EXPERIMENTAL STUDY OF LEAD AND ELASTOMERIC DAMPERS FOR BASE ISOLATION SYSTEMS IN LAMINATED NEOPRENE BEARINGS

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SYNOPSIS:

This report describes a series of experiments carried out on the shaking table at the Earthquake Simulator Laboratory of the Earthquake Engineering Research Laboratory, involving a base isolation system which incorporated multilayer isolation bearings of Neoprene, a polychloroprene rubber. Several forms of isolation system using the same basic bearing design but including inserts of different materials in a central hole in each bearing were studied. The inserts were used to enhance the damping properties of the system and to improve the response. The results indicate that there are no difficulties in designing an effective isolation system in polychloroprene rubber and that the multilayer elastomeric bearings can substantially reduce the seismic loads experienced by a building and its contents. Elastomeric inserts were effective in improving the response only to a limited extent. The use of lead inserts to enhance the damping was very effective in controlling the displacement. There is an increasing interest in the use of base isolation as a way of reducing the effects of earthquakes on structures. There is general acceptance of the concept but doubts about its implementation center on the question of suitable bearings. Experiments of the kind reported here, on large models where scaling effects are minimized, can allay the fears of the seismic engineering profession that bearings may not be available.

INTRODUCTION:

An experimental study has recently been carried out on the shaking table of the Earthquake Engineering Research Center of the University of California of a base isolation system incorporating multilayer bearings in polychloroprene rubber (Neoprene). This study was funded by the Polymer Products Department, Elastomers Division of E.I. du Pont de Nemours & Co. (Inc.), Wilmington, Delaware, manufacturers of the Neoprene Oil States Industries, Inc., Bearing Pad Division, Athens, Texas manufactured and donated the bearings for this project. Similar maintenance-free Neoprene bearing pads for prestressed concrete bridges have been made by Oil States Industries, Inc. for over 25 years. The Du Pont Neoprene was compounded and compression molded with steel shims in a one-step process to form

the multilayer bearings. Du Pont engineers designed the bearings to provide the structural model with a natural frequency of approximately 0.6 Hz in the horizontal direction and 16 Hz in the vertical. A cylindrical bearing design was preferred so as to minimize the formation of localized stress points.

The dimensions of each bearing were as follows: a cross sectional area of 20.6 in² (132.87 cm²), an effective elastomer height of 2.5 in (64 mm); a total height of 5.5 in (140 mm) and an inside diameter of 2 in. (51 mm); 44 layers of Neoprene, each layer approximately 0.1057 in. (1.45 mm) thick; 43 layers of 16 gauge steel, each layer approximately 0.1060 in. (1.52 mm) thick; and end plates 7 in. x 7 in. (178 mm) square and 0.250 in. (6.4 mm) thick. Two sets of bearings were manufactured, one set in 50A durometer hardness Neoprene and another in 40A hardness. In static compression stress tests each bearing supported three times the required 20,000 lb (90 kN) load with no sign of failure. A typical lead-filled bearing and its cross-section is shown in Figure 1.

The controlling design criterion for base isolation systems is relative displacement between the ground and the building. As the isolation frequency is reduced the relative displacement increases. One way of reducing the relative displacement without increasing the acceleration is to increase the effective damping in the bearings. Part of the present study is to assess the effectiveness of elastomeric inserts in increasing the damping in the bearings and improving the response of the isolation system.

The bearings were manufactured with a central hole 2.0 in. (51 mm) in diameter; this allowed the insertion of cylindrical

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Fig. 1. A typical lead-filled bearing and its cross-section.

Fig. 2. Five-storey, three-bay one-third scale structural model used in base-isolation experiments.

plugs of other materials. The insert material is constrained by the steel plates of the bearing to deform almost entirely in pure shear. In the experimental program three damping materials were studied: two of these were elastomeric materials, ADIPRENE urethane rubber and VAMAC ethylene/acrylic elastomer, while the third was lead. At 20°C ADIPRENE has a damping factor[‡] $\tan \delta$ of 0.1 and VAMAC has a damping factor of 0.25. Cylinders of the three materials were cast and machined to 2.0 in. (51 mm) diameter and 5.5 in. (140 mm) high and pressed into the bearings. In the case of the lead inserts only two of the four bearings were filled: since the table motion is in one horizontal direction, no complication arises if two are filled and two not. There were thus six different foundation systems in the test series, namely:

- 1) fixed base (FB);
- 2) 50A durometer hardness bearings (50D);
- 3) 40A durometer hardness bearings (40D);
- 4) 50A durometer hardness bearings with ADIPRENE inserts (50/A);
- 5) 50A durometer hardness bearings with VAMAC inserts (50/V);
- 6) 50A durometer hardness bearings with lead inserts (50/L).

The experimental model used is shown in Fig. 2. It is a five-story frame mounted on two heavy (16WF) base floor girders that are supported by four sets of rubber bearings resting on load cells. The load cells are anchored onto the shaking table with high-tension stress rods. The dead load is provided by concrete blocks tied down to the frame at various floor levels as shown in Fig. 2. The weight of the dead load totals 72,000 lb (320 kN) which gives an approximate total weight of 80,000 lb (360 kN) for the entire structure. Thus, a compressive force of approximately 20,000 lb (90 kN) is produced in each bearing. The dead load provided by the concrete blocks produces stress levels comparable to those in a full-scale structural frame, and the geometrical scale factor of the model is roughly 1/3. The corresponding time scale factor is

$\sqrt{3}$.

The installation of the bearings under the frame is shown in Fig. 3. Each bearing is mounted on a load cell to allow continuous monitoring of the shear forces experienced by the bearings during a test. The base beams on which the frame is mounted are attached directly to the top plate of the bearing as shown in Fig. 3.

Although the experimental model has four columns per frame, each frame is carried on only two bearings. It is impractical to carry each frame on a bearing under each column, as would be done in an actual structure, since this would require a very small bearing design

and the bearings as manufactured are about as small as can be made by standard techniques. A disadvantage of the use of four bearings under the model rather than eight is that the base frame girders are much larger relative to the structural frame than they would be in a full-scale structure: the appearance of the model exaggerates the proportions that a base slab in a real building would have. Although unfortunate, this is unavoidable particularly in view of the fact that the stability of laminated isolation bearings becomes more critical as the isolation mass per bearing is reduced at a fixed isolation frequency.

Test Program:

Four earthquake input signals, based on records of historical California earthquakes, were used for this test series: each was time scaled at a factor of $\sqrt{3}$. This time scaling of the earthquake inputs corresponds to the geometrical scale of the model, and the acceleration response of the model to these inputs should correspond to the actual acceleration of a real structure to the historical earthquakes. The displacements in the model should correspond to one third of those for a real structure.

The four earthquake records used were the El Centro 1940 NOOE component, the Pacoima Dam 1971 S16E component, the Taft 1950 S69E component, and the Parkfield 1966 N65E component. In addition, pull-back tests were carried out to determine the response of the model in free vibration. In these tests the model was pulled in one direction by a wire attached to the second floor and a bolt was cut, allowing the model to snap back. Data were collected during the free-vibration period. This allows the frequencies of the system to be evaluated.

The pull-back tests and the four simulated earthquake tests were carried out on the model for all foundation conditions except the lead-filled bearings.

Frame Response:

The pull-back tests of the frame in the fixed-base condition gave fixed-base frequencies of 3.9 Hz, 12.4 Hz, and 20.0 Hz. On the 50-durometer bearings the first three frequencies were found to be 0.75 Hz, 6.1 Hz, and 14.8 Hz. The 0.75 Hz isolation frequency corresponds to a vibration mode which is roughly a rigid body translation of the frame, while the other two frequencies correspond to the first two structural modes of the model. The stiffness of a single 50-durometer bearing assuming that the total weight of the frame was 80,000 lb (360 kN) and on the basis of a 0.75 Hz isolation frequency is approximately 1150 lb/in. (200 N/mm). For the 40-durometer bearings the pull-back test gave 0.50 Hz, 6.0 Hz, and 14.8 Hz for the three lowest frequencies. The estimated stiffness of a single 40-durometer bearing in this case is thus 500 lb/in. (90 N/mm).

‡ Data obtained from Rhevibron (Toyo Baldwin Co. Ltd)

When the ADIPRENE cylinder was inserted into the 50-durometer bearings the

Fig. 3. A bearing mounted on a load cell on the shaking table.

Fig. 4a Frame accelerations for El Centro input signal, with different isolation conditions.

Fig. 4b Frame accelerations for Pacoima Dam input signal, with different isolation conditions.

Fig. 4c Frame accelerations for Taft input signal, with different isolation conditions.

Fig. 4d Frame accelerations for Parkfield input signal, with different isolation conditions.

Fig. 5a Frame accelerations for El Centro input signal showing fixed-base response.

Fig. 5b Frame accelerations for Pacoima Dam input signal showing fixed-base response.

Fig. 5c Frame accelerations for Taft input signal showing fixed-base response.

three lowest frequencies were 1.0 Hz, 6.2 Hz, and 15.0 Hz. The stiffness of a single ADIPRENE filled bearing is thus 2,000 lb/in. (360 N/mm). For the bearings with the VAMAC inserts the frequencies were 0.8 Hz, and 14.9 Hz, and the individual bearing stiffness was 1,300 lb/in. (230 N/mm). No pull-back tests were performed on the lead-filled bearings due to the inherent nonlinear response of lead.

The response of the frame to the three earthquake signals is summarized in Tables 1a, 1b, and 1c; no vertical signal is available for the Parkfield record. Tables 2a and 2b list the responses to the signals with horizontal excitation only, with the vertical input suppressed.

The effectiveness of the various foundation conditions in reducing the forces applied to the structure is shown in Figures 4a through 4d, where the measured accelerations at all floor levels are plotted. In these plots the accelerations for the model in the fixed-base condition are omitted. Had they been included, the scale would have had to be so reduced that the differences in accelerations between the various cases would have been obscured. Comparisons of accelerations when isolated and when the frame is fixed at the base are shown in Figure 5 (a), (b), (c), (d). The accelerations for the fixed-base case increase almost linearly from the bottom of the frame to a maximum at the fifth floor and generally the maximum is roughly four times the table acceleration. Figures 4a and 5a show the accelerations in the frame when the El Centro signal is used. The maximum table acceleration is roughly 0.54g and the fifth floor acceleration for the fixed-base case is 1.9g. Each isolated case shows accelerations which are roughly constant with height and less than the table acceleration. The 50D bearings show accelerations of roughly 0.1g in the frame and adding the VAMAC inserts increases the acceleration only slightly. Adding the ADIPRENE inserts increases the accelerations to 0.12g and adding the lead inserts doubles the accelerations. Generally it can be said that the elastomeric inserts increase the accelerations slightly, but reduce relative displacements across the bearings. In the El Centro record the relative displacement is 2.6 in. (66 mm) with the unfilled 50D bearings, across the VAMAC filled bearings it is 2.3 in. (58 mm), and across the ADIPRENE filled bearings it is 1.5 in. (38 mm).

The 40D bearings show the greatest reductions in acceleration. The accelerations are 11% of the table input and 2.3% of the corresponding fifth floor acceleration in the fixed-base condition.

The results for the other records are similar. For the Parkfield signal, for example, the reductions are somewhat less than for the El Centro signal, but again the 50D bearings produce accelerations of 0.1g and the 40D bearings accelerations of 0.05g, but here the peak input is 1.75g,

so that the reductions over the fixed-base case are still substantial. For the Pacoima Dam record and the Taft record the reductions are greater than those for the Parkfield signal.

Bearing Response:

- (a) Unfilled and elastomer filled bearings

The bearings in the experimental program were mounted on shear load cells which record the shear forces experienced during a test. Relative displacement of the base frame with respect to the floor was also measured. The hysteresis loops generated by the bearings during a test can therefore be plotted. Examples for the unfilled and filled bearings during a large cycle of displacement in the El Centro record are shown in Figures 6 through 9. From these curves it is possible to estimate the equivalent linear viscous damping factor based on the ratio of the area of the hysteresis loop to the maximum stored energy. Denoting the area of the hysteresis loop by W_D and the maximum stored energy by W_s , the equivalent linear viscous damping factor ξ (i.e the ratio of the viscous damping coefficient to that for critical damping) for the fundamental isolated mode is given by $\xi = W_D / 4\pi W_s$. For the 40D bearings the damping is approximately 10% of critical, while for the 50D bearings with ADIPRENE inserts is 8% of critical and for the 50D bearings with VAMAC inserts the damping ratio is 10%. These damping ratios are consistent with those obtained from the pull-back tests which were found to be approximately 11%-13% of critical.

The measured damping in the structural system is, in each case, much higher than would be expected from the damping factor for the Neoprene itself. The damping factor $\tan \delta$ for both the 50A durometer and the 40A durometer hardness Neoprene was recorded as 0.1 at 11 Hz. A value of 0.1 for $\tan \delta$ translates into an equivalent viscous damping factor of 5% of critical in the fundamental isolated mode of the structure. Damping factors in Neoprene do not vary much with frequency and if at all decrease with decreasing frequency. The shear strains are very much larger in the bearings than in the dynamic testing of the rubber: at the maximum displacement of the 50D bearings in the El Centro signal, 2.6 in. (66 mm) the shear strain in the rubber exceeds 100%. The fact that the equivalent viscous damping ratio for the bearing with the ADIPRENE insert is due to the increase in frequency rather than to increased damping. The VAMAC inserts produce a 15% increase in stiffness and an increase in the energy dissipated but the damping ratio itself is unchanged.

The conclusion to be drawn from these results is that the inserts are not effective in reducing response. The effect of the ADIPRENE could be achieved more simply merely by using a larger bearing, while the influence of the VAMAC insert, although it does add some energy dissipation, is not significant. There

‡ Data obtained from Rhevibron (Toyo Baldwin Co. Ltd).

Fig. 5d Frame accelerations for Parkfield input signal showing fixed-base response.

Fig. 6 Hysteresis loops for 40D bearings, El Centro signal.

Fig. 7 Hysteresis loops for 50D bearings, El Centro signal.

EL CENTRO V=0, H=200 DUPONT FILLED

Fig. 8 Hysteresis loops for 50D bearings with ADIPRENE® inserts, El Centro Signal.

Fig. 9 Hysteresis loops for 50D bearings with VAMAC® inserts, El Centro signal.

810219.08 50D EL CENTRO V=0, H=300

Fig. 10 Hysteresis loops for 50D bearings under largest El Centro signal, showing reduced stiffness and increased damping.

Fig. 11 Hysteresis loop for isolation system with 50D bearings and two lead inserts.

Fig. 12 Normalized frame accelerations, showing increased isolation under increased earthquake intensity.

simply is not enough material in the insert to dissipate enough energy to produce a worthwhile change in the response.

The response of the 50D bearings without inserts was tested further to determine the limiting displacement to which the bearings could be subjected. The input signal was increased from a peak horizontal acceleration of 0.54g to 0.83g, which produced a maximum bearing displacement of 4.2 in. (107 mm): this displacement indicates a shear strain of 170% in the elastomer. The frame accelerations increased from 0.10g to 0.12g. Thus structural accelerations change only slightly with a large increase in earthquake intensity: the explanation for this is that the bearing properties are changing in a manner favourable to the protection of the structure. This characteristic of base-isolated systems makes them particularly attractive in situations where the earthquake input cannot be accurately defined, and is a further advantage over conventional approaches to earthquake-resistant design relying on structural ductility which are less immune to excitations grossly exceeding design levels. That the effective stiffness is reduced and the effective damping increased for these large bearing deformations is clear from the hysteresis loops shown in Figures 10 (a) and (b). The fattening of the loops at the large excursion is clear and in two bearings there is a reduction in stiffness. The two bearings with the reduced stiffness are those for which there is an increased compressive load due to the overturning moment. Although the overturning moment is small since the frame accelerations are small (the increase in bearing load is only 20%), the additional compressive load coupled to the large lateral displacement has a large effect on the horizontal stiffness.

(b) Lead-Filled Bearings

The response of the structural model on the lead-filled bearings is markedly different from that on the unfilled or elastomer-filled bearings. The lead appears to act as if it were almost rigidly perfectly plastic with a yield shear stress of approximately 1.4 kips/in² (9.6 kN/mm²). The response of the frame for very small input motion is thus similar to the fixed-base response, however as the intensity of the motion increases the effective stiffness drops and the amplification of the input acceleration is reduced. As the lead yields, significant energy dissipation occurs. In effect, the lead acts as a mechanical fuse and an energy dissipator, and the damping per cycle increases almost linearly with displacement. In this way the lead produces an almost ideal isolation system and combined with the compactness of the lead/bearing assembly produces a very effective system. A typical hysteresis loop for the lead-filled bearing system is shown in Figure 11.

The accelerations experienced by the frame on the lead-filled bearings are always less than the input accelerations for the comparison cases shown in Figures 4a through

4d. They are higher than for other foundation systems, but the relative displacements are lower. For the El Centro signal with a peak table acceleration of 0.54g, the frame accelerations (Figure 4a) are between 0.20 and 0.25g and the frame responds more or less as a rigid body. The relative displacement at the bearings is reduced to 0.86 in (22 mm) from 2.6 in. (66 mm) for the unfilled bearings.

The nonlinear response of the system and the increased isolation with increased input intensity is shown in Figures 11 and 12. To demonstrate this effect the model was subjected to a series of El Centro input motions with steadily increasing intensity from a peak acceleration of 0.115g to one of 1.46g. The maximum table displacement and acceleration produced by the shaking table can be varied by the span setting, which is directly related to the maximum table displacement. In this system, a peak table displacement of + 130 mm, which is the limit of table motion, is arbitrarily given a span setting of 1000. Lower span numbers correspond to proportionately lower peak table displacements. To demonstrate the increased isolation with increased intensity the accelerations in the frame have been plotted as normalized with respect to the peak table acceleration. The convergence to a reduction factor of 40% of the input acceleration is clear (Figure 12). A plot of normalized displacement, normalized fifth floor acceleration, and normalized base acceleration is shown in Figure 12, as a function of input span. It is interesting to note that while the accelerations decrease, the relative displacement remains almost exactly equal to the peak table displacement over the entire range of input.

CONCLUSIONS:

The experimental program has shown that the multilayer isolation bearings of polychloroprene can be effective in protecting buildings from damage by earthquake ground motion. The bearings are capable of sustaining a relative lateral displacement of 75% of their diameter without buckling and the material of sustaining a shear strain of 170% without failure. The reductions in maximum acceleration experienced by the superstructure as compared to conventionally designed structures vary with earthquake signal, but are not less than a factor of 10 and can be much higher.

The peak earthquake accelerations at which the above maximum deformations of the bearings were achieved were 0.835g. For most buildings and structures in California the peak design accelerations are not greater than 0.4g and in such cases a simple rubber bearing isolation system would suffice. At that level of peak earthquake acceleration the maximum relative displacement would be on the order of 6 in. (152 mm) for bearings with 10% of critical damping as in this study and around 8 in. (203 mm) if the bearings had a damping factor of only 5% of critical.

For nuclear plants the very low probability seismic events for which the plant must be designed could require a much higher design peak acceleration than

Fig. 13 Normalized relative displacement, showing increased isolation under increased earthquake intensity.

Fig. 14 Cost comparison of medical building with conventional construction and when isolated.

COST COMPARISON		ADD	DEDUCT
46 BASE ISOLATORS		\$46000	
RETAINING WALL 720'x10'x\$20		\$144000	
BASEMENT SLAB SEPARATION 240'x120'x\$2		\$57000	
MISC. OTHER		\$30000	
SEISMIC BRACING SHEAR WALLS 720'x73'x\$3			\$158000
FLOOR AND ROOF DIAPHRAGMS, CONNECTIONS 240x120x7x\$0.3			\$80000
CEILING BRACING 240x120x7x\$0.6			\$86000
BRACING MECHANICAL AND ELECTRICAL COMPONENTS			\$80000
		\$277000	\$384000
		\$ 384000	
		- \$ 277000	
SAVING : \$ 107000 PLUS COST OF BRACING LOOSE EQUIPMENT			

could be accommodated by a simple rubber bearing base isolation system. The energy-dissipating base isolation system in which rubber bearings and lead inserts are integrated then becomes an ideal choice for seismic protection. No other structural design strategy can simultaneously protect a structure at such earthquake intensities and limit the forces applied to sensitive internal equipment.

The seismic qualification of equipment has always been of concern in the design of critical components in nuclear power plants, but the design of equipment for seismic loading has become important in non-nuclear installations as well, the cost of internal equipment in, for example, a telephone exchange potentially being several times the cost of the building in which it is housed. The most compelling argument for base isolation may thus be the protection afforded internal equipment and piping. While the main structure of a building, power plant or hospital can be protected from the damaging effects of an earthquake attack with relative ease, the necessary strengthening of the main structure increases the seismic loads transmitted to nonstructural components and equipment. The response of non-structural components is determined primarily by the response of the primary structure to earthquake ground motion and not by the ground motion itself. The design process for components to be housed in conventionally founded structures is particularly difficult, complicated both by uncertainties in the specification of motion and by uncertainties about the properties of the primary structure. Such uncertainty can be avoided and safer design realized by the alternative approach of constructing buildings on base isolation systems such as those described above. The major benefit of base isolation to piping design is that, due to the fact that the primary structure above the isolation system moves as a rigid body, the displacement time histories of all support points of a piping system will be identical.

The effectiveness of base isolation on multilayer elastomeric bearings has been demonstrated by these and other experiments.

The experiments reported here on the multilayer elastomeric bearings with lead inserts are particularly relevant in view of the use of lead filled bearings in the new William Clayton building in Wellington. The practical implementation of this approach is a major step forward in anti-seismic design.

The remaining unanswered question in the implementation of base isolation is the cost. The bearings themselves are not expensive items, particularly if many are manufactured. Increased foundation costs are required mainly because of the need for a seismic gap around the structure. This would require the foundation pit to be surrounded by a retaining wall. The gap would be covered by an elastomeric seal and the foundation pit used for parking, for example, or mechanical purposes.

The savings on the other hand on the

construction of the superstructure could offset these increased costs. Seismic shear walls would be diminished and other structural elements reduced. Bracing for ceiling suspended components and for mechanical and electrical components would be reduced.

A study was carried out[‡] of the comparative cost of an isolated and conventionally founded six-storey medical building with roughly 170,000 square feet as shown in Figure 14. A potential savings using base isolation of \$US107,000 was estimated for the structural system alone. However, further savings could be possible since the major portion of the cost of a medical facility is in sensitive equipment. If this equipment must be braced or attached to walls in such a way as to protect it against earthquakes its mobility will be greatly reduced. Equipment that cannot be moved conveniently from one location to another within the building due to earthquake bracing will have to be replicated many times. Thus, it seems clear that base isolation must reduce the cost of buildings where the protection of equipment is paramount. Decreased costs with increased safety are the driving force behind all structural engineering research, but aseismic base isolation offers the best method for the achievement of these goals.

The full details of this testing program are available in Report UCB/EERC-81/16, Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley, October 1981.

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‡ A.S. Tarics, Reid and Tarics Associates, San Francisco.

	H Table Accel (g)	H Base Accel (g)	H Fl 5 Accel (g)	H Table Displ (in)	Rel Base Displ (in)	Base Shear (k)	V Table Accel (g)	V Fl 5 Accel (g)
Fixed Base	0.520	0.500	1.894	0.924	0.000	69.1	0.365	0.675
50/Lead	0.543	0.260	0.345	0.914	0.931	10.91	0.399	0.764
50/ADIPRENE®	0.553	0.235	0.408	0.914	1.509	8.01	0.400	0.752
50/VAMAC®	0.536	0.154	0.234	0.917	2.331	7.02	0.402	0.619
50 Durometer	0.562	0.171	0.208	0.914	2.362	7.13	0.415	0.664
40 Durometer	0.555	0.104	0.169	0.915	2.160	3.04	0.422	0.585

Table 1(a) El Centro input signal: V=200, H=200

	H Table Accel (g)	H Base Accel (g)	H Fl 5 Accel (g)	H Table Displ (in)	Rel Base Displ (in)	Base Shear (k)	V Table Accel (g)	V Fl 5 Accel (g)
Fixed Base	1.042	2.602	4.550	1.522	0.200	166.0	0.622	1.914
50/Lead	1.282	0.466	0.716	1.534	2.450	16.32	0.583	0.804
50/ADIPRENE®	1.319	0.190	0.358	1.527	2.672	10.39	0.589	0.667
50/VAMAC®	1.296	0.181	0.205	1.527	2.058	6.69	0.613	0.656
50 Durometer	1.287	0.210	0.220	1.523	2.011	6.22	0.557	0.638
40 Durometer	1.290	0.165	0.266	1.534	1.734	2.95	0.618	0.655

Table 1(b) Pacoima Dam input signal: V=200, H=300

	H Table Accel (g)	H Base Accel (g)	H Fl 5 Accel (g)	H Table Displ (in)	Rel Base Displ (in)	Base Shear (k)	V Table Accel (g)	V Fl 5 Accel (g)
Fixed Base	0.536	0.464	1.640	1.862	0.020	59.8	0.520	0.523
50/Lead	0.548	0.322	0.336	1.817	1.519	13.82	0.436	0.443
50/ADIPRENE®	0.546	0.244	0.230	1.806	2.761	10.96	0.441	0.523
50/VAMAC®	0.541	0.189	0.191	1.806	2.972	8.66	0.445	0.470
50 Durometer	0.527	0.173	0.225	1.804	3.430	8.03	0.404	0.480
40 Durometer	0.541	0.122	0.143	1.817	2.893	3.97	0.450	0.496

Table 1(c) Taft input signal: V=350, H=350

	H Table Accel (g)	H Base Accel (g)	H Fl 5 Accel (g)	H Table Displ (in)	H Base Displ (in)	H Fl 5 Displ (in)	Rel Base Displ (in)	Base Shear (k)
Fixed Base	0.379	0.861	1.810	1.526	1.692	3.178	0.117	66.0
50/Lead	0.377	0.320	0.361	1.508	2.053	2.374	1.878	14.43
50/ADIPRENE®	0.374	0.202	0.218	1.511	3.174	3.407	3.366	11.81
50/VAMAC®	0.370	0.117	0.123	1.513	2.410	2.542	2.629	7.33
50 Durometer	0.375	0.098	0.112	1.514	2.321	2.373	2.565	6.76
40 Durometer	0.378	0.052	0.067	1.511	1.426	1.489	2.771	3.28

Table 2(a) Parkfield input signal: V=0, H=300

	H Table Accel (g)	H Base Accel (g)	H Fl 5 Accel (g)	H Table Displ (in)	H Base Displ (in)	H Fl 5 Displ (in)	Rel Base Displ (in)	Base Shear (k)
Fixed Base	0.555	0.681	2.629	0.908	0.920	1.936	0.138	95.9
50/Lead	0.553	0.245	0.271	0.910	1.197	1.338	0.885	11.26
50/ADIPRENE®	0.531	0.119	0.134	0.915	1.695	1.822	1.480	7.98
50/VAMAC®	0.535	0.103	0.112	0.910	2.200	2.330	2.263	6.95
50 Durometer	0.534	0.100	0.110	0.909	2.255	2.306	2.589	6.63
40 Durometer	0.543	0.050	0.059	0.912	1.309	1.372	2.077	2.81

Table 2(b) El Centro input signal: V=0, H=200