SIX-STORY TEST ISOLATED STRUCTURE

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Introduction

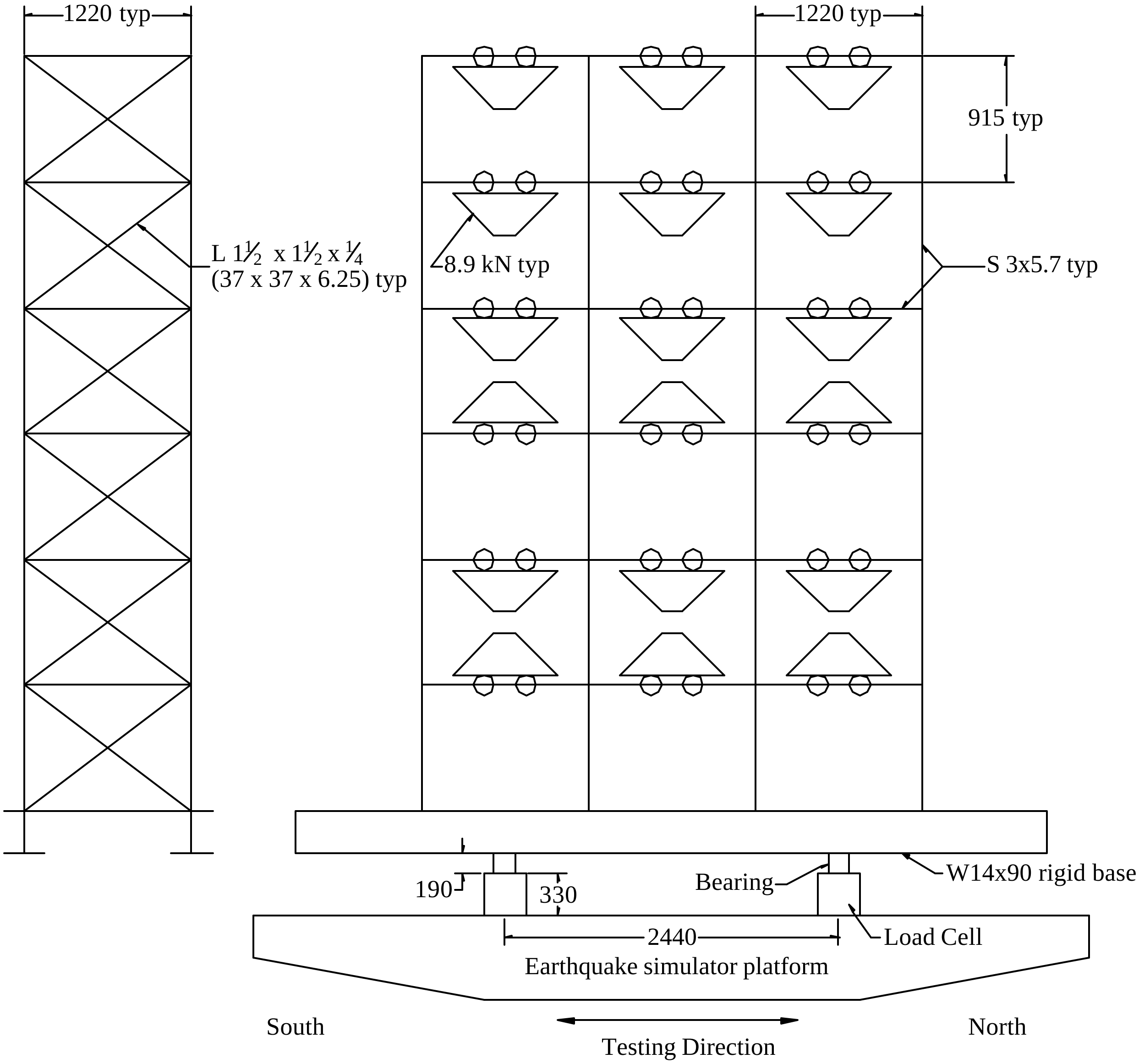
A six-story steel model is proposed for use as a permanent seismically isolated test structure to serve as demonstration and instructional tool for SEESL and NEES.

Model Structure Description

Six-Story Model

The six-story model is identical to that used in previous testing of energy dissipation and seismic isolation systems at the University at Buffalo (Reinhorn et al., 1989; Mokha et al., 1990; Constantinou et al., 1990; Wolff and Constantinou, 2004). It represents a section in the weak direction of a steel moment-resisting frame.

The test structure is shown in Figures 1 and 2. All column and beam sections are S3x5.7, and all out-of-plane braces (weak direction) are L 1½x1½x¼ (37x37x6.25 mm). Braces may also be attached in the strong model direction, as shown in Figure 2. The structure is attached to a rigid base comprised of two AISC W14x90 sections, 5.2 m long with four transversely connected beams. The model has six stories of 0.914 m height each, giving a total height of 5.486 m above the base. The model is three bays by one bay in plan, each bay being 1.22 m wide, for total plan dimensions of 1.22 m by 3.66 m. Concrete blocks are used to add mass to satisfy similitude requirements, bringing the total weight, including the base, to 233 kN (in the modification of the model described herein, the base weight will increase by 5 kN, for a total model weight of 238 kN). The structure was constructed to have a length scale of 4. Other scale factors used in prior testing are presented in Table 1.



(all units in mm)

Figure 1 Schematic of Six-Story Isolated Model Structure (prior to modifications)

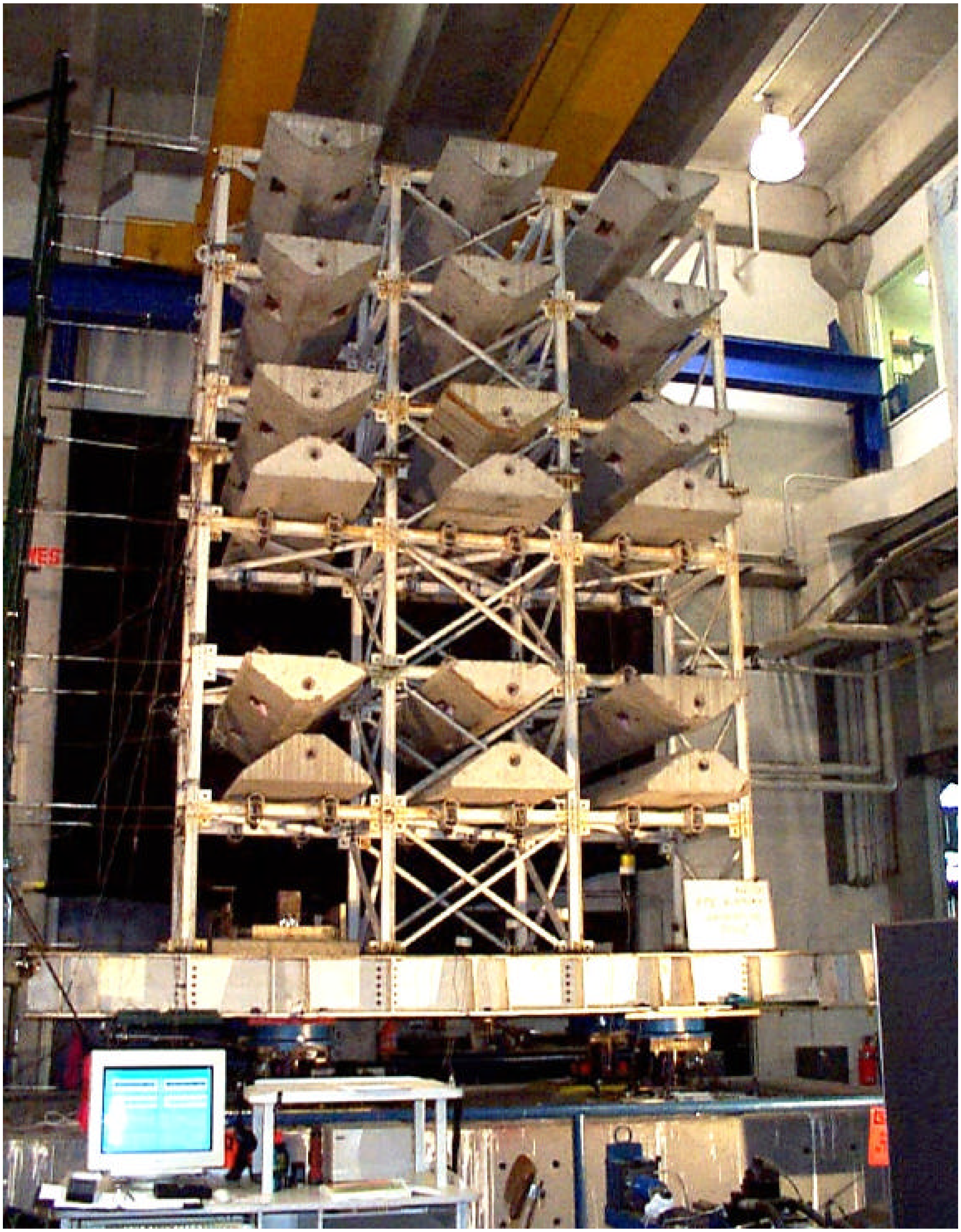


Figure 2 Photograph of Six-Story Isolated Model Structure prior to Modification on the University at Buffalo Earthquake Simulator (Wolff and Constantinou, 2004)

Table 1 Scale Factors Used in the Model Structure

QUANTITY	DIMENSION[1]	SCALE FACTOR
Linear Dimension	L	4
Displacement	L	4
Time	T	2
Velocity	LT^{-1}	2
Acceleration	LT^{-2}	1
Frequency	T^{-1}	½
Stress / Pressure	$ML^{-1}T^{-2}$	1
Force	MLT^{-2}	16
Strain	-	1

1. L = length, T = time, M = mass

Properties of Model in Various Superstructure Configurations and in the Fixed Base Condition

The properties of the six-story model structure in its fixed base condition were identified by Wolff and Constantinou (2004). Three configurations in the strong direction were identified by shake table testing with a banded white noise (0 to 40 Hz) with acceleration amplitude of 0.05 g. The configurations are moment frame, braced frame and asymmetrically braced frame; each shown in Figure 3.

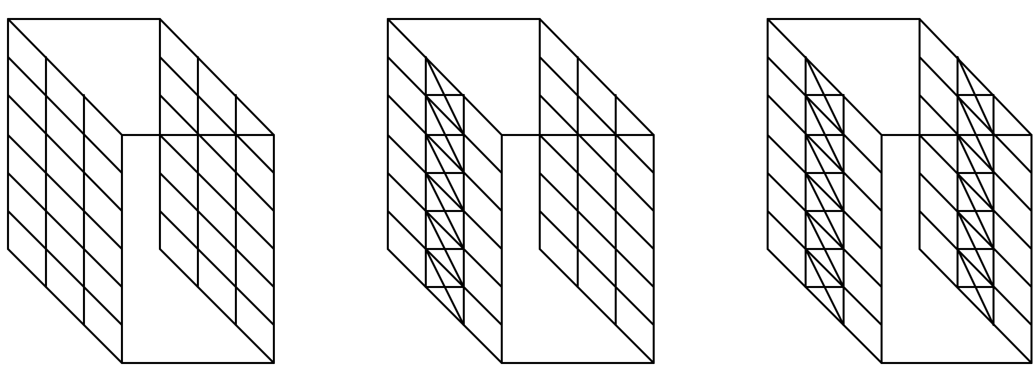


Figure 3 Moment Frame, Braced Frame and Asymmetrically Braced Configurations

Transfer functions were obtained as the ratio of the Fourier transform of the horizontal acceleration of each floor (average of accelerations recorded on east and west sides of model) of the structure to the Fourier transform of the base horizontal acceleration (average of east and west sides, measured at the W14x90 sections; see Figure 1). The transfer functions were used to identify the frequencies, damping ratios and mode shapes of the model. The procedure followed in the identification of the model properties is described in Reinhorn et al. (1989). Table 2 shows the results of this analysis for the first six significant modes of the moment frame.

Table 2 Characteristics of Fixed Base Moment Frame Structure

Experimental

Mode	Frequency (Hz)	Damping Ratio	Mode Shape					
			Floor 1	Floor 2	Floor 3	Floor 4	Floor 5	Floor 6
1	2.34	0.048	0.22	0.43	0.60	0.77	0.94	1.00
2	7.90	0.019	-0.52	-1.05	-0.98	-0.41	0.40	1.00
3	13.65	0.011	0.98	1.02	-0.27	-1.27	-0.59	1.00
4	19.79	0.003	-2.21	0.48	1.99	-0.28	-1.67	1.00
5	25.45	0.014	2.51	-1.66	0.14	2.40	-2.86	1.00
6	29.54	0.018	-2.16	4.94	-4.96	4.22	-2.50	1.00

Identification of the asymmetrically braced frame presented difficulties in determining the correct damping ratio for the torsional mode. By following the same procedures as for the other two frames, information is lost by averaging the east and west acceleration histories. The damping ratio of the torsional mode was determined approximately by examination of free vibration records of the difference of the accelerations recorded on east and west sides of model. The damping ratio is on the order of 0.02.

Tables 3a and 3b present the properties of the first three modes of the asymmetrically braced and symmetrically braced frame configurations, respectively. The first and third modes of the asymmetrically braced frame structure are the first two modes that are predominantly in the direction of testing, correspondingly, the first two modes of the symmetrically braced structure. The second mode of the asymmetrically braced frame structure is a torsional mode.

Figures 4 thru 6 present the plots of transfer function amplitude versus frequency for the three frame configurations of Figure 3. In some cases the true peak of the function was not captured and had to be extrapolated from the slopes on each side of the peak to complete the identification. In all three figures, the frequency content is presented in the range of 0 to 35 Hz. This range contains the first six modes for the moment frame, and the first three modes for the other two configurations.

Identification of the structure in the weak direction has not been recently performed. A complete identification of the structure will be required.

Table 3 Modal Properties of the Asymmetrically and Symmetrically Braced Fixed Base Structure

a. Asymmetrically Braced Experimental

Mode	Frequency (Hz)	Damping Ratio	Mode Shape					
			Floor 1	Floor 2	Floor 3	Floor 4	Floor 5	Floor 6
1	3.32	0.042	0.20	0.39	0.55	0.73	0.91	1.00
2	5.32	0.020 [1]	0.26	0.38	0.50	0.63	0.86	1.00
3	12.80	0.016	-0.62	-1.11	-0.97	-0.41	0.38	1.00

1. See comments in text.

b. Symmetrically Braced Experimental

Mode	Frequency (Hz)	Damping Ratio	Mode Shape					
			Floor 1	Floor 2	Floor 3	Floor 4	Floor 5	Floor 6
1	4.00	0.040	0.17	0.34	0.49	0.67	0.87	1.00
2	17.09	0.017	-0.67	-1.16	-0.96	-0.43	0.38	1.00
3	30.70	0.009	1.00	1.06	-0.71	-1.38	-0.63	1.00

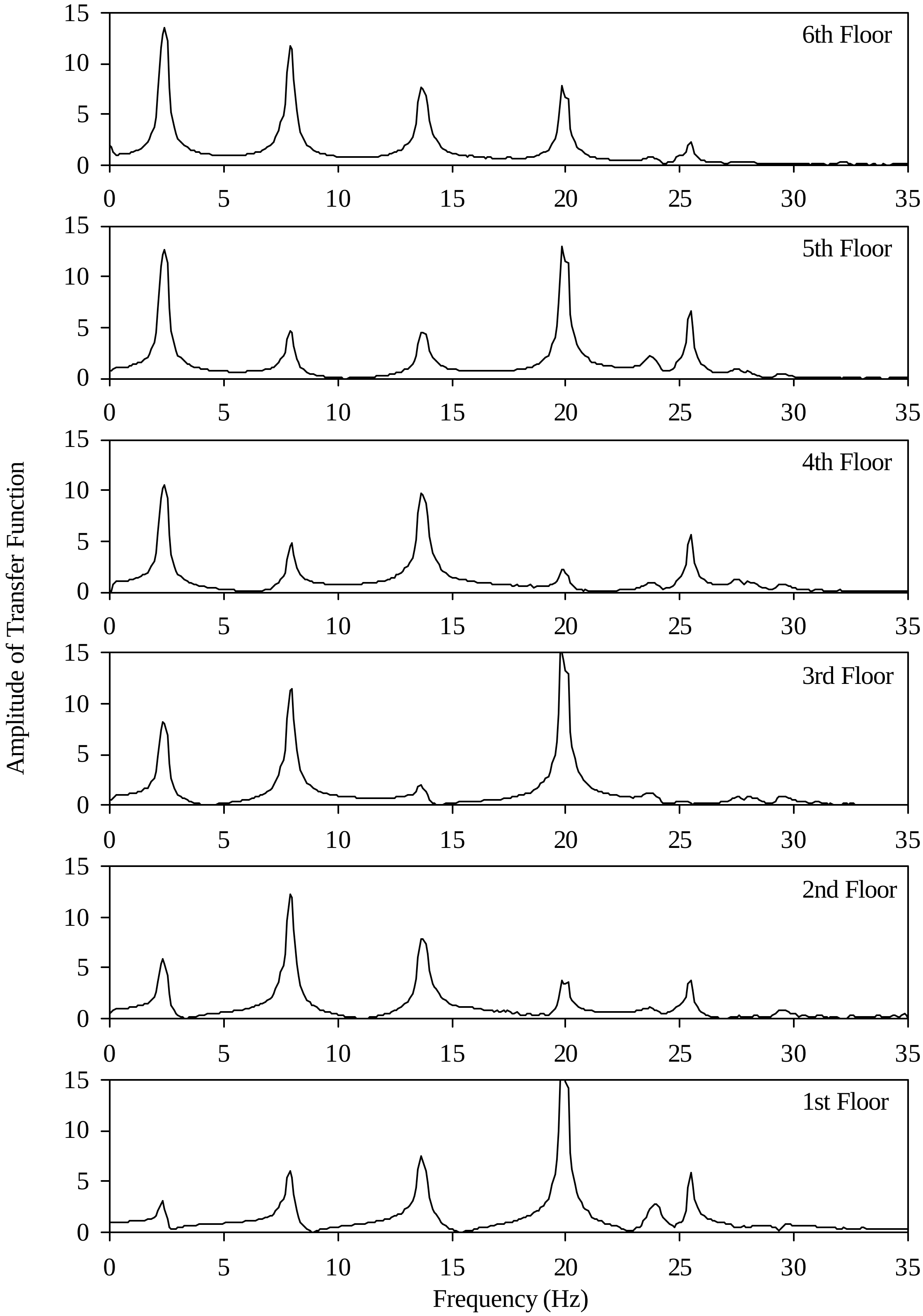


Figure 4 Transfer Function Amplitudes Obtained from White Noise Excitation of Moment Frame Structure

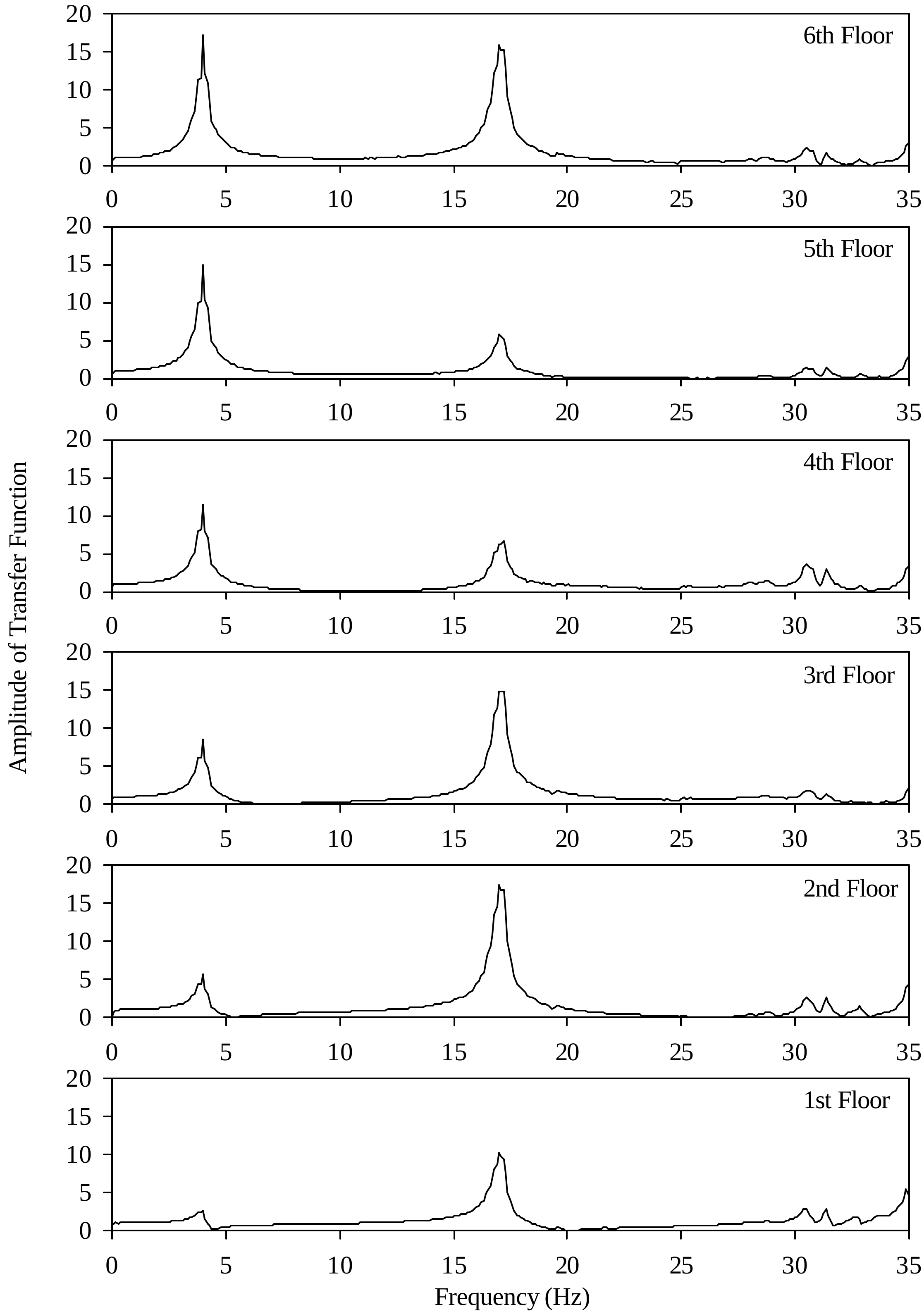


Figure 5 Transfer Function Amplitudes Obtained from White Noise Excitation of Symmetrically Braced Frame Structure

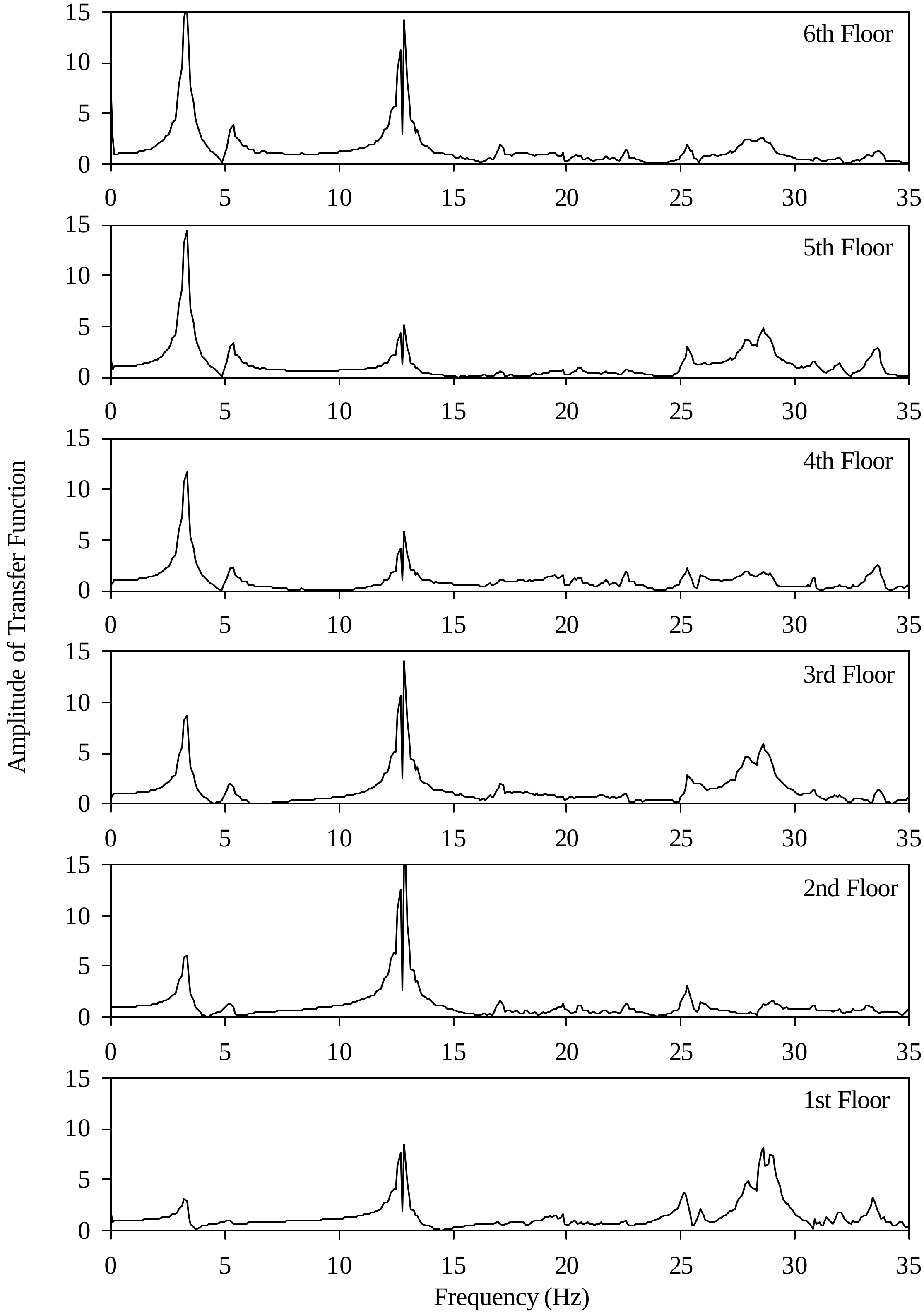


Figure 6 Transfer Function Amplitudes Obtained from White Noise Excitation of Asymmetrically Braced Frame Structure

Instrumentation

The instrumentation of the six-story model structure will consist of load cells, accelerometers, and displacement transducers. Accelerations and absolute displacements will be recorded on the three locations at each floor level, at the base of the structure, and on the simulator platform, all in the horizontal direction. In addition, the vertical acceleration above and below one bearing will be recorded. Four load cells at the base of the structure will measure vertical and shear forces in the four bearings.

Important response quantities need to be measured by both direct and indirect means to provide redundancy for checking the accuracy of important measurements. To check accelerations, the absolute displacement at that location may be double differentiated to obtain the history of acceleration. To check shear forces in the load cells, the base shear may be calculated by summing the inertial forces at each floor level. Each floor's inertial force may be calculated by multiplying the recorded average acceleration (from the two instruments on two sides of the floor) by the mass of that floor.

Description of Isolation System

The isolation system consists of four double concave Friction Pendulum (FP) bearings of the construction shown in Figures 7 and 8. The bearing consists of two concave surfaces and an articulated doubly-spherical slider. The effective radius of the bearing (sum of radii of the two concave surfaces minus the bearing height) will be 880 mm (corresponding to period of 1.88 second in the model scale), the displacement capacity will be 150 mm and the gravity load on each bearing will be 60kN.

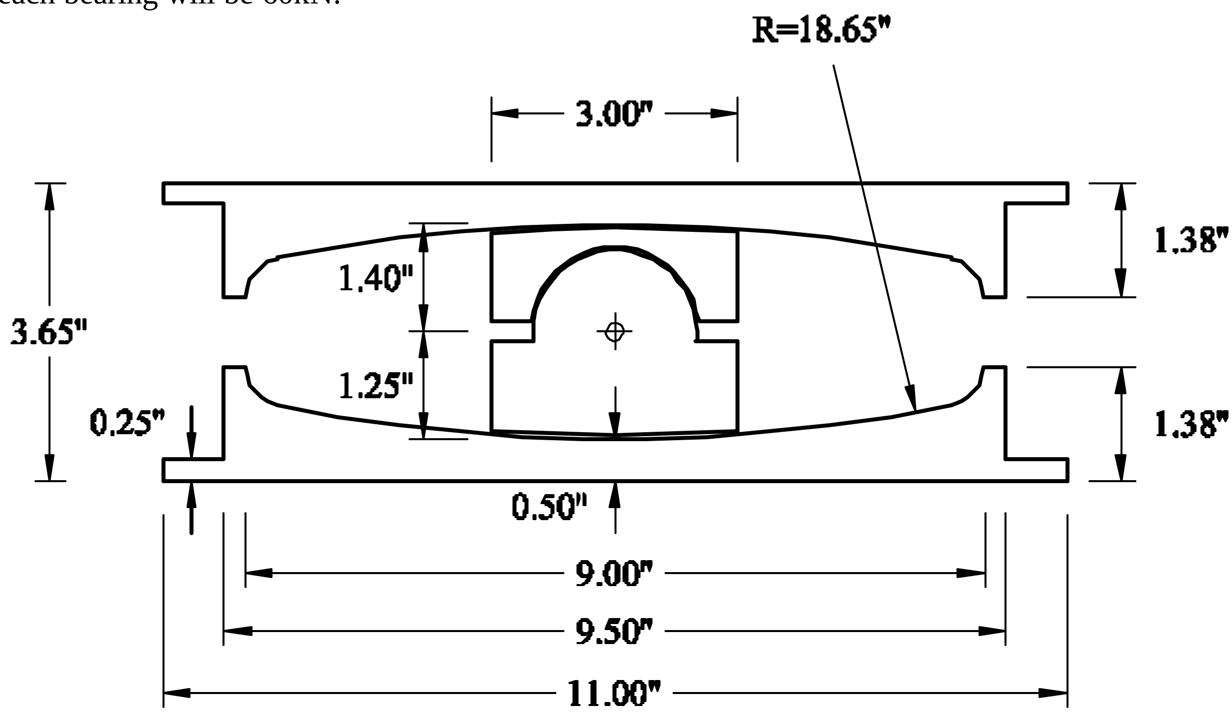


Figure 7 Geometry of Double Concave FP Bearing

Figure 8 View of Double Concave FP Bearing

Installation of Isolation System

To accommodate the double concave bearings and avoid uplift of any bearings during bi-directional testing, the base of the model was modified and extended as shown in Figures 9 through 13. Two HSS 16x8x5/16 tubes were installed on top of the W14x90 beams shown in Figure 3. The FP bearings are installed below the two HSS sections. The modification to the frame allows for unobstructed views of the bearings during testing.

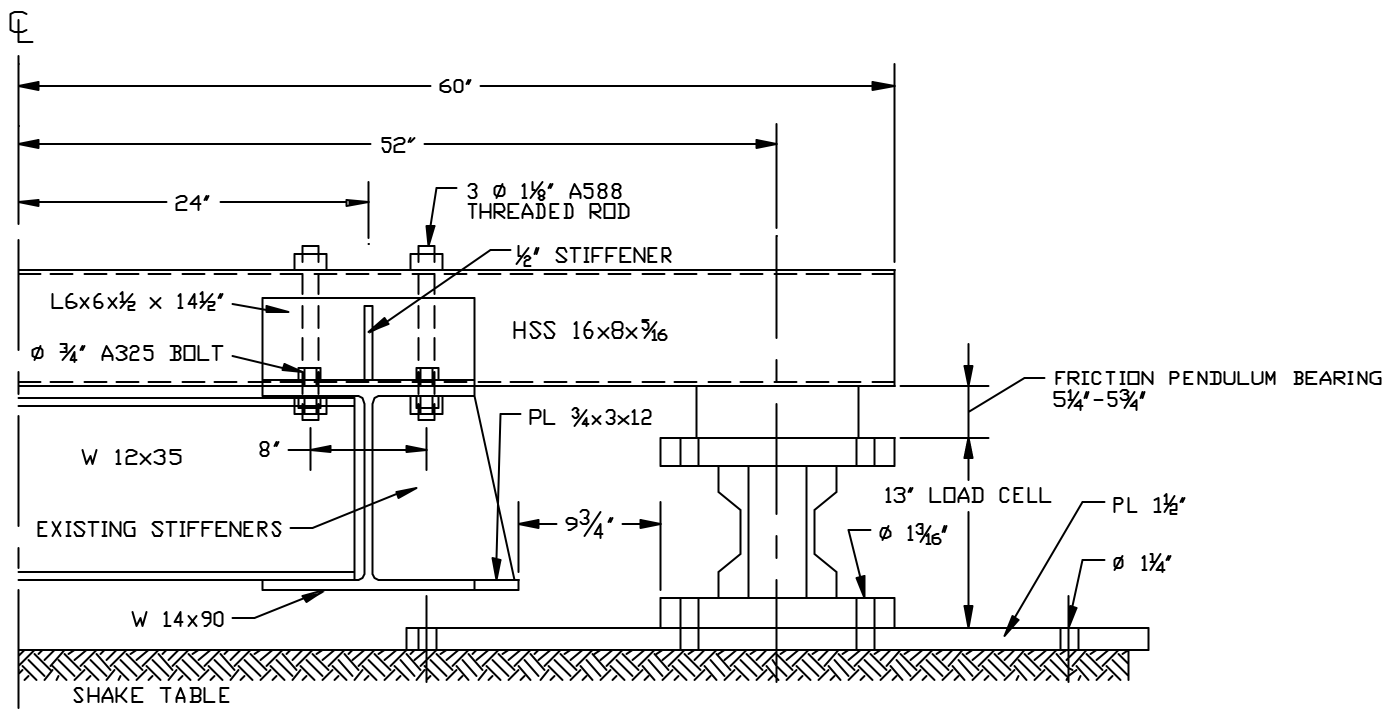


Figure 9 Modified Model Base and Bearing Installation

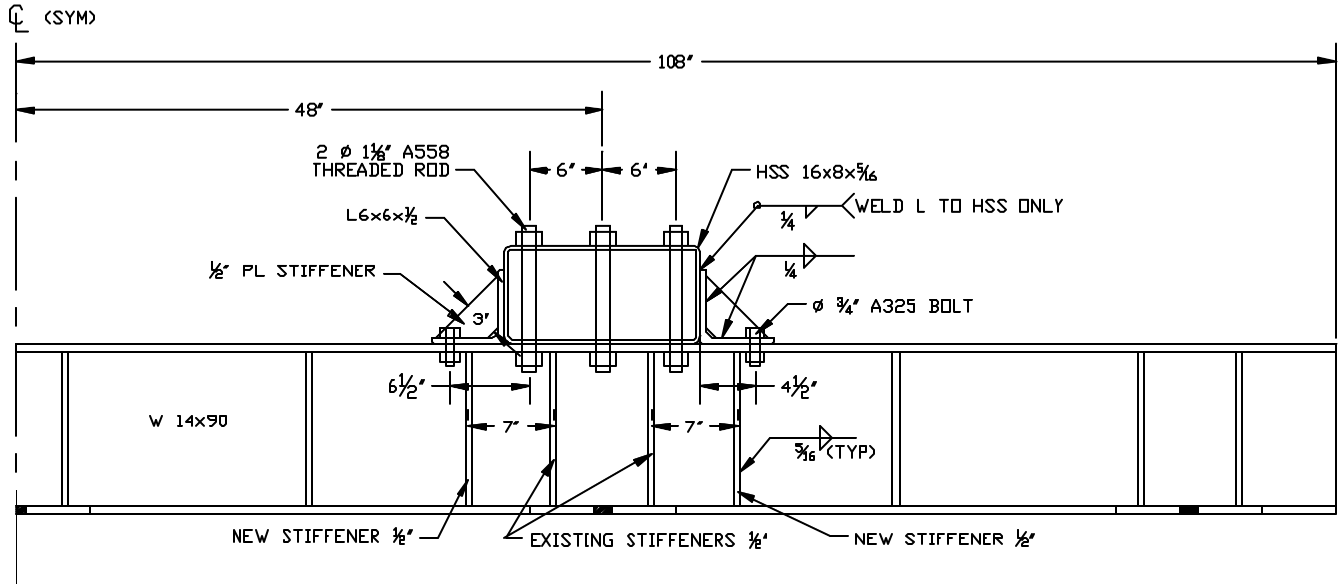


Figure 10 Elevation of the Modified Base of the Model at the W14x90 Sections

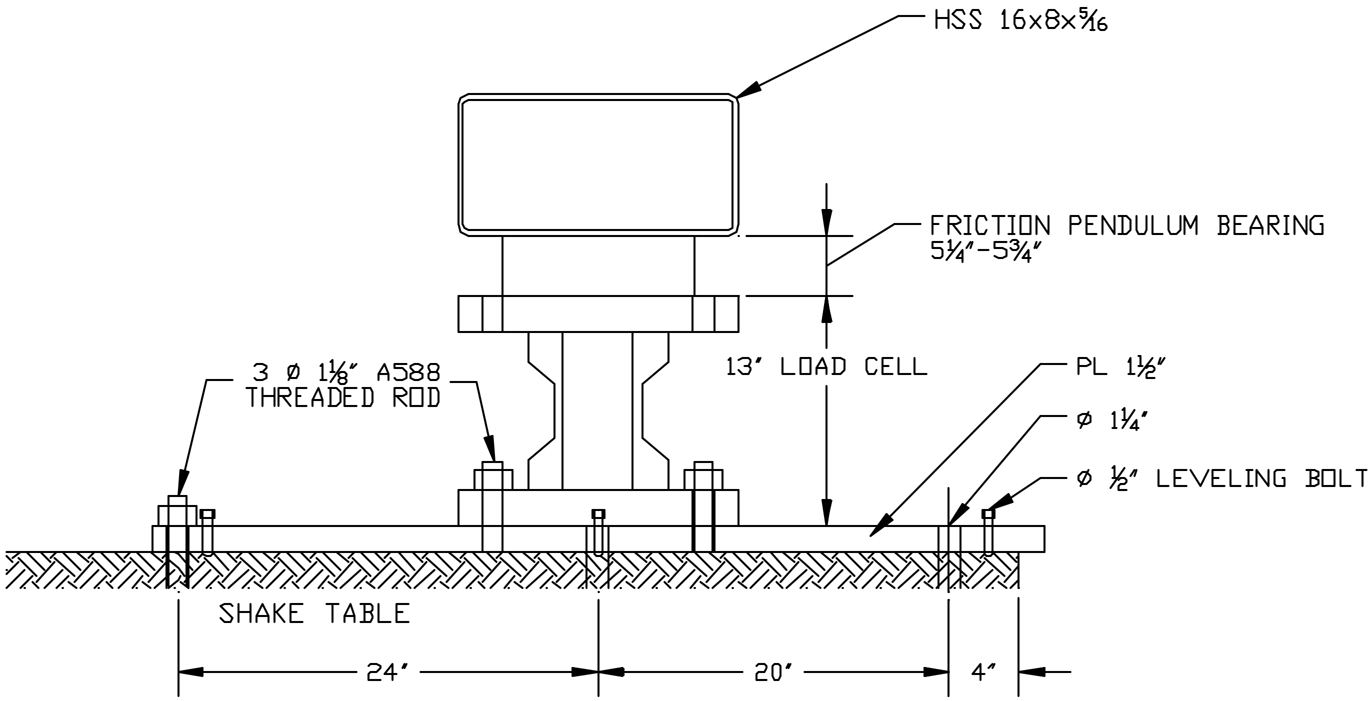


Figure 11 Elevation of the Bearing Installation

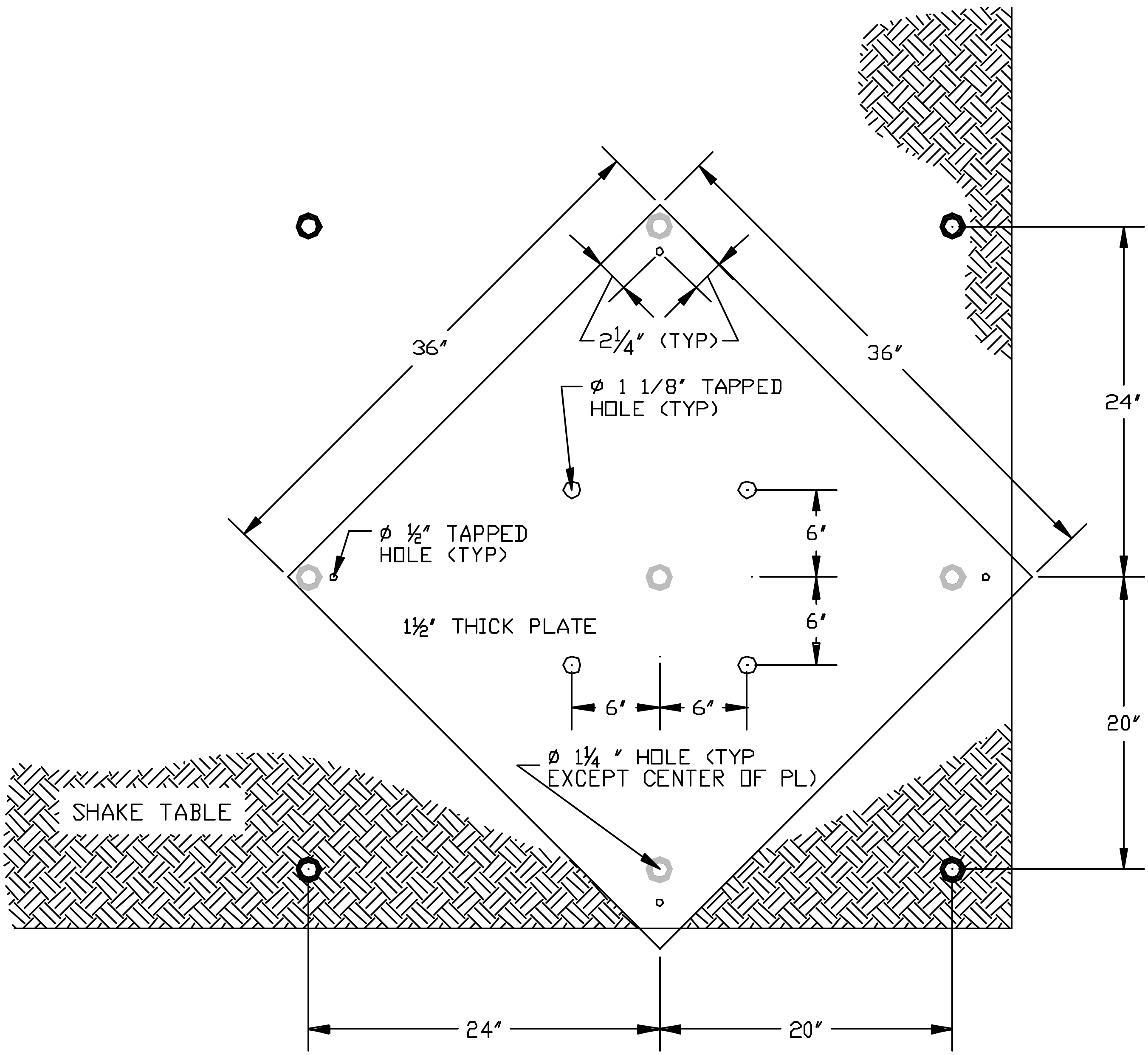


Figure 12 Plan of Connection Plate to the Earthquake Simulator

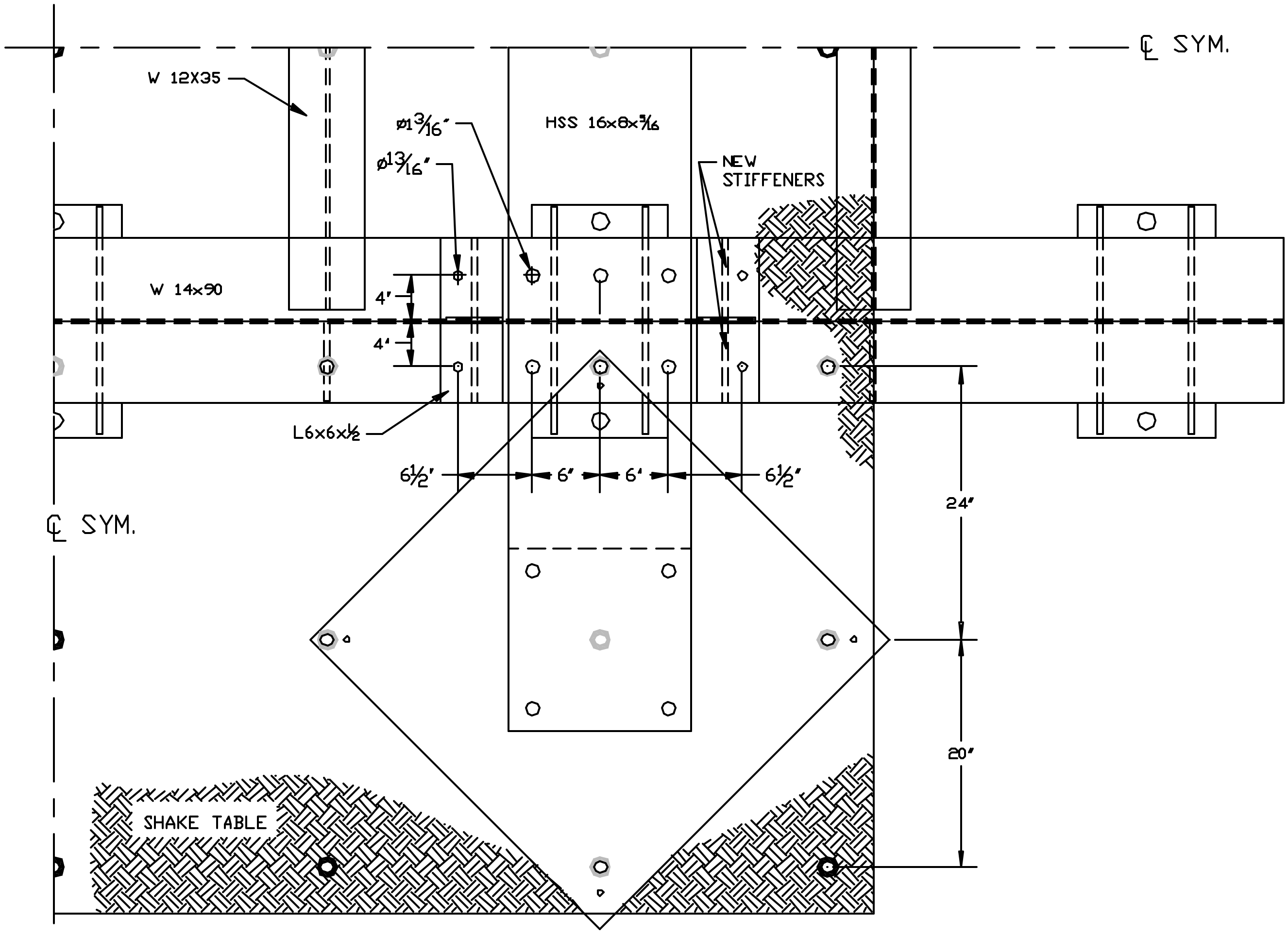


Figure 13 Partial Plan of Base and Connections

References

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3. Reinhorn, A. M. et al. (1989), "1:4 Scale Model Studies of Active Tendon Systems and Active Mass Dampers for Aseismic Protection", Report No. NCEER-89-0026, National Center for Earthquake Engineering Research, State University of New York, Buffalo, New York.

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