DAMPING DETERMINATION FROM FULL-SCALE EXPERIMENTS

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ABSTRACT

The influence of some factors which affect the evaluation of the damping characteristics of large panel prefabricated as well as reinforced concrete frame building is discussed. The principles and procedure of full-scale forced vibration studies of such structures are also presented.

The damping characteristics of the structural normal modes of vibration are obtained as a function of the input excitation force or as a function of the inter-storey displacements due to the forced vibration excitation. The presented procedure enables the selection of structural damping values to be done in a rational and systematic manner.

INTRODUCTION

The earthquake resistant design of buildings is of extreme importance because of the devastating consequences in case of failure of such structures under seismic forces. Unfortunately, the dynamic characteristics as influenced by the foundation and the amplitude of the structural displacements on the dynamic response are complex enough to be analysed accurately.

It is generally agreed that buildings should be designed and constructed to withstand moderate earthquakes without damage and large earthquakes, with some, if possible, prescribed damage. Hence, the analysis considers the linear elastic and non linear response of the structure. Complete knowledge of the structural characteristics and the correct mathematical representation of the same is a primary requirement for prediction of the dynamic behaviour.

The design loads in a building obtained from an earthquake response analysis are a function of building damping. While it is possible to systematically characterize the inertia and stiffness properties of a building using the existing analytical or in current time finite element techniques, it is not possible in general to characterize the damping in this way. Generally in the design, damping in a building is quantified by means of establishing of numerical values of a viscous damping coefficient for each normal mode of vibration. Such an approach offers the advantage of mathematical simplicity and enables the design engineer to establish damping values consistent with general building response amplitudes.

The study of full-scale building response has been an area of considerable research (1, 3, 4, 6, 8, 9, 10, 11, 12). Only the IZIIS staff have carried out force vibration full-scale experiments on 40 reinforced concrete and brick-masonry buildings, 5 steel and reinforced concrete bridges and 8 rock-fill and concrete dams. The improvement of electronic measurements and excitation equipment in the recent years has enabled the professionals to obtain estimates of building natural periods, modal damping coefficients, and mode shapes of vibration accurately and rapidly. While such full-scale

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tests have usually been limited to low response amplitudes, they have provided valuable insight into the dynamic response of buildings.

In the design, the use of damping values obtained from low amplitude tests information can result in calculated responses that exceed those expected during earthquake excitation. Newmark and Hall (5) have suggested general damping magnitudes based on low level full-scale test results and observed laboratory damping versus amplitude trends. These suggestions are based on general member stress levels obtained from a response analysis. Since many structures are present in a building, often some members are highly stressed while others have low stress ratios. Thus, the systematic application of such a criterion for design is unclear. Hart and Vasudevan (2), on the other hand, have suggested a more reliable procedure for damping magnitude estimation. Their procedure is based on observation of 5 steel and 7 reinforced concrete Southern California buildings, subjected to the February 9, 1971, San Fernando earthquake, and using acceleration versus time records, modal damping is estimated. As a result of that investigation, it is proposed a developed relationship between the amplitude of the building basement record of 0% damped pseudo velocity response spectrum at the modal period and the magnitude of the modal damping.

Although the accuracy in evaluating the damping characteristics and the response have generally been improved through the use of computers and the possibilities of a more accurate formulation of a mathematical model of a structure, more experimental data are urgently needed. Experimental studies will provide the necessary information to determine the accuracy of the assumptions which are used to formulate the mathematical model. Considering the complexity of several factors influencing the response of buildings, it is obvious that the prototype studies will yield the information necessary to formulate an accurate mathematical model of the structure. At present, only forced vibration studies using vibration generators will provide rapidly this information.

DAMPING ESTIMATION FROM BUILDING FULL-SCALE FORCED VIBRATION EXPERIMENTS

The exciters used in forced vibration studies at the Institute of Earthquake Engineering and Engineering Seismology,Skopje,Yugoslavia,are like several vibration generators built during the last years,of two-mass,counter-rotating,excentric-weight type.The weights rotate in horizontal planes about the same vertical shaft.By means of this equipment, sinusoidally varying forces can be applied to the structure along a predetermined axis.As baskets containing the weights rotate in opposite directions,maximum forces are attained twice each cycle when the baskets pass one another.When the baskets are 90° to the force axis,the centrifugal forces are opposed,and thus no resultant force is produced.

To obtain information on the dynamic properties of a building,the response of the building is measured under a steady-state forced vibration.Natural frequencies (periods) and damping coefficients are determined by measuring the response of the structure over a range of forced vibration frequencies extending from 1 to 9 cycles per second.The response is commonly recorded by observing the signal derived from several accelerometers (maximum 0.25). By using two generators on the top floor,symmetrically placed with respect to the center of gravity of the floor,mode shapes can be determined for each of the natural frequences.To determine these mode shapes the response of the building at a number of predetermined floor level locations is recorded while being subjected to force vibration excitation frequences corresponding to the natural frequencies.

The definition of damping from building response records is an integral part of the so called "system identification" applied research. The main objective of such an investigation is to identify the dynamic parameters of the building. For this purpose, permanent investigations have been carried out in IZIIS on different types of buildings, the residential buildings prevailing. The precast large panel buildings applied with various modifications as typified structures all over Yugoslavia have been included in these research programmes. The tests have been carried out on full-scale structures using the above described equipment. Thus, for each force level the resonant frequency of the building, the elastic deformations and the damping involved can accurately be determined.

Damping is defined from amplitude-frequency curves (half-power bandwith method) or by the free damped oscillations excited by the generators (transient die-down response and logaritmhmic decrement method).

Included in the analysis are data on 12 buildings constructed in large panel systems and 10 buildings constructed in reinforced concrete frame systems.

For each of the two structural systems investigations were carried out regarding the dependance between: input force and damping, generalized force and damping, as well as generalized acceleration and damping. The systems were excited by force acting at the top floor (Fig. 1). Then studied was the dependance between the relative storey deformation (γ) at the lowest floor and the damping (Fig. 1).

The results obtained by the analysis are shown in Figures 2 through 9. Presented in Fig. 2 is the dependance between the relative storey deformation and the damping coefficient for large panel cast systems. Fig. 3 illustrates the dependance between the relative storey deformation and the damping coefficient for reinforced concrete frame systems. The dependance between the input force and the damping coefficient for large panel cast systems is shown in Fig. 4.The dependance between the generalized force and the damping coefficient for large panel prefabricated systems is presented in Fig. 5. Fig. 6 illustrates the dependance between the generalized acceleration and the damping coefficient for large panel prefabricated systems. Fig.7 shows the dependance between the input force and the damping coefficient for reinforced concrete frame systems. Fig. 8 shows the dependance between the generalized force and the damping coefficient for reinforced concrete frame systems. Presented in Fig. 9 is the dependance between the generalized acceleration and the damping coefficient for reinforced concrete frame systems. The values of the regression coefficients for the I, II, and III order curves, obtained by the least square method are presented in Tables 1 and 2 for large panel, and reinforced concrete frame systems, respectively.

CONCLUSIONS

-The results obtained in this paper are only a part of the broad investigation program for definition of dynamic characteristics of divers types of buildings with special attention paid to damping. Part of these investigations are presented in reference (8).

-The obtained results are in support to the fact that increase of the input force, generalized force, i.e. generalized acceleration results in increase of damping.

-Increase of the relative storey deformation results in increase of damping, too.

REFERENCES

1. Boukamp,J.G., and Stephen,R.M.,"Ambient and Forced Vibration Study of a Multistorey Pyramid-Shaped Building, "Proc. of the Fifth World Conference on Earthquake Engineering, Rome,Italy,1973.

2. Hart,G.C. and Vasudevan R.,"Earthquake Design of Buildings:Damping" Journal of the Structural Division,Proc.of the American Society of Civil Engineers, Vol. 101,No. ST. 1, January 1975.

3. Hudson,D.E."Response Testing of Full-Scale Structures ", Journal of the Engineering Mechanics Division,ASCE, Vol. 90, No. EM3,Proc. Paper 3923, June,1964.

4. Keightley, W.O.,"Vibration Tests of Structures", Earthquake Engineering Research Laboratory Report,California, 1961.

5. Newmark,N.M., and Hall,W.J.,"Seismic Design Criteria for Nuclear Reactor Facilities", Proc.of the Fourth World Conference on Earthquake Engineering,Santiago, Chile,1969.

6. Paskalov,T.,"Structural Vibration Theory", Lecture Notes for Post-Graduate Courses in Earthquake Engineering,IZIIS, Skopje, 1976.

7. Paskalov, T.,"Seismic Force Determination for High-Rise Buildings", IZIIS Publication No.13, Skopje, 1968 (In Macedonian).

8. Paskalov,T., Taskov,Lj.,"Damping Determination from Full-Scale Experiments",Sixth European Conference of Earthquake Engineering, Dubrovnik,1978.

9. Petrovski,J., Paskalov,T., Jurukovski,D., and Percinkov,S., "Dynamic Behaviour of High-Rise Buildings with Shear Walls", IZIIS, Publication No.22, Skopje, 1970 (In Macedonian).

10. Petrovski,J.,et al."Dynamic Full-Scale Investigation of a 13 - Storey Prefabricated Structure,System "Vranica" in Sarajevo,IZIIS, Reports No.LDI-77-6, Skopje, 1977 (In Serbo-Croatian).

11. Jurukovski,D., and Percinkov,S.,"Full-Scale Forced-Vibration Test of a 22-Storey Prefabricated Structure in Zemun-Belgrade", IZIIS,Publication, No.LDI-77-2, Skopje, 1977 (In Serbo-Croatian).

TABLE No. 1 – REGRESSION COEFFICIENTS FOR LARGE PANEL BUILDINGS

Regression Coefficients		A(o)	A(1)	A(2)	A(3)
Curves in Fig. 4 "P–λ" Diagram	I Degree	0.191 + 01	0.246 – 03	–	–
	II Degree	0.145 + 01	0.912 – 03	–0.153 – 06	–
	III Degree	0.190 + 01	–0.244 – 03	0.481 – 06	–0.904 –10
Curves in Fig. 5 "P*–λ" Diagram	I Degree	0.163 + 01	0.646 – 03	–	–
	II Degree	0.754 + 00	0.331 – 02	–0.119 – 05	–
	III Deegree	0.723 + 00	0.354 – 02	–0.149 – 05	0.936 - 10
Curves in Fig. 6 "s*–λ" Diagram	I Degree	0.182 + 01	0.589 + 00	–	–
	II Degree	0.151 + 01	0.125 + 01	–0.147 + 00	–
	III Degree	0.117 + 01	0.249 + 01	–0.780 + 00	0.767 – 01
Curves in Fig. 2 "γ–λ" Diagram	I Degree	0.964 + 00	0.123 + 00	–	–
	II Degree	0.212 + 00	0.278 – 02	0.920 – 04	–
	III Degree	0.974 + 00	0.121 + 00	0.648 – 07	0.296 – 05

TABLE No. 2 – REGRESSION COEFFICIENTS FOR REINFORCED CONCRETE FRAME BUILDINGS

Regression Coefficients		A(o)	A(1)	A(2)	A(3)
Curves in Fig. 7 "P–λ" Diagram	I Degree	0.110 + 01	0.284 – 03	–	–
	II Degree	0.114 + 01	0.204 – 03	0.260 – 07	–
	III Degree	0.101 + 01	0.676 – 03	–0.356 – 06	0.782 –10
Curves in Fig. 8 "P*–λ" Diagram	I Degree	0.115 + 01	0.276 – 03	–	–
	II Degree	0.112 + 01	0.349 – 03	–0.199 – 07	–
	III Deegree	0.117 + 01	0.196 – 03	0.857 – 07	–0.166 – 10
Curves in Fig. 9 "s*–λ" Diagram	I Degree	0.127 + 01	0.262 + 00	–	–
	II Degree	0.130 + 01	0.131 + 00	0.121 + 00	–
	III Degree	0.610 + 00	0.629 + 01	–0.128 + 02	0.710 + 01
Curves in Fig. 3 "γ–λ" Diagram	I Degree	0.810 + 00	0.866 – 01	–	–
	II Degree	0.158 + 01	0.113 – 02	0.283 – 04	–
	III Degree	0.823 + 01	0.648 – 01	0.500 – 08	0.119 – 06

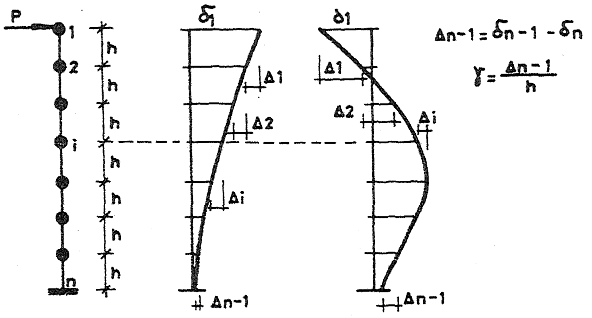

Fig. 1. Discrete scheme of multi-defree of-freedom system

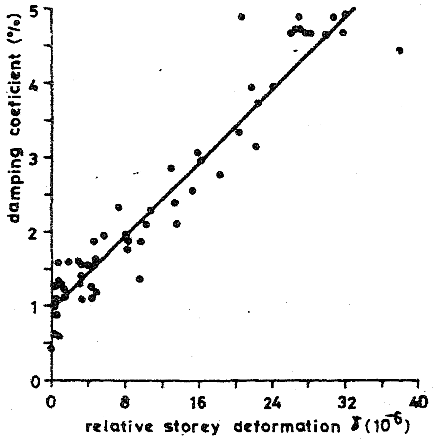

Fig. 2. Dependence between relative storey deformation and damping coefficient for large panel precast buildings

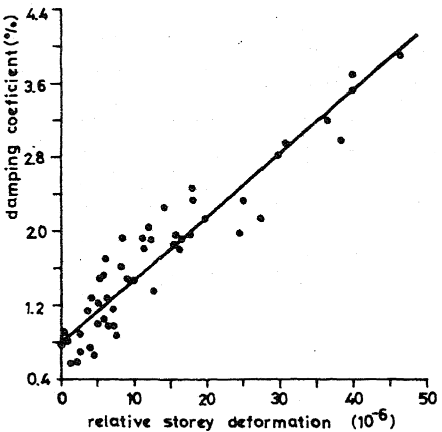

Fig. 3. Dependence between relative storey deformation and damping coefficient for reinforced concrete frame buildings

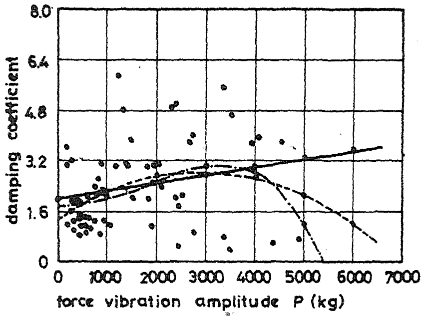

Fig. 4. Dependence between input force amplitude and damping coefficient for large panel precast buildings

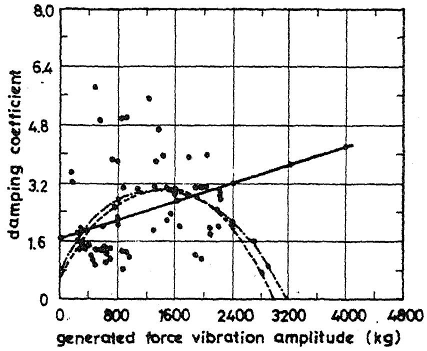

Fig. 5. Dependence between generalized force and damping coefficient for large panel precast buildings

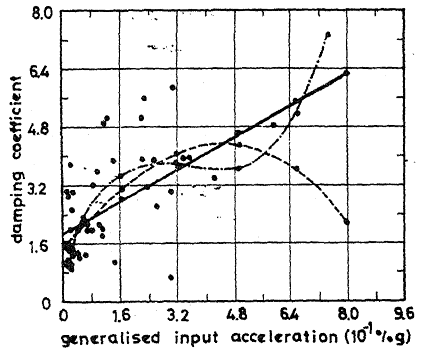

Fig. 6. Dependence between generalized acceleration and damping coefficient for large panel precast buildings

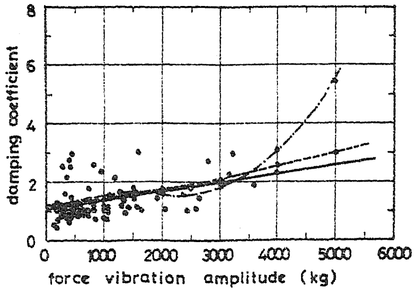

Fig. 7. Dependence between imput force amplitude and damping coefficient for reinforced concrete frame buildings

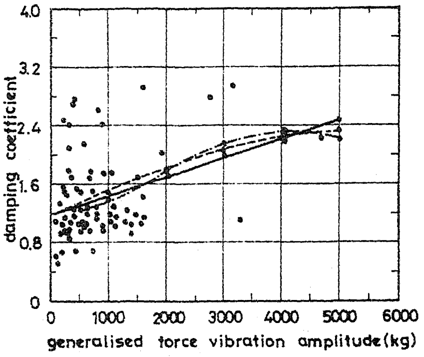

Fig. 8. Dependence between generalized force and damping coefficient for reinforced concrete frame buildings

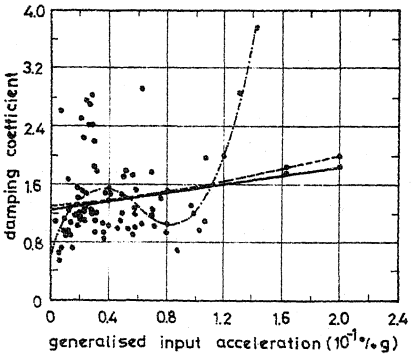

Fig. 9. Dependence between generalized acceleration and damping coefficient for reinforced concrete frame buildings