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THE EFFECT OF PTMD ON THE MODAL PARAMETERS OF THE WATER TANK BY FINITE ELEMENT METHOD

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ABSTRACT:

Earthquake engineers have taken many precautions in their building designs to protect and minimize destructive effects. In this way, many new design and reinforcement methods have been developed against seismic loads. The use of a pendulum tuned mass damper (PTMD) is one of the developed methods. One of the most important negative aspects of the use of PTMD is the increase in the structural period. Therefore, in this study, the effects of PTMD on periods and mode shapes in symmetrically reinforced concrete water tank model were investigated. For this, two models with and without PTMD were created by the finite element method and modal parameters were compared. As a result of the data obtained, it has been observed that the water tank model makes more balanced displacements, as can be understood from the mode shapes, without increasing the period of the water tank to a dangerous level. It is known that PTMD reduces the seismic effect by acting in the opposite direction to the seismic effect on the structure. Pendulum tuned mass damper can be used in reinforced concrete water tanks, provided that it does not increase period too much.

Keywords: Pendulum tuned mass damper; mode shape; period; RC water tank; FEM.

I. INTRODUCTION:

Most of the structures found in earthquake hazardous areas are subject to various destructive effects caused by seismic loads.[1],[2],[3],[4],[5]. Buildings located in seismically active regions are under high risk of severe damages caused by harmful earthquake loads. [6]. In recent years, in the world and our country, the determination of the effect of vibrations on structures and structural behavior has become very important. [7]. PTMDs (Pendulum Tuned Mass Damper) consist of a pendulum system of mass supported by a cable moving around a fixed point. They are often modeled as a simple pendulum. For small angular oscillations, they behave like a TMD. They can be modeled using the equivalent stiffness and damping ratio. Therefore, the design methodology for both the TMD system and the PTMD systems is the same. PTMD designs are cheaper to manufacture and last longer. Approximately 50% of the structures using TMD system in the world use it. The effect of using PTMD in buildings on dynamic performance is almost the same as TMD. Generally, the PTMD is rectangular in shape with the four corners spaced 90 degrees apart from each other. The stiffness of PTMDs is the maximum amount of the spring that can be supported by the cable. The modulus of the cable is not much and TMDs have the advantage that the stiffness is a function of the stiffness of the cable. Hence, it can be made with light wires and cables. PTMD systems are most suitable for large or double-sided strong walls. However, it’s not a suitable option for buildings with curved surfaces. PTMD systems are typically used in more expensive large buildings as compared to TMDs, due to higher cost of the cable. It is used in many high-rise buildings and tube structures. PTMD are characterized by long installed cables used in the mass damper part of the structure. PTMD structures are complex a structure with multiple axes (short arms extending from arrangement, single axis, and long axis). The physical arrangements of these systems can be modular or have rigid geometry. Light wires or flexible cable are used for PTMD structure. It's do not contribute much to building performance in terms of noise and vibration, but they help to reduce the resonant frequencies. PTMD systems are also often seen in architectural and bridge design to control the non-dynamic loads. Its design is more complex, different in form and function than TMDs. Its shape, connections and motion components can be different for different modules. The design of the PTMD system is also different from TMD's system. Similarly, the forces and vibrations in the PTMD system are also different from those in the TMD system. The damping ratio in a PTMD system is larger than the damping ratio in a TMD. The damping ratio measures the damping ability of a system. It indicates how much energy is absorbed and dissipated in the system, or how much energy is absorbed and dissipated per unit of mass. The damping ratio is used as a parameter for the optimization of PTMD systems. A damping ratio higher than 1 is better than the maximum damping ratio of system, but a lower damping ratio is always better than the maximum damping ratio of a TMD system. Many PTMDs have been designed and tested to operate at different frequencies and for different needs. The range of frequencies that can be operated depends on the material, the wire, and the wind load. The type of mass damper arrangement determines the frequency range that can be operated. For example, for buildings that need to be lightweight or have very low mass load, the maximum frequency range can be limited to a few Hz. For structures that require a higher frequency, the maximum frequency can be restricted to higher than 50 Hz. The best for PTMD system is for applications in which high damping factor is required. The best design is when the mass damping factor is 1.5 or higher. When the mass damping factor is much higher than 1, it will need large amounts of cable. Therefore, large PTMD systems are seldom used in buildings. The primary advantages of PTMD system are that it is light and flexible. Flexibility is one of the main features of a flexible cable. It can be constructed in several configurations to produce a unique mass damping. It is easy to design and use, yet it is much cheaper than rigid cable systems. In addition, it does not increase the wind load on the building. High specific stiffness can be achieved in PTMD structure. It's a passive design that is inherently able to maintain a constant specific stiffness. The unique stiffness in the structure is a significant advantage over conventional systems in which the stiffness is created by adding rigid bars and frames. While material and shape modifications can improve the performance of the system, there are some drawbacks. The stiffness and the specific mass can change with changes in the wind load. Also, the specific stiffness may not be able to dissipate the wind load and an inversion may occur with higher wind loads, leading to an increase in damping ratio. Inverse of specific mass is stiffness and the ratio of the damping factor. If there is a high damping ratio, there is low stiffness and vice versa. Therefore, the damping ratio is determined by the specific mass and the stiffness.

Researchers have carried out many studies using both the finite element method and the finite element method. There are many studies by the authors using the finite element method before. In this study, studies [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19] on the use of the finite element method were used. In addition, the authors have comparative studies [20], [21], [22], [23], [24], [25] using more than one method, including the finite element method. In these studies, the effect of the finite element method was compared with the operational and experimental modal analysis method. With all this knowledge, this new study has been carried out. Researchers have conducted studies [26], [27], [28], [29], [30], [31], [32] about pendulum tuned mass damper (PTMD).

The aim of this study is to observe the effects of pendulum tuned mass damper (PTMD) effect to the modal parameters (mode shapes and periods) of reinforced concrete water tank with the finite element method. For this purpose, a concrete reinforced water tank model was created and a modal analysis of the water tank model created by the finite element method was carried out.

II. DESCRIPTION OF RC WATER TANK:

It is a reinforced concrete water tank with a height of 20 m and a diameter of 4 m. The wall thickness is 20 cm. The concrete class of the water tank was chosen as C30/37. The steel rebar class of the water tank was chosen as S420. The reinforced concrete water tank finite element model was created using the SAP 2000 package program. The water tank is modeled as hollow. The finite element model of the water tank is given in figure 1.

Fig. 1. 3D Finite element model of the reinforced concrete water tank

III. DESCRIPTION OF PTMD:

It is placed vertically at the top of the water tank, has a mass of 10 kN, fixed in the x-y-z axes, has a stiffness of 100000, 1000, 1000 kN/m and damping of 50, 10, 10 kNs/m, respectively. Location of PTMD in water tank is given in figure 2.

Fig. 2. Location of PTMD

IV. ANALYSIS AND RESULTS:

The water tank was first analyzed in its current state using SAP2000 with the finite element method, then PTMD was added to the top floor and the same analysis was repeated and the results were compared.

A. Results of the Model Water Tank without PTMD:

The water tank was analyzed without adding pendulum tuned mass damper (PTMD) by finite element method. The first 5 modes were taken into account in the analysis. Obtained results are presented in figures 3,4,5,6,7 as periods and mode shapes.

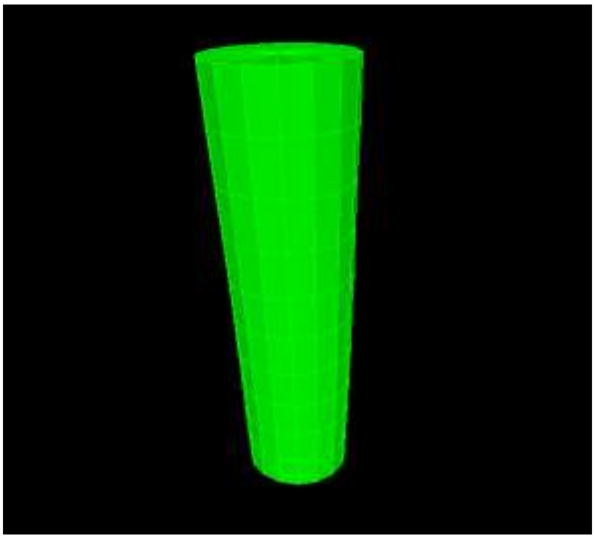

Fig. 3. Mode Shape and Period of Mode 1= 0.2325 s

It is seen that Mode 1 is translational mode shape.

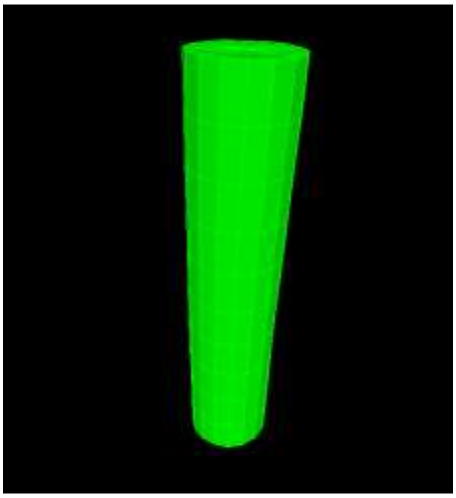

Fig. 4. Mode Shape and Period of Mode 2= 0.2186 s

It is seen that Mode 2 is translational mode shape.

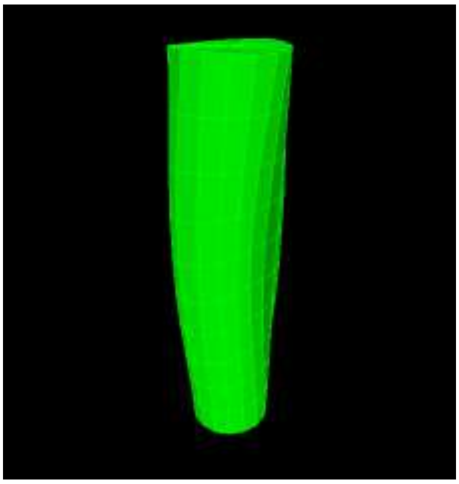

Fig. 5. Mode Shape and Period of Mode 3= 0.1456 s

It is seen that Mode 3 is torsional mode shape.

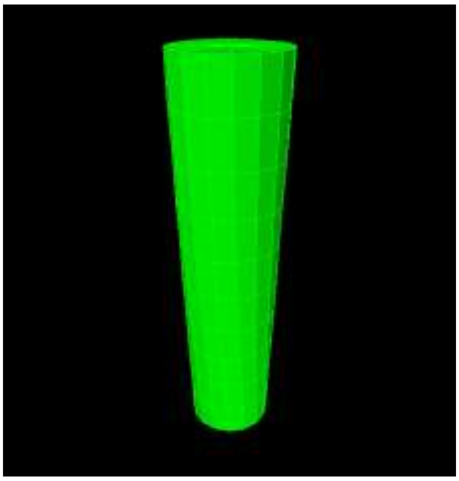

Fig. 6. Mode Shape and Period of Mode 4= 0.1327 s

It is seen that Mode 4 is torsional mode shape.

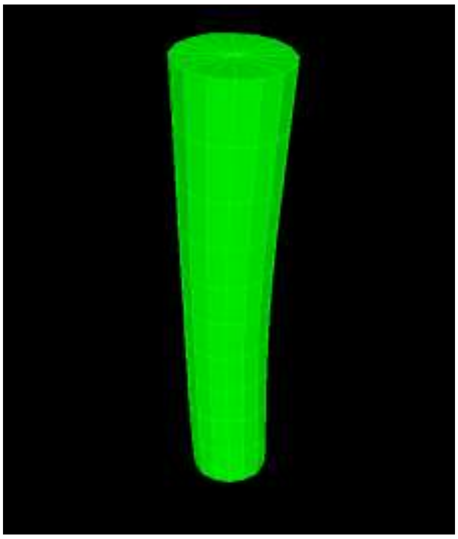

Fig. 7. Mode Shape and Period of Mode 5= 0.1246 s

It is seen that Mode 5 is translational mode shape.

B. Result of the Model Water Tank with PTMD:

The water tank was analyzed with adding pendulum tuned mass damper (PTMD) by finite element method. The first 5 modes were taken into account in the analysis. Obtained results are presented in figures 8,9,10,11,12 as periods and mode shapes.

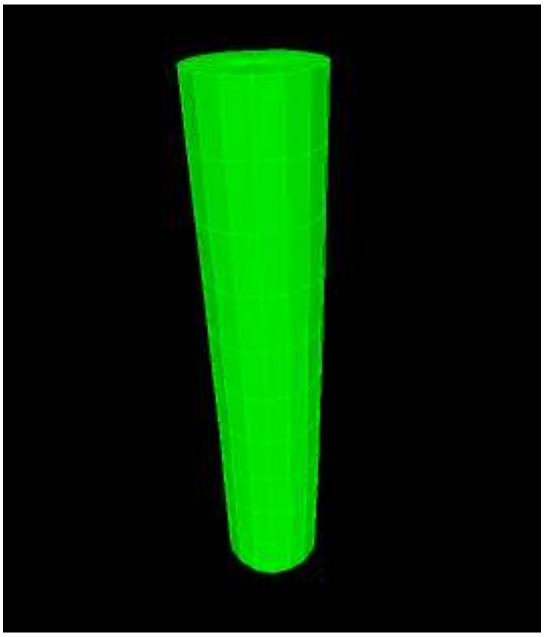

Fig. 8. Mode Shape and Period of Mode 1= 0.2454 s

It is seen that Mode 1 is translational mode shape.

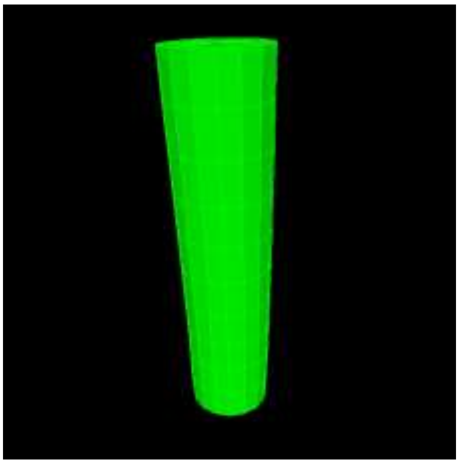

Fig. 9. Mode Shape and Period of Mode 2= 0.2305 s

It is seen that Mode 2 is translational mode shape.

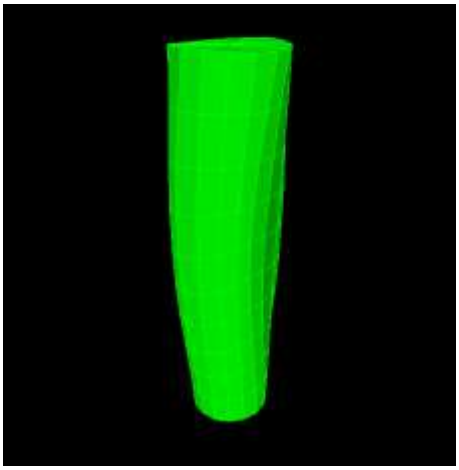

Fig. 10. Mode Shape and Period of Mode 3= 0.1567 s

It is seen that Mode 3 is torsional mode shape.

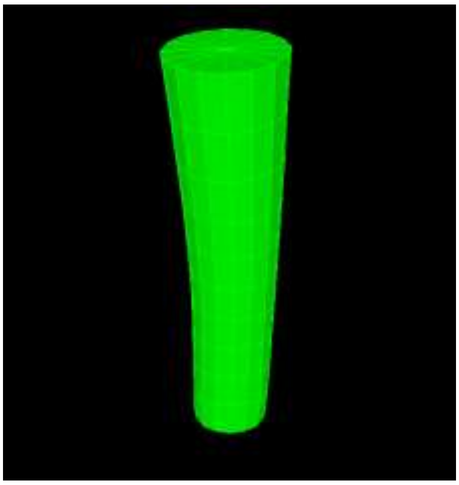

Fig. 11. Mode Shape and Period of Mode 4= 0.1428 s

It is seen that Mode 4 is translational mode shape.

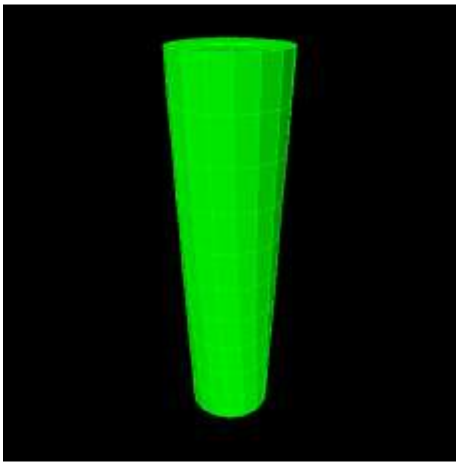

Fig. 12. Mode Shape and Period of Mode 5= 0.1301 s

It is seen that Mode 5 is torsional mode shape.

C. Comparison of Analysis Results:

The comparison of period of the model with PTMD and without PTMD model is given in Table 1.

TABLE I. COMPARISON PERIOD OF WITHOUT PTMD MODEL AND WITH PTMD MODEL

Mode	1	2	3	4	5
Without PTMD Period (s)	0.2325	0.2186	0.1456	0.1327	0.1246
With PTMD Period (s)	0.2454	0.2305	0.1567	0.1428	0.1301
Difference (s)	0.0129	0.0119	0.0111	0.0101	0.0055
Difference (%)	5.55	5.44	7.62	7.61	4.41

The comparison of mode shapes of the model with PTMD and without PTMD model is given in Table 2.

TABLE II. COMPARISON MODE SHAPES OF WITHOUT PTMD MODEL AND WITH PTMD MODEL

Mode	1	2	3	4	5
Without TMD Mode Shapes	Translational	Translational	Torsional	Torsional	Translational
With TMD Mode Shapes	Translational	Translational	Torsional	Translational	Torsional

V. CONCLUSIONS:

The percentage changes in the parameters of the model water tank are listed below.

In the mode 1, the period difference between non-PTMD and PTMD status was obtained as 0.0129 s. The effect of PTMD reinforcing as a percentage was determined as 5.55%.

In the mode 2, the period difference between non-PTMD and PTMD status was obtained as 0.0119 s. The effect of PTMD reinforcing as a percentage was determined as 5.44%.

In the mode 3, the period difference between non-PTMD and PTMD status was obtained as 0.0111 s. The effect of PTMD reinforcing as a percentage was determined as 7.62%.

In the mode 4, the period difference between non-PTMD and PTMD status was obtained as 0.0101 s. The effect of PTMD reinforcing as a percentage was determined as 7.61%. In addition, when the mode shape is examined, it is seen that it transforms from torsion to translation.

In the mode 5, the period difference between non-PTMD and PTMD status was obtained as 0.0055 s. The effect of PTMD reinforcing as a percentage was determined as 4.41 %. In addition, when the mode shape is examined, it is seen that it transforms from translation to torsion.

As a result of the study, it has been observed that the water tank model makes more balanced displacements, as can be understood from the mode shapes, without increasing the period of the water tank to a dangerous level It was observed that the period values increased only 7.62 percent at the most and 4.41 percent at the least. PTMD reduced the seismic effect by acting in the opposite direction to the seismic effect on the structure. It can be used in PTMD reinforced concrete water tanks, provided that it does not increase the period too much.

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