

Seismic Response Improvement of Existing Prototype School Buildings Using Water Tanks, Port Said City, Egypt

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Abstract

There is a global trend for seismic response improvement of new buildings to reduce cost and future damage. It is also important to improve existing structures that are designed without consideration of seismic load or using old provisions that cannot meet the new one. The objective of this paper is to draw attention to evaluate existing reinforced concrete school buildings, then to present a proposed methodology to improve the behaviour of such schools with low cost especially in a developing country. The proposed method uses overhead water tanks as a tuned mass damper. A pushover analysis has been performed to evaluate the existing schools and perform a feasibility study to select the best solution to achieve seismic response improvement of the existing structure. Of course, the proposed methodology can be applied easily to other existing structures.

Keywords

Existing Structures, Tuned Mass damper (TMD), Seismic improvement, Pushover Analysis, Water Tank

1. Introduction

Egypt is a developing country and many buildings are not designed to sustain lateral seismic loads. Moreover, there is no governmental interest to evaluate, upgrade buildings to sustain lateral loads or to check buildings with current Egyptian code for loads.

Schools are considered lifeline structures in Egypt, because of its high occupancy, being used as a shelter in

case of a catastrophic problem, and its importance to keep development in education and future.

After 1992 Dahshour Earthquake, the Egyptian government has established the Governmental Authority for Educational Buildings (GAEB) and released Egyptian code for loads ECP 201-1993 [1]. GAEB has designed schools as prototypes based on the number of classes and the capacity of each class. After the construction of schools, GAEB is interested in repair of non-structural elements, e.g. fences, windows, doors, etc. Moreover, GAEB does not have the authority to evaluate or upgrade of existing schools to sustain current lateral loads from ECP 201-2012 [2] that has been released and approved after ECP 201-1993.

This paper presents an evaluation of an existing school prototype building under 1993 and 2012 Egyptian codes, and then displays a proposed system for seismic response improvement. The proposed seismic improvement methodology is based on using water tanks as a Tuned Mass Damper (TMD). Pushover analysis is used as a tool and technique to evaluate the nonlinear behaviour of existing building and examine the feasibility of the proposed improvement method.

2. Current Situation and Case Study Discussion

Although many research works addressed the problem of seismic risk evaluation of existing building in Egypt [3]-[5], none of them has considered the nonlinear behaviour of such structures.

Port Said is a coastal city in Egypt and located in zone 3 on the seismic zone map [1] [2]. The building under study is an existing school building with a capacity of 33 classes as shown in **Figure 1**. The building is constructed in the nineties after 1992 Dahshour Earthquake. The building is designed to resist seismic loads as per ECP 201-93. Material characteristics of concrete and rebar are 25 MPA and 360 MPA, respectively. The building is five stories height with three bays in the Y direction and ten bays in the X direction. Most of the beams dimension varies from 250×550 mm to 250×800 mm, while columns dimensions range from 300×500 mm to 300×800 mm, and 140 mm slab thickness. **Figure 2** displays typical story framing plan. Most of Port Said's Schools foundations are Raft or strap foundation; thus, the columns are considered with fixed supports.

SAP 2000 V17 [6] is used to evaluate the chosen prototype building. Two evaluation steps have been done, first to evaluate existing building using old ECP201-1993 code, second, to evaluate existing building using the current ECP 201-2012 code.

Table 1 displays summarized seismic factors selected from ECP 201-1993 and corresponding resultant base shear, while **Table 2** displays summarized seismic factors selected from ECP 201-2012 and corresponding resultant base shear. It is noticed that the resultant base shear from ECP 201-2012 is greater than the resultant base shear from ECP-201 1993 by 50%. The factors used in ECP 201-2012 are referenced from Eurocode 8 [7] that helped to use Eurocode 8 that built in SAP analysis.



Figure 1. School building prototype.

Liquid Damper TLD based on wave-structure interaction [10] to reduce lateral displacement of structures. Experimental studies [11] and analytical studies [12] for TLD have been carried out to evaluate the effect of TLD on structure behaviour. The use of TMD and TLD at the same time cannot be done in a developing country because TLD requires maintenance and special equipment to propagate wave sloshing.

Moreover, some researchers discuss the combination of TMD and TLD at the same model and its effect on earthquake response control of buildings [13] considering many parameters such as liquid height, mass, and frequency of water tank. A feasibility study of variable tanks as TMD has been implemented to improve the seismic response of structures during the design stage and select the optimum solution [14].

It worthy to mention that American code ACI 350.3 [15] and ECP 201-2012 [2] consider a design of tanks to

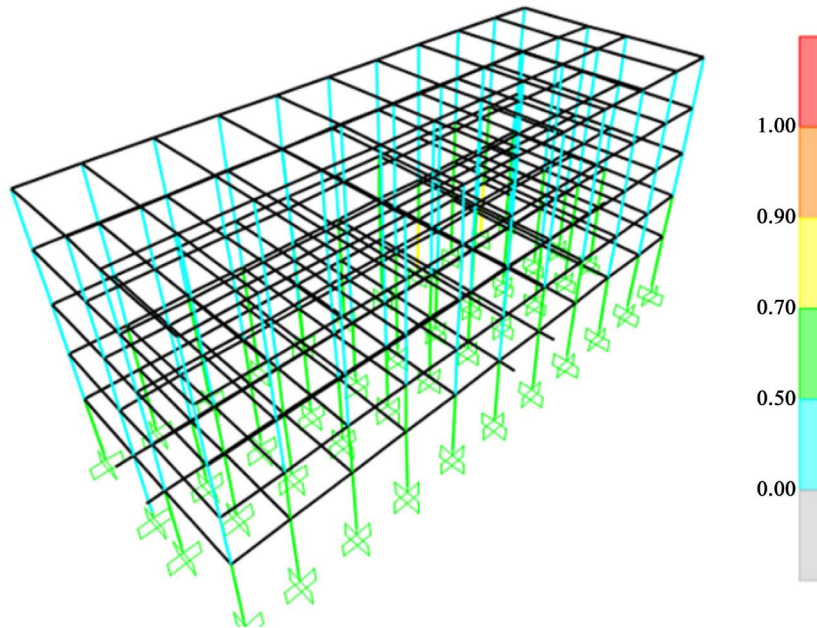


Figure 3. Elements are safe under application of ECP 201-1993 seismic loads.

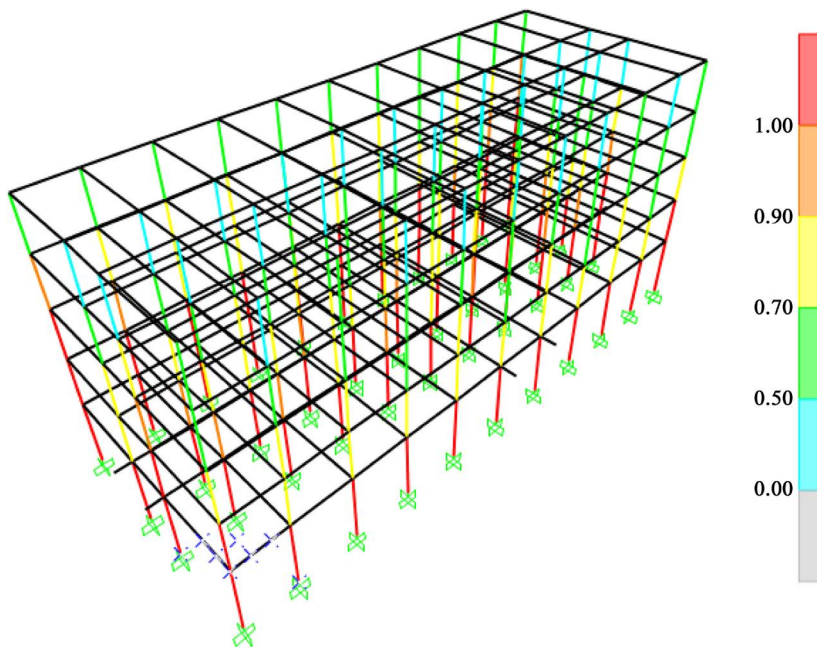


Figure 4. Some vertical elements cannot sustain current ECP 201-2012 seismic loads.

resist lateral load developing from water structure interaction (impulsive and convective force), *i.e.*, to design water containing tanks itself without considering the effect of tanks at the roof of structures.

3.2. Application on TMD on a Case Study

This paper presents a study for improvement of an existing school building in Port Said, Egypt. As Egypt is a developing country, the proposed methodology is to use tanks as a TMD. This paper presents an appropriate solution for existing important structures in developing country, and draws attention to improving seismic behaviour of existing structures with low cost using tanks to act in two options; the first is to satisfy the fire fighting requirement of Civil Defence Authority (CDA), second, is to improve the seismic response behaviour of the existing building.

This study has been done considering variation in the mass ratio (water to structure mass ratio μ) in two cases. The first case with one tank at the centre of the roof area, the second case with two tanks on the roof located in a symmetrical position as displayed in **Figure 5**. **Figure 6** shows a graph illustrating the 20 cases considered. For each case, it is considered that the variation of water height with fixation of tank dimensions and fixation of water height and variation of tank sizes. The total number of groups under this study is four groups each group contains five models with different mass ratio μ . **Table 3** presents all cases of tank mass damper.

Three-dimensional pushover analysis has been done for 20 models in X and Y direction using SAP 2000 V 17. Then a feasibility study of various water TMDs is studied using pushover analysis. This feasibility study has been done to evaluate which case is the optimum solution to improve the seismic response of the existing building.

4. Pushover Analysis

Pushover analysis is a nonlinear static analysis which is widely used all over the world to evaluate of buildings. This paper uses pushover analysis as a tool to evaluate existing structure with and without tanks. The analysis procedure is done based on a gradually lateral movement of structure to reach a target displacement. The target displacement based on building height and applied lateral load. During this movement, there is a formation of plastic hinges in each step.

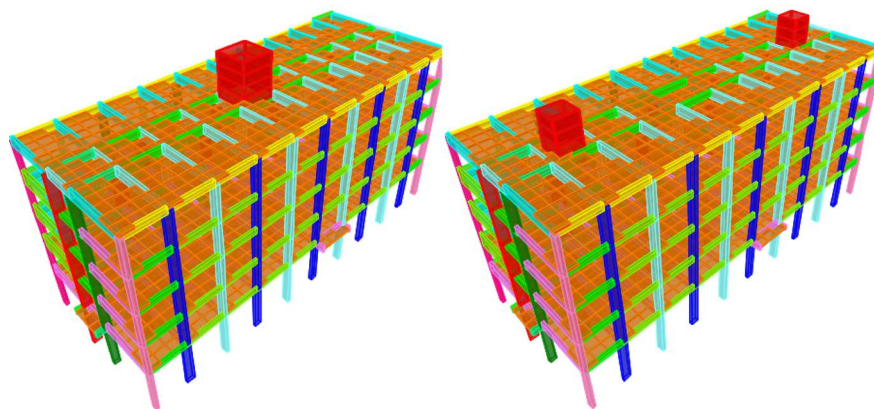


Figure 5. Case 1 with one tank and Case 2 with two tanks.

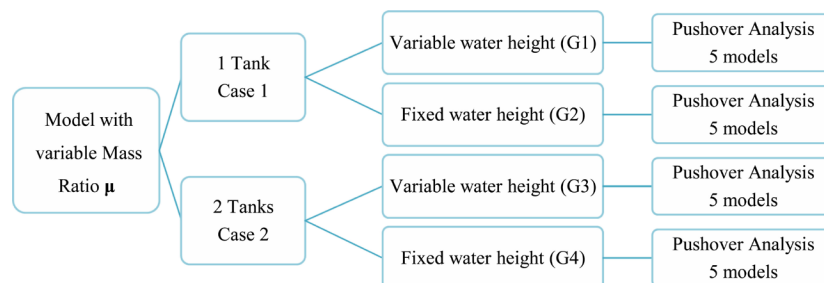


Figure 6. Graphical representation of considered cases.

4.1. Previous Studies

Pushover analysis has been used in many researches as a technique to evaluate structures, and discuss nonlinear behaviour of structures such as:

- Devi and Nandini, (2015) [16], studied the seismic demand on reinforced concrete structures using pushover analysis. A Comparison between uniform and non-uniform structures has been done. They concluded that structures with a uniform profile in elevation have more lateral load capacity compared to structures with the non-uniform profile in elevation.
- Oyguc and Boduroglu, (2012) [17], presented a research paper on seismic capacity of irregular reinforced concrete structure using experimental studies on a prototype building, then compared results with three-dimensional pushover analysis using SAP 2000.
- Bhatti, and Varum, (2012) [18], discussed the performance-based nonlinear static pushover analysis for the seismic design of reinforced concrete buildings.
- Yasrebinia and Pourshrfi (2012) [19], presented a study for three-dimensional analysis of irregular structures, using four, six and eight stories buildings. Then studied the variation of load pattern, load value and direction effect on results of three-dimensional pushover analysis.
- Ismaeil, (2014) [20], performed a pushover analysis to study and evaluate a four-story existing reinforced concrete flat slab building in the Sudan.
- Pednekar *et al.*, (2015) [21], Performed three-dimension pushover analysis of reinforced concrete structures. The buildings under study have five, six and seven story. Finally, they compared the results between models.

4.2. Technique of Evaluation

The analysis using sap 2000 provides the capacity curve, *i.e.*, the force-displacement curve as shown in **Figure 7**. This figure shows the level of plastic hinges [22] [23]. Besides, the analysis results provide the performance point where the capacity curve of the structure intersects the demand curve of the applied lateral load as shown in **Figure 8** ATC-40 [22].

After reaching the performance point and corresponding T effective, one can indicate the level, number of plastic hinges and corresponding base shear. **Table 4** presents the performance level of a building based on the definition of plastic hinges [23]. **Figure 8** shows different stages of plastic hinges [22].

Table 3. Variation of tank size and water height considering variation of mass ratio (μ).

Mass Ratio μ	Water Volume m^3	1 Tank		2 Tank	
		Variable Water Height G1	Fixed Water Height G2	Variable Water Height G3	Fixed Water Height G4
		B \times L \times H (m)	B \times L \times H (m)	B \times L \times H (m)	B \times L \times H (m)
0.25%	7.6	3 \times 3 \times 0.85	1.95 \times 1.95 \times 2.00	2 \times 2 \times 0.95	1.38 \times 1.38 \times 2.00
0.50%	15.2	3 \times 3 \times 1.69	2.76 \times 2.76 \times 2.00	2 \times 2 \times 1.90	1.95 \times 1.95 \times 2.00
0.70%	22.8	3 \times 3 \times 2.53	3.38 \times 3.38 \times 2.00	2 \times 2 \times 2.85	2.38 \times 2.38 \times 2.00
1.00%	30.4	3 \times 3 \times 3.78	3.90 \times 3.90 \times 2.00	2 \times 2 \times 3.80	2.76 \times 2.76 \times 2.00
1.50%	45.6	3 \times 3 \times 5.00	4.78 \times 4.78 \times 2.00	2 \times 2 \times 5.70	3.38 \times 3.38 \times 2.00

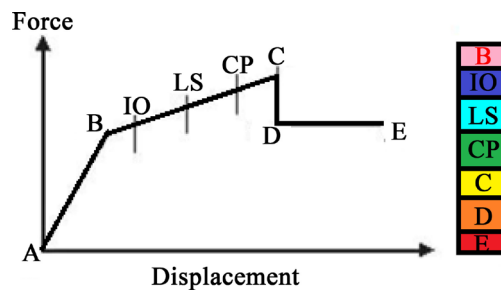


Figure 7. Different stages of plastic hinges.

5. Discussion of Results

5.1. Force-Displacement Curve

Figure 9 displays force-displacement curve for the building without tanks in X and Y directions, while Figure 10 presents force-displacement curve for the building with tanks in X and Y direction. It is noted that the force-

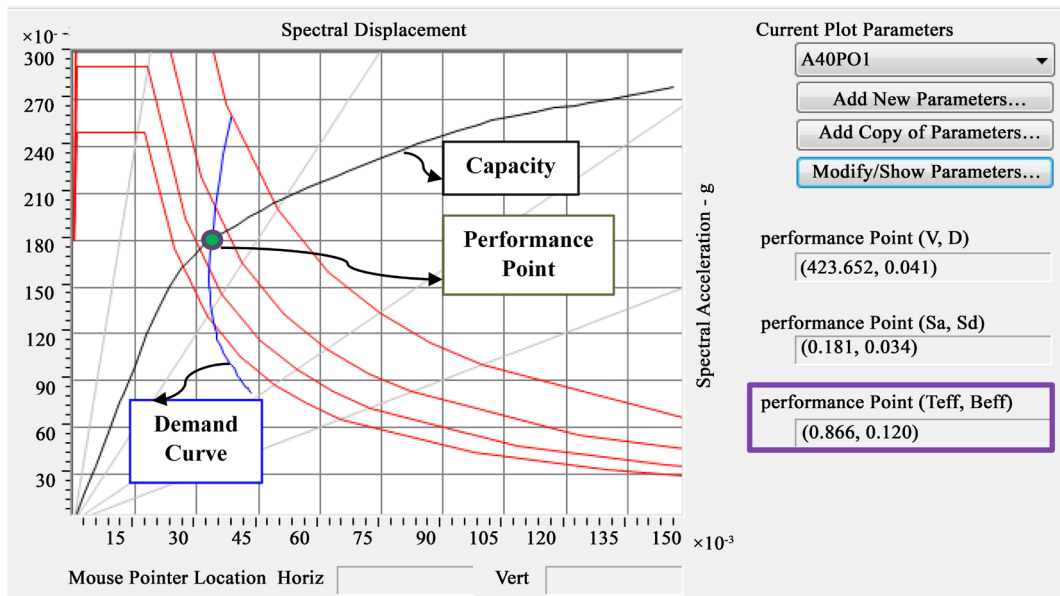


Figure 8. Pushover curve [22].

Table 4. Performance level of building [22].

Level	Description
Operational	Very light damage, no permanent drift, structure retains original strength and stiffness; all systems are normal
Immediate Occupancy (IO)	Light damage, no permanent drift, structure retains original strength and stiffness, elevator can be restarted, Fire protection operable
Life Safety (LS)	Moderate damage, some permanent drift, some residual strength and stiffness left in all stories, damage to partition, building may be beyond economical repair
Collapse Prevention (CP)	Severe damage, large displacement, little residual stiffness and strength but loading bearing column and wall function, building is near collapse

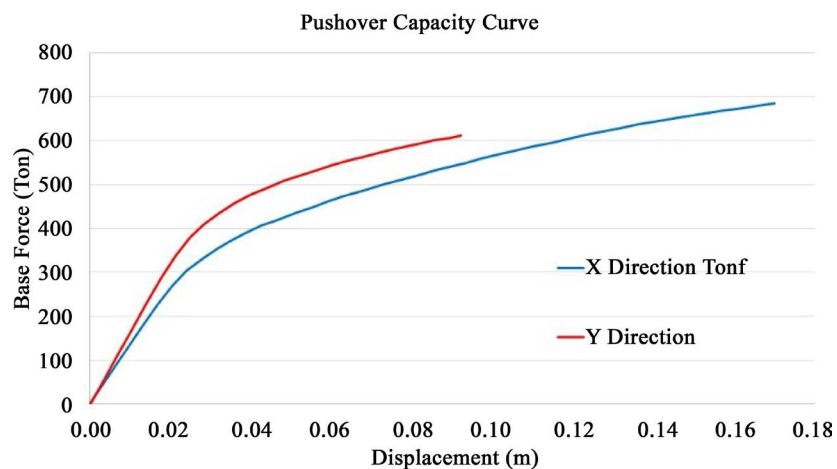
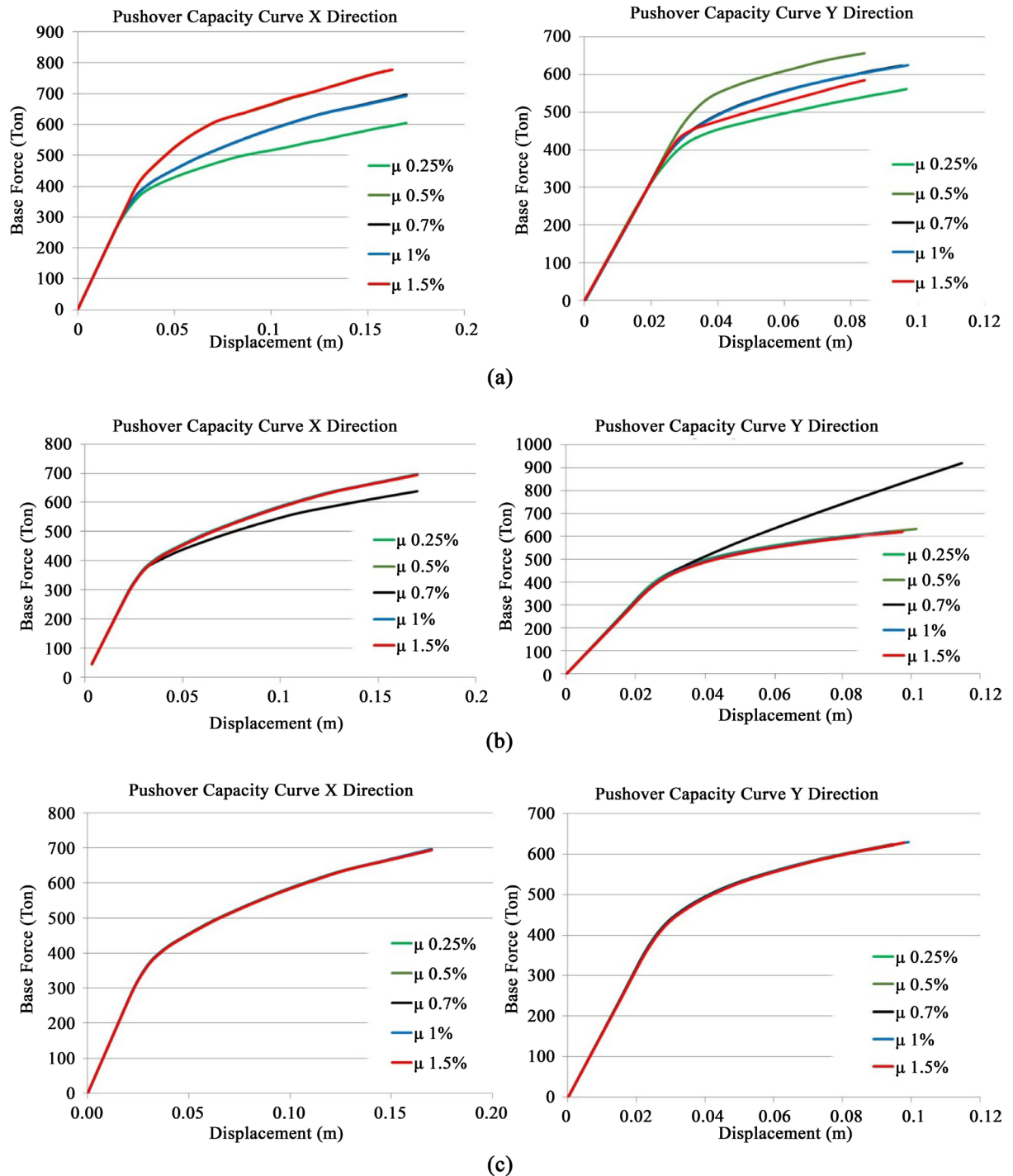


Figure 9. Force-displacement curve for building without tank.

displacement curve is affected by the variation of mass ratio in the presence of one tank as shown in **Figure 10(a)** and **Figure 10(b)**, while the force-displacement curve is not affected by variation of the mass ratio in the presence of two tanks as shown in **Figure 10(c)** and **Figure 10(d)**.

5.2. Performance Point and Formation of Plastic Hinges

Table 5(a) and **Table 5(b)** display performance point and number of plastic hinges for building without tanks in X and Y-directions, respectively. While **Table 6** presents a comparison between each group (with tanks) con-



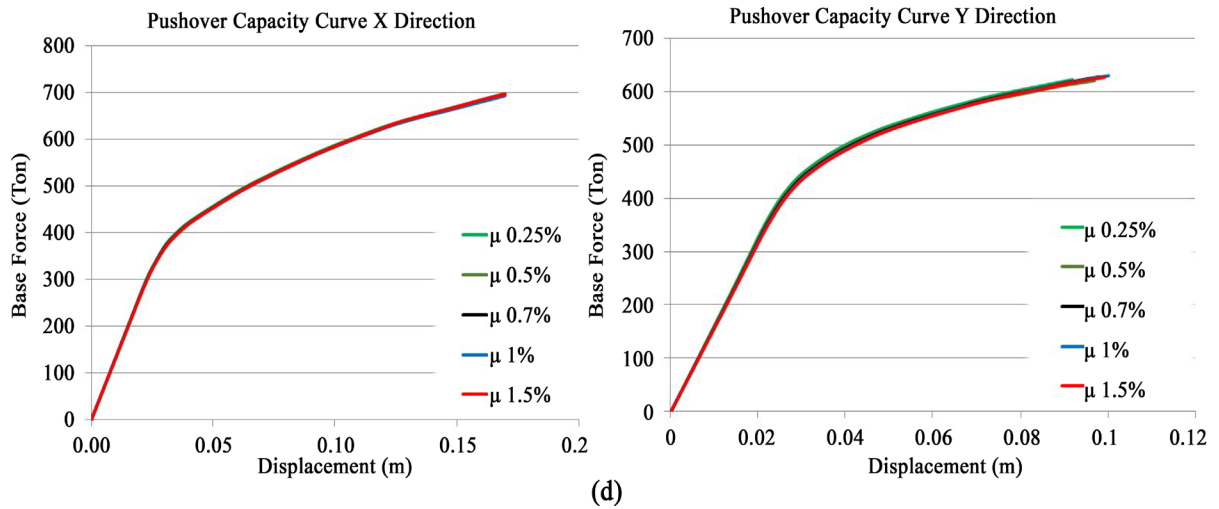


Figure 10. (a) Force-Displacement curve for building with 1 tank (G1), (b) force-Displacement curve for building with 1 tank (G2), (c) force-Displacement curve for building with 2 tanks (G3), (d) force-Displacement curve for building with 2 tanks (G4).

Table 5. (a) Performance points at X-Direction for building without tank, (b) performance points at Y-Direction for building without tanks.

(a)

Direction	Teff	Step	T	Base shear (ton)	Displacement (m)	B to IO	IO to LS	LS to CP
X	1.124	22	1.1194	532.36	0.0860	464	1	0
		23	1.1371	542.17	0.0901	467	7	0

(b)

Direction	Teff	Step	T	Base shear (ton)	Displacement (m)	B to IO	IO to LS	LS to CP
Y	1.107	12	1.0764	493.415	0.044	295	17	0
		13	1.1106	509.186	0.048	305	23	0

Table 6. (a) Comparison between performance points at X-Direction for (G1), (b) comparison between performance points at Y-Direction for (G1), (c) comparison between performance points at X-Direction for (G2), (d) comparison between performance points at Y-Direction for (G2), (e) comparison between performance points at X-Direction for (G3), (f) comparison between performance points at Y-Direction for (G3), (g) comparison between performance points at X-Direction for (G4), (h) comparison between performance points at Y-Direction for (G4).

(a)

μ %	Teff	Step	T	Base shear (ton)	Displacement (m)	B to IO	IO to LS	LS to CP
0.25%	1.193	21	1.1874	499.00	0.085	487	39	0
		22	1.2185	505.31	0.090	486	50	0
0.50%	1.033	21	1.0185	618.47	0.075	521	21	0
		22	1.0505	627.53	0.080	512	35	0
0.70%	1.108	22	1.0957	545.55	0.083	468	1	0
		23	1.1162	555.88	0.087	472	3	0
1.00%	1.113	22	1.1128	551.70	0.086	471	2	0
		23	1.1311	561.09	0.090	475	8	0
1.50%	1.043	21	1.0380	622.80	0.078	520	25	0
		22	1.0659	631.02	0.082	515	37	0

(b)

μ %	Teff	Step	T	Base shear (ton)	Displacement (m)	B to IO	IO to LS	LS to CP
0.25%	1.172	12	1.1618	463.98	0.044	318	32	0
		13	1.1998	472.07	0.048	321	42	0
0.50%	1.037	12	1.0038	551.02	0.040	345	26	0
		13	1.0781	571.98	0.046	359	44	0
0.70%	1.093	14	1.0879	522.63	0.048	333	21	0
		15	1.1281	536.22	0.052	345	30	0
1.00%	1.098	13	1.0673	511.96	0.045	317	16	0
		14	1.0998	525.56	0.049	337	21	0
1.50%	1.155	13	1.1466	489.89	0.045	225	56	0
		14	1.1786	499.41	0.049	334	62	0

(c)

μ %	Teff	Step	T	Base shear (ton)	Displacement (m)	B to IO	IO to LS	LS to CP
0.25%	1.096	22	1.0856	546.25	0.082	466	1	0
		23	1.1015	554.62	0.086	470	2	0
0.50%	1.102	27	1.1881	596.37	0.105	491	37	0
		28	1.2096	607.72	0.111	490	47	0
0.70%	1.156	23	1.1488	518.97	0.085	521	0	0
		24	1.1667	526.49	0.089	529	0	0
1.00%	1.11	22	1.0970	545.47	0.083	468	1	0
		23	1.1159	555.31	0.087	471	3	0
1.50%	1.12	22	1.1180	550.76	0.086	472	2	0
		23	1.1419	563.43	0.091	475	12	0

(d)

μ %	Teff	Step	T	Base shear (ton)	Displacement (m)	B to IO	IO to LS	LS to CP
0.25%	1.08	13	1.0625	515.36	0.044	316	18	0
		14	1.0981	529.39	0.048	338	26	0
0.50%	1.087	13	1.0631	513.84	0.045	313	17	0
		14	1.0957	527.19	0.049	338	23	0
0.70%	0.985	17	0.9772	650.44	0.063	287	0	0
		18	0.9931	686.27	0.069	290	0	0
1.00%	1.096	14	1.0898	523.00	0.048	334	21	0
		15	1.1309	537.56	0.053	345	30	0
1.50%	1.107	13	1.0639	507.50	0.045	320	10	0
		14	1.0945	521.27	0.049	340	20	0

(e)

μ %	Teff	Step	T	Base shear (ton)	Displacement (m)	B to IO	IO to LS	LS to CP
0.25%	1.105	21	1.0961	499.00	0.0851	462	1	0
		22	1.1167	505.31	0.0900	467	4	0
0.50%	1.108	22	1.0983	557.59	0.0878	469	4	0
		23	1.1198	570.69	0.0934	469	20	0
0.70%	1.11	22	1.0896	541.05	0.0811	460	0	0
		23	1.1183	555.75	0.0872	467	3	0
1.00%	1.114	21	1.0937	541.37	0.0813	461	0	0
		22	1.1210	555.58	0.0872	469	2	0
1.50%	1.12	21	1.1054	544.45	0.0830	463	1	0
		22	1.1242	554.04	0.0871	470	2	0

(f)

μ %	Teff	Step	T	Base shear (ton)	Displacement (m)	B to IO	IO to LS	LS to CP
0.25%	1.09	13	1.0694	514.96	0.0448	318	18	0
		14	1.1036	528.74	0.0489	339	24	0
0.50%	1.093	13	1.0729	571.98	0.0459	319	17	0
		14	1.1027	584.83	0.0501	338	23	0
0.70%	1.095	13	1.0683	511.99	0.0443	317	17	0
		14	1.1026	526.32	0.0485	334	23	0
1.00%	1.099	13	1.0693	511.41	0.0446	316	16	0
		14	1.1004	525.07	0.0485	334	21	0
1.50%	1.104	11	1.0075	479.74	0.0376	303	0	0
		12	1.0422	496.38	0.0413	317	5	0

(g)

μ %	Teff	Step	T	Base shear (ton)	Displacement (m)	B to IO	IO to LS	LS to CP
0.25%	1.096	21	1.0760	541.72	0.080	459	0	0
		22	1.1031	555.77	0.086	467	2	0
0.50%	1.104	18	1.0025	501.17	0.065	427	0	0
		19	1.0231	511.07	0.069	434	0	0
0.70%	1.109	21	1.0968	545.78	0.083	461	1	0
		22	1.1201	557.80	0.088	471	3	0
1.00%	1.116	22	1.0981	542.97	0.082	462	1	0
		23	1.1198	553.98	0.087	468	2	0
1.50%	1.124	28	1.2320	607.99	0.111	475	50	0
		29	1.2570	620.45	0.118	486	53	0

(h)

μ %	Teff	Step	T	Base shear (ton)	Displacement (m)	B to IO	IO to LS	LS to CP
0.25%	1.081	13	1.0660	515.88	0.044	316	20	0
		14	1.1080	531.41	0.049	335	30	0
0.50%	1.089	13	1.0709	515.78	0.045	318	18	0
		14	1.1019	528.27	0.049	339	23	0
0.70%	1.094	13	1.0720	514.74	0.045	318	17	0
		14	1.1033	527.57	0.049	339	22	0
1.00%	1.101	13	1.0753	513.82	0.046	318	16	0
		14	1.1038	526.13	0.049	334	21	0
1.50%	1.108	13	1.0793	513.14	0.046	318	16	0
		14	1.1067	525.47	0.049	335	21	0

sidering performance points and number of plastic hinges in both directions X and Y.

Comparing the results shown in [Table 5](#) and [Table 6](#) it is noticed that; the model with 0.7% mass ratio give the best results as far as the number and type of plastic hinges. This will lead to improving the seismic response of the studied prototype building. This is summarized in [Table 7](#) which displays a comparison between performance points and number of plastic hinges in all cases with $\mu = 0.7\%$ in both directions X and Y. This confirms that the G2 group with 0.7% mass ratio is the best solution for the seismic improvement of the chosen building.

5.3. Comparison with Previous Results

This study shows that; the use of one tank has a significant effect on improving the seismic response of the

Table 7. Comparison between performance points at X and Y-Directions for all groups with $\mu = 0.7\%$.

$\mu = 0.7\%$		Direction	Teff	Step	T	Base shear (ton)	Displacement (m)	B to IO	IO to LS	LS to CP	Rank	
1 Tank	Variable water height	X	1.108	22	1.0957	545.55	0.083	468	1	0	D	
				23	1.1162	555.88	0.087	472	3	0		
		Y	1.093	14	1.0879	522.63	0.048	333	21	0		
	15			1.1281	536.22	0.052	345	30	0			
	Fixed water height	X	1.156	23	1.1488	518.97	0.085	521	0	0		A
				24	1.1667	526.49	0.089	529	0	0		
Y		0.985	17	0.9772	650.44	0.063	287	0	0			
	18		0.9931	686.27	0.069	290	0	0				
2 Tank	Variable water height	X	1.11	22	1.0896	541.05	0.0811	460	0	0	C	
				23	1.1183	555.75	0.0872	467	3	0		
		Y	1.095	13	1.0683	511.99	0.0443	317	17	0		
	14			1.1026	526.32	0.0485	334	23	0			
	Fixed water height	X	1.109	21	1.0968	545.78	0.083	461	1	0		B
				22	1.1201	557.80	0.088	471	3	0		
Y		1.094	13	1.0720	514.74	0.045	318	17	0			
	14		1.1033	527.57	0.049	339	22	0				

studied building more than the use of two tanks. However Patil *et al.* [9] found that the use of multiple mass dampers gave better results for the overall displacement of the structure. This can be explained by the fact that; his results have been obtained without considering the nonlinear behaviour of the structure as in this paper.

The results obtained herein agrees with those obtained by Dattatray *et al.* [8] that show that tanks with 1/2 to 2/3 water depth have better effect more than full tanks, as shown in **Table 3**.

Besides, the mass ratio of 0.7% that gives best results agrees with the mass ratio of 0.7% to 3% obtained by Dattatray *et al.* [8] and Tejashri *et al.* [14].

It is worthy to mention that; the present study considers the nonlinear behaviour of structure while other previous studies considered the static linear analysis.

6. Summary and Conclusions

Seismic response evaluation has been done for existing school prototype building based on the current code for loads, and some vertical elements could not sustain seismic loads. Use the water Tank as TMD is the proposed methodology to improve seismic response for the building. Pushover analysis is performed as a tool to identify the best tank from 20 proposals for different mass ratios, water heights, tank dimensions and number of tanks. It is found that:

1) Using one tank is better than using two tanks with the same mass ratio, and this result is presented in the force-displacement curve.

2) The mass ratio of 0.7% is the best value that can improve the seismic behaviour of the existing prototype school building.

3) Not all the discussed tanks can upgrade the seismic building performance. Some of them decrease the building performance, so it is important to make iterations to select the best solution.

4) The proposed methodology is economical and can be easily performed in all existing reinforced concrete school buildings as it satisfies the following criteria.

a) Meet the civil defence requirement for adding tanks at the roof for fire fighting purposes.

b) Improve seismic performance of the structure.

c) Tanks as a TMD do not need maintenance, just to keep water volume constant.

5) In General, the mass ratio of 0.5% to 1.0% gives better performance more than the other mass ratios.

Therefore, it is recommended that:

- 1) The proposed methodology can be applied in old buildings to improve the seismic response of structures.
- 2) The proposed method is economical and the tanks are used for fire fighting and plumbing issue and are used to improve the seismic response of structures, so it is appropriate for developing countries.
- 3) Three-dimensional pushover analysis can be done to evaluate existing buildings.
- 4) For the new buildings, it is important to study the effect of top roof tanks on the behaviour of structure regarding lateral loads.
- 5) American (ACI) and Egyptian (ECP) codes should pay attention to the top-roof tanks. As some can improve the response of structures while others can be harmful to the structure in case of seismic loads.

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