Relative Displacement Response Spectrum with Pounding Effect

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The application of Menshin Design results in the decrease of lateral forces induced in structures. However it leads to the increase in displacements of the isolated structures. Consequently, there is the possibility of pounding of the structures separated by a gap. This paper presents the effect of pounding on displacement responses by using the model of two single-degree-of-freedom oscillators subjected to the same ground motion. To include the pounding into the analysis, the laws of conservation of momentum and energy are applied.

***Key Words** : Menshin design, Seismic isolation, Relative displacement response spectrum, Pounding effect*

1. Introduction

By the application of Menshin Design, it is realized that a certain amount of lateral 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 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 $u_2(t)$, respectively. The maximum absolute values of $u_1(t)$ and $u_2(t)$ are represented as S_{D1}^p and S_{D2}^p for the case of the presence of pounding, or S_{D1} and S_{D2} when pounding does not occur. For the benefit of meaningful interpretation, the maximum displacements are normalized as $R_{D1}^p = S_{D1}^p / S_{D1}$ and $R_{D2}^p = S_{D2}^p / S_{D2}$; the gap as $R_G = \Delta_G / \Delta S_D$ in which the parameter ΔS_D is the maximum relative displacement of two oscillators without pounding[1].

3. The characteristics of displacement responses with pounding effect

To study the pounding effect on displacement responses, we use three ground motions which are generated by fitting to the Type-I design acceleration response spectrum for soil condition type III (soft soil)[2]. Fig. 2 illustrates the acceleration response spectrums of the three ground motions. In addition, other three ground motions are obtained by exchanging positive and

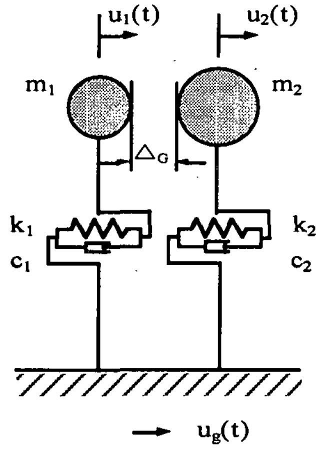

Fig. 1 Idealized model for the analysis

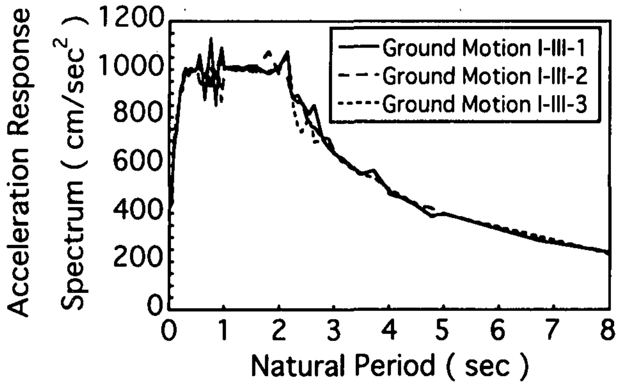

Fig. 2 Acceleration response spectrum of spectral-fitted ground motions.

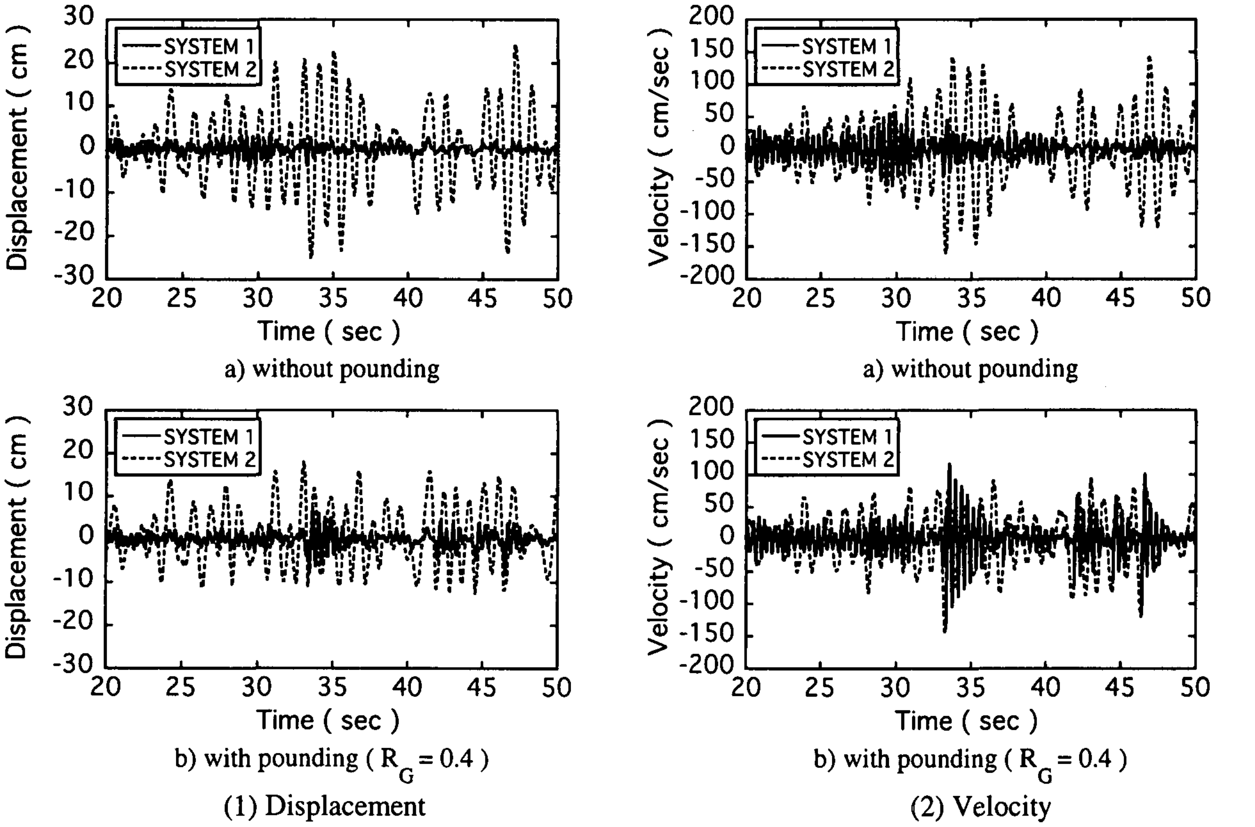

Fig. 3 Comparison of displacement and velocity responses with/without pounding (T_1 = 0.4 sec, T_2 = 1.0 sec, mass ratio = 1, and ground motion I-III-1)

negative signs of the three spectral-fitted ground motions in order to take into account the effect of direction of ground motions. The damping ratio of 0.05 which is the practical value for structures of moderate size is used in the analysis. In order to consider the phenomenon of pounding, the laws of conservation of momentum and energy are applied with the assumption of no energy loss in pounding. The effect of pounding on displacement response is depicted by Fig. 3. It is explicitly seen that if the gap is large enough to avoid pounding, there is quite large difference in velocity responses of two systems. In contrast, if the gap is so small that it causes pounding, the amplitudes of velocity responses of both systems are around the same level. It is because there is the exchange of velocities of two systems at the moment of pounding. The exchange of velocities, then, contributes to the increase of displacement of the system having shorter natural period, and to the decrease of displacement of the system having longer natural period. Such an aspect can be observed from Fig. 4 showing the analytical results in terms of normalized displacements (R^p_{D1} and R^p_{D2}) and

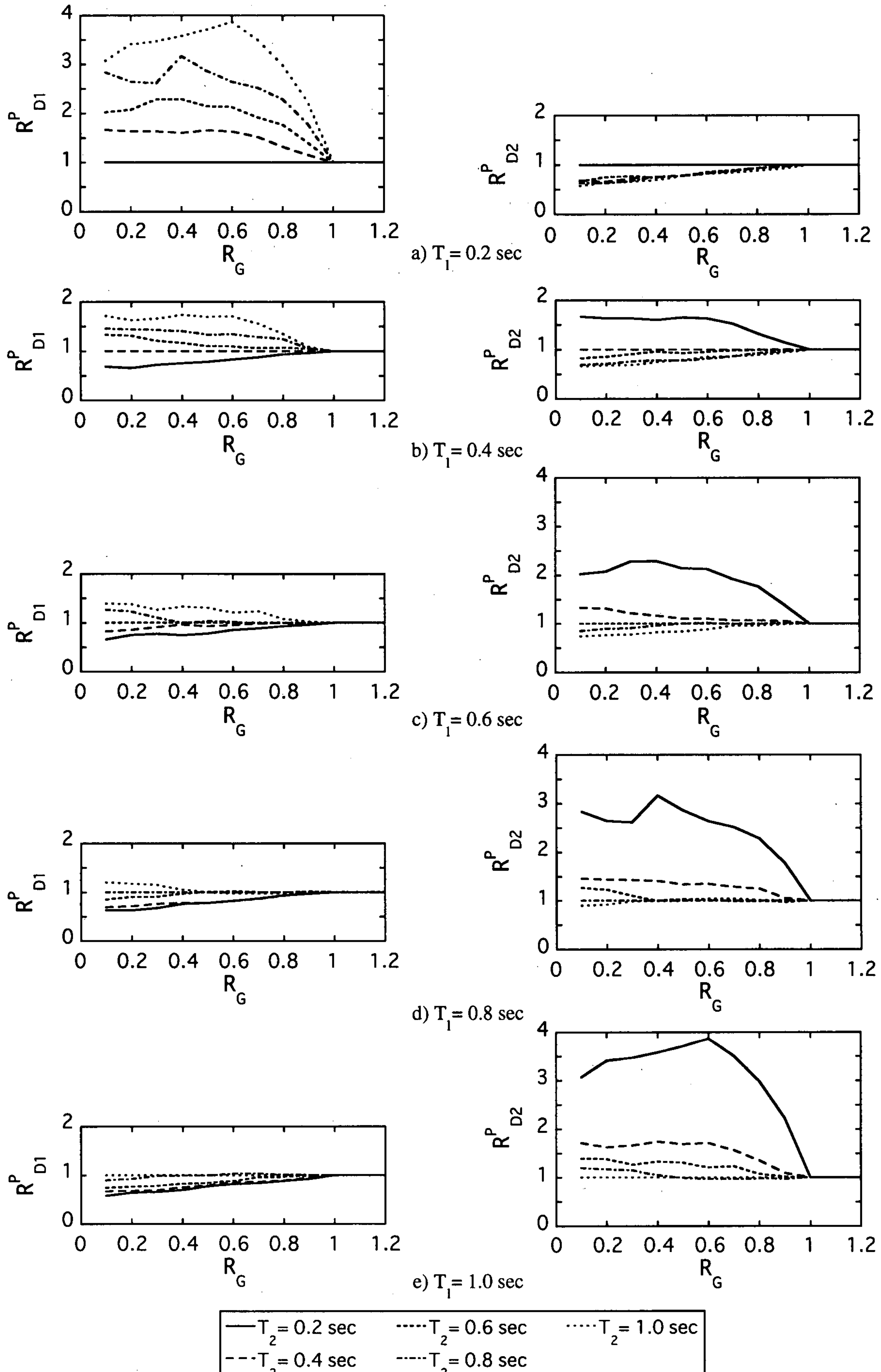

Fig. 4 Average normalized displacement vs normalized gap (for mass ratio = 1)

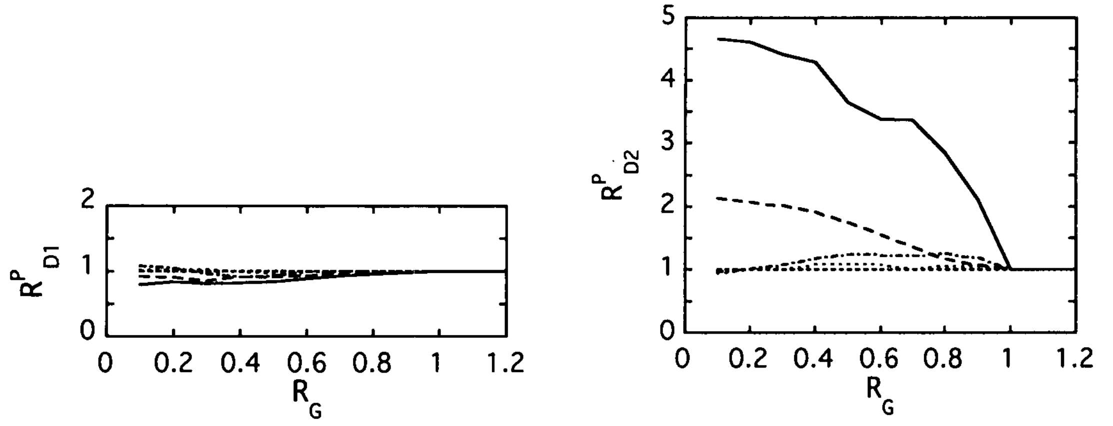

Fig. 5 Average normalized displacement vs normalized gap (for $T_1 = 0.6$ sec and mass ratio = 0.2)

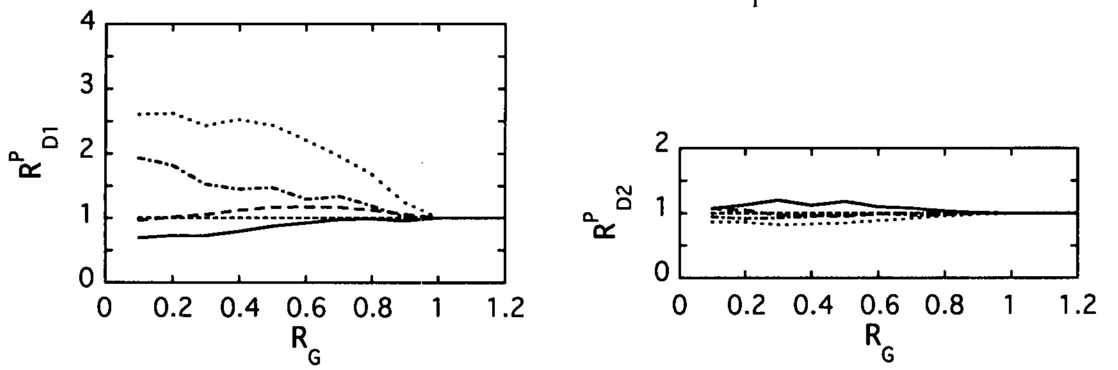

Fig. 6 Average normalized displacement vs normalized gap (for $T_1 = 0.6$ sec and mass ratio = 5)

normalized gap (R_G) with the variation of T_1 and T_2 for $m_2 / m_1 = 1$. The results are obtained by taking average of normalized displacements of the six ground motions. It is obvious that due to the pounding the system of longer natural period has the decrease of displacement while the system of shorter natural period has the increase of displacement. Moreover, the larger the difference between T_1 and T_2 is, the more displacements of the system having shorter period increase.

In the analysis, we also consider the effect of mass ratio (m_2 / m_1) by using mass ratio of 0.2 and 5. Fig. 5 and 6 represent average normalized displacements for T_1= 0.6 sec and mass ratio of 0.2 and 5 respectively. Due to the difference of masses, the normalized displacement of lighter mass increases, while the normalized displacement of heavier mass decreases if compared with the case of $m_2 / m_1 = 1$. It is because the heavier mass tends to transfer larger momentum or velocity to the lighter mass.

4. Conclusion

The pounding of two structural segments has the effect on displacement responses in the manner that

1) The system of longer natural period has the decrease of displacement while the system of shorter natural period has the increase of displacement.

2) The larger the difference between T_1 and T_2 is, the more increase in displacements will be.

3) Due to the effect of mass ratio, the normalized displacement of lighter mass increases while the normalized displacement of heavier mass decreases if compare with the case of $m_2 / m_1 = 1$.

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