Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.V)

7-10-1

EFFECT OF LARGE DAMPING ON EARTHQUAKE RESPONSE

Robert D. HANSON,[1] Jian-ping WU[2] and Samir A. ASHOUR[3]

[1]Professor of Civil Engineering, University of Michigan, Ann Arbor, Michigan, 48109-2125, USA
[2]Dept. of Civil Engineering, Univ. of Michigan, Ann Arbor, Michigan
[3]Dept. of Civil Engineering, P.O. Box 9027, King Abdulaziz Univ., Jeddah 21413, Saudi Arabia

SUMMARY

An earthquake resistant design philosophy which relies upon increased stiffness and damping rather than increased strength and ductility has been investigated. The effect of adding supplemental mechanical damping devices in a structure on its elastic and inelastic earthquake response is described in terms of response spectral procedures.

INTRODUCTION

For many years it has been recognized that damping in our structures has been beneficial by limiting the maximum responses of the structures when subjected to earthquake ground motions. Damping has been used as an important parameter in the display of the earthquake ground motion effects as reflected by the earthquake response spectra. Previous studies of damping effects on response have been confined to those with small damping because the inherent damping in real structures is small and uncertain. Only when the inelastic energy dissipation is included with the inherent elastic energy dissipation does the equivalent viscous damping exceed 2 to 5 percent of critical. When utilizing mechanical damping devices to control earthquake responses it is important to separate the effects of mechanical device energy dissipation and those of inelastic member yielding and fracture. Thus, the model used herein retains the inelastic energy dissipation by structural members within the nonlinear mathematical model and adds equivalent viscous damping to represent the inherent structural elastic and mechanical device energy dissipation.

New technology is being applied to produce effective supplemental dampers for installation into engineered structures. Among the devices previously reported are those which utilize metallic yielding (Ref. 1), frictional slip (Ref. 2), viscous material action (Ref. 3), or acrylic material shear deformations (Ref. 4). Other devices are currently being developed. While the energy dissipation characteristics of these devices may not be ideally viscous, each can be related with varying degrees of accuracy to an equivalent viscous damping coefficient which may be taken as amplitude and frequency dependent.

The purpose of this paper is to provide an understanding of the consequences of increasing system damping. To achieve this purpose the effect of damping on the elastic and inelastic response displacement of simple structures is illustrated.

EFFECT OF DAMPING ON DISPLACEMENT RESPONSE SPECTRA

The displacement response spectra, SD, is a key parameter in estimating the maximum displacement responses in each mode of a building for past earthquakes or for a specified design spectra. This spectral displacement decreases as damping increases. Ashour (Ref. 5) developed a relationship for the change in SD of elastic systems with changes in damping and correlated these with results obtained from existing earthquake accelerogram records.

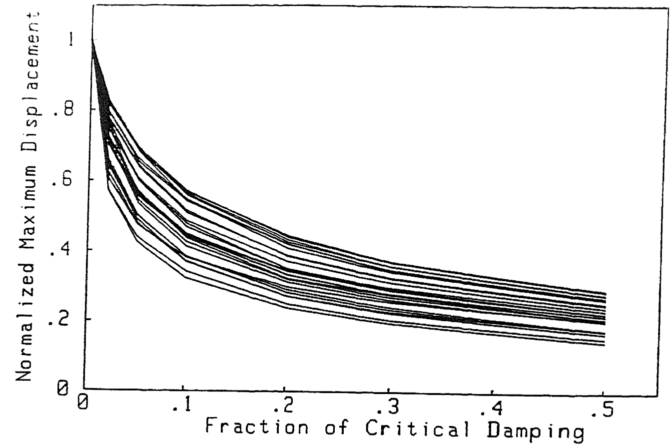


Fig. 1 Zero Damping Mean Displacement Reduction

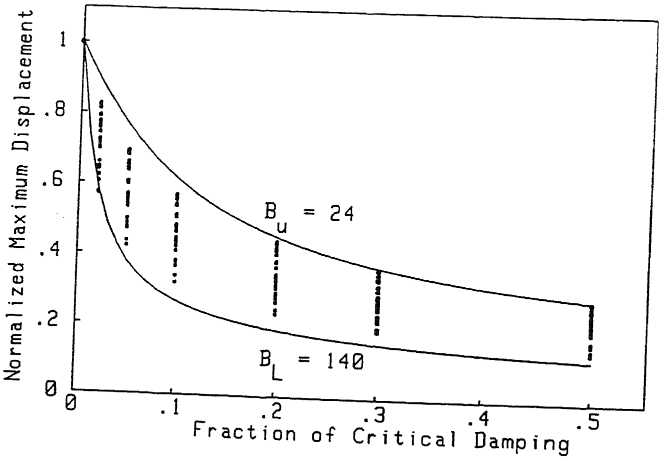


Fig. 2 Zero Damping Bounding Curves

Elastic Response. The natural periods, Tn, used in the study were 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 seconds which covers a representative range of natural periods. Three real and twelve artificial earthquake records were used for excitation input. Damping values used were 0, 2, 5, 10, 20, 30, 50, 75, 100, 125 and 150 percent of critical. The values of SD for a given Tn and damping factor were normalized with respect to the SD at Tn for zero damping for each earthquake record and were then averaged over the 15 records to obtain a mean value for each period and fraction of critical damping. Fig. 1 shows the resulting relation for the mean value of SD as a function of period and damping. These curves can be represented by simple decaying functions,

$$R = [\{1 - e^{-2\beta B}\}/\{2\beta B\}]^{1/2}$$

where β is the selected fraction of critical damping and B is a coefficient which was evaluated for zero initial damping normalization to be 24 for the upper bound and 140 for the lower bound, Fig. 2. Similar response modification functions have been evaluated for spectra normalized at 2 percent and 5 percent of critical damping (Ref. 5).

Inelastic Response. The inelastic response evaluations are more difficult to establish on a comparative basis. Wu (Ref. 6) used one artificial and nine real earthquake records to study the elastic-plastic response of single degree systems. One form for presentation of his conclusions uses the peak ground parameters as a basis to derive the inelastic response spectra. Fig. 3 gives the Response Spectra amplification factor at a period of 0.1 second for damping from 10 to 50 percent and ductilities from one to six. The effect of increasing damping and ductility can be seen. The amplification factor in the velocity region is shown in Fig. 4. Similar results for the displacement region response can be given. In these figures β is the fraction of critical damping and μ is the structural ductility factor. Thus, it can be seen that supplemental damping can effectively reduce structural yielding demands by an earthquake.

It is interesting to note that the Spectra Displacement amplification factors can be divided into terms including the viscous damping of the system and separate terms including the structural inelastic yielding. The inelastic deamplification factors for the three regions of concern are plotted in Fig. 5 with the corresponding data including damping from 10 to 50 percent of critical. The relatively small scatter of the data with changes in damping illustrates the point that spectral modifications for high damping and for inelastic action can be considered separately. Thus our previous experience with inelastic spectral modifications can be retained while incorporating modifications for high damping.

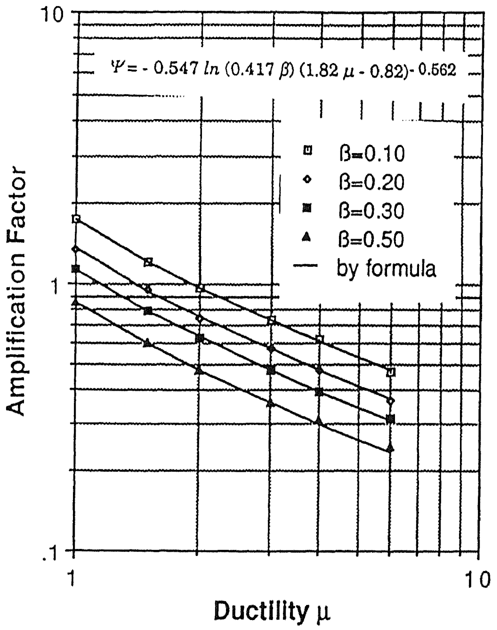


Fig. 3 Amplification Factors at T = 0.1 Seconds

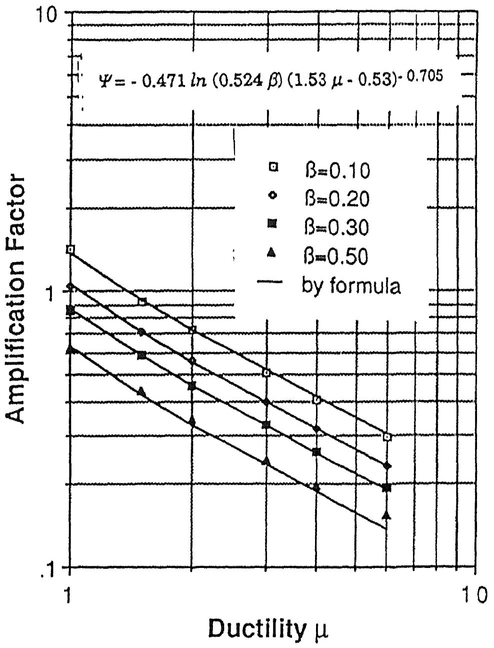
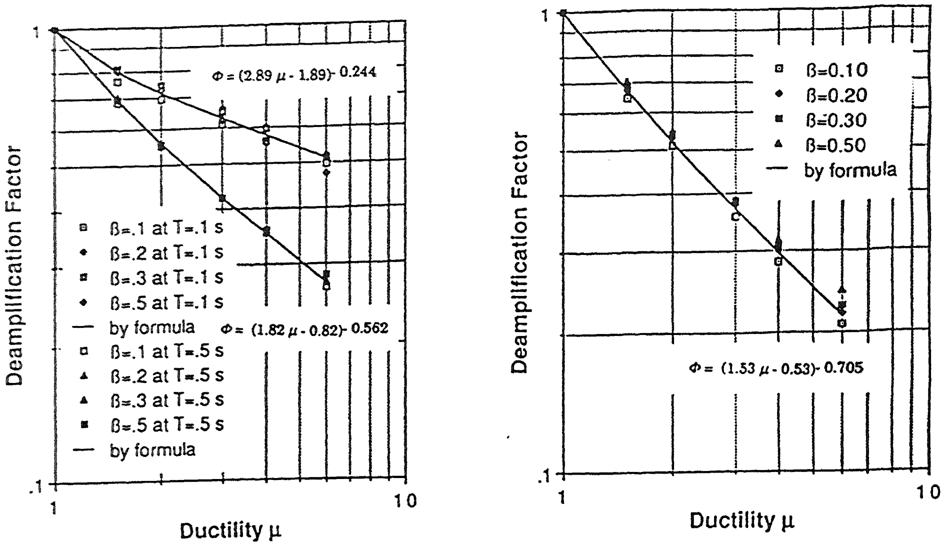
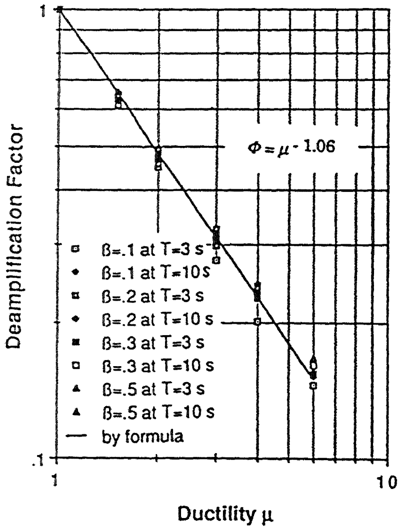


Fig. 4 Amplification Factors in Velocity Region



(a) Acceleration Region (b) Velocity Region



(c) Displacement Region

Fig. 5 Ductility Deamplification Factors

CONCLUSIONS

1. The effect of damping on the elastic displacement response spectra was represented by simple decay functions for damping up to 150% of critical. These results demonstrate that the addition of supplemental damping devices has more effect in the region of small damping than in the region of high damping.

2. The effect of high damping and inelastic structural response on the spectral amplification values of ground motion characteristics can be separated into the effects caused by high damping and and the effects caused by member ductility.

3. Addition of supplemental damping devices are more effective in reducing the corresponding earthquake response spectral values in the mid period region (velocity region) than in the low (acceleration controlled region) and high (displacement controlled region) period regions. Nevertheless additional damping makes the structures less sensitive to earthquake peculiarities.

ACKNOWLEDGEMENTS

This paper is based upon research supported by the National Science Foundation under Grant No. ECE-8512726. The opinions expressed herein are those of the authors and do not necessarily represent the opinions of the sponsor. The research reported herein was done by Samir Ashour and Jianping Wu in conjunction with their Ph.D. studies at the University of Michigan. Their originality and contribution to this effort are gratefully acknowledged.

REFERENCES

1. Kelly, J.M. and Skinner, M.S., "Review of Current Use of Energy-Absorbing Devices," UCB / EERC - 79/10, Univ. of California, Berkeley, February, 1979.

2. Pall, A.S. and Marsh, C., "Response of Friction Damped Braced Frames," Journal of the Structural Division, ASCE, Vol. 108, No. 6, June, 1982, pp. 1313-1323.

3. Scholl, R.E., "Brace Dampers: An Alternative Structural System for Improving the Earthquake Performance of Buildings," Proceedings, 8WCEEE, San Francisco, California, July, 1984, pp. 1015-1022.

4. Hanson, R.D., Bergman, D.M. and Ashour, S.A., "Supplemental Mechanical Damping for Improved Seismic Response of Buildings," Third USA National Conference on Earthquake Engineering, Charleston, SC, August, 1986, Vol. II, pp. 1129-1140.

5. Ashour, Samir A., "Elastic Seismic Response of Buildings With Supplemental Damping," Ph.D. Dissertation, Dept. of Civil Engineering, University of Michigan, January, 1987.

6. Wu, Jianping, "Statistical Study of the Inelastic Response of Structures With High Damping Subjected to Earthquakes," Ph.D. Dissertation, Dept. of Civil Engineering, University of Michigan, November 1987.