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Introduction of Pounding Effect into Relative Displacement Response Spectrum

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1. Introduction

By the application of Menshin Design, it is realized that a certain amount of forces in isolated structures can be reduced; on the other hand, it results in the increase in displacement responses. Consequently, there is the possibility of pounding of two isolated structures which are separated by a gap. Focusing on the consequences of pounding effect, the research has been conducted so as to clarify the problem.

2. Analytical model

In the analysis, structural segments are idealized as two single-degree-of-freedom oscillators separated by a gap Δ_G, as shown in Fig. 1. The oscillators m_1 and m_2 are assumed to be subjected to the same ground motion. The natural period and the damping ratio are denoted as T_1 and ξ_1 respectively for the oscillator m_1; T_2 and ξ_2 for the oscillator m_2. The displacements of oscillators relative to their bases are denoted as $u_1(t)$ and $u_2(t)$, and the maximum absolute values of $u_1(t)$ and $u_2(t)$ are represented as S^P_{D1} and S^P_{D2} in case of the presence of pounding, or S_{D1} and S_{D2} when no pounding occurs. For the sake of meaningful interpretation, the maximum displacements are normalized as $r_{D1} = S^P_{D1}/ S_{D1}$ and $r_{D2} = S^P_{D2}/ S_{D2}$; the gap as $r_G = \Delta_G / \Delta S_D$ in which the parameter ΔS_D is the maximum relative displacement of the two oscillators without pounding.

3. The characteristics of displacement responses with pounding effect

To study the pounding effect on displacement responses, two ground motions recorded at JMA Kobe Observatory in the Kobe Earthquake and at JMA Kushiro Marine Observatory in the Kushiro-oki Earthquake are selected. The acceleration response spectrums of the two ground motions are illustrated in Fig. 2. The mass ratio (m_1/m_2) which is a necessary parameter in the concept of conservation of momentum and energy applied at the moment of pounding is selected to be equal to one. In addition, no energy loss in pounding is assumed for the benefit of ideal simple interpretation. The damping ratio of 0.05 which is the practical value for structures of moderate size is used in the computation. Fig. 3 shows the normalized displacements with the variations in r_G and T_2 for $T_1 = 1.0$ sec and the Kobe record. It is obviously seen that the larger difference between T_1 and T_2 is, the more decrease in r_{D1} and increase in r_{D2} will be (Fig. 4). In contrast, r_{D1} and r_{D2} for the Kushiro record shown in Fig. 5 exhibit the absolutely opposite trends to those of the Kobe record. Such a contradiction arises from the fact that for the Kushiro record having the predominant period of about 0.4 sec, the displacement and velocity responses are extremely amplified when the natural period of an oscillator corresponds to the predominant period. For the Kobe record, Fig. 2 shows that there is not so sharp peak as compared to the Kushiro record. Hence the displacement and velocity responses virtually depend only on the natural periods of structures. It is worthy to point out that due to the pounding the system of larger displacement and velocity responses will have the decrease in displacements, whereas the system of smaller displacement and velocity responses will have the increase in displacements. It is because the exchange of velocities occurs at the moment of pounding. The system having lower velocity before pounding has the increase in velocity after pounding which, in turn, leads to the increase in displacement.

4. Conclusion

The pounding of two structural segments has the effect on displacement responses in the manner that it can lead to the increase in the displacement response of the system which has smaller displacement and velocity responses prior to the pounding.

5. References

Kawashima, K., and Sato, T. (1996) Relative Displacement Response Spectrum and Its Application, *Eleventh World Conference on Earthquake Engineering*, Acapulco, Mexico.

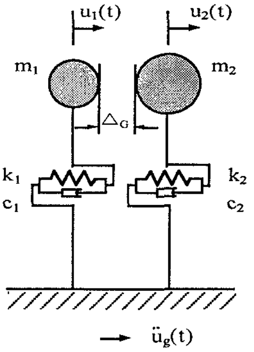

Fig. 1 Idealized model for the analysis

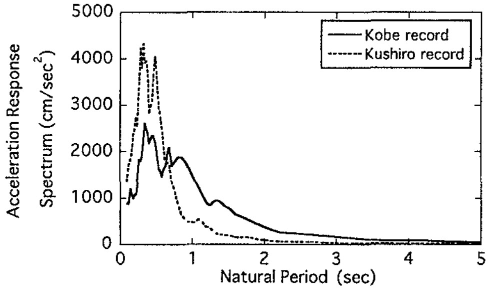

Fig. 2 Acceleration Response Spectrum of ground motions

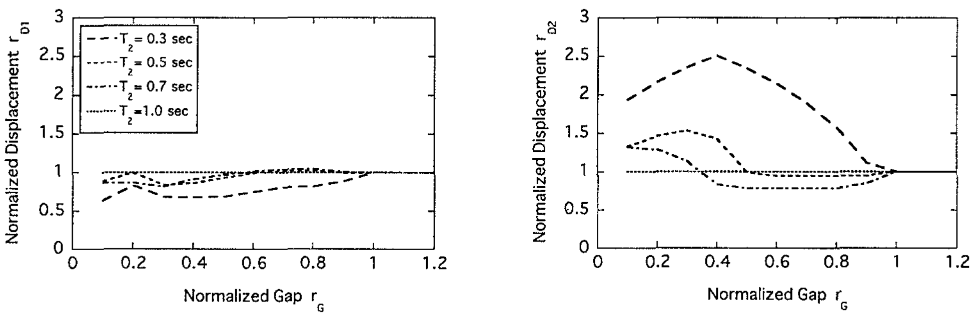

Fig. 3 Normalized displacement vs normalized gap for $T_1 = 1.0$ sec (Kobe record)

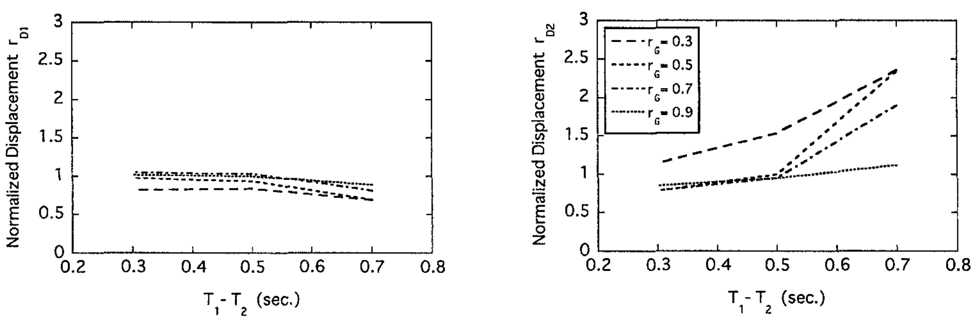

Fig. 4 Normalized displacement vs difference in natural periods for $T_1 = 1.0$ sec (Kobe record)

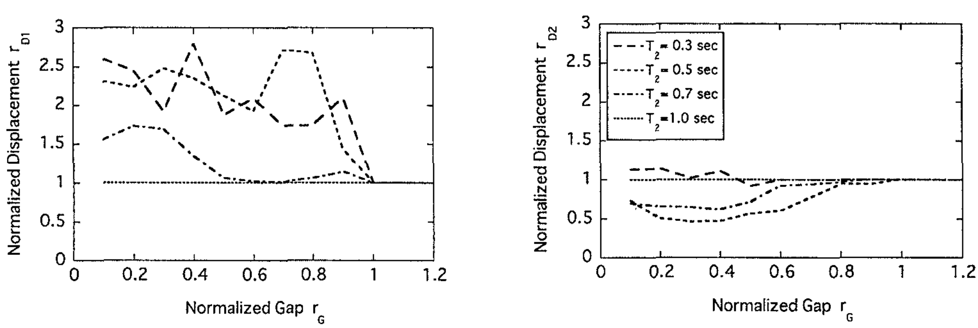

Fig. 5 Normalized displacement vs normalized gap for $T_1 = 1.0$ sec (Kushiro record)