentially disastrous outcomes. Consequently, the ramifications of tank failures extend beyond financial losses and can pose severe risks to community health and safety. Historical events, such as the Long Beach earthquake, illustrate the critical need for enhanced tank design and resilience (Barlow & Righter, 2019). The impact of these disasters often involves contamination of water supplies and can precipitate widespread crises. Thus, the design and maintenance of these tanks must account for potential environmental factors and stressors (Dhanasekar et al., 2018). Heightened awareness of these risks has spurred significant research endeavors aimed at improving tank safety and reliability. By focusing on robust engineering practices, industries can mitigate the risks associated with fluid storage tanks. Historically, the consequences of not adequately maintaining and securing fluid storage tanks have led to catastrophic scenarios. The 1933 Long Beach earthquake exemplifies how structural failures can disrupt essential water delivery systems, resulting in public health emergencies (Khalid & Qureshi, 2020). This earthquake highlighted the vulnerabilities of drinking water tanks, which suffered damage that severely hampered water availability in the affected regions. Similarly, the San Fernando earthquake in 1971 revealed the physical dangers posed to combustible liquid storage tanks, emphasizing the need for rigorous safety protocols (Franchek & Wang, 2017). Fires ignited by these failures exacerbated the disaster, creating chaotic conditions for emergency responders and communities alike. These events serve as reminders of the potential hazards associated with inadequate tank storage systems (Ghadiri & Jahedaro, 2019). Researchers and engineers have since prioritized developing standards and guidelines to enhance the resilience of tanks against seismic activities and other natural disasters. Understanding the mechanical behaviors of different tank designs under stress is crucial in this ongoing effort. Improved materials and construction techniques can lead to tanks that withstand such calamities better. Ongoing studies focus on integrating innovative designs that can accommodate vast amounts of fluids without compromising safety (Chen et al., 2021).

The field of fluid storage tank design has seen significant advancements driven by extensive research and technological progress. Both theoretical analyses and experimental studies have contributed to a deeper understanding of material performance and tank behavior under various conditions (Akkari & Al-Rashid, 2020). Researchers utilize advanced modeling techniques to predict how tanks respond to seismic forces and the impact of environmental factors. By simulating real-world scenarios, they can identify weaknesses within existing designs and propose enhancements (Moshref & Banerjee, 2023). Moreover, the incorporation of new materials has the potential to revolutionize tank construction, allowing for greater durability and resistance to chemical exposure (Pereira & Lima, 2022). This is particularly vital in industries where corrosive substances are stored, necessitating tanks that can endure harsh conditions. Key advancements also involve developing monitoring systems that can alert operators to structural weaknesses before catastrophic failures occur. Sensors and IoT technologies provide real-time data on tank integrity, enabling proactive maintenance interventions (Zhang &

An, 2022). As the industry evolves, embracing such innovative approaches will be essential to ensure safety and efficiency in fluid storage practices. Continuous investment in research will help ensure that fluid storage tanks meet the dynamic needs of industrial applications. Looking to the future, the importance of fluid storage tank safety cannot be overstated, especially in light of climate change and increasing environmental regulations. As natural disasters become more frequent and severe, there is an urgent need for proactive measures to enhance the resilience of storage systems (Ghadiri & Jahedaro, 2019). Future research should focus on developing universally applicable standards that can be customized according to regional risks and specific fluid characteristics. Collaboration among industry stakeholders, researchers, and regulatory bodies will be critical in establishing these guidelines (Moshref & Banerjee, 2023). Additionally, incorporating sustainable practices in tank design can lead to environmentally friendly solutions that meet modern safety standards. The role of education and training for personnel in tank management also cannot be overlooked. Ensuring that workers are well-informed about best practices will enhance overall safety (Pereira & Lima, 2022). Furthermore, interdisciplinary approaches that bridge engineering, environmental science, and disaster management will yield comprehensive solutions to tank safety challenges. The integration of machine learning and artificial intelligence can also enhance predictive maintenance efforts, ensuring that tanks remain safe and functional over time (Zhang & An, 2022). In conclusion, the ongoing commitment to research and innovation in fluid storage tank design is vital to safeguarding industries and communities alike.

Fluid storage tanks are critical infrastructure components in various industries, yet they are susceptible to damage from a variety of factors, chief among them being seismic activity. Numerous tanks across different countries have sustained significant damage due to earthquakes in recent years, highlighting the need for a thorough seismic assessment of these structures (Khalid & Qureshi, 2020). Therefore, designing fluid storage tanks that can better withstand seismic forces is of paramount importance. Fluid storage tanks are commonly categorized into three primary types: above-ground tanks, ground-level tanks, and underground or semi-buried tanks. Among these categories, above-ground tanks are the most prevalent due to their numerous advantages such as increased capacity, ease of construction, and enhanced safety features (Moshref & Banerjee, 2023). They primarily serve to maintain adequate water pressure in various applications, while underground tanks are often utilized for fuel storage in urban settings, including gas stations. Ground-level storage tanks, on the other hand, vary widely in size and can be employed in various industries. They can range in diameter from just a few meters to several hundred meters, thus offering remarkable versatility (Pereira & Lima, 2022). These tanks are further divided into restrained and unrestrained categories, providing insights into their design and functionality. Unrestrained tanks typically rest on flexible foundations, making them easier and cheaper to construct than their restrained counterparts. However, investigations following past earthquakes have demonstrated that unrestrained tanks are generally more vulnerable to seismic impacts than restrained tanks (Dhanasekar et al., 2018). In restrained conditions, tanks are anchored to their foundations, which significantly reduces the risk of uplift during seismic events. While this anchoring is beneficial, it also introduces challenges, including the potential for tank wall rupture or lifting of the tank along with its foundation due to the effects of horizontal and vertical ground motion (Barlow & Righter, 2019). Understanding how tank foundations interact with these structures is essential for improving their performance under both restrained and unrestrained conditions. This understanding is critical, especially for the design of large storage tanks that must remain operational despite potential seismic threats. Typically, storage tanks are divided into two major types: above-ground and ground-level tanks. Each type has its own set of advantages and applications, determining their suitability for specific environments and purposes. Ground-level tanks can be constructed either as buried or semi-buried structures, thus adding further flexibility to storage capabilities.

When it comes to large volumes of fluid storage, ground-level tanks are often regarded as more cost-effective than above-ground designs. Additionally, to maintain required fluid pressure, either underground systems can be implemented or tanks can be constructed in elevated locations, such as hills (Akkari & Al-Rashid, 2020). In many cases, especially where water is supplied to extensive consumption networks located away from elevated sources, using ground-level tanks is impractical. This scenario necessitates the construction of above-ground tanks for efficient fluid distribution. Above-ground tanks can take various forms, including pedestal tanks with central shafts or framed structures, which can be further classified as either restrained or unrestrained designs using moment frames (Ghadiri & Jahedaro, 2019). The choice between reinforced concrete and steel frames primarily depends on site conditions and intended use. In less urbanized regions, some above-ground tank pillars may even feature traditional brick materials, demonstrating the diversity of construction methods employed in tank design. This adaptability allows for effective solutions tailored to geographical and economic contexts. As the field of fluid storage tank design continues to evolve, ongoing research aims to optimize robust structures that can withstand environmental stresses, including earthquakes. The integration of innovative materials and designs, combined with advanced modeling techniques, has been instrumental in enhancing the resilience of fluid storage systems (Chen et al., 2021). Emerging technologies, such as IoT sensors, can improve monitoring capabilities, ensuring early detection of potential issues (Zhang & An, 2022). On an administrative level, collaboration among engineers, researchers, and regulatory bodies will be crucial in establishing guidelines that ensure safety and reliability in tank operations. Furthermore, the importance of rigorous training for personnel involved in tank management cannot be understated, as it directly contributes to operational safety (Pereira & Lima, 2022). As we move forward, understanding the complexities of fluid storage tank behavior will be vital in creating safer and more effective designs that can adapt to the challenges posed by natural disasters. In conclusion, a concerted effort in research, development, and application of best practices will ensure that fluid storage tanks meet the demands of varying environments while keeping safety at the forefront. Figure 1 shows examples of various above-ground tank designs. In this article, the term "above-ground tanks" specifically refers to tanks with a central shaft or central column, which are simply referred to as above-ground tanks. (Fig. 1)

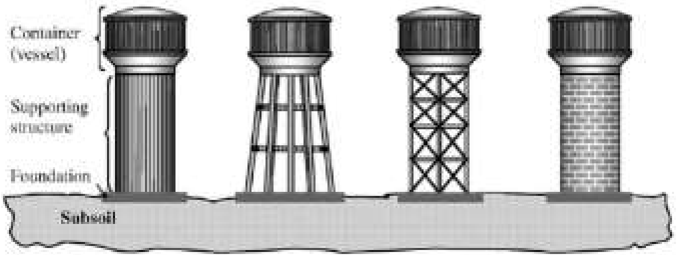

Figure 1 - Common types of air tanks: (from left to right), air tank with a central reinforced concrete base, air tank with a reinforced concrete frame base, air tank with a steel frame base, air tank with a traditional material base.

As shown in Figure 1, above-ground concrete tanks consist of three main structural elements, and considering that these elements include the primary specifications of the structure, the foundation is generally constructed in a radially supported manner. The effects of soil-structure interaction are not considered in this research; therefore, we refrain from discussing that aspect. The supportive base and the tank section containing the fluid are collectively referred to in this research as the base and tank, respectively. Among various geometric shapes, cylindrical tanks have been constructed more than other forms, as they possess a more suitable geometry for urban spaces from an architectural perspective. However, rectangular (cubical) tanks have more extensive research backgrounds, particularly in the context of ground-level tanks, which exhibit similar behavior to above-ground tanks. Shape Memory Alloys (SMA) are materials that possess unique characteristics. These materials return to their original shape in response to a stimulus, which can be stress or heat. In simpler terms, a material is in a stable state, and if it undergoes deformation, it can return to its original shape within a specific temperature range or due to a stress stimulus. This property is referred to as “shape memory.” The shape memory effect in alloys was discovered in 1932 in a cadmium-sodium alloy. This characteristic allows shape memory metals to return to their original shape after undergoing deformation when subjected to a temperature higher than their transformation temperature. (Fig. 2)

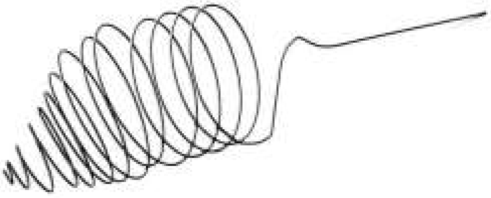

Figure 2: View of a shape memory alloy

The transformation temperature can be lower than the ambient temperature, in which case the material will behave like a spring. At the transformation temperature phase, the alloy experiences a reversible phase change from the martensite solid state to the austenite state. However, it is important to note that both phases have different properties compared to each other. The function of the shape memory alloy is such that when it is in its martensite phase, it can easily deform and take on a new shape. However, if the same alloy is heated and reaches the transformation temperature, it returns to the austenitic phase and regains its previous shape. In fact, at the transformation temperature, a solid-state phase change begins. This transformation temperature depends on the alloy compositions and some other factors. This process is referred to as “shape memory.” (Fig. 3)

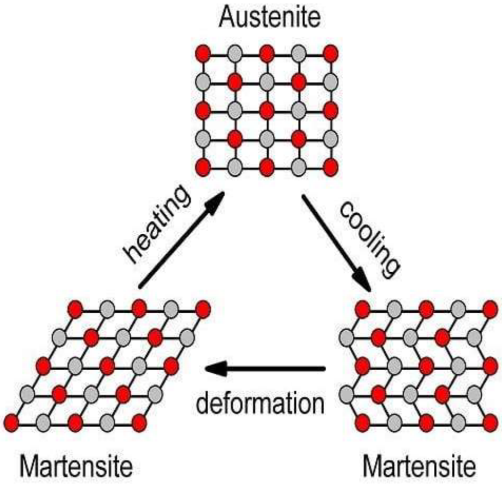

Figure 3: View of the shape memory alloy structure

Shape memory alloys can return from significant deformations caused by bending or stretching to their original state. If the deformations are within a reversible range, the process of deformation and return to the original state in these alloys can be repeated millions of times.

MATERIALS AND METHODS

Methodology

Introduction to Geometry

This research aims to study and evaluate the behavior of above-ground tanks under horizontal and vertical earthquake components in the context of the structural behavior of an above-ground tank. This will be modeled once with a sample without SMA materials, considering the effects of the materials, and once with SMA materials using the ABAQUS software. The specifications of these models and the effective parameters of these samples are outlined, as described in the general specifications in Table 1 and shown in Figure 3, where the geometric characteristics of the studied model samples are modeled in the ABAQUS software. (Fig. 4) (Tab. 1)

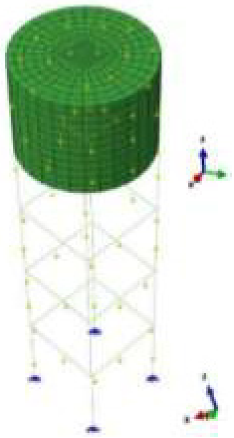

Figure 4: Geometric view of the modeled group sample

S400 Steel rebar

To define the nonlinear behavior of steel S in this research, the steel reinforcement bars made of hollow 400-grade steel are assumed to have a bilinear stress-strain curve in the software. Therefore, it is sufficient to specify two slopes for the initial and secondary elasticity models, along with the yield stress value. The specifications of the 400-grade steel used in this modeling are shown in Tables 2 to 5. (Tab. 2-4)

Table 2: Linear isotropic mechanical properties of steel rebar in samples of all groups

Young's Modulus (MPa)	Poisson's Ratio
2.05E105	0.3

Table 3: Bilinear isotropic mechanical properties of steel in samples of all groups

Yield Stress (MPa)	Plastic Strain
465	0
600	0.12

Table 4: Steel rebar specifications

Steel Type	Young's Modulus (Pa)	Density (kg/m^3)	Poisson's Ratio
St37	2.05E105	7850	0.3

Mechanical properties of concrete

There is a concrete damaged plasticity model for defining concrete in the Abaqus software, which has a general capability for modeling the behavior of concrete or any other material with semi-brittle behavior. This model utilizes the concept of isotropic failure in the elastic range alongside compressive behavior in the plastic range to model the non-elastic behavior of concrete. In this research, the models examined in the study groups used concrete with compressive strengths of 25 megapascals, with the behavior of concrete following elastic and plastic properties. Figure 5-8 shows the stress-strain curve of the concrete used in the modeling of the samples in this study. (Tab. 5)

Table 1: Geometric characteristics and effective parameters of the study samples

Model Name	Shape Type	Cross-Section Width	Geometric Sample Height	Overall Height of Water Storage Tank	Effective Parameter
A	Circular	2500 mm	7500 mm	2000 mm	Without SMA
B	Circular	2500 mm	7500 mm	2000 mm	With SMA

Table 5: Mechanical properties of modeling sample concrete

Type	Compressive Strength (MPa)	Density (kg/m^3)	Name and Type of Concrete
1	25	2500	Concrete Type 1

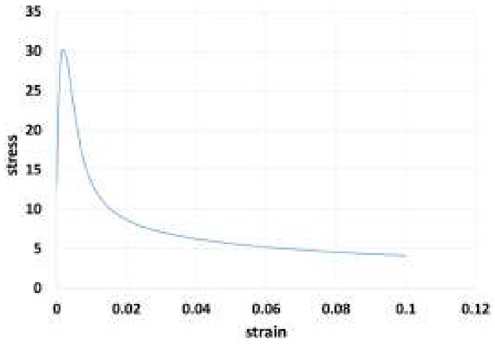

Figure 5: Stress-strain diagram of concrete used in modeling samples

Validation

L. Kalani and colleagues used laboratory studies with ABAQUS for the validation of the software program sample in 2014. After modeling the laboratory sample studies in ABAQUS and comparing two hysteresis curves, we observed that the difference between the force-displacement curves of the two samples was very SMAll, with a slight difference of about 5 percent. The studied sample and their force-displacement curve are shown in the figure below.

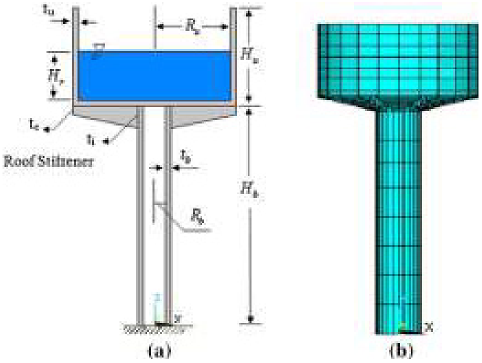

Figure 6: Geometric shape of the validated sample from laboratory studies by L. Kalani et al.

To view the results of the solution, you must run the CAE in Explicit Standard after the analysis appears in one of the two methods. The ABAQUS/Viewer window is used for visualization only. The output and various contours of the model parameters can be observed in the figures below.

DISCUSSION AND FINDINGS

In this section, the results of the finite element analysis of the concrete storage tank trench modeling are discussed. The model is classified under two types: model A (SMA model without materials) and model B (SMA model with materials). The results obtained are presented below in comparison with the results of the finite element analysis. (Fig. 9)

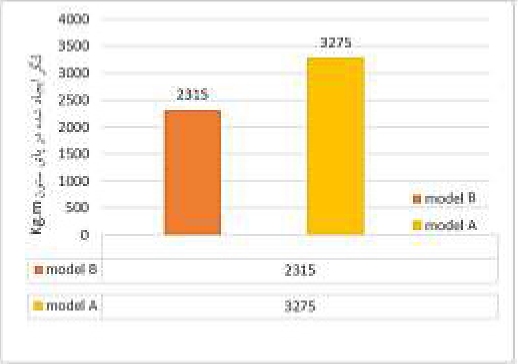

Figure 9: Comparison of the amount of moment created at the foot of the column model (SMA model with materials) B and (SMA model without materials) A

Model with materials (B) and model without materials (A) According to the comparison of the anchor created at the foot of the column of the model, a 29% reduction in the anchor at the foot of the structure was observed in concrete tanks, with the placement of materials (SMA). (Fig. 10)

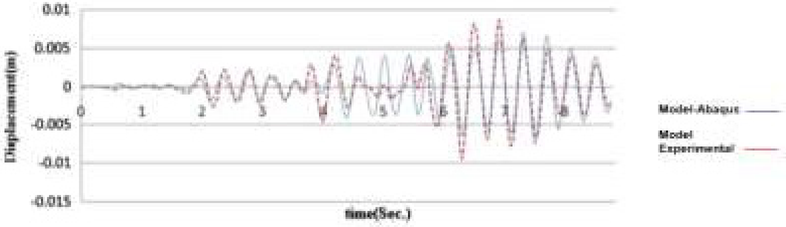

Figure 7: Comparison of validated graphs of laboratory studies by L. Kalani et al.

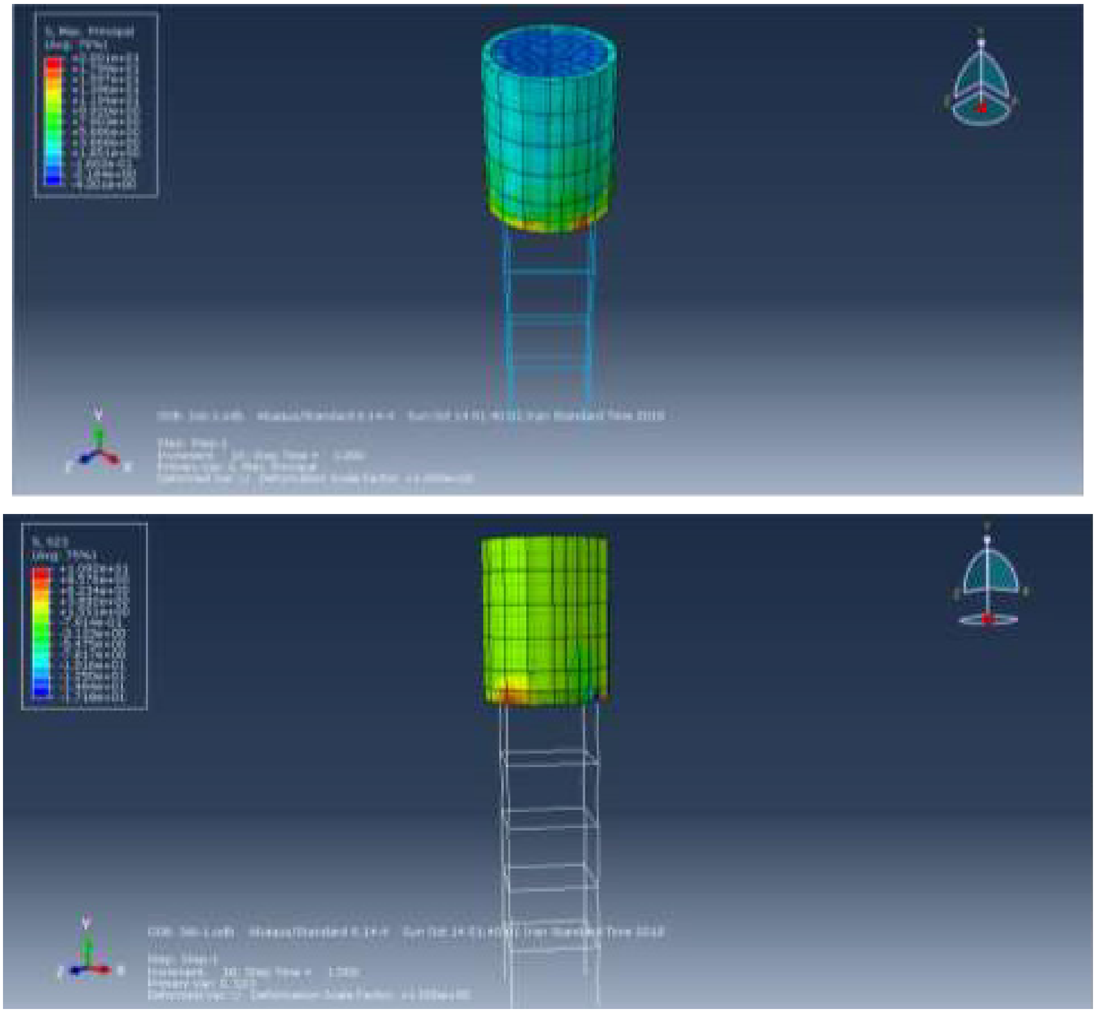

Figure 8: View of the stress contour resulting from the finite element analysis of the concrete tank model

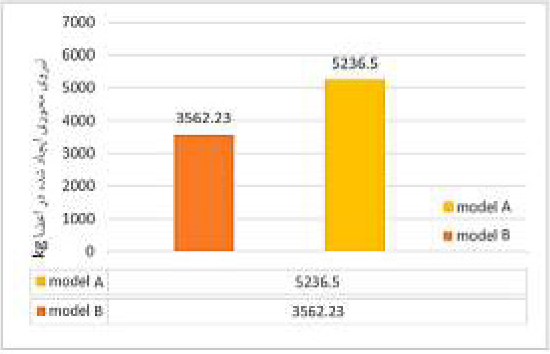

Figure 10: Comparison of the axial force generated at the foot of the column in the SMA model with materials (A) and the SMA model without materials (B)

With (B) and (A) model without materials, the axial force created at the foot of the column was compared, and a 31% reduction in the axial force in the concrete tank was observed, with the placement of (SMA) materials at the foot of the column in the structure due to the earthquake force. (Fig. 11)

According to the comparison of the stress created in the tank body of the model, 34% of the stress created in the structure is observed. / A reduction of 91 SMA was observed, by placing the materials (SMA). (Fig. 12)

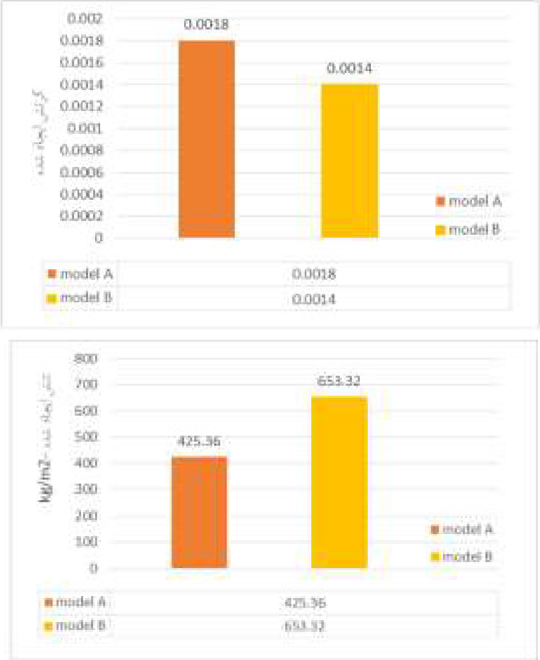

Figure 11: Comparison of the amount of stress created in the column body (SMA model without materials) and (B model) (SMA model without materials)

Model with (B) and model without materials (A) Figure 11: Comparison of the strain value created in the column body of model with materials (B) and model without materials (A) On the nonlinear behavior of the structure after modeling the samples studied in the SMA program in order to investigate the effect of materials and the second case with SMA finite element analysis of Abaqus and after conducting a study analysis of the structural model in the first case without materials and analysis (Nsp) The results of the finite element analysis under two nonlinear static analysis of materials (Imperial Valley, El Alamo, Northern Calif) The time history of the seismic maps of the earthquakes are obtained, which are presented in the graphs of the structure capacity curve and the displacement history graph. From the finite element analysis of the type (SMA and the structural model) without materials (SMA) By comparing the results of the analysis of the structural model (with materials) on the structural behavior, SMA pushover analysis and comparison of the force-displacement graphs in investigating the parameter of the effect of the materials, the results showed that by using materials, it will increase by 7%. The bearing capacity of the structure is about 17/32 %. (Fig. 13)

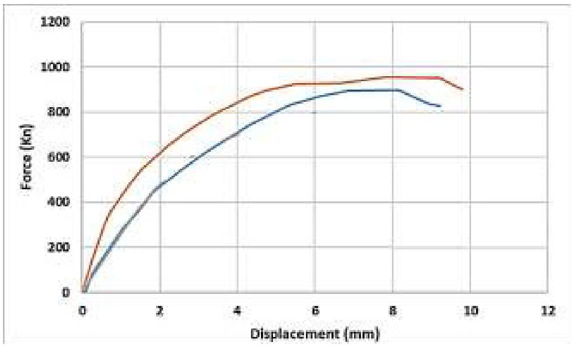

Figure 13: Force-displacement diagram of concrete tank model (without materials) and with materials (SMA)

After conducting seismic time history analysis of the three seismic records, comparing the results of the time history analysis of the above earthquake records and considering the maximum response of the concrete tank model (with SMA materials) and the concrete tank model (without materials) from the analysis of the components (SMA) and the seismic time history analysis and comparing the displacement history graphs in the study of the material effect parameter, it was found that the displacement ratio on the concrete tank will decrease by 24% / SMA by about 43 SMA, which was found by working with SMA materials. (Fig. 14)

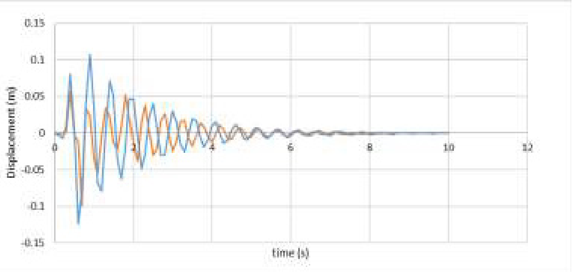

Figure 14: Comparison of displacement time history graphs (model with and without materials) from three earthquake records (Imperial Valley, El Alamo, Northern Calif.)

RESULTS AND CONCLUSION

After modeling and conducting finite element analyses, the following results were obtained in this study:

- Based on the comparison of the moment generated at the base of the column (model without damper) and (model with damper), it was observed that placing the damper in the concrete storage tanks reduces the moment at the base of the structure by 31%.
- Regarding the comparison of the axial force generated at the base of the column (model without damper) and (model with damper), it was observed that placing the damper in the concrete storage tank results in a 92% reduction in the axial force at the base of the column due to earthquake forces.
- In terms of the comparison of the stress generated in the tank body (model without damper) and (model with damper), it was found that the inclusion of the damper leads to a 91% reduction in the stress developed in the structure.
- Regarding the comparison of the strain generated at the base of the column (model without damper) and (model with damper), it was observed that placing the damper in the elevated concrete tank results in a 14% reduction in the strain developed in the structure.

From the finite element analysis results of the structure model (SMA model with materials) compared to the structure model without materials (SMA model), it was concluded that the load-bearing capacity of the structure will increase by approximately 17-32%.

After conducting the seismic analysis of the concrete using time history, it was found that the displacement will decrease by about 24% when utilizing the materials.

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