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Parametric Study of Structure-Soil-Structure Interaction in Time and Frequency Domains

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ABSTRACT: In this paper, focusing on structure-soil-structure interaction, dynamic behavior of two adjacent structures with flexible base is studied. The main identifiers of this structure-soil-structure interaction system are defined with dimensionless parameters. With considering a logical range of the parameters, various states including most practical cases are calculated. Soil flexibility and dynamic correlation between two adjacent structures through the soil are accounted for using springs and dashpots at the base of the structures. The equations of motion are solved in time and frequency domains for two adjacent single degree of freedom systems to make it possible to study parametrically the effect of structure-soil-structure interaction on the responses. As a result of harmonic analysis, natural frequencies with and without considering damping, damping ratios and amplitude of the system's dynamic responses are calculated and compared with those of the single building (no adjacency). Also, the cases prone to a possible pounding are recognized. By analyzing such a system in both time and frequency domain, it is shown that with appropriate arrangements, both of the analysis procedures result in the same responses for an interaction problem.

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1. INTRODUCTION

Two neighboring structures can impact each other. Such a phenomenon is called pounding. In addition, cross interaction of adjacent structures through a soft soil can exchange the vibration energy between buildings and make the problem even more complex.

Ghandil et al. [1] extended the equivalent linear method of soil dynamics for the effects of overburden stresses of two adjacent buildings. They divided the soil medium to near-field and far-field domains and modified the shear modulus and damping ratio of soil in the near-field soil medium.

Kirkwood and Dashti [2] studied the dynamic response of two adjacent structures resting on liquifiable soil using centrifuge test. They concluded that it was possible to minimize the foundation and structure's response by appropriate positioning of the structures. Bybordiani and Arici [3] examined the dynamic responses of two adjacent buildings including story drifts and the base shear with regard to the clear distance. It was observed that at close distances, cross-interaction of two tall buildings being much different in lateral stiffness could result in seismic resposes even larger than those occuring in a similar single building on rigid base. Ngo et al. [4] explored the height and mass differences as parameters affecting the dynamic responses of two adjacent buildings using centrifuge experiments. In the tests, increase of the response of the smaller building and its reduction for the larger building were observed with regard to their single building counterparts.

In this study, effects of pounding and soil flexibility on the inelastic response of selected adjacent steel structures are studied. Clear distances up to the seismic codes prescribed value are considered. A coupled model of springs and dashpots is utilized for through-the-soil interaction of the adjacent structures, for two types of soft soils.

2. METHODOLOGY

The system under study is shown in Figs. 1 and 2. Deliberately, The system has been taken to be simple enough for the dynamic charactersitics as well as the dynamic response trends to be more easily understood. For this purpose, each neighboring structure is replaced with its fundamental mode mass and stiffness. Moreover, the flexibility and infinity of soil are modelled by the use of springs and dampers, respectively. The cross-interaction between the two buildings is modelled using the coupled springs and dampers that transfer the translational and rotational motions from one foundation to the other one.

In Fig. 1, m_i, m_{bi}, I_i, I_{bi}, c_i, k_i, and h_i are respectively the structural mass, mass of the base, inertial mass moment of the structure, inertial mass moment of the base, damping coefficient, lateral stiffness, and height of the building and the index i is structure's counter (i=1, 2). Moreover, k_h, k_r, c_h, and c_r are respectively the stiffness and damping coefficients of soil for sway and rocking motions representing soil flexibility for the single buildings, and k_{hc}, k_{rc}, c_{hc}, and

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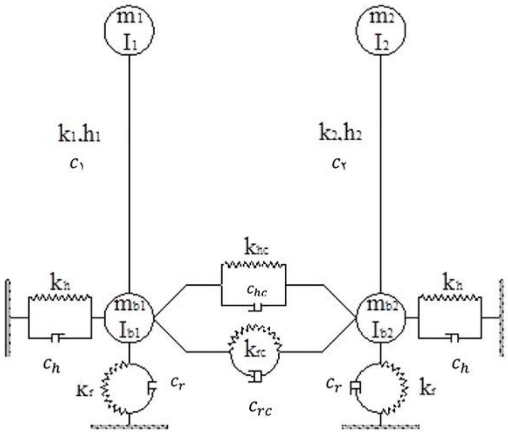

Fig. 1. The analytical model of the adjacent structures.

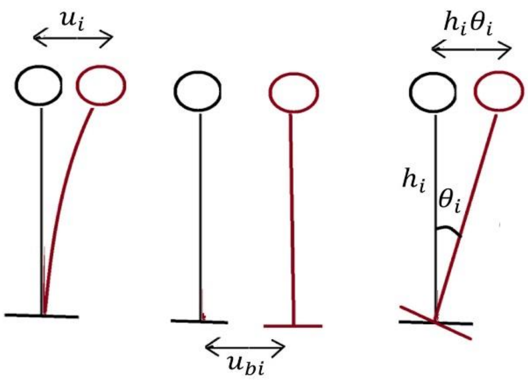

Fig. 2. The dynamic degrees of freedom.

c_{rc} are respectively the stiffness and damping coefficients of soil for sway and rocking motions representing soil flexibility for the cross interacting adjacent buildings. In this paper, the soil stiffness and damping coefficients suggested by Mulliken and Karabalis [5] have been used.

The equations of motion of the 6-degree of freedom system of Fig. 1 in the frequency domain are summarized as Eq. (1):

$$\left(-\hat{a}^2[\mathrm{M}]+i\hat{a}[\mathrm{C}]+[\mathrm{K}]\right)\{\bar{\mathrm{U}}\}=\{\bar{\mathrm{P}}\} \tag{1}$$

where $[\mathrm{M}]$, $[C]$, $[\mathrm{K}]$, $\{\bar{\mathrm{P}}\}$, and $\{\bar{\mathrm{U}}\}$ are respectively the mass, damping, and stiffness matrices and the equivalent force vector and the displacements vector of the system. Moreover, $\hat{a}$ is the frequency ratio and i is the imaginary number. A similar equation appears also in the time domain under harmonic motion without the i factor.

3. RESULTS AND DISCUSSION

The natural frequencies of the system are calculated by putting the right part of Eq. (1) equal to zero. They are normalized to the case of a similar single building. The resulting values are displayed as functions of the non-dimensional clear distance $(\bar{d}=d/a)$ in Fig. 3 for the case of a system representing tall buildings, where d is the clear distance between buildings and a is the half width of the foundation.

As observed, inclusion of the cross-interaction results in increase of the natural frequencies in most of the cases. While the maximum increase is for the mode primarily related to the motion at base, vibration of the structural masses witnesses not much variation in natural frequency.

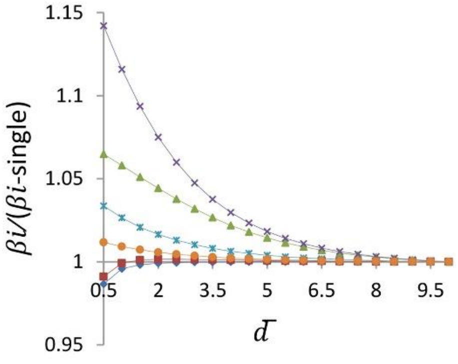

Fig. 3. Variation of the natural frequencies normalized to those of the single building.

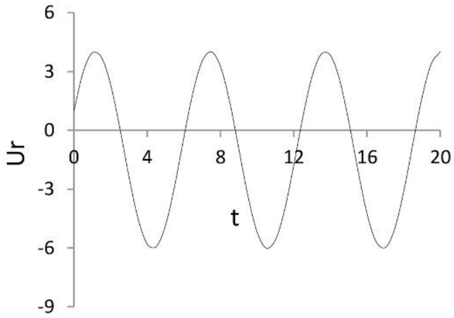

Fig. 4. Time history of the distance between the structural masses.

The dynamic response of the system under a unit harmonic loading is calculated by solving Eq. (1) in the frequency or time domain. For instance, for the case equivalent to two tall buildings (similar to that of Fig. 3), time history of the relive distance U_r between the structural masses is shown in Fig. 4 for a close distance $\bar{\mathrm{d}}=0.1$. Frequency of the applied motion is assumed to be equal to the fixed base frequency the mass stiffer in lateral motion. Clearly, the masses collide with each other for the time instances when U_r is negative in the Fig.

4. CONCLUSIONS

Dynamic characteristics and responses of two adjacent buildings were determined in this study using a simple system of two lumped masses resting on structural and soil springs. It was concluded that cross-interaction could increase the natural frequencies up to 20%. For the harmonic response, both increase and decrease in response, up to about 40%, were seen in different cases. It was also shown that it was very likely for the pounding to occur at practical cases.

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