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ESTIMATION OF STRENGTH REDUCTION FACTORS FOR ELASTOPLASTIC STRUCTURES: MODIFICATION FACTORS.

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SUMMARY

Strength reduction factors which permit the estimation of strength demands of multi-degree-of-freedom (MDOF) systems from strength demands of single-degree-of-freedom (SDOF) systems are evaluated. The study is based on the computation of modification factors for ten steel moment resisting frame buildings undergoing different levels of inelastic deformation when subjected to 92 earthquake ground motions. The ground motions used were recorded on different soil conditions corresponding to firm (site classes A, B, C and D according to the 1997 NEHRP Provisions) and soft sites. The influence of four main parameters was studied: (1) multimode effect and heightwise variation of ductility demand; (2) heightwise and fundamental period variation of modification factor, (3) soil conditions and (4) level of inelastic deformation of the structure. It is concluded that the modification factor is primarily affected by the level of inelastic deformation; there is small effect of the site type on the mean amplification factor (even for soft soils); the multimode effect (mainly the first two modes) has a significant influence on the modification factor for longer-period elastic buildings and decreases with inelastic behavior. Although this multimode effect has influence on certain cases, heightwise variation gives a better representation for the modification factor. Inelastic MDOF systems attracts more base shear than their corresponding SDOF systems (period equal to MDOF system fundamental period) and an opposite effect is observed for elastic systems. Two simplified expressions proposed to estimate the modification factor are presented.

INTRODUCTION

Most buildings are designed for a base shear smaller than the elastic base shear associated with strong ground shaking, expecting them to deform beyond elastic behavior. Seismic codes allow reduction in design forces produced by nonlinear behavior, accounted for in force-based earthquake resistant design, through the use of strength reduction factors. The strength reduction factor due to nonlinear behavior for SDOF systems, R_μ, corresponds, for design purposes, to the maximum reduction in strength in order to limit the displacement ductility demand to the predetermined maximum tolerable ductility in a structure that will have a lateral strength equal to the design strength. This reduction factor has been the object of several studies, resulting in a better understanding of its behavior, but few studies have been presented for strength reduction factors of MDOF systems.

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The strength reduction factor or modification factor of MDOF systems, R_M , modifies the base shear yield strength of a SDOF system in order to obtain the base shear yield strength of a MDOF structure to ensure that the maximum story displacement ductility demand does not exceed the allowable ductility of the MDOF system; both systems should have the same fundamental period.

Most of the studies about strength reduction factors of MDOF systems reach to similar conclusions: 1) the relationship between the required yield deformation and the absolute maximum deformation of the associated linear system may be considered for systems having two or three degrees of freedom, the same as for a SDOF system with the same fundamental period (Veletsos and Vann [12]) ; 2) for systems of more than two degrees of freedom, story ductility demands differ significantly from those corresponding to SDOF systems with the same fundamental period (Veletsos and Vann [12], Nassar and Krawinkler [7]); 3) the maximum story ductility demand for MDOF systems and its deviation is higher than the target ductility ratio of the first mode SDOF system and increases with period and ductility ratio (Nassar and Krawinkler [7], Seneviratna and Krawinkler [10]); 4) the required strength for specified target ductility ratios depends strongly on the type of failure mechanism, multimode effects and heightwise variation of ductility demand (Seneviratna and Krawinkler [10], Chopra [2]). 5) the earthquake magnitude, distance from the epicenter, peak ground acceleration and duration do not affect significantly the modification factor (Bazzurro and Cornell [1]).

The objective of this paper is to present part of the results of a study on strength reduction factors of MDOF systems. Structural models used for this study reproduce moment-resisting frame buildings realistically, in order to obtain a better understanding of the MDOF system and investigate the dispersion on the relationship between the base shear demands on SDOF to MDOF structures. Another aim of the study is to provide modification factors on lateral strength demands derived from SDOF systems in order to estimate lateral strengths required for MDOF structures in order to control maximum story displacement ductility demands when subjected to strong ground motions, and incorporate these factors in the inelastic design of multistory buildings.

STRUCTURAL MODELS, GROUND MOTIONS AND METHOD OF ANALYSIS

Structural Models

Ten steel moment-resisting frame (SMRF) buildings with 4, 8, 12, 16 and 20 stories were considered in this study. The structural plan is the same for all buildings, as shown in Figure 1. All buildings were assumed to have a non-uniform lateral stiffness distribution and a uniform mass distribution over their height. Steel members design was performed according the lateral load distribution of the UBC-1994 [11]. Member stiffnessess were determined in order to obtain representative fundamental periods of vibration for each building similar to the period of earthquake records of instrumented existing SMRF buildings. Each member section was selected according to resistance design of strong-column/weak-beam behavior; however, hinge formation at columns can be expected and ductility demands could change along the height of the buildings.

Two different fundamental periods were assigned to each building with the same height; buildings with fundamental period given by T = 1.78 x 0.0853 $h_n^{3/4}$ where h_n is the total height of the building in meters (or T = 1.78 x 0.035 $h_n^{3/4}$ when h_n is given in feet) were considered as flexible MDOF systems and buildings with fundamental period given by T = 1.07 x 0.0853 $h_n^{3/4}$ (or T = 1.07 x 0.035 $h_n^{3/4}$ when h_n is given in feet) were considered as rigid MDOF systems. These fundamental periods provide upper and lower bounds of those obtained from instrumented SMRF buildings in California [5]. It is important to note that the resulting flexible MDOF buildings barely satisfy the maximum story drift limitations of the UBC-94 when subjected to lateral loads corresponding to zone 4. On the other hand, rigid MDOF buildings barely satisfy the maximum story drift limitations of the Mexico City Seismic Code [3] when subjected to lateral loads corresponding to soft soil of Mexico City.

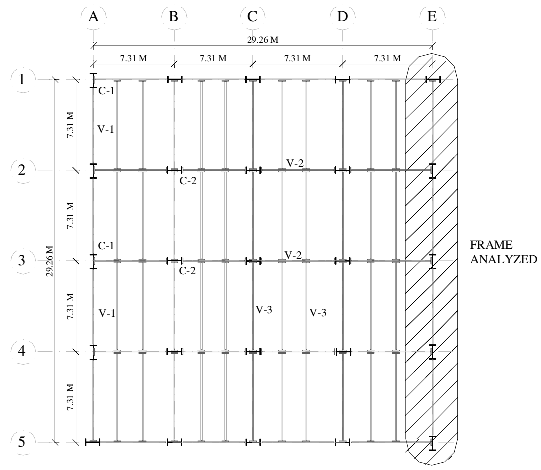

Figure 1. Structural Plan View of the multi-story buildings used in this study.

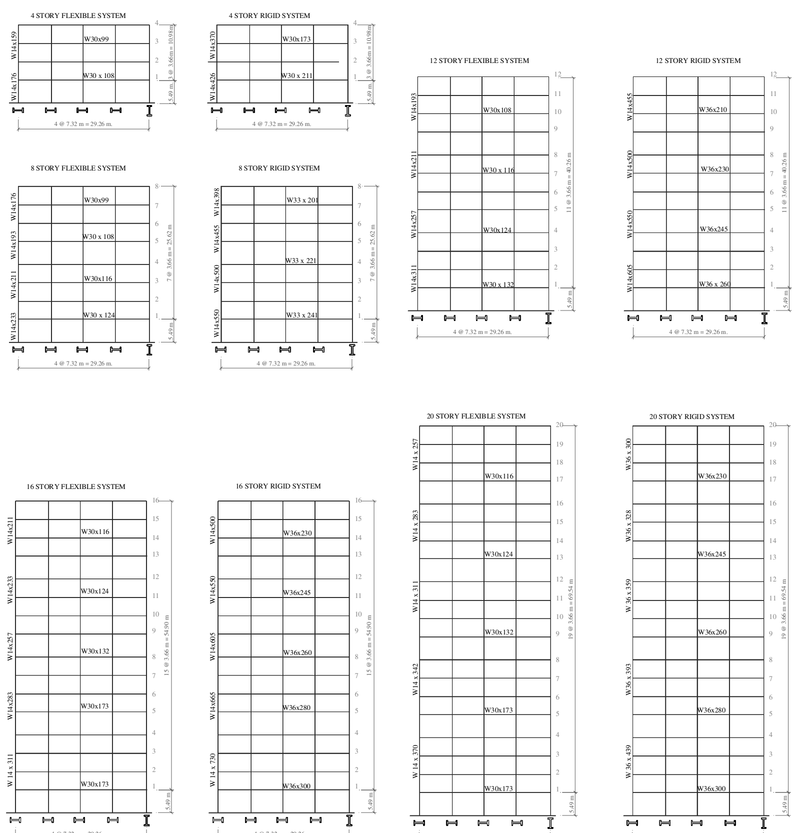

Figure 2. Analyzed frames for flexible and rigid buildings.

Analyzed frames are shown in Figure 2; it is shown in each frame the steel section for beams and columns for different levels. The dynamic characteristics for each system are shown in Table 1, such as the fundamental and second mode periods of vibration, the first and second mode effective modal mass normalized by the total mass of the system, the ratio of the base shear yield strength to the weight of the structure and the ratio of the roof lateral displacement to the total height of the structure. These last two ratios were calculated with a pushover analysis with a elasto-plastic behavior.

An equivalent SDOF system was defined for each analyzed frame; these SDOF systems have the same weight and fundamental period of their respective MDOF.

Table 1. Dynamic properties of studied MDOF systems.

System	T_1 (s)	T_2 (s)	M_1 / M_T	M_2 / M_T	V_{by} / W	γ_{yroof} (%)
4 story flexible	1.27	0.39	0.94	0.05	0.30	1.03
4 story rigid	0.77	0.25	0.93	0.06	0.86	0.91
8 story flexible	2.02	0.68	0.88	0.08	0.21	0.90
8 story rigid	1.19	0.40	0.88	0.09	0.42	0.70
12 story flexible	2.68	0.93	0.84	0.11	0.15	0.87
12 story rigid	1.63	0.56	0.84	0.11	0.33	0.74
16 story flexible	3.26	1.15	0.82	0.12	0.15	0.96
16 story rigid	1.97	0.68	0.83	0.11	0.33	0.82
20 story flexible	3.84	1.34	0.81	0.13	0.13	0.98
20 story rigid	2.37	0.79	0.78	0.13	0.26	0.69

Ground Motions.

All analyzed frames were subjected to 92 strong ground motion records as listed in Tables 2 and 3. The first data set shows on Table 2 includes ground motions from 46 strong ground motion stations recorded on different soil conditions corresponding to rock and firm sites corresponding to site classes A,B, C and D according to NEHRP Provisions,1997 [4].

The second set presented on Table 3 includes 46 strong ground motions recorded on soft soils corresponding to the Lake Zone with site class III of the Mexico Federal District Code, 1987.[3]. The main purpose of selecting 4 different soil conditions was to verify the effect of the modification factor in each type of soil and state a general conclusion.

Method of Analysis.

The base shear yield strength required for a SDOF system to not exceed the maximum allowable ductility is estimated as

$$V_{SDOF}(\mu = \mu_i) = \frac{V_{SDOF}(\mu = 1)}{R_\mu} \tag{1}$$

where $V_{SDOF}(\mu = 1)$ is the base shear yield strength required to maintain the SDOF system elastic and R_μ is the strength reduction factor derived from SDOF systems.

For multistory buildings the lateral strength required to avoid story displacement ductility demands larger than the maximum allowable ductility, μ_i can be estimated from

Table 2. Set of ground motions recorded on rock and firm sites.

Earthquake	Station Name Location	Epicentral distance	Magnitud M_s	Components and Maximum Accelerations				Site class NEHRP
Loma Prieta	Gilroy 1, Gavillan Coll.	10.90	7.1	90	433.6	360	426.6	A,B

Northridge	Los Angeles, Gritfith Park	24.50	6.8	360	162.9	270	282.1	A,B
Whittier	Los Angeles, Gritfith Park	22.30	6.1	0	-133.8	360	-121.4	A,B
Loma Prieta	San Francisco, Cliff House	87.40	7.1	0	-73.1	90	-105.7	A,B
Loma Prieta	San Francisco, Pacific Heights	81.20	7.1	270	60.2	360	46.3	A,B
Loma Prieta	Point Bonita	88.10	7.1	297	71.4	207	69.9	A,B
San Fernando	Los Angeles, Gritfith Park	21.00	6.5	180	183.7	270	173.7	A,B
Whittier	Garvey Reservoir Abutment	11.30	6.1	60	-367.1	330	-468.2	C
Northridge	Castaic Old Ridge Route	38.62	7.5	360	504.2	90	557.1	C
San Fernando	Glemdale, 633 E. Broadway	18.00	6.5	110	265.7	200	-209.1	C
Loma Prieta	Corralitos, Eureka Canyon	2.20	7.1	90	469.4	360	617.7	C
Loma Prieta	Saratoga, Aloha Ave.	12.40	7.1	90	316.2	0	494.5	C
Loma Prieta	Woodside, Fire Station	39.40	7.1	90	79.7	0	79.5	C
Kern County	Santa Barbara, Courthouse	85.00	7.7	42	-87.8	132	128.6	C
Imperial	El Centro, Parachute Test	15.00	6.8	225	106.9	315	200.2	C
Kern County	Los Angeles, Hollywood	107.00	7.7	90	41.2	180	-58.1	D
Loma Prieta	Gilroy 2, Hwy 101 Bolsa	12.60	7.1	90	316.3	0	394.2	D
Northridge	Los Angeles, Hollywood	22.53	6.8	360	381.4	90	227.0	D
San Fernando	Los Angeles, Hollywood	23.00	6.5	90	-207.0	180	167.3	D
Whittier	Vernon, Cmd Terminal	11.10	6.1	7	-267.3	277	-239.9	D
Imperial	El Centro #4, Anderson Road	7.00	6.8	140	483.6	230	-349.7	D
Imperial	El Centro #7, Imperial Valley	1.00	6.8	230	453.7	140	326.8	D
Imperial	El Centro #6, 551 Huston	1.00	6.8	140	-368.7	230	-428.1	D

Table 3. Set of ground motions recorded on soft sites.

Ground Motion Date	Station Name Location	Epicentral distance km	Magnitude M_s	Components and Maximum Accelerations			
25-april-89	CENTRO (ALAMEDA)	10.90	6.9	NS	-45.75	EW	37.43
25-april-89	ROMA NORTE	24.50	6.9	NS	-40.62	EW	37.28
25-april-89	ROMA (LAS CIBELES)	22.30	6.9	NS	54.40	EW	46.31
25-april-89	XOCHIPILLI	87.40	6.9	NS	43.55	EW	57.00
25-april-89	TLATELOLCO	81.20	6.9	EW	47.31	NS	32.35
24-october-93	TLATELOLCO	88.10	6.6	EW	8.10	NS	-8.37
25-april-89	VALLE GOMEZ	21.00	6.9	EW	47.09	NS	-38.29
25-april-89	MEYEHUALCO	11.30	6.9	EW	29.69	NS	54.55
25-april-89	PCC SUPERFICIE	38.62	6.9	EW	43.09	NS	42.35
25-april-89	VILLA DEL MAR	18.00	6.9	EW	-47.35	NS	49.57
25-april-89	BUENOS AIRES	2.20	6.9	EW	-58.89	NS	54.41
25-april-89	CORDOBA	12.40	6.9	EW	-39.09	NS	72.99
25-april-89	SCT (B2)	39.40	6.9	EW	-37.12	NS	37.50
19-sept-85	SCT (B2)	85.00	8.1	EW	167.91	NS	97.64
24-october-93	SCT (B2)	15.00	6.6	EW	10.96	NS	10.87
10-dic-94	ROMA (LAS CIBELES)	107.00	6.3	N90E	-9.57	N00E	-8.13
23-may-94	ROMA (LAS CIBELES)	12.60	6.3	N90E	-11.96	N00E	13.88
23-may-94	LA VIGA	22.53	6.3	N90E	4.90	N00E	5.86
23-may-94	SCT (B1)	23.00	6.3	N90E	5.74	N00E	5.26
10-dic-94	SCT (B1)	11.10	6.3	N90E	13.40	N00E	-10.77
7-june-92	TLATELOLCO	7.00	5	N90E	2.98	N00E	2.97
15-may-93	UAM IZTAPALAPA	1.00	5.8	N90E	8.57	N00E	5.95
24-oct-93	UAM AZCAPOTZALCO	1.00	6.6	N00E	7.51	N90E	5.98

$$V_{MDOF}(\mu = \mu_i) = \frac{V_{SDOF}(\mu = 1)}{R_\mu \, R_M} \tag{2}$$

where R_M is the modification factor that takes into account the difference in lateral strength demands in MDOF structures to SDOF structures given by

$$R_M = \frac{V_{SDOF}(\mu = \mu_i)}{V_{MDOF}(\mu = \mu_i)} \qquad (3)$$

This modification factor was evaluated for six target ductility ratios: 1, 1.5, 2, 3, 4 and 5. It was evaluated using the following methodology:

1. $V_{MDOF}(\mu = \mu_i)$ was computed by scaling the intensity of the ground motion until the maximum story displacement ductility ratio in the MDOF structure was, within a 1% tolerance, equal to the target ductility. The scaling factor was obtained by an iterative procedure using Drain 2DX [8].
2. $V_{SDOF}(\mu = \mu_i)$ was computed by iteration on the lateral strength of the SDOF system when subjected to the same ground motion and scale factor of the previous step until the displacement ductility ratio in the MDOF structure was, within a 1% tolerance, equal to the target ductility.

RESULTS.

General response for modification factors.

Note that all graphs presented show the inverse of the modification factor to maintain consistency with the relation of modification factor used in previous studies [1,7,10]. This value is the factor by which the lateral strength of the SDOF needs to be multiplied to control the maximum ductility for MDOF structure.

The ratio between the lateral strength demand on MDOF to SDOF systems in order to control the maximum ductility ratio is presented in Figures 3 and 4. The blue line on each graph represents the mean modification factor for each height. From the results in figures 3 and 4 the following observations are made:

* As in previous studies, most elastic MDOF systems attract lower base shear than those predicted by the SDOF system with the same fundamental period as the MDOF system (equivalent SDOF system). It can be seen that this is always the case for systems on soft soils (Fig. 4), but for the 20 story buildings in stiff soil this behavior is reverse, the reason is that there is more data dispersion for the systems built in hard soil than in soft soil, and therefore the inverse of the modification factor increases. In the next section the reason for this increase in the dispersion, specially for elastic systems is explained.
* Inelastic MDOF systems attracts more base shear than their equivalent SDOF systems resulting in an increase of the modification factors as the ductility ratio increases.
* Modification factors increases as the height of the building increase. For the 20 story building (tallest system for this study) the maximum mean modification factor is between 2 and 2.5, meaning that this tall building should be designed with twice the base shear strength of a SDOF system.
* The dispersion increases as the number of stories increases.

Multimode effect and heightwise variation of ductility demand.

Because of the level of dispersion found the in modification factor, it was investigated in more detail for all systems, in particular the ones with the highest level of dispersion: buildings of 12 stories and taller. As an example the 12 story elastic flexible building subjected to Northridge Earthquake, station Los Angeles

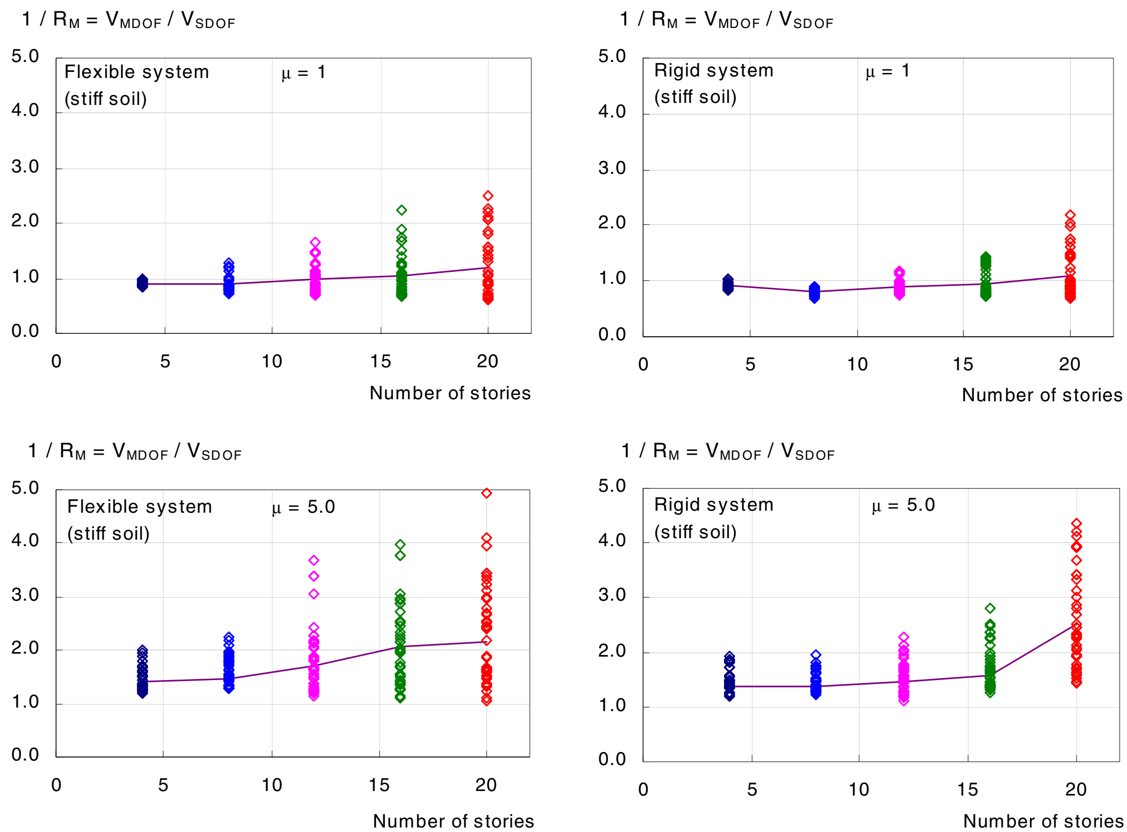

Figure 3. Inverse of the modification factor for flexible and rigid systems subjected to motions recorded on hard soil.

Gritfith Park, is selected. Table 4 shows the first three modal periods of this building, the base shear strength computed for this MDOF system for an allowable ductility =1, the base shear strength computed for its SDOF equivalent system when subjected to the same motion and its modification factor.

Table 4. Dynamic Properties and Strenght for 12 flexible system subjected to L.A.G.P.

T_1 (S)	T_2 (S)	T_3 (S)	$V_{b\ MDOF}$ (T)	$V_{b\ SDOF}$ (T)	$V_{b\ MDOF}$ / $V_{b\ SDOF}$
2.61	0.91	0.53	56	30	1.86

Graphics for elastic systems (μ=1) in Figure 3, show that SDOF systems attracted more base shear than MDOF systems. Again expectation the 12 story building demands more base shear than its equivalent SDOF system. To explain this behavior, the dynamic response for this particular system to this ground motion was determined, leading to the story ductility demands and shear distribution presented in Figure 5. The acceleration response spectrum for a SDOF system subjected to LA Grifith Park is shown in Figure 6.

The heightwise variation of ductility demand of Figure 5 show the contribution of the second mode of the 12 story flexible building due to the LA Grifith Park ground motion. Using the acceleration response spectra, the acceleration of the SDOF equivalent system is determined using the fundamental period of the MDOF system. Watching the spectra for this motion, the acceleration for this latter period is minimal respective to the acceleration for the second mode period. As a consequence, the $V_{b\ SDOF}$ of Table 4 is small. This behavior may indicate, that there is a contribution of higher modes in the response of this system, but

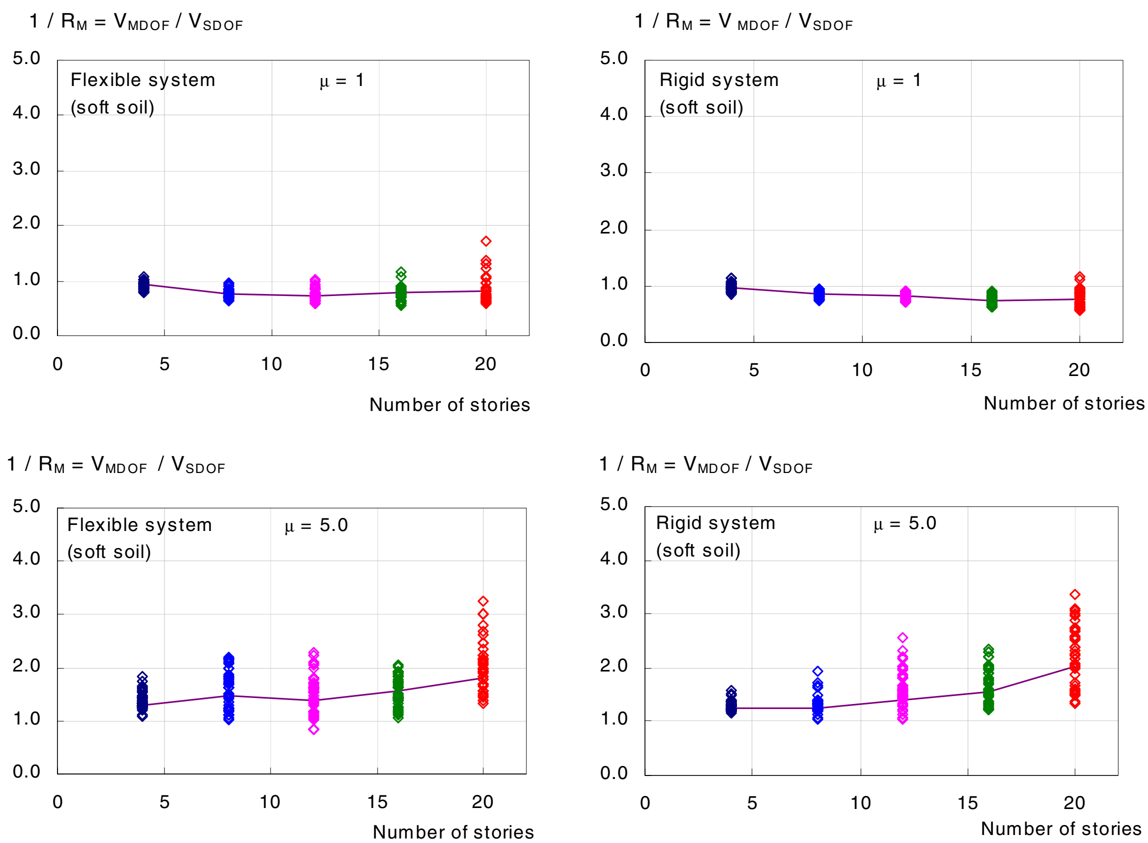

Figure 4. Inverse of the modification factor for flexible and rigid systems subjected to motions recorded on soft soil.

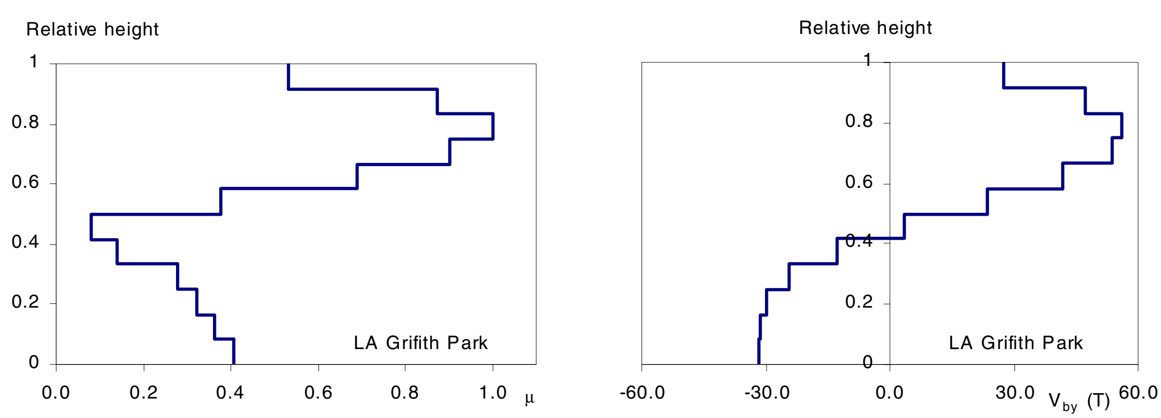

Figure 5. Story ductility demands and shear distribution for 12 elastic flexible system

This behavior is not enough to corroborate a higher mode contribution, because there are other records with the same characteristics and this particular 12 story system behave in a first mode. To investigate the characteristics of the motion records, the frequency content of each acceleration record was determined by plotting their Fourier amplitude spectra.

Fourier amplitude spectra for LA Grifith Park is shown in figure 6. The Fourier spectra of LA Grifith Park shows that the response is strongest at low periods, and that for periods greater than 1.2s. the amplitude of this motion is very low. The fundamental period of the 12 story building is 2.61 s., a period in which a SDOF system have very low amplitude but its second mode period , 0.91 s, is in the high amplitude range, causing a significant contribution of the second mode to the building response. This influence of the frequency content of the ground motion was examined for all systems and all ground motions, and every time there was a modification factor greater than the mean (upward dispersion) the reason was the influence of second (8 and 12 stories) and third (16 and 20 stories) mode contributions.

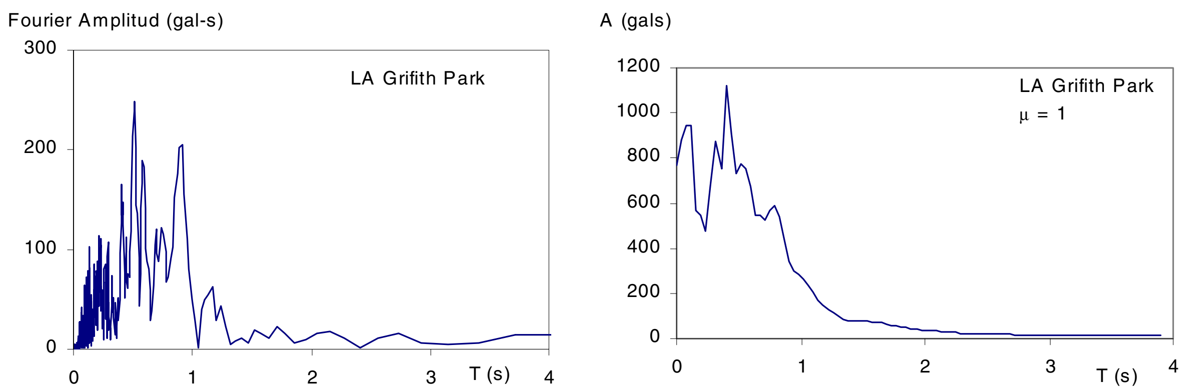

Figure 6. Fourier amplitude spectrum and acceleration response spectrum of SDOF system. 270 component of LA Grifith Park

The mode contributions are expected when the systems behave elastically, but as the systems turn to elastoplastic behavior the influence of the higher modes diminishes, and as Veletsos and Vann [13] explain, the response approaches that of the SDOF inelastic system. To demonstrate that as a consequence of the mode contributions, elastic systems present higher dispersion which latter diminishes, the coefficient of variation of each system for different allowable ductilities is calculated. The results are shown in Figure 7.

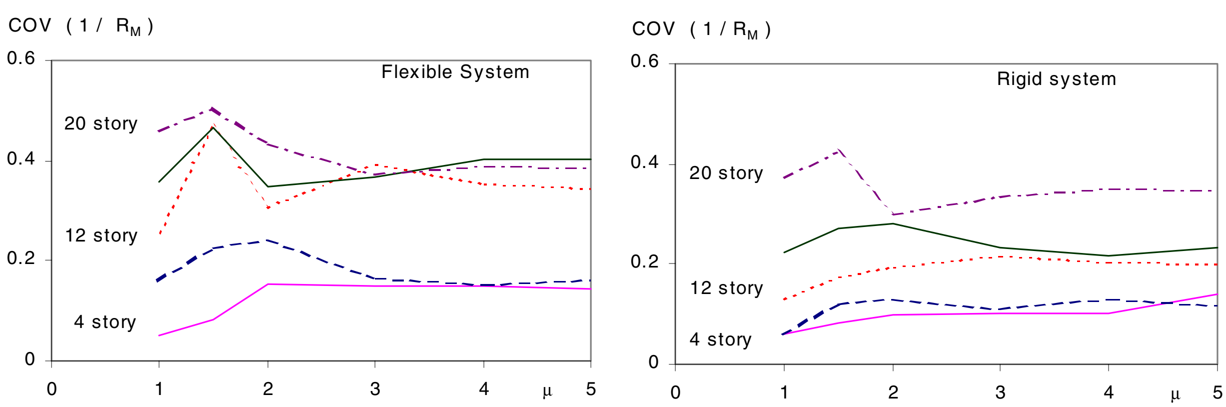

Figure 7. Coefficient of variation for modification factor (rigid and flexible systems) due to hard soil.

The following observations are made from Figure 7: a) for short and medium rigid buildings, dispersion increases as ductility increases; b) for medium flexible and high rigid buildings there is a concentration of dispersion for a ductility equal to 2, and the dispersion of elastic systems is slightly smaller than for high elastoplastic systems; c) for high flexible systems, dispersion is higher for the elastic and the beginning of the elastoplastic (μ = 1,1.5 and 2) system and decreases as the elastoplastic behavior increases (μ = 5).

Heightwise and fundamental period variation of the modification factor.
To appreciate the heightwise variation of the modification factor and compare the response between flexible and rigid systems, mean amplification factors for both systems and different type of soils are shown as a function of the number of stories in Figure 8. It can be seen that: 1) each system has a consistent and smooth pattern, and for practical purposes, it is the same for all ductility demands, 2) flexible amplification factors for hard soils are higher than those evaluated for rigid systems; the opposite happens for elastic behavior and buildings higher than ten stories in soft soils, 3) although there is a difference of mean factors between systems, for practical purposes all systems can be considered as one, regardless of whether they were designes as rigid or flexible.

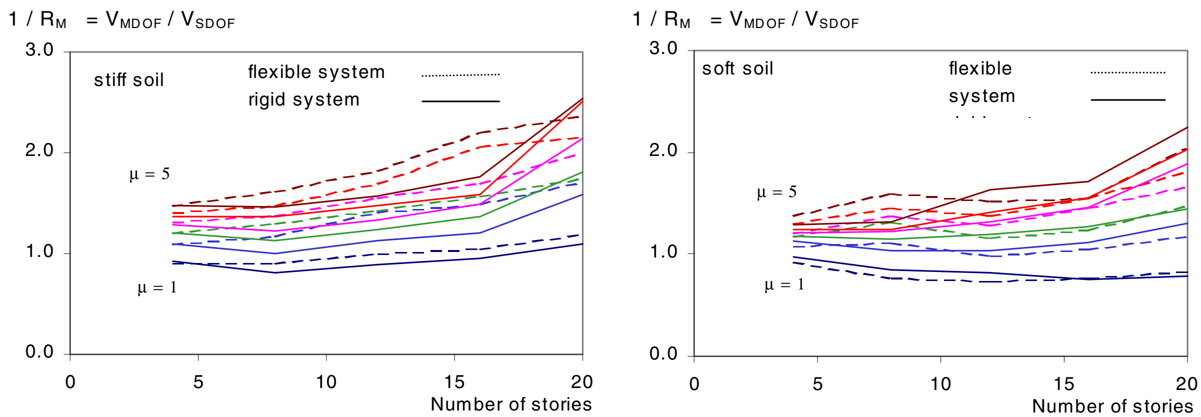

Figure 8. Inverse of the media of modification factor for flexible and rigid systems subjected to motions recorded on soft soil in terms of number of stories.

The variation of the media modification factor in terms of the fundamental period of vibration is shown in Figure 9. The following observations can be made from the figure: 1) The trend of the modification factor its quite similar for all levels of ductility; 2) when the factor of a rigid system, because of its fundamental period, is placed between two factors belonging to flexible systems, a peak point appears. This behavior can be seen in periods equal to 1.26 s and 2.37 s, showing that joining different systems produce a discontinuity in the behavior of the modification factor.

Note that the modification factor can be determined from a smooth curve like the one shown in the graph for the heightwise variation; each system (flexible and rigid) is plotted separately. As with the heightwise variation, a smooth pattern is obtained because each type of system presents a similar story deformation, roof displacement, and heightwise variation of ductility. This idea is demonstrated in figure 10 because these two systems are the upper and lower limit of flexibility of a building, they will also be the upper and lower limit for the modification factor. Thus depending of the kind of building or maximum deformation allowed, the designer can choose an intermediate value for this factor and calculate the base shear to some target ductility.

The modification factor shows a more intuitive and smoother distribution in terms of the number of stories, therefore a direct comparison is made between the mean factor due to records on firm sites to the records on soft soil.

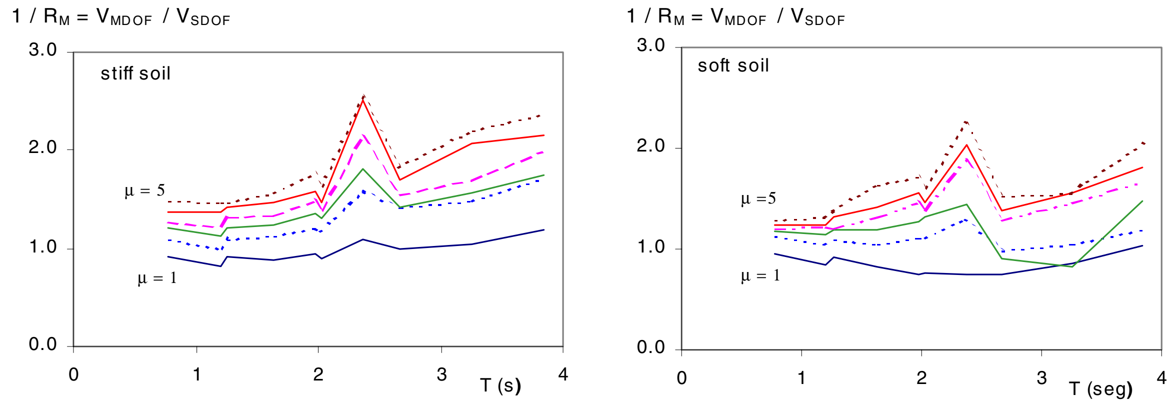

Figure 9. Mean amplification factors for hard and soft soil, in function of the fundamental period.

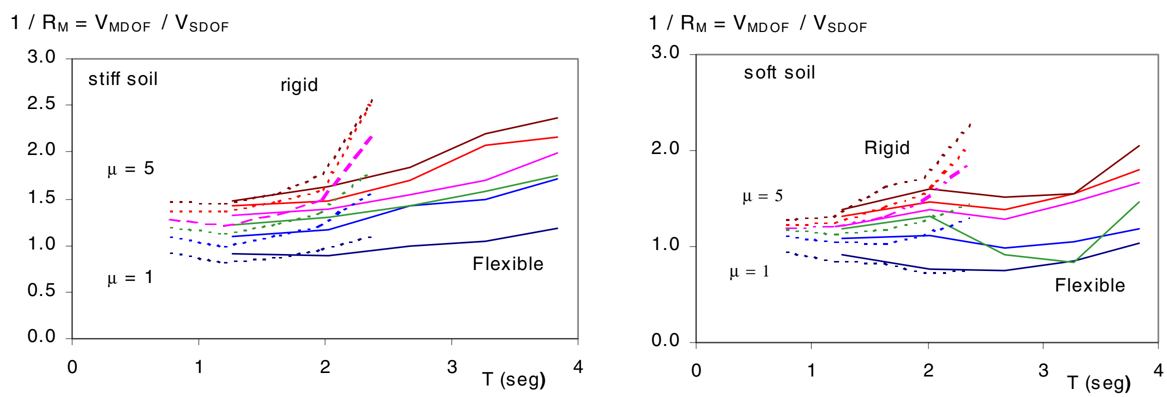

Figure 10. Mean amplification factors for flexible and rigid systems for hard and soft soil, in function of the fundamental period.

This comparison is plotted in figure 11. From this figure it can be observed that: a) the trend presented by the mean of the modification factors for both types of soil is similar; b) for short buildings and low level of ductility the modification factor is the same for both types of soils; c) the maximum difference (approximately 20%) between types of soil is for elastic medium-tall buildings (more than 8 stories); d) as the ductility increases the difference of behavior for a stiff and soft soil decreases; e) for high levels of ductility the difference is constant with different building heights (approximately 10%).

Two expressions were obtained to evaluate the mean factors shown in Figure 11 as a function of the number of stories and the level of ductility. These expressions are shown in equations 4 and 5 for stiff and soft soils respectively [10].

$$R_M = 0.589exp\left(\frac{0.586}{\mu}\right) + a(N_n) - b(N_n)^2 \quad (4)$$

$$R_M = \frac{0.774}{1 - 8.3098exp(-3.948\mu)} + a(N_n) - b(N_n)^2 \quad (5)$$

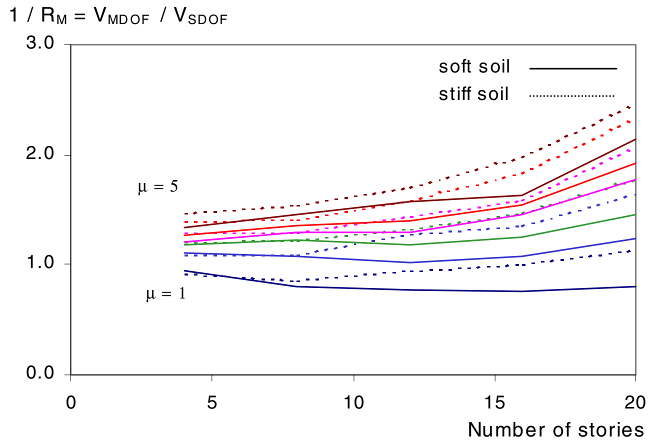

Figure 11. Mean amplification factors for hard and soft soil, in function of number of stories.

In this expressions N_n is the number of stories, μ is the target ductility and *a* and *b* are parameters tabulated on Table 5. The modification factors obtained with the use of these expressions are presented in Figure 12, where they are compared graphically to the mean modification factors.

Table 5. Parameters *a* and *b* for the modification factor expressions.

	Stiff soil		**Soft soil**	
μ	*a*	*b*	*a*	*b*
1	.006	-.0007	0.065	-0.0023
1.5	.006	-.0008	0.042	-0.0019
2	.004	-.0008	0.029	-0.0016
3	.006	-.0009	0.017	-0.0012
4	.008	-.0010	0.008	-0.0008
5	.003	-.0008	-0.001	-0.0005

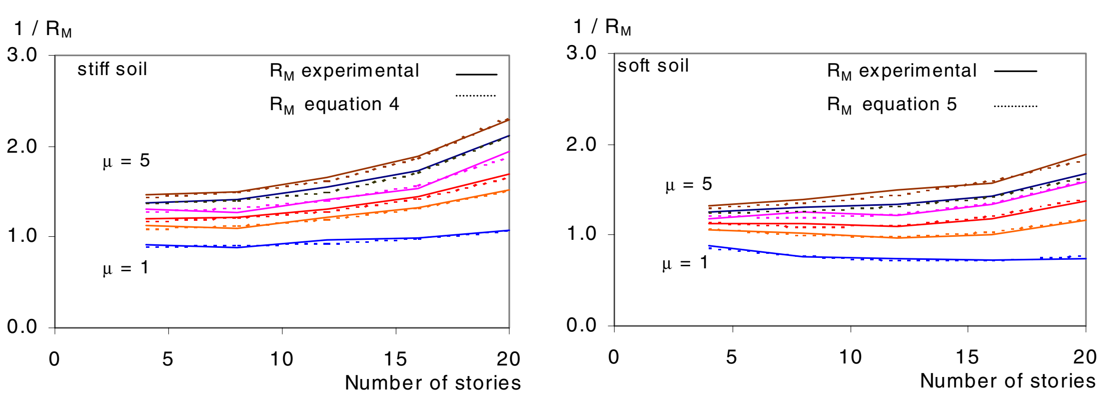

Figure 12. Comparison of mean amplification factors evaluated with equations 4 and 5.

Influence of soil conditions.
The influence of site conditions is shown in Figure 13, where mean amplification factors are shown as a function of the number of stories and site conditions, for ductility values of 2 and 5.
It can be seen again that the amplification factors for site classes A-B and C are slightly larger than those for site classes D and soft soils; in other words, the difference between modification factors increases as the number of stories increases. In terms of the ductility, the modification factor increases, but the difference between soil conditions and number of stories remains similar. Analyzing only mean factors, the difference between site classes is small even considering soft soils as included in this study.

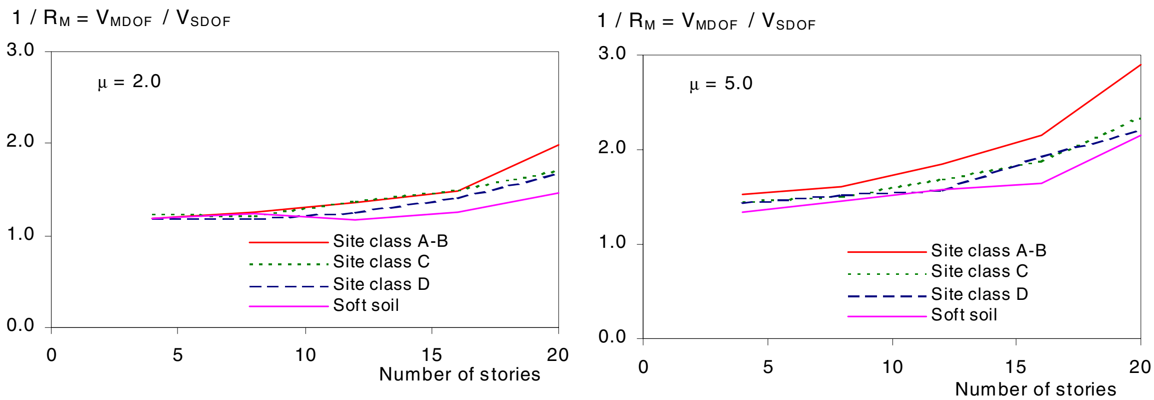

Figure 13. Influence of site conditions on mean amplification factor.

CONCLUSIONS

The purpose of this study is to obtain a better understanding about the parameters that influence the response of MDOF systems, with a particular focus on base shear strength in order to incorporate these results in the inelastic design of multistory buildings. The following conclusions can be drawn from the results of this study:

1. The behavior of the modification factors is primarily affected by the ductility ratio; the modification factor increases as the ductility ratio increases, for inelastic systems. In general, for elastic systems the modification factor decreases as the building height increases.
2. The dispersion existing on the modification factors is strongly correlated to the frequency content of the earthquake. Records with small amplitudes for periods greater than 1.2 s affect medium and tall buildings, introducing the contribution of higher-modes (second mode for medium systems and second and third mode for tall buildings) into the dynamic response. This effect is present in elastic systems and in the first levels on inelastic systems (μ = 1.5 and 2). As the systems turn more inelastic the level of dispersion decreases, in some cases even lower than for the elastic case.
3. Heightwise variation of the modification factor is understood in this study as the influence of the number of stories in a MDOF system in the trend of the modification factor. From the results presented in this study, the modification factor plotted as function of the number of stories of a building presents a smooth curve with no irregularities, which results in a better understanding of its behavior.
4. The influence of the fundamental period on the modification factor introduces irregularities, due to the inclusion of two systems with different flexibility and strenght in the same graph. If the

systems are plotted in separate graphs , the maximum and minimum values establish the limits of the modification factor.

5. Inelastic MDOF systems sustain more base shear than their corresponding SDOF systems (period equal to the fundamental period of the MDOF system).
6. It was shown that the effect of the site type on the computation of the mean amplification factor is small. It is important to note than motions recorded on soft soils were also included in this study and that the response of the amplification factors was similar to the calculated for stiff soils.
7. Two simplified expressions to estimate the modification factor, as a function of the number of stories of the MDOF systems are presented.

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