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Passive Control of Vibrations of High-Rise Structure Using Tuned Liquid Damper under Wind and Earthquake Excitations

M. Fahimi Farzam[1] , B. Alinejad , R. Maroofiazar , H. Kazemi Sormoli

Department of Engineering, University of Maragheh, Maragheh, Iran

ABSTRACT: One of the essential issues in structural engineering is preparing resident comfort and a sense of security for the residents of high-rise structures against earthquakes and strong winds. Therefore, the use of control systems has been considered under dynamic loads. Tuned liquid damper is an affordable and helpful device for controlling the vibrations of the structure under dynamic lateral loads. In this study, a standard high-rise structure has been modeled in ANSYS software under earthquakes (far and near-field) and wind and the interaction between wind and structure has been investigated. Tuned Liquid Damper was used to reduce the responses of the structure under far-field records (El-Centro 1940 and Hachinohe 1968), near-field records (Northridge 1994 and Kobe 1995), and wind. The responses of the structure such as displacement, velocity, acceleration, pressure, and streamline around the structure have been analyzed and also, the aerodynamic behavior of the high-rise structure against the wind has been investigated. Averagely, the results show that the Tuned Liquid Damper could reduce the maximum displacement of the structure to 16% under far-field records, 0.5% under near-field records, and 13% under the wind.

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1- Introduction

Different control techniques are developed to decrease structural responses and to improve the structural dynamic behavior under dynamic lateral loads. One of the best methods for protecting structures against external excitations is using control systems. Control systems are categorized into passive, active, semi-active, and hybrid control [1]. Performance evaluation of control systems under external excitations such as far and near-field earthquakes and wind are one of the most critical problems. In 2020, Farzam et al. [2] investigated the performance of a Magnetorheological (MR) damper installed on a 10-story shear building. In the wind tunnel practice on building aerodynamics, the Commonwealth Advisory Aeronautical Council (CAARC) tall building model is usually adopted to calibrate experimental techniques. In 2009, Brun and Awruch [3] investigated the effect of wind on the standard CAARC building. In 2019, Shirzadeh and Eimani simulated standard CAARC structure under four various wind velocities, and they examined mesh independence of the wind tunnel with four different types of meshing [4].

In this research, the CAARC standard high-rise structure with a height of 180 m under wind and earthquakes is investigated, and a Tuned Liquid Damper (TLD) is used to reduce the vibrations of the structure. Some particular items of this study are such as (1) evaluating various responses of CAARC standard structure under wind force, (2) performance assessment of TLD on a standard structure against the wind, (3) modeling of TLD fluid nonlinear motion and sloshing, including fluid-solid interaction.

2- The Numerical Model to Simulate

The CAARC standard tall building model is presented in Fig. 1. The full-scale dimensions of the building model are as follows: height (H) = 180 m; length (L) = 30 m; width (W) =45 m. According to the dimensions given in Fig. 1, the wind tunnel was simulated in ANSYS software.

The wind profile characteristic is shown in Fig. 1 and the earthquake records used are benchmark International Association of Structural Control (IASC) earthquakes. These earthquake records are two far-field (El Centro 1940 and Hachinohe 1968) and two near-fields (Northridge 1994 and Kobe 1995).

In this study, one TLD is simulated on the roof of the structure. The dimensions of TLD are as follows: length, width, and height are 15.5, 12.5, and 4 m, respectively. The two parameters of mass ratio and water ratio are assumed to be 1.5%, and 0.2, respectively, and the depth of water is 3 m.

*Corresponding author's email: m.farzam@maragheh.ac.ir

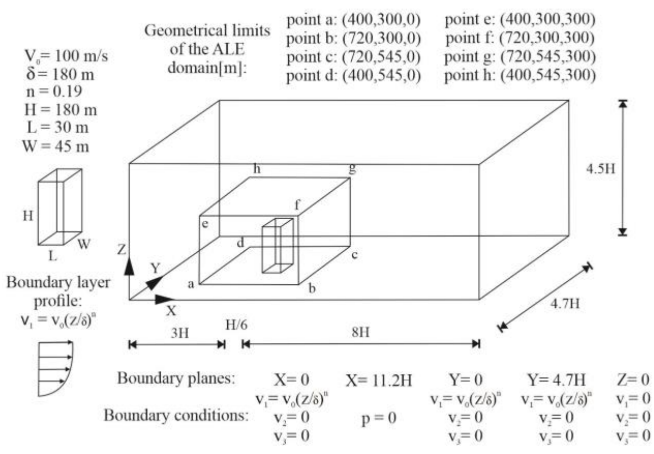


Fig. 1. Geometrical characteristics and boundary conditions used in the aeroelastic analysis of a high-rise building model

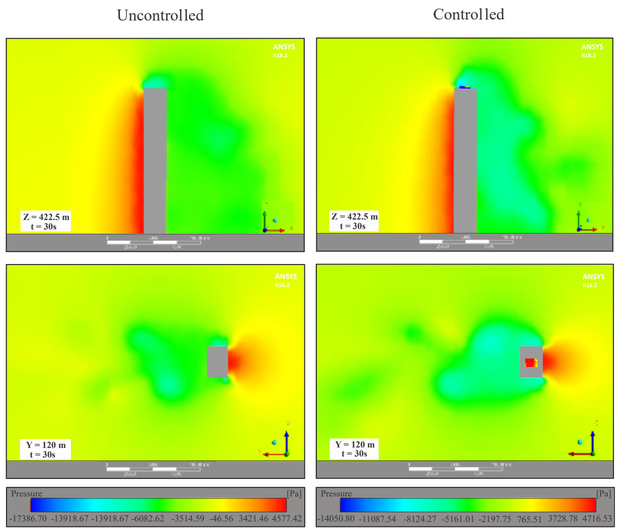
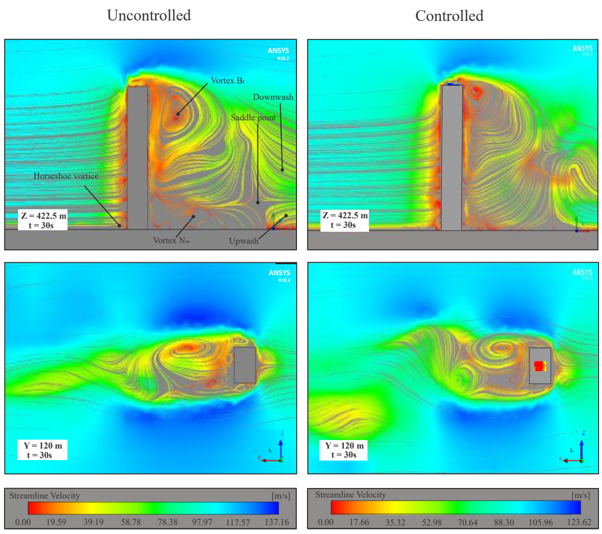


Fig. 2. Distribution of pressure in plans of XY and XZ for controlled and uncontrolled modes



.Fig. 3. streamlines in plans of XY and XZ for controlled and uncontrolled modes

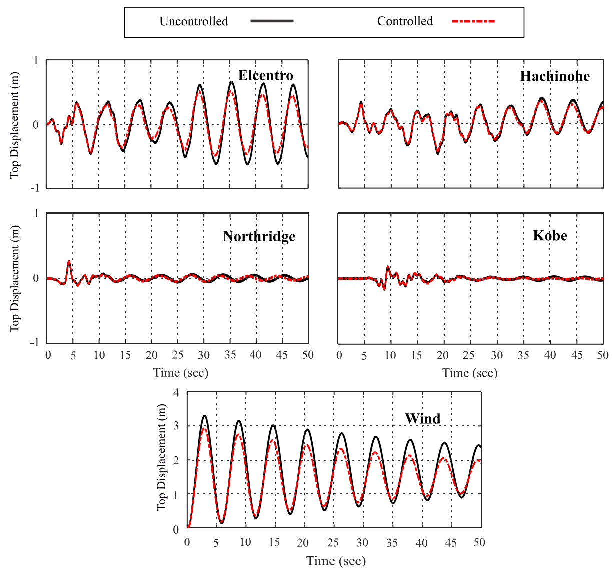


Fig. 4. The top of structure Longitudinal displacement's time history under wind and four near and far-field records for controlled and uncontrolled modes

3- Results and Discussion

To investigate the standard CAARC tall building aerodynamic effect, obtained pressure contours and streamlines around the structure, and the building maximum responses have been studied under four earthquake records by ANSYS simulations. The distribution of pressure contours around the uncontrolled and controlled high-rise structure are described against wind load with a maximum velocity of 100 m/s. In Fig. 2, the pressure contour can be well observed on a plane XY at Z = 422.5 m (center of the high-rise structure) and on a plane XZ at Y = 120 m (2/3 of the structure's height).

Streamlines around the high-rise structure are shown in Fig. 3, where they are presented on horizontal (XY) and vertical (XZ) planes. The level of the XY plane is 422.5m, and the level of the XZ plane is 120m. In Fig. 3, horseshoe vortices, Vortex Bt, Vortex Nw, Saddle point, Downwash, and Upwash have been marked [5].

The displacement time history of the CAARC structure under the wind, far and near-field earthquake records are shown in Fig. 4.

4- Conclusions

Some important remarks can be pointed out from the results obtained, which may be summarized as follows:

•The structural responses under wind far and near-field earthquakes have a sound reduction, respectively. The reduction percentages of structural responses for maximum displacement, velocity, and acceleration are 22%, 11%, and 3% under El-Centro, and 10%, 12%, and 0% under Hachinohe, respectively. Also, the reduction of maximum displacement, velocity, and acceleration for the Kobe earthquake was equal to 0%, 5%, and 8%, and for the Northridge earthquake was 1%, 1%, and 3%, respectively. Finally, the maximum displacement, velocity, and acceleration under wind vibration are 13%, 6%, and 2%, respectively.

•According to the studies, the average response reduction for maximum displacement, velocity, and acceleration at different heights of the structure is 9%, 5%, and 3%, respectively. In other words, the TLD is better performing in reducing displacement than velocity and acceleration.

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