23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

OPTIMUM DESIGN OF TUNED LIQUID COLUMN DAMPER FOR HIGH-RISE BUILDING

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Abstract: *Tuned mass damper for high-rise building has been designed. Two numerical models with different detail have been used. The influence and performance of tuned mass damper has been analyzed. Its effects have been checked for both models – simplified and full 3D Finite Element Method model. Alternatively tuned liquid damper has been assumed and its basic characteristics, like eigenfrequencies and mode shapes, have been calculated.*

Keywords: Tuned mass damper, Tuned liquid column damper, Dynamic response, High-rise building.

1. Introduction

A tuned mass damper (TMD) for high-rise building with total height of 280 m (Fig. 1) has been assumed for decreasing of dynamic effects. The modification of TMD via using the water tank effect so-called Liquid Column Damper (TLCD) and its modifications have been investigated many times as in Yalla and Kareem (2003) or Soto and Adeli (2013). The primary aim is to reduce dynamic vibrations caused by different sources like wind effects, earthquake etc. The structure has been modeled by FEM (Fig. 1a) and for checking purposes modeled also as 7 degree of freedom (7 DOF) system (Fig. 1b), where the influence of damping could be checked easier, but without the lack of significant accuracy. Second model has been tuned such a way, that it finally had the same basic dynamic response in one plane (eigenfrequencies and eigen modes) as the original 3D model.

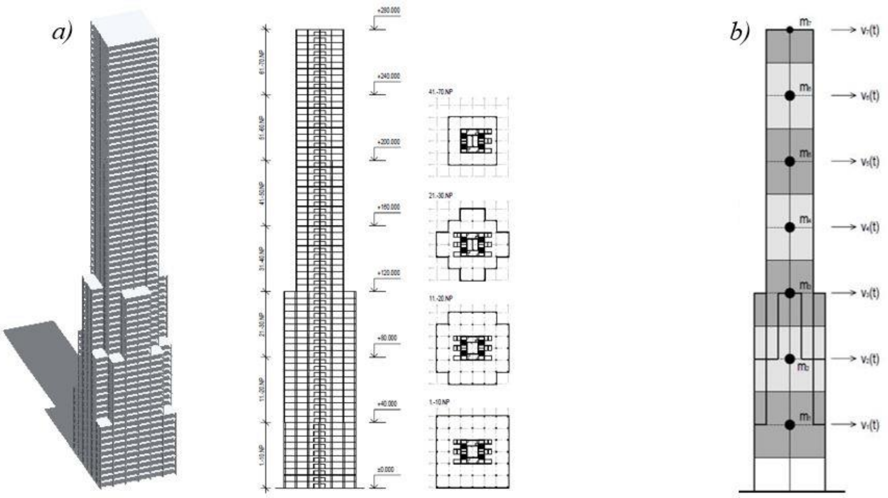

Fig. 1: The high-rise building a) original 3D model with thousands DOF b) simplified model with 7 DOF.

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Eigenfrequencies and eigen modes (Fig. 2) have been calculated for both models and they are very close each to other.

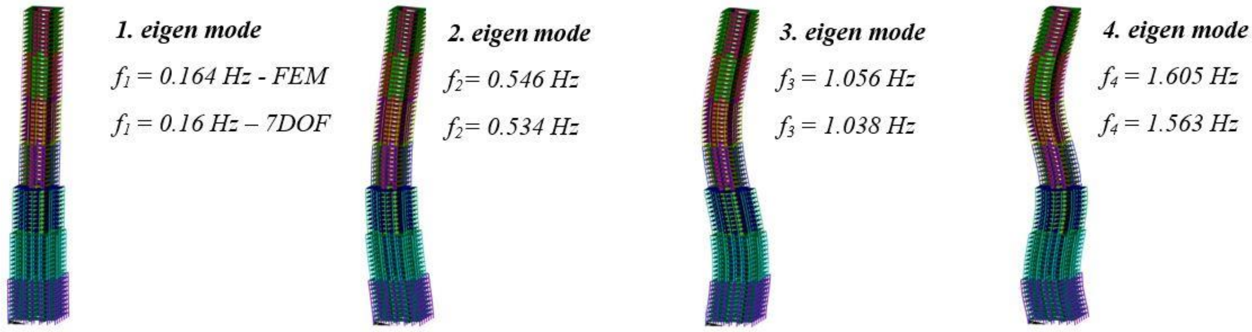

Fig. 2: Eigenfrequencies and eigen modes.

2. Methods

Theory of optimal design of TMD is derived for SDOF in e.g. Flesch (1993) because of complexity of general solution, but some authors used also much complicated assumptions (McNamara, 1977 and Kareem, Kijewski, Tamura, 1999). Then this results can be used for MDOF system too, with only small compromise in accuracy. The simplified model with 7 DOFs (Fig. 1 b) is then used for checking the real behavior of damper working on MDOF system.

2.1. Single degree of freedom system with damper

For the effectiveness of TMD, some parameters must be optimally selected (Penzien, Clough, 2003 and Sokol, Tvrda, 2016). These parameters are given by the equations:

$$\mu = \frac{m_2}{m_1} \tag{1}$$

$$\alpha = \frac{1}{1+\mu} = \frac{\omega_2}{\omega_1} \tag{2}$$

$$\xi_{opt} = \sqrt{\frac{3 \cdot \mu}{8(1+\mu)^3}} \tag{4}$$

$$\omega_2 = \omega_1 \cdot \alpha = \sqrt{\frac{k_2}{m_2}} \tag{3}$$

$$c_2 = 2 \cdot m_2 \cdot \omega_2 \cdot \xi_{opt} \tag{4}$$

$$k_2 = m_2 \cdot \omega_2^2 \tag{5}$$

In practice, stiffness effect in equation (5) is usually assumed as pendulum effect calculating for its length

$$L = \left(\frac{1}{\omega_2}\right)^2 \cdot g \tag{6}$$

2.2. Effective mass of system

Due to the fact that all characteristics from (1) to (6) are derived for SDOF there is necessary to calculate the effective mass of MDOF system

$$M_{eff} = \frac{2E_k}{\dot{v}_d^2} \tag{7}$$

where E_k is kinetic energy of the whole system, $\dot{v}_d$ is velocity at the place where TMD is located.

2.3. Design of TLCD

There is proposed a variant of TMD system using liquid column damper, where the effect of pendulum is represented by column of water moving in the vessel. The location inside of the building is clear in Fig. 3 and it takes the top 4 stories of the building. There is used only the one direction TLCD because of lack of time and only for checking purposes, but still without the lack of the accuracy, because an alternative TLCD can be assumed in perpendicular direction. In next paragraphs the performance of this system is checked.

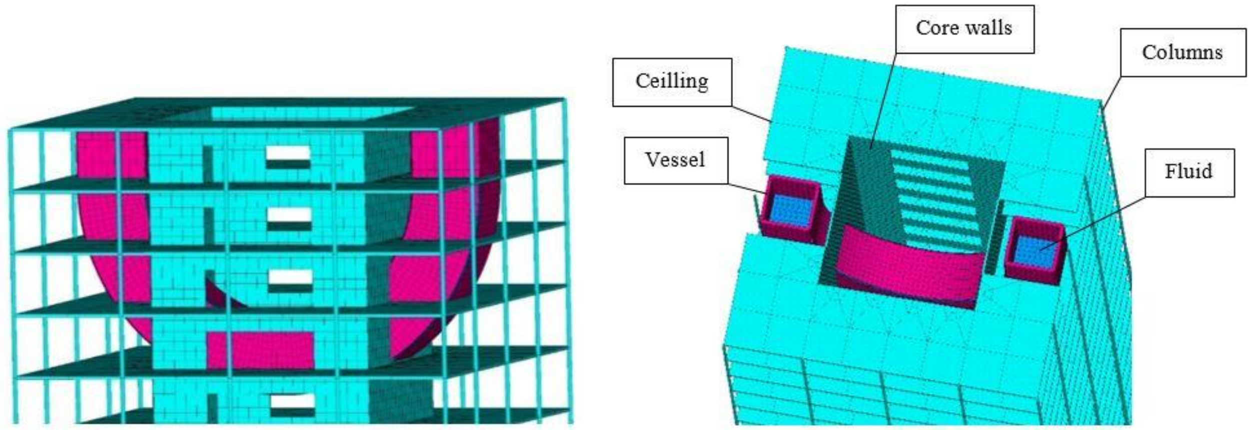

Fig. 3: Location of TLCD.

For calculating of eigenfrequencies of the water inside the vessel FEM has been used. 3D FEM model was created form shell and fluid elements. A vessel of half cylindrical shape with upper additional parts has been considered. Contact between vessel and water elements has been assumed only in perpendicular direction to the common surface, representing the effects of hydraulic pressure.

Tab. 1: Eigenfrequencies of the pendulum and the water inside of vessel.

	Calculation	**Weight [t]**	**1. eigenfrequency [Hz]**
Pendulum L = 9.6 m	*Analytical*	392.890	0.161
Water r = 9.6 m	*ANSYS*	412.881	0.162

In Tab. 1 it is possible to compare eigenfrequencies between simple pendulum and water moving inside of the vessel (Fig. 4a). Splashing effects of water are also included as you can see in higher eigen modes (Fig. 4b).

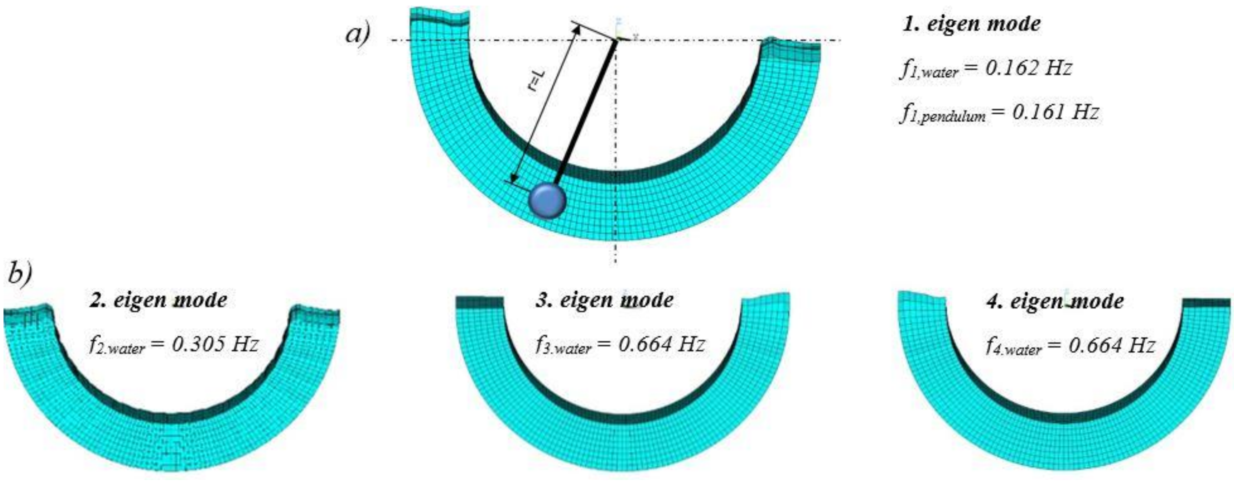

Fig. 4: Eigen modes of water inside of half cylindrical vessel a) the first eigen mode; b) more eigen modes.

2.4. Assessment of dynamic effects

Real dynamic response has been checked on 7 DOF system using time history analysis. The building was subjected to harmonic load representing e.g. wind effects. By activation of TMD (TLCD), maximum displacement on the top of building was reduced more by 40 % (Fig. 5).

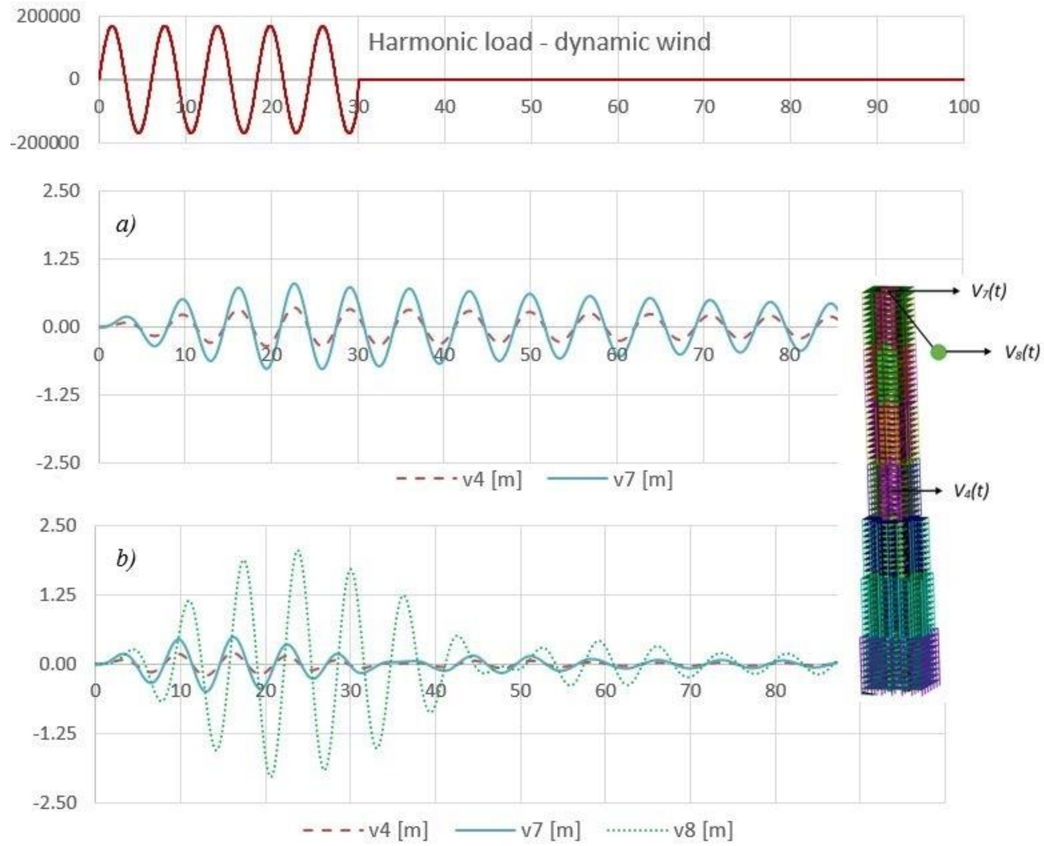

Fig. 5: Dynamic response of structure on harmonic load a) without damper; b) with damper.

3. Conclusions

The structure has been modeled by FEM and for checking purposes modeled as simplified 7 DOF system, with the same basic dynamic response in one plane as the original 3D model. TMD has been designed for elimination of vibrations of dynamic load. Assuming that the length of pendulum equals to the radius of water inside of half cylindrical vessel an alternative TLCD has been designed and its performance has been checked. TLCD has been modeled by FEM and placed into FEM model of high-rise building. Dynamic response has been assessed on MDOF system. The structure without and with damper has been subjected to harmonic load to assess of dynamic effects. Maximum displacement on the top was decreased by 40 %.

Acknowledgement

This paper has been supported by the Slovak Research and Development Agency (SRDA) – grant from research program No. APVV-0236-12.

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