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Dynamic responses of vertical transportation systems in tall buildings under seismic excitations

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Abstract: Tall buildings are susceptible to significant lateral sway in the events of earthquake. Seismic ground motions generally contain low-frequency waves which resonate with the fundamental mode of the buildings. This affects vertical transportation systems, such as lifts, installed in the buildings. Resonance interactions between the building structure and modular vertical transportation installations such as lifts arise then. This can induce the lateral motions of the car/counterweight system, and consequently lead to severe damage in the lift installations. This paper aims to present a detailed Finite Element (FE) model that can predict the dynamic responses of the car/ counterweight system installed in tall building structures under seismic excitations. An analytical model is also developed based on the structural dynamics theories, and the results are then compared with those obtained from the FE models. The results of this study can be used to develop design strategies to mitigate the effects of earthquakes on vertical transportation systems.

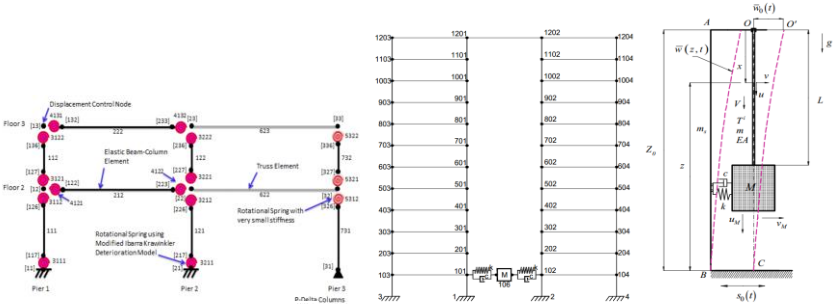
Keywords: Dynamic responses, seismic ground motions, lift, Finite Element (FE) analysis, tall buildings

1. Introduction

In this paper, a detailed nonlinear FE model using Open System for Earthquake Engineering Simulation (OpenSees) [1] is developed to obtain the dynamic behaviour of a lift car/ counterweight system under earthquake. The El Cenro earthquake data are used in the model [2]. An analytical model is also presented to predict the dynamic responses of a cable-mass system which represents a lift suspension rope-car/ counterweight system under seismic conditions. Finally, the seismic responses generated from the analytical model are compared with those obtained from the FE simulations.

2. Results and Discussion

2D models of high-rise buildings made of steel moment-resisting frames are built in OpeenSees FE software. The primary members of the steel frame (i.e. beams and columns) are modelled using elastic beam-column elements connected by zeroLength elements which serve as rotational springs to represent the structure's nonlinear behaviour, as shown in Fig.1 (a). The springs follow a bilinear hysteretic response based on the Modified Ibarra Krawinkler Deterioration Model [3]. The reinforcement concrete core is modelled in the mid-spam of the frame to take into account the effect of the lift shaft. The mass M is connected to the shaft a spring-viscous damping element of effective coefficient of stiffness k the coefficient of damping c (see Fig.1 (b)). The analytical model is developed using a cable-mass system mounted within a vertical cantilever host structure subject to ground motion $s_0(t)$, as shown in Fig.1 (c) [4]. The mass M is suspended on the cable of length L and is constrained horizontally within the host structure by a spring-viscous damping element.



(a) FE OpenSees (b) FE OpenSees (c) Analytical model

Fig. 1. Modelling of a high-rise building with lift

The maximum seismic responses of the lift car/ counterweight, including lateral displacement ($d_{M,max}$) and acceleration ($a_{M,max}$), obtained from FE and analytical models are listed in Table 1 for 12, 20 and 50 storeys buildings. To investigate the effect of the lift location along with the height of the building, each structure is analysed twice when the mass (M) is located at the bottom and top storeys.

Table 1. Comparison between maximum seismic responses of the lift in the buildings with various number of storeys obtained from FE and analytical models

Number of storeys	Vertical location of the lift	Natural frequency (Hz)	$d_{M,max}$ (m) FE model	$d_{M,max}$ (m) Analytical model	$a_{M,max}$ (m/s^2) FE model	$a_{M,max}$ (m/s^2) Analytical model
12	1st storey	1.42	0.009	0.008	1.921	1.988
	12th storey		0.115	0.105	3.128	3.250
20	1st storey	1.96	0.014	0.012	3.059	3.288
	20th storey		0.188	0.162	4.517	4.874
50	1st storey	2.78	0.032	0.025	8.816	10.570
	50th storey		0.276	0.204	12.335	15.036
Average error (%)			15%		11%	

3. Concluding Remarks

The following main conclusions can be drawn: (I): The location of the lift along the height of the building can significantly affect the seismic response. The responses at the top floors are 13 times the response at the bottom floors. (II) A good agreement can be achieved between the results of FE and analytical models for the lower storey buildings (e.g. 12 storey) when the frame response either remains in the elastic stage or shows slight plasticity into their beam and column elements. However, a 40% error is observed for the results of higher storey buildings (e.g. 50 storey) when significant plasticity is developed in the main structural elements. This is attributed to the fact that the developed analytical model is unable to take into account the plastic behaviour of the building into calculations.

References

[1] MCKENNA F, FENVES G L, SCOTT M H, JEREMIC B, Open system for earthquake engineering simulation (OpenSees), Pacific Earthquake Engineering Research Center, University of California, Berkeley (CA), 2000.

[2] Pacific Earthquake Engineering Research Center (PEER), Strong Ground Motion Databases, El Centro Earthquake.

[3] IBARRA L F, KRAWINKLER H, Global Collapse of Frame Structures under Seismic Excitations: Pacific Earthquake Engineering Research Center, 2005.

[4] KACZMARCZYK S, The modelling and prediction of dynamic responses of slender continua deployed in tall structures under long-period seismic excitations. *J. Phys.: Conf. Ser.* 2018, **1048**(012005).