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PAPER

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Effect of column size on the seismic capacity of elevated reinforced concrete water tank

M I Adiyanto[1*], A A A Damit[1], S N Yaakup[1], S A H S Mustapha[2,3], S C Chin[1]

[1]Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
[2]Department of Quantity Surveying, Faculty of Architecture, Planning, and Surveying, Universiti Teknologi Mara, Seri Iskandar, Perak, Malaysia
[3]AS2 Consult Sdn. Bhd., Seri Iskandar, Perak, Malaysia

Email: mirwan@ump.edu.my

Abstract. Elevated reinforced concrete water tanks are one of the most essential structure to major cities and also in rural areas before, during and after a disaster such earthquake. It is important to prevent elevated reinforced concrete water tank from collapse so the water supply can be maintained. One of the methods used to evaluate the seismic capacity of elevated reinforced concrete water tank is the pushover analysis. Pushover analysis is based on the assumption that structure oscillate predominantly in the first mode or in the lower modes of vibration during a seismic event. The objective of this project is to study the effect of column size on the seismic capacity of elevated reinforced concrete water tank. A total number of 10 models of elevated reinforced concrete water tanks consist of 4 storey and 7 storey has been used for this project. All models have been designed repeatedly to 5 different size of column for each storey, where the beam size is fixed for each model. All models have been designed based on BS8110 to represent the existing elevated reinforced concrete water tanks. Then the pushover analysis has been conducted on all models to study the seismic capacity of elevated reinforced concrete water tank. An adequate information on seismic demands imposed on the structural system and its components by the designed ground motion will be provided from the pushover analysis. Based on the pushover analysis conducted in this study, the elevated RC water tank with larger size of column tend to have higher value of force at yield limit state and ultimate limit state.

1. Introduction

Earthquakes are stated to be one of the greatest disasters of nature in this world [1]. In public water distribution system, elevated reinforced concrete (RC) water tank was used widely in the entire world as an important part of lifeline system especially in earthquake prone regions. Due to the most important structure before, during, and after a disaster such as earthquake, it is important to maintain the seismic safety of elevated RC water tanks. Elevated RC water tanks also called as elevated service reservoirs [2] typically consist of a square/circular shape of container and either concrete or steel supporting tower.

Elevated RC water tanks are a structure that has a large mass concentrated at the top of slender column which have supporting structure. Hence, these structures are especially vulnerable to horizontal forces due to earthquakes. Thus, it is important for elevated RC water tanks to remain functional after the earthquake where water tanks are the most essential as water supply system for providing storage of water, drinking purpose, fire suppression as well as many other applications.

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This study investigated the seismic capacity of existing elevated RC water tank via pushover analysis as per ATC-40 [3] & FEMA-356 [4], which provide the target displacement and the yielding mechanism. The seismic capacity of existing elevated RC water tank has been evaluated by using SAP2000 software [5]. The effect of column size on seismic capacity and lateral displacement has become the main focus for this study. The capacity curve, and lateral displacement at yield limit state and ultimate limit state for each water tank models are presented for discussion.

2. Model and Methodology

In this study, the method used to investigate the effect of column size on the seismic capacity of elevated RC water tank is the pushover analysis. Five sets of every 4 storey and 7 storey elevated RC water tanks with different size of column were designed based on BS8110 [6]. All models were adopted from typical existing elevated RC water tank in Malaysia. All models used in this study is regular in plan and the list of models used are shown in Table 1 and Table 2 for the 4 storey and 7 storey, respectively.

Table 1. Column and beam sizes for 4 storey elevated RC water tank models

Models	Column Size (mm)	Beam Size (mm)
N4A	300 x 300	200 x 400
N4B	350 x 350	200 x 400
N4C	400 x 400	200 x 400
N4D	450 x 450	200 x 400
N4E	500 x 500	200 x 400

Table 2. Column and beam sizes for 7 storey elevated RC water tank models

Models	Column Size (mm)	Beam Size (mm)
N7A	400 x 400	250 x 450
N7B	450 x 450	250 x 450
N7C	500 x 500	250 x 450
N7D	550 x 550	250 x 450
N7E	600 x 600	250 x 450

BS8110 [6] which is currently used for design of RC buildings in Malaysia has been referred to design the elevated RC water tank models in this study. All models were designed using Esteem software [7] in order to obtain the number and size of steel reinforcement for beams and columns. Concrete compressive strength, f_{cu}=30 N/mm^2 and yield strength of steel, f_y= 460 N/mm^2 has been considered for design purpose.

From the Esteem software, the steel reinforcement details can be selected only if the structural integrity were accepted and there are no failed members in the structure. The diameter of flexural reinforcement for beam and column used in both 4 storey and 7 storey elevated RC water tank models is between 16mm to 20mm and 16mm to 25mm, respectively. Meanwhile, the diameter of shear reinforcement for both beam and column is between 6mm to 10mm. The 4 storey models of elevated RC water tank were generated into 5 sets of models with different size of column and fixed size of beam as shown in Table 1. The storey height and bay width for the 4 storey models is equal to 3.0m as shown in Figure 1. Furthermore, the 7 storey models of elevated RC water tank were also generated into 5 sets of models with different size of column and fixed size of beam as shown in Table 2. The storey height and bay width for the 7 storey models is equal to 3.5m and 5.0m, respectively as shown in Figure 2.

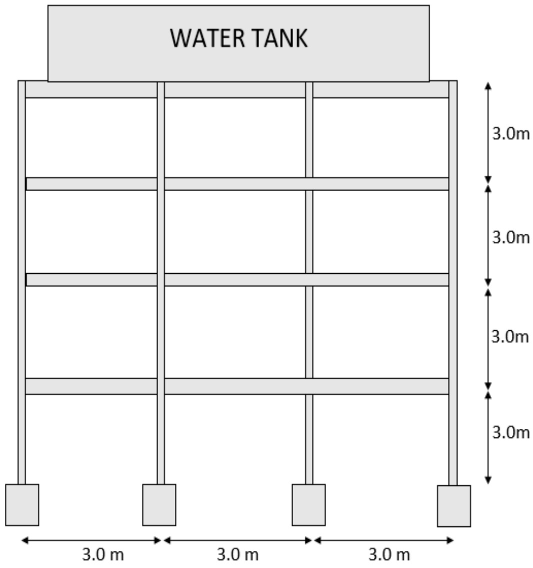

Figure 1. Elevation view of 4 storey elevated RC water tank

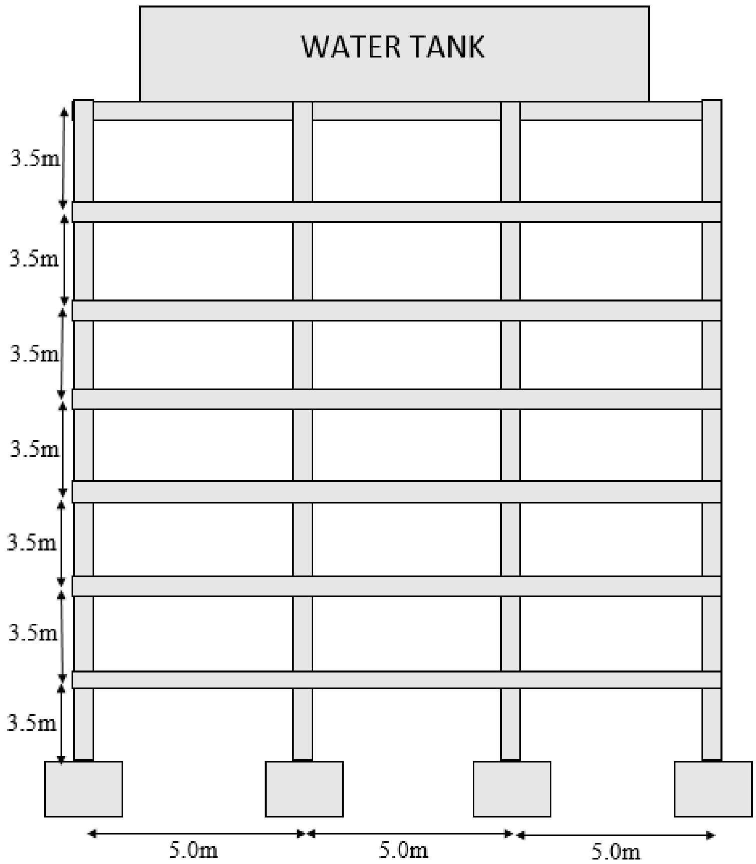

Figure 2. Elevation view of 7 storey elevated RC water tank

Then, CUMBIA program [7] was used to determine the non-linear properties of the structural elements. In this process, the cross section details of Beams and columns for all elevated RC water tank models were analysed. As a result, the typical shape for moment-curvature curve and moment-axial interaction curve for every beam and column were plotted as shown in Figure 3 and Figure 4, respectively. The moment-curvature curve illustrates the stiffness, strength and cross-sectional ductility [8].

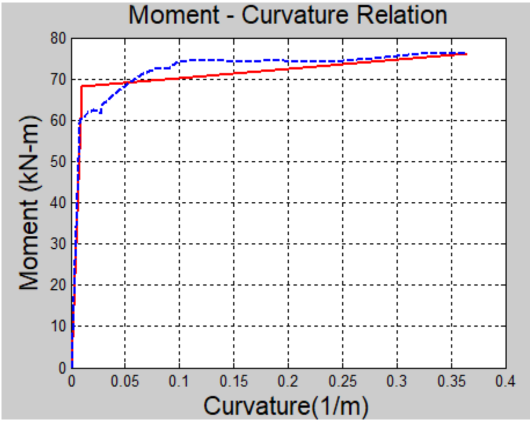

Figure 3. Moment-curvature curve

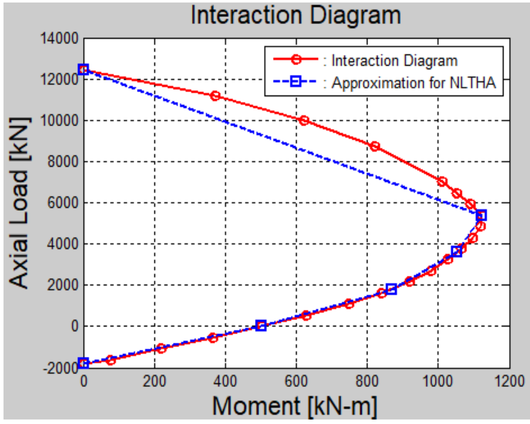

Figure 4. Moment-axial interaction curve

Finally, SAP2000 software [5] was used for pushover analysis. The latter was conducted under the factored gravity load combination and static lateral earthquake forces. The capacity curve and the lateral displacement at yield limit state and ultimate limit state for each water tank had been obtained. The typical shape of capacity curve is shown in Figure 5.

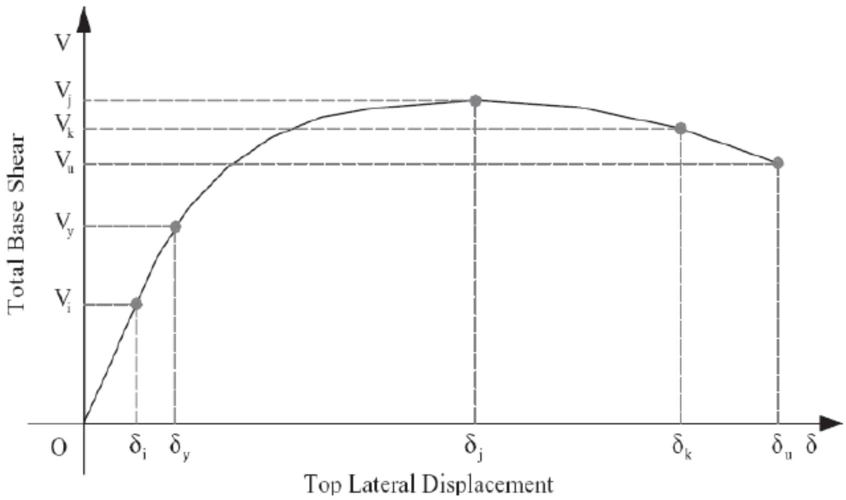

Figure 5. Typical capacity curve for structural systems subjected to horizontal load [8]

3. Result and Discussion

3.1. Capacity Curve

As mentioned in early section, main focus of this study is to investigate the effect of column size on seismic capacity of elevated RC water tank. The seismic capacity can be represented by capacity curve which is a graph of relationship between horizontal loads known as base shear force, F_b and lateral displacement. The capacity curves for all 4 storey and 7 storey elevated RC water tank models are presented in Figure 6 and Figure 7, respectively.

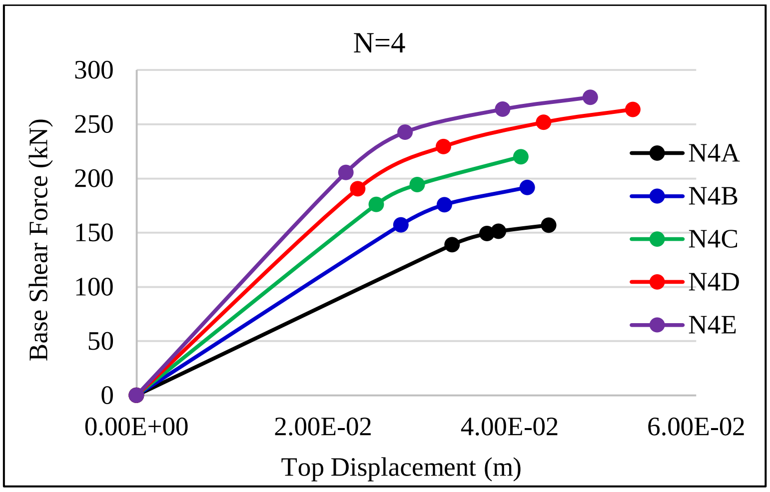

Figure 6. Capacity curve for 4 storey elevated RC water tank

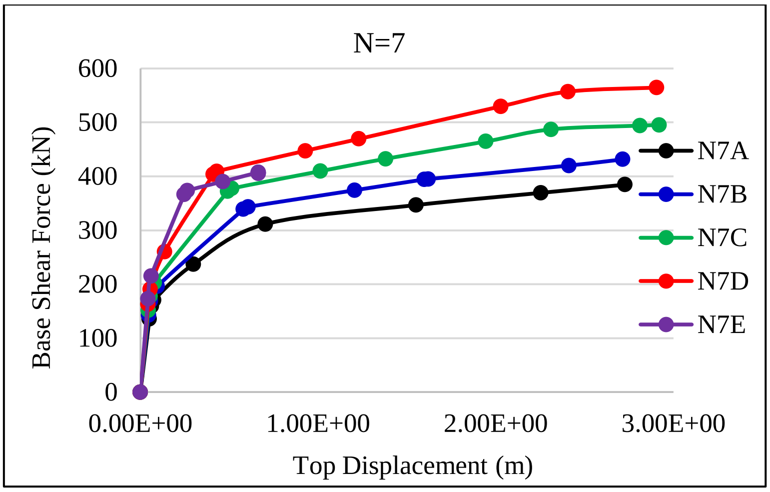

Figure 7. Capacity curve for 7 storey elevated RC water tank

From Figure 6 and Figure 7, it is clear that column size strongly influencing the seismic capacity of elevated RC water tank. Result shows that models with larger column size tend to be stronger than the models with smaller column size. This results are in similar pattern for both 4 and 7 storey elevated RC water tank models. Table 3 and Table 4 present the magnitude of yield and ultimate forces for all 4 storey and 7 storey elevated RC water tank models, respectively.

Table 3. Yield and ultimate forces for 4 storey elevated RC water tank models

Models	Yield Force (kN)	Ultimate Force (kN)
N4A	138.97	157.01
N4B	157.36	191.85
N4C	176.11	220.12
N4D	190.51	263.78
N4E	205.70	274.93

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Table 4. Column and beam sizes for 7 storey elevated RC water tank models

Models	Yield Force (kN)	Ultimate Force (kN)
N7A	236.92	384.58
N7B	339.15	431.44
N7C	372.46	495.43
N7D	403.75	593.69
N7E	336.40	405.62

Table 3 shows that the larger column size used in the elevated RC water tank, the longer the structure takes to yield and reach its ultimate state. For this group, the yield forces is in range of 138.97kN to 205.70kN while the ultimate forces lies in range of 157.01kN to 274.93kN. Meanwhile, Table 4 shows similar pattern of result for all models except for the N7E model. The latter yield faster than the N7B model whereas the yield forces for N7E and N7B are equal to 336.40kN and 339.15kN, respectively. Besides, N7E model has ultimate force equal to 405.62kN compared to N7B model which has ultimate force equal to 431.44kN. This result is caused by percentage of total area of steel reinforcement provided, As_{prov} for column element. Based on design detail, the total area of steel reinforcement provided, As_{prov} for columns of N7E model is only around 1.1% of total area of column cross section, which is provided to pass the minimum requirement of BS8110 [6]. This percentage is relatively lower compared to N7B, N7C, and N7D models. As a result, columns for N7E model are weaker than columns for N7B, N7C, and N7D models.

3.2. Lateral Displacement

This study also investigated the effect of column size on lateral displacement of elevated RC water tank when subjected to horizontal load. Figure 8 and Figure 9 present the lateral displacement at yield state for all 4 storey and 7 storey elevated RC water tank models, respectively. As depicted in Figure 8 and Figure 9, the magnitude of lateral displacement of every storey at yield state is strongly influenced by the column size. The larger column size tends to reduce the magnitude of lateral displacement. From Figure 8, the N4E model has the lowest magnitude of lateral displacement which is around 35% lower compared to N4A model. For the case of 7 storey elevated RC water tank, the magnitude of lateral displacement for N7E model is around 16% lower compared to N7A model. This is strongly related to stiffness where larger column size tend to have higher stiffness, result in lower displacement.

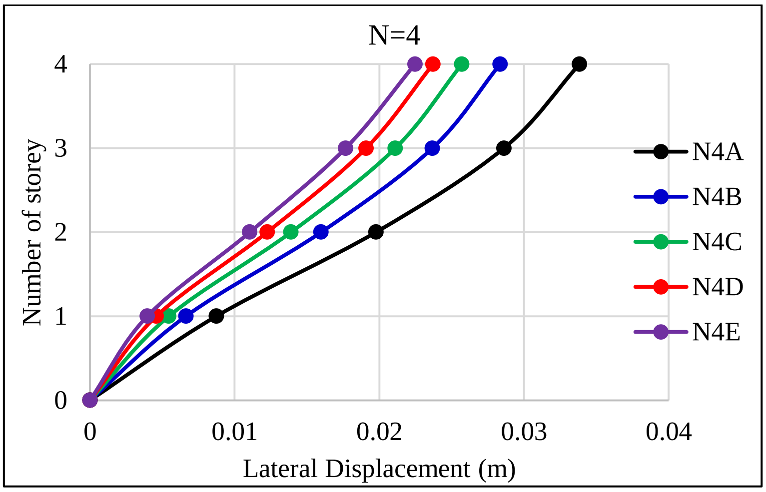

Figure 8. Lateral displacement at yield for 4 storey elevated RC water tank

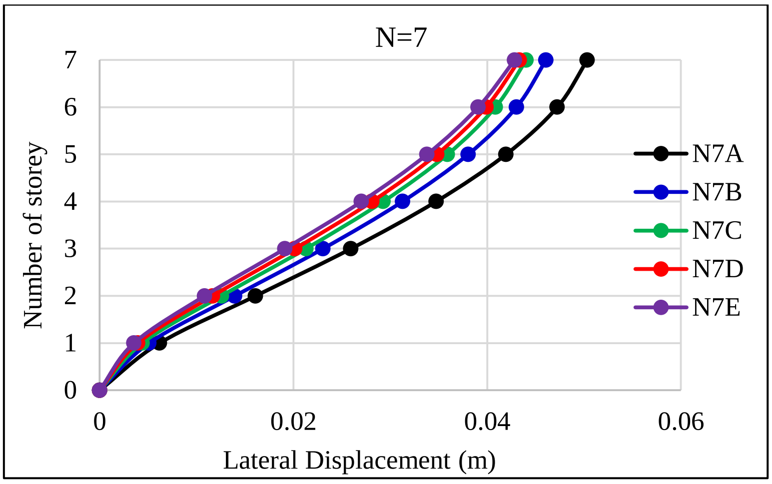

Figure 9. Lateral displacement at yield for 7 storey elevated RC water tank

4. Conclusion

This study investigated the effect of column size on the seismic capacity of 4 storey and 7 storey elevated RC water tank. The typical elevated RC water tank has been designed based on BS8110 [6] to represent the existing elevated RC water tanks in Malaysia. A total number of 10 models of elevated RC water tanks consist of 4 and 7 storeys has been used for pushover analysis by using SAP2000 [5] in order to obtain the capacity curve and lateral displacement at every storey. There are few conclusions that can be drawn from this study as follows:

- Column size strongly influencing the strength of elevated RC water tank to withstand the horizontal load. Larger column size tend to increase the seismic capacity via higher magnitude of yield and ultimate forces.
- Column size also strongly influencing the magnitude of lateral displacement at every storey when subjected to horizontal load. Larger column size tend to reduce the magnitude of lateral displacement due to its higher stiffness

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