UTILIZATION OF CSMIP STRONG-MOTION RECORDS TO RATIONALIZE HORIZONTAL FORCE FACTORS (C_p)

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ABSTRACT

The California Strong Motion Instrumentation Program (CSMIP) of the Department of Mines and Geology has obtained and processed a number of significant building response records from its network of seismographs in California. This study was conducted using strong motion data to investigate the performance of nonstructural elements and building components under actual earthquake loadings and to improve the seismic provisions of the building codes. The study includes the analysis of building response records obtained primarily from the Loma Prieta earthquake of 1989.

INTRODUCTION

The seismic design of elements of structures and nonstructural components supported by structures is governed by the Uniform Building Code (UBC) and by the California Building Code, Title 24, Part 2 (CBC) for public school and hospital construction. The lateral design force, F_p, is determined by the product of Seismic Zone (Z), Importance Factor (I), the Horizontal Force Factor (C_p) and the weight (W_p). The current seismic demand values (C_p) are presented in Table No. 23-P of the 1991 edition of the Uniform Building Code (UBC-91).

In the current code formulation, the value of C_p is intended to account for several phenomena including:

- The response characteristics of equipment and components
- The frequency content of the input ground motion (for ground mounted items) or building motion (for items located above ground)
- The ductility and redundancy of equipment and components.

By relying on a simple factor (C_p) to account for these complex phenomena, the code approach makes broad assumptions on the behavior and response of elements and components. Furthermore, the code assigns a single value of C_p = 0.75 for seismic design of a wide variety of different items that may have significantly different response characteristics.

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The C_p values in Table 23-P have been selected based upon the judgement of experienced engineers. While there is no evidence to suggest that the current code approach is inadequate, a comprehensive technical rationale for this approach is lacking. Thus, the current code approach may be overly conservative in some cases and not conservative in others.

The purpose of this study is to examine the current code approach in light of actual strong motion data (building response and ground response) collected by CSMIP and the U.S. Geological Survey (USGS) during the Loma Prieta and Landers California earthquakes. These recorded motions will be used to determine the actual seismic demand on nonstructural components and equipment, both ground mounted and building mounted. The actual seismic demand determined in this manner will then be compared with the applicable code required demand. The study will identify variables which have an influence on the actual seismic demand and establish trends with these variables.

The study will also address the capacity, redundancy and ductility of nonstructural components and equipment. Since these are broad topics which require extensive work beyond the scope of this study, the objective here will be to quantify these phenomena to the extent possible using available data and information from post-earthquake damage reports made available to CSMIP.

The most important objective of the study is to combine experience data on seismic demand and capacity in order to propose an improved, rational approach for the seismic design of nonstructural components and equipment. Specifically, the objectives are to develop a new code format and to establish design parameters on a preliminary basis. These parameters would be subject to refinement and revision in the future as more strong motion data and other information becomes available on the seismic demand and capacity of nonstructural components and elements.

PROPOSED DESIGN FORMULATION

In general, a rational approach for the seismic design of nonstructural elements and building components may be expressed as follows:

$$F_p = \frac{S_a \cdot W_p}{R_c}$$

where

F_p = the total lateral force requirement

S_a = the first mode spectral acceleration of the item under consideration obtained from the design response spectrum

W_p = the weight of the item under consideration

R_c = a performance factor which reduces the actual seismic demand to a level compatible with elastic design methods.

In this general formulation, S_a would be obtained from a ground response spectrum for ground mounted items and from a floor response spectrum for floor mounted items. Within the context of UBC and CBC design methodology, the disadvantage of this general formulation is that neither ground response nor floor response spectra are typically available as part of the code design process. However, this problem can be overcome by defining a new seismic demand coefficient C_p' as follows:

$$S_a = PGA \cdot C_p'$$

where

PGA = the site peak ground acceleration (represented by the product $Z \cdot I$ for code design)

C_p' = seismic demand coefficient.

As suggested in the paper, values of C_p' can be obtained from interpretation of strong motion data. Given these definitions, the proposed formulation for design of nonstructural components and elements is as follows:

$$F_p = \frac{PGA \cdot C_p' \cdot W_p}{R_c}$$

or

$$F_p = \frac{Z \cdot I \cdot C_p' \cdot W_p}{R_c}$$

The primary purpose of this paper is to use strong motion data to determine typical values of C_p' and R_c.

DESCRIPTION OF STRONG MOTION DATA

The strong motion data used to accomplish the goals of this study consists primarily of ground response and building response records obtained and processed by CSMIP during the Loma Prieta earthquake of October 17, 1989 [1,2]. Two additional sets of response records obtained by CSMIP during the Landers earthquake of June 28, 1992 and one set of building response records obtained by USGS during the Loma Prieta earthquake were also used. A summary of this data is provided in Table 1.

The data used in the study consisted of corrected time histories and corresponding response spectra for 0%, 2%, 5%, 10%, and 20% of critical damping. In general, the records from each recording station includes 3 orthogonal components of ground motion at the basement or first floor level and horizontal components of building motion at intermediate floor levels above grade.

DETERMINING VALUES OF C_p' FROM STRONG MOTION DATA

The floor and ground response spectra described in the previous section may be used to determine values of C_p'. This can be accomplished recalling the previously defined relationship between S_a and C_p' and expressing these values as functions of equipment period, t:

$$S_a(t) = PGA \cdot C_p'(t)$$

or

$$C_p'(t) = \frac{S_a(t)}{PGA}$$

Thus, $C_p'(t)$ may be thought of as a nondimensional spectral shape or transfer function which, when multiplied by the PGA, gives the spectral ordinate as a function of period, $S_a(t)$.

In determining $C_p'(t)$ from strong motion data, it is important to consider 4 different circumstances: ground mounted items, floor mounted items, rigid items, and flexible items.

For ground mounted items, $C_p'(t)$ is appropriately determined using ground response spectra (GRS). In this case, $C_p'(t)$ strictly represents the dynamic amplification characteristics inherent in ground motion and depends primarily on earthquake magnitude, distance from fault, soil type, and period and damping of equipment.

For floor mounted items, $C_p'(t)$ is obtained from floor response spectra (FRS). In addition to the factors mentioned in the previous paragraph, $C_p'(t)$ for floor mounted items depend on the dynamic properties of the building in which the items are mounted, the location of the item within the building, and the period and damping of the item.

For design purposes, it is convenient to further simplify the formulation $C_p'(t)$ to eliminate the period dependence, the fundamental mode period of the nonstructural element or component under consideration. In general, designers will be unable to precisely define the periods of such items, so it makes little sense to develop a design procedure that is period dependent. A more simplistic approach is to define C_p' separately for rigid equipment and flexible equipment.

C_p' values for rigid equipment are determined from recorded response spectra by taking the maximum value of $C_p'(t)$ for $t \leq 0.06$ second.

To determine C_p' values for flexible equipment or component items mounted above grade within buildings it is necessary to consider the period of the item under consideration and the fundamental mode period of the building within which the strong motion data was recorded. The maximum values of C_p' would typically but not always occur when these periods are close or equal to each other. For the purpose of establishing simple and conservative design rules it is necessary to make an assumption about the relationship between the periods of equipment or components and the periods of the buildings within which these items are located. In this study it has been assumed all items that are considered "flexible" (i.e., nonrigid) have periods that correspond to the period range of the fundamental mode of the building. Specifically, it has been assumed that the period range of flexible equipment or components will be in the range of 0.6T to 1.4T where T is the fundamental mode period of the building. Using this period range is consistent with the 1991 NEHRP provisions [3].

To determine a single value for C_p' for flexible items, the values of the function $C_p'(t)$ was examined in the range $0.6T \leq t \leq 1.4T$. Within this range, the mean value and standard deviation of the function $C_p'(t)$ were identified, and the single value of C_p' were calculated as follows:

$$C_p' = \text{Mean } C_p'(t) + \text{One Standard Deviation of } C_p'(t).$$

C_p' computed as shown above was used in this study for flexible equipment located at roof level in buildings. For simplification of the C_p' derivation, a damping value of 5% of critical was used because it is approximately equal to the average of 2%, 5% and 10% which represents the dynamic characteristics of the majority of equipment and nonstructural components.

In order to determine the C_p' factor from measured records, the response period of the building within which the records were obtained must be ascertained. These periods were determined primarily from the 1992 CSMIP sponsored study where Cole, et al. [4] compared the building periods measured from earthquake recorded response to the UBC period formulation for the different types of buildings. Most of the buildings included in this study were also in Cole's work. Where the periods were not available from Cole or where other than the fundamental mode produced the largest C_p' value, the building periods were estimated for this study from CSMIP recordings. As part of this study it was acknowledged that for the long period buildings, the peak of the spectral value (and maximum C_p') may occur in higher modes, depending on the ground motion characteristics.

DETERMINING VALUES OF R_c FROM STRONG MOTION DATA

As previously defined, R_c for equipment and component items is a performance factor which reduces the actual earthquake demand to a level that is compatible with elastic design methods. R_c is similar to R_w used in the UBC formulation for seismic base shear in that R_c is intended to reflect the ability of equipment and components to adequately perform at levels of seismic demand that exceed their elastic design capacity. More specifically, R_c may be considered as the ratio between the ultimate or failure load capacity to the elastic design capacity as follows:

$$R_c = \frac{\text{Failure Load Capacity}}{\text{Elastic Design Capacity.}}$$

One way to establish R_c is by testing and analysis of equipment and components to establish the numerator and denominator of this ratio. If the code approach suggested in this paper is adopted, the manufacturers and suppliers of these items will eventually be encouraged to provide the necessary data for their products to establish these values. Until this is accomplished, it is possible to obtain a first estimate of R_c by considering the performance of equipment and components in buildings that were instrumented and subjected to strong earthquake motion (i.e., the buildings listed in Table 1).

If the post-earthquake investigation of such items revealed that an element or component was not damaged due to the strong motion recorded during the earthquake, one can conclude that the failure capacity equalled or exceeded recorded demand. If the post-earthquake investigation revealed that an element or component was damaged, it would indicate that the failure capacity was less than the recorded demand. Under this condition, the actual failure capacity must be determined based on the strength and dynamic properties of the item in question.

Although the damage from the Loma Prieta earthquake was extensive at many locations, damage to the nonstructural elements in those structures that were instrumented by the CSMIP strong motion instruments did not appear to be severe. From the post-earthquake investigation reports that were made available, the nonstructural components and equipment in the buildings that were instrumented by the strong motion recorders fared quite well and the damage to components and elements was quite limited. If it is assumed that the equipment was undamaged, this leads to the conclusion that the failure capacity of the equipment was equal to or greater than the earthquake demand. For the purpose of this study, it was assumed that the nonstructural items in the instrumented buildings were on the verge of failure during the earthquake motion for which the building response was recorded. This implies that the actual demand experienced by these items during the earthquake was equal to the failure capacity of these items. This is recognized as a potentially conservative assumption. If the actual failure capacity is much greater than the demand experienced during the recorded earthquake, this will lead to an underestimate of R_c.

To complete the determination of R_c it is necessary to quantify the elastic design capacity of the nonstructural items in the instrumented buildings. For this study it was assumed that the elastic design capacity was equal to the code design requirement (i.e., ZIC_p) that was applicable at the time the item was designed or installed. If one accepts the premise that the code is a minimum requirement, this assumption is potentially unconservative to the extent that the actual design capacity may have exceeded the code required strength.

Given these assumptions, the formulation of R_c from strong motion data may be expressed as follows:

$$R_c = \frac{\text{Failure Load Capacity}}{\text{Elastic Design Capacity}} = \frac{\text{Recorded Earthquake Demand}}{\text{Code Design Requirement}} = \frac{PGA \cdot C_p'}{Z \cdot I \cdot C_p}$$

where PGA and C_p' are as previously defined and are specific to each instrumented building record.

It is recognized that the formulation of R_c in this manner involves rather board assumptions, and there is no basis to believe that for any given component the conservative and unconservative aspects of the formulation will be self-canceling. However, it is reasonable to expect that the central trend of R_c can be established by examining and interpreting R_c as determined above from a large body of data. Nevertheless, R_c as indicated above was calculated and tabulated as part of this study.

INTERPRETATION OF DATA

Based on the above formulations, the C_p' and R_c factors were obtained using strong motion data from the instrumented buildings (Table 1) and the respective seismic design coefficients (Table 2). For the purpose of comparison, the largest values of C_p' and R_c for rigid and flexible items determined for each building are listed in Table 3. The values thus derived were essentially all from the motions at the roof.

For rigid items, the value of C_p' ranges from 1.72 to 4.63 with an average value of 2.90. It should be noted that these values approximately represent the amplification factor between the peak ground acceleration and the maximum floor (roof) acceleration. Both the range of values and the average is consistent with expectations and observations from previous earthquakes.

For flexible items, the value of C_p' ranges from 5.28 to 23.56 with an average of 11.58. These values indicate the potential for large response amplification if the component period coincides with the building period. The largest value has resulted from a response of one of the higher modes of a long period building. This points to the need for considering the contribution of higher mode response in the design of components and elements.

A revealing comparison is the C_p' ratio of flexible and rigid components which were observed from the analysis of these records. This ratio can be compared with the multiplier of 2 or 4 currently in the CBC for flexible items. Although the use of the factors is not based solely on the amplification alone, it is of value to look at the amplification that takes place in the buildings. The result is shown in Column 8 of Table 3. The ratios range from a low of 2.56 (Station 23) to a high of 6.32 (Station No. 17) with an average value of 3.90. A closer examination indicates that those stations with high ratios appeared to result on taller (long period) buildings where the largest C_p' for the building resulted from the response of higher modes, again pointing to the need to consider higher modes.

The R_c values in Table 3 are obtained by multiplying the C_p' by the PGA and dividing it by ZIC_p. For an initial comparison, the seismic design coefficients were all taken as equal with $ZC_p = 0.2$ and $I = 1$. For a comparison of the performance factor, the R_c for the rigid items ranges from a low of 0.69 to a high of 6.01 with an average value of 1.89. For the flexible items, R_c ranges from 2.05 to 18.75 with an average value of 7.10. These values may be somewhat misleading because not all of the components and elements were designed for the same seismic coefficients (i.e., $ZIC_p = 0.2$) and because the motion level for most of the buildings was not large enough to test the limit of the R_c value.

Upon closer examination of the data, only those buildings where the PGA was greater than 0.2g and the PFA was greater than 0.5g were studied (Table 4). For the rigid item condition, the R_c values range from 2.0 and 6.01 with an average of 3.21. For the flexible condition, R_c ranges from 6.15 to 18.75 with an average of 10.87. These values were calculated based on the seismic design coefficient, $ZIC_p = 0.2$.

To further refine these values, the seismic design coefficient used in the original design or for upgrade of a respective site was considered. The numerical value of the specific design or upgrade was available for some, others were more qualitative in nature. Therefore, the performance factor is discussed more in quantitative terms.

- Station 1: $R_c = 6.01$ and 18.75 for rigid and flexible items, respectively. The owner apparently performed a major upgrade of the facility several years before the Loma Prieta earthquake to comply with seismic requirements which were much higher than that required by the code, even for an essential facility. Based on discussions with the facility representative and assuming that the seismic design coefficient might have been greater than 1.0g, the revised R_c values would be 1.20 and 3.75 for rigid and flexible items, respectively. There was no apparent damage at this location. Equipment racks displaced more than a foot, but the function of the facility was not disrupted.

- Station 33: $R_c = 4.77$ and 15.90 for rigid and flexible items, respectively. Here also, the owner upgraded the equipment support in this facility before the Loma Prieta earthquake. The facility was upgraded for a seismic coefficient (ZIC_p) of 0.5g. The R_c values based on the actual design would be 1.91 and 6.36 for rigid and flexible, respectively. There were reports of limited minor damage at this facility (e.g., an expansion anchor failure due to an inadequate edge distance), but this was not in the building that was instrumented by the CSMIP.

- Station 14: $R_c = 3.18$ and 14.05 for rigid and flexible items, respectively. The building was designed and built after the San Fernando earthquake of 1971, but prior to the incorporation of new provisions for essential facilities into the code. However, special consideration was apparently taken into account in the form of additional bracing for equipment. Consequently, an importance factor of 1.5 was assumed. This results in the revised seismic design coefficient, $ZIC_p = 0.3g$, which reduces the R_c factors to 2.12 and 9.37 for rigid and flexible items, respectively. The reported damage included a fan unit pipe support, partition cracking, and a fallen suspended ceiling.

- Stations 2, 4 and 18: The buildings and their contents for these two stations were built a using seismic design coefficient (ZC_p) = 0.3; I is assumed to be 1.0 since the structures are not classified as essential facilities.

Taking these increased seismic design coefficients into consideration, the threshold level of performance factors were adjusted as shown on Table 4. These values range from 1.20 to 3.02 with an average value of 2.06 for rigid items and 3.75 to 9.85 with an average of 6.86 for flexible items.

The fourth column of Table 4 presents an amplification factor entitled Flex/Rigid. This amplification ratio ranges from 2.56 to 4.42 with mean value of 3.37. This amplification can be interpreted as a factor which relates the seismic demand for flexible items to the demand for rigid items mounted at the roof level. This amplification factor is somewhat comparable to C_p found in the codes for flexible versus rigid items. In the UBC this amplification is 2 whereas in the CBC the amplification is 4. The range of the data in Table 4 approximately covers the range of requirements between the UBC and CBC.

The factors derived in this study (C_p' and R_c for rigid and flexible items) will need considerable refinement and further research before they can be adopted into a new code requirement for design of components and elements. Nevertheless, it is of value to examine the proposed code format in light of the factors C_p' and R_c obtained by this study and to compare the resulting design requirement to current Code. For this purpose, the average values of C_p' and R_c obtained in this study are used:

	Flexible Items	Rigid Items
C_p'	11.58	2.90
R_c	6.78	2.06
C_p'/R_c	1.71 $\approx$ 1.75	1.41 $\approx$ 1.5

A comparison of the new proposed code format with UBC and CBC for items located above grade in a structure is presented below.

Proposed formulation:

Rigid Items: $$F_p = \frac{ZIC_p'W_p}{R_c} \approx 1.5ZIW_p$$

Flexible Items: $$F_p = \frac{ZIC_p'W_p}{R_c} \approx 1.75ZIW_p$$

Current Code Formulation:

Rigid Items: $F_p = ZIC_pW_p = 0.75ZIW_p$

Flexible Items: $F_p = 2ZIC_pW_p = 1.5ZIW_p$
(UBC)

Flexible Items: $F_p = 2ZIC_pW_p = 1.5ZIW_p$
(CBC - resonance prevented)

Flexible Items: $F_p = 4ZIC_pW_p = 3.0ZIW_p$
(CBC - resonance possible)

For rigid items, C_p'/R_c is 1.5, twice the applicable coefficient of 0.75 found in both codes. For flexible items, C_p'/R_c is comparable to the requirements of the UBC ($2C_p = 1.50 \leq 2.0$) and CBC (for flexible but restrained items). However, $C_p'/R_c = 2.0$ is less than the CBC requirements for flexible, unrestrained items ($4C_p \leq 3.0$) In this case, one may interpret the code to underestimate the seismic demand on flexible items install in public schools or hospitals.

However, R_c was based on the assumption that all the equipment anchorage in this study had reached the threshold of damage. Consequently, R_c was a lower bound. The method proposed herein is rational because it utilizes earthquake experience data to formulate an equivalent elastic seismic design coefficient, C_p'/R_c. However, because the ratio C_p'/R_c is highly sensitive to uncertainties in R_c, and due to the lack of abundant damage data, the result is considered inconclusive. Also, the formulation based primarily on the Loma Prieta data does not provide definitive conclusion to justify change of the current code formulation. The formulation for flexible items with several variables that influence the outcome requires closer examination. Based on the above results, it is recommended to view the conclusions herein as preliminary and the need for further research as imperative.

SUPPLEMENTAL PARAMETRIC STUDIES

Several other parameters were examined as part of this study in order to determine factors which influence C_p. The results of the studies are summarized below:

AMPLIFICATION AT VARIOUS FLOOR LEVELS: In addition to the amplification observed at the roof level in conjunction with the determination of C_p' and R_c, the amplification that takes place at other floors was studied. The result for rigid items is shown in Table 5A. There is a trend for an increase in amplification with height. The result is similar to the study by Drake and Gillengerten [5] performed on a larger sample of buildings and earthquakes, including some of the buildings considered in this study. A result from the study of flexible items is shown in Table 5B. A similar but larger amplification at essentially all levels was observed.

INFLUENCE OF STRUCTURE TYPE: Another set of parameters investigated include the characteristics of the buildings such as building height, lateral force resisting system, and construction materials. The amplification factors and the performance factors reported herein were correlated with the lateral force resisting system type and height of the buildings, as discussed below.

The buildings were grouped into two structural system types, namely moment resisting frames and shearwall structures. There were ten steel frame and one concrete frame buildings in the data set. For the shearwall buildings, there were twelve without frames and eight with frames. All of the buildings were evaluated in terms of the lateral force resisting system and building height. The results from this study showed very little correlation between the performance factors and the building classification.

INFLUENCE OF SOIL In addition to the soils information provided by CSMIP in association with its strong motion earthquake data, additional soils information was obtained by Geotechnical Consultants, Inc. [6]. The parameters studied were site geology, foundation type and soil profile. An attempt to correlate amplification and performance values with these foundation and soil data was not successful. Additional data from other earthquakes and additional data from free field station near the buildings may produce a better correlation.

CONCLUSIONS AND RECOMMENDATIONS

Based on the analyses of the structural response records from the Loma Prieta earthquake provided by CSMIP to rationalize horizontal force factors, the following conclusions and recommendations are made:

(1) The performance factors for the rigidly mounted elements and equipment appear to range between 2 and 4. For the flexible items, the factors range between from 6 to 12.

(2) The level of motion from the Loma Prieta earthquake for the buildings studied does not appear to be large enough to adequately test the appropriateness of the reported performance factors in the proposed code formulation. It would be of great value to apply this methodology to the Northridge earthquake experience records when the data becomes available. (Just prior to the submittal of this paper, strong motion records from the Sylmar hospital was made available. They are currently being studied for presentation at the SMIP94 seminar.)

(3) The amplification factors increase with building height. The amplification, using all of the data from this study, ranged from 1.17 to 4.63 with an average of 2.70 for the rigid condition and from 1.36 to 7.51 with an average of 3.94 for the flexible condition.

(4) The ratio of C_p'/R_c for rigid items was found to be twice the applicable C_p found in the codes (1.5 versus 0.75), implying that the code requirements for rigid items may be too low. On the other hand, C_p'/R_c for flexible items was found to be less than 2, compared to flexible, unrestrained items with $C_p \leq 3.0$ for CBC. However, the lack of abundant damage data suggests that additional data is necessary to reach a more definitive conclusion.

(5) The correlation was poor between the performance factors and the structure type and local geology.

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TABLE 1 - STRONG MOTION STATION INFORMATION
(CSMIP Loma Prieta Data, Unless Otherwise Noted)

Sta. No.	Building Name	Stories Above/Below	Structure Type	Distance (km)	Peak Horizontal Acceleration (g)	
					Ground	Bldg
1	Watsonville Commercial	4/0	RC-SW	18	0.36	1.20
2	Hollister Warehouse	1/0	Tilt-Up	48	0.36	0.50
3	Gilroy Commercial	2/0	URM-BW	28	0.29	0.60
4	San Jose Office	3/0	Stl-MRF	21	0.20	0.58
5	Saratoga Gymnasium	1/0	RC-SW	27	0.35	0.59
6	San Jose Residential	10/0	RC-SW	33	0.11	0.37
7	San Jose Commercial	10/0	RC-SW+MF	33	0.10	0.33
8	San Jose Govt Office	13/0	Stl-MRF	35	0.10	0.33
9	Palo Alto Office	2/0	RM-SW	50	0.21	0.40
10	Redwood City Office	3/0	RC-SW+MF	57	0.05	0.18
11	Belmont Office	2/1	RC-SW	65	0.11	0.19
12	San Bruno Office	9/0	RC-SW	81	0.11	0.32
13	San Bruno Office	6/0	RC-MRF	81	0.14	0.38
14	So. San Francisco Hospital	4/0	Stl-MRF	85	0.16	0.64
15	San Francisco School	6/0	RC-SW+MF	95	0.09	0.28
16	San Francisco Commercial	18/1	Stl-MRF	95	0.16	0.28
17	San Francisco Office	47/2	Stl-BF	96	0.16	0.46
18	Milpitas Industrial	2/0	Tilt-up	43	0.14	0.58
19	Hayward Office	6/1	RC-SW+MF	69	0.11	0.33
20	Hayward Office	13/0	Stl-MRF	70	0.08	0.24
21	Hayward School	4/0	RC-SW	70	0.05	0.13
22	Oakland Residential	24/0	RC-SW+MF	91	0.18	0.37
23	Oakland Office	2/0	RM-SW+MF	92	0.25	0.52
24	Piedmont School	3/0	RC-SW	93	0.07	0.15
25	Berkeley Hospital	2/1	StL-BF	97	0.12	0.28
26	Richmond Govt Office	3/1	RC-SW+MF	108	0.11	0.23
27	Richmond Office	3/0	Stl-MRF	112	0.11	0.31
28	Walnut Creek Commercial	10/0	RC-SW+MF	98	0.10	0.22
29	Pleasant Hill - Commercial	3/0	RC-SW	102	0.12	0.18
30	Concord - Residential	8/0	RM-SW	105	0.06	0.23
31	Palm Springs - Hospital*	4/1	Stl-MRF	43	0.07	0.21
32	San Bernardino - Hospital*	5/0	Stl-MRF	82	0.08	0.32
33	Palo Alto - Hospital**	7/1	RC-SW+MF	47	0.36	1.10

*-Landers Earthquake, **-USGS station, RC-Reinforced Concrete, Stl-Steel, SW-Shear Wall, URM-Unreinforced Masonry, BW-Bearing Wall, MF-Moment Frame, MRF-Moment Resisting Frame

TABLE 2 - SUMMARY OF SEISMIC DESIGN COEFFICIENTS

SUMMARY OF Z, I and Cp FACTORS							Partitions, ext. walls above ground, Masonry/conc. fences, Storage racks,cabinets,book stacks Suspended ceilings, access floors, Tanks and vessels, Mech/elec equipment		Cantilievered parapets, Ornamentations, appendages Chimneys, stacks, towers, tanks on legs, above roof Signs, billboards	
No.	Building	Stories	Building Type	Design Date	I	Z	C or Cp	ZC, ZCp or ZICp	C or Cp	ZC, ZCp or ZICp
1	Watsonville	4	Commercial	1948		4	0.05	0.2	0.25	1
2	Hollister	1	Warehouse	1979	1	1	0.3	0.3	0.8	0.8
3	Gilroy	2	Commercial	1916		4	0.05	0.2	0.25	1
4	San Jose	3	Office	1983	1	1	0.3	0.3	0.8	0.8
5	Saratoga	1	Gymnasium	1971		1	0.2	0.2	1	1
6	San Jose	10	Residential	1971		1	0.2	0.2	1	1
7	San Jose	10	Commercial	1964		1	0.2	0.2	1	1
8	San Jose	13	Office	1972		1	0.2	0.2	1	1
9	Palo Alto	2	Office	1973		1	0.2	0.2	1	1
10	Redwood City	3	Office	1967		1	0.2	0.2	1	1
11	Belmont	2	Office	1973		1	0.2	0.2	1	1
12	San Bruno	9	Office	1972		1	0.2	0.2	1	1
13	San Bruno	6	Office	1977	1	1	0.3	0.3	0.8	0.8
14	So. San Francisco	4	Hospital	1972		1	0.2	0.2	1	1
15	San Francisco	6	School	1968		1	0.2	0.2	1	1
16	San Francisco	18	Commercial	1964		1	0.2	0.2	1	1
17	San Francisco	47	Office	1978	1	1	0.3	0.3	0.8	0.8
18	Milpitas	2	Industrial	1984	1	1	0.3	0.3	0.8	0.8
19	Hayward	6	Office	1966		1	0.2	0.2	1	1
20	Hayward	13	Office	1969		1	0.2	0.2	1	1
21	Hayward	4	School	1961		1	0.2	0.2	1	1
22	Oakland	24	Residential	1964		1	0.2	0.2	1	1
23	Oakland	2	Office	1964		1	0.2	0.2	1	1
24	Piedmont	3	School	1973		1	0.2	0.2	1	1
25	Berkeley	2	Hospital	1964		1	0.2	0.2	1	1
26	Richmond	3	Office	1948		4	0.05	0.2	0.25	1
27	Richmond	3	Office	1984	1	1	0.3	0.3	0.8	0.8
28	Walnut Creek	10	Commercial	1970		1	0.2	0.2	1	1
29	Pleasant Hill	3	Commercial	1972		1	0.2	0.2	1	1
30	Concord	8	Residential	1974		1	0.2	0.2	1	1
31	Palm Springs	4	Hospital	1967		1	0.2	0.2	1	1
32	San Bernardino	5	Hospital	1986	1.5	1	0.3	0.45	0.8	1.2
33	Palo Alto	7	Hospital (Bldg. E)	1968		1	0.2	0.2	1	1

TABLE 3 - AMPLIFICATION AND PERFORMANCE FACTORS

Sta. No.	Name	T (sec)	PGA	PFA	C_p' (Rigid)	C_p' (Flex)	Flex/ Rigid	R_c** (Rigid)	R_c** (Flex)
1	Watsonville	0.35	0.36	1.20	3.34	10.43	3.12	6.01	18.75
2	Hollister	0.80	0.25	0.50	2.04	6.63	3.25	2.55	8.30
3	Gilroy	0.40	0.29	0.60	2.08	6.78	3.26	3.02	9.85
4	San Jose	0.69	0.18	0.55	3.09	11.88	3.84	2.78	10.70
5	Saratoga	0.18	0.24	0.46	1.93	5.47	2.83	2.32	6.55
6	San Jose	0.70	0.09	0.37	3.92	16.89	4.31	1.76	7.60
7	San Jose	0.8	0.10	0.33	3.28	14.81	4.52	1.64	7.40
8	San Jose	2.23	0.09	0.32	3.77	14.42	3.82	1.70	6.50
9	Palo Alto	0.34	0.21	0.40	1.90	5.88	3.09	2.00	6.15
10	Redwood City	0.17	0.05	0.18	3.56	14.89	4.18	0.89	3.70
11	Belmont	0.18	0.11	0.19	1.75	5.44	3.11	0.96	3.00
12	San Bruno	1.20	0.11	0.32	2.88	10.44	3.63	1.58	5.75
13	San Bruno	1.10	0.11	0.38	3.37	14.52	4.31	1.85	8.00
14	S. San Francisco	0.71	0.16	0.64	3.98	17.59	4.42	3.18	14.05
15	San Francisco	0.74	0.09	0.28	2.95	12.51	4.24	1.33	5.65
16	San Francisco	0.75	0.16	0.28	1.75	5.37	3.07	1.40	4.30
17	San Francisco	1.00*	0.10	0.46	3.73	23.56	6.32	1.87	11.80
18	Milpitas	0.20	0.14	0.58	4.13	16.86	4.08	2.89	11.80
19	Hayward	0.67	0.11	0.33	3.34	10.68	3.20	1.84	5.85
20	Hayward	0.43*	0.08	0.24	1.96	11.19	5.71	0.78	4.50
21	Hayward	0.22	0.05	0.13	2.57	12.38	4.82	0.64	3.10
22	Oakland	0.55*	0.18	0.37	2.12	6.16	2.91	1.91	5.55
23	Oakland	0.50	0.25	0.52	2.06	5.28	2.56	2.58	6.60
24	Piedmont	0.18	0.07	0.15	2.06	5.91	2.87	0.72	2.05
25	Berkeley	0.33	0.10	0.28	2.74	12.66	4.62	1.37	6.35
26	Richmond	0.33	0.11	0.23	1.82	6.86	3.77	1.00	3.75
27	Richmond	0.60	0.08	0.31	3.75	15.83	4.22	1.50	6.35
28	Walnut Creek	0.80	0.05	0.22	4.63	18.62	4.02	1.16	4.65
29	Pleasant Hill	0.38	0.08	0.13	1.72	6.57	4.82	0.69	2.65
30	Concord	0.74	0.06	0.23	3.94	18.24	4.63	1.18	5.45
31	Palm Springs	0.71	0.07	0.21	3.02	13.81	4.57	1.06	4.85
32	San Bernardino	0.50	0.08	0.32	3.95	16.86	4.27	1.58	6.75
33	Palo Alto	0.35	0.36	1.10	2.65	8.83	3.33	4.77	15.90

(*) - higher mode period, (**) - For $ZC_P=0.2$

TABLE 4 - AMPLIFICATION AND PERFORMANCE FACTORS

Sta. No.	Name	T (sec)	Flex/ Rigid	R_p** (Rigid)	R_o** (Flex)	Adjusted ZIC_p	Adjusted R_o (Rigid)	Adjusted R_o (Flex)
1	Watsonville	0.35	3.12	6.01	18.75	1.0	1.20	3.75
2	Hollister	0.80	3.25	2.55	8.30	0.3	1.70	5.53
3	Gilroy	0.40	3.26	3.02	9.85	0.2	3.02	9.85
4	San Jose	0.69	3.84	2.78	10.70	0.3	1.85	7.13
5	Saratoga	0.18	2.83	2.32	6.55	0.2	2.32	6.55
9	Palo Alto	0.34	3.09	2.00	6.15	0.2	2.00	6.15
14	S. San Francisco	0.71	4.42	3.18	14.05	0.3	2.12	9.37
18	Milpitas	0.20	4.08	2.89	11.80	0.3	1.93	7.33
23	Oakland	0.50	2.56	2.58	6.60	0.3	2.58	6.60
33	Palo Alto	0.35	3.33	4.77	15.90	0.5	1.91	6.36

(**) - For $ZC_P=0.2$

TABLE 5 - AMPLIFICATION AT VARIOUS LEVELS

(A: RIGID ITEMS)

	BASE	0.25H	0.50H	0.75H	H
AVERAGE VALUES	1.0	1.38	1.68	1.85	2.70
MAXIMUM VALUES	1.0	2.17	2.97	3.74	4.63
MINIMUM VALUES	1.0	0.87	1.01	1.03	1.17

H = Height of building.

(B: FLEXIBLE ITEMS)

	BASE	0.25H	0.50H	0.75H	H
AVERAGE VALUES	1.0	1.55	2.25	2.79	3.94
MAXIMUM VALUES	1.0	2.95	5.02	6.01	7.51
MINIMUM VALUES	1.0	0.86	1.01	1.00	1.36

H = Height of building.