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AMBIENT AND FORCED VIBRATION STUDIES OF A MULTISTORY TRIANGULAR-SHAPED BUILDING

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INTRODUCTION

The availability of high speed digital computers and the sophistication of the idealization of structures and the computer model formulation of the structure have made available the elastic, and in certain structural systems, the inelastic response of structures when subjected to earthquakes. However, the accuracy of the results in large measure depend upon the computer model formulation of the structure and its foundation. Dynamic field test data covering the complete dynamic characteristics of full-scale structures and providing natural frequencies, mode shapes, and damping values have been considered essential in the development of computer-model formulation techniques. These test data are particularly important in determining the feasibility of special computer programs, which are principly developed for specific structural systems. Also, to assess the feasibility of general purpose computer programs, in predicting accurately the response of buildings with complex configurations and to accumulate a body of information on the dynamic properties of structures, especially when these structures have novel design features, a number of dynamic tests have been conducted on full-scale structures (1).

For the above reasons dynamic tests, using forced and ambient methods, were performed on the Century City South-Theme Tower in Los Angeles. Because of the favorable advantages of the ambient vibration method in dynamic testing of full-scale structures it was desirable to compare both methods in order to assess the accuracy of each method in evaluating the dynamic properties of the structural systems.

DESCRIPTION OF THE BUILDING

The Century City Theme Towers, located in Los Angeles, California, are built as twin South and North Towers. Both buildings from the structural and architectural point of view are practically identical. The dynamic tests were performed on the South Tower during November 1974 and March, 1975 (2). The building is a multi-story steel structure, forty-four stories in height above the plaza level, and six under ground parking levels. The height of the building above the plaza level is about 575 feet, with the equilateral triangular floor plan having sides of 254 feet. Figure 1 shows the tested South Tower looking from the South-West.

The steel frame structure extends from B level to the roof and consists of core triangular frames with three corner columns connected with deep beams at the second floor of the building. From the second floor to the roof, the core steel framing continue like in the lower floors whereas the exterior walls are constructed as three identical moment resistant frames with twenty-three bays of 10 feet 2 inches. A deep steel girder covering the top two floors is rigidly connected to all three exterior frames. Thus, the structural system consists of the equilateral triangular core and exterior moment resistant frames connected at each floor with shear end connected beams. Figure 2 shows a section through the building and figure 3 shows a floor plan of the building at the 42nd floor.

The three corner columns are built-up triangular steel columns, the core frame columns are rolled sections of W14 shape, and the core beams are in general rolled sections, mostly wide flange shape varying from W12 to W36. Exterior columns consist of standard wide flange sections and built-up sections. Exterior frame spaced beams are built-up girders with a constant depth of four feet and changeable plate thickness. Deep exterior frame beam on the top of the building and the second floor are also built-up sections with a depth of twenty-eight feet, and seven feet, respectively.

The structural steel used on the building for both the beams and the columns is A36 and A50, the latter high strength steel being used in general in the lower floors.

EXPERIMENTAL PROGRAM

1. Forced Vibration Study

In order to subject the building to forced vibrations, rotating-mass force-vibration generators or shaking machines were mounted on the floor of the building and oriented so as to induce the maximum forces in the North-South and East-West directions as shown in Figure 3. A complete description of the vibration generators is given elsewhere (3). Figure 4 shows a single vibration generator in place on the 42nd floor. With the appropriate adjustments to the vibration generator equipment it was possible to produce translational or torsional vibrations of the building.

The transducers used to detect horizontal floor accelerations of the building were Statham A4 linear accelerometers, with a maximum rating of $\pm$ 0.25 g. The electrical signal from all accelerometers were fed via amplifiers to a Honeywell Model 1858 Visicorder. For the translational motions the accelerometers were located near the center of the floor and oriented so as to pick up the appropriate North-South or East-West accelerations. For recording the torsional motion accelerometers were properly oriented near the center of exterior South wall and near the corner column on the North side of the building. A total of approximately eleven floors were selected for measurements of the accelerations. To determine the resonant frequencies of the building the accelerometers were in general located at the 42nd floor. The mode shapes were evaluated from records taken at the different elevations.

2. Ambient Vibrations Study

In recent years a method for testing of full-scale structures based on wind and microtremor-induced vibrations has been developed. The ambient vibration study of the dynamic properties of the structures is a fast and relatively simple method of field measurements. It does not interfere with normal building function, and the measuring instruments and equipment can be installed and operated by a small crew.

The objective of performing the ambient vibration study was to obtain dynamic properties of the building, and then compare these results with those obtained from the forced vibration study to assess efficiency of both techniques.

The ambient vibration study of the Century City South-Theme Tower was carried out on March 19, 1975. The building was practically in the same condition as it was during the performance of forced vibration study in November 1974. Wind direction and velocity on the day of dynamic test measured at nearby Santa Monica airport was almost constant at azimuth 200-230°, and velocity of 9-14 mph.

The wind induced vibrations were measured using Kinemetrics Ranger Seismometers, Model SS-1, with a Model SC-1 Signal Conditioner and recorded on a model DDS-1103 Kinemetrics Digital Data System. The Honeywell Model 1858 Visicorder was used to display and monitor the four signal levels during the tape recording. The set up of this equipment is shown in Figure 5.

MATHEMATICAL MODEL

A mathematical computer model of the South Theme Tower was formulated to assess the dynamic properties for the N-S and rotational characteristics. The response of the translational and rotational modes were considered independent of each other.

MACTUB a special purpose computer program developed in the Division of Structural Engineering and Structural Mechanics of the Department of Civil

Engineering at the University of California, Berkeley, was used to compute the mode shapes and frequencies of the building. A complete description of the program is given in Reference (4).

Employing an extension of the finite element concept, MACTUB was created for the analysis of multistory tube structures consisting of an assembly of plane frames. Each element incorporates a rectangular portion of a frame consisting of a number of columns and a number of beams. Elements are interconnected at nodes along their sides. Both static and dynamic analysis can be performed, assuming linear material behavior.

RESULTS

In the forced vibration tests, the first six E-W and the first five N-S translational modes were excited, as well as, the first six torsional modes. Frequency response curves, in the region of the resonant frequencies were obtained for each of these modes.

The curves are plotted in the form of normalized displacement amplitude versus exciting frequency. The ordinates were obtained by dividing the measured acceleration by the square of the exciting frequency (cps) and then by the square of the circular frequency (rad/sec). Hence, the displacement amplitudes reflect the effect of a force amplitude that would be generated by the eccentric masses rotating at 1 cps. Damping capacities were obtained from the normalized frequency response curves by the formula: $\zeta = (\Delta f)/(2f)$, where ζ = damping factor (% of critical damping), f = resonant frequency and Δf = difference in frequency of the two points on the resonance curve with amplitides of $1/\sqrt{2}$ times the resonant amplitude. A typical resonant frequency curve is shown in Figure 6.

The translational resonant frequencies and damping factors evaluated from the curves are summarized in Table 1 along with the results obtained for the torsional resonant frequencies. Table 1 also summarized the results from the ambient study along with the analytical results for the translational and torsional resonant frequencies.

A comparison of the mode shapes for the first five translational N-S resonant frequencies and the first three torsional frequencies are shown in Figure 7.

CONCLUSIONS

The dynamic properties of the translational modes in the N-S and E-W directions, as well as the torsional modes of the Century City South-Theme Tower, were determined by full-scale dynamic tests.

The resonant frequencies from both studies are in very good agreement in all separated modes of vibration with the maximum difference smaller than 2%. The ratios of the observed higher mode frequencies with respect to the fundamental one from both dynamic studies of the building indicate that the overall structural response is predominantly of the shear type.

Comparison of the forced and ambient vibration experiments demonstrate that it is possible to determine with adequate accuracy the natural frequencies and mode shapes of typical modern buildings using the ambient vibration method. Difficulties in evaluation of equivalent viscous damping factors from ambient vibrations studies are present and probably it will be more realistic from this type of study to expect assessment of the range of damping factors, rather than damping values associated with each mode of vibration.

A comparison of the translational analytical results show very good agreement with the experimental studies, the maximum differences ranging from about 3% at the first mode to about 14% at the higher modes. It would appear from the first translational mode shape that the actual building is slightly more flexible than what the analysis indicates. In comparing the torsional analytical results with the experimental the differences are in the range of 10%.

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TABLE 1 COMPARISON OF RESONANT FREQUENCIES AND DAMPING FACTORS

Mode No.	Translational E-W				Translational N-S					Torsional				
	Forced		Ambient		Forced		Ambient		Anal.	Forced		Ambient		Anal.
	f (cps)	ξ (%)	f (cps)	ξ (%)	f (cps)	ξ (%)	f (cps)	ξ (%)	f (cps)	f (cps)	ξ (%)	f (cps)	ξ (%)	f (cps)
1	0.267	2.62	0.263	2.37	0.267	4.34	0.273	3.30	.276	0.357	1.34	0.347	0.90	.403
2	0.76	1.51	0.76	1.33	0.783	1.60	0.791	1.28	.725	0.99	0.81	1.0	0.43	1.089
3	1.317	1.18	1.338	0.35	1.373	1.64	1.397	1.17	1.267	1.69	0.95	1.70	0.16	1.840
4	1.89	1.27	1.914	0.26	1.973	1.72	2.015	0.74	1.821	2.47	1.01	2.49	0.13	2.625
5	2.74	1.73	2.695	0.17	2.85	1.49	2.852	0.55	2.394	3.317	1.36	-	-	3.465
6	3.133	2.39	3.096	-	-	-	3.15	0.15	-	4.133	1.51	-	-	-

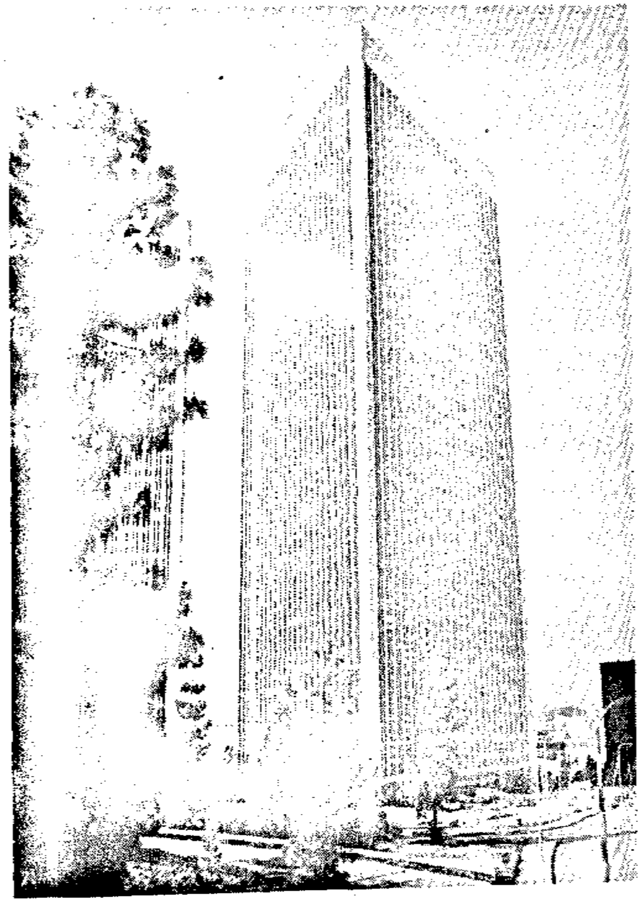

FIG. 1 CENTURY CITY SOUTH TOWER, L.A., CALIFORNIA

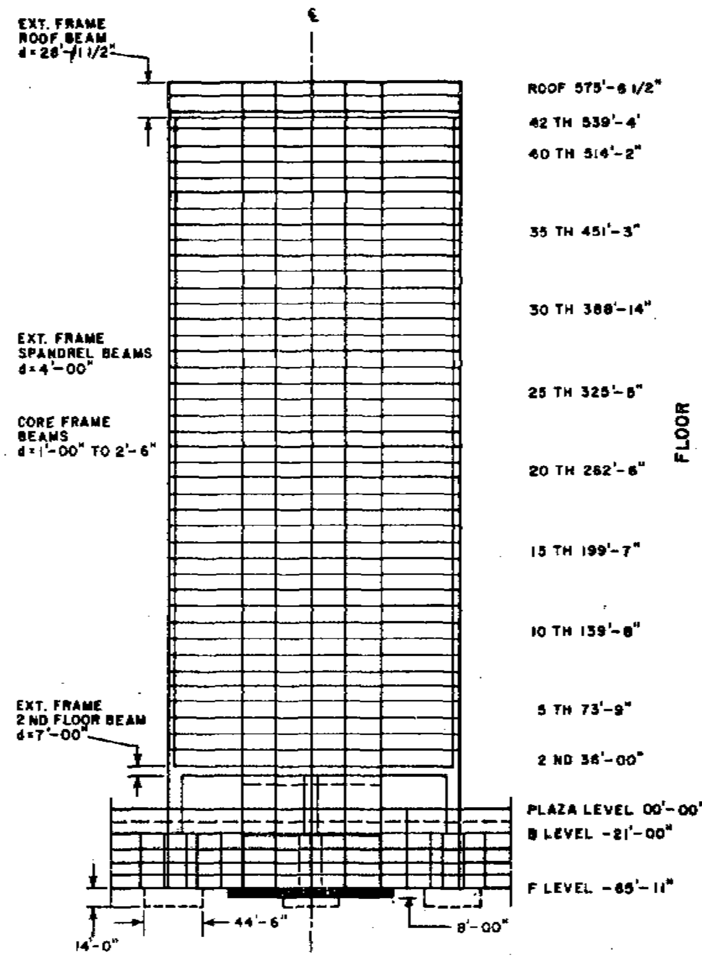

FIG. 2 SECTION THROUGH BUILDING

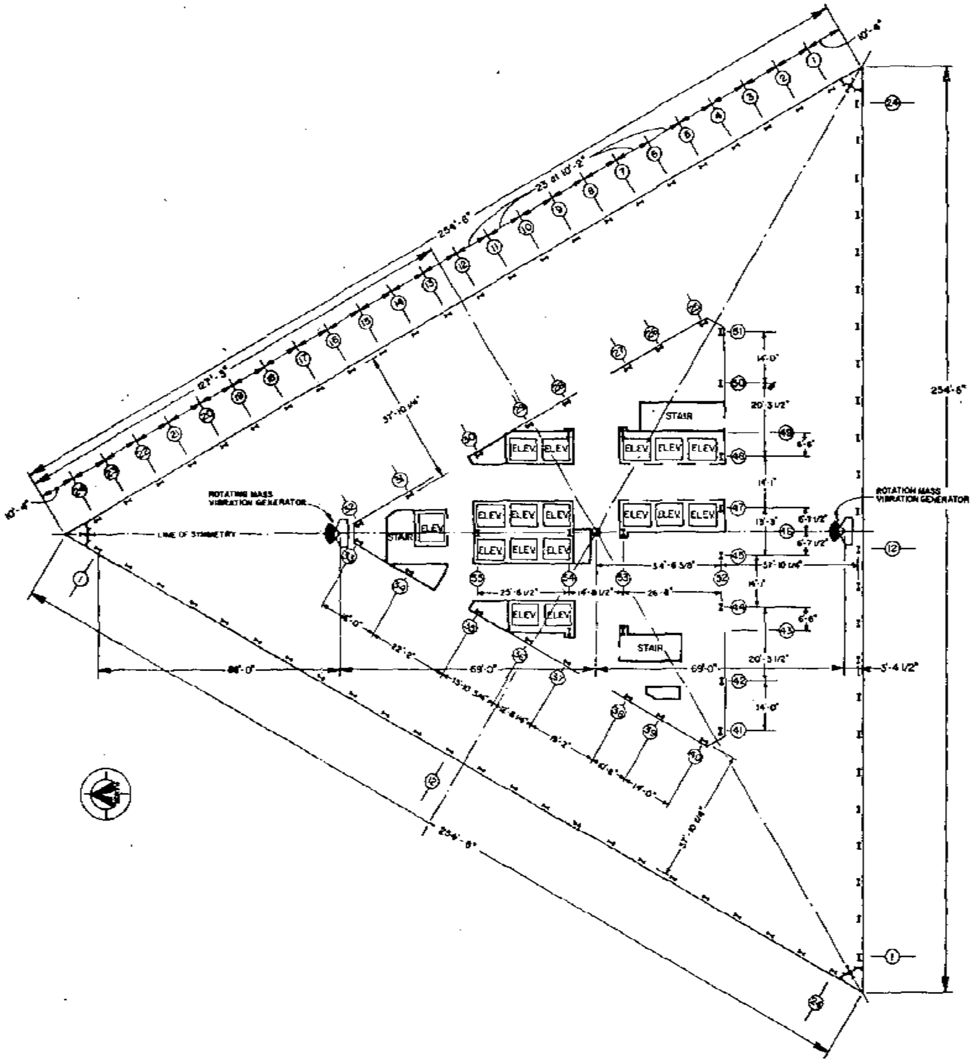

FIG. 3   FLOOR PLAN AT 42ND FLOOR

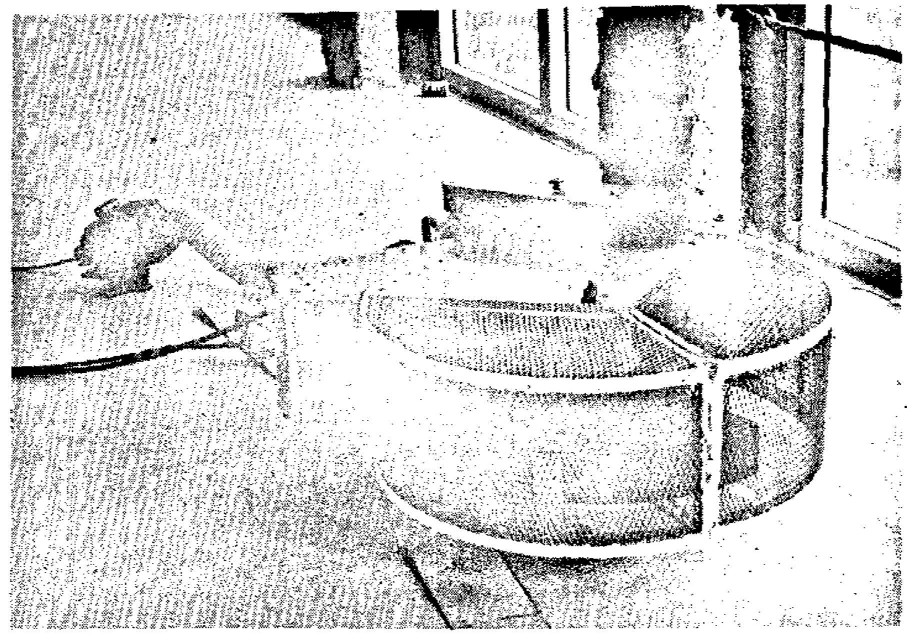

FIG. 4   VIBRATION GENERATOR AT 42ND FLOOR

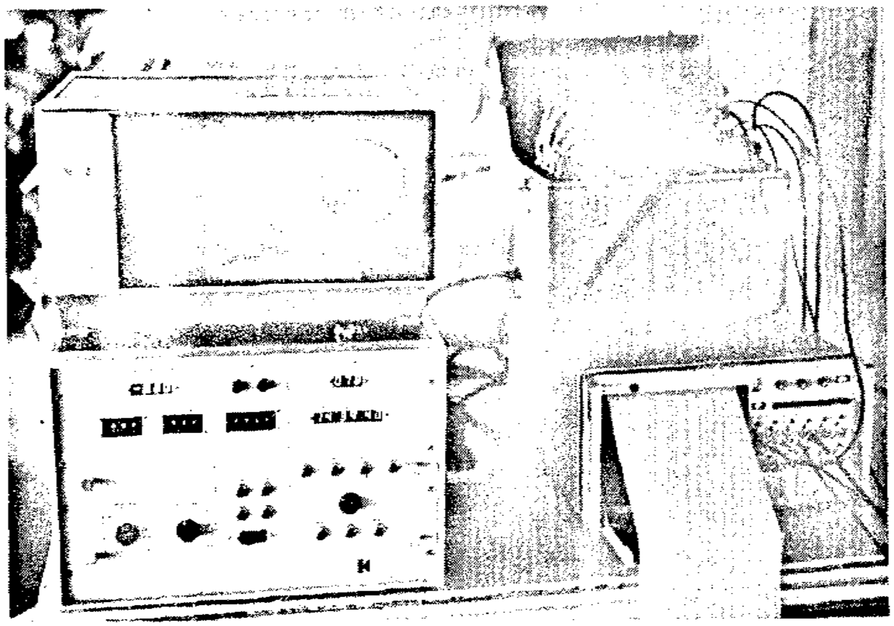

FIG. 5 AMBIENT RECORDING EQUIPMENT

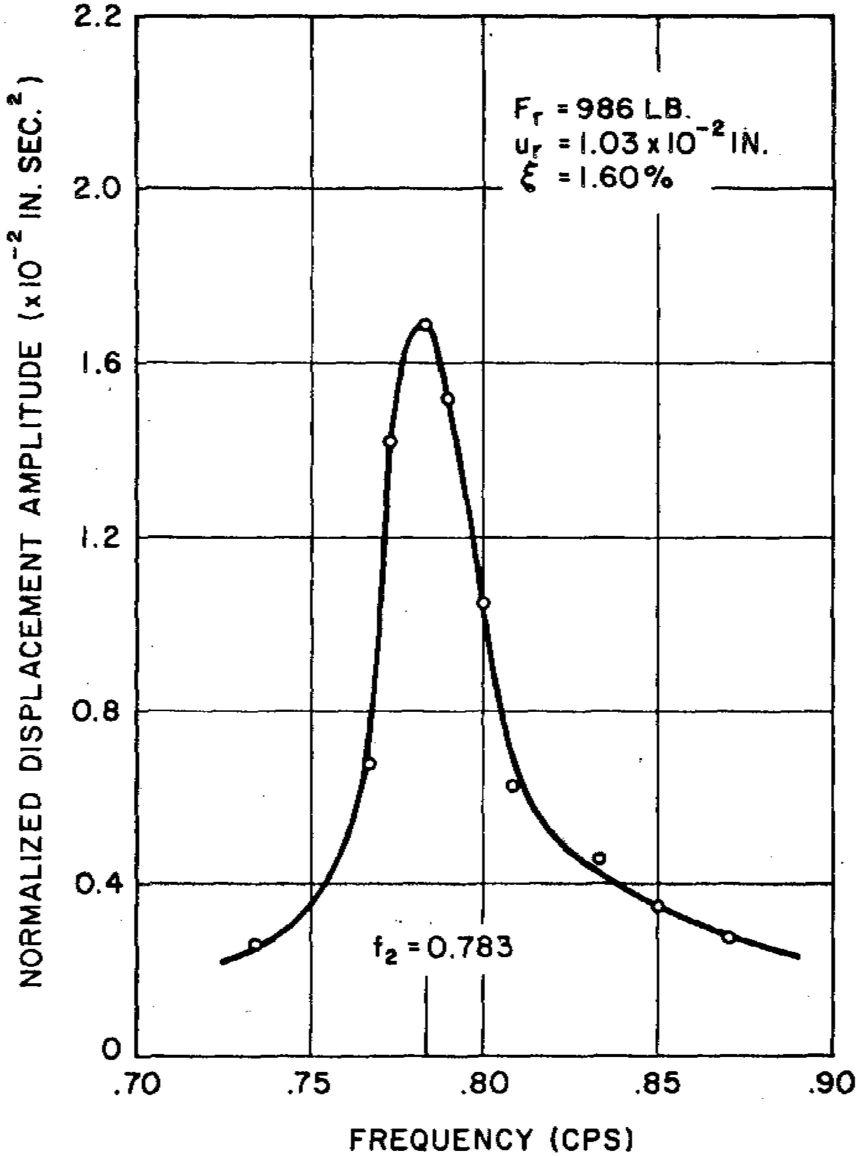

FIG. 6 TYPICAL FREQUENCY RESPONSE CURVE

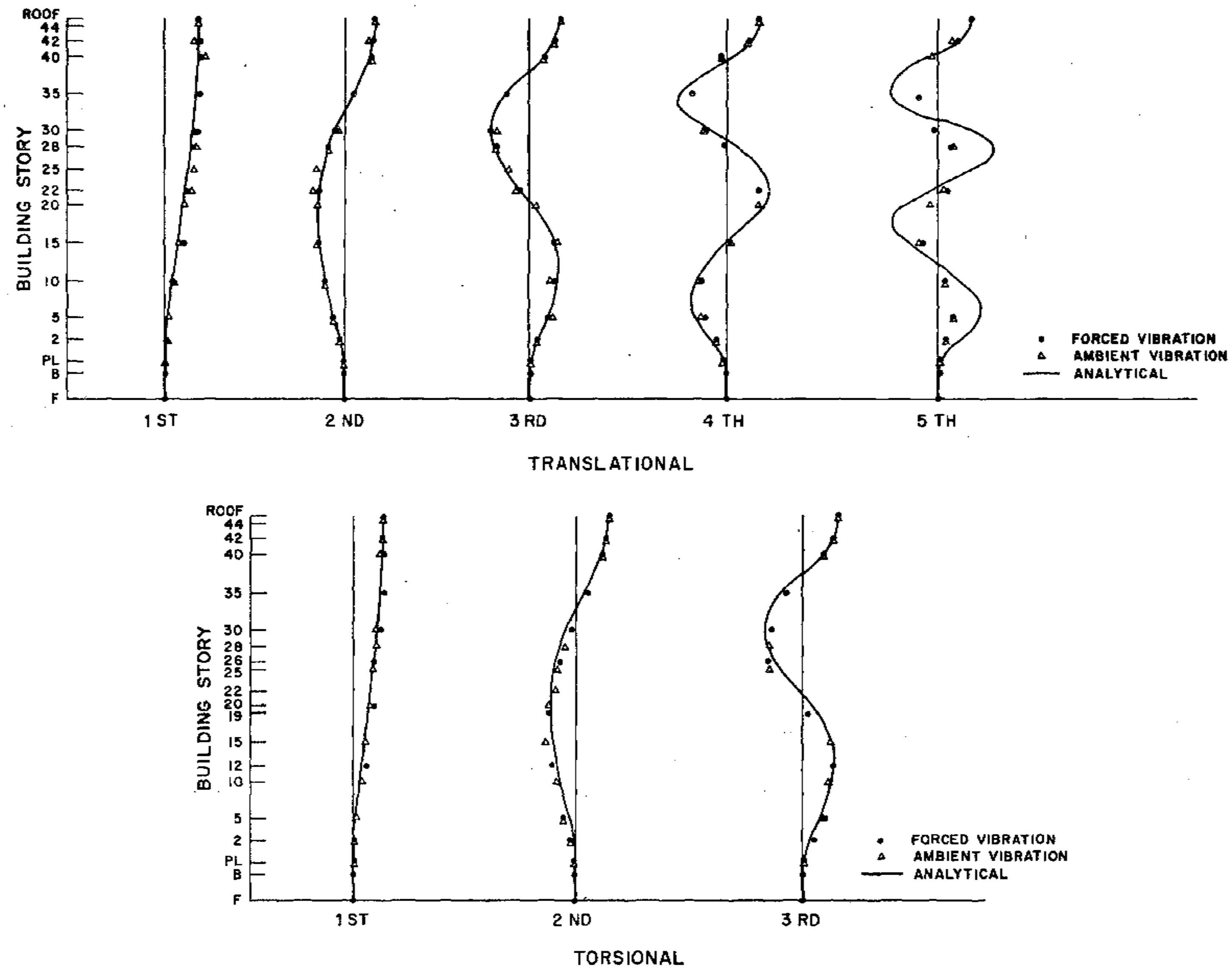

FIG. 7 TYPICAL MODE SHAPES