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SE-1

DESIGN METHOD OF ISOLATING AND ENERGY DISSIPATING SYSTEM FOR EARTHQUAKE RESISTANT STRUCTURES

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SUMMARY

This paper suggests a new design method for earthquake resistant structure using isolating and energy dissipating system. This method is based on shaking table tests and dynamic analysis. A series of experiment on the shaking table have been carried out with a 1/4 scale steel frame. Different sinewave waveforms and simulated earthquake records were inputed to shaking table. Different kinds of energy dissipating devices were mounted in structure. Comparing the theoretical results with the testing results shows that both values are very nearly, means the method presented by authors is reasonable and suitable for practical engineering design.

INTRODUTION

The isolating and energy dissipating system consists of structure, isolating and energy dissipating devices mounted between the structure and ground. It can effectively isolate the structure from ground motion in earthquake, offer high damping to dissipate the energy transmitted to the structure. So it can attenuate the structure response to very small value from ground motion, then prevent whole structure from damage in a severe earthquake attack. This gives engineers a new way for design of earthquake resistant structure. But it is very needful to have an quantitative, reliable and simple method accepted by engineering design.

The method presented by authors uses acceleration-contrel to limit the structural response in earthquake. Depending on the importance of building which relating to different requirement of safty, and the seismic zone the building located which relating to different possible maximum acceleration spectrum values, design an isolating and energy dissipating system which acceleration response can be limitted to an acceptable level. In that case, the structure response in severe earthquake is nearly as same as in minor earthquake or wind load, and the structure may work nearly in elastic range only. The whole building, including structure, interior component, decoration, building content, instrumentation and so on, are fully prevented from damage during a severe earthquake attack. Also, the design procedure would change from designing a whole structure for earthquake resistance to only designing an isolating and energy dissipating device. The designing procedure becomes very simple.

The method is based on a series of experiment on the shaking table and dynamic analysis. The testing results show that this new method is very reliable and suitable for practical engineering design.

BASIC SYSTEM AND MATHEMATICAL MODEL

There are four kinds of isolating and energy dissipating devices (Fig.1) are used in general engineering design :

1. Roller isolator combines with mild steel component energy dissipater (Ref.1,2).
2. Rubber pads isolator combines with leadplug dissipater(Ref.3,4).
3. Sand layer (Ref.5)
4. Friction damper (Ref.6)

Four parameters can be found in any isolating and energy dissipating system :

1. Structural mass M
2. Load-displacement curve of device (Fig.2) given from pseudo statical testing of steel component.
3. Elastic stiffness K of device given from load-displacement curve (Fig.2)
4. Equivalent viscous damping C_e of energy dissipating device given from the area enclosed by load-displacement curve (Fig.2).

The structure responds to earthquake motion primarily as a system of single degree of freedom because the structure is very rigid comparing with the soft layer of isolator and energy dissipater (Ref.1). A mathematical model with M, K and C_e is shiwn in Fig.3. If the ground acceleration response $\ddot{X}_g$ is known, then the structural acceleration response $\ddot{X}_a$ and maximum relative displacement D_u can be controlled by designing a suitable isolating and energy dissipating device using the method suggested in this paper.

SHAKING TABLE TESTS

The tests were carried out on An earthquake simulator table which has a floor dimension of 10ft·10ft. The overall dimension of four storries steel frame is 10ft·4.6ft in plan and 12.8ft high. The totle mass of structure and loading concrete blocks are 16 kips, see Photo.1.

The roller and mild steel curved plates were used as isolating and dissipating device (Photo.2). Five kinds of curved plates were tested. A series of pseudo tests were finished for curved plates (Ref.1,7) before shaking table tests. Four sine-waveforms (Freq. w=1.0, 2.0, 3.0, 4.0, HZ) and three simulated earthquake records (EL Centro, Sanfernando, Parkfield) were inputed to the shaking table, which predominant Freq. w was found from the Fourier spectra of acceleration record.

Four accelerometers were used to measure the structure acceleration response $\ddot{X}_a$ at every stories of structure. The relative displacement D_u between the first story column and the shaking table was measured with linear variable differential transformer (LVDT). All of the measured data were then processed by a computer with a operating software system.

DYNAMIC ANALYSIS AND FORMULA

<u>Equivalent damping ratio E</u> From Fig.3, the basic differential equation of motion is given as:

$$M \ddot{X}_a + C_e \dot{X}_a + K X_a = C_e \dot{X}_g + K X_g \qquad (1)$$

where M is the structural mass. C_e is the equivalent viscous damping of isolating and energy dissipating system. K is the elastic stiffness of isolating and energy dissipating system. X_g $\dot{X}_g$ $\ddot{X}_g$ are the ground response of displacement, velocity and acceleration respectively in earthquake. X_a $\dot{X}_a$ $\ddot{X}_a$ are the structure response of displacement, velocity and acceleration respetively in earthquake.

Define $E_e = C_e / 2Mw_n$ as EQUIVALENT DAMPING RATIO,

$w_n = K/M$ as the NATURAL FREQUENCY of system.

Solve Eq.(1) with finding transfer function and get :

$$E_e = \frac{1}{2(w/w_n)} \sqrt{\frac{1-AR^2 [1-(w/w_n)^2]^2}{AR^2 - 1}} \qquad (2)$$

where $AR = \ddot{X}_a / \ddot{X}_g$ is called ACCELERATION ATTENUATION of system.

Maximum relative displacement D_u From Fig.3, the basic differential equation of motion can be written:

$$M \ddot{D}_u + C_e \dot{D}_u + K D_u = -M \ddot{X}_g$$

where D_u $\dot{D}_u$ $\ddot{D}_u$ are maximum relative displacement, velocity and acceleration respectively between structure and ground.

Solve this equation with finding transfer function and get :

$$D_u = \frac{\ddot{X}_g}{w^2} \sqrt{\frac{(1-AR^2)\ (w/w_n)^2}{(w/w_n)^2 - 2}} = X_g * r \qquad (3)$$

Define $r = \sqrt{\frac{(1-AR^2)\ (w/w_n)^2}{(w/w_n)^2-2}}$ as DISPLACEMENT FACTOR

Comparing the theoretical value D_u with measuring value $[D_u]$ from tests (Table 1) show that the $D_u/[D_u] = 0.98-1.67$,D_u are almost all greater than $[D_u]$. I means Eq.(3) is suitable and conservative in designing.

Acceleration attenuation ratio AR The damping ratio E_e is related to the area enclosed by the hysteresis loop and find :

$$E_e = \frac{C_e}{2 M w_n} = \frac{2(1-1/U)}{U \pi} \cdot \frac{1}{(w/w_n)} = B \frac{1}{(w/w_n)} \qquad (4)$$

Define $B = \frac{2(1-1/U)}{U\pi}$ as ENERGY DISSIPATION DAMPING RATIO

$U = D_u / D_y$ as DUCTILITY FACTOR

The value of B represent the basic value of E_e , and deponds on the value of U.

Substitute Eq.(4) into Eq.(2) and get :

$$AR = \frac{\ddot{X}_a}{\ddot{X}_g} = \sqrt{\frac{1+4B^2}{4B^2 + [1-(w/w_n)^2]^2}} \sqrt{\frac{w}{W_n}} \qquad (5)$$

This is the final expression of ACCELERATION ATTENNUATION AR

Now, comparing the theoretical values AR from Eq.(5) with the measured values [AR], shown in Fig.4.5 and know :

(a) The ratio AR/[AR] approaches 1.0, it means that Eq.(5) gives reasonable estimation.

(b) The theoretical valres AR are always larger than measured valuds [AR], it means that Eq.(5) gives conservative results for practical design.

CONCLUSION

1. The design method of isolating and energy dissipating system suggested by authors is very reasonable and simple. Knowing the site maximum acceleration response $\ddot{X}_g$,suggesting allowed structural acceleration response $\ddot{X}_a$ and the relative displacement (D_u), design the isolator and energy dissipator with yielding force P_y , yielding displacement D_y and elastic stiffness K (Fig.2). Using Eq.(3),(5) get AR and D_u . If AR$\leqslant \ddot{X}_a/\ddot{X}_g$, $D_u<(D_u)$, then it is satisfied.

2. The formulas presented in this paper can be used in practical design with enough safety.

3. This method not only can be used in general structures, but also in special structures (such as pools, tanks, towers and pipe line etc.), many kinds of equipment and instrumentation for earthquake resistant design.

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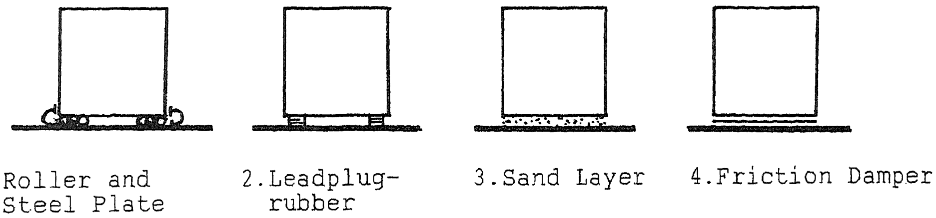

Fig.1. Isolating and Energy Dissipating Devices

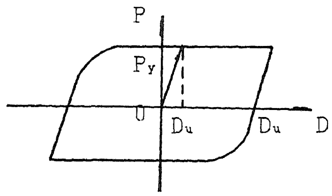

Fig.2. Load-Disp. Loop

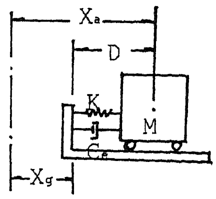

Fig.3. Mathematic Moder

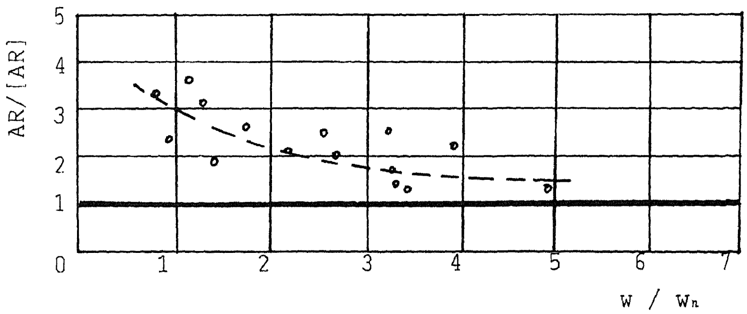

Fig.4. Attenuation Ratio over Frequency Ratio for Sinusoidal Excitation

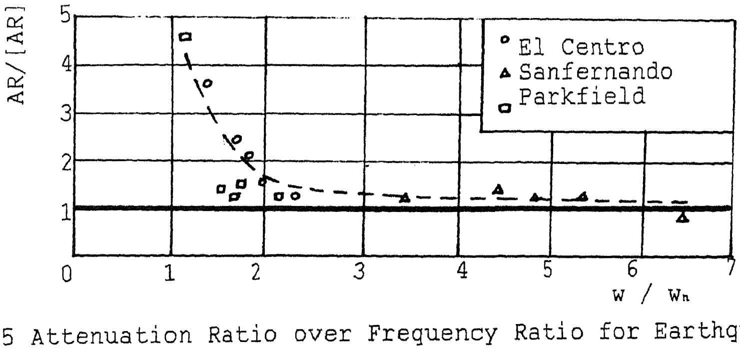

Fig.5 Attenuation Ratio over Frequency Ratio for Earthquake Excitation

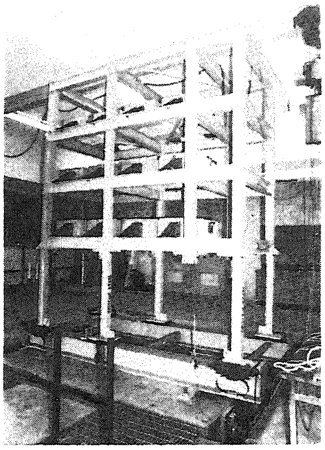

Photo.1. Shaking Table Test with 1/4 Sca`e Steel Frame

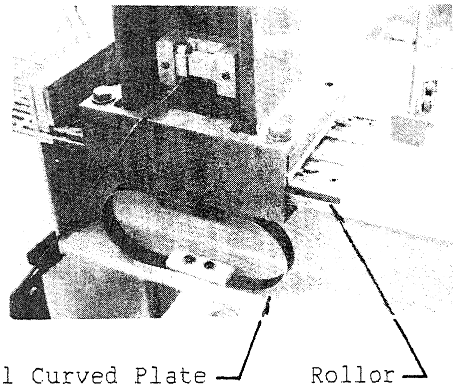

Photo.2. Rollor Isolator and Steel Curved Plate dissipator

Table. 1. Displacement Ratios for Different Frequencies of Sinusoidal Excitation and Different Energy Dissipator

Energy Dissipator	Frequency of Sinewave Inputed (HZ)	w/w_n	AR= $\ddot{X}_a/\ddot{X}_g$ from Tests	r	D_u from Eq.(3)	$[D_u]$ from Tests	$D_u/[D_u]$
8E1	0.6					2.106	
	3.0	1.33	0.45			1.399	1.19
	2.0	2.64	0.08	1.18	1.89	1.581	1.48
	0.9	3.85	0.03	1.07	2.28	1.538	
4E2	1.0	1.21	0.42			1.871	
	2.0	2.64	0.09	1.18	1.88	1.526	1.23
	3.0	3.95	0.03	1.07	2.28	1.531	1.49
6E2	1.0	1.21	0.56			1.946	
	2.0	2.41	0.13	1.23	1.97	1.604	1.23
	3.0	3.62	0.05	1.09	2.31	1.502	1.54
2E3	1.0	1.11	0.52			1.901	
	2.0	2.22	0.12	1.29	2.07	1.579	1.31
	3.0	3.34	0.04	1.10	2.34	1.492	1.57
	4.0	4.45				1.305	
4E3	1.0	0.86	0.87			2.114	
	2.0	1.73	0.20	1.70	2.72	1.668	1.63
	3.0	2.59	0.07	1.19	2.53	1.515	1.67
	4.0	3.45	0.05	1.10	0.94	0.957	0.98