QUANTIFYING THE EFFECTS OF SOIL-STRUCTURE INTERACTION FOR USE IN BUILDING DESIGN

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ABSTRACT

This research seeks to investigate the effects of soil-structure interaction (SSI) for regular buildings, validate current analysis techniques, and investigate the degree to which SSI contributes to the code based R factor for a variety of building and soil conditions. The research includes the analysis of strong motion records for 11 CSMIP building/free-field pairs to investigate the reduction in building response due to soil-structure interaction. The research also includes SSI analyses using the FLUSH computer program for four CSMIP buildings sites, comparison of recorded with model response, and comparison of the predicted base shear reduction using FLUSH and ATC 3-06 to the actual reduction recorded.

INTRODUCTION

The successful performance of buildings subjected to strong earthquake ground motions depends on their strength, the selected structural system and configuration, as well as the detailing and interconnection of the structural elements. Strong motion recordings taken during large earthquakes continue to show that properly designed buildings are capable of sustaining large recorded ground accelerations with little or no damage even though these motions far exceed their calculated strength. Recent experience in the Loma Prieta earthquake demonstrated that structures subjected to 30 to 40% g peak ground acceleration did not experience the kind of damage that would have been predicted using purely elastic analysis techniques.

Current seismic design provisions used in the United States include large reduction coefficients called R factors to account for this phenomena. These factors range in value from 1.5 to 12 and are used to define a suitable design base shear from an elastic response spectrum. From a structural design point of view, the key components making up the R factor include over-strength, redundancy, damping, multi-mode effects, system ductility, and soil-structure interaction (SSI). It is commonly recognized that extensive research is needed to justify and refine the arbitrarily established R values and tailor their use for new design.

It is often assumed that the motion experienced at the base of a building is the same as the free-field ground motion. This is only true if the structure is thought to be supported on soil which is rigid. For most soil conditions, the motions at the base of the building can be significantly different than in the free-field, and may even include a rocking component in addition to horizontal translational and vertical components [1]. This phenomena has been commonly termed soil-structure interaction.

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This research seeks to investigate the beneficial effects of soil-structure interaction for regular buildings, validate current analysis techniques, and investigate the degree to which it contributes to the code based R factor for a variety of building an soil conditions.

SUMMARY OF PREVIOUS WORK

Although the concept of soil-structure interaction has been in the literature for a number of years, most of the research has been centered on massive, concrete embedded structures such as nuclear reactors. The number of researchers investigating the response of conventional buildings, however, has been steadily increasing.

Seed, in his Nabor Cabrillo Lecture of 1986 [2], observed that the peak acceleration due to earthquake ground motion decreases significantly as the depth of the soil deposit increases. This was verified by records from a number of strong motion sites with downhole, vertical arrays of instruments such as the USGS instrument at Menlo Park, California, an array at Narimasu, Japan, and the EERC array at Richmond Field Station, California. As further evidence, a number of nearby pairs of buildings, each pair with one building constructed on the ground surface and one with a full basement, was compared by Seed and Lysmer [3] for peak ground accelerations during the San Fernando, California earthquake of 1971. In 7 of the 8 cases studied, the peak acceleration recorded at the base of the building with a basement was on the average about 27% less than the building founded on the ground surface. Seed neglected to add the case to the table of data presented where an increase was observed. He concluded that this reduction in pga with depth was "not a chance phenomena, but a pattern attributable to deterministic effects" [2].

Seed [2], also postulated that "inertial interaction tends to cause a slight reduction in the intensity of motions developed at the base of the structure compared with the intensity of motions developed in the free field... for most structures the effect will be small, of the order of about +10 to -20%." He based this observation not on building base shear reductions, but rather on a reduction in peak ground acceleration. This range of values for the amount of reduction due to SSI is similar to the range predicted by ATC 3-06, but has yet to be verified with a large amount of experimental data.

The effect of inertial soil-structure interaction on building response is well documented in ATC 3-06 [1], published by the Applied Technology Council in 1978 and based on the work of Valestos and others. A hand procedure based primarily on the period of the building, shear wave velocity and shear modulus of the soil, and foundation damping is discussed. In general, the ATC procedure shows that the effects due to SSI are small, on the order of +0 to -15% for most buildings. In addition, a number of limits are placed on the calculations so that the amount of reduction due to SSI is limited to -30%. For example, both the "effective" height and weight of the building are taken as 70% of the actual height or weight in the ATC 3-06 calculations. The procedure is based primarily on analytical solutions and classical mechanics and has been compared with only a few actual building records.

Fenves and Serino studied soil-structure interaction effects for the Hollywood Storage building in Los Angeles using the 1987 Whittier earthquake for their analysis [4]. They found that using a 3D finite-element model for the structure and using soil-springs to model the soil provided good results. In the conclusions, Fenves proposes, "a more detailed modelling of the foundation and soil, accounting for embedment, piles, and soil layers, may improve the correlation between the model and the recorded transfer functions, particularly in the short period range." [4]

INVESTIGATION OF REDUCED PGA WITH DEPTH

One of the basic parameters in judging the strength of earthquake ground motion is the peak ground acceleration (pga) at a free field or building site. The peak ground acceleration is the largest recorded acceleration (positive or negative) during an event at any time point in the record. Although caution should be used when comparing pga values since the values occur at different times for every record and often at very high frequencies, they are in general, a good indication of an earthquake's intensity.

Seed has found that one of the most influential parameters effecting the amount of reduction due to soil-structure interaction is depth of embedment of the structure. Seed suggested that the difference in pga between the ground and the basement can be used as a rough indication of the amount of reduction in motion due to SSI.

In Table 1, the peak ground accelerations at a number of CSMIP building sites are listed along with each corresponding free-field station. The records in the table are separated by those having basements (Table 1a) and those constructed on the ground surface (Table 1b). The data of buildings with basements is an extension of the work presented by Seed and Lysmer for the 1971 San Fernando earthquake but has a number of significant differences.

Table 1a compares peak ground acceleration values at the base of each building as compared to a nearby free field instrument whereas Seed and Lysmer used nearby pairs of buildings, one on the ground surface and one embedded. Now that the data is available, the use of free field stations is probably more appropriate since it more accurately represents the true response at the ground surface. The percent change surprisingly varies from -43.5 to +30.5%.

Seed and Lysmer used records with particularly strong shaking. On average, the ground motions they used had a pga of about 0.20g. Looking at Table 1a, a number of observations can be made. For small earthquakes, those with peak ground accelerations ≤ 0.8, the motions actually increased or stayed the same for buildings with basements (with the exception of the First Federal Savings Building in Pomona). For stronger earthquakes, Table 1a shows that buildings with basements generally show a reduction in motion, in some cases as much as 43.5% (First Federal Savings Building - Upland).

Looking at Table 1b, for buildings without basements, earthquakes with pga's ≤ 0.08 increase the motion at the base when compared to the free field (except for the 15-story Government Office building in Los Angeles and the Medical Office Building in Lancaster). Even with stronger shaking (pga ≥ 0.8), some buildings, including the 3-story Office building in San Bernadino as well as the 1-story Supermarket building in Fortuna, continue to show large increases in motion. In fact, the Imperial Valley County Services building had the largest increase in response, one of the largest ground pga values, and was the only building on the list that was severely damaged.

It is clear that the amount of reduction in peak ground acceleration is dependent on the soil conditions and the level of ground shaking experienced at a particular site. Reductions in the -40% range have occurred.

GROUND MOTION ANALYSIS

A ground motion analysis technique was developed to investigate the amount of reduction in response due to soil-structure interaction using simple tools, recorded strong motion records, and existing techniques. The analysis technique is predicated on pairs of records (building and free-field) for each earthquake to be investigated. Although CSMIP has many building instruments, only a small percentage have free-field instruments in close enough proximity to make this type of analysis. Because the response of many regular buildings is dominated by their fundamental mode of vibration, response spectra for the free field and for the building base were compared in the fundamental period range.

The first step was the determination of building period. For each building record in each principal direction, the fourier transform is taken of the time history at the roof and the time history at the base (see Figure 1). The roof spectrum is divided by the base spectrum to form a transfer function which is plotted against frequency. An example is shown in Figure 2 for the EW direction of Hollywood Storage building. The first peak is characteristically the building's fundamental frequency. This method was used by Cole et.al. in a recent CSMIP study on building periods [5].

It has been suggested that the building period will lengthen as an earthquake progresses and the building begins to yield. However, when the entire 30 to 40 second time history is used in the calculations of the transforms, this effect is lost. To accurately follow the change in building period over time, the time history was divided into a number of five second windows. The transfer function of roof/base fourier transform was computed for each time window and these were plotted together on one graph (see Figure 2). In this way, the period of the building during the time of strong ground shaking can be observed separately from the building period after the shaking has stopped and the building is vibrating harmonically. Note that the period of Hollywood Storage building started at 0.57 sec., lengthened to 0.66 sec., and then shortened to about 0.62 sec. (see Figure 2). The period used was typically the harmonic period of the structure after shaking had stopped. This was usually always close to the average period over the entire time history range.

After the building period has been determined, the response spectrum at the base of the building is plotted with the response spectrum for the properly rotated direction of the free-field on the same graph. If a line is drawn at the building fundamental period, a reduction in motion between the base and free-field curves can often be observed at or slightly above the building period (see Figure 3). This reduction can better be seen by dividing the base by the free-field response spectrums and plotting the spectral ratio. Frequencies with a spectral ratio below 1.0 show a reduction in spectral acceleration. At the building's fundamental period, this shows as a valley in the graph (see Figure 4). The results of each strong motion record investigated are shown in Table 2.

Looking at Table 2, the results for the reduction in building base motion vary considerably from a low of -40 to a high of +40%. However, a number of important observations can be made. The valley that occurs in the Hollywood Storage - EW record also appears in many of the other records with reductions that vary from -15 to -40%. However, in 9 of the 22 records studied, an increase in the response occurred. The same behavior seemed to occur for various sizes of earthquakes, soil conditions, and various types of construction. No trends are currently apparent. Also, there seems to be no correlation with the results shown in Table 1, even for the exact same building and earthquake.

SOIL-STRUCTURE INTERACTION ANALYSIS

In order to investigate the validity of current analysis techniques for conventional buildings, a number of sites were chosen for more detailed analysis. The four sites chosen, Richmond City Hall, Imperial Valley County Services building, Hollywood Storage building, and Hayward - 13-story CSUH Administration building, were selected to represent a variety of different building and soil types (see Table 2). The analysis procedure is based on the FLUSH soil-structure analysis program, using commercially available techniques and procedures.

The stick model is developed using a two-dimensional or three-dimensional full-frame SAP90 model of the building. The model is loaded with static unit loads and the displacements are computed. If the building is a stiff, shearwall building, like Richmond City Hall, the building is assumed to behave like a shear beam. The shear areas are backcalculated from the story shears and the displacements, and the moments-of-inertia are assumed to be very large. If the building is a more flexible moment frame building, like the Hayward - CSUH Admin. building, the building is assumed to act like a cantilevered frame. The shear areas and moments-of-inertia are backcalculated from the displacements and rotations at each story. The stick model is then checked against the full-frame model for proper modal behavior and matching displacements and fundamental period of vibration. Each building model is unique and care must be taken to accurately model each building as a multi-degree-of-freedom stick model.

The soil profile is developed from a geotechnical report utilizing logs of borings at the building site and shear wave profile where available. When possible, the data was based on borings that went down to bedrock. In many places however, such as the Los Angeles basin, borings stop well short of this depth. For these sites, an educated estimate of the shear wave velocity profile past the depth at which the borings stop was made.

The soil-structure interaction analysis developed for this study uses FLUSH, a SSI program developed by Lysmer et. al.[6]. The program uses a two-dimensional finite element mesh representing differing soil characteristics with depth and lateral extent, and can approximate the behavior in three-dimensions by the use of energy-dissipating dashpots in the out-of-plane direction. For buildings with basements, the basement condition was modelled as rigid. The soil finite element used in FLUSH incorporates non-linear material behavior. Each mesh was generated such that the model would be valid for frequencies up to 15 Hz. Since the motions in the soil are assumed to be vertically propagating S-waves, the influence of frictional piles, such as used for Hollywood Storage building, was neglected since they do not significantly influence the horizontal response motions.

The four buildings were analyzed in both principal directions except CSUH which is symmetric in both directions. The results of the seven soil-structure interaction analyses completed for this study are summarized in Table 3. In addition, the response spectrums for one direction of each building are plotted in Figures 5 through 8. On each graph is plotted the response spectrum for the recorded time history at the base of the building versus the corresponding response spectrum for the FLUSH analysis. Three other columns are included in Table 3 for comparison. The "Record" column shows the results of analyses of stick models using the response spectrum recorded at the base of the building as the input motion and calculating the reduction compared to the result using the free-field response spectrum as the input motion. The "ATC 3-06" column shows the amount of reduction calculated using the hand procedure in ATC 3-06. The "Other Studies" column shows the results of other SSI analyses which looked at the same buildings (Fenves and Serino [4]).

In some cases, the FLUSH procedure accurately captures the spectral shape at the base of the structure and the pga recorded at various levels in the superstructure for Hollywood Storage building, Richmond City Hall, and Hayward - CSUH Admin. building (see Figures 5, 7, and 8). However, for the Imperial Valley County Services building, the results of the FLUSH analysis are not in as good agreement with the recorded motions (see Figure 6). First, the motion at the base of the building is significantly higher than the free field motion over the entire period range. This is contrary to all other records we looked at for this study. It is unusual that the base of the building amplified the free-field motion even at very low periods (high frequency motion) which is usually not amplified by typical structures. Second, the computed building response using FLUSH is strongly influenced by the free-field control motion. The model is not able to reproduce the high spectral amplification in the period range between 0.2 to 0.5 seconds seen in the building base record. In addition, the results from the FLUSH analyses do not seem to correlate well with what is seen by the building strong-motion records.

The comparison of the results using FLUSH for Hollywood Storage building look very comparable to the results obtained by Fenves and Serino [4] (see Table 3). This suggests that for stiff, uniform sites with low to moderate levels of seismic excitation, the linear soil springs used by Fenves and Serino appear to be acceptable.

Looking at the "FLUSH" and "ATC 3-06" columns of Table 3, there appears to be reasonable correlation between the two analyses. For Richmond City Hall in the NS direction, Imperial County Services in the EW direction, and Hollywood Storage in both directions, the results are very good, within about 10% of each other. However, for Richmond City Hall in the EW direction, Hayward CSUH for both directions, and Imperial County Services in the NS direction, the hand procedure over-predicts the FLUSH analysis results. For a preliminary assessment, it appears that the ATC 3-06 hand procedures provide the right order of magnitude estimate of base shear reductions due to SSI for many sites. It is not surprising that reasonable correlation occurs between FLUSH and ATC 3-06 since both procedures are analytically based.

CONCLUSIONS

An analysis of strong motion records for 11 CSMIP building/free-field pairs to investigate the reduction in building response due to soil-structure interaction has been completed. Soil-structure interaction analyses using the FLUSH computer program for four CSMIP buildings sites, comparison of recorded with model response, and comparison of the base shear reduction using FLUSH with the results of stick models, an ATC 3-06 hand analysis, and previous analyses have also been completed. Based upon the data collected, the following observations were made:

(1) Buildings are not simple, static structures, but are complex and respond non-linearly during dynamic excitation. Soil-structure interaction is a complex phenomena and is difficult to predict. Both significant increases and significant decreases are observed.

(2) Seed and Lysmer's observations that there is a reduction of base motion expressed in terms of pga with increased depth seem to be generally true for regular buildings with basements when the pga during a strong motion event is greater than 0.1g. Unfortunately, there is little correlation between pga reductions and reductions in base shear.

(3) The building period changes with time and is difficult to pinpoint, particularly for

(3) The building period changes with time and is difficult to pinpoint, particularly for low-rise buildings. This makes the results from any analysis based on building period, and the results from our technique as well, more difficult to predict. It also make a change in the code, for example a reduction due to SSI based on building period, nearly impossible.

(4) Using the difference in recorded spectral accelerations to predict the amount of base shear reduction due to soil-structure interaction is not supported by the records studied.

(5) The FLUSH soil-structure models and procedure do not correlate well with the records studied.

(6) It is too early to propose any method to incorporate into building codes to account for soil-structure interaction. More research needs to be done utilizing the most recent CSMIP strong motion records for instrumented buildings.

(7) CSMIP should be encouraged to place free field instruments near instrumented buildings so we may obtain more data pairs and continue to investigate the effects of SSI on building response. Also, vertical instruments are needed at opposite sides of a building's base to monitor rocking in buildings where this might be anticipated.

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Buildings With Full or Partial Basements

Building	Earthquake	Maximum Acceleration		Percent change
		Base	FF	
Los Angeles - Hollywood Storage Building	Big Bear	0.03	0.03	0.0%
Pomona - First Federal Savings Building	Big Bear	0.03	0.03	0.0%
Los Angeles - 54-Story Office Building	Landers	0.04	0.04	0.0%
Los Angeles - 12-Story Commercial/Office	Landers	0.04	0.04	0.0%
Los Angeles - 52-Story Office Building	Landers	0.05	0.04	+25.0%
Los Angeles - 9-Story Office Building	Landers	0.05	0.04	+25.0%
Pomona - First Federal Savings Building	Whittier	0.05	0.07	-28.6%
Pomona - First Federal Savings Building	Landers	0.06	0.07	-14.3%
Hayward - 13-Story CSUH Admin. Building	Loma Prieta	0.09	0.08	+12.5%
Palm Springs - 4-Story Hospital	Big Bear	0.08	0.09	-11.1%
Palm Springs - 4-Story Hospital	Landers	0.06	0.09	-33.3%
Richmond - Richmond City Hall	Loma Prieta	0.12	0.13	-7.7%
Los Angeles - Hollywood Storage Building	Whittier	0.13	0.21	-38.1%
Pomona - First Federal Savings Building	Upland	0.13	0.23	-43.5%

TABLE 1a - Change in Maximum Acceleration Between Base of Building and Free Field

Buildings Constructed on Top of Ground Surface

Building	Earthquake	Maximum Acceleration		Percent change
		Base	FF	
Los Angeles - 15-Story Government Office Bldg.	Big Bear	0.03	0.04	-25.0%
Los Angeles - 15-Story Government Office Bldg.	Landers	0.03	0.04	-25.0%
Los Angeles - 17-Story Residential Building	Big Bear	0.04	0.04	0.0%
Los Angeles - 17-Story Residential Building	Landers	0.05	0.04	+25.0%
Lancaster - Medical Office Building	Whittier	0.06	0.06	0.0%
Sylmar - Olive View Medical Center	Landers	0.06	0.06	0.0%
Sylmar - Olive View Medical Center	Whittier	0.06	0.06	0.0%
Long Beach - Harbor Administration Building	Whittier	0.07	0.07	0.0%
Eureka - 5-Story Residential Building	Petrolia Aftershock #1	0.08	0.07	+14.3%
Lancaster - Medical Office Building	Landers	0.07	0.08	-12.5%
Piedmont - 3-Story School Building	Loma Prieta	0.08	0.08	0.0%
Palm Desert - 4-Story Medical Office Building	Landers	0.06	0.09	-33.3%
Palm Desert - 4-Story Medical Office Building	Big Bear	0.07	0.09	-22.2%
San Bernadino - 3-Story Office Building	Landers	0.11	0.09	+22.2%
San Bernadino - 3-Story Office Building	Big Bear	0.13	0.10	+30.0%
San Bernadino - 1-Story Commercial Building	Big Bear	0.06	0.12	-50.0%
San Bernadino - 9-Story Commercial Building	Big Bear	0.08	0.12	-33.3%
San Bernadino - 1-Story Commercial Building	Landers	0.09	0.12	-25.0%
San Bernadino - 9-Story Commercial Building	Landers	0.10	0.12	-16.7%
Fortuna - 1-Story Supermarket Building	Petrolia	0.14	0.12	+16.7%
Fortuna - 1-Story Supermarket Building	Cape Mendicino (87)	0.18	0.15	+20.0%
Eureka - 5-Story Residential Building	Petrolia	0.16	0.17	-5.9%
Fortuna - 1-Story Supermarket Building	Petrolia Aftershock #1	0.18	0.19	-5.3%
El Centro - Imperial County Services Building	Imperial Valley	0.35	0.27	+30.5%
San Jose - 3-Story Office Building	Loma Prieta	0.20	0.28	-28.6%
Hollister - 1-Story Warehouse	Loma Prieta	0.36	0.38	-5.3%

TABLE 1b - Change in Maximum Acceleration Between Base of Building and Free Field

Bldg. Name	Bldg. Type	Foundation Type	Site Geology	# Stories[1]	EQ	FF PGA	Dir	Bldg. Period	% change
Hayward - CSUH	Conc. MF	Bearing Piles	Franciscan rock	13/0	Loma Prieta	0.08	E	1.39	-20%
							N	1.39	-40%
Hollister Warehouse	Tilt-up w/ plywood roof	Spread footings	Alluvium	1/0	Loma Prieta	0.38	E	0.73	0%
							N	0.15	-15%
Piedmont Jr. High School	Conc. shearwalls	Spread footings w/ tie beams	Weathered serpentine	3/0	Loma Prieta	0.08	N	0.16	+20%
							E	0.16	-8%
Richmond City Hall	Conc. MF	Spread footings	Alluvium	3/1	Loma Prieta	0.13	S	0.29	+40%
							W	0.25	-20%
San Jose - Office Bldg.	Steel MF	Spread footings	Rock	3/0	Loma Prieta	0.28	W	0.71	-10%
							N	0.74	-13%
Lancaster - MOB	Masonry bearing walls	Conc. piers w/ grade beam	Alluvium	3/0	Whittier	0.06	E	0.12	-12%
							N	0.09	-42%
Long Beach - Harbor Admin. Bldg.	Steel MF	Bearing Piles	Deep alluvium	7/0	Whittier	0.07	N	1.20	+7%
							E	1.41	+5%
LA - Hollywood Storage Bldg.	Conc. shearwalls (EW)	Bearing Piles	Alluvium over shale & sndstone	14/ partial	Whittier	0.21	N	2.27	+6%
							E	0.60	-32%
Pomona - First Federal Savings	Conc. MF	Spread footings?	Alluvium	2/1	Whittier	0.07	W	0.27	-9%
							N	0.26	+1%
Sylmar - Olive View Medical Center	Conc. and steel shearwalls	Spread footings	Alluvium	6/0	Whittier	0.06	N	0.30	+34%
							E	0.27	+24%
Imperial Valley County Services Bldg.	Conc. shearwalls (NS)	Spread footings	Alluvium	6/0	Imperial Valley	0.27	N	0.50	+14%
							E	1.00	0%

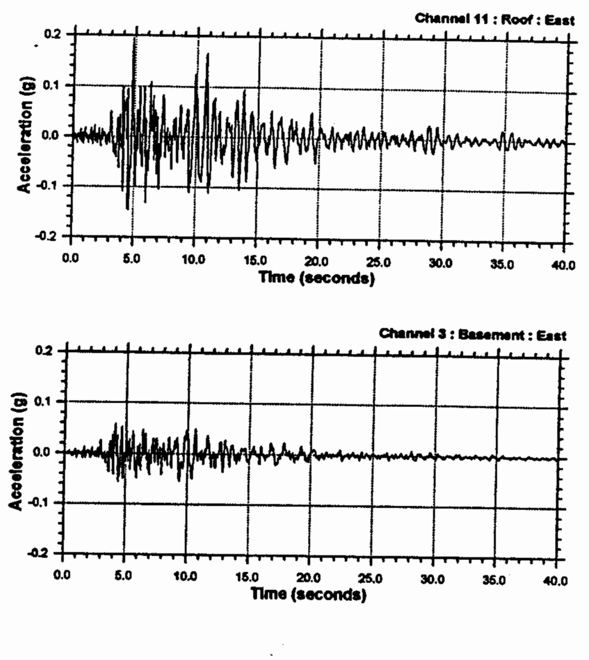
[1]Above ground/below ground

TABLE 2 - Comparison of Percent Reductions in Response

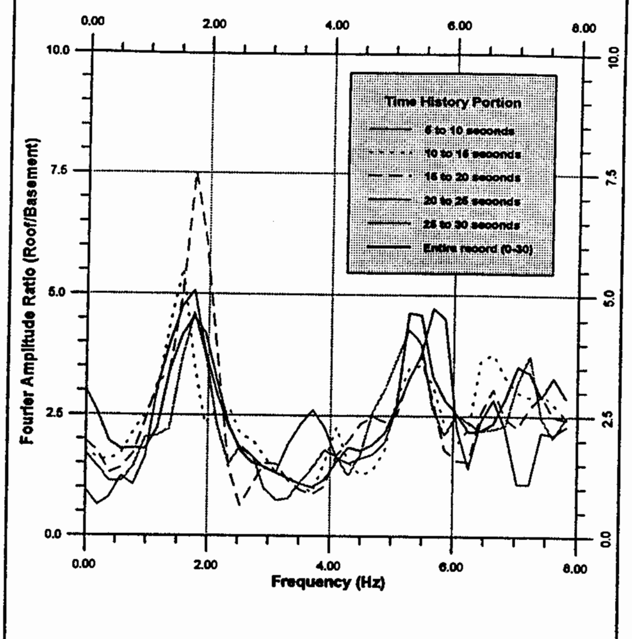
Building Name	Direction	Percent Reduction in Base Shear			
		Record	FLUSH	ATC3-06	Other Studies*
Richmond City Hall	NS	+7%	-20%	-25%	-
	EW	-28%	-16%	-30+%	-
Imperial County Services	NS	+5%	+4%	-15%	-
	EW				-
Hollywood Storage	EW	-34%	-15%	-15%	-17%
	NS	-4%	-2%	-8%	-3%
Hayward CSUH	NS/EW	-21%	+3%	-4%	-

* Fenves and Serino, "Evaluation of Soil-Structure Interaction in Buildings During Earthquakes."

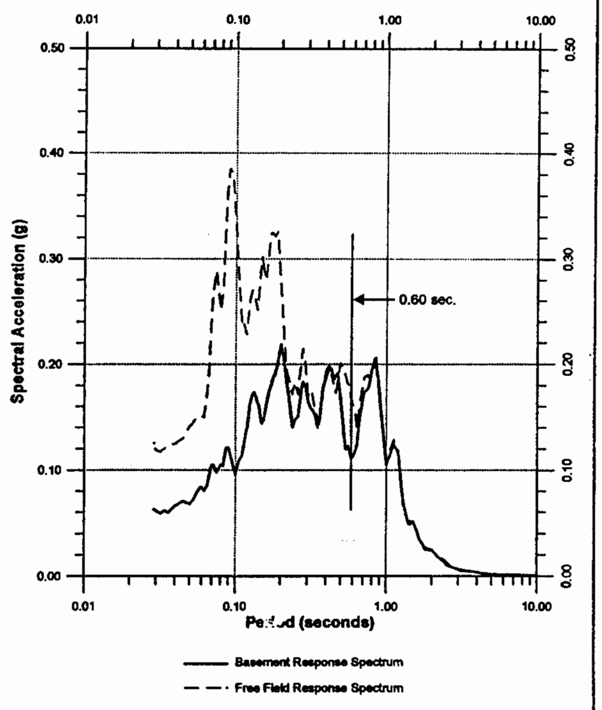
TABLE 3 - Reduction in Response Due to Soil Structure Interaction



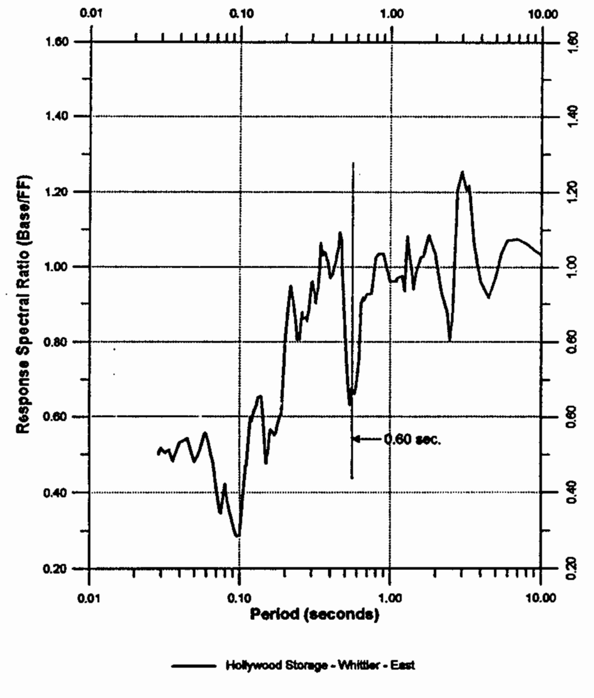
SMIP Directed Research Project | Poland, Mejia, Soulages, Sun | Corrected Time Histories - East-West Direction, Hollywood Storage Building, Whittier - 10/1/87 | Figure 1



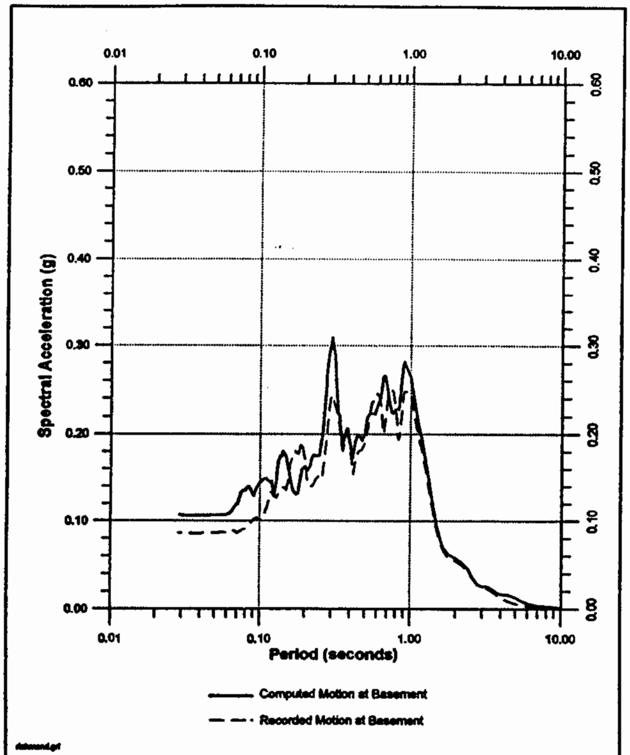
SMIP Directed Research Project | Poland, Mejia, Soulages, Sun | Fourier Aplitude Ratio, Hollywood Storage Building, Whittier - 10/1/87 - East | Figure 2



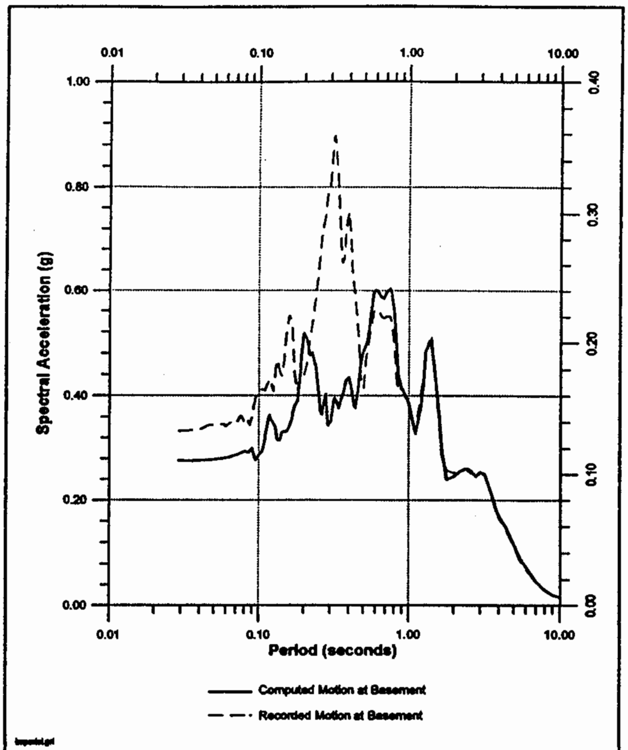
SMIP Directed Research Project | Poland, Mejia, Soulages, Sun | Response Spectrums, Hollywood Storage Building, Whittier - 10/1/87 - East | Figure 3



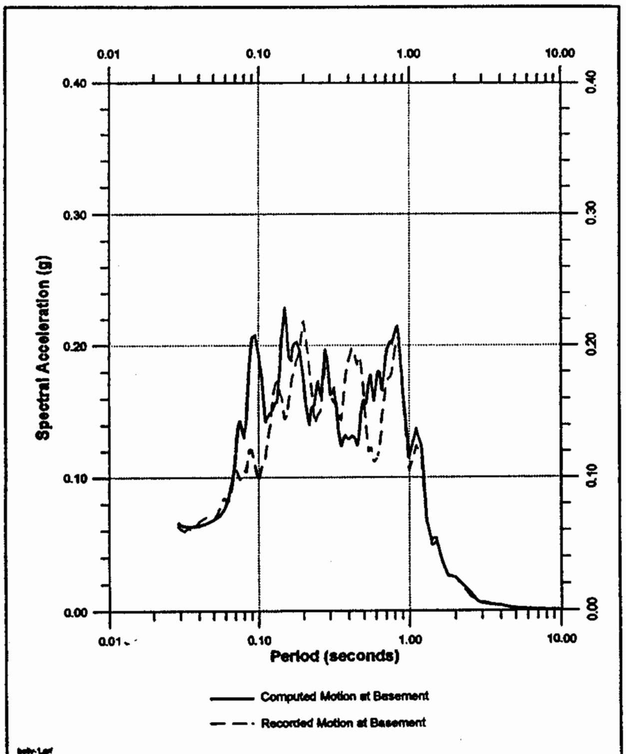
SMIP Directed Research Project | Poland, Mejia, Soulages, Sun | SSI Response Reduction, Hollywood Storage Building, Whittier - 10/1/87 - East | Figure 4



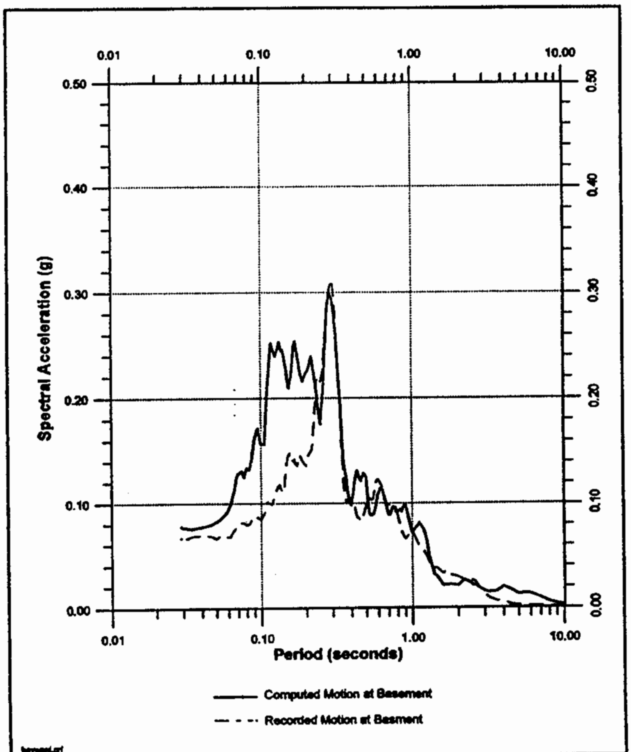
SMIP Directed Research Project	Response Spectrums Richmond City Hall Loma Prieta - 10/17/89 - West	Figure
Poland, Mejia, Soulages, Sun		5



SMIP Directed Research Project	Response Spectrums Imperial Valley County Sevices Bldg. Imperial Valley - 10/15/79 - East	Figure
Poland, Mejia, Soulages, Sun		6



SMIP Directed Research Project	Response Spectrums Hollywood Storage Building Whittier - 10/1/87 - East	Figure
Poland, Mejia, Soulages, Sun		7



SMIP Directed Research Project	Response Spectrums 13 Story CSUH Admin. Bldg. Loma Prieta - 10/17/89 - North	Figure
Poland, Mejia, Soulages, Sun		8