AMPLIFICATION OF ELASTIC INTERSTORY DRIFT DUE TO LARGE PERMANENT DISPLACEMENTS IN NEAR-FIELD GROUND MOTIONS

Institute of Industrial Science, The University of Tokyo Member ○ Mladen V. KOSTADINOV
Asian Institute of Technology Member Fumio YAMAZAKI

Introduction

Near-field seismic records can contain large-amplitude long-period pulses caused by the forward directivity effect. This pulse-type ground motion has great damage potential to flexible or base-isolated structures. Large permanent ground displacements that result from dip or oblique slip events can enhance the impact of near-fault motion to structures. Present study addresses an attempt to quantify the increase of the elastic drift ratio due to large permanent displacements in near-field pulse-like ground motions.

Superposition of permanent displacement and pulse-type near-field ground motion

Waveforms recorded at near field demonstrated that for engineering purposes both permanent and forward directivity pulse-type motions can be approximated by simple functional expressions. In this study are used the harmonic shapes suggested by Markis (1997)

$$d_p(t) = \frac{V_p}{2}t - \frac{V_p}{2\omega_p}\sin(\omega_p t), \qquad 0 \le t \le T_p \tag{1}$$

$$d_d(t) = \frac{V_d}{\omega_d} - \frac{V_d}{\omega_d}\sin\left(\omega_d t + \frac{\pi}{2}\right), \qquad 0 \le t \le T_d \tag{2}$$

where V denotes the maximum velocity, ω – the circular frequency and T – the period of the pulses, t is the time, subscripts p and d indicate the permanent and the forward directivity pulse correspondingly. The magnitude of permanent displacement equals $d_{p,\max}=V_pT_p/2$. Expressions for velocity and acceleration can be obtained by differentiation of Eqs. (1) and (2). Figure 1 depicts displacement and velocity time histories of the two types pulse-like motions.

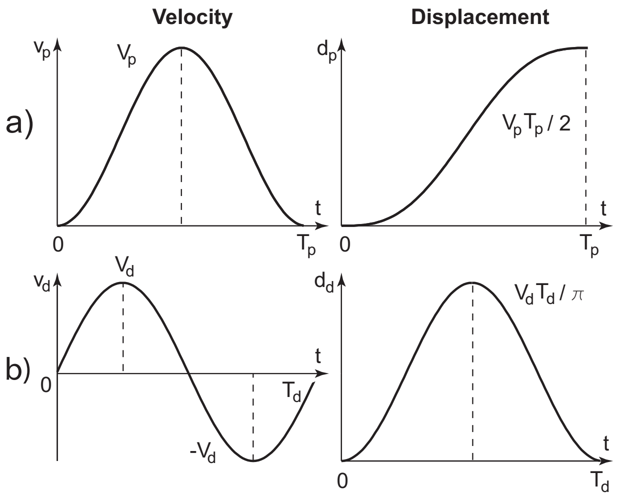

Fig. 1. Displacement and velocity time histories of harmonic pulses defined by a) Eq. (1) and b) by Eq. 2

Utilizing the above waveforms, a simple model that accounts for the simultaneous action of the permanent and forward directivity displacements is considered. The model features a linear superposition of both pulses under the following assumptions: 1) periods of the pulses are equal; and 2) pulses take place in the same time i.e. there is no relative delay.

By superimposing the pulses given by Eqs. (1) and (2) in accordance to the model, a new pulse shape, $d(t)$, is obtained as

$$d(t) = d_p(t) + d_d(t) \tag{3}$$

The value of the final displacement in the superimposed pulse will be $d_{p,\max}$. A comparison how the waveform defined by Eq. (3) fits an actual ground motion is shown in Figure 2. The seismic record is the NS-component at Rinaldi Receiving Station in the 1994 Northridge earthquake with the permanent displacement specially preserved. The pulse waveform is constructed by using the following values of the pulse parameters: V_p = 79 cm/s, V_d = 132 cm/s, T_p = 1.26 s that are obtained by fitting the maximums. The harmonic velocity pulse matches well the shape of the recorded ground motion, while the displacement pulse exhibits larger maximal amplitude because of the model employed.

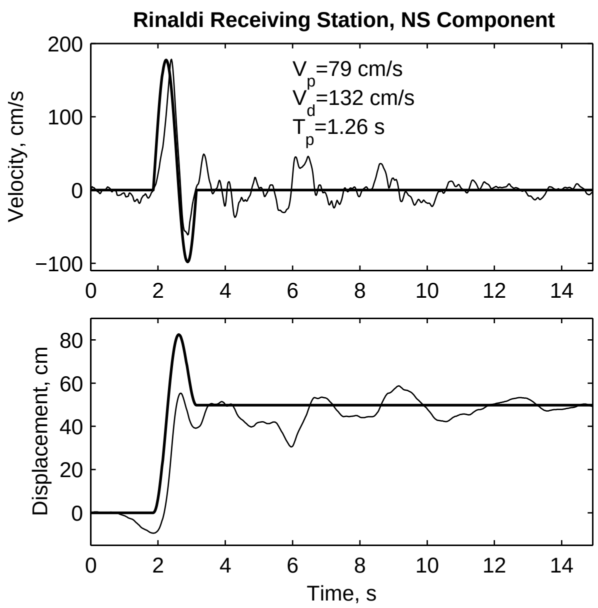

Fig. 2. Approximation of Rinaldi Receiving Station velocity and displacement time histories with harmonic pulses by Eq. (3).

Drift spectrum

Drift spectrum was proposed by Iwan (1997) as a simple measure of the interstory drift ratio associated with near-field

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***Contact Address*:** 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Tel. 03-5452-6098 Ext. 58064, Fax 03-5452-6386

strong ground motions. It is based on the response of the uniform elastic shear-beam structural model subjected to horizontal base motion displacement. The shear strain in this model corresponds to the actual-structure drift ratio. Similarly to the response spectrum, the drift spectrum plots the maximum elastic drift ratio with respect to the structure period *T*.

Figure 3 illustrates the base-level drift spectrum for the record at Rinaldi Receiving Station and harmonic-pulse ground motion. The peak of both curves is centered near the pulse period and have the same magnitude. At larger periods, both spectra follow the same declining trend. This resemblance justifies the use of Eq. (3) in the analysis.

Elastic drift demands

Large permanent displacements developed at near-fault sites will increase the maximum amplitude of the pulse-like ground shaking and consequently the structure response to it. To quantify this amplification, the ratio of the elastic drift demands due to pulse-like motions with and without permanent displacement is investigated.

Let us define the ratio of maximum velocities of permanent-displacement and forward-directivity pulses as $k=V_p/V_d$. The range of this ratio is assumed to be between 0 and $2/\pi$. The lower bound corresponds to a ground motion with no permanent displacement while the upper one implies that the maximum amplitudes of the shapes given by Eqs. (1) and (2) are equal.

For a given value of V_d and k, the time histories of $d_p(t)$ and $d(t)$ are constructed. The drift spectra due to the both motions are computed and their ratio, r_s, is obtained. Figure 4 displays the r_s ordinates with respect to the normalized pulse period for values of k = 0.2, 0.4 and 0.6. It is seen that the drift spectrum ratio fluctuates around the unity for periods less than around $1.5T_p$ and goes constant with ordinate $r_{s,\max}$ at larger periods. The steady trend is a consequence of the spectrum computation procedure that is based on linear summation.

Variation of the maximum spectrum ratio $r_{s,\max}$ with respect to the velocity ratio k is depicted in Figure 5. The amplification of the elastic drift demand is 10% for k=0.2 and almost reaches 35% for k=0.6. The linear trend of this relationship can be expressed as:

$$r_{s,\max} = 0.56k + 1.0 \qquad (4)$$

Using Eq. (4), the minimum level of k, above which the amplification of the drift ratio needs to be taken into account can be obtained.

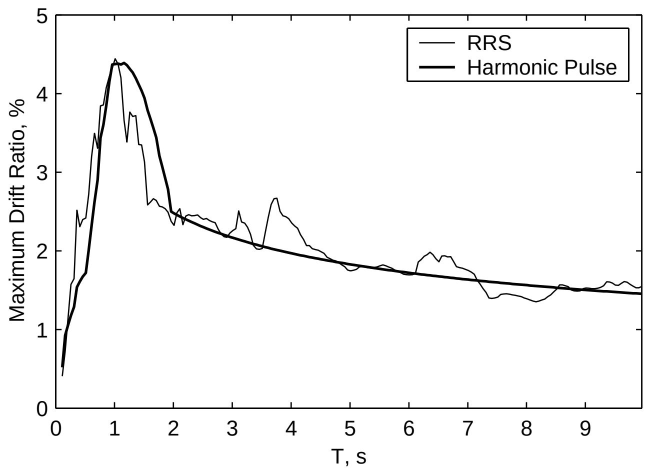

Fig. 3. Base-level drift spectrum for the NS component at Rinaldi Receiving Station and harmonic pulse; 2% damping.

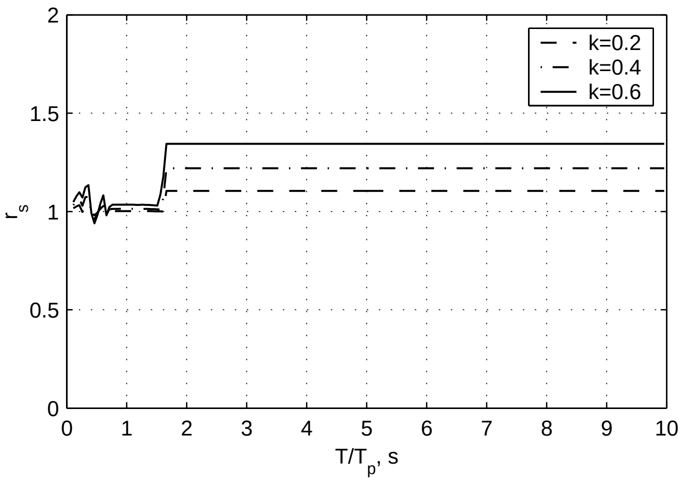

Fig. 4. Drift demand ratio d_r for different values of the velocity ratio *k*.

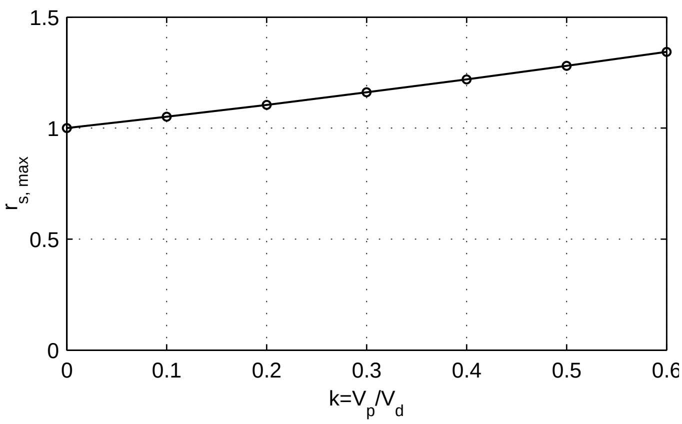

Fig. 5. Relationship between the velocity ratio *k* and the maximum drift demand ratio $r_{s,\max}$.

Conclusion

Introduced is a simple model of simultaneous action of the permanent and forward-directivity displacement fields. By computing the drift spectra for motions with and without permanent displacement, the amplification of the elastic drift ratio is estimated. The increase of the drift demands take place at periods larger than 1.5 times the pulse period and can reach up to 35%.

References:

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