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HYSTERETIC DETERMINATION OF THE RESPONSE FACTORS Rμ ACCORDING TO STRUCTURAL TYPES.

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SUMMARY

In this paper the response factors Rμ and the inelastic spectra are obtained, taking into account the hysteretic behavior of soils S1, S2, S3 and S4, for different types of structures: concrete frames, concrete frames and masonry, steel frames, and reinforced concrete walls. For a one-dimensional analysis, five accelerograms in rock and source distances between 3.4 km and 337 km were utilized in alluvial soil depths between 10 and 70 meters. To include non linear behavior of soils the Ramberg-Osgood model controlled by the unified formula of Ishibashi-Zhang-1993 was used and for the structures the hysteretic smooth model of Sivaselvan-Reinhorn-2000 was used. In total 180 accelerograms on surface are used for structural inputs. The responses obtained were the values of the characteristic periods Tg valid for the structural type, the expected ductility μ and the type of soil; they can take a standard application. The value of Tg corresponding to the point down the smooth tangent to the lineal regression curves, in order to have a safe design.

ANTECEDENTS

The response factors (R) have been studied taking into account the bilinear behavior and stiffness degradation, achieving approximate expressions in function of ductility and the structural period (Nassar and Krawinkler [1]). The results of these factors are validated applying an indirect method, with inelastic spectra generated "exactly" by means of the direct method (Vidic et al., [2]). Most of the earthquake resistant codes, as the Venezuela Covenin Code 1756-2001 [3], apply Inelastic Design Spectral (IDS) based on empiric response factors R.

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The direct method for R allows us to obtain the linear elastic response spectra by means of statistical procedures. The average spectra are "softened" with an involvement obtained by means of regression analysis. It has intended a representative function of inelastic spectra depend on fundamental period of the structure T and on displacement ductility μ (Riddell, [4]). The adoption of the same displacements rule R=μ for long periods has let to include these values for the structural systems, which has been questioned, considering doubtful the application of a single value of R (ATC-19, [5]).

OBJECTIVES

This paper determines the IDS for soils, distance to fault and structural types classified by the Covenin Code 1756-2001 [3], according to the following methodology: (a) Select inputs in rock, considering near, intermediate and far sources. (b) Obtain the surface response for each soil changing depths from 10 to 70 meters, by means of the one-dimensional program WAVES and considering the soil hysteretic behavior (Hart and Wilson, [6]). (c) Determine the elastic and inelastic response spectra considering the appropriate hysteretic behavior to each structural type (NSPECTRA, Reinhorn et al., [7]). (d) Calculate the average spectra of Rμ, as the ratio of the elastic spectra to the inelastic ones, for each ductility μ. (f) Define the spectral functions of Rμ for each soil, the distance to the fault, structural type and ductility μ. (g) Define the Elastic Design Spectra (EDS) with the average obtained. (h) Obtain the IDS starting from the elastic spectra, by means of the factors Rμ.

HYSTERETIC BEHAVIOR OF STRUCTURES AND SOILS

To determine the inelastic response spectra, the degradation of stiffness and strength, and the pinching of the hysteretic loops are considered. In this paper the Softened Pattern is adopted (Sivaselvan and Reinhorn, [8]), conceived for structures of reinforced concrete. This model is incorporated in NSPECTRA, and allows to reproduce the degradation of Single Degree Of Freedom systems (SDOF) by means of similar parameters as those outlined by Kunnath and Reinhorn [9], that relate the SDOF systems under static loads and those obtained with the softened model. The NSPECTRA program calculates the response spectra and other averages from 200 records, for periods between 0.05 and 5.0 seg., with different levels of ductility. The response reduction factor Rμ it is obtained according to the expression:

$$R\mu = \frac{F_y(\mu = 1)}{F_y(\mu > 1)} \quad (1)$$

The Sivaselvan and Reinhorn [8] patterns implemented in NSPECTRA (version 2.0, 1998), IDARC and IDARC-Bridges (1987), include the stiffness degradation, strength degradation, pinching of hysteretic loops and hardening for closing of joints. In a recent paper the authors take two hysteretic models: one with stiffness degradation (model Q) and a bilinear model. The average results indicate differences between the spectrum of reduction factors R with degradation and when degradation is not admitted. The values of the first one are lower than the second and they have an asymptotic behavior below the ordinates corresponding to the expected ductility. The results are functions of the ductility, the fundamental period of the structure and of the predominant period Tg (Vidic et al., [2]). The determination of the parameters of the softened hysteretic patterns is achieved by the comparison of stress-strain diagram of SDOF structures, designed according to codes (reinforced concrete and structural steel), with the diagrams obtained modifying the diverse parameters.

The earthquakes applied were: Kobe 1995 (1067.3 cm/sec^2; 3.4 km); Cape Mendocino 1992 (1019 cm/sec^2; 15 km); Michoacán 1985 (138.49 cm/sec^2; 21 km); Miyagi Oki 1978 (206.7 cm/sec^2; 116 km) and Michoacán 1985 (50.1cm/seg^2; 337 km). It is important to point out that the influence of the near fault earthquakes on the hysteretic behavior of soils and the structures is studied.

HYSTERETIC BEHAVIOR OF SOILS

The site effect in the IDS, led to study its effect on the response factors R (Miranda, [10]). The consideration of this effect is carried out with elastic response spectra of different typical profiles for their geotechnical and dynamic characteristics (Rivero and Lobo-Quintero, [11]). The profiles are modeled with the one-dimensional WAVES program, that considers horizontal strata as finite elements and they are analyzed applying the hysteretic model of Ramberg-Osgood. The response of the soil at the surface is used in the model as an input accelerogram. The control parameters that characterize the dynamic behavior of soils are obtained comparing the unified equations of Ishibashi-Zhang [12], with the hysteretic equations of Ramberg-Osgood for different strata thickness, applied to the types of soils except rock, for thickness of strata of 10, 20, 30, 40, 50, 60 and 70 meters. Each soil type is modeled taking element thicknesses of one meter for depths smaller than 40 m. For greater depths, elements of 5 meters of thickness are selected (Rivero, [13]).

SELECTED STRUCTURAL TYPES

The selection of the structural types is made by comparison of the results of the stress-strain diagrams of models designed according to the corresponding state of the art, and those obtained when varying the parameters of the NSPECTRA. The structural types are shown in Figure 1 and the ductility levels, selected from Covenin 1756-2001 [3], are shown in Table 1. These levels are incorporated in the program to obtain the response spectra and these are used to determine the response reduction factor R.

Table 1. Ductility levels. Covenin 1756-2001.

Structural type	ND1	ND2	ND3
Reinforced concrete frames	2	4	6
Reinforced concrete and masonry frames	2	4	6
Steel frames	2.5	4.5	6
Reinforced concrete walls	1.5	3	4.5

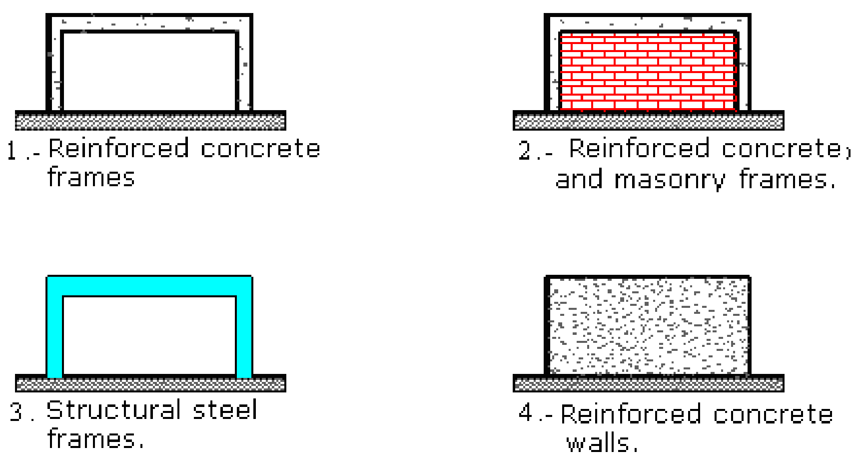

Figure 1. Selected structural types.

SPECTRAL RESPONSE REDUCTION FACTORS (R) AND INFLUENCE FACTORS

The values are applied to all acceleration spectra groups and ductility levels. In this paper there are 187,920 relations of acceleration or values Rμ that groups and averages in four soils and structural types. The obtained spectra represent the hysteretic behaviors of the structural models: (1) The comparison of the profiles of Rμ, doesn't give evidence that the epicentral distance influences in a decisive way. (2) As the soils become less rigid, the ordinates are indifferent to the depth of the records. For concrete and steel frames, when the ductility is high, they present slight variations with greater ordinates as the depth is increased. For concrete walls, the behavior in the area of short periods presents enough irregularities or jumps that give a clear relationship between the spectral ordinates and the depths of the strata. (3) When consider different types of soils, this condition stays invariable only for low levels of ductility. For different soils and low ductilities (μ=2) there are no significant variations. With high ductilities, the differences between the spectral ordinates stop to be worthless, giving variations up to 15%, for soft strata if compared with hard strata or soft rocks. This is true for short periods, giving smaller differences in intermediate and long periods (4) Each structural type gives uniform profiles for concrete frames and for concrete frames with masonry, with a branch of constant ordinates. For steel frames, in rocky or rigid strata, the spectra present "tips" or jumps for short periods and more toward the period of it initial break.

According to the analysis, the averages are grouped and ordered according to the geotechnical characteristic corresponding to S1, S2, S3 and S4 soils. Also, average records are separated according to structural types: frames of concrete, frames of concrete with masonry, steel frames and concrete. With the variations observed the standard deviation is calculated for each group of spectra and the spectra of Rμ is obtained taking the average less one standard deviation.

DETERMINATION OF THE CHARACTERISTIC PERIOD

One of the most important parameters of R is the period starting from which the response reduction factors stop being influenced by the period of the structure and depend only on ductility. The codes of earthquake resistant design as Covenin 1756-2001 [3] admit that these characteristic periods depend on factors like the ductility and the structural type. The determination of these predominant or characteristic periods depends on the irregular behavior of R, in soft soils and structural types (Table 2). For this condition, a linear regression is made for the branch dependent on ductility, giving a line very near to a horizontal one, with slopes that oscillate from 5% for framed structures, increasing to 20% for structural walls. Also, the curve is softened for the upward branch, dependent on the period.

It is assumed that the characteristic period corresponds to the point in which the softened curve is tangent to the line obtained by lineal regression according to the procedure of Riddell et al., [14]. The difference is that the branch dependent on the period is adjusted below the softened curve, and not above, because for the area of short periods the factors Rμ are bigger than those calculated, conducing to an unsafe design. In this way the idealized factors of Rμ are smaller that calculated, giving a safer design for the short periods.

Recent studies, have located the characteristic periods (Tg) in accordance with the levels of ductility, being 0.2 sec. for low ductilities (μ=1.5); 0.8 sec. for intermediate ductilities (μ=3) and one second for higher ductilities (μ=4) (Miranda, [15], [16]). Also values of the characteristic period in function of the type of soil, with values of 0.5 sec. for rock, 0.75 seg. for alluviums and 1.0 sec. for the soft ones (Aschheim, [17]). Both tendencies are reflected in the results obtained in this paper, because the values of the characteristic periods increase with the ductility. Also, it can be seen that the values of the characteristic periods increase as the soils become softer (Table 3). This Chart allows the inclusion adjusted normative requirements to the hysteretic behavior of the structural systems and into account the source.

Table 2. Predominant or characteristic periods, Tg.

Reinforced concrete frames

	S1	S2	S3	S4
μ = 2	0.12	0.22	0.34	0.60
μ = 4	0.19	0.29	0.47	0.71
μ = 6	0.25	0.38	0.74	0.82

Reinforced concrete frames and masonry

	S1	S2	S3	S4
μ = 2	0.16	0.24	0.31	0.62
μ = 4	0.22	0.31	0.64	0.85
μ = 6	0.27	0.50	0.87	1.05

Steel frames

	S1	S2	S3	S4
μ = 2.5	0.19	0.20	0.27	0.60
μ = 4.5	0.26	0.32	0.48	0.71
μ = 6	0.32	0.51	0.65	0.83

Reinforced concrete walls

	S1	S2	S3	S4
μ = 1.5	0.15	0.33	0.58	0.63
μ = 3	0.26	0.42	0.82	0.88
μ = 4.5	0.35	0.50	1.04	1.12

IDEALIZED SPECTRA OF RESPONSE REDUCTION FACTORS

The average spectra of R in simple and approximate form with bi-lineal expressions present the following characteristic: an upward branch until the characteristic period, after which the line becomes strongly dependent on the ductility. The equations of the response spectra Rμ and the charts with the values of the parameters of the equations, follows in tables 3, 4, 5 and 6 corresponding to structural types, the distance of faults, the type of soil and the predominant period Tg.

For $T < Tg$: $$R_\mu = 1 + \mu . T/(a . T_g) \quad (2)$$

For $T > Tg$: $$R_\mu = 1 + \mu/a + b . T \quad (3)$$

The application of the indirect method is made starting from the elastic design spectra for the four groups of soils, each structural type and each design level. The spectral ordinates are determined dividing the ordinates of the elastic spectrum into the factors Rμ calculated according to the equations (2) and (3), with the parameters of the inelastic spectra of the tables 4, 5, 6 and 7. The average spectra of Rμ minus one standard deviation corresponding to reinforced concrete frames, reinforced concrete frames and masonry, steel frames and structural walls in different soils (S1, S2, S3, S4) and sources distances (near, intermediate, far) are shown in figures 2, 3, 4 and 5. The parameters shown in Table 3 are only the average of EDS to be included in a code as Covenin 1756-2001, where β is the amplification factor of soil, Tg is the average predominant period, T^* is the characteristic period and p is the exponent of descending branch of the spectra.

S4 0.70 2.20 2.90 1

Table 3. Parameters of elastic design spectra EDS.

Soil	Tg	T^*	β	p
S1	0.15	0.35	2.35	1
S2	0.25	0.70	2.45	1
S3	0.40	1.25	2.55	1
S4	0.70	2.20	2.90	1

The equations of the elastic design acceleration Ad to EDS are the following, where Ao is the maximum acceleration of soil.

$$T < T_g \qquad A_d = A_0\left[1 + \frac{T}{T_g}.(\beta - 1)\right] \tag{4}$$

$$T^{+} \leq T \leq T^{*} \qquad A_d = A_0 .\beta \tag{5}$$

$$T > T^{*} \qquad A_d = A_0 .\beta.\left(\frac{T^{*}}{T}\right)^{p} \tag{6}$$

Table 4. Inelastic Factors a and b. Reinforced Concrete Frames

PARAMETERS OF INELASTIC SPECTRA FOR REINFORCED CONCRETE FRAMES.										
Soil		Near Fault			Intermediate Fault			Far Fault		
	Duct. μ	Tg	a	b	Tg	a	b	Tg	a	b
S1	**μ=2**	0.11	2.7027	0.0302	0.19	2.4691	0.0018	0.19	2.4691	0.0018
	μ=4	0.15	1.7778	-0.0114	0.24	1.6504	-0.0132	0.24	1.6504	-0.0132
	μ=6	0.23	1.6438	-0.1279	0.28	1.6179	-0.0634	0.28	1.6179	-0.0634
S2	**μ=2**	0.20	3.7915	0.0610	0.23	3.2300	0.0316	0.23	3.2300	0.0316
	μ=4	0.25	1.9630	0.0121	0.27	1.8657	0.0074	0.27	1.8657	0.0074
	μ=6	0.33	1.8939	-0.0255	0.37	1.7685	-0.0252	0.37	1.7685	-0.0252
S3	**μ=2**	0.24	3.3552	0.0613	0.28	2.6965	0.0267	0.28	2.6965	0.0267
	μ=4	0.28	1.7675	0.0024	0.32	1.7194	0.0100	0.32	1.7194	0.0099
	μ=6	0.34	1.7633	-0.0240	0.43	1.6498	0.0191	0.43	1.6498	0.0191
S4	**μ=2**	0.32	3.9078	0.0965	0.34	2.6980	0.0402	0.34	2.6980	0.0402
	μ=4	0.46	1.7844	0.0275	0.44	1.7468	0.0429	0.44	1.7468	0.0429
	μ=6	0.54	1.8809	0.0009	0.64	1.6617	0.1263	0.64	1.6617	0.1263

Table 5. Inelastic Factors a and b. Reinforced Concrete Frames and Masonry.

PARÁMETERS OF INELASTIC SPECTRA FOR REINFORCED CONCRETE FRAMES AND MASONRY										
Soil		Near Fault			Intermediate Fault			Far Fault		
	Duct. μ	Tg	a	b	Tg	a	b	Tg	a	b
S1	**μ=2**	0.14	2.4691	-0.000037	0.14	2.4691	-0.000037	0.14	2.4691	-0.000037
	μ=4	0.18	1.6667	-0.0464	0.18	1.6667	-0.0464	0.18	1.6667	-0.0464
	μ=6	0.25	1.4337	-0.1728	0.25	1.4337	-0.1728	0.25	1.4337	-0.1728
S2	**μ=2**	0.18	3.0769	0.0160	0.18	3.0769	0.0160	0.18	3.0769	0.0160
	μ=4	0.28	1.7699	-0.5393	0.28	1.7699	-0.5393	0.28	1.7699	-0.5393
	μ=6	0.38	1.5748	-0.1055	0.38	1.5748	-0.1055	0.38	1.5748	-0.1055
S3	**μ=2**	0.28	2.6178	0.0090	0.28	2.6178	0.0090	0.28	2.6178	0.0090
	μ=4	0.44	1.5848	-0.0599	0.44	1.5848	-0.0599	0.44	1.5848	-0.0599
	μ=6	0.68	1.4228	-0.1348	0.68	1.4228	-0.1348	0.68	1.4228	-0.1348
S4	**μ=2**	0.54	2.7701	0.0269	0.54	2.7701	0.0269	0.54	2.7701	0.0269
	μ=4	0.84	1.5729	-0.0551	0.84	1.5729	-0.0551	0.84	1.5729	-0.0551
	μ=6	0.94	1.4652	-0.0680	0.94	1.4652	-0.0680	0.94	1.4652	-0.0680

Table 6. Inelastic Factors a and b. Steel Frames.

PARÁMETERS OF INELASTIC SPECTRA FOR STEEL FRAMES.										
		Near Fault			Intermediate Fault			Far Fault		
Soil	Duct. μ	Tg	a	b	Tg	a	b	Tg	a	b
S1	**μ=2.5**	0.175	2.1645	0.0196	0.19	1.9608	-0.0100	0.65	1.8034	0.3545
	μ=4.5	0.225	2.2324	0.0484	0.21	1.5924	-0.0250	0.19	2.0747	0.0160

	μ=6	0.24	1.7477	0.1222	0.25	1.4951	0.0089	0.225	2.6408	0.0446
S2	**μ=2.5**	0.16	2.5615	0.0312	0.18	2.3364	-0.0020	0.30	1.8205	0.1677
	μ=4.5	0.18	2.0794	0.1156	0.21	1.8315	-0.0128	0.20	2.5510	0.0303
	μ=6	0.21	2.0101	0.1788	0.24	1.6000	0.0503	0.23	2.0671	0.1130
S3	**μ=2.5**	0.23	2.6813	0.0305	0.25	2.1930	0.0332	0.27	2.0033	0.1790
	μ=4.5	0.28	1.9885	0.0024	0.31	1.8367	0.1127	0.275	2.2321	0.0352
	μ=6	0.33	1.5676	-0.1171	0.4	1.6575	0.0927	0.37	1.9149	0.1582
S4	**μ=2.5**	0.33	2.5536	0.0222	0.375	2.1758	0.0674	0.46	1.8750	0.2505
	μ=4.5	0.41	1.9100	-0.0182	0.52	1.9092	0.2785	0.375	2.1428	0.0473
	μ=6	0.51	1.4782	-0.0682	0.19	1.9608	-0.0100	0.56	1.8367	0.1955

Table 7. Inelastic Factors a and b. Structural Walls.

PARÁMETERS OF THE INELASTIC SPECTRA FOR STRUCTURAL WALLS										
		Near Fault			Intermediate Fault			Far Fault		
Soil	Duct. μ	Tg	a	b	Tg	a	b	Tg	a	b
S1	**μ=2**	0.10	3.9536	0.0268	0.12	3.5980	0.0182	0.17	3.5731	0.0007
	μ=4	0.15	3.0804	0.2059	0.19	2.1589	0.1322	0.27	2.3943	-0.0124
	μ=6	0.21	3.1876	0.3750	0.28	2.0345	0.2662	0.39	2.3173	0.0020
S2	**μ=2**	0.23	11.1773	0.0033	0.28	5.1742	0.0089	0.35	4.9538	0.7450
	μ=4	0.27	12.7605	0.0576	0.37	2.8249	0.0710	0.42	2.6906	0.4199
	μ=6	0.44	11.1386	0.0977	0.45	2.7675	0.1248	0.53	2.4956	0.7433
S3	**μ=2**	0.41	9.8814	0.0007	0.46	5.0693	0.1043	0.66	3.4811	0.0138
	μ=4	0.72	9.1547	0.0747	0.77	3.5010	0.4192	0.77	1.9481	0.1416
	μ=6	0.91	8.6059	0.1454	0.94	3.3587	0.6891	0.94	1.8396	0.2964
S4	**μ=2**	0.53	6.1275	0.0744	0.60	3.6621	0.0549	0.63	3.5336	0.0060
	μ=4	0.76	6.8384	0.3923	0.84	2.3385	0.2849	0.90	1.9816	0.0095
	μ=6	0.92	7.7734	0.6215	1.09	2.2310	0.5029	1.19	1.7763	-0.0116

The analysis of the results contained in the figures 2, 3, 4 and 5, determines the fulfillment of the rule of the equal displacements as it is shown in Table 8, according to the following conclusions:

1. The concrete frames fulfill the rule in hard soils for any source, but don't in soft soils with intermediate and far sources.
2. The concrete frames and masonry always fulfill the rule.
3. The steel frames have an erratic behavior and have a tendency to not fulfill the rule in soft soils with intermediate and far sources. They fulfill it in intermediate sources and hard soils.
4. Structural walls only fulfill the rule in soft soils.

An application of the equations (1), (2), (3), (4) and (5), the tables (2). (3), (4), (5), (6) and (7) is shown in Table 9 and Figure 6, to obtain the IDS.

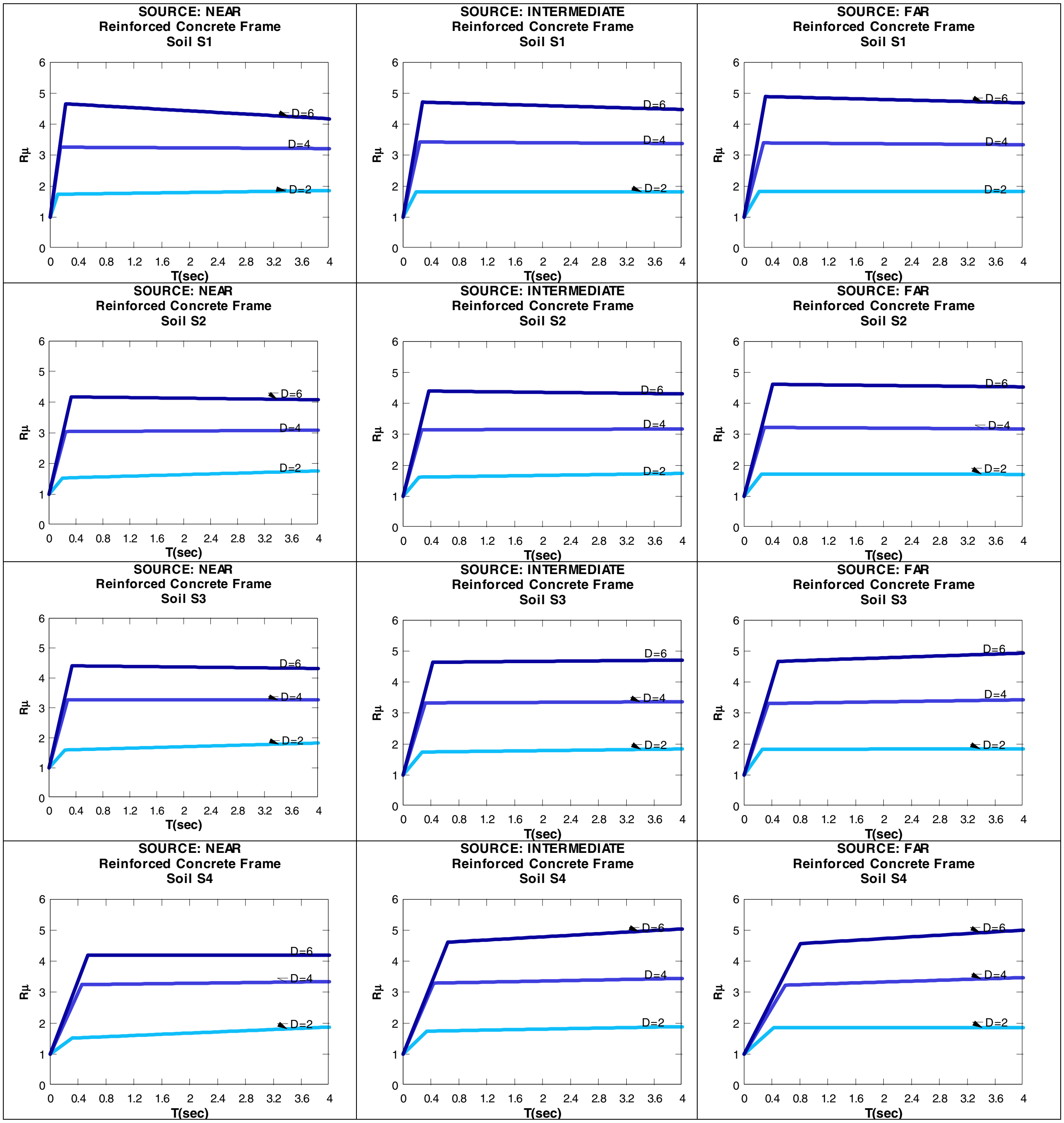

Figure 2. Average spectra of Rμ less one standard deviation of reinforced concrete frames to different soils S1, S2, S3, S4, and three sources: near, intermediate and far.

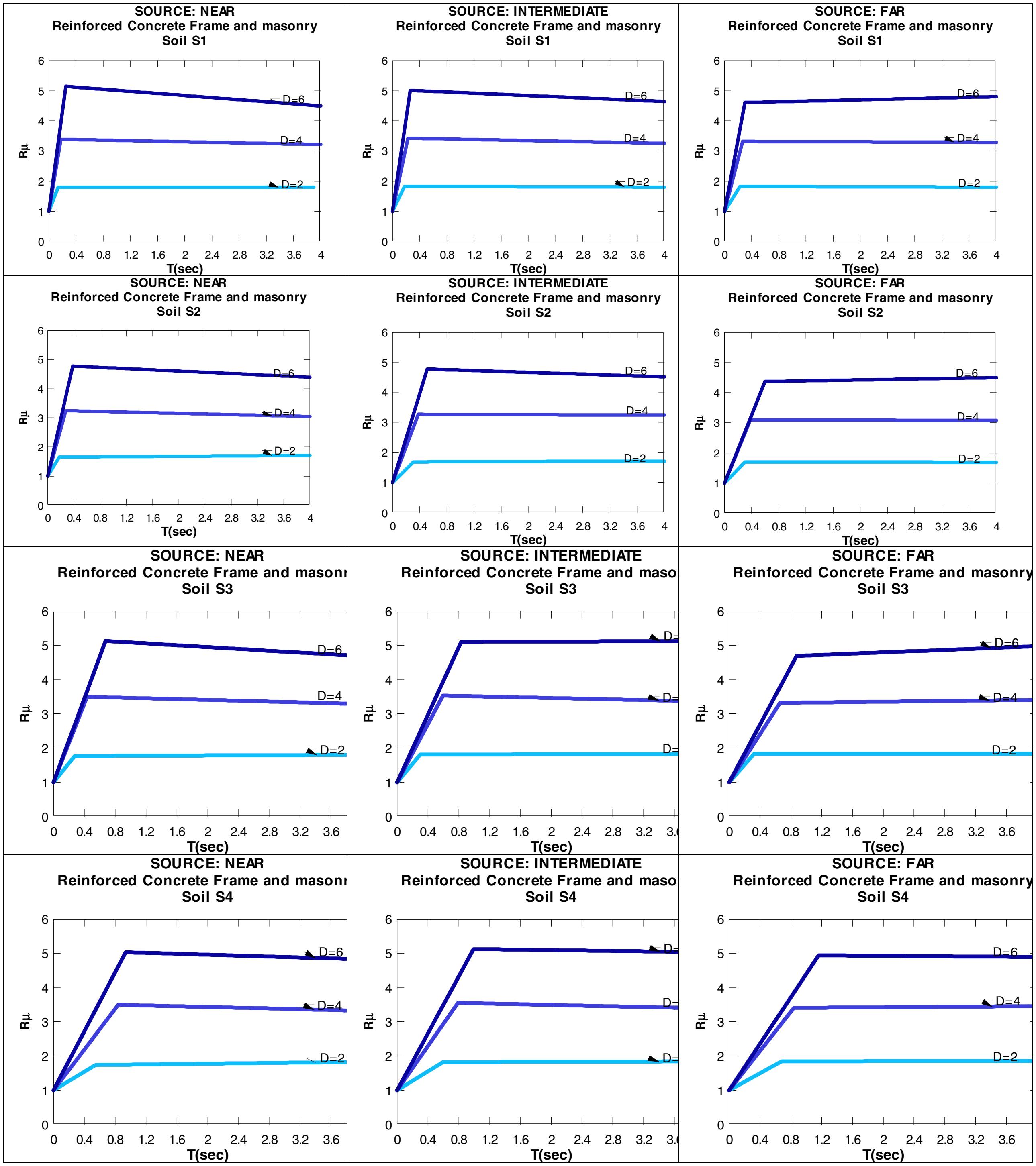

Figure 3. Average spectra of Rμ less one standard deviation of reinforced concrete frames and masonry to different soils S1, S2, S3, S4, and three sources: near, intermediate and far.

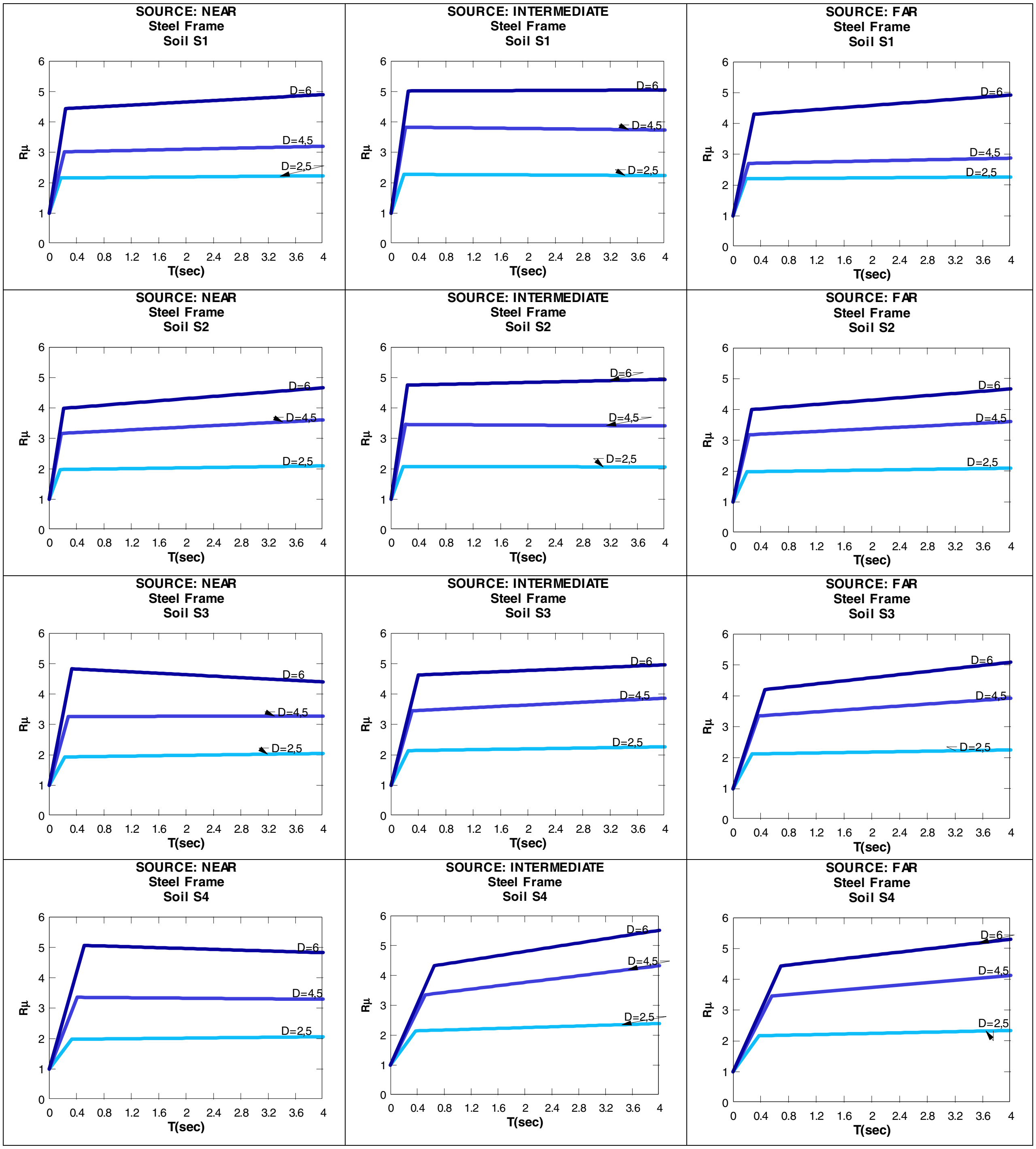

Figure 4. Average spectra of Rμ less one standard deviation of steel frames to different soils S1, S2, S3, S4, and three sources: near, intermediate and far.

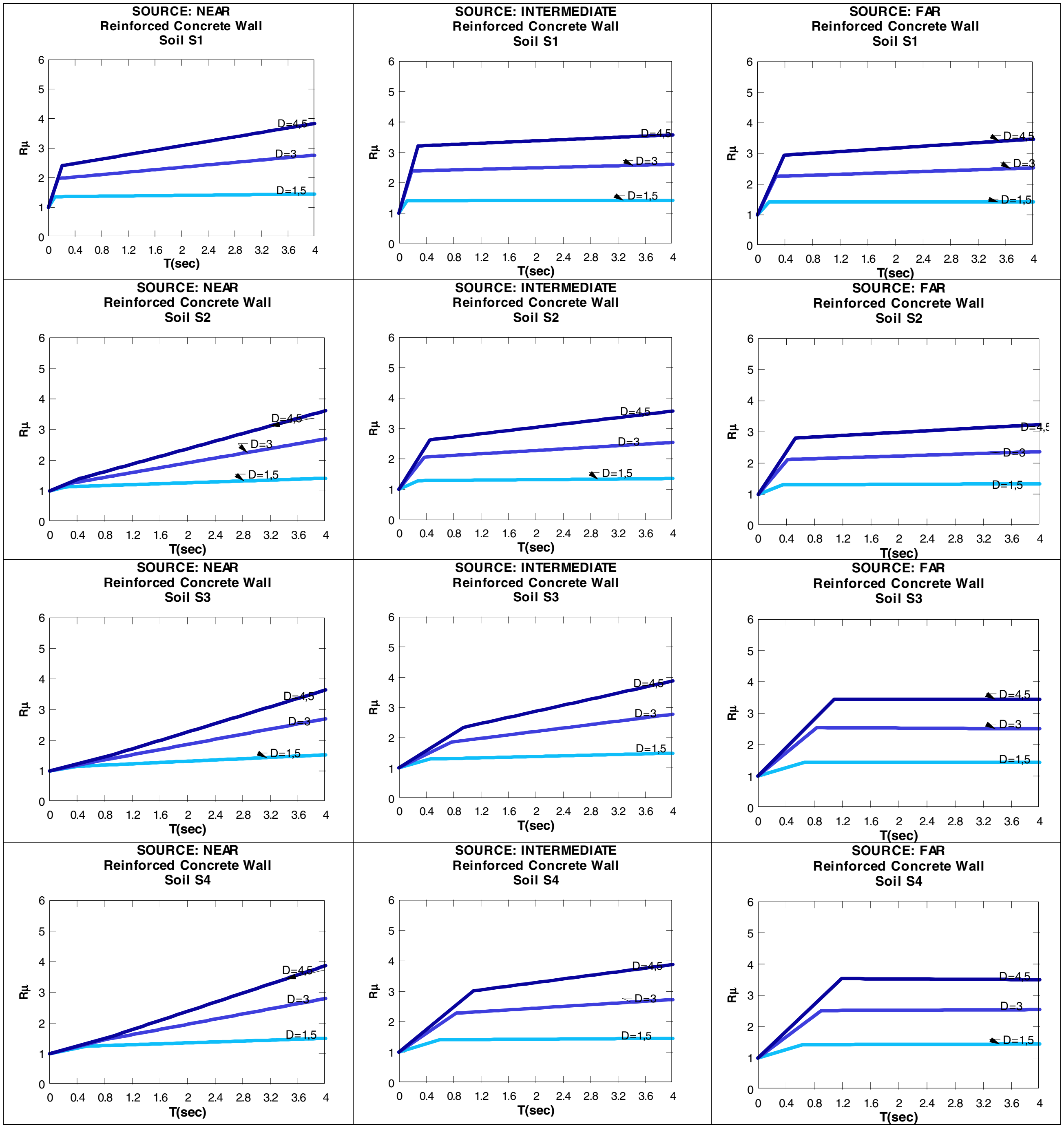

Figure 5. Average spectra of Rμ less one standard deviation of reinforced concrete walls to different soils S1, S2, S3, S4, and three sources: near, intermediate and far.

Table 8. Fulfillment of the rule of equal displacements.

SUELO	Structural Type	Near	Intermediate	Far
S1	Frame Concrete	Yes	Yes	Yes
	Frame Concrete with Masonry	Yes	Yes	Yes
	Steel Frames	No	Yes	No
	Structural Walls	No	No	No
S2	Frame Concrete	Yes	Yes	Yes
	Frame Concrete with Masonry	Yes	Yes	Yes
	Steel Frames	No	Yes	No
	Structural Walls	No	No	No
S3	Frame Concrete	Yes	Yes	No
	Frame Concrete with Masonry	Yes	Yes	Yes
	Steel Frames	Yes	Yes	No
	Structural Walls	No	No	Yes
S4	Frame Concrete	Yes	No	No
	Frame Concrete with Masonry	Yes	Yes	Yes
	Steel Frames	Yes	No	No
	Structural Walls	No	No	Yes

An application of the equations (1), (2), (3), (4) and (5), the tables (2). (3), (4), (5), (6) and (7) it shown in the sheet calculation or Table 9 and Figure 6, to obtain the inelastic spectra of design ISD.

Table 9. Sheet calculation to Inelastic Design Spectra.

<u>Calculation of inelastic design spectra</u>

Tipo de suelo: S2

Parameters of elastic spectra

β	2.45	(Table 3)
T*	0.7	(Table 3)
p	1	(Table 3)

Structural type: Frame of concrete and masonry (Table 5)

Level of design: 3 Ductility = 6

Spectral parameters Rμ (Near fault)

Tg	0.38	(Table 5)
a	1.5748	(Table 5)
b	-0.1055	(Table 5)

Period (T)	Ad (elastic)	Factor Rμ	Ad (inelastic)
0.00	1.000	1.0000	1.0000
0.10	1.382	2.0026	0.6899
0.18	1.668	2.7546	0.6054
0.38	2.450	4.8100	0.5094
0.50	2.450	4.7573	0.5150
0.70	2.450	4.7362	0.5173
0.80	2.144	4.7256	0.4536
1.00	1.715	4.7045	0.3645
1.20	1.429	4.6834	0.3052
1.40	1.225	4.6623	0.2627
1.60	1.072	4.6412	0.2309
1.80	0.953	4.6201	0.2062
2.00	0.858	4.5990	0.1865
2.50	0.686	4.5463	0.1509
3.00	0.572	4.4935	0.1272
3.50	0.490	4.4408	0.1103
4.00	0.429	4.3880	0.0977

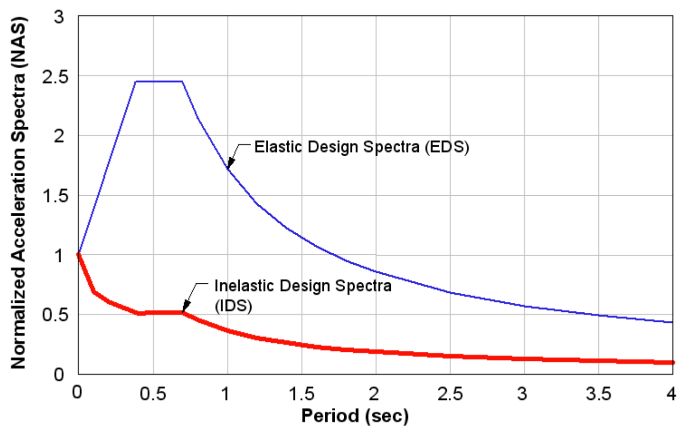

Figure 6. Inelastic design spectrum of concrete with masonry frame at near fault.

COMPARISON OF THE INELASTIC DESIGN SPECTRA (IDS) WITH COVENIN 1756-2001

As it can be seen in Figure 7, the variation is not uniform and depends on the structural type, the soil type and the ductility. Comparisons were also carried out in steel frames and structural walls. The steel frames exceed by 40% the ordinates of Covenin 1756-2001, that repeats for the S1 and S2 soils and in S3 soils reaches values of 50% in the area of the short and intermediate periods. The S4 soils present differences that exceed by 40% in the areas of short and intermediate periods, which increases to 60% for long periods. For steel frames this behavior is the same for all the levels of ductility. The concrete frames show marked differences for different levels of ductility. For S1 soils, the differences of ordinates are less than 20% for low ductilities (μ=2). For high ductilities (μ=6) the values are in the order of 40%, the tendency is the same for S2 and S3 soils.

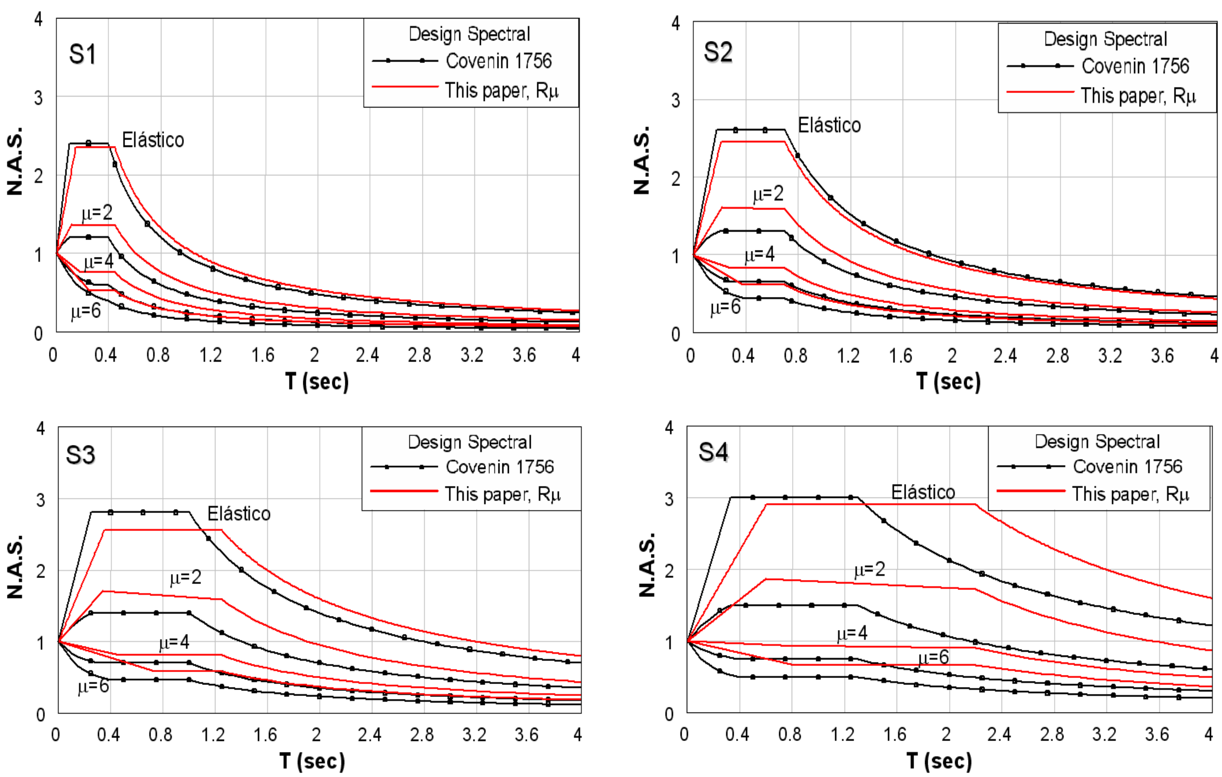

Figure 7. Comparison of the design spectra. Reinforced concrete frames for Rμ = 1, 2, 4, 6.

The behavior changes for S4 where the elastic design spectrum has one period T*= 2.2 sec., significantly displaced toward the right, when compared with Covenin for S4 (T*=1.3 sec). Similar behavior is observed for the frames of concrete and masonry, where it is evidenced in a clearer way that the differences of average ordinate values are larger than 15% for μ=2, of 20% for μ=4 and 30% for μ=6. The descending branches of the spectra don't show greater differences mainly for high ductilities. The spectral design of concrete walls exhibit small differences of ordinates (smaller to 10%) when the ductility is low (μ=1.5) for S1 soils. For larger ductilities, the difference is increased up to 40% for all the types of soils.

The general comparison of the design spectra leads to conclude that those calculated according to the factors R proposed by the Norma Covenin 1756-2001 are less conservative in the areas of short and intermediate periods with respect to the IDS calculated with the factors Rμ, determined in this paper, considering the hysteretic characteristics of structural types and the influence of inelastic response of soils on the spectral ordinates. It is important to consider the characteristic period Tg, calculated according to the geotechnical characteristics of soils and to the ductility for each structural type, since the values in Covenin 1756-2001, come from studies carried out fundamentally on hard soils.

CONCLUSIONS AND RECOMMENDATIONS

1°. The applicability of the indirect method is verified for the determination of the inelastic design spectra. The use of the hysteretic softened model that allows to represent the degradation of stiffness, strength deterioration and pinching, produces response spectra factors R, with inferior values to those calculated with hysteretic models that don't admit degradation or model it in a partial way.

2°. The ordinates of the calculated inelastic spectra obtained by the application of factors of reduction R of the Covenin 1756-2001, are smaller in the areas of the short and intermediate periods, in comparison with the inelastic spectra calculated with the response factors Rμ proposed in this paper, presenting differences that average 40% in the areas of short and intermediate periods.

3°. Little difference exists toward the area of the long periods and in the descending branch of the design spectra. The factor of response reduction Rμ is influenced by the site effects, generating smaller ordinates as the soils become less rigid or the thickness of the strata increases.

4°. The spectra of Rμ present a uniform profile in the case of rigid soils, on the other hand they present slight depressions for the case of less rigid soils, in the range of the long periods, for concrete frames.

5°. The distance of faults influences the response spectra factors of Rμ, presenting increments in the spectral ordinates for the case of records of near source with regard to records of distant source, for all the levels of ductility, and for the range of short periods.

6°. This paper introduces better criteria as to the fulfillment of the equal displacement rule according to structural type, soil type and distance to source.

7°. In the definition of the representative expressions of response factors the determination of the characteristic period Tg is important. This period increases in soft soils when the ductility increases. In the spectra of, the dependent branch of the ductility, presents a horizontal form, and it evidences its dependence of the period, in a growing way for low ductilities and falling for high ductilities.

8°. It is convenient to use simple expressions for response factors Rμ as bi-lineal equations (2) and (3), that allow to calculate in an efficient way the ordinates of the inelastic design spectra IDS. The values of Rμ corresponding to SDOF systems are the basis of the values of R in multi-degree of freedom structures MDOF.

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