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SOIL STRUCTURE INTERACTION EFFECTS ON MULTISTOREY R/C STRUCTURES

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Abstract: *This paper addresses the behavior of multistorey structures considering soil structure interaction under earthquake excitation. For this purpose, sample 3, 6, 9 storey RC frames are designed based on Turkish Seismic Design Code and analyzed in time domain with incremental dynamic analysis. Strength reduction factors are investigated for generated sample plane frames for 64 different earthquake motions recorded on different site conditions such as rock, stiff soil, soft soil and very soft soil. According to the analysis result, strength reduction factors of sample buildings considering soil structure interaction are found to be almost always smaller than design strength reduction factors given in current seismic design codes, which cause an unsafe design and non-conservative design forces.*

Keywords: Incremental dynamic analysis, soil structure interaction, strength reduction factor

1. INTRODUCTION

Current seismic provisions allow nonlinear response of building structures in the event of strong ground motions due to economic factors. As a matter of such a design approach, strength reduction factor (R_μ) which is the ratio of elastic base shear to the one required for a target ductility level are used in seismic design codes. Most of the seismic design codes currently applied in structural design do not take into consideration the soil structure phenomenon. It has been known for many years that soil structure interaction affects the elastic strength demand of structures because of the longer period and higher damping ratio of interacting system compared to the fixed base case. However, soil structure interaction effects on inelastic displacement ratios and strength reduction factors – especially for multi storey structures – have not been the topic of comprehensive researches, yet.

Strength reduction factors have been the topic of several investigations so far. The first well-known studies on strength reduction factors were conducted by Veletsos and Newmark [1] and Newmark and Hall [2]. They proposed formulas for strength reduction factors as functions of structural period and displacement ductility to be used in the short-, medium- and long period regions. Alternative formulas were proposed by Lai and Biggs [3] and Riddell et al. [4]. The first study that considered the effects of soil conditions on the strength reduction factors was conducted by Elghadamsi and Mohraz [5].

Another study which considered the site effects on the strength reduction factors was conducted by Nassar and Krawinkler, also considering the effects of yield level, strain hardening ratio and the type of inelastic material behavior [6]. More recently, Miranda [7] studied the influence of local site conditions on strength reduction factors, using a group of 124 ground motions classified into three groups as; ground motions recorded on rock, alluvium and very soft soil. During last decade, soil-structure interaction effects on strength reduction factors have been the topic of some investigations. Aviles and Perez-Rocha studied on strength reduction factors using the great 1985 Michoacan earthquake recorded at one site representative of the lakebed zone in Mexico City [8]. Also Ghannad et al. [9] studied on strength reduction factors for two different aspect ratios (h/r = 1, 3) two values of non-dimensional frequency (a_0 = 1, 3) and three levels of nonlinearity (μ = 2, 4, 6).

In this study, the seismic behavior of multi storey structures considering soil structure interaction effects is investigated. For this purpose, sample 3, 6, 9 storey plane frames were generated according to Turkish Seismic Design Code [10]. Incremental dynamic analyses were performed for those sample buildings using 64 ground motions recorded on different site conditions such as rock, stiff soil, soft soil and very soft soil. Strength reduction factors are investigated for generated sample plane frames.

Strength reduction factor (R) is defined as the ratio of elastic base shear to design strength of a building whereas the ductility part of strength reduction factor (R_μ) can be defined as the ratio of elastic base shear to actual strength of a building. In this study, elastic base shear is calculated separately for each record using the scale factor obtained from incremental dynamic analysis. This scale factor is obtained as the factor which causes the first yield point of building. Strength reduction factors are obtained as the ratio of elastic base shear which is the product of mass times spectral acceleration at first period of vibration and scale factor from which elastic behavior is not valid anymore, to design base shear of buildings.

2. GEOMETRY OF SAMPLE FRAMES AND GROUND MOTIONS

Sample 3, 6 and 9 storey RC frames are designed and detailed according to Turkish Seismic Design Code [10]. All frames are designed to be a moment resisting frame having three bays with a span length of 3m and a storey height of 3 m. The characteristic compressive strength of concrete is assumed to be 25 MPa for the design of the sample buildings and Steel Grade 420 is considered for reinforcing steel, which has characteristic yield strength of 420 MPa. Aspect ratios, number of stories and initial periods of sample buildings are given in Table 1.

Table 1. Sample buildings

Aspect ratio (h/r)	1	2	3
Number of stories	3	6	9
Initial period (s)	0.54	0.91	1.25

3. ANALYSIS PLATFORM AND RESPONSE PARAMETERS

For incremental dynamic analysis, the SeismoStruct computer package capable of predicting the large displacement behavior of space frames under static or dynamic loading, taking into account both geometric nonlinearities and material inelasticity using fibre approach to represent the cross-section behavior where each fibre is associated with a uniaxial stress-strain relationship is used [14].

To obtain the seismic performance and/or considered structural parameters such as strength reduction factors of sample buildings for both fixed-base and interacting cases from inelastic dynamic analysis results, definitions for response parameters are needed. The most important limit state in the response of the buildings to obtain strength reduction factors is yielding. The criteria used for defining yielding is classified into two groups; local and global criteria. The local yield criterion is defined as the first point when the strain in the longitudinal tensile reinforcement exceeds the yield strain of steel or the cover concrete crushes. The material strains corresponding to these situations are, 0.002 for cover concrete (ε_{co}) and 0.0021 for reinforcing steel (ε_{sy}), respectively. For global criteria, the yield capacity of the structure is defined as the point where the incremental dynamic analysis curve leaves the linear path.

4. STRENGTH REDUCTION FACTORS

Strength reduction factor (R) of sample buildings for both fixed-base and interacting cases are calculated from incremental dynamic analyses. Variation of mean strength reduction factors of interacting case with aspect ratio for different soil classes is shown in Figure 1. The top line shows the mean strength reduction factors of soil class A whereas the bottom line shows the factors of soil class D. Strength reduction factors of soil class B and C are between these lines. It can be seen from this figure that, strength reduction factors decrease from soil class A to D.

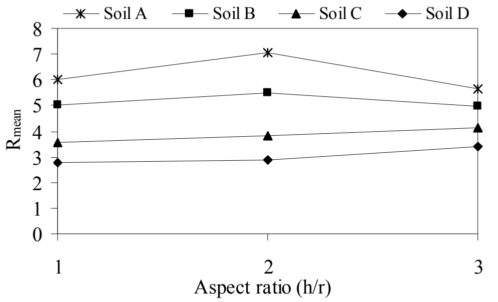


Figure 1. Variation of mean strength reduction factors of interacting case with aspect ratio

Figure 2 shows the histogram of R̃ factor for all sample buildings regardless of difference in soil classes. The strength reduction factor given in codes for the considered sample buildings is also shown in figures with dashed line. It can be seen from the figures that, strength reduction factors calculated considering soil structure interaction are generally smaller than the one given in codes.

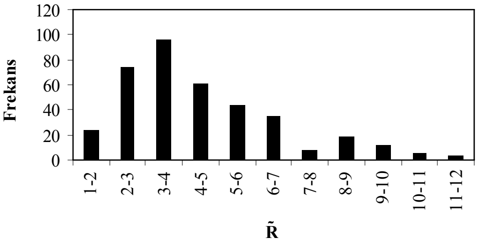


Figure 2. Histograms of R factor considering soil structure interaction for allsoil classes

Table 2. Earthquake ground motions used in analyses

Earthquake	Mag	Station	Station number	Distance (km)	Comp. 1	PGA (g)	PGV (cm/s)	Comp. 2	PGA (g)	PGV (cm/s)	C
Loma Prieta 18/10/89	7.1	Coyote Lake Dam	57217	21.8	CYC195	0.151	16.2	CYC285	0.484	39.7	A
Loma Prieta 18/10/89	7.1	Monterey City Hall	47377	44.8	MCH000	0.073	3.5	MCH090	0.063	5.8	A
Loma Prieta 18/10/89	7.1	SC Pacific Heights	58131	80.5	PHT270	0.061	12.8	PHT360	0.047	9.2	A
Northridge 17/01/94	6.7	Lake Hughes 9	127	28.9	L09000	0.165	8.4	L09090	0.217	10.1	A
Northridge 17/01/94	6.7	Wrıghtwood - Jackson Flat	23590	68.4	WWJ090	0.056	10	WWJ180	0.037	7	A
Northridge 17/01/94	6.7	Sandberg Bald Mtn	24644	43.4	SAN090	0.091	12.2	SAN180	0.098	8.9	A
Kocaeli 17/08/99	7.8	Gebze	-	17	GBZ000	0.244	50.3	GBZ270	0.137	29.7	A
Northridge 17/01/94	6.7	MT Wılson-Cıt Sta.	24399	36.1	MTW000	0.234	7.4	MTW090	0.134	5.8	A
Loma Prieta 18/10/89	7.1	Anderson Dam Downstream	1652	20	AND270	0.244	20.3	AND360	0.24	18.4	B
Northridge 17/01/94	6.7	Castaic Old Ridge	24278	25.4	ORR090	0.568	52.1	ORR360	0.514	52.2	B
Northridge 17/01/94	6.7	LA Century City North	24389	18.3	CCN090	0.256	21.1	CCN360	0.222	25.2	B
Kocaeli 17/08/99	7.8	Arçelik	-	17	ARC000	0.218	17.7	ARC090	0.149	39.5	B
Loma Prieta 18/10/89	7.1	Golden Gate Bridge	1678	85.1	GGB270	0.233	38.1	GGB360	0.123	17.8	B
Northridge 17/01/94	6.7	Ucla Grounds	24688	16.8	UCL090	0.278	22	UCL360	0.474	22.2	B
Northridge 17/01/94	6.7	LA Univ. Hospital	24605	34.6	UNI005	0.493	31.1	UNI095	0.214	10.8	B
Düzce 12/11/99	7.3	Lamont 1061	1061	15.6	1061-E	0.107	11.5	1061-N	0.134	13.7	B

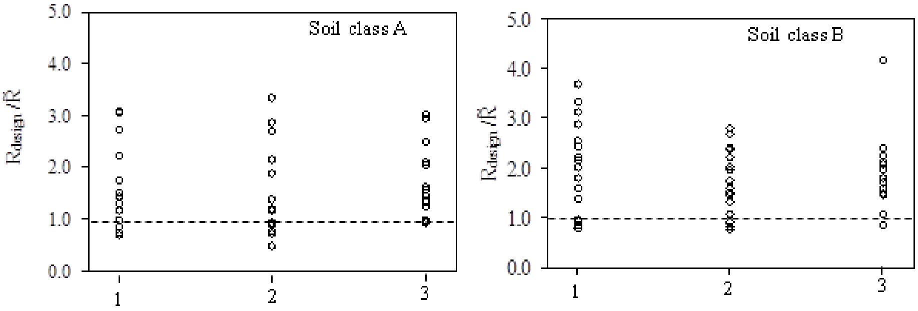
Mag: Magnitude, C: Site Class

Table 2. Earthquake ground motions used in analyses (cont.)

Earthquake	Mag	Station	Station number	Distance (km)	Comp. 1	PGA (g)	PGV (cm/s)	Comp. 2	PGA (g)	PGV (cm/s)	Site class
Landers 28/06/92	7.4	Yermo Fire Station	22074	26.3	YER270	0.245	51.5	YER360	0.152	29.7	C
Loma Prieta 18/10/89	7.1	Hollister - South & Pine	47524	28.8	HSP000	0.371	62.4	HSP090	0.177	29.1	C
Northridge 17/01/94	6.7	Downey-Birchdale	90079	40.7	BIR090	0.165	12.1	BIR180	0.171	8.1	C
Northridge 17/01/94	6.7	LA-Centinela	90054	30.9	CEN155	0.465	19.3	CEN245	0.322	22.9	C
Imperial Valley 15/10/79	6.9	Chihuahua	6621	28.7	CHI012	0.27	24.9	CHI282	0.254	30.1	C
Imperial Valley 15/10/79	6.9	Delta	6605	32.7	DLT262	0.238	26	DLT352	0.351	33	C
Loma Prieta 18/10/89	7.1	Gilroy Array #4	57382	16.1	G04000	0.417	38.8	G04090	0.212	37.9	C
Düzce 12/11/99	7.3	Bolu	Bolu	17.6	BOL000	0.728	56.4	BOL090	0.822	62.1	C
Loma Prieta 18/10/89	7.1	Appel 2 Redwood City	1002	47.9	A02043	0.274	53.6	A02133	0.22	34.3	D
Northridge 17/01/94	6.7	Montebello	90011	86.8	BLF206	0.179	9.4	BLF296	0.128	5.9	D
Superstition Hills 24/11/87	6.6	Salton Sea Wildlife Refuge	5062	27.1	WLF225	0.119	7.9	WLF315	0.167	18.3	D
Loma Prieta 18/10/89	7.1	Treasure Island	58117	82.9	TRI000	0.1	15.6	TRI090	0.159	32.8	D
Kocaeli 17/08/99	7.8	Ambarli	-	78.9	ATS000	0.249	40	ATS090	0.184	33.2	D
Morgan Hill 24/04/84	6.1	Appel 1 Redwood City	58375	54.1	A01040	0.046	3.4	A01310	0.068	3.9	D
Düzce 12/11/99	7.3	Ambarlı	-	193.3	ATS030	0.038	7.4	ATS300	0.025	7.1	D
Kobe 16/01/95	6.9	Kakogawa	0	26.4	KAK000	0.251	18.7	KAK090	0.345	27.6	D

Mag: Magnitude

Figure 3 shows the variation of ratio of design strength reduction factors given in codes to calculated strength reduction factors considering soil structure interaction against period for soil classes A to D, respectively. It can be seen from the figure that, strength reduction factors of interacting systems are almost always smaller than the design strength reduction factors given in codes. Thus, using the fixed-base strength reduction factor for interacting case lead to non conservative design forces.



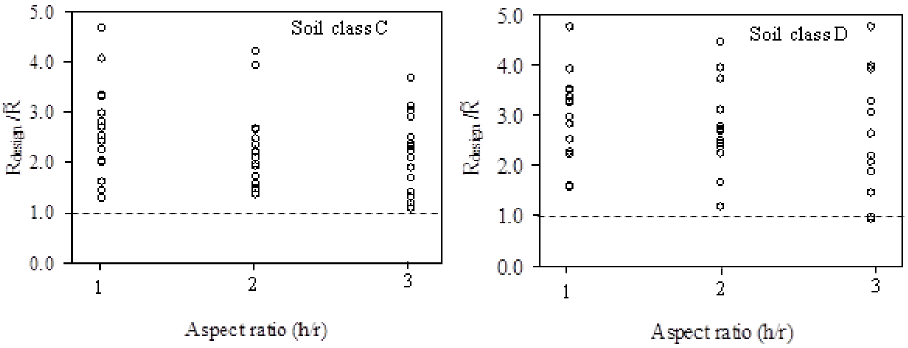


Figure 3. Ratio of strength reduction factor calculated considering soil structure interaction to design strength reduction factor for soil classes

5. CONCLUSIONS

In this study, the seismic behavior of multi storey structures considering soil structure interaction effects is investigated. For this purpose, sample 3, 6 and 9 storey plane frames were generated according to Turkish Seismic Design Code. Incremental dynamic analyses were performed for those sample buildings using 64 ground motions recorded on different site conditions such as rock, stiff soil, soft soil and very soft soil to determine the yielding and collapse capacity of each sample building. The following conclusions can be drawn from the results of this study. Variation of mean strength reduction factors of interacting case with aspect ratio for different soil classes is shown in Figure 1. It can be seen from this figure that, strength reduction factors decrease from soil class A to D. The ratio between the cases of soil class A and D can be up to 2.0.

The histogram for strength reduction factor values considering soil structure interaction is given in Figure 2. It is seen that strength reduction factors calculated considering soil structure interaction are generally smaller than the one given in codes. There is a limited similar tendency for soil classes A and B. This case leads an unsafe design in case of primary soil structure interaction effects. The strength reduction factor values considering soil structure interaction are almost always lower than the strength reduction factor value given in codes for design for all sample buildings investigated. Especially for soil classes C and D, soil structure interaction effects on strength reduction parameters can’t be neglected. Thus, using the fixed-base strength reduction factor for interacting case, lead to non-conservative design forces.

6. REFERENCES

[1] Veletsos A.S., Newmark N.M., *Effect of inelastic behavior on the response of simple systems to earthquake motions.* Proceedings of the Second World Conference on Earthquake Engineering, Tokyo, 895–912, 1960.
[2] Newmark, N.M., Hall, W.J., *Seismic design criteria for nuclear reactor facilities.* Report No. 46, Building Practices for Disaster Mitigation, National Bureau of Standards, U.S. Department of Commerce, pp.209-236, 1973.
[3] Lai S.P., Biggs J.M., *Inelastic response spectra for a seismic building design.* Journal of Structural Engineering, ASCE, 106:1295–310, 1980.
[4] Riddell R., Hidalgo P., Cruz E., *Response modification factors for earthquake resistant design of short period structures.* Earthquake Spectra; 5(3):571–90, 1989.
[5] Elghadamsi, F.E., Mohraz, B., *Inelastic earthquake spectra.* Earthquake Engineering and Structural Dynamics, Vol. 15, pp. 91-104, 1987.
[6] Nassar, A.A., Krawinkler, H., *Seismic demands for SDOF and MDOF systems.* Report No.95, The John A. Blume Earthquake Engineering Center, Stanford University, Stanford, California, 1991.
[7] Miranda, E., *Site dependent strength reduction factors.* Journal of Structural Engineering, ASCE, Vol.119, No.12, 1993.
[8] Aviles, J., Perez-Rocha, L.E., *Influence of foundation flexibility on R_μ and C_μ factors*. Journal of Structural

Engineering, ASCE, Vol.131, No.2, 2005.

[9] Ghannad, M.A., Jahankhah, H., *Site-dependent strength reduction factors for soil-structure systems.* Soil Dynamics and Earthquake Engineering, 27: 99-110, 2007.

[10] Ministry of Public Works and Settlement, Turkish Seismic Design Code, Ankara, 2007. [in Turkish]

[11] Applied Technology Council - ATC, Seismic evaluation and retrofit of concrete buildings. ATC-40, Applied Technology Council, California, 1996.

[12] Applied Technology Council - ATC, Quantification of building seismic performance factors. ATC-63, Applied Technology Council, California, 2008.

[13] Boore, D.M., *Some notes concerning the determination of shear-wave velocity and attenuation.* Proceedings of geophysical techniques for site and material characterization, p. 129-34, 1993.