PERFORMANCE OF ISOLATED BUILDINGS DURING NEAR-FAULT GROUND MOTION TYPE PULSES

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ABSTRACT:

This paper explores the performance of isolated buildings under near-fault motions by applying a simulated near-fault motion model and a number of recorded near-fault motions. By means of spectra, the effects of such factors as pulse periods of near-fault motions and fault distances on isolated buildings are analyzed, and a comparison with far-field motions is made to analyze the changes of isolated building displacements and the accelerations of superstructures. What's more, the influences of damping ratios of isolated buildings on cushioning effects are discussed. The results suggest that long period near-fault motions can increase the isolated building displacements significantly, while the acceleration responses increase slightly, and damping can reduce the isolated building responses under near-fault motions effectively.

KEYWORDS: Near-fault，isolated buildings，response spectrum

1. INTRODUCTION

The recent several major earthquakes, such as the 1994 Northridge, California, the 1995 Kobe, Japan, the 1999 JiJi, Taiwan, the 1999 Koceili, Turkey, and the 2003 Bam, Iran, are mostly characterized by pulse type seismic waves with long periods and great amplitudes. Most researchers believe, under near-fault motions, the isolated layer displacements of isolated buildings are much greater than those under far-field ground motions. In this case, what plays the decisive role in the responses of isolated buildings, the pulse period, the fault distance in near-fault earthquakes, or the ratio of building period to pulse period? In addition to the effects on isolated layer displacements, will near-fault earthquakes increase the acceleration of isolated buildings of superstructure?

Having analyzed non-isolated buildings under near-fault motions, Andereson et al (1987), consider that the responses depend on pulse period of near-fault earthquake. Moreover, if the ratio of pulse period to structure period is more than 1.0, the structure may get very serious damage. Malhotra (1999) holds that long period building under near-fault motions type pulse may produce higher base shearing force and drifts. Yang et al. (2007) have made a time history analysis with a specific isolated building and discussed the effects of near-fault motions on isolated structures. The results show that the isolated layer displacements under near-fault motion are larger than those under far-field motions, but the top floor acceleration are smaller than those under far-field motions. Near-source factors, which ranges from 1 to 2 according to the type and the distance of earthquake sources, was introduced into the design response spectrum of the 1997 UBC to take near-fault motion influence into consideration(ICBO 1997). China has no concrete regulations concerning design response spectra under near-fault earthquake, and it is suggested that design response spectra under strong earthquakes be referred to. As for base-isolated structures, it is prescribed that the computed results of important buildings should be multiplied by 1.5 (within 5km) and 1.25(beyond 5km) if the seismic wave does not involve near-fault effects. Accordingly, Chinese standards regard the isolated layer displacements and accelerations of superstructure under near-fault motions are greater than those under far-fault motions. The amplitudes are increased by 1.25~1.5 times.(GB50011-2001 2001)

Added damping is needed in the design of isolated buildings under near-fault motions to prevent large isolated layer displacements. But Kelly et al (2000) maintain that adding too much damping will reduce the cushioning effect of the superstructure of base-isolated buildings. With a case of isolated buildings and a number of seismic waves of different pulse periods, John F. Hall et al (2002) verified the effects of added damping and reached different conclusion from that of Kelly. John asserts adding 20% damping is reasonable. If damping is added further, the isolated layer displacements will decrease, while the superstructure drifts increase a little. But this does not have obvious adverse effects.

Since no consensus has been reached in these researches, this paper makes a detailed and systematic discussion on the performance of isolated buildings. By means of spectra, the effects of such factors as pulse periods of near-fault motions and fault distances on isolated buildings are analyzed, and a comparison with far-field motions is made to analyze the changes of isolated building displacements and the accelerations of superstructures. What's more, the influences of damping ratios of isolated buildings on cushioning effects are discussed.

2. SEISMIC WAVES

2.1 near-fault motions

Two sets of near-fault seismic waves are adopted in this paper, one set is simulated, and the other is recorded. The former uses the method discussed in Murat's study (2007), in which the acceleration time-history is defined as:

$$\ddot{u}_g = se^{-\zeta_p \omega_p t}(-\zeta_p \omega_p \sin \omega_p \sqrt{1-\zeta_p^2}\, t + \omega_p \sqrt{1-\zeta_p^2} \cos \omega_p \sqrt{1-\zeta_p^2}\, t) \qquad (2.1)$$

Where, $\omega_p = \dfrac{2\pi}{T_p \sqrt{1-\zeta_p^2}}, s = \dfrac{V_p}{e^{-\zeta_p \omega_p t_p} \sin \omega_p t_p \sqrt{1-\zeta_p^2}}, t_p = \dfrac{\tan^{-1}(\sqrt{\dfrac{1}{\zeta_p^2} - 1})}{\omega_p \sqrt{1-\zeta_p^2}}$

In this equation, ζ_p =40% is only one pulse; V_p, T_p are the pulse velocity and the pulse period respectively, expressed as:

$$\ln(V_p) = -2.31 + 1.15 M_w - 0.5 \ln(r)$$
$$\log_{10}(T_p) = -2.5 + 0.425 M_w \qquad (2.2)$$

Where M_w, r are the earthquake magnitude and the fault distance.

The recorded near-fault motions are shown in table 1(Anil, 2001).

2.2 Far-field motions

In order to compare the effects of near-fault motions on isolated buildings with those of far-field motions, we use the recorded far-field waves, as shown in table 2(Anil, 2001).

Table1 The recorded near-fault earthquake waves

Near-fault motions	Sites and direction	fault Distance (km)	Peak acceleration(g)	Peak velocity(cm/s)	Pulse duration(s)
Northridge,1994	Sylmar, Olive View Hospital,360°	6.4	0.843	129.6	2.6
Northridge,1994	Sylmar, Olive View Hospital,90°	6.4	0.604	78.2	0.5
Northridge,1994	Rinaldi,DWP Sta.77,228°	7.1	0.84	166.1	1.25
Northridge,1994	Rinaldi,DWP Sta.77,318°	7.1	0.472	73.0	2.7
Imperial Valley,1979	Elcentro,Array #5, 230°	1.0	0.38	90.5	3.9
Loma Prieta,1989	Gilroy Array 2#,90°	12.7	0.32	39.1	1.4
Morgan Hill,1984	Gilroy 6	11.8	0.29	36.4	1.1
Landers,1992	Lucerne	1.1	0.72	97.6	5.0
Kobe,1995	Takatori,0°	0.3	0.616	120.7	1.3
Kobe,1995	Takatori,90°	0.3	0.611	127.1	1.2
Chi-chi,1999	TCU065 -W	0.98	0.81	126.2	4.5
Chi-chi,1999	TCU065 -N	0.98	0.60	78.8	6.4
Erzikan,1992	95 Erzincan -W	2.0	0.496	64.3	2.1
Erzikan,1992	95 Erzincan -N	2.0	0.515	83.9	1.9

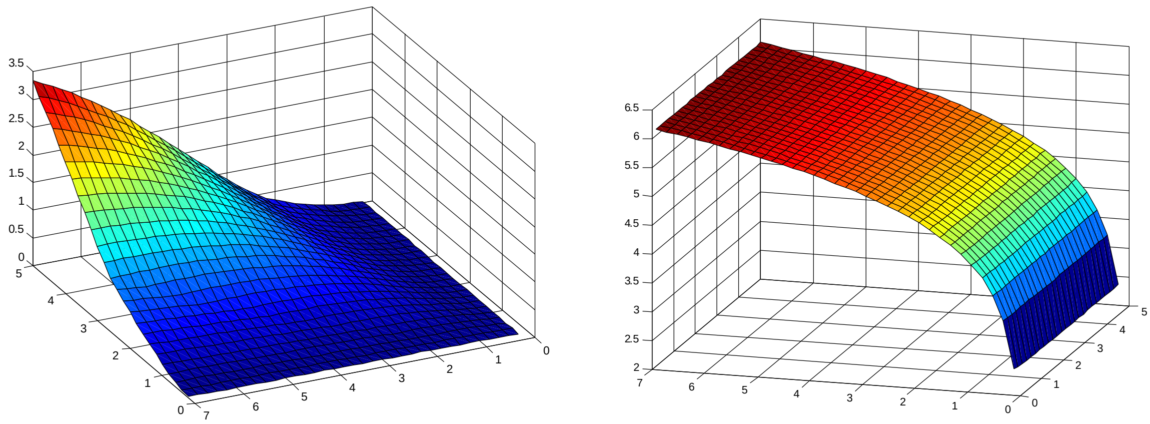
Table 2 The recorded far-field motions

Far-field motions	Sites and direction	Distance of fault(km)	Peak acceleration(g)	Peak velocity(cm/s2)
Kern country,1952	Taft, 011	41	0.178	17.5
Kern country,1952	135LA-Hollywood,90°	120.5	0.044	6.0
San Fernando, 1971	Castaic,291°	24.9	0.268	25.9
Coalinga,1983	Parkfield,0°	42.8	0.114	9.6
El Alamo,1956	117 Elcentro,Array #9, 180°	130.0	0.033	4.1
Aqaha,1995	Elat-EW	93.8	0.097	14.0
Chi-chi,1999	CHK-E	67.9	0.04	5.1
Landers,1992	Burbark-N,250°	162.1	0.049	7.2

3. ANALYSIS AND DISCUSSION

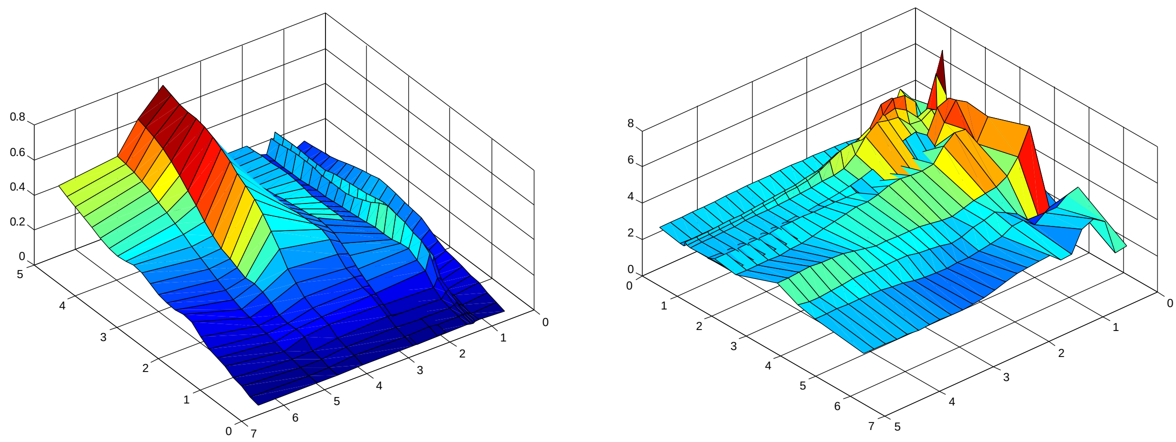
3.1 Effects of pulse periods on the response of isolated buildings

Suppose the natural vibration periods vary between 1s to 5s, the structure damping ratio is 0.15, the peak acceleration of all the simulated and recorded earthquake waves is 300cm/ s^2, the fault distance r of the simulated earthquake is 5km, and the pulse periods vary between 0 and 5s. In the following figure, *SD* and *SA* stand for the maximum displacement and the maximum acceleration respectively, while T_n represents the natural vibration period.



a) Displacement spectrum b) Acceleration spectrum

Figure 1. Spectrum of isolated buildings under simulated near-fault motions



a) Displacement spectrum b) Acceleration spectrum

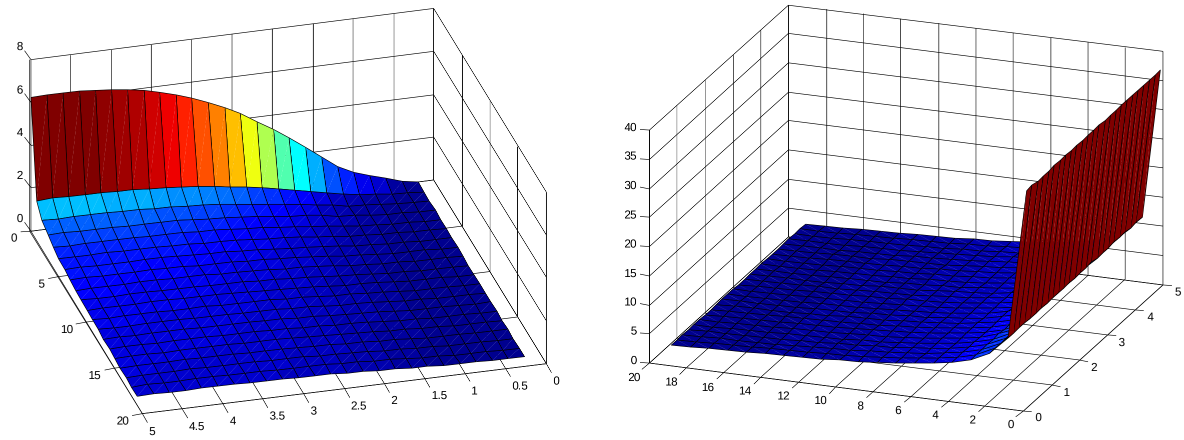
Figure 2. Spectrum of isolated buildings under recorded near-fault motions

In Fig 1a~1b the effects of pulse periods on isolated building responses are shown. With the rise of pulse periods of earthquake waves, the displacements and accelerations of isolated buildings both increase. In addition, the effects of pulse periods on isolated buildings exceed their effects on accelerations. When the pulse period is larger than 2s, the responses to isolated building accelerations are nearly the same. When the natural vibration period equals the pulse period, the displacement of isolated buildings will increase prominently, whereas no marked changes happen to the acceleration.

In Fig 2a~2b the effects of pulse periods on isolated building responses under recorded near-fault motions are shown. Though the shapes of Fig 2a~2b are much different from those of Fig1a~1b, the rules governing the response changes are almost the same. With the rise of pulse periods, the isolated building displacement increase remarkably, and the acceleration remains the same. When the pulse period equals the natural vibration period, however, the displacement and acceleration are not in their maximum, but associated with seismic waves. This indicates the features of specific seismic waves, such as the fundamental period, have clearly effects on isolated buildings. Therefore, the increase of pulse periods will cause greater displacements and accelerations of isolated buildings, especially the former. If the pulse period is close to the isolated building period, the isolation effect will be poor.

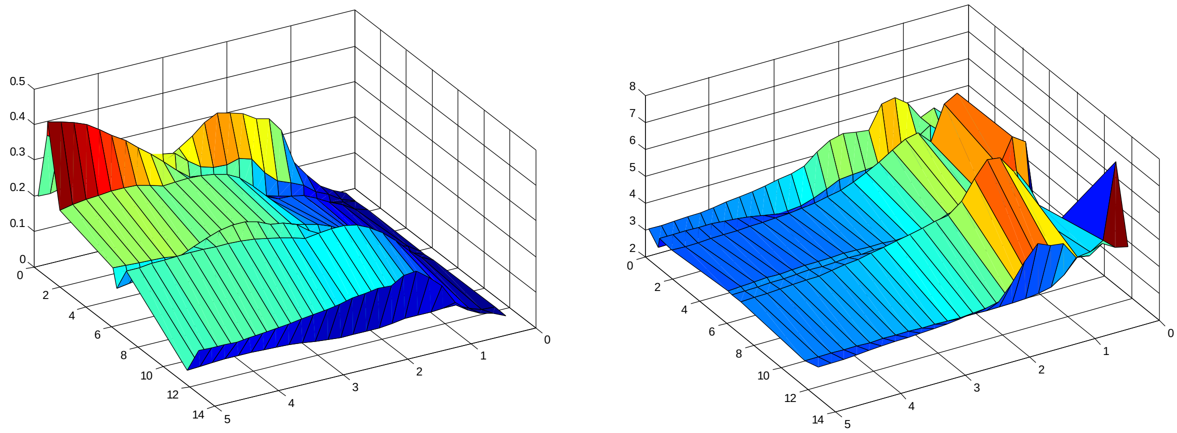
3.2 The effects of fault distance on the responses of isolated buildings

In Fig 3a~3b the effects of fault distances on isolated building responses are shown. With the decrease of fault distances, the displacements and acceleration responses both increase. When the fault distance is within 5km, the displacement and the acceleration will increase promptly. When the fault distance is within 1km, the displacement responses will be magnified 3-6 times compared with those of non-isolated buildings, and the



a) Effect of fault distances on displacements b) Effect of fault distances on acceleration

Figure 3. Effect of fault distances on isolated buildings under simulated near-fault motions



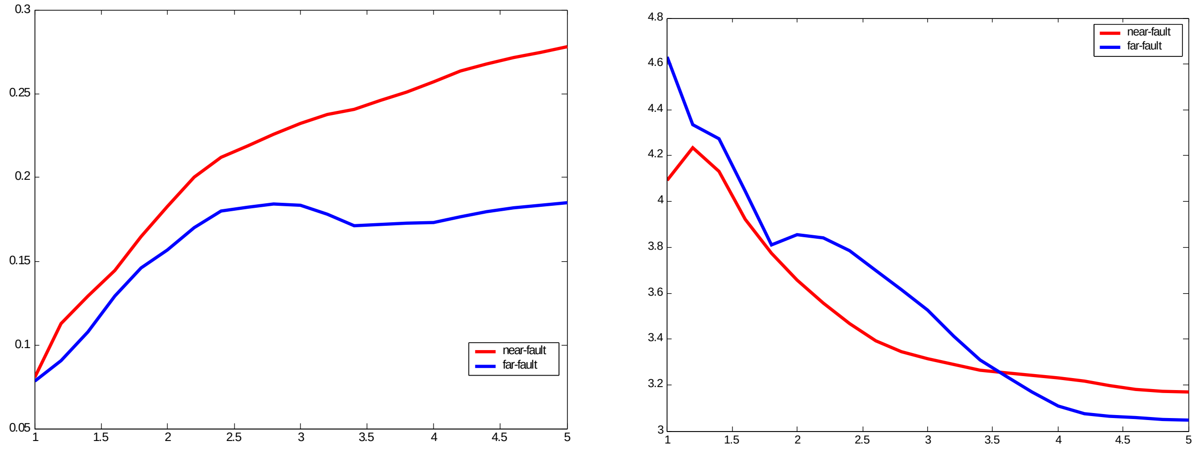
a) Effect of fault distances on displacements b) Effect of fault distances on acceleration

Figure 4. Effect of fault distances on isolated buildings under recorded near-fault motions

In Fig4a~4b the relation of fault distances and peak responses under recorded seismic waves is shown. With the increase of fault distances, the displacement responses decrease, and the acceleration responses remain basically the same. When the fault distance is less than 5km, the peak displacement responses increase obviously. When the fault distance is less than 1km, the displacement responses will increase a lot compared with those of non-isolated buildings, and the displacement responses increase markedly, while the acceleration responses decrease strikingly.

3.3 A contrast between the responses of isolated buildings under near-fault and far-field motions

In Fig.5 a contrast is made between the responses of isolated buildings under near-fault and far-field motions. The full lines represent the mean values of isolated building responses under 14 near-fault motions, and the dotted lines are the mean values of isolated building responses under 8 far-field motions.



a) Displacement spectrum b) Acceleration spectrum

Figure 5. Contrast between the response spectrum of isolated buildings under near-fault and far-field motions

Fig 5a indicates that the isolated building responses under near-fault motions are much greater than those under far-field motions. With the increase of natural vibration periods of isolated buildings, the gap between the two kinds of responses will increase about 1.2-1.5 times. Fig 5b shows that the acceleration responses under far-field motions are slightly larger than those under near-fault motions when the natural vibration periods of isolated buildings are below 3.5s. When the natural vibration periods of isolated buildings are above 3.5s, the acceleration responses are slightly larger than those under far-field motions, but the acceleration responses of both are relatively small. This indicates that the effects of near-fault motions on isolated buildings lie mainly in isolated building displacements, while their effects on isolated building accelerations are insignificant.

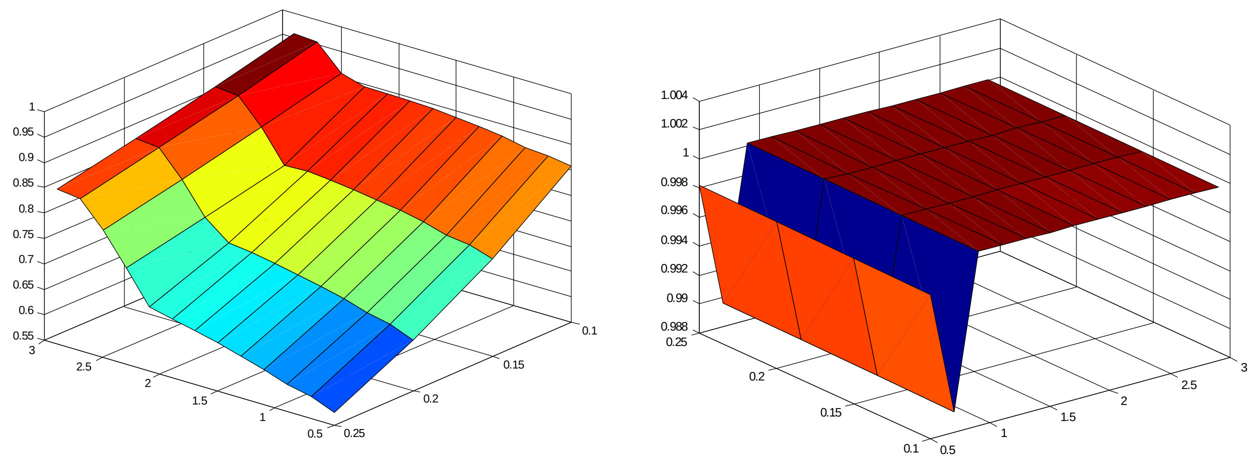
3.4 Effects of damping ratio on the response of isolated buildings

The displacement criteria and the acceleration criteria are defined as respectively (Z,Xu, 2007),

$$J_D = \frac{SD(\zeta = 10\% \sim 25\%)}{SD(\zeta = 5\%)}, J_A = \frac{SA(\zeta = 10\% \sim 25\%)}{SA(\zeta = 5\%)} \tag{3.1}$$

Where *SD* is the peak displacement and *SA* is the peak acceleration, ζ is the damping ratio.

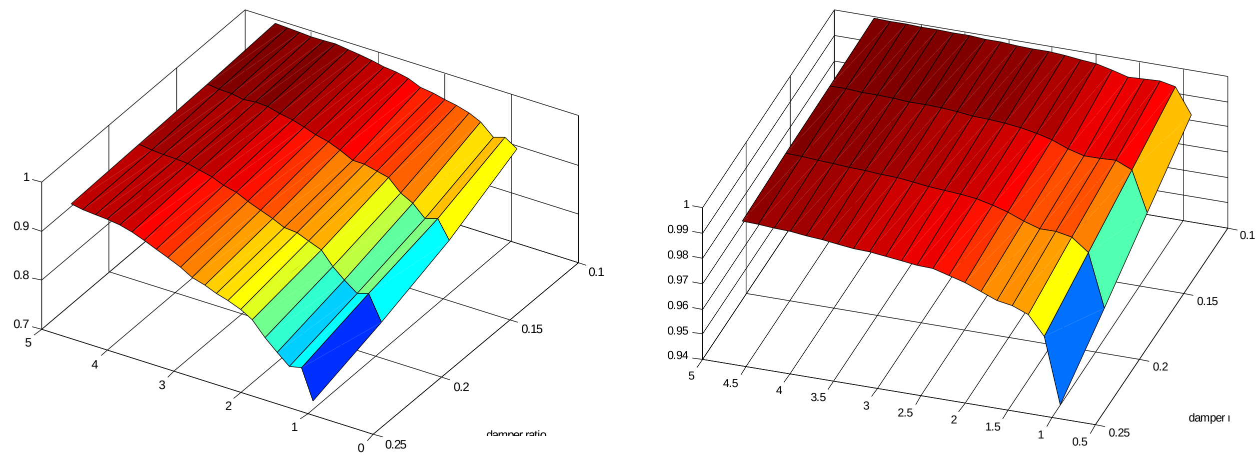
In Fig 6a~6b the damping ratio effects under simulated pulse seismic waves are shown. The influences of T_n / T_p (the ratio of structure period to pulse period) and damping ratio effects of isolated buildings can be seen. The results suggest the greater the structure damping is, the smaller the displacement criteria is. But the accelerations criteria do not change. Therefore, the added damping can reduce the isolated building responses under near-fault motions effectively. Fig 6a~ 6b also show that J_D, J_A relate to T_n / T_p. The smaller T_n / T_p is, the smaller J_D is. J_A is the minimum when $T_n / T_p \approx 0.75$, therefore, the best effects can be achieved when $T_n / T_p \approx 0.75$.



a) Effects of structure damping on displacement b) Effects of structure damping on acceleration

Figure 6. Effects of structure damping on isolated building under simulated near-fault motions

In Fig 7a~7b the effects of damping on the cushioning effects of isolated buildings under recorded seismic waves are shown. The curves in the figures represent the mean values of 14 near-fault motions. It can be seen that the performance of simulated recorded waves is similar to that of simulated seismic waves, but the effects of added damping have something to do with T_n / T_p. When T_n / T_p <1, increasing damping can improve the performance of isolated buildings remarkably.



a) Effects of structure damping on displacement b) Effects of structure damping on acceleration

Figure 6. Effects of structure damping on isolated building under recorded near-fault motions

4 CONCLUSIONS

Some conclusion can be drawn after the above analysis.

1. Near- fault motions with long pulse periods cause an increase in both displacements and acceleration of isolated buildings, and the increase in the former is more evident. In this case, efforts should be made to prevent the pulse periods from being close to the natural vibration periods of isolated buildings, so as to avoid damage to isolated buildings.

2. The nearer the fault distance is, the more damage to isolated buildings is. When the fault distance is less

than 1km, the displacement responses are about 3-6 times those of non-isolated buildings. But the increase in the acceleration responses is slight.

3. Under near-fault motions, the displacement responses increase markedly than those under far-field motions, and the acceleration responses are same. This indicates that the effects of near-fault motions on isolated buildings lie mainly in isolated building displacements. As to isolated buildings under near-fault motions, Chinese Code for Seismic Design of Buildings is conservative.

4. When damping is added to about 20%, the performance of isolated building can be clearly improved. In addition, the effects of added damping are related to T_n / T_p. If T_n / T_p is less than 1, increasing damping can improve the performance of isolated buildings significantly.

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