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Seismic Performance of an Elevated Water Tank by Employing Fluid Viscous Dampers Considering Hydrodynamic Effect

Shraddha Bhattarai[1*] and Rajan Suwal[2]

[1]Mid-West University, Surkhet, Karnali, Nepal
[2] Institute of Engineering, Pulchowk Campus, Pulchowk, Lalitpur, Nepal

* Author to whom correspondence should be addressed; E-Mail: *ersrda7@gmail.com*

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Abstract

For water supply and storage systems, elevated water tanks are essential infrastructure. They can be the only source of water in times of emergency, so it is imperative that they keep functioning. With a huge mass at the top of slender columns, they act like an inverted pendulum. The design of the elevated water tank is compromised because, in most cases, designers only take consideration of the hydrostatic effect of water, ignoring the hydrodynamic effect. Thus, the hydrodynamic effect of water has been considered in this study. This study examines three different stagings for a rectangular tank with a 4 m water tank height and a 3 m staging height: 6, 9, and 12 for empty and full tank situations. The fluid viscous dampers (FVDs) in the tank are also considered in this study. FVD is a device that absorbs seismic vibrations. They can be utilized for both the retrofit as well as the new design. ETABs 2020 have been used in the analysis to ensure the tank's seismic performance. The study shows that base shear, modal mass participation, story displacement, inter-story drift, and damping all improved when FVDs were installed.

Keywords

Elevated Tank, Hydrodynamic effect, Dampers, Seismic performance, ETABs

1. Introduction

Nepal is in constant threat of an earthquake due to its positioning, which is above the Indian and Eurasian plates, where the Indian plate is moving towards the north and colliding with the Eurasian plate [1]. An earthquake causes a sudden release of energy, which generates seismic waves that travel to the earth's surface. It causes a halt in the development process and can even put the development in reverse gear[2]. Elevated tanks are strategically significant lifeline structures used for water distribution and storage. During time of crisis, elevated water tank may be the sole source of water, so it needs to function continuously. Elevated tanks are considered essential in the event of an earthquake because of the massive mass concentrated at the top of the slender columns, which act as an inverted pendulum. During an earthquake, lateral forces cause a sloshing effect inside the tank, which yields additional forces. Thus, proper modelling and analysis of water tanks considering hydrodynamic effects is essential. In practice, it has been found that designers only consider the hydrostatic effect of water, neglecting the hydrodynamic effect which causes sloshing.

Codes available have more emphasis on ground structures and are limited to elevated water tanks [3].

Around the globe, failures of water tanks during or after earthquakes are suspected to have resulted from many reasons; for instance, dynamic buckling caused by overturning moments of seismically induced water inertia and surface slosh waves, additionally due to unsuitable design of supporting systems, wrong choice of supporting structures, and underestimated demand and overestimated strength [4]. Figure 1 shows the failure of a rectangular elevated tank.

Figure 1: Collapsed Slender and Weak Framed Stagings of Water Tanks in Manfera Village [5]

Dampers are the devices that absorb the seismic energy and reduce the deformation of structures during ground motions [6]. Among various passive energy dissipating devices Fluid viscous dampers (FVDs) are more widely used in buildings. FVDs enhance the performance of the structures. Figure 2 shows the damper in mid-stoke position.

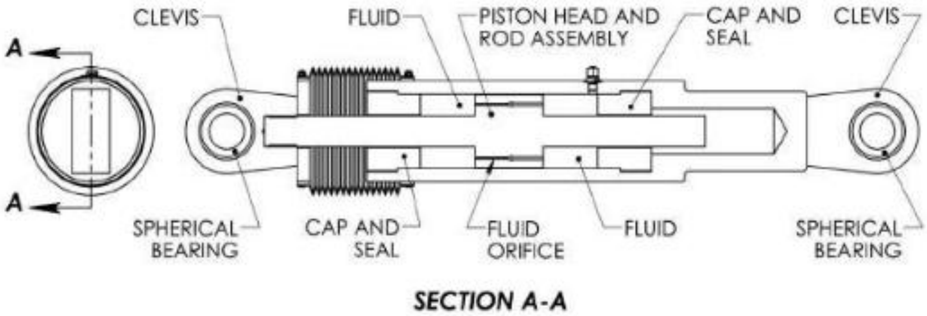


Figure 2: Typical Fluid Damper and parts [7]

Damper can be used in both new construction and retrofit work. It reduces amount of damage earthquake causes to the structure which prevents injuries. It makes a structure cost effective, as it lowers amount of steel structure needed and makes the structure more resilient to future earthquake [8]. Fluid viscous damper absorbs seismic energy and reduces the deformation of the structure, protecting the structure integrity and controlling the structural damage [9] .

The use of Fluid Viscous Dampers (FVD) in civil engineering is done to improve seismic protection in buildings. This study analyzes structural response with and without FVD for low and high-rise structures, with a focus on damper installation and damping coefficient (C_d). The study indicates FVD's potential to improve dissipative properties without increasing stiffness. FVD at alternate story for both high- and low-rise building showed good results compared to installed at every story [7]. A study of a 15-story steel frame using non-linear dynamic ground acceleration using ETABS software revealed that using friction dampers reduced story displacement by 25.52%, whereas fluid viscous dampers reduced story shear, drift, and acceleration by 27.75%, 30.39%, and 15.27%, respectively. These findings emphasize the necessity of passive energy dissipation in earthquake-resistant constructions [10]. A study that focused on analyzing seismic behavior of buildings with dampers using Cheerapunji earthquake acceleration data. The study evaluates seismic responses such as displacement, story drift, and modal parameters, where 3 different buildings G+5, G+10, G+15 were analyzed with time history analysis which dampers as rigid links. With installation of damper better seismic performance is obtained, dampers are efficient and better in energy dissipation. They significantly increase stability without increasing stiffness of structure [11].

Dampers are essential for controlling vibration during earthquakes, with different types and layouts influencing their behavior. This study looks into the application of fluid viscous dampers (FVD) in a G+19-story high-rise RC construction. The study uses ETABS software to calculate seismic responses, drift, base shear, and energy dissipation. The results show that models with dampers had greater drift than permitted limits, and the software proposes positions with 80 dampers for the best benefit in terms of drift, energy dissipation, and cost [6]. The usage of Fluid Viscous Dampers (FVDs) in structural engineering and compares their performance to four bracing system layouts as chevron bracing, diagonal bracing, toggle bracing and X-bracing. Nonlinear analysis is performed using SAP2000. The study found that FVD can greatly minimize earthquake motion by modifying structural characteristics such as inter-story drift. The chevron model was most effective in high-rise buildings, with link dampers absorbing 66%, 72%, and 79% of input energy, respectively. The study emphasizes the application of FVD in a variety of industries, including military, aerospace, and building structures [12].

1.1 Significance and Rationale of Research

The Gorkha earthquake of 2015 with 7.8 magnitude has highlighted Nepal's vulnerability to seismic hazard. It caused widespread damage and destruction where it killed thousands of people and caused a significant damage to infrastructures structures. Nepal is in constant threat of earthquake due to its position and the tectonic plate movement. The occurrence of earthquake is pretty frequent and we can even expect a large earthquake in future, thus seismic resilience is vital. Earthquake causes a halt in the development process or even puts it into a reverse gear [2]. As we all know by now that an earthquake is an unpredictable phenomenon which has caused major loss in human and economic life which is well observed in past, thus it is very important to have the seismic resilience to protect ourselves as well as the buildings and infrastructure that we have created for the ease of the people. When a building or a structure or a bridge fails, it not only causes harm both the economy of the country and people. As we have seen on 2015 Gorkha earthquake, many people have died due to collapse of buildings and structures. A prime example is Dharahara where people were present at the time of the occurrence of earthquake and they got buried as the structure collapsed. The life safety is a very important factor to be considered while designing a structure. Elevated tanks are one of a very critical structure that are vulnerable to earthquake forces. Elevated tanks are subjected to dynamic water pressure during the ground motion which is usually not incorporated by the designer on design which also have the significant effect. We can see Intze tank and circular tank mostly constructed but not the rectangular tank. During past earthquake, shaft supporting tanks were collapsed, mostly lacking the requirement to meet earthquake resistance, while frame staging performed the better, but there is still record of failure of few frames staging supported water tank, thus incorporating a viscous damper which absorbs the seismic energy can be beneficial. The main objective of this research is to find out the performance of water tank after incorporating fluid viscous damper for which the following sub objectives are set: i) To evaluate the seismic performance of an elevated water tank with and without fluid viscous damper ii) To evaluate the performance of an elevated water tank by considering hydrodynamic behavior of water during strong ground motions. This study focuses on reinforced concrete elevated rectangular water tanks. A finite element model was developed using ETABS, and the analysis was conducted based on the NBC and IS codes, considering commonly used water tank dimensions. However, there are several limitations to this research. Soil-structure interaction effects were not considered. The study is limited to reinforced concrete frame staging rectangular elevated water tanks. Secondary effects, such as temperature variations, creep, and shrinkage, were excluded from the analysis. Additionally, staircase loads and vertical ground motion were not accounted for in this study.

2. Methodology, modelling and analysis

Careful steps were taken to examine the seismic performance of elevated water tanks, utilizing numerical modelling to analyse the structural response and deformation behaviour of the tanks. The process began with problem identification following a thorough literature review. A rectangular water tank was modelled in ETABS 2020 software for three different staging cases—6, 9, and 12 stagings—under both empty and full tank conditions. Linear and non-linear time history analyses were performed, incorporating hydrostatic and hydrodynamic effects of water. Ground motion was selected and matched with the target spectrum using spectral matching and scaling as per NBC 105:2020. Models with and without fluid viscous dampers (FVDs) were analysed to evaluate their impact. The seismic structural response and deformation parameters of the tank were compared for different staging configurations, water conditions, and water effects. Finally, the results were interpreted, and conclusions were drawn based on the findings.

2.1 Configurations and Characteristics of Elevated Water Tank

3 different staging cases with each staging height of 3 m were modelled, the structural elements of which are indicated in Table 1. Each tank has 8 rectangular columns. Analysis was performed on ETABs 2020, considering codes such as NBC105:2020, IS 456:2000, IS 1893:2016 Part II, and IS 3370: Part II. The non-linear time history analysis with selected sub-duction zone earthquakes is employed considering the target spectrum of soil type D (very soft) and spectral matching procedures prescribed by codes. Sizing of primary elements and tanks are illustrated in Table 1 and Table 2 respectively. The FVDs used in this study are tabulated in Table 3, which is adopted from Taylor Devices Inc. Figure 3 shows the

plan of the base slab of the water tank, while Figures 4 and 5 illustrate the elevation and 3D view, respectively, of a 12-staging elevated water tank with Fluid Viscous Dampers (FVD).

Table 1: Dimension of Primary Structural Members

Description	3m Staging Height		
	6 Staging	9 Staging	12 Staging
Column (mm*mm)	800*800	1000*1000	1200*1200
Beam (mm*mm)	550*700	600*800	700*900
Secondary Beam (mm*mm)	400*550	400*550	400*550

Table 2: Description of Tank Vessel

Dimension of Tank	12m*12m
Bottom Slab Thickness	200mm
Top Slab Thickness	100mm
Rectangular Wall Thickness	250mm
Height of Tank	4m

Table 3: Description of FVD

Description	Value
Model Number	17180
Force	3000 kN
Weight	701 kg

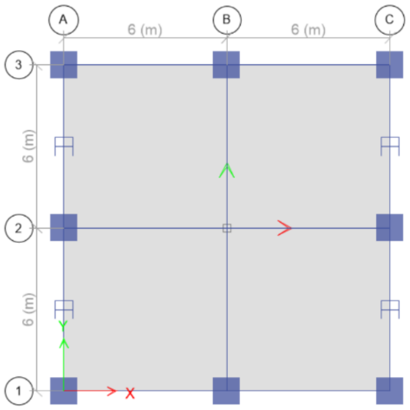


Figure 3: Plan of Base Slab of Water Tank

2.2 Modelling Assumptions and Procedures

The following modelling assumptions and procedure are undertaken to prepare finite element model and for structural analysis using nonlinear time history analysis.

i) The elevated water tank of 3 different stagings, for example 6 stagings, 9 stagings and 12 stagings are modelled using finite element software (ETABS 2020) assuming the base of footing is fixed 2.3 meters below ground level with the following description of the tank; Location: Nepal; Seismic Zone: V; Soil type: Medium; Tank type: Rectangular; Staging Configuration: Rectangular; Staging Geometry: Rectangular

ii) Column and Beam modelled as two nodes with 6 degrees of freedom at each node. Whereas, Slab and Walls modelled as thin shell element having 4 nodes and 6 degrees of freedom at each node.

iii) Load due to self-weight and water are modelled as dead load and staircase load is not considered. Water load is considered for 3.45m along the height of wall and 0.55m is for free board.

iv) Earthquake load is considered in both X- direction and Y-direction with the following details: Seismic zone factor (Z) = 0.36 (Very Severe); Site Type = II (Medium Soil); Importance factor (I)= 1.25; Response Reduction (R)= 4

v) Wind Load is wind pressure acting on the structure. IS: 875(Part3): Wind Loads on tank Structures is adopted for the design; Wind speed (Vb) = 47 m/s; Terrain Category = 2; Structure Sub- Class = B; Risk Coefficient (k1 Factor) = 1.07; Topography (k3) = 1

vi) Load of water on slab acts due to gravity which can be calculated as

Load = height of water * density of water

vii) P= AX+BY+Cz+D equation is used to calculate the water pressure on the wall.

viii) Impulsive and Convective pressure of water on wall and base of the tank is calculated IS 1893 (Part 2) and applied as link elements obey the rules mentioned in ETABS technical manual. Different link elements are connected for hydrodynamic effect at various height of tank. For example, impulsive mass and stiffness are provided up to impulsive height of tank along the perimeter of rectangular water tank to resemble impulsive effect of water during excitation using impulsive link elements. Whereas mass of convective portion of water applied at Centre and stiffness is provided at circumferences using convective link elements behaves like dynamic water condition.

ix) Load combination and mass source are defined and formulated using NBC 105:2020 and IS456:2000

x) Damper specification is adopted from Taylor Devices inc. For this research Taylor Devices model number 17180 is incorporated in design. Nonlinear exponential damper as link element applied to the various level of tank in inverted V bracing shape. Force (kN)= 3000 kN; Weight (Kg)= 701 kg

xi) Response spectrum as per NBC 105: 2020 is loaded and scale factor is fixed to match the base shear with equivalent static and then model validated with theoretical period, and response of tank structure comparing with the literature review.

xii) Nonlinear hinges are defined for column (PM2M3) and beam (PM3) in the model with the complete liner design of concrete structure after passing all members according to IS456:2000.

xiii) In this structural engineering research, nonlinear time history analysis (NTHA) is; a thorough technique, used to assess a structure's performance under dynamic loads, including earthquakes. The spectral matching techniques and target spectrum at maximum considered earthquake (MCE) are applied to a structural model with multiple ground motion measurements to evaluate the model's responsiveness over time for taking into consideration the inelastic behavior of materials and structures. To provide a more realistic evaluation of how well a structure performs in real-world situations, the hydrodynamic behavior is applied assuming to occur in devastating ground motion scenarios. Furthermore, NTHA is carried out to turn on FVD so that the response of structures to destructive earthquakes examined.

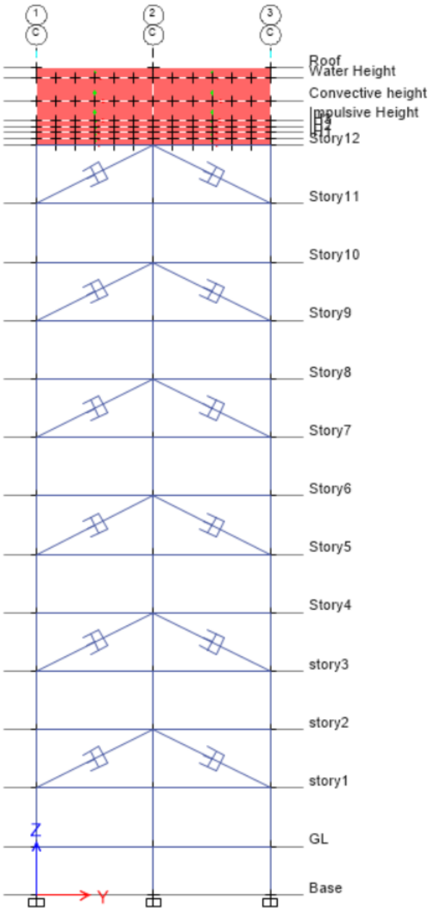


Figure 4: Elevation of 12 Staging Elevated water tank with FVD

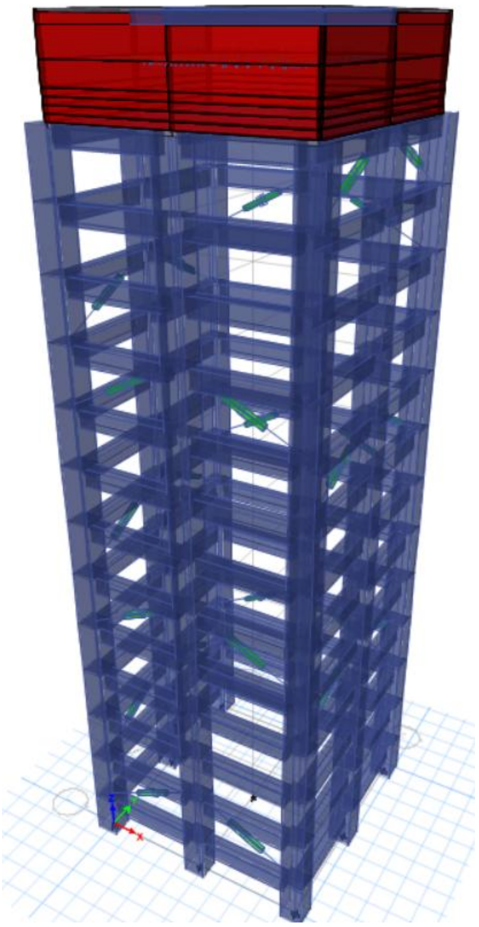


Figure 5: 3-D View of 12 Staging Elevated water tank with FVD

3. Results and discussions

After modelling the tank with proper load application from the codal provisions. Linear and non-linear time history analysis was performed. And then responses of the structures were compared. Out of the 6, 9, and 12 stagings, the 12-staging's outcome is the most significant and essential for proceeding forward with the discussion.

3.1 Maximum Storey Displacement

The maximum storey has been seen in the level of convective height of the tank along the x-direction as 774.3 mm, where the roof slab of the tank is displaced by 762.5 mm. The displacement from convective height to roof slab was due to hydrodynamic behavior of the water during ground excitations. The response reduction ductility factor is assumed to be unity during nonlinear time history analysis. After installation of 24 dampers, the maximum storey level displacement was 631.8 mm and 621.6 mm in the level of convective height and roof slab, respectively. Thus, after incorporating 24 dampers, displacement is reduced by around 17%.

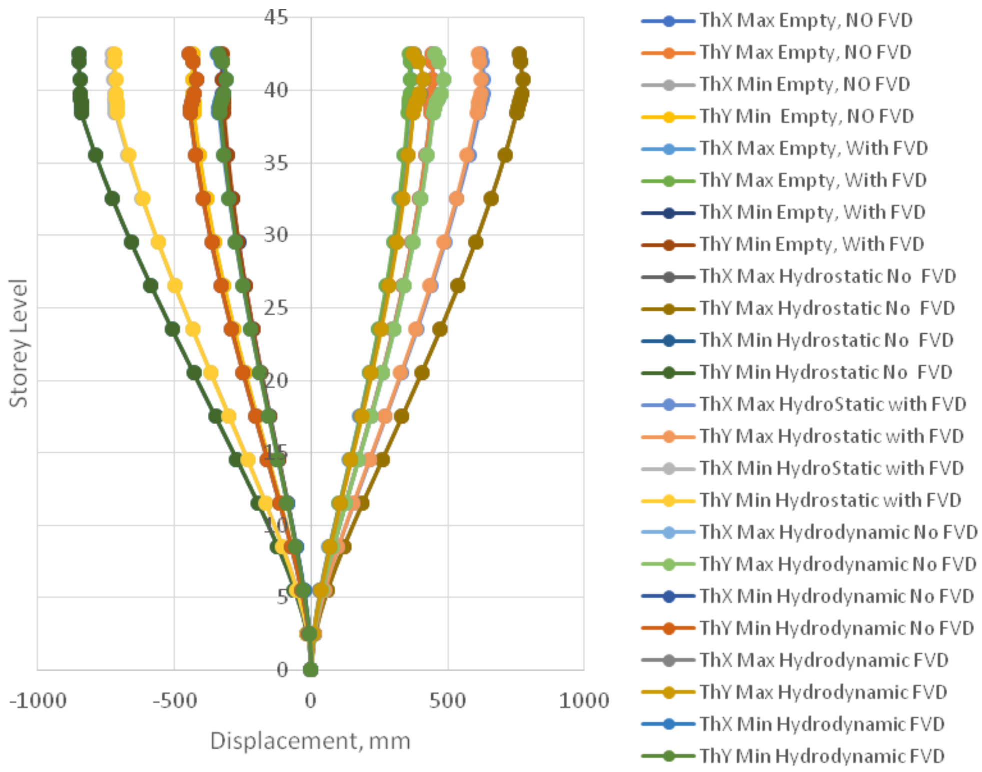


Figure 6 shows the storey displacement response of 12 staging elevated water tanks for 4 Maximum Considered Earthquake (MCE) along the storey level, from which we have abstracted the maximum value and tabulated it on Table 4. Also the storey level displacement of a 12-staging elevated water tank is presented in Table 4.

Table 4: Maximum Story Displacement of 12 staging Elevated Water tank

		Without FVD		With FVD	
Story	Elevation	ThX Max	ThY Max	ThX Max	ThY Max
Roof	42.5	762.5	762.5	621.6	613.5
Water Height	41.95	767.3	767.3	625.7	617.4
Convective height	40.78	774.3	774.3	631.8	623.2
Impulsive Height	39.79	771	771	628.7	620.2
IH3	39.4675	767.8	767.8	626	617.5
IH2	39.145	763.4	763.4	622.3	613.9
IH1	38.8225	758.5	758.5	618.3	610
Story12	38.5	753.5	753.5	614.1	606
Story11	35.5	709.4	709.4	577.3	571.1
Story10	32.5	658	658	535	530.8
Story9	29.5	600.9	600.9	489	485.5
Story8	26.5	539.1	539.1	439.7	435.8
Story7	23.5	473.2	473.2	386.7	383.2
Story6	20.5	404	404	330.5	328.5
Story5	17.5	332.4	332.4	272.6	271.3
Story4	14.5	259.5	259.5	214	212.1
story3	11.5	187.4	187.4	155.2	153.7

story2	8.5	118.8	118.8	98.1	98.5
story1	5.5	58.6	58.6	48.2	49.2
GL	2.5	14.6	14.6	12.2	12.2
Base	0	0	0	0	0

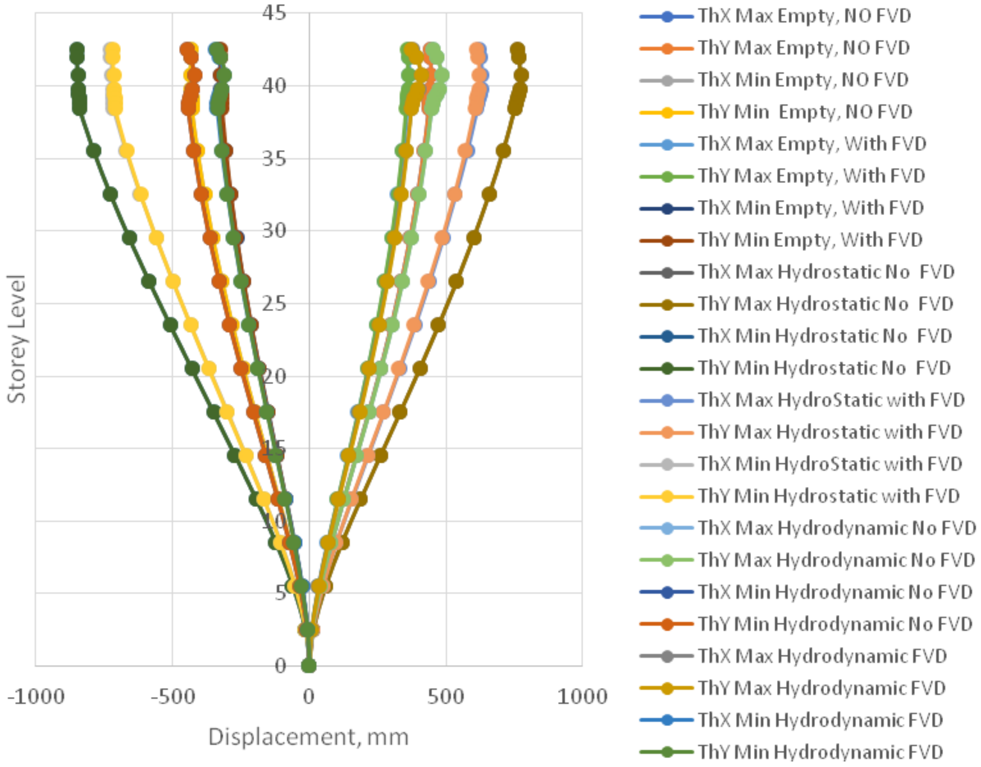


Figure 6: Comparison of Max Storey Displacement of 12 staging under Time History-Various water conditions

3.2 Drift

Incorporation of FVD suggests there is a 12–13% reduction in storey drift. Table 5 illustrates inter-storey drift response of 12-stagings elevated water tank where maximum response has been seen at storey 6 i.e. approximately mid height of the tank as 0.0265 along x and y directions when no dampers were incorporated. After incorporating 24 dampers, this response has reduced to 0.0226 along both directions. At the level of rectangular tank, the drift response has increased at first stage IH1 as 0.0188 and then reduced to 0.0105 at roof level in case of without dampers. This scenario of inter-storey drift is seen due to dynamic behavior of water in the tank.

When only the rectangular tank portion is considered, the maximum inter-storey drift response of the elevated water tank is seen at the bottom of the impulsive effect, and this effect might overturn the tank from the bottom if the height of the tank is increased by more than 5 times the lateral dimensions. For this, anchorage should be provided. But, in this study, the height of the elevated water tank from the ground is less than 5 times the lateral dimension. So, as per the codes IS 1893:2016 Part II and IS 3370: Part II, anchorage at the bottom of the tank is not required.

After incorporating dampers, these trends have decreased by 13% and 10% in the level of IH1 and roof, respectively. While at the level of mid-height of the tank, which is level 6, the inter-storey drift response has decreased by 15.5%.

For purposes of comparison, Figure 7 plots the maximum response story level inter-story drift response of four pairs of bi-directional excitations in accordance with NBC 105:2020 nonlinear time history criteria. In order to assess the performance requirements, structural response, and deformation parameters under seismic action, it represents the maximum response of all these ground motions at the MCE level rather than the actual response of a single or particular earthquake. From which Table 5 indicates the maximum response of inter-storey drift at a particular storey level among 4 bi-directional ground motions.

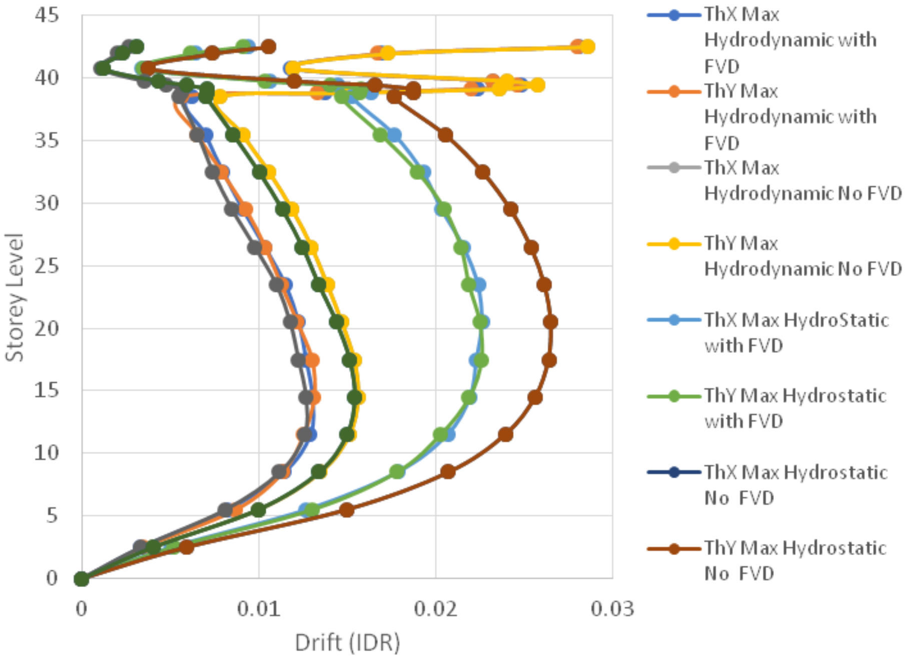


Figure 7: Max Time History Drift Comparison for various water condition of 12 Stagings

Table 5: Drift of 12 staging Elevated water tank Considering Hydrostatic Condition

		Without FVD		With FVD	
Story	Elevation	ThX Max	ThY Max	ThX Max	ThY Max
Roof	42.5	0.0105	0.0105	0.0094	0.0091
Water Height	41.95	0.0074	0.0074	0.0064	0.0062
Convective height	40.78	0.0037	0.0037	0.0034	0.0034
Impulsive Height	39.79	0.012	0.012	0.0106	0.0104
IH3	39.4675	0.0165	0.0165	0.0145	0.0141
IH2	39.145	0.0187	0.0187	0.0163	0.0158
IH1	38.8225	0.0188	0.0188	0.0163	0.0157
Story12	38.5	0.0177	0.0177	0.0153	0.0147
Story11	35.5	0.0205	0.0205	0.0177	0.0169
Story10	32.5	0.0227	0.0227	0.0193	0.019
Story9	29.5	0.0243	0.0243	0.0204	0.0205
Story8	26.5	0.0254	0.0254	0.0216	0.0214
Story7	23.5	0.0262	0.0262	0.0224	0.0219
Story6	20.5	0.0265	0.0265	0.0226	0.0225
Story5	17.5	0.0264	0.0264	0.0223	0.0226
Story4	14.5	0.0256	0.0256	0.022	0.0219
story3	11.5	0.0239	0.0239	0.0207	0.0203

story2	8.5	0.0207	0.0207	0.0178	0.0178
story1	5.5	0.015	0.015	0.0127	0.013
GL	2.5	0.0059	0.0059	0.005	0.0052
Base	0	0	0	0	0

3.3 Base Shear

Results show a 14–17% average reduction in base shear after incorporation of FVD on a water tank only considering the hydrostatic condition. While taking the case without dampers, the maximum base shear has been observed in the X direction for Gorkha-Y direction motion as 27090 KN and reduced to 25123 KN when 24 dampers are incorporated, which is a reduction of 7.2%. Table 6 represents base shear along x and y directions due to the bi-directional earthquake excitation. After considering the 24 dampers, minimum base shear has been recorded as 17769 KN along the y direction due to Loma Pareta, which is 22545 KN in the case of the without dampers condition. The variety of data in Table 6 is due to the frequency content, intensity, depth, and directional characteristics of subduction zone ground motions radially available to the PEER database.

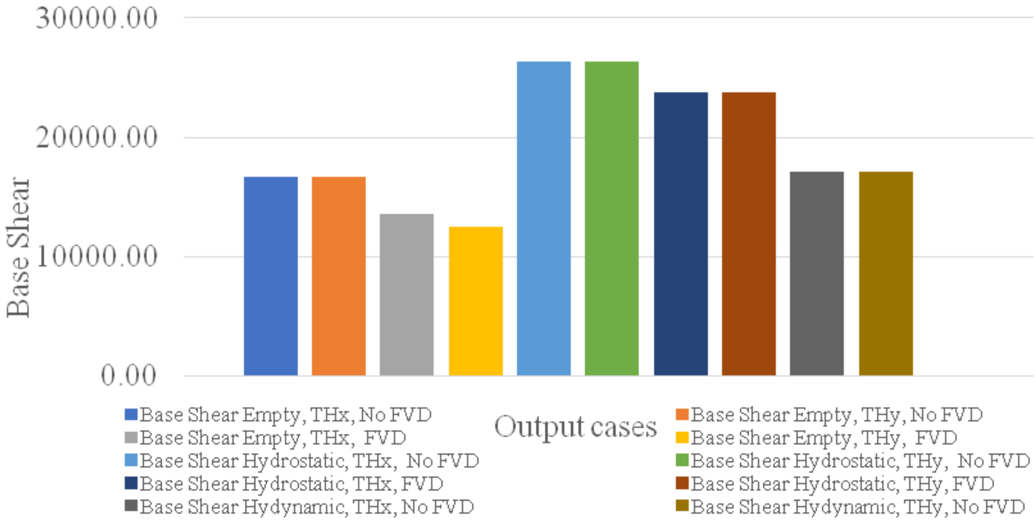


Figure 8 represents the maximum value of base shear response under 4 bi-directional MCE level excitations, from which we have extracted the maximum value of each storey level and tabulated it in Table 6.

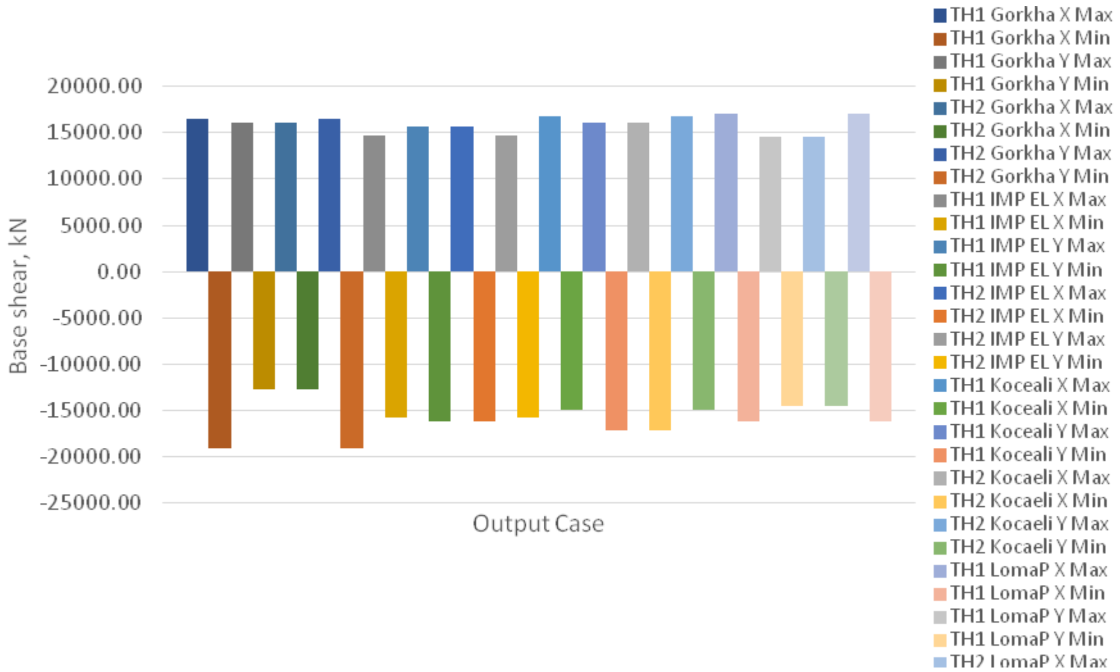


Figure 9 and Figure 10 represent the base shear response of individual earthquakes without FVD and with FVD Case, respectively.

Figure 8 : Base Shear Comparison of 12 Staging 4 Bi-Directional Time History Ground Motions

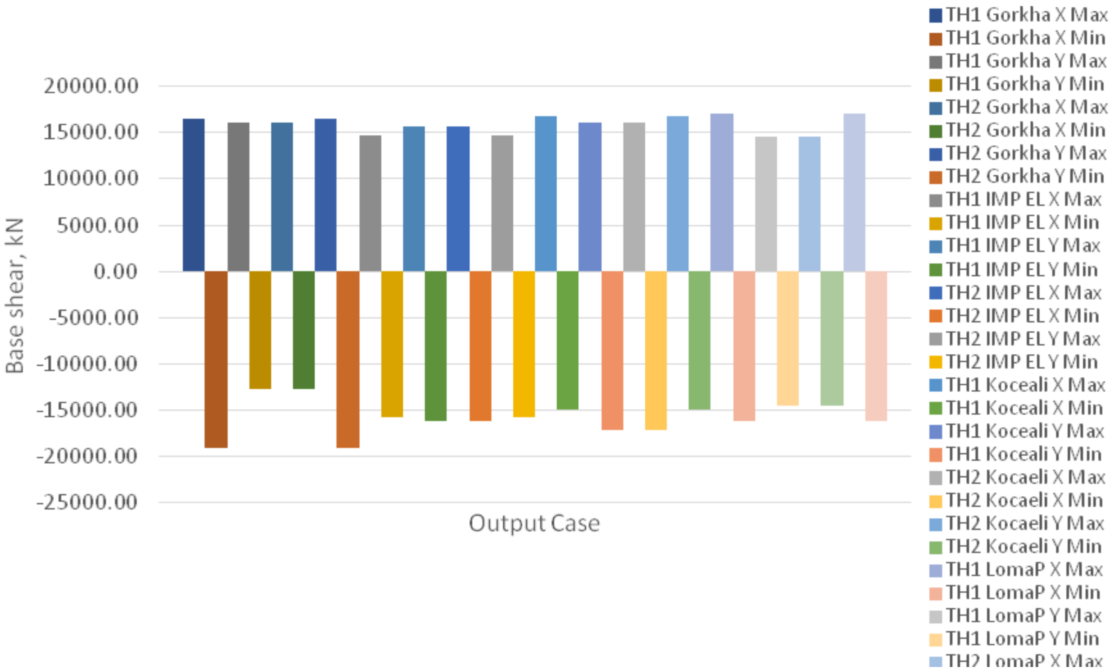


Figure 9 : Base shear of 12 Stagings, Hydrodynamic without FVD

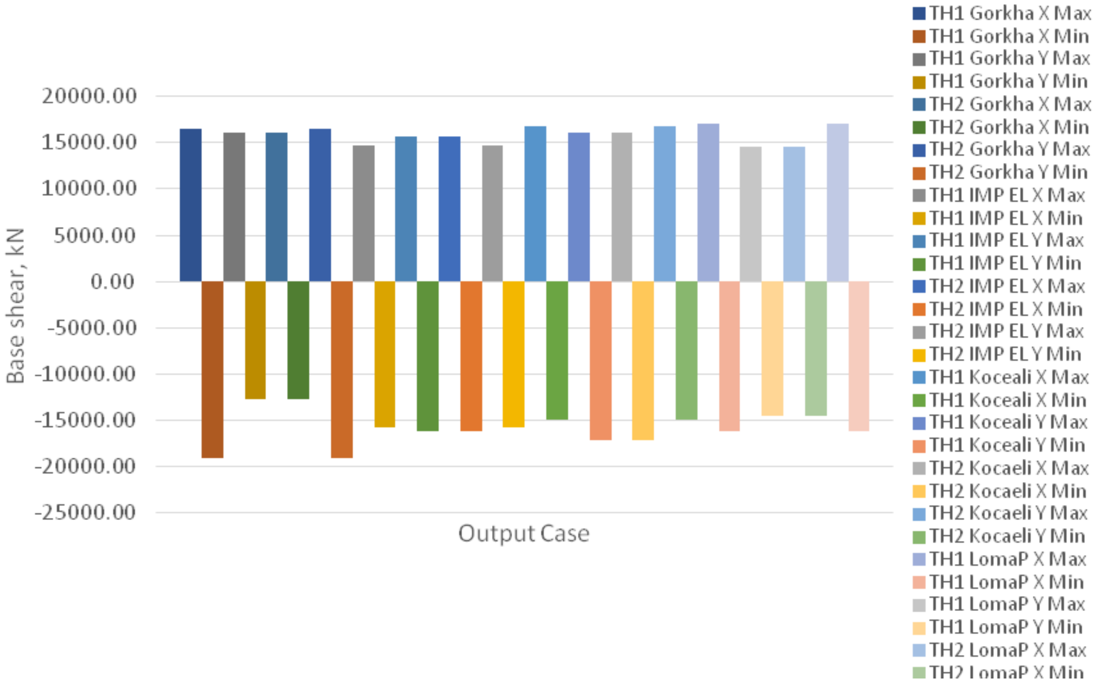


Figure 10 : Base shear of 12 Stagings, Hydrodynamic with FVD

Table 6: Base Shear of 12 staging Elevated water tank Considering Hydrostatic Condition

Ground Motions	FX (kN)	FY (kN)	FX (kN)	FY (kN)
TH1 Gorkha X Max	26029	24858	23607	18889
TH1 Gorkha Y Min	-27090	-21408	-25123	-16807
TH2 Gorkha X Max	24858	26029	21062	20015
TH2 Gorkha Y Min	-21408	-27090	-19140	-21787
TH1 IMP EL X Max	22929	25359	18654	20991
TH1 IMP EL Y Min	-23510	-23407	-18686	-18285

TH1 LomaP X Max	26363	22675	23718	18435
TH1 LomaP Y Min	-23160	-22545	-21474	-17769
TH2 LomaP X Max	22675	26363	18630	23742
TH2 LomaP Y Min	-22545	-23160	-17860	-21487
TH1 Koceali X Max	23195	22985	20828	18644
TH1 Koceali Y Min	-26843	-23288	-22474	-19035
TH2 Kocaeli X Max	22985	23195	18926	20842
TH2 Kocaeli Y Min	-23288	-26843	-19283	-22287
TH2 IMP EL X Max	25359	22929	21231	18460
TH2 IMP EL Y Min	-23407	-23510	-18523	-18528

3.4 Energy Dissipation and Damping

After considering 24 dampers in the elevated water tank, the damping due to FVDs has been seen as maximum in case of hydrodynamic condition of the water tank, which is 15% average damping. This damping reduced to 12.29% in case of hydrostatic conditions, and again increased to 14.95% in the case of an empty water tank, which is illustrated in Table 7. The dynamic behavior of water also contributed to damping and energy dissipation by 2.71%.

Figure 11 represents energy dissipation and damping under a specific earthquake, from which we have taken average energy damping and tabulated it in Table 7.

Figure 12 indicates damping components under the Gorkha earthquake of 2015, where fluid viscous damping has been shown in a sky-blue color.

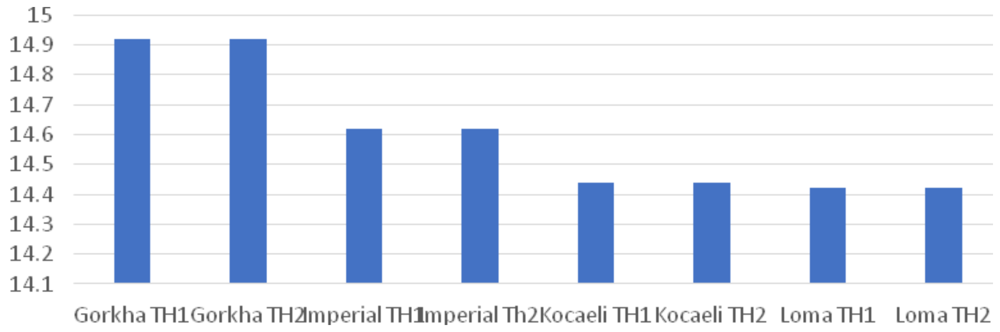
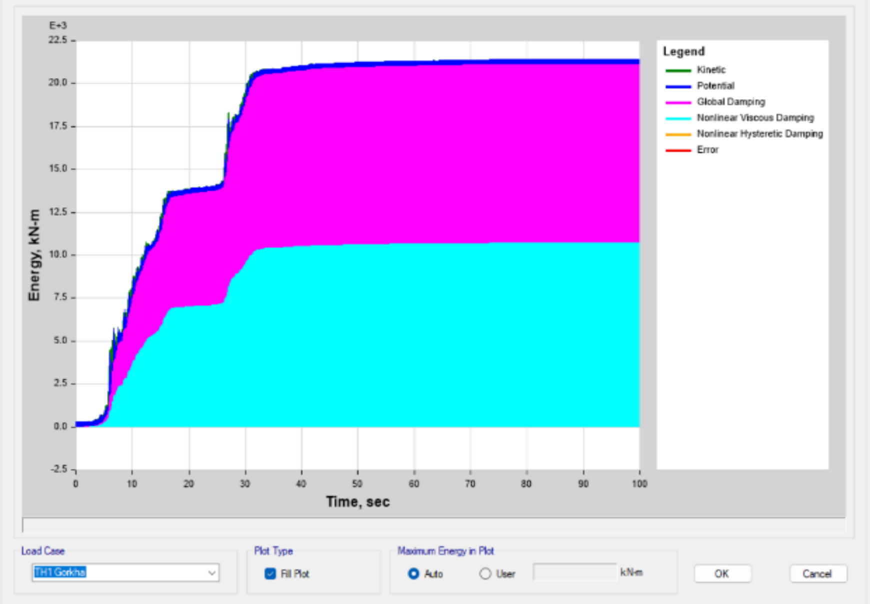


Figure 11: Percentage of Total Damping of 12 staging MCE Level EQ of Hydrodynamic tank

Table 7: Energy Dissipation and Damping of an elevated water tank having 12 stagings

Tank Condition	Total % of Average Damping
Empty	14.95
Hydrostatic	12.29
Hydrodynamic	15



Load Case: TH1 Gorkha

Plot Type: ☑ Fill Plot

Maximum Energy in Plot: ● Auto ○ User kN-m

Figure 12: Energy components of 12 staging Hydrodynamic tank with FVD in MCE level Gorkha EQ

4. Conclusions

Form the observation of result presented above, it can be concluded that Fluid viscous damper installed in the Elevated Water tank reduces following structural responses and support the structure to diminish the vibration of tank.

- The installation of 24 FVDs resulted in a 17% reduction in storey displacement and a 13% reduction in inter-story drift of the elevated water tank. However, this trend varies at the tank level because of hydrodynamic characteristics of water which are impulsive and convective effects.
- The average damping's energy dissipation at the tank has been shown to be 15% when accounting for the dynamic behavior of the water during ground excitation.
- The base shear is influenced by the characteristics of earthquake occurrence such as the Gorkha-Y directional excitation had the highest base shear along the X-direction at the bottom of the water tank, while the Y-directional Loma Parieta ground excitation had the lowest base share along the Y-direction.
- It is recommended to use fluid viscous dampers installed in the elevated water tank to provide water supply services immediately in post disaster settings.

From the results above we can conclude that installation of FVDs enhances the structural performance of elevated water tank. It is recommended that researchers perform pushover analysis to ensure the performance level of an elevated water tank in both with FVD and without FVD scenarios. Also, this study suggests comparing the outcomes of the performance check with the outcomes of nonlinear dynamic time history analysis.

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Conflicts of interest statement

There are no conflicts of interest of authors with any stakeholders in Nepal or outside of the country. The paper assigns the views of the authors only based on information and data presented herein. The contents do not reflect the official views of any authority in Nepal. This paper does not suggest any standard specification or regulation for elevated water tank construction in Nepal that is necessary unless the government enforces regulation.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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