Comparative Study on Single and Double Base Isolated Elevated Water Tanks under Earthquake Load

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Abstract: **Seismic tremors, or earthquakes, can cause structural failures and casualties, impacting socio-economic stability, especially in areas with advanced developments. Elevated water tanks, common in urban areas, are particularly vulnerable to seismic damage. Base isolation, a proven technique for mitigating earthquake effects, can enhance the performance of such structures by reducing seismic energy transmission and shifting the structure's natural frequency away from dominant ground motion frequencies, thereby minimizing damage. The increasing urbanization has led to the widespread construction of elevated water tanks, which are highly susceptible to damage during seismic events. Earthquakes can significantly impact the structural integrity of these tanks, leading to potential failure and social-economic disruptions. To mitigate the seismic risks, Base Isolation is a proven technique that can effectively reduce the harmful effects of earthquakes on structures.**

This study evaluates the performance of a double base isolated elevated water tank (Intze tank) under both far-field and near-field earthquake scenarios. In this design, isolators are installed both at the base and at the mid-stage of the staging, enhancing the tank's ability to withstand seismic forces. The seismic responses of the double base isolated tank are compared to those of a single base isolated tank (with an isolator only at the base) and a fixed base tank (without isolation). The results demonstrate the advantages of double base isolation in reducing seismic responses, thereby improving the structural performance of elevated water tanks during earthquakes.

Keywords: **Seismic Isolation, Elevated Water Tank, Base Isolation, Earthquake Performance, Double Base Isolation, Intze Tank, Seismic Responses, Structural Integrity.**

I. INTRODUCTION

Seismic activity, commonly referred to as earthquakes, involves ground movements that can lead to structural failures and casualties. These movements generate energy released as primary and secondary waves, which transmit vibrations to structures through their foundations. Depending on the intensity, these vibrations can cause cracks, settlements, and damage. A structure's ability to deform and return to its original shape is called its elastic limit. If deformation exceeds this limit, cracks form, though ductility can mitigate severe damage. Increased ductility reduces damage by enhancing structural resilience, albeit with higher costs.

Seismic design focuses on life safety and structural stability. Early approaches emphasized rigid and robust constructions, but these often led to brittle, sudden failures. Modern seismic engineering prioritizes damping, redundancy, ductility, and energy dissipation, incorporating advancements like seismic isolation systems.

The Boston Molasses Disaster of 1919, caused by poor tank design and construction, highlighted the risks of structural failure, with inadequate testing and weak materials leading to catastrophic outcomes. Similar failures have occurred due to faulty welding and substandard materials. Storage tanks, especially those holding flammable substances, pose additional hazards when empty due to combustible atmospheres. Seismic isolation, particularly base isolation, is a key strategy for protecting structures like hospitals and emergency facilities, reducing seismic loads and preserving functionality. While technologies like base isolation and dynamic vibration control are improving, challenges remain in adapting devices for certain seismic waves and ensuring cost-effective reliability, with future innovations expected to enhance structural safety and occupant comfort.

Base isolation, a widely used passive control technique, decouples a structure from ground motion by installing isolators at the base, between the foundation and superstructure. This method minimizes the transfer of seismic energy to the structure. A perfectly rigid structure would move identically to the ground, experiencing the same acceleration. Conversely, a perfectly flexible structure would remain stationary while the ground moves, experiencing no acceleration. Base isolation aims to balance these extremes, reducing structural response and damage during earthquakes.

II. LITERATURE REVIEW

Rohan G. Raikar et al. (2024) investigated the use of X-plate dampers to mitigate vibrations and structural damage to water tanks under blast-induced ground motions. Nonlinear time history analysis evaluated tanks of 50 m³ and 1500 m³ capacities with and without dampers. The X-bracing pattern proved most effective for the 50 m³ tank, while K-bracing was optimal for the 1500 m³ tank, significantly reducing displacement, shear force, and bending moment. The research highlighted the effectiveness of X-plate dampers and bracing configurations in enhancing the resilience of elevated water tanks. Sudhanshu Bhatt and Ramanuj Jaldhari (2024) studied on seismic performance of circular elevated water tanks was analyzed using STAAD Pro, focusing on soil types, water levels, and bracing configurations. Experimental design revealed that soil compliance, water content, and bracing systems significantly impacted base shear, displacement, and overturning moment. The study emphasized the importance of advanced seismic design strategies for elevated water tanks, given their unique vulnerabilities due to concentrated top mass and slender supports. Krishna Kumar Kori & Ankita Singhai (2024) explored various systems like dampers, base isolators, and shear walls for dissipating seismic energy, emphasizing strategic placement for improved efficiency. A detailed literature review highlighted the performance of these systems under earthquake conditions, analyzing their interactions with seismic forces. The study offered insights into optimizing structural designs, focusing on enhancing the seismic resistance of buildings and elevated water tanks through advanced energy dissipation methods. Gino Baby & Glory Joseph (2024) assessed the seismic performance of elevated water tanks using lead rubber bearing (LRB) isolators to mitigate seismic impacts. Nonlinear time history analysis in SAP2000 compared fixed base and base-isolated tanks under distinct ground motions. LRB isolators reduced base shear, displacement, and other structural responses by 75–95%, demonstrating their effectiveness in enhancing the seismic resilience of tanks in earthquake-prone areas. Mayank Singh Suryavanshi & Priyanka Dubey (2023) examined the seismic behavior of Intz water tanks with and without base isolation, employing manual design and SAP2000 modeling. Triple friction pendulum isolators were introduced for seismic zone V, reducing deflection and base shear significantly compared to fixed-base designs. The study concluded that triple friction pendulum isolators are highly effective for seismic protection in high-risk zones. M. V. Waghmare et al. (2022) investigated on the seismic behavior of RC elevated water tanks was evaluated using numerical modeling, considering multi-degree freedom systems for staging and two-mass systems for tank-liquid interaction. Nonlinear analysis revealed higher displacement and velocity at the convective level, especially for tanks with higher aspect ratios. The study emphasized the importance of nonlinear analysis over linear methods for accurate seismic performance assessments. Dr. S. B. Borghate & Mayank Kale (2022), in this study a Sheet Molding Compound (SMC) Panel water tank was designed and analyzed under various wind and seismic zones using SAP2000. The tank's performance was assessed under different load combinations, and lateral loads were compared. Static analysis was performed due to the structure's frequency exceeding 1 Hz, and the design adhered to Indian standards. The study provided insights into structural behavior under combined wind and seismic forces. Sanket Nimbekar et al. (2021) studied on seismic performance of elevated water tanks was evaluated using SAP2000, focusing on Zone IV. Base isolation effectively reduced forces acting on the tanks during seismic events, enhancing resilience. The study emphasized the importance of incorporating base isolation systems to mitigate earthquake-induced damage to critical infrastructure. Mor Vyankatesh K. & More Varsha T. (2017) compared the seismic performance of elevated water tanks with framed staging and concrete shaft supports. Tanks on concrete shafts experienced higher base shear and moments, posing greater risks in high seismic zones. The research highlighted the importance of structural configurations and dynamic analysis for optimal design. Ankush N. Asati & Dr. Mahendra S. Kadu (2016), seismic behavior of circular water tanks with various staging arrangements was analyzed.

Radial configurations with six staging levels were found most effective, and full tank conditions proved more critical than empty ones. The study emphasized the significance of staging configurations in enhancing seismic resilience. Mayur S. Khandve & Manisha V. Waghmare (2015) examined the performance of elevated water tanks with Roll-N-Cage (RNC) isolators using real earthquake data. RNC isolators effectively reduced seismic responses for both slender and broad tanks, highlighting their potential for improving resilience in seismic zones. Prasad S. Barve & Ruchi P. Barve (2015) investigated the impact of height-to-diameter (h/d) ratios on the seismic behavior of Intz tanks. Higher h/d ratios increased impulsive fluid pressure, base shear, and moments. The findings underscored the importance of selecting optimal h/d ratios for tank design. Dr. R. S. Talikoti & Mr. Vinod R. Thorat (2014) studied on effectiveness of base isolation systems and cross-bracing was analyzed for multistoried buildings. Base isolation significantly reduced seismic forces compared to non-isolated designs, demonstrating its potential for enhancing structural resilience during earthquakes.

III. METHODOLOGY

For this study purpose a water tank is designed with different model and analyzed in SAP.

Model 1 Fix base structure

Model 2 Base isolated structure in which base of the structure is isolated with the help of one link joint isolators

Model 3 Double isolated structure in which base is isolated with one link joint isolator and at the level of staging, isolation is done by two link joints.

Table 1 Design Data of Tank

Design Data	Specification
Desired Capacity of tank	442.84m^3
Height of FSL from top of foundation beam	26 m
Grade of Concrete used	M-25 (Foundation)&M-30 (For container)
Grade of Steel used	Fe 415
Safe bearing capacity of soil	100 kN/m^2
Seismic Zone	III

Table 2 Dimension of Intze Type Tank

Intze Type Tank Component	Dimensions(m)
Top Diameter of Tank (D)	10
Bottom Diameter of Tank (D_1)	6
Outer Diameter of cylindrical Shaft (D_2)	1.5
Rise of Top dome (h_0)	2
Rise of Conical Dome (h_1)	2
Rise of Bottom Dome (h_2)	1.5
Height of cylindrical Shaft (h_3)	5

Table 3 Dimensions of Staging

Components	Dimensions(mm)
Size of columns	600 × 600
Size of beams	400 × 600
Size of foundation beam	500 × 700
Size of ring beam	150 × 150
Size of bracing	400 × 600
Upper slab thickness	100
Side wall thickness	200

IV. RESULTS AND DISCUSSION

The figures in this section illustrate the comparative seismic responses of elevated water tanks under different base configurations: fixed-base (without isolators), single base isolation, and double base isolation. These comparisons evaluate parameters such as maximum story displacement, shear, and drift to determine the effectiveness of isolation techniques in enhancing seismic performance.

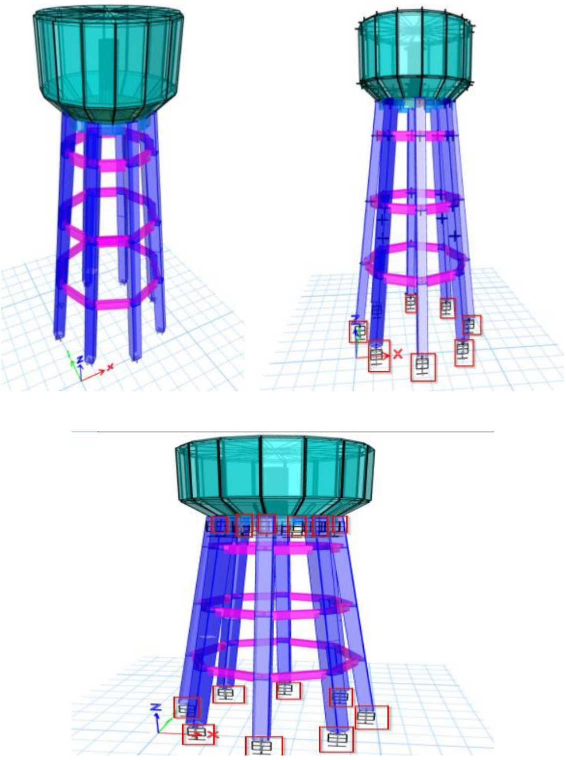
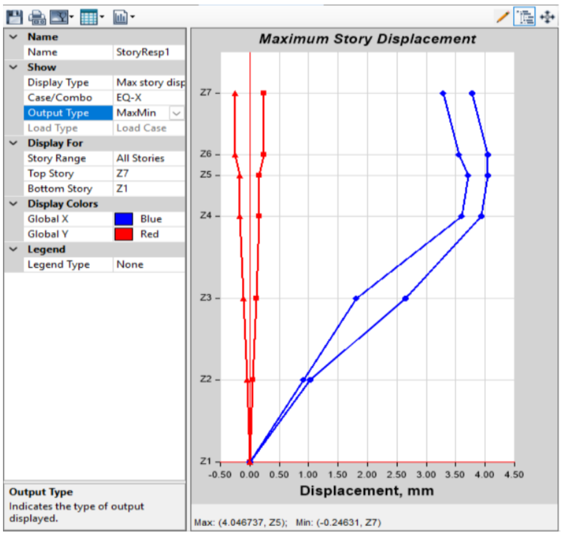


Fig. 1 (a) Without Base Isolator (b) Single Isolated Structure (c) Double Isolated Structure



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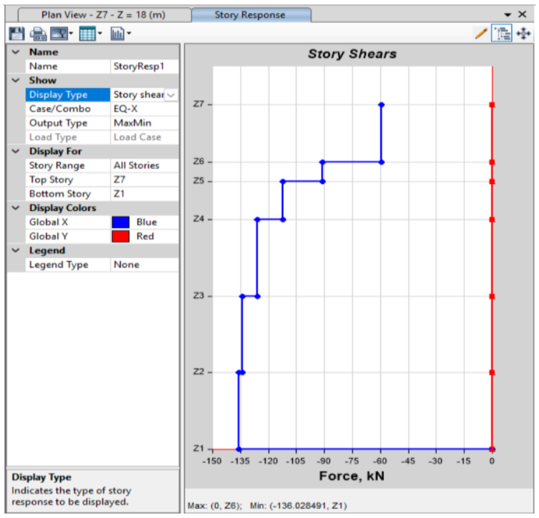
Show	
Display Type	Max story disp
Case/Combo	EQ-X
Output Type	MaxMin
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Z7
Bottom Story	Z1
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Output Type
Indicates the type of output displayed.

Max: (4.046737, Z5); Min: (-0.24631, Z7)

Fig. 2 Max Story Displacement without Isolators



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Show	
Display Type	Story shear
Case/Combo	EQ-X
Output Type	MaxMin
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Z7
Bottom Story	Z1
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
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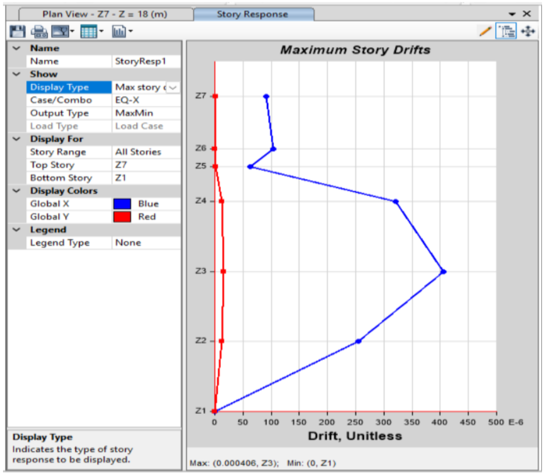
Max: (0, Z6); Min: (-136.028491, Z1)

Fig. 3 Max Story Shear without Isolator



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Load Type	Load Case
Display For	
Story Range	All Stories
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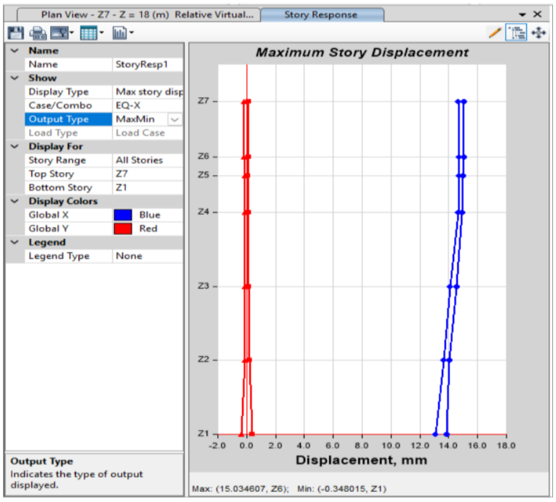
Bottom Story	Z1
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
Indicates the type of story response to be displayed.

Max: (0.000406, Z3); Min: (0, Z1)

Fig. 4 Maximum Story Drift without Isolators



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Show	
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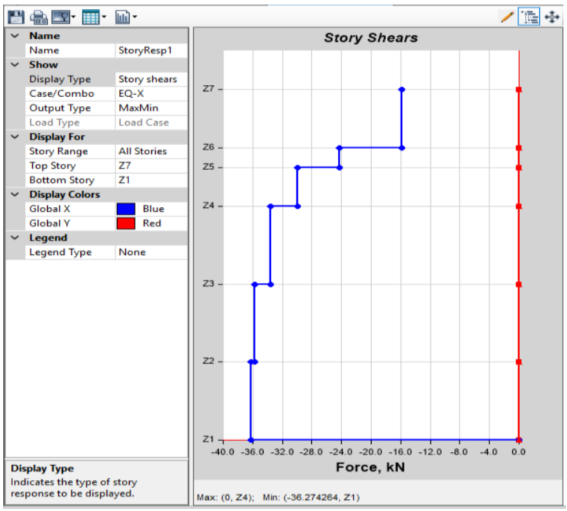
Case/Combo	EQ-X
Output Type	MaxMin
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Z7
Bottom Story	Z1
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Output Type
Indicates the type of output displayed.

Max: (15.034607, Z6); Min: (-0.348015, Z1)

Fig. 5 Max Story Displacement with Single Isolator



Name	
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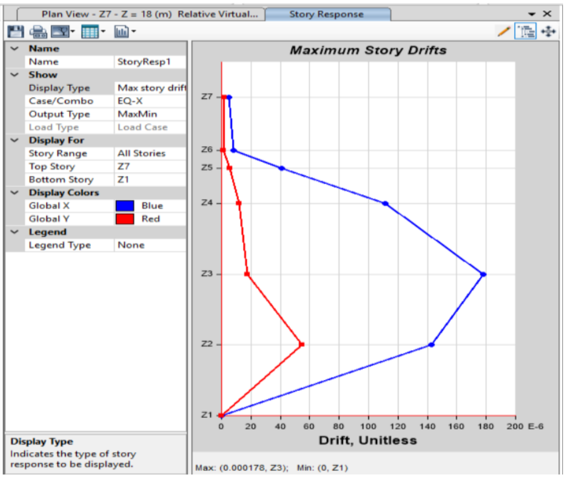
Case/Combo	EQ-X
Output Type	MaxMin
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Z7
Bottom Story	Z1
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
Indicates the type of story response to be displayed.

Max: (0, Z4); Min: (-36.274264, Z1)

Fig. 6 Max Story Shear with Single Base Isolator



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Case/Combo	EQ-X
Output Type	MaxMin
Load Type	Load Case
Display For	
Story Range	All Stories
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Bottom Story	Z1
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
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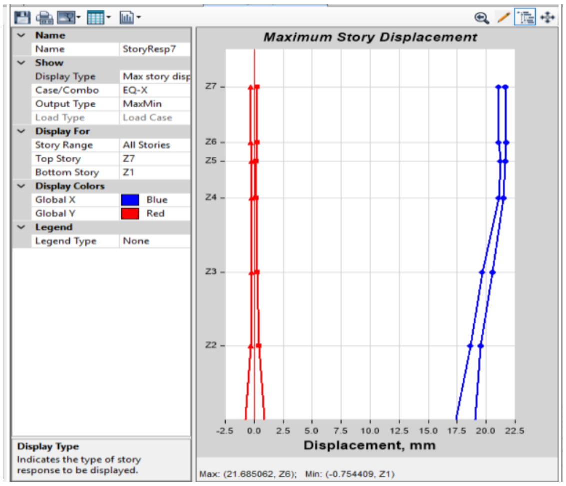
Max: (0.000178, Z3); Min: (0, Z1)

Fig. 7 Max Story Drift with Single Base Isolator



Name	
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Display Type	Max story disp
Case/Combo	EQ-X
Output Type	MaxMin
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Z7
Bottom Story	Z1
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
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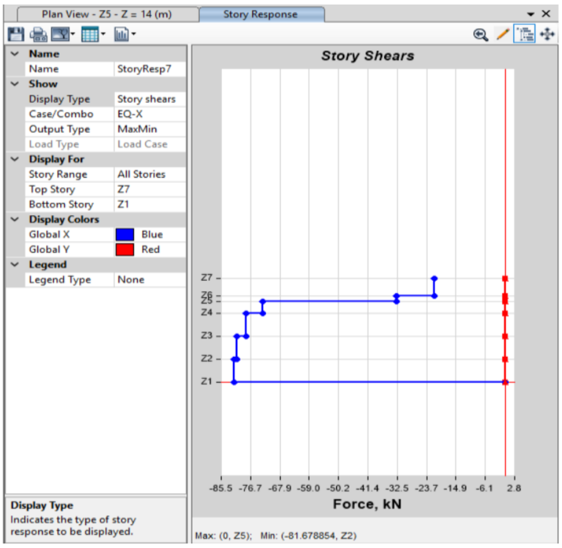
Max: (21.685062, Z6); Min: (-0.754409, Z1)

Fig. 8 Max Story Displacement with Double Isolator



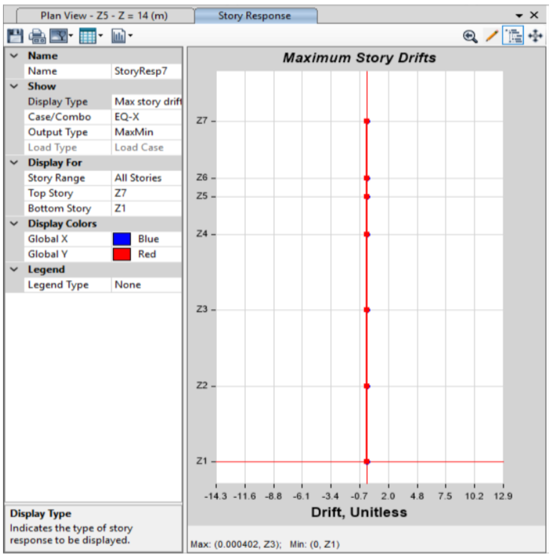
Plan View - Z5 - Z = 14 (m) | Story Response

Name	
Name	StoryResp7
Show	
Display Type	Story shears
Case/Combo	EQ-X
Output Type	MaxMin
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Z7
Bottom Story	Z1
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
Indicates the type of story response to be displayed.

Max: (0, Z5); Min: (-81.678854, Z2)

Fig. 9 Max Story Shear with Double Isolator



Plan View - Z5 - Z = 14 (m) | Story Response

Name	
Name	StoryResp7
Show	
Display Type	Max story drift
Case/Combo	EQ-X
Output Type	MaxMin
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Z7
Bottom Story	Z1
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
Indicates the type of story response to be displayed.

Max: (0.000402, Z3); Min: (0, Z1)

Fig. 10 Max Story Drift with Double Isolator

V. CONCLUSIONS

The comparative analysis of the seismic responses of elevated water tanks under different base isolation scenarios, corresponding to without, single and double base isolators. Here are the inferred conclusions for each model.

Model 1 Without Isolators

- Max Story Displacement: The elevated water tank experiences significant story displacement under seismic loads without any isolators, indicating the vulnerability of fixed-base designs to earthquake effects.
- Max Story Shear: Story shear values are considerably high for the tank without isolators, showing increased stress and potential risk of structural failure under seismic conditions.
- Maximum Story Drift: The absence of isolators leads to substantial story drift, reflecting greater deformation and higher susceptibility to damage during earthquakes.

Model 2 Single Base Isolator

- Max Story Displacement: Introducing a single base isolator reduces the maximum story displacement compared to the fixed-base design, demonstrating improved seismic performance.
- Max Story Shear: The implementation of a single base isolator leads to a noticeable decrease in story shear, reducing the stress on the structure and enhancing stability.
- Max Story Drift: With a single isolator, story drift is significantly mitigated, indicating lower deformation and better structural resilience.

Model 3 Double Base Isolator

- Max Story Displacement: A double base isolation system achieves the lowest story displacement among all configurations, how casing its superior ability to manage seismic forces.
- Max Story Shear: The story shear values are minimized with double isolation, further highlighting the advantages of this configuration in reducing seismic stresses.
- Max Story Drift: Double base isolation exhibits the least story drift, confirming its effectiveness in controlling structural deformation and enhancing earthquake resistance.

Overall, the study concludes that double base isolation significantly improves the seismic performance of elevated water tanks compared to single base isolation and fixed-base configurations.

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