EXPERIMENTAL INVESTIGATION OF THE DYNAMIC BEHAVIOR OF BUILDING PARTITIONS AND SUSPENDED CEILINGS DURING EARTHQUAKES

Satwant S. Rihal (I)
Gary Granneman (II)
Presenting Author: Satwant S. Rihal

SUMMARY

This paper presents the results of an ongoing experimental research program to investigate the dynamic behavior of non-structural building partitions and suspended ceiling systems during earthquakes.

Dynamic testing of typical building partition and suspended ceiling systems (representative of current practices) has been carried out using an MTS electro-hydraulic closed-loop system. Input excitation is sinsusordal and specimens are subjected to cyclic motions of controlled amplitudes and frequencies. Three types of dynamic tests have been conducted: damping, sine-sweep, and block cyclic. Preliminary test results include fundamental dynamic properties (e.g., damping, natural frequencies) and relationship between input cyclic motions and component damage. Effectiveness of current building code provisions and installation practices have been investigated.

INTRODUCTION

Studies of observed building damage caused by recent earthquakes, e.g., Coalinga, California (1983), San Fernando, California (1971), and Anchorage, Alaska (1964), etc., have clearly demonstrated that consequences of architectural (non-structural) component damage are significant both in terms of their economic impact and the resulting hazard to building occupants, owners and to the public at large. The need for mitigation of of building component damage during future earthquakes has been recognized (Ref. 2, 4, 5). Mitigation of the building component damage requires an understanding of the dynamic behavior of such systems during earthquake motions. Previous studies (Ref. 4, 5) have shown that building component behavior during earthquakes may be characterized by (i) acceleration effects, (ii) relative horizontal displacement (drift) effects, (iii) impact/pounding effects. The major emphasis of the current investigation is to experimentally investigate the dynamic behavior of building partitions and suspended ceilings including evaluation of fundamental dynamic properties, e.g., damping and natural frequencies.

(I) Professor, Architectural Engineering Department

(II) Professor, ET/EL Department
California Polytechnic State University, San Luis Obispo, California 93407

OBJECTIVES OF DYNAMIC TESTING PROGRAM

The general objective of the dynamic testing program is to assess the effectiveness of Uniform Building Code (Ref. 9) provisions and current practices governing the design and installation of building partitions and suspended ceiling systems.

The detailed objectives of the dynamic testing program are to investigate:

1. The behavior of unbraced and braced suspended ceilings--without any partitions.
2. The behavior of building partitions subjected to motions normal to the plane of the partitions.
3. The behavior of unbraced and braced suspended ceilings with partial-height partitions including the interaction between these two components.
4. The behavior of unbraced and braced suspended ceilings with full-height partitions including effects of perimeter detailing on overall component behavior.

TEST SPECIMENS

Test specimens selected are representative of common current practices. Building partitions are framed with steel studs with gypsum wallboard as facing material. Suspended ceilings are typical exposed tee-grid ceilings with lay-in acoustical tiles. All suspended ceilings are 12 ft. x 16 ft. in plan. All partitions are 12 ft. wide. Partial-height partitions are 8 ft. high and full-height partitions are 10 ft. high. Installation of building partitions and ceiling test specimens is done according to accepted current practices. The test specimens may be categorized into the following groups:

Specimen Nos. 1, 2, 3

Suspended ceilings only without any partitions; unbraced, braced (splayed wire bracing) and braced with vertical strut.

Specimen Nos. 4A, 4B, 4C, 5B, 6

Partial-height partition with braced suspended ceiling without and with fluorescent light fixtures (4A and 4B). Specimen 4C is the same as specimen 4B except that bookshelves were added. Specimen 5B is the same as Specimen 4B except that ceiling bracing consists of splayed wire bracing with vertical strut. Specimen 6 is the same as Specimen 4B except that ceiling bracing consists of two-wire diagonal bracing at top of partial-height partition.

Specimen Nos. 8, 9, 10, 9A

These consist of full-height partitions with suspended ceiling (including light fixtures) attached at partition end and unattached at opposite end (steel-stud framed soffit). Ceiling bracing configurations are (a) no bracing--Specimen No. 8, (b) 45° splayed wire bracing--specimen No. 9, (c) 45° splayed wire bracing with vertical strut--specimen No. 10. Specimen No. 9A was similar to specimen No. 9 except with addition of vertical suspension wires at 8 inches maximum at unattached perimeter (2 ft. o.c.) and one vertical suspension wire at point of splayed wire bracing.

Complete details of test specimens and their installation are presented elsewhere (Ref. 7).

TESTING SCHEME

The dynamic testing scheme consists of a structural steel grid simulating a structural horizontal diaphragm, that is allowed to roll freely on a wheel and bearing assembly. The building partitions and suspended ceilings under test are attached to the steel grid at the top. Partitions are also fastened at the bottom to a precast concrete base bolted to the laboratory floor slab. The partition and ceiling test specimens are subjected to cyclic racking motions using an MTS electro-hydraulic closed-loop system. The excitation is sinusoidal and specimens are subjected to dynamic displacements at controlled magnitudes and frequencies.

DYNAMIC TEST CONTROL PARAMETERS/TEST PROCEDURE

All test specimens were subjected to the following tests:

Test No. I	Damping Test.
Test No. II:	Sine-sweep Test (command peak displacement is fixed and frequency is varied over a pre-selected range).
Test No. III:	Block Cyclic Test (frequency is fixed and specimens are subjected to several complete cycles of loading for each increasing level of peak command horizontal displacement starting with 1/16, 1/8, 1/4, 3/8, 1/2, 3/4, 1, 1-1/4, 1-1/2. . .)

Complete details of all test control parameters are presented elsewhere (Ref. 7).

TEST INSTRUMENTATION

Honeywell Visicorder Model 1858, MUX/DEMUX and HP FM Data Recorder comprise the major components of test data recording. Data acquisition of test specimen responses are provided by LVDT's, accelerometers and a load-cell. Each sensor output was conditioned by a module preamp in the Honeywell Visicorder Model 1858 which provides an almost immediate hard copy of each transducer's response. From the Visicorder's buffered output drivers, the seven signals are sent through a parallel to series multiplexer (MUX) to give three channels of data and one time signal for recording. The recorder is a HP3960A four-channel, three-speed, data recorder using FM recording of signals from DC up to 5000 Hz., at 15 ips. This provides a permanent one-quarter inch magnetic tape recording of all data to be processed later by the MINC-23 data acquisition system. Retreival of any one transducer's response is provided by playing back the magnetic tape through a series-to-parallel demultiplexer (DEMUX). Additional hard copy recording of a transducer's response is also obtained through a strip chart recorder (B & K Model 2309). A video television recorder and camera provide a visual record of test specimen response and provides an accurate account of behavior of that specimen.

The MTS electro-hydraulic closed-loop servo-system provides the input excitation. The system provides a maximum of six inches (±3") of stroke. Complete details of dynamic test control equipment and instrumentation are presented elsewhere (Ref. 7).

TEST RESULTS

Dynamic responses of the twelve test specimens tested to date were manually analyzed and a partial summary of the test results is presented in Table I. Average damping ratio β calculated from the ceiling LVDT traces for all the test specimens are found to range between 0.024-0.139. The sine-sweep test data was analyzed to search for the frequencies at which peak response acceleration and displacement amplitudes of ceiling reached maximum values compared to peak responses of the loading grid. Typical graphs of frequency vs. peak response ratios of ceiling vs. loading grid are shown in Figures 1 and 2.

For all test specimens, peak response acceleration for loading grid varies between 0.005g-0.33g whereas the peak response acceleration for ceiling varies between 0.030g-2.16g. Maximum peak acceleration ratios ranged from 2.5-7.4 and natural frequencies varied between 0.2-5.6 Hz. For all test specimens, peak response displacement for loading grid varies between 0.008 in.-0.467 in., whereas the corresponding peak displacement response for the ceiling was found to be between 0.06 in.-3.40 in. Maximum values of peak displacement ratios ranged from 3.09-8.00 and natural frequencies were found to be between 0.8 Hz.-4.4 Hz. The results of block cyclic tests for specimen Nos. 1, 2, 4A, 4B, and 5B, in the form of graphs between peak-command displacement and peak response ratios of ceiling vs. loading grid (both acceleration and displacement) are presented elsewhere (Ref. 7). Detailed results of observed specimen behavior and threshold levels of damage are documented elsewhere in a comprehensive report (Ref. 7).

CONCLUSIONS

The results of dynamic tests to date have clearly shown that response and behavior of building partitions and suspended ceilings is influenced both by acceleration and displacement levels and their frequencies. Comparison of the response and behavior of specimen Nos. 1, 2, 3 (ceilings only) with those of specimen Nos. 4A, 4B, 4C suspended ceilings with partial-height partitions shows that UBC provision of the 45°

splayed wire ceiling bracing is satisfactory for providing stability to partial-height partitions. The test specimens with splayed wire bracing and vertical strut seemed to be initially stiffer than the specimens without vertical strut. For all specimens, the behavior was characterized by eventual slackening of the splayed wire bracing, observed uplift and some damage to ceiling main runners and their intersection with cross tees at point of bracing. The specimens with vertical strut at point of splayed wire bracing had less observed ceiling uplift than those without vertical strut.

Threshold level of damage to contents (books on shelves) is given by results obtained for specimen No. 4C. This damage occurred at frequency of about 2 Hz. and peak command displacement between 1-2.75 inches. Examination of results for specimen Nos. 8, 9, 10, 9A clearly show that ceiling perimeter details are a predominant factor influencing damage to suspended ceiling and partitions. Extensive damage to suspended ceilings occurred at the unattached ceiling parimeter at frequencies between 4-4.8 Hz., and peak command displacement of one inch (specimen Nos. 8, 9, 10). Addition of vertical suspension wires at cross tees (Specimen 9A) at 8 inches maximum from unattached ceiling perimeter prevented the ceiling tiles from crashing down but damage was caused by pounding of the cross tees into the perimeter angle. This perimeter damage occurred at 3.6 Hz., and a peak command displacement of 2.5 inches. In all tests, the only partition damage was loosening of some screws caused by sinusoidal excitation of the test specimens.

ACKNOWLEDGEMENTS

The author acknowledges the participation and assistance of Dr. David Hatcher and Professor Jacob Feldman of the Architectural Engineering Department in the development of the testing scheme and facility. The participation and assistance provided by many student research assistants and Bob Myers, Technician, Architectural Engineering Department, is acknowledged. The material assistance provided by Chicago Metallic Corporation (Don Moore, Western Manager) is acknowledged. The advice and encouragement of the project advisory committee is acknowledged. The reported work was carried out under a grant from the National Science Foundation Grant No. CEE-81-17965 with Satwant S. Rihal as the principal investigator. The support and encouragement of Dr. Fred Krimgold, Program Director, NSF is gratefully acknowledged.

REFERENCES

1. de Silva, Clarence W., Dynamic Testing and Seismic Qualification practice, Lexington Books, 1983.

2. EERI/NSF Workshop on Non-structural Issues, Los Altos, California, April 1983.

3. Earthquake Environment Simulation, Proceedings of a NSF Workshop, San Francisco, California, February 1974.

4. McCue, G.M., Skaff, Ann and Boyer, J.W., Architectural Design of Building Components for Earthquakes, a report on research conducted by MBT Associates, San Francisco, under a grant from the National Science Foundation, 1978.

5. Rihal, Satwant S., Racking Tests of Non-structural Building Partitions, Final Technical Report submitted to the National Science Foundation (Grant No. PFR-78-23085); Architectural Engineering Department Report ARCE R80-1, California Polytechnic State University, San Luis Obispo, California, December 1980.

6. Rihal, Satwant S., Non-structural (Architectural) Component Damage Caused by Coalinga, California, Earthquake of May 2, 1983, report submitted to the Earthquake Engineering Research Institute, June 1983.

7. Rihal, Satwant S., and Granneman, Gary, Dynamic Behavior of Non-structural Building Partitions and Ceiling Systems During Earthquakes, research report submitted to the National Science Foundation, November 1983.

8. Seismic Hazard Assessment of Non-structural Ceiling Components - Phase I, final report for National Science Foundation, ANCO Engineers, Inc., Culver City, California, September 1983.

9. Uniform Building Code Standards, 1982 Edition, International Conference of Building Officials, Whittier, California, 90601.

NSF SPONSORED RESEARCH PROJECT: DYNAMIC TESTING OF BUILDING PARTITIONS AND CEILING SYSTEMS

TABLE I: SUMMARY OF TEST RESULTS

	Test No. I Damping Test	Test No. II Sine Sweep Test							
Specimen No.	Damping Factor β	Peak Acc. Grid	Peak Acc. Clg.	Ratio A Clg. / A Grid	Freq. Hz.	Peak Δ Grid Inches	Peak Δ Clg. Inches	Ratio Peak Δ Clg. / Peak Δ Grid	Freq. Hz.
1	2.90%	0.03 g	0.167 g	5.06	0.8 Hz.	0.467"	3.40"	7.28	0.8 Hz.
2	4.42%	0.012 g	0.075 g	6.00	3.0 Hz.	0.008"	0.060"	7.50	3.5 Hz.
3	8.8%	0.13 g	0.48 g	3.69	2.4 Hz.	0.44"	1.36"	3.09	1.8 Hz.
4A	4.2%	0.005 g	0.030 g	6.00	0.6 Hz.	0.04"	0.18"	4.50	3.0 Hz.
		0.015 g	0.050 g	3.33	2.5 Hz.				
4B	5.3%	0.01 g	0.05 g	5.00	0.2 Hz.	0.28"	1.84"	6.6	2.0 Hz.
		0.015 g	0.04 g	2.67	0.4 Hz.				
		0.050 g	0.125 g	2.50	3.0 Hz.				
4C	6.3%	0.015 g	0.11 g	7.33	0.2 Hz.	0.32"	1.24"	3.88	1.6 Hz.
		0.02 g	0.09 g	4.50	0.4 Hz.				
		0.04 g	0.12 g	3.00	2.5 Hz.				
5B	2.4%	0.10 g	0.40 g	4.00	2.0 Hz.	0.44"	1.84"	4.18	1.6 Hz.
6	13.9%	0.05 g	0.37 g	7.40	3.0 Hz.	0.04"	0.32"	8.00	3.00 Hz.
8	8.2%	0.18 g	0.99 g	5.88	5.6 Hz.	0.18"	0.76"	4.22	4.4 Hz.
9	5.9%	0.18 g	1.2 g	6.67	4.6 Hz.	0.17"	0.74"	4.35	4.2 Hz.

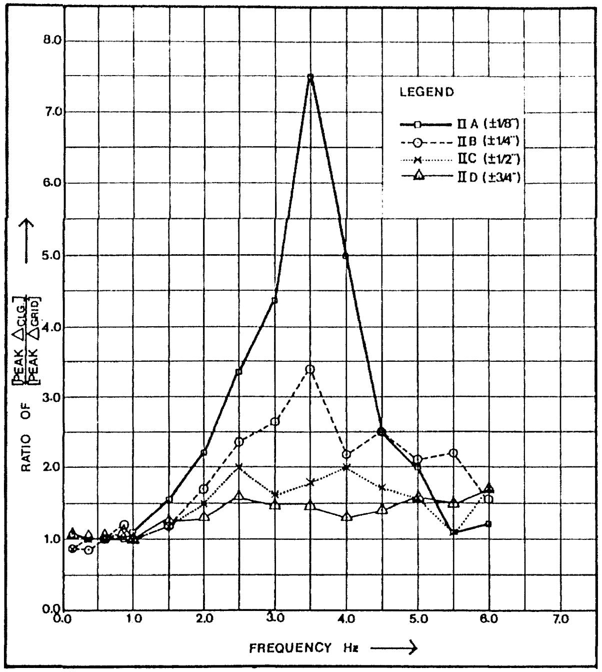

Fig. 1 Specimen No. 2 Sine-Sweep Test Frequency vs. Peak Response Displacement Ratio Clg./Grid

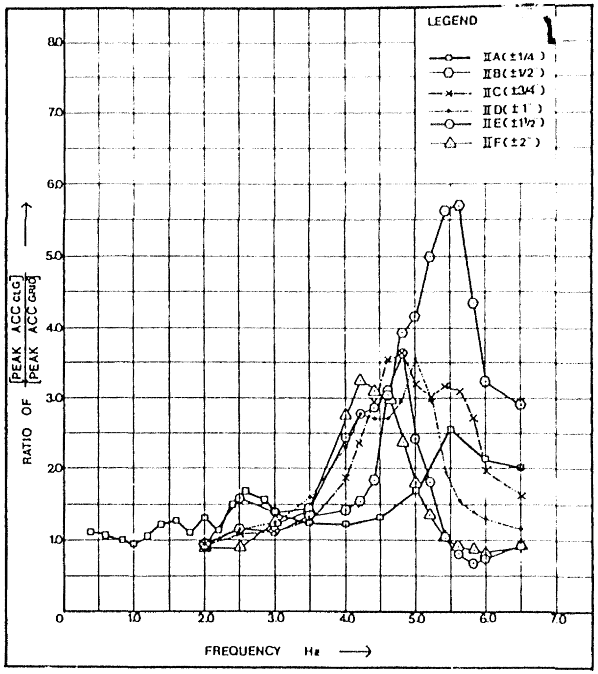

Fig. 2 Specimen No. 8 Sine-Sweep Test Freq. vs. Peak Response Acc. Ratio Clg./Grid

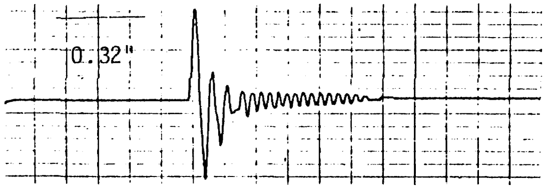

Fig. 3 Damping Test - Specimen No. 9 Ceiling LVDT Trace

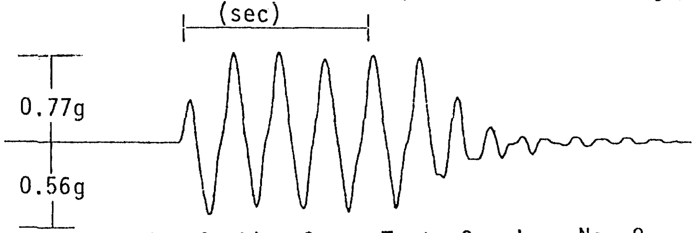

Fig. 4 Sine-Sweep Test Specimen No. 8 Ceiling Axial Accelerometer Freq.≈4Hz.