Theme Report on Topic 9
DYNAMIC TESTS ON STRUCTURES

by

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SYNOPSIS

Presented is a brief report on the thirty papers assigned to TOPIC 9 - DYNAMIC TESTS ON STRUCTURES. While some coverage is given in these papers to experimental techniques, including certain recommendations for improvements, they generally concentrate on the interpretation of dynamic test results in terms of structural performance under seismic conditions. The tests were performed on real buildings, test buildings, building frames, water tanks, chimneys, dams, and a suspension bridge. Some general overall observations are made regarding the content of these papers and certain recommendations are given for future testing.

OBJECTIVE

The main objective of conducting dynamic tests on structures is to improve and verify mathematical modelling which is intended to realistically represent prototype behavior under seismic conditions. Therefore, such tests must concentrate on obtaining dynamic response characteristics of complete structure-foundation systems, including force-deformation, energy absorption, and failure characteristics. Ultimately, the objective of performing dynamic tests on structures is to improve seismic resistant designs and, through analyses, to verify that adequate levels of safety have been provided.

EXPERIMENTAL TECHNIQUES

Various types of dynamic excitation were used in the test programs reported including ambient ground motions, microtremors, wind, impact, mechanical vibration, hydraulic actuator forces, shaking table motions, and strong seismic ground motions; thus, the dynamic forces imposed varied greatly in their time-history characteristics, spatial distributions, and intensities. Dynamic force-deformation characteristics were obtained through standard measurements of force, displacement, velocity, acceleration, and strain which, when combined with visual observations, provided the means for determining failure characteristics. Correlation of test results with analytical predictions were made using well-known methods of dynamic analysis. Recently developed Fast Fourier Transform techniques aided greatly in this effort.

The on-line system described in paper No. 1* represents a significant new development in controlling dynamic testing. When testing with hydraulic actuators using displacement electronic control, this system allows the displacement command signals to be consistent with the test structure's response to a prescribed earthquake excitation; thus, the command signals are coupled to the actual force-deformation characteristics of the structure being tested. While this on-line system has been applied to only a single actuator case, its use could be extended to multi-actuator applications.

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* See LISTING OF PAPERS

As pointed out in paper No. 2, a need exists for developing improved measurement techniques for dynamic testing. Laser displacement measurements, photogrammetry, and telemetry were techniques mentioned which could assist in this development. Whatever techniques are used, it is important to know the possible quantitative errors present in experimental results. As pointed out in paper No. 3, regression analyses can be used for this purpose.

TEST RESULTS

A. REAL BUILDINGS

1. General - Papers Nos. 4 and 5 present results of dynamic tests performed on numerous buildings in Japan. Without identifying specific buildings, quantitative results showing dynamic response characteristics for different classes of buildings and foundation conditions are given.

Using test data from vibration measurements on many high-rise buildings under ambient, forced vibration, and actual earthquake conditions, the authors of paper No. 4 obtained natural periods of vibration and equivalent damping ratios for translational and torsional modes by applying Fourier analysis techniques to the motions measured at numerous floor levels. Although these results have wide scatter, the general trends show the damping ratio to be inversely proportional to period of vibration (except in the long period range) and to be considerably less for the fundamental mode than for higher modes. The approximate relationship between fundamental period T_1 and its damping ratio h was found to be $h = 0.04/T_1$ and $h = 0.02/T_1$ for soft and hard soil conditions, respectively. It was concluded by the authors that for analysis purposes the mechanism of equivalent viscous damping for buildings should be coupled to a mechanism representing foundation damping under rocking conditions. Combining these two mechanisms, their analytical results correlated well with experimental results.

In paper No. 5, the authors present the results of vibration tests carried out on 18 tall buildings to obtain periods of vibration and equivalent damping ratios and they present similar results obtained by analyzing the measured response of 11 tall buildings during earthquakes. The vibration tests showed the relationship between fundamental period T_1 and number of stories N to be approximately $0.06N<T_1<0.10N$ and $0.03N<T_1<0.06N$ for steel frame buildings and for reinforced concrete and reinforced concrete-steel composite frame buildings, respectively. On the average, the second and third periods of vibration were related to the fundamental period as given by $T_2 = 0.33T_1$ and $T_3 = 0.19T_1$, respectively, for all construction types. The fundamental torsional period T_T was found equal to $0.8T_1$ on the average but in some cases it was found to be nearly equal to T_1. The damping ratios for the modes in general were found to be in the ranges $.005<h<.020$ and $.015<h<.060$ for steel frame buildings and for reinforced concrete and reinforced concrete-steel composite frame buildings, respectively. From the results obtained for the 11 buildings subjected to earthquake excitations, it was found that the fundamental periods had increased by about 13 percent over their corresponding values obtained from vibration tests. These longer periods due to the higher response (10 - 50 times) produced by earthquake excitation over the response developed by mechanical excitation, indicate that buildings generally act as nonlinear softening systems.

2. Oak Center Towers Building - Paper No. 6 presents the results of forced vibration tests carried out on the Oak Center Towers, an eleven-story reinforced masonry building located in Oakland, California. It is constructed with reinforced concrete block shear walls and prefabricated prestressed concrete slab

floor elements. The foundation consists of spread footings under each shear wall. Mode shapes, frequencies, and damping ratios were obtained from the test results. All of these quantities were significantly affected by foundation and in-plane floor flexibilities. The fundamental transverse frequency (2.78 cps) was found to be nearly equal to the fundamental torsional frequency (2.83 cps) showing considerable coupling between these two modes. The damping ratios in the various modes examined were in the range 2 to 9 percent depending upon the relative importance of foundation damping. Consistent with this observation, damping was much higher in the fundamental transverse mode than in the second transverse mode. Analytical predictions of shapes and frequencies for the first and second modes correlated well with experimental results but large discrepancies were found in these same correlations for higher modes.

3. Millikan Library Building - Paper No. 7 presents the results of forced vibration tests carried out on the Millikan Library, a nine-story reinforced concrete building located on the campus of the California Institute of Technology in Pasadena, California. During the tests, closely spaced three-dimensional measurements of the motions on many floors were recorded along with selected strain measurements. This extensive set of measurements permitted a close examination of the deformation patterns produced; thus, providing valuable information on the type and amount of interaction between the various structural elements, e.g., between frames and shear walls, between structural and nonstructural systems, and between building and foundation. The shear walls were observed to act much like Euler beams with shearing deformations included and the foundation was observed to contribute significantly to the flexibility of the overall structural system (4 and 25 percent of the roof translation in a fundamental mode were produced by translation and rotation of the basement slab, respectively).

4. Ralph M. Parsons Building - Paper No. 7 also presents the results of forced vibration tests carried out on the Ralph M. Parsons Company World Headquarters building, a twelve-story steel frame building located in Pasadena, California. Like the Oak Center Towers building, the test results show strong interference or coupling between translational and torsional modes. The authors indicate that such coupling could produce stresses 75% higher in outer columns than would be produced with purely uncoupled translational motion and they properly question whether or not codes adequately provide for such a possibility. Similar to many buildings, the Ralph M. Parsons building responds with large interaction between structural and nonstructural systems under small-amplitude test conditions. It was found that this interaction appreciably increased the frequencies of the first three translational modes in the N-S direction. As pointed out by the authors, this strong interaction would undoubtedly be greatly lessened under large-amplitude seismic conditions, i.e., the building would act as a nonlinear softening system. The damping ratios for the various modes were found to be in the range 2.5 to 6.5 percent of critical; thus, showing considerable scatter and influence from the interaction of structural and nonstructural systems.

5. Jet Propulsion Laboratory Building 180 - Paper No. 8 presents the results of forced vibration tests carried out over a period of 12 years on Building 180 of the Jet Propulsion Laboratory, Pasadena, California, a nine-story steel frame structure supported on continuous strip footings. The results obtained reveal the variable nature of the building's dynamic characteristics over that period due to changes in mass and stiffness distributions. Using natural frequencies measured upon completion of the steel frame and the corresponding frequencies measured later upon completion of the building and considering mass changes due to the addition of materials (concrete to columns, fireproofing of girders and trusses, air conditioning, windows, facing, etc.), it was determined that the building's

overall stiffness had increased over this final phase of construction by factors of 1.75 and 1.45 in the N-S and E-W directions respectively; thus showing the large influence of the nonstructural system on overall stiffness. Later during the San Fernando, California, earthquake of 1971, measurements of the building's response indicate that these same overall stiffnesses decreased during the earlier part of the motion by factors of 1.69 and 1.51, respectively, showing nonlinear softening behavior. Subsequent repair resulted in the building regaining some of its stiffness lost during the earthquake. All of the above changes in stiffness emphasize the difficulties in arriving at realistic mathematical models for buildings.

B. TEST BUILDINGS

1. Reinforced Concrete Frame Buildings - Results of vibration tests on a full-scale four-story reinforced concrete test building having no nonstructural elements located at the Nevada Test Site of the U. S. Energy Research and Development Administration are reported in paper No. 9. Using a large mechanical vibrator capable of producing force amplitudes up to 5,500 kg at frequencies greater than 1.6 H_z, amplitudes of response were developed sufficiently large to produce major damage, i.e., spalling of concrete on columns and yielding of reinforcing steel. Initially, nondestructive tests were performed, exciting 4 translational modes in the elastic range. Next, by exciting the structure at its lowest mode frequency, a destructive test causing major damage was performed. Finally, post-destructive tests at force amplitudes comparable to the nondestructive tests were carried out. During the initial nondestructive tests, the period of the lowest mode increased about 25 percent from low to high amplitude conditions and the corresponding damping ratio increased from 1.25 to 1.75 percent of critical; thus, showing a slightly nonlinear softening system. This same fundamental mode showed an increase in period by 60-70 percent with a corresponding increase in damping ratio to 4 percent of critical from the non-destructive to post-destructive state. During the destructive test, the fundamental mode period increased from 0.52 seconds in the elastic range to 0.90 seconds in the range of major damage with corresponding changes in the damping ratio from 2.2 to 5.5 percent of critical.

Paper No. 10 presents the results of static and shaking table tests on a 1:3 scale model of a rectangular five-story reinforced concrete building having 4 rigid frames in each horizontal direction with precast concrete floors. This building was tested in a bare state, i.e., without any nonstructural elements. Four successive static monotonic loadings were applied at the fifth floor level (1) an initial loading in the elastic range, (2) a loading following shaking table tests which produced micro-cracking, (3) a loading following shaking table tests which produced major cracking, and (4) a loading following shaking table tests which produced major damage in the vicinity of beam-column joints. Stiffness degradation by a factor of 3.8 was noted from the initial elastic loading to the final loading prior to reaching a collapse state. In the shaking table tests, damping ratios were found to range from less than 1% in the uncracked condition to a maximum of about 3.5% for amplitudes of response near failure. Undoubtedly, these damping ratios would have been much higher had typical nonstructural elements been added to the building. Consistent with observed reductions in stiffness, large increases in the natural periods were measured. Failure characteristics were noted by observing the development of major cracking in the vicinity of the beam-column joints.

Using the results of shaking table tests on a 1:3 scale model of a five-story prefabricated reinforced concrete building, the authors of paper No. 11 made comparisons with the results obtained analytically using a mathematical model which assumed rigid floors in their own plane. This assumption was shown to be incorrect and that floor flexibility greatly influenced the distribution of lateral shear to the transverse frames. In fact it was shown that for this structure a central frame would carry 1.5 to 2 times the load it would be required to carry if the floors were indeed rigid in their own plane.

2. Small Brick Buildings - In paper No. 12, a tilting platform 8½ ft x 8½ ft was used to test the lateral resistance of 9 pairs of brick structures 4 ft x 6 ft x 31 in. high, one brick thick, laid in 1:5 lime-sand mortar, sand, mud, and no mortar at all. A 1350 lb roof slab rested on foam rubber on the walls. The table was then mounted on wheels and pulsed horizontally to attempt to relate building-strength under repetitive pulses to strength under static tilt. Building performance under static tilt was quite consistent while performance under pulse loading showed wide scatter. The two kinds of tests produced similar patterns of failure in the mortared buildings; however, the unmortared buildings were more vulnerable to the pulse type excitation.

C. TEST FRAMES

1. Reinforced Concrete Frames - The results of hydraulic actuator displacement control tests simulating earthquake conditions on 4 one-story reinforced concrete frames having different natural periods of vibration are given in paper No. 1. Using a mathematical model based on the authors' fully defined hysteretic stress-strain relationship for concrete and the Ramberg-Osgood stress-strain relationship for reinforcing steel, good correlations were obtained between analytical predictions and experimental results.

2. Reinforced Concrete Shear Wall-Frame Structures - Paper No. 13 presents the results of shaking table tests on (1) a pair of three-story one-bay reinforced concrete frames, and (2) a similar pair of frames built monolithically with a three-story slender shear wall. Scaled earthquake motions in one horizontal direction were applied with the intensity of the first test run (for 3 specimens) being roughly comparable to the intensity of a design earthquake. The intensities of motion were doubled with each successive test run until failure of the specimen occurred. The test results show that reinforced concrete frame structures (with or without shear walls) can withstand very intense earthquake motions provided they are carefully designed to prevent diagonal shear failures, anchorage failures, and brittle compressive failures. Thus, it is important that columns have a sufficient web reinforcement to develop the maximum possible shear controlled by end moment capacities and that the exterior columns be designed to carry the additional axial forces caused by overturning effect without brittle compressive failure or tensile fracture of the reinforcement.

3. Infilled Reinforced Concrete Frames - Results of shaking table tests on 8 models consisting of two parallel 1:4 scale three-story brick infilled reinforced concrete frames are presented in paper No. 14. These models differed only in geometry of door and window openings and in bracing around openings which consisted of vertical and horizontal lintels. A concrete block was supported at the top of each specimen to simulate building weight and vertical prestressing cables were used to reproduce axial stresses in the frame columns. Each specimen was subjected to seismic excitations of sufficient numbers, intensities, and durations to simulate the lifetime seismic environment of the prototype structure. The test results showed that good performance can be achieved provided favorable interaction between frames and infill walls is developed through proper confinement around openings. Such confinement can be obtained using both vertical and horizontal reinforced lintels carried through and connected to beams and columns of the frame,

respectively. Using finite element modelling, the authors found good correlation between analytical predictions and experimental results, even for response into the cracking stage.

4. Reinforced Concrete Frames With Partition Walls - Subjecting 1:6 scale, one-bay, three-story, reinforced concrete frame models, with and without partition walls, to free vibration and harmonic base excitation, the author of paper No. 15 found that partition walls appreciably affect dynamic response. Therefore, their stiffnesses should be considered in mathematical modelling of the complete structural system.

5. Steel Frames - The results of cyclic loading tests on single rectangular steel rigid frames having various kinds of bracings are presented in paper No. 16. Subjecting the two columns of each frame to constant loads, pairs of self-equilibrating loads are alternately applied diagonally across the frame producing the desired cyclic loading. The elasto-plastic behavior of each frame, including post-yield buckling of bracings, is measured and correlated with analytical predictions. Examining high-strain fatigue life shows it to be relatively shorter for braced frames over unbraced frames.

Paper No. 17 presents the results of tests carried out on one-story, single-bay steel rigid frames having joints of different types. It was pointed out that if the zones of plastic deformation should include joint welds, the failure of the frame will often be caused by early fracture in the welds; thus greatly reducing the ductility of the overall system. To avoid such failures, it was shown that tapered sections near the joint forcing the plastic zones of deformation away from welds were effective. However it was shown that when using tapered sections, proper strength and ductility is achieved only when premature local buckling in flanges and webs and overall buckling of columns are presented. The importance of providing adequate strength and ductility in design is emphasized.

The results of monotonic unidirectional static loading of spatial one-story mild-steel frames are given in paper No. 18. Due to the nonsymmetrical arrangements of 3 pipe columns, eccentricities were present which caused torsion and translation in two horizontal directions to occur. Such results are simply a reminder that proper consideration should be given to the effects of eccentricities on dynamic response. As pointed out in paper No. 19, consideration should also be given to the influence of interconnecting members on the combined stiffness of parallel plane frames.

D. WATER TANKS

The seismic performance of a water tower, consisting of an inverted truncated shell supported concentrically on a cylindrical column, is discussed in paper No. 20. Tests were performed to study the sloshing problem and its influence on fluid pressures and stresses in the conical shell. The total coupled seismic response of the fluid-tower system with a critical volume of water is examined at amplitudes of response up to failure. Clearly, the dynamics of the fluid system greatly affects overall tower response under seismic conditions and therefore should be considered realistically in design, not only in sizing of structural elements but also in the earlier selection of overall tank geometry.

E. CHIMNEYS

Results of an analysis of the seismic behavior of the chimney of the TVA 1200 MW fossil steam generating power plant, Unit 3, at Paradise, Kentucky, are presented in paper No. 21. This chimney consists of two tapered concentric cylindrical shells having no significant structural inter-connections. Time-histories of tip deflection, base shear, and overturning moment were obtained by modal analysis using various values for damping ratios and using the N-S component of the 1940 El Centro, California, earthquake as input. Also using a refined quadrilateral plate element modelling, stress distributions around flue openings were obtained. It is clear that such analyses which are straightforward, would be very useful if carried out during the design phase. The first three mode shapes and frequencies of the chimney were measured and were found to agree well with the results of analysis.

F. DAMS

Paper No. 22 describes a field test program being conducted by the Italian National Board for Electric Power to obtain the dynamic characteristics of the most important Italian dams. Using mechanical vibrators, shapes, frequencies, and damping ratios for at least four modes are measured and, by placing a vibrator at discrete locations on the crest, transfer functions between force input (maximum amplitude 10 tons; frequency range 2-15 H_z) at each point and velocity response at discrete locations are obtained. These transfer functions are then correlated with those of a finite element model with the intent of verifying and improving mathematical modelling. Damping ratios were found in the range 1 to 3 percent for arch dams and in the range 4 to 8 percent for gravity dams with no noticeable variation with mode number. Reservoir-dam interaction has been found to be important and is still being investigated.

The results of forced vibration tests on 2 earth-fill and 2 rock-fill dams in Yugoslavia are given in paper No. 23. Measured mode shapes, frequencies, and damping ratios are used to develop realistic mathematical models for low amplitude response. Dam-foundation interaction and, in some cases, reservoir-dam interaction were found important and should be included in mathematical modelling. Damping ratios were found to be highly variable in the range 2 to 9 percent.

G. SUSPENSION BRIDGE

Mode shapes, frequencies, and damping ratios for the Lion's Gate Suspension Bridge in Vancouver, Canada, as measured under ambient and impact loading conditions, are presented in paper No. 24. Using both continuum and discrete mathematical models, excellent agreement between measured and calculated frequencies for vertical modes and the lowest horizontal mode was obtained. Some difficulty was experienced however in obtaining good correlation for torsional modes, apparently due to inaccurate evaluations of the bridge girder's torsional stiffness. The measured low-amplitude damping ratios varied greatly over the range 0.3 to 1.6 percent.

OVERVIEW OF TEST PROGRAMS

A. GENERAL

As stated previously, the main objective of conducting dynamic tests on structures is to improve and verify mathematical modelling which is intended to realistically represent prototype behavior under seismic conditions. Consistent with this objective, dynamic tests have been carried out on small, medium-, and full-scale components, assemblages, and complete structural systems using various types of excitation.

B. SMALL-SCALE TESTS

Obviously for economic reasons, the use of small-scale models for dynamic testing should be encouraged whenever the results obtained permit, either directly or indirectly through analysis, realistic predictions to be made of prototype performance under seismic conditions. Such is the case when modelling structural systems which are designed to remain essentially elastic during strong motion earthquakes. Prototype response can be predicted directly from the test results in this case provided similitude conditions as discussed in papers Nos. 25 and 26 are met and provided realistic boundary and loading conditions are maintained. These latter conditions can be maintained effectively through the use of modern electronically controlled shaking tables of the type described in paper No. 27 on which models, including boundary elements (e.g., a three-dimensional dam including portions of foundation and abutments), are mounted.

Since gravity and seismic forces scale differently, a centrifuge can be used to modify the effective gravity forces; thus, bringing into agreement the associated similitude conditions. The small-scale simple oscillator models made of different materials and the nine-story large-panel dwelling models described in paper No. 28 were tested within a centrifuge for this purpose and were subjected to simulated seismic excitations. This particular investigation was carried out to study the influence of foundation conditions on response. It was found, as in other investigations, that both damping and fundamental period of vibration increased substantially when changing from hard to soft foundation conditions.

Examples of structural types designed to remain essentially elastic during strong motion earthquakes are arch and arch-gravity dams as described in paper No. 29. Optical techniques were used extensively in this investigation to measure mode shapes, frequencies and dynamic stress distributions.

The use of small-scale models for testing into the inelastic range is very limited due to extreme difficulties in interpreting prototype behavior from the test results. Paper No. 26 discusses the basic principles which must be adhered to when modelling in the inelastic range. These principles require the development of new modelling materials with specified properties which, in many cases, are very difficult to produce. Therefore, it is impossible to assess the future success of small-scale testing into the inelastic range of response. Undoubtedly, it will be quite limited, thus greater emphasis should be placed on medium and full-scale testing.

C. MEDIUM-SCALE TESTS

One approach to mathematical modelling of prototype structural systems is to combine sub-element models representing individual structural components and/or assemblages into global models representing complete systems. Therefore, much dynamic testing has been carried out on medium-scale structural elements and assemblages for this purpose. Once the force-deformation and failure characteristics of these sub-elements have been defined in terms of loading and structural parameters, these same characteristics are supposedly fully defined for the global models. Unfortunately, in some cases, extrapolation of medium-scale test data to the prototype structure is questionable. Further, realistic representations of the many complex interactions (e.g., between frames and walls, frames and floors, super-structure and foundation, structural and nonstructural systems) in the prototype model are still very uncertain. Although this approach to modelling prototype structures through medium-scale testing has many deficiencies, it must continue due to the severe limitations of small-scale testing and the high cost of full-scale testing. To implement this approach, the development of effective and efficient three-dimensional nonlinear dynamic analysis procedures must continue as well.

D. FULL-SCALE TESTS

Establishing mathematical models for prototype structures through testing of full-scale structures has the distinct advantage that the uncertainties involved in extrapolating dynamic characteristics from one scale to another are removed. If these full-scale structures are only test structures, the validity of using the test results directly in characterizing prototype structures depends on the degree to which the test structures actually represent real structures. For example, if a full-scale building is tested without a nonstructural system (fire proofing, partitions, windows, facings, etc.), its dynamic characteristics can be very different from the prototype structure it represents. Therefore, when testing full-scale structures, it is desirable that they be constructed exactly like real complete structures and that they be placed on similar foundations. Further, to obtain maximum information on true seismic performance, it is desirable that the tests be carried out with realistic loadings producing response well into the inelastic range. To fully meet these conditions, the tests would obviously have to be performed under actual earthquake conditions similar to the design earthquake. This suggests that limited numbers of real buildings in regions of high seismicity should be fully instrumented to measure their dynamic response characteristics during future earthquakes.

Due to the long return period for high magnitude earthquakes, most dynamic tests on real structures have been carried out using mechanical vibration or ambient ground motions as the source of excitation. Unfortunately, due to the low-amplitudes of response produced, the results obtained have limited value. Certainly they cannot provide information on force-deformation characteristics into the inelastic range or information on failure characteristics. They do however provide valuable information which can be used to improve or validate mathematical modelling in the low amplitude range.

In the past, most dynamic tests under forced vibration and ambient conditions have been performed on high-rise buildings. The information obtained usually consists of mode shapes, frequencies, and damping ratios; the latter being highly variable with structural type, foundation condition, and amplitude of response. In view of the vast amount of such information already collected, it would seem desirable to concentrate future testing on unusual high-rise buildings and that they be instrumented fully so that in addition to obtaining mode shapes, frequencies, and damping ratios, quantitative data will also be obtained on deformation patterns and interaction effects, e.g., interactions between structure and foundation, frames and walls, frames and floors, and structural and nonstructural systems. Further, it is suggested that these tests be carried out during various stages of construction and, later, after the occurrence of each earthquake of significant intensity. Should an important building be subjected to internal fire, forced vibration tests as described in paper No. 30 can be used to indicate possible damage incurred.

In addition to testing unusual high-rise buildings, future forced vibration tests should also be carried out on selected low-rise buildings of various types, including industrial buildings. Similar tests should be carried out on other structural types, e.g., freeway bridge structures, nuclear power reactor structures, industrial plant facilities, dams, etc.

Recognizing the limitations of low-amplitude dynamic tests on structures, it is clear that an effort should be made to test large-scale complete structures, closely simulating real structures, under conditions producing high amplitude response similar to that produced by high intensity earthquake motions. Therefore, further consideration should be given to the development and use of large-scale testing facilities.

CONCLUDING REMARK

An attempt has been made in this brief report on TOPIC 9 - DYNAMIC TESTS ON STRUCTURES to summarize the significant test results contained in the 30 papers listed below and to present some general observations with recommendations for future testing. Undoubtedly, due to lack of time and space, inadequate reporting has been made on many of the papers. For this possible shortcoming, the present author expresses his sincere apologies.

LISTING OF PAPERS

1. Okada, T., and Seki, M., "A Simulation of Earthquake Response of Reinforced Concrete Buildings".

2. Ward, H. S., "Experimental Techniques and Results for Dynamic Tests on Structures and Soils".

3. Hiromatsu, T., "Regression Analysis on Resonance Curves of Forced Vibration Tests and Its Error Estimation Due to Microtremors".

4. Kobayashi, H., and Sugiyama, N., "Viscous Damping of Structures Related to Foundation Conditions".

5. Ohta, T., Adachi, N., Uchiyama, S., Niwa, M., and Takahashi, K., "Results of Vibration Tests on Tall Buildings and Their Earthquake Response".

6. Stephen, R. M., and Bouwkamp, J. G., "Dynamic Behavior of An Eleven Story Masonry Building".

7. Foutch, D. A., and Jennings, P. C., "Dynamic Tests of Full-Scale Structures".

8. Foutch, D. A., and Housner, G. W., "Observed Changes in the Natural Periods of Vibration of A Nine Story Steel Frame Building".

9. Chen, C. K., Czarnecki, R. M., and Scholl, R. E., "Vibration Tests of a 4-Story Concrete Structure".

10. Mihai, C., Diaconu, D., Manolovici, M., Marinescu, ST., Cirlan, ST., Iticovici, M., Amariei, D., and Soroceanu, I., "On the Static and Seismic Behavior of A Structural Model of An Industrial Storied Hall".

11. Negoita, A., Missir, I., and Schärf, F., "Seismic Analysis of Multistory Prefabricated Framed Structures".

12. Munski, K. D., and Keightley, W. O., "Tilting Platform for Measuring Earthquake Resistance of Small Buildings".

13. Otani, S., "Earthquake Tests of Shear Wall-Frame Structures to Failure".

14. Ravara, A., Mayorga, A., and Carvalho, C., "Seismic Tests of Infilled Reinforced Concrete Frames".

15. Mirabal, Y. M., "The Influence of Partition Walls on The Rigidity of Frame Structures".

16. Yamada, M., Tsuji, B., and Nakanishi, S., "Elasto-Plastic Behavior of Braced Frames Under Cyclic Horizontal Loading".

17. Korchynsky, I. L., and Aliev, G. A., "Behavior of Structures During Earthquakes Beyond the Limits of the Elastic Stage".

18. Focardi, F., "Experiments on the Spatial Behavior of Plastic Frames".

19. Basak, A. K., and Gupta, Y. P., "Experimental Determination of Lateral Stiffness Characteristics of Space Framed Three Dimensional Steel Structures".

20. Diaconu, D., Manolovici, M., Iticovici, M., Marinescu, S., Carlan, S., and Soroceanu, I., "Seismic Response of Elevated Water-Towers, With Tronconic Tanks and Central Tube, Taking Into Account the Water Swinging Effect".

21. Yang, T.Y., Kayser, K. W., and Shiau, L. C., "Theoretical and Experimental Studies of Earthquake Response of A Chimney". Refer paper No. 45, theme 3-26

22. Calciati, F., Castoldi, A., Fanelli, M., and Mazzieri, C., "In Situ Tests for the Determination of the Dynamic Characteristics of Some Italian Dams".

23. Paskalov, T. A., Petrovski, J. T., Jurukovski, D. V., and Taskovski, B. M., "Forced Vibration Full-Scale Tests on Earth-Fill and Rock-Fill Dams."

24. Rainer, J. H., and Van Selst, A., "Dynamic Properties of a Suspension Bridge".

25. Monahenico, D. V., "Principles of Physical Modelling of Structures Resistant to Earthquakes".

26. Bostjancic, J., "Model Materials Suitable for Dynamic Tests of Models in the Plastic Range".

27. Diaz, J. A., and del Valle, E.,"Dynamics Laboratory of The National University of Mexico".

28. Aliev, G. A., "Influence of Properties and Stressed State of Foundation Soils on Absorption and Diffusion of Energy of Seismic Vibrations".

29. Belogorodsky, B. A., Malyshev, L. K., and Panteleev, A. A., "The Solution of Seismic Stability Problems on Small-Scale Models by Optic Methods".

30. Srinivasulu, P., Lakshmanan, N., and Vaidyanathan, C. V., "Assessment of A Multistoreyed Building by Vibration Tests".