SECTION 3

EXPERIMENTAL AND ANALYTICAL STUDY OF WIRE ROPE ISOLATION SYSTEMS FOR EQUIPMENT

To determine the effectiveness of wire rope isolation systems, as well as to verify the validity of the mathematical models developed for wire rope isolators, an equipment cabinet was tested on the shake table. It was subjected to floor earthquake motions under isolated and non-isolated conditions. In all tested systems, the cabinet was supported by four wire rope isolators. Due to its slender configuration, the cabinet could undergo substantial rocking motion. Three systems of different stiffness characteristics were tested, while a forth one was only analyzed. The results of the experimental and analytical studies are presented in this section. However, the analytical modeling is described in section 4.

Another experimental study with a different configuration of wire rope isolators and different equipment is described in section 5.

3.1 Description of Equipment and Isolation System

The tested equipment is shown in Figure 3-1. The equipment is 74 in.(1880 mm) in height and has plan dimensions of 22 in. by 30 in.(559 mm by 762 mm). It consists of five horizontal diaphragms (isolator level, levels 1, 2, 3 and top level) which are connected together by side walls, only in the longitudinal direction. Its weight is 400 lbs (1784 N) and the center of mass was determined to be at the height of level 1 and at the geometric center of the cabinet's plan. The radius of gyration of the equipment about a horizontal axis passing through the center of mass and parallel to the longitudinal direction of the cabinet was determined to be 22.83 in. (580 mm).

In the three tested configurations and the one analyzed configuration, the isolation system consisted of four wire rope isolators placed at a distance of 18.25 in. (463.6 mm) in the transverse direction as shown in Figure 3-1. Seismic excitation was applied in the vertical and transverse directions so that the isolators were subjected to combined vertical and roll motions. The four isolation systems are identified as systems 1, 2, 3 and 4. System 1 consisted of isolators No.1 (Table 2-I), system 2 consisted of isolators No.2 and so forth.

Views of the isolated cabinet (system 2 with helical wire isolators No.2) on the shake table are shown in Figure 3-2.

3.2 Instrumentation and Experimental Program

The instrumentation consisted of twenty one channels. Fifteen of these channels, nine accelerometers and six displacement transducers, monitored the response of the equipment, and the rest, three accelerometers and three displacement transducers, monitored the shake table response.

Figures 3-3 and 3-4 show the instrumentation diagram.

The equipment was tested in its transverse direction under isolated and non - isolated (fixed) conditions. Identification tests of the non - isolated equipment gave a fundamental frequency of 10.3 Hz and viscous damping ratio of 0.6% in the transverse direction. The earthquake excitation consisted of the 1952 Taft (Kern County, CA, Taft Lincoln School tunnel, component N21E and vertical), 1940 El Centro (Imperial Valley, CA, component S00E and vertical) and 1971 Pacoima Dam (San Fernando, CA component S74W and vertical) records. The characteristics of these earthquake motions are listed in Table 3-I. The Taft and El Centro motions were filtered through an actual 7-story building in an attempt to generate floor motions.

The 7-story building is the reinforced concrete building tested using the full-scale pseudo-dynamic testing facility at Tsukuba, Japan under the U.S. - Japan cooperative research program (Okamoto 1985). Available information and experimental data for this structure enabled the development of a detailed inelastic model for the structure using program IDARC (Park 1987). The computed time histories of acceleration at the 5th and 7th floors of this structure were used as input to the shake table without any time scaling. The very small weight of the equipment in relation to that of a typical floor (≈1/1000) let us neglect equipment-structure interaction in the analysis.

Figures 3-5 to 3-11 show the horizontal components of ground and floor acceleration histories (as produced by the shake table) and their acceleration and displacement spectra. The vertical components of acceleration were transmitted through the structure unchanged. One may note the considerable amplification and filtering of the horizontal components of the ground motions at the higher floors of the structure. The 5%-damped acceleration spectra of the upper floor motions show considerable amplification in the range of 0.4 to 0.8 secs, the range which contains the fundamental period of the yielding 7-story structure. The spectra of the 7th floor El Centro motion are consistent with published floor response spectra for the design of equipment (Chen 1988). The motions used in this experimental program are identical to those used by Makris 1992a and 1992b in testing of the same cabinet with another isolation system.

3.3 Test Results

The recorded peak response of the cabinet under isolated and non - isolated (fixed) conditions is presented in Tables 3-I to 3-VIII. The values listed in these tables were recorded by the instruments listed in Table 3-IX. An immediate observation is made in the results of Tables 3-II to 3-VIII: systems 2 and 3 were not effective. The accelerations of the cabinet in these two systems were in most cases higher than in the fixed cabinet. However, system 2 was effective in reducing accelerations by factors of the order of two in the strongest motions (Taft 7th floor, El Centro 7th floor and Pacoima).

In explaining this behavior, the dynamic characteristics of the three systems were determined in free vibration tests. Time histories of the horizontal displacement of the center of mass of the isolated cabinet are shown in Figure 3-12. From these displacement histories it was possible to determine the effective period of free vibration and the corresponding equivalent viscous damping ratio for systems 1 and 3 from the data of the first half cycle of motion. The damping ratio was determined by the logarithmic decrement method (Clough 1975). These dynamic properties, which are amplitude dependent due to the nonlinear hysteretic behavior of wire rope isolators, are listed in Table 3-X. The values of period indicate that system 3 (4-coil isolator) is about twice as stiff as system 1 (2-coil isolator). Moreover, system 1 has significantly more capability to dissipate energy than system 3. This is primarily the reason for the better performance of system 1.

Evidence for this may be obtained by comparing the experimental responses of the two systems for the Taft 7th floor excitation (Table 3-IV). The two systems undergo displacements at the center of mass of 2.2 and 4.5 in.(56 and 114 mm), respectively, thus within the range in which the free vibration results are valid. From the response spectra of the input motion (Fig. 3-7) and using the dynamic characteristics of Table 3-X it is easily demonstrated that the response of system 3 is about twice as much as that of system 1.

The higher energy dissipation capability of system 1 may be also demonstrated by comparing the moment-rotation relations of the two systems in the Taft 7th floor test. The isolated cabinet responds primarily in rocking (compare values of horizontal and vertical isolator displacements in Tables 3-II to 3-VIII). Accordingly, its dynamic characteristics may be determined from the relation between the moment exerted to the base by the isolators, M, and the rotation, θ, of the base. Using the experimental histories of vertical isolator displacement, equations 2-2 and 2-5 to 2-7 were numerically integrated to obtain the time histories of vertical force exerted to the base by each isolator. Denoting as a the half distance between isolators (see Figs. 3-1 and 3-3) we have

$$M = 2(F_S - F_N)a \tag{3-1}$$

$$\theta = \frac{U_S - U_N}{2a} \tag{3-2}$$

where F_S, U_S are the force and displacement of the isolator located at the south side (see Fig. 3-3) and F_N, U_N are the force and displacement of the isolator located at the north side. Figure 2-13 shows the M - θ loops for systems 1 and 3 in the Taft 7th floor test. It is interesting to note that these loops exhibit symmetric hysteretic behavior, unlike the force - displacement loops of individual isolators (see Fig. 2-11).

The dynamic characteristics of effective period of free vibration, T, and equivalent viscous damping ratio, ξ, are determined from

$$T = 2\pi \left(\frac{I}{K_r}\right)^{1/2} \tag{3-3}$$

$$\xi = \frac{W_D}{4\pi W_S} \tag{3-4}$$

where K_r = rotational stiffness from the slope of the M-θ relation, I = moment of inertia of the cabinet about an axis passing through the center of the isolation system ($I = mr^2 + mh^2$), W_D = energy under the moment-rotation loop and W_S = strain energy stored at maximum displacements (Clough 1975). These characteristics are T = 0.93 secs, ξ = 0.11 for system 1 and T = 0.62 secs, ξ = 0.05 for system 3. Periods are lower than those determined in free vibration testing (Table 3-X) because the horizontal flexibility of the isolators was not accounted for. The damping ratios are almost identical to those determined in free vibration tests.

The preceding analysis of experimental results and discussion demonstrates that damping in wire rope isolators is dependent on the amplitude of deformation. At large deformations, as those expected in strong floor earthquake motions, damping ratio may be insufficient. This is the reason for the ineffectiveness of the tested systems 2 and 3. Even system 1, which was effective in reducing accelerations, had equivalent damping ratio of about 0.1 of critical which is regarded as moderately high. The possibility of further improvement of damping capability by use of very stiff wire rope isolators is analytically investigated in the next subsection of this report.

3.4 Analytical Investigation of a Very Stiff Wire Rope System

In an attempt to understand the behavior of very stiff wire rope systems, a system consisting of four helical wire rope isolators of the type No.4 (see Fig. 2-15 and Table 2-I and section 2 for description) was analytically studied. The isolators were assumed placed as in the tested systems. The analysis was performed by numerical integration of the governing constitutive and dynamic equilibrium equations as described in section 4. Calculated peak response values for horizontal excitation only are listed in Table 3-XI and compared to the corresponding experimental values for the fixed equipment.

The analytical results certainly contain some error since the flexibility of the cabinet was not considered in the analysis. The contribution of the flexibility of the cabinet may be important in the analysis of very stiff wire rope systems. Assuming that the analytical results are correct, we observe that the wire rope system resulted in some improvement of the seismic performance of the cabinet for all input motions. Concentrating on two of the cases in Table 3-XI (Taft 7th floor and Pacoima ground) we plot the moment-rotation loops of the system (Fig. 3-14) from where the dynamic characteristics (equations 3-3 and 3-4) are determined to be: $T = 0.14$ secs, $\xi = 0.23$ for the Taft 7th floor input motion and $T = 0.19$ secs, $\xi = 0.3$ for the Pacoima input. Damping is as large as desired for control of the response. The fact that the performance of the wire rope supported cabinet was not significantly improved in comparison to the fixed cabinet is merely a result of the very high stiffness of the tested cabinet (frequency of 10.3 Hz under fixed conditions). Had the fixed cabinet had a lower frequency (say 5 Hz), its acceleration response would have been much larger because of its inability to dissipate energy ($\xi = 0.006$).

It may be concluded that overall, the seismic behavior of equipment may be substantially improved by supporting them on stiff wire rope isolators. Under such conditions, the isolators undergo small displacements, exhibit large damping capacity and prevent the occurrence of resonances.

Table 3-I - Characteristics of Earthquake Excitation in Testing Program (1 in.= 25.4 mm).

Record	TAFT	EL CENTRO	PACOIMA
	Kern County, CA July 21, 1952 Taft Lincoln School Tunnel	Imperial Valley, CA May 18, 1940 El Centro	San Fernando, CA February 9, 1971 Pacoima Dam
Site	Rock	Stiff Soil	Rock
Magnitude	7.6	6.6	6.6
Local MMI	VII	VIII	IX
Distance from Source (Km)	56	8	3
Horizontal Component	N21E	S00E	S74W
Pk. Horizontal Displacement (in.)	2.64	4.28	4.26
Pk. Horizontal Velocity (in/s)	6.19	13.17	22.73
Pk. Horizontal Acceleration (g)	0.16	0.35	1.08
Pk. Vertical Displacement (in.)	1.98	2.19	7.60
Pk. Vertical Velocity (in/s)	2.63	4.27	22.95
Pk. Vertical Acceleration (g)	0.11	0.21	0.71

Table 3-II - Recorded Peak Response of Isolated Equipment for Taft Ground Motion. Value in Parenthesis is for Combined Horizontal and Vertical Input Motion (1 in.= 25.4 mm).

TAFT N21E GROUND				
	ISOLATED SYSTEM 1	ISOLATED SYSTEM 2	ISOLATED SYSTEM 3	FIXED
ACCELERATION (g)				
Table Horizontal	0.155 (0.155)	0.155 (0.153)	0.154 (0.154)	0.154 (0.152)
Isolator Horizontal	0.166 (0.165)	0.168 (0.158)	0.150 (0.154)	0.156 (0.157)
Level 1 Horizontal	0.100 (0.110)	0.163 (0.179)	0.186 (0.171)	0.187 (0.193)
Top Horizontal	0.220 (0.215)	0.262 (0.297)	0.305 (0.292)	0.250 (0.255)
Table Vertical	0.002 (0.121)	0.005 (0.117)	0.006 (0.123)	- (0.112)
Isolator S Vertical	0.055 (0.156)	0.031 (0.120)	0.045 (0.127)	- -
Isolator N Vertical	0.059 (0.222)	0.030 (0.138)	0.055 (0.162)	- -
Top Vertical	0.050 (0.216)	0.031 (0.135)	0.047 (0.157)	0.008 (0.118)
DISPLACEMENT (in)				
Table Horizontal	1.242 (1.224)	1.243 (1.223)	1.244 (1.222)	1.268 (1.354)
Isolator Horizontal	0.122 (0.103)	0.018 (0.022)	0.067 (0.070)	- -
Level 1 Horizontal	0.665 (0.657)	0.254 (0.238)	0.366 (0.463)	0.039 (0.039)
Top Horizontal	1.211 (1.221)	0.431 (0.395)	0.676 (0.860)	0.063 (0.063)
Table Vertical	0.013 (0.479)	0.012 (0.480)	0.012 (0.479)	- (0.433)
Isolator S Vertical	0.247 (0.258)	0.058 (0.052)	0.126 (0.173)	- -
Isolator N Vertical	0.198 (0.221)	0.074 (0.068)	0.119 (0.153)	- -

Table 3-III - Recorded Peak Response of Isolated Equipment for Taft 5th Floor Motion. Value in Parenthesis is for Combined Horizontal and Vertical Input Motion (1 in.= 25.4 mm).

TAFT N21E 5th FLOOR				
	ISOLATED SYSTEM 1	ISOLATED SYSTEM 2	ISOLATED SYSTEM 3	FIXED
ACCELERATION (g)				
Table Horizontal	0.266 (0.261)	0.262 (0.259)	0.262 (0.261)	0.272 (0.268)
Isolator Horizontal	0.289 (0.338)	0.299 (0.304)	0.290 (0.288)	0.276 (0.273)
Level 1 Horizontal	0.166 (0.173)	0.370 (0.322)	0.576 (0.552)	0.372 (0.378)
Top Horizontal	0.447 (0.449)	0.633 (0.540)	1.099 (1.065)	0.529 (0.378)
Table Vertical	0.002 (0.122)	0.005 (0.121)	0.007 (0.120)	- (0.119)
Isolator S Vertical	0.189 (0.325)	0.056 (0.127)	0.243 (0.256)	- -
Isolator N Vertical	0.131 (0.254)	0.111 (0.148)	0.281 (0.320)	- -
Top Vertical	0.118 (0.264)	0.093 (0.142)	0.332 (0.363)	0.021 (0.113)
DISPLACEMENT (in)				
Table Horizontal	1.672 (1.644)	1.670 (1.646)	1.674 (1.644)	1.654 (1.673)
Isolator Horizontal	0.256 (0.173)	0.327 (0.239)	0.444 (0.438)	- -
Level 1 Horizontal	1.731 (1.698)	1.070 (0.715)	3.105 (2.943)	0.043 (0.063)
Top Horizontal	3.214 (3.182)	1.805 (1.209)	5.882 (5.570)	0.083 (0.094)
Table Vertical	0.021 (0.479)	0.021 (0.479)	0.021 (0.479)	- (0.457)
Isolator S Vertical	0.768 (0.798)	0.235 (0.155)	1.388 (1.306)	- -
Isolator N Vertical	0.616 (0.583)	0.345 (0.227)	1.373 (1.311)	- -

Table 3-IV - Recorded Peak Response of Isolated Equipment for Taft 7th Floor Motion. Value in Parenthesis is for Combined Horizontal and Vertical Input Motion (1 in.= 25.4 mm).

TAFT N21E 7th FLOOR				
	ISOLATED SYSTEM 1	ISOLATED SYSTEM 2	ISOLATED SYSTEM 3	FIXED
ACCELERATION (g)				
Table Horizontal	0.469 (0.474)	0.473 (0.471)	0.475 (0.470)	0.475 (0.479)
Isolator Horizontal	0.673 (0.677)	0.537 (0.499)	0.484 (0.516)	0.482 (0.490)
Level 1 Horizontal	0.260 (0.250)	0.608 (0.580)	0.679 (0.674)	0.700 (0.726)
Top Horizontal	0.625 (0.639)	1.130 (0.979)	1.304 (1.293)	1.167 (1.199)
Table Vertical	0.006 (0.124)	0.008 (0.126)	0.009 (0.125)	- (0.114)
Isolator S Vertical	0.262 (0.302)	0.248 (0.279)	0.609 (0.550)	- -
Isolator N Vertical	0.255 (0.297)	0.261 (0.272)	0.573 (0.529)	- -
Top Vertical	0.230 (0.299)	0.230 (0.248)	0.769 (0.711)	0.044 (0.118)
DISPLACEMENT (in)				
Table Horizontal	2.105 (2.064)	2.105 (2.064)	2.105 (2.062)	2.075 (2.102)
Isolator Horizontal	0.302 (0.214)	0.687 (0.581)	0.615 (0.584)	- -
Level 1 Horizontal	2.234 (2.209)	2.404 (1.952)	4.535 (4.440)	0.094 (0.106)
Top Horizontal	4.163 (4.167)	4.099 (3.305)	8.998 (8.785)	0.185 (0.213)
Table Vertical	0.032 (0.478)	0.033 (0.478)	0.032 (0.478)	- (0.445)
Isolator S Vertical	1.031 (1.054)	0.702 (0.494)	2.069 (1.948)	- -
Isolator N Vertical	0.806 (0.753)	0.758 (0.667)	2.516 (2.443)	- -

Table 3-V - Recorded Peak Response of Isolated Equipment for El Centro Ground Motion. Value in Parenthesis is for Combined Horizontal and Vertical Input Motion (1 in.= 25.4 mm).

EL CENTRO S00E GROUND				
	ISOLATED SYSTEM 1	ISOLATED SYSTEM 2	ISOLATED SYSTEM 3	FIXED
ACCELERATION (g)				
Table Horizontal	0.373 (0.383)	0.377 (0.382)	0.367 (0.381)	0.361 (0.368)
Isolator Horizontal	0.600 (0.609)	0.463 (0.412)	0.469 (0.519)	0.368 (0.374)
Level 1 Horizontal	0.277 (0.300)	0.405 (0.360)	0.490 (0.466)	0.536 (0.556)
Top Horizontal	0.546 (0.586)	0.795 (0.673)	0.903 (0.991)	0.877 (0.898)
Table Vertical	0.004 (0.154)	0.008 (0.191)	0.008 (0.193)	- (0.204)
Isolator S Vertical	0.190 (0.233)	0.218 (0.228)	0.252 (0.431)	- -
Isolator N Vertical	0.196 (0.241)	0.101 (0.216)	0.149 (0.323)	- -
Top Vertical	0.201 (0.241)	0.085 (0.219)	0.169 (0.315)	0.028 (0.209)
DISPLACEMENT (in)				
Table Horizontal	2.213 (2.252)	2.213 (2.252)	2.214 (2.247)	2.240 (2.240)
Isolator Horizontal	0.401 (0.428)	0.392 (0.282)	0.248 (0.309)	- -
Level 1 Horizontal	2.626 (2.879)	1.324 (0.947)	1.307 (2.023)	0.083 (0.079)
Top Horizontal	4.753 (5.256)	2.247 (1.626)	2.489 (3.864)	0.157 (0.185)
Table Vertical	0.035 (0.539)	0.036 (0.537)	0.038 (0.540)	- (0.504)
Isolator S Vertical	1.145 (1.295)	0.379 (0.252)	0.521 (0.867)	- -
Isolator N Vertical	0.844 (0.899)	0.363 (0.278)	0.492 (0.793)	- -

Table 3-VI - Recorded Peak Response of Isolated Equipment for El Centro 5th Floor Motion. Value in Parenthesis is for Combined Horizontal and Vertical Input Motion (1 in.= 25.4 mm).

EL CENTRO S00E 5th FLOOR				
	ISOLATED SYSTEM 1	ISOLATED SYSTEM 2	ISOLATED SYSTEM 3	FIXED
ACCELERATION (g)				
Table Horizontal	0.424 (0.424)	0.428 (0.427)	0.429 (0.428)	0.417 (0.422)
Isolator Horizontal	0.408 (0.448)	0.529 (0.584)	0.684 (0.860)	0.424 (0.429)
Level 1 Horizontal	0.379 (0.377)	0.792 (0.703)	0.925 (1.603)	0.529 (0.762)
Top Horizontal	0.771 (0.765)	1.117 (1.020)	1.355 (2.048)*	0.729 (0.761)
Table Vertical	0.006 (0.196)	0.012 (0.192)	0.012 (0.194)	– (0.210)
Isolator S Vertical	0.376 (0.446)	0.098 (0.228)	0.382 (1.452)	– –
Isolator N Vertical	0.367 (0.352)	0.115 (0.309)	0.320 (1.069)	– –
Top Vertical	0.463 (0.454)	0.101 (0.277)	0.386 (1.242)	0.038 (0.214)
DISPLACEMENT (in)				
Table Horizontal	4.241 (4.237)	4.243 (4.238)	4.250 (4.233)	4.213 (4.252)
Isolator Horizontal	0.698 (0.671)	0.920 (0.747)	0.533 (4.820)	– –
Level 1 Horizontal	5.760 (5.497)	2.910 (2.290)	3.239 (10.240)*	0.094 (0.098)
Top Horizontal	10.652 (10.157)	4.859 (3.804)	6.225 (15.360)*	0.177 (0.173)
Table Vertical	0.132 (0.518)	0.131 (0.518)	0.132 (0.518)	– (0.472)
Isolator S Vertical	2.921 (2.763)	0.725 (0.567)	1.196 (4.084)	– –
Isolator N Vertical	2.618 (2.428)	0.967 (0.759)	1.622 (3.550)	– –

* : Value exceeded the limit of instrument.

Table 3-VII - Recorded Peak Response of Isolated Equipment for El Centro 7th Floor Motion. Value in Parenthesis is for Combined Horizontal and Vertical Input Motion (1 in.= 25.4 mm).

EL CENTRO S00E 7th FLOOR				
	ISOLATED SYSTEM 1	ISOLATED SYSTEM 2	ISOLATED SYSTEM 3	FIXED
ACCELERATION (g)				
Table Horizontal	0.905 (0.736)	0.720 (0.747)	0.725 -	0.728 (0.693)
Isolator Horizontal	1.361 (1.219)	1.050 (0.975)	1.856 -	0.745 (0.711)
Level 1 Horizontal	0.594 (0.550)	1.408 (1.272)	1.773 -	0.985 (0.968)
Top Horizontal	1.057 (0.987)	2.048* (1.960)	2.048* -	1.780 (1.777)
Table Vertical	0.017 (0.192)	0.024 (0.190)	0.019 -	- (0.205)
Isolator S Vertical	0.434 (0.485)	0.474 (0.509)	1.458 -	- -
Isolator N Vertical	0.733 (0.764)	0.369 (0.484)	1.412 -	- -
Top Vertical	0.825 (0.853)	0.473 (0.444)	1.526 -	0.073 (0.213)
DISPLACEMENT (in)				
Table Horizontal	5.190 (5.191)	5.192 (5.202)	5.200 -	5.157 (5.157)
Isolator Horizontal	0.749 (0.656)	1.715 (1.558)	1.284 -	- -
Level 1 Horizontal	6.444 (6.344)	5.860 (5.246)	10.240* -	0.177 (0.177)
Top Horizontal	11.860 (11.752)	9.903 (8.868)	15.360* -	0.350 (0.343)
Table Vertical	0.197 (0.514)	0.196 (0.514)	0.198 -	- (0.487)
Isolator S Vertical	3.279 (3.262)	1.588 (1.424)	4.186* -	- -
Isolator N Vertical	2.705 (2.553)	2.187 (1.939)	3.728 -	- -

* : Value exceeded the limit of instrument.

Table 3-VIII - Recorded Peak Response of Isolated Equipment for Pacoima Dam Ground Motion. Value in Parenthesis is for Combined Horizontal and Vertical Input Motion (1 in.= 25.4 mm).

PACOIMA DAM S74W GROUND				
	ISOLATED SYSTEM 1	ISOLATED SYSTEM 2	ISOLATED SYSTEM 3	FIXED
ACCELERATION (g)				
Table Horizontal	0.800 (0.829)	0.816 (0.826)	0.815 (0.830)	0.867 (0.867)
Isolator Horizontal	1.545 (1.951)	1.074 (1.009)	1.012 (1.250)	0.876 (0.896)
Level 1 Horizontal	0.572 (0.767)	0.775 (0.759)	0.783 (0.600)	1.136 (1.181)
Top Horizontal	0.985 (1.300)	1.716 (1.804)	1.548 (1.450)	2.610 (2.650)
Table Vertical	0.010 (0.801)	0.017 (0.788)	0.017 (0.791)	- (0.778)
Isolator S Vertical	0.529 (1.776)	0.490 (1.012)	0.751 (1.198)	- -
Isolator N Vertical	0.495 (2.048)*	0.419 (1.042)	0.571 (0.916)	- -
Top Vertical	0.532 (2.026)*	0.370 (1.095)	0.612 (0.942)	0.093 (0.811)
DISPLACEMENT (in)				
Table Horizontal	4.053 (3.984)	4.054 (3.985)	4.058 (3.982)	4.055 (4.094)
Isolator Horizontal	1.042 (1.187)	0.833 (0.774)	0.491 (0.513)	- -
Level 1 Horizontal	7.038 (7.368)	2.976 (2.820)	3.305 (2.845)	0.157 (0.283)
Top Horizontal	12.857 (13.517)	5.077 (4.854)	6.284 (5.492)	0.343 (0.433)
Table Vertical	0.120 (2.778)	0.120 (2.778)	0.121 (2.776)	- (2.890)
Isolator S Vertical	3.519 (3.600)	0.883 (0.843)	1.500 (1.252)	- -
Isolator N Vertical	2.696 (3.169)	0.765 (0.759)	1.090 (1.024)	- -

* : Value exceeded the limit of instrument.

Table 3-IX - Relation Between Quantities in Tables of Response and Recording Instruments.

Response	Quantity in Tables 3-II to 3-VIII	Instrument in Fig. 3-3
Acceleration	Table Horizontal	AFCH
	Isolator Horizontal	AHBC
	Level 1 Horizontal	AH1C
	Top Horizontal	AHTC
	Table Vertical	AFCV
	Isolator S Vertical	AVBS
	Isolator N Vertical	AVBN
	Top Vertical	AVTN
Displacement	Table Horizontal	DLAT
	Isolator Horizontal	DHBE-DLAT
	Level 1 Horizontal	DH1E-DLAT
	Top Horizontal	Max(DHTE-DLAT,DHTW-DLAT)
	Table Vertical	DVRT
	Isolator S Vertical	DVBS
	Isolator N Vertical	DVBN

Table 3-X - Dynamic Characteristics of Isolated Cabinet as Determined from Pull-Release Tests (1 in.=25.4 mm).

System	Range of Amplitude of Displacement of C.M. (inch)	Period of Free Vibration (sec)	Equivalent Viscous Damping Ratio
1	2.8 - 2	1.15	0.11
3	3.6 - 3	0.82	0.06

Table 3-XI - Analytical Peak Response of Equipment System 4 and Experimental Peak Response of Fixed Cabinet (1 in.= 25.4 mm).

	Taft 5th		Taft 7th		El Centro 5th		El Centro 7th		Pacoima Ground	
	System 4	Fixed	System 4	Fixed	System 4	Fixed	System 4	Fixed	System 4	Fixed
Top Horizontal Acceleration (g)	0.583	0.529	1.126	1.167	0.618	0.729	1.223	1.780	1.474	2.610
Top Horizontal Displacement (in)	0.107	0.083	0.305	0.185	0.143	0.177	0.358	0.350	0.613	0.343
Isolator Horizontal Displacement (in)	0.014	-	0.036	-	0.018	-	0.043	-	0.063	-
Isolator Vertical S Displacement (in)	0.018	-	0.053	-	0.021	-	0.052	-	0.088	-
Isolator Vertical N Displacement (in)	0.016	-	0.046	-	0.024	-	0.062	-	0.117	-

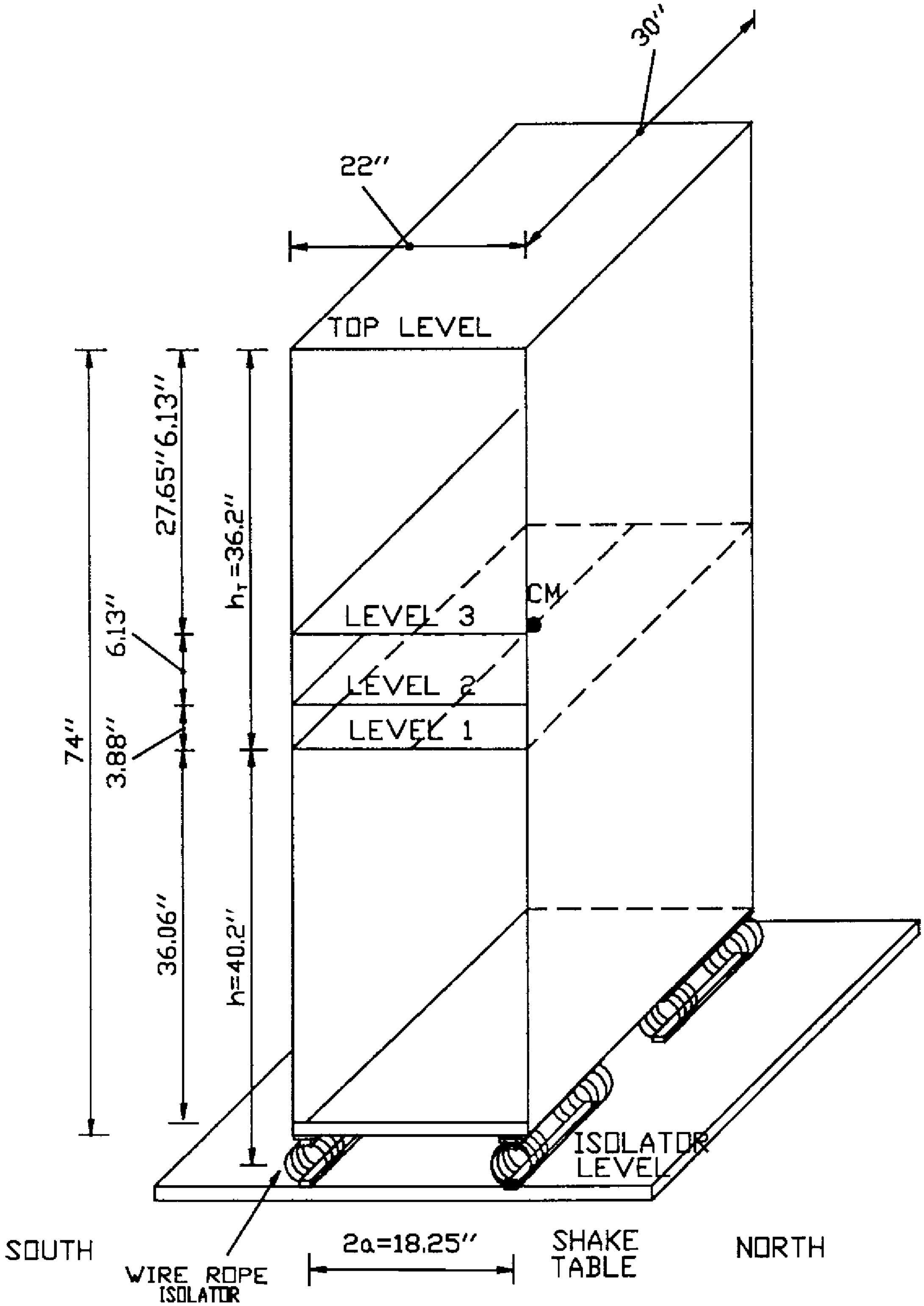

Figure 3-1 Tested Equipment Cabinet (1 in.= 25.4 mm).