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Design parameter dependent force reduction, strength and response modification factors for the special steel moment-resisting frames

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Abstract. In current ductility-based earthquake-resistant design, the estimation of design forces continues to be carried out with the application of response modification factors on elastic design spectra. It is well-known that the response modification factor (R) takes into account the force reduction, strength, redundancy, and damping of structural systems. The key components of the response modification factor (R) are force reduction (R_μ) and strength (R_S) factors. However, the response modification and strength factors for structural systems presented in design codes were based on professional judgment and experiences. A numerical study has been accomplished to evaluate force reduction, strength, and response modification factors for special steel moment resisting frames. A total of 72 prototype steel frames were designed based on the recommendations given in the AISC Seismic Provisions and UBC Codes. Number of stories, soil profiles, seismic zone factors, framing systems, and failure mechanisms were considered as the design parameters that influence the response. The effects of the design parameters on force reduction (R_μ), strength (R_S), and response modification (R) factors were studied. Based on the analysis results, these factors for special steel moment resisting frames are evaluated.

Keywords: design parameter; special steel moment resisting frames; response modification factor; force reduction factor; strength factor

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1. Introduction

In current earthquake-resistant design, structures are designed for the lateral design forces taken to be much smaller than those for a perfectly elastic structure. This was based on the prerequisite that well-detailed seismic framing systems could sustain large inelastic deformations without collapse, and develop lateral strengths exceeding their design strength. As the results of this design philosophy, the design base shear is calculated by dividing the base for elastic response by response modification factor (R). It is reported that the response modification factor (R) takes into account the capacity to dissipate energy, over-strength, redundancy, and damping of structural systems (ATC-19 1995, ATC-34 1995). The key components of the response modification factor (R) are force reduction (R_μ) and strength (R_S) factors. The response modification (R) and strength (R_S) factors presented in design specifications mostly depend on engineering judgment and on some observations during experiments and past

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earthquakes. The UBC and IBC recommend a value of 8.5 for response modification factor (R), and 2.8 for strength (refer to over-strength) factor (R_S) for special steel moment resisting frames (UBC 1997 and ICC 2000). However, these single values for response modification (R) and strength (R_S) factors have been pointed out the lack of rationality by several researchers including ATC-19 and ATC-34 reports (ATC-19 1995, ATC-34 1995, Kim, J. K. and Choi, H. H. 2005, Galíndez, N. and Thomson, P. 2007, Asgarian, B and Shokrgozar, H. R. 2009, Can, O. Z and Cen, T. 2009, Mahmoudi, M and Zaree, M. 2010, etc).

The main objective of this paper is to explore the dependence of the force reduction (R_μ), strength (R_S), and response modification (R) factors for special steel moment resisting frames on the design parameters such as the number of stories, framing systems, failure mechanisms, soil profiles, and seismic zone factors. A total of 72 prototype steel frames were designed to investigate force reduction (R_μ), strength (R_S) and response modification (R) factors considering the above-mentioned design parameters. The influences of the design parameters on these factors were studied.

2. Design of special steel-moment-resisting frames

2.1 Prototype model frames

A series of prototype steel frames were designed to investigate the force reduction (R_μ), strength (R_S) and response modification factors (R). Designs for 4, 8, and 16-stories were performed, following the AISC provisions (*AISC*, 1994, 2002) and UBC standards (*UBC*, 1997). The story height was 5,486 mm for the bottom story and 3,658 mm for all the other stories. All the structures had a 3-bay x 4-bay plan, with bay dimensions of 7,315 mm × 7,315 mm. Only the behavior in the 3-bay direction was investigated. Fig. 1 shows the typical floor plan and member identifications for 16-story. Each frame was designed as a braced frame under the assumption that the lateral stability was provided by diagonal bracing, shear wall or equivalent means. Therefore, the effective length factor (K) for column was calculated less than 1.0. Models were developed based on *UBC 1997* for two structural framing systems: the perimeter frame (*PF*) and the distributed frame (*DF*), as illustrated in Fig. 1.

For the PF model, only the perimeter frames correspond to the moment-resisting frame (MRF). For the DF model, all the frames in the 3-bay direction correspond to the moment-resisting frame (MRF). The dead load was 4.8 kN/m^2 on all levels. The live design load was 2.4 kN/m^2 for the floors and 1.2 kN/m^2 on the roof. Some member sizes of the basic SCWB and WCSB frames in the three–bay direction are provided in Table 1 with the member identities are given in Fig. 1.

Researches have historically focused on beam hinges, that is, strong-column weak-beam (SCWB) steel frames, because they are more ductile than column hinges, that is, WCSB frames. With regard to SCWB joints, one of the following relationships shall be satisfied for special steel-moment-resisting frames and are assured by UBC (*UBC* 1997) and ICC (*ICC* 2000).

$$\frac{\Sigma Z_C(F_{yc} - P_{uc}/A_g)}{\Sigma Z_b F_{yb}} \geq 1.0 \tag{1}$$

$$\frac{\Sigma Z_C(F_{yc} - P_{uc}/A_g)}{V_n d_b H/(H - d_b)} \geq 1.0 \tag{2}$$

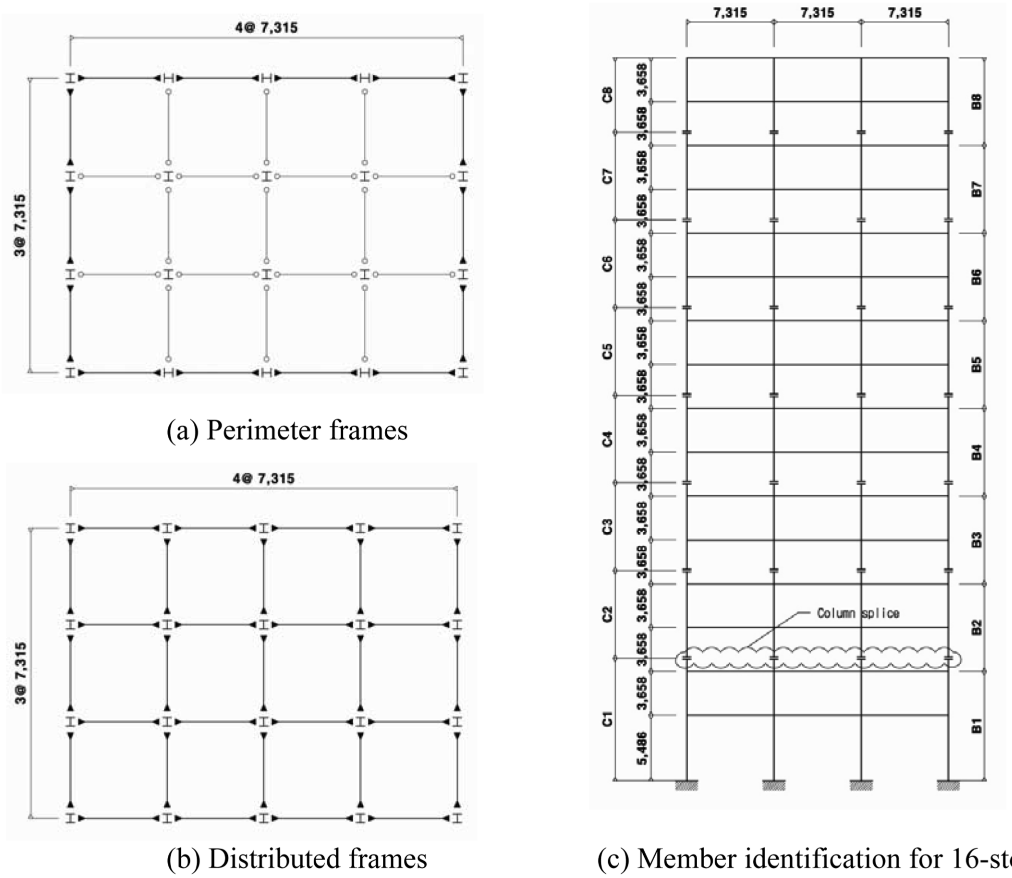


Fig. 1 Floor plan and member identification for 16-story

It is sometimes uneconomical or impractical, however, to determine the SCWB behavior at each joint. Consequently, UBC(UBC 1997) and NEHRP (FEMA-302 1997) permit the use of WCSB joints under specific conditions. In any of the following cases, the strength of the joint need not satisfy Eq. (1) or (2):

· Columns with $P_{uc} < 0.3\ F_{yc}\ A_g$;
· Columns in any story that have a ratio of the design shear strength to the design force that is 50% greater than the story above; and
· Any column not included in the design for the resistance of the required seismic shears, but included in the design for the resistance of axial overturning forces.

A total of 72 frames were designed for the following permutations.
• SCWB and WCSB failure mechanisms.
• Perimeter frames (PF) and distributed frames (DF).
• Structures with 4, 8, and 16 stories.
• Site categories with S_A, S_C and S_E.
• Seismic zone factors with Z = 0.2 (Z2B) and 0.4 (Z4).

Table 1 Some member sizes of prototype frames

Member ID	8-stroy, soil profile, S_A, and seismic zone factor, Z=0.4			
	SCWB PF	SCWB DF	WCSB PF	WCSB DF
	(a) Girders			
B4	W16*45	W18*50	W18*71	W18*55
B3	W21*68	W18*50	W24*84	W24*76
B2	W24*76	W18*55	W27*94	W27*114
B1	W24*94	W18*60	W30*99	W30*116
	(b) Interior columns			
C4	W16*67	W12*106	W16*50	W12*65
C3	W18*119	W12*120	W18*60	W12*120
C2	W21*132	W12*152	W21*101	W12*230
C1	W27*161	W12*190	W21*132	W12*252
	(c) Exterior columns			
C4	W12*50	W10*68	W12*30	W12*40
C3	W12*79	W10*77	W12*53	W12*72
C2	W12*106	W10*88	W12*72	W12*106
C1	W12*136	W10*100	W12*96	W12*136

In general, the size of structural member is controlled by *Strength criteria* or *Drift criteria* (A. A. Vasilopolus et al, 2008, M. S. Hayalioglu et al, 2007, P. Torkzadeh, et al, 2008). In SCWB PF models, most sizes of the structural members were controlled by drift criteria. In SCWB DF models, some sizes of the structural members were controlled by drift criteria in higher seismic design intensity ranges, but it were controlled by strength criteria in lower seismic design intensity ranges. In WCSB PF models, some sizes of the structural members were controlled by drift criteria in higher seismic design intensity ranges, but it were controlled by *Exception criteria*, that is, columns with $P_{uc} < 0.3\ F_{yc}\ A_g$, in lower seismic design intensity ranges. In WCSB DF models, most sizes of the structural members were controlled by exception criteria except for extreme higher seismic design intensity ranges. These *Exception criteria* caused the some extreme values of the strength factors (R_S) in WCSB models, especially in lower seismic design intensity ranges.

2.2 Pushover Analysis

The pushover analysis is an evaluation method in which force and deformation demands are estimated from a nonlinear static, incremental, and inelastic analysis. The pushover analysis of the frames was performed with DRAIN-2D+ computer program (Tsai, K. C. and Li, J. W., 1994). Eigenvalue analyses were carried out to determine the elastic natural periods and mode shapes of the model frames. Then pushover analyses were performed by subjecting a structure to monotonically increasing lateral forces proportional to the fundamental mode shape. The DRAIN-2D+ beam-column element (element 2), with 1% strain hardening, is the primary element used in these analyses.

The effects of panel zone and contribution of the floor slab were not included. The welded beam-to-column joints are taken to be fully restrained (FR) joints, defined as joints which results in less than 5% contribution to the frame displacement (FEMA-274 1997). Table 2 shows the fundamental period and % of mass participation for each frame.

The ductility ratio (μ) can be computed at the system, story, and element levels. At the system and story levels, force reduction ratio (μ) is generally expressed in terms of the displacement ductility ratio.

Table 2 Fundamental period and % of mass participation

Soil profile	Zone factor	Story	SCWB PF		SCWB DF		WCSB PF		WCSB DF	
			T1 (sec)	Mass (%)	T1 (sec)	Mass (%)	T1 (sec)	Mass (%)	T1 (sec)	Mass (%)
Sa	0.2	4	2.003	89.00	1.332	92.33	2.061	90.64	1.196	92.07
		8	3.274	83.56	2.327	85.93	2.583	80.28	1.403	81.33
		16	3.841	76.57	4.246	80.76	3.697	73.07	1.767	71.14
	0.4	4	1.461	91.30	1.332	92.33	1.473	89.51	1.337	93.14
		8	2.172	80.26	2.294	85.53	2.252	84.16	1.496	82.82
		16	2.961	79.21	2.941	78.89	2.990	78.64	1.794	68.83
Sc	0.2	4	1.461	91.30	1.332	92.33	1.463	91.31	1.339	93.02
		8	2.374	81.77	2.294	85.53	2.337	84.01	1.488	84.62
		16	3.476	78.20	3.174	78.50	3.410	77.28	1.767	71.14
	0.4	4	1.112	91.47	1.067	91.02	1.113	90.57	1.054	92.45
		8	1.791	83.44	1.752	84.79	1.825	84.63	1.530	82.22
		16	2.661	78.42	2.669	79.10	2.703	81.14	1.794	68.83
Se	0.2	4	1.019	90.77	1.067	91.02	1.072	89.41	0.968	91.32
		8	1.703	82.27	1.653	84.39	1.692	82.58	1.530	82.22
		16	2.806	78.40	2.872	77.92	2.885	78.48	1.794	68.83
	0.4	4	1.019	90.77	1.007	90.84	1.015	90.39	0.980	92.32
		8	1.396	84.19	1.405	85.07	1.409	83.17	1.307	85.55
		16	2.348	78.97	2.325	80.04	2.432	79.70	1.791	71.34

For the purpose of this study, the displacement ductility ratio at the system level is used to determine the force reduction factor. The procedure used to estimate the strength of a building was straightforward, but required the analyst to select a limiting state of response. Typical limiting responses include maximum inter-story drift and maximum plastic hinge rotation. The practical drift limit for the *Life Safety* and *Collapse Prevention* performance might have been 0.02 and 0.04, respectively (FEMA-274 1997). The drift limit to estimate the displacement ductility ratio is assumed 0.04 inter-story drift at any story.

3. Evaluation methology and procedures

A systematic evaluation strategy of the force reduction (R_μ), strength (R_S), and response modification (R) factors is presented in Fig. 2 (Uang, C. M. 1991, ATC-19 1995).

In this figure, V_e correspond to the elastic response strength of the structure. The maximum base shear in an elasto perfectly plastic behavior is V_0. The force reduction factor (R_μ) is defined as the ratio of elastic response strength (V_e) to maximum base shear in actual behavior (V_0). The strength factor (R_s) is defined as the ratio of maximum base shear in actual behavior (V_0) to design base shear (V_d).

3.1 Force Reduction Factors for SDOF Systems

The force reduction factors (R_μ) for SDOF systems were calculated from nonlinear time history analysis for elastic perfectly plastic SDOF systems. A group of 1860 ground motions recorded on a wide range of soil conditions during 47 different earthquakes were considered to compute the force reduction factors for SDOF systems (Kang, C. K. and Choi, B. J., 2002, 2004, 2010). Based on the results of regression analysis, the following simplified expressions were proposed to computer force

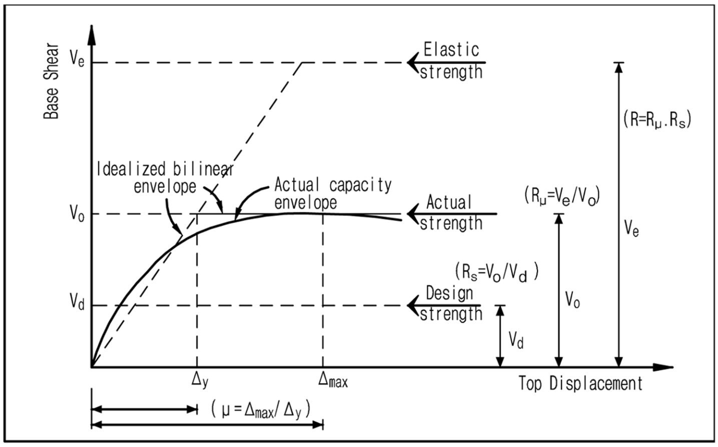


Fig. 2 Evaluation of force reduction, strength and response modification factor

reduction factors.

$$R_{\mu,\,SDOF} = 1 + \frac{T}{\phi} \tag{3}$$

In this expression, ϕ is a function of the displacement ductility ratio (μ), the period (T), and the site conditions (Kang, C. K. and Choi, B. J., 2010).

3.2 Force Reduction Factor for MDOF Systems

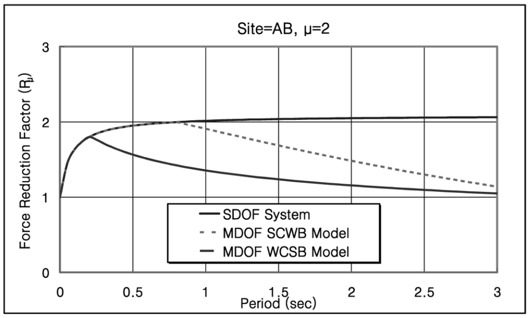
For real structures, this force reduction factor ($R_{\mu,SDOF}$) was modified to account for multi-degree-of-freedom (MDOF) effects. In practice, most structures need to be modeled as MDOF systems and have a much more complex behavior than SDOF systems, particularly in the non-linear range. Thus, the force reduction factor of SDOF systems must be modified for the design of MDOF structures.

Nassar and Krawinkler (1991) and Miranda (1997) provided some of the answers to the assessment of the strength demands of inelastic MDOF systems for their comparison with their SDOF counterparts. The modification factor (R_M) was proposed to account for MDOF systems, based on these previous studies. It was reported that modification factor (R_M) decreases with an increasing story displacement ductility ratio (μ) and period (T). The simplified expressions for MDOF modification factors (R_M) were given by Appendix (Kang, C. K. and Choi, B. J., 2010).

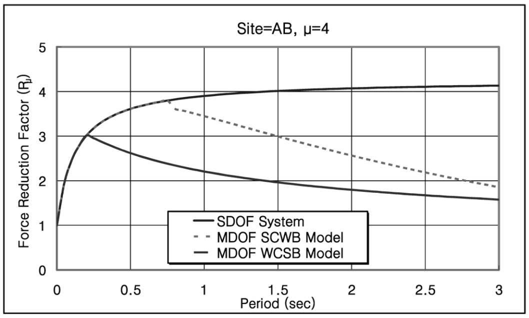
The force reduction factors for MDOF systems were calculated by following expressions.

$$R_{\mu} = R_{\mu,\,SDOF} \times R_M \tag{4}$$

The force reduction factors of the SDOF and MDOF systems, when subjected to the ground motions recorded at site AB (rock site) during earthquakes with a displacement ductility ratio $\mu = 2$ and 4, are shown in Fig. 3. As shown in these figures, the force reduction factors of the SDOF systems approached the target displacement ductility ratios, whereas those of the MDOF systems decreased rapidly in the long period range. As shown in Fig. 3, the MDOF effects for WCSB models are more prominent than SCWB models.



(a) μ=2



(b) μ=4

Fig. 3 Force reduction factors of the SDOF and MDOF systems in Site AB

3.3 Strength factors

The strength factor (R_s) is the ratio between the actual structural strength (V_0) and design base shear strength (V_d). Non-linear static analysis can be used to estimate the strength of a building or framing system. The non-linear static analysis of the frames was performed with DRAIN-2D + computer program (Tsai, K. C. and Li, J. W., 1994). The following expressions were used to compute the strength factors (R_s).

$$R_s = \frac{V_0}{V_d} \tag{5}$$

3.4 Response modification factors

Consequently, the response modification factors (R) for prototype structures were calculated by multiplying force reduction factor (R_μ) for MDOF systems and strength factors (R_s) together as following manners.

$$R = R_\mu \times R_S \tag{6}$$

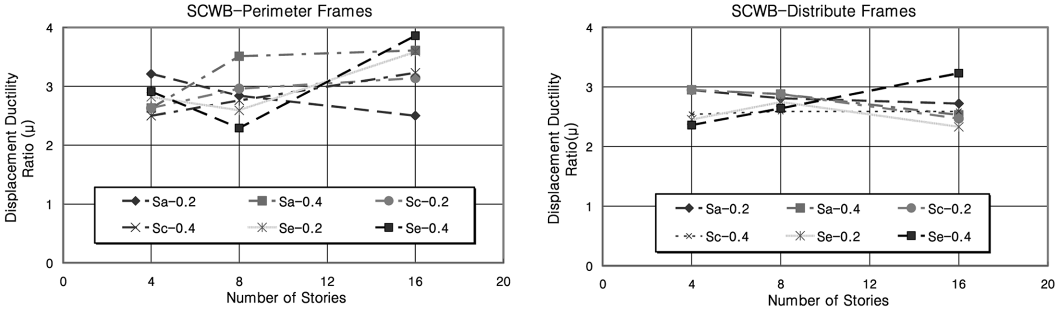
4. Effects of design parameters

4.1 Number of Stories

The variations of displacement ductility ratio (μ) and force reduction factors (R_μ) with the number of stories for SCWB models are shown Figs. 4 and 5, respectively. From these figures, the following observations are made for SCWB models.

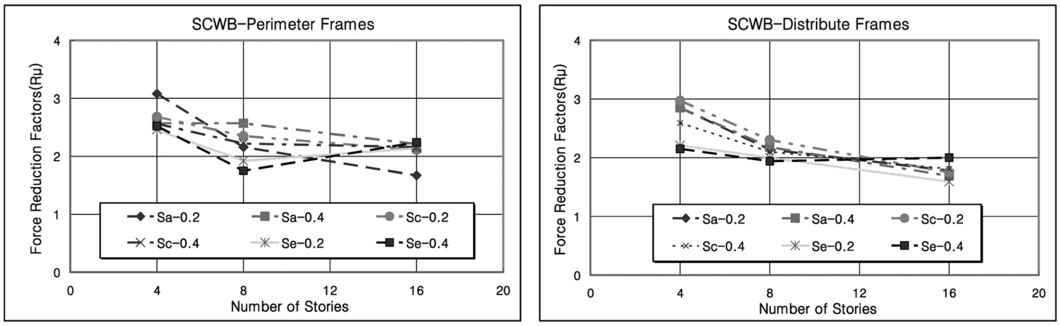
- It showed that the displacement ductility ratios (μ) are generally increased with the increasing the number of stories.
- However, the more number of stories are increased, the more force reduction factors (R_μ) are decreased. This trend is because of the decrease in modification factor (R_M) with the increase the number of stories and displacement ductility ratio, as shown in Fig. 3.

The strength (R_s) and response modification (R) factors with the number of stories for SCWB models



(a) SCWB-Perimeter Frames (b) SCWB-Distributed Frames

Fig. 4 Variations of displacement ductility ratio (μ) with the number of stories



(a) SCWB-Perimeter Frames (b) SCWB-Distributed Frames

Fig. 5 Variations of R_μ factors with the number of stories for SCWB models

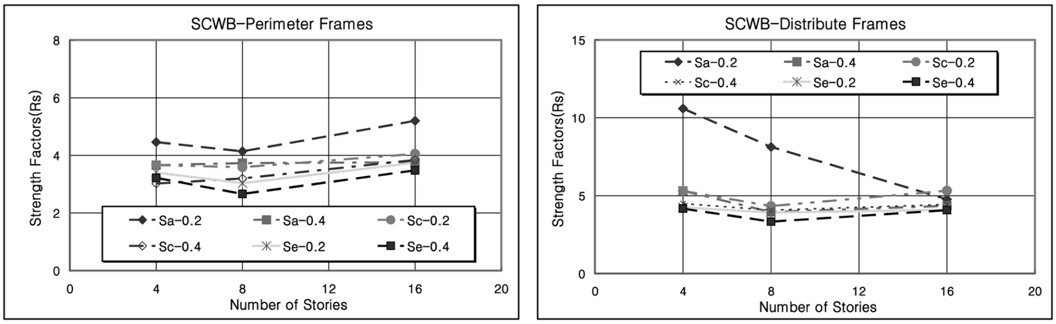
are shown Figs. 6 and 7, respectively. From these figures, the following observations are made for SCWB models.

- It showed that the more stories are increased, the more strength (R_s) and response modification factors(R) are decreased.
- In comparison of force reduction and strength factors, the variations of strength factors with the number of stories are more remarkable than force reduction factors.
- In comparison of perimeter and distributed frames, the variations of strength and response modification factors with the number of stories for distributed frames are more remarkable than perimeter frames.

Figs. 8 and 9 show the variations of displacement ductility ratio (μ) and force reduction factors (R_μ) with the number of stories for WCSB models. As shown in these figures, the displacement ductility ratios (μ) and force reduction factors (R_μ) are decreased with the increasing the number of stories.

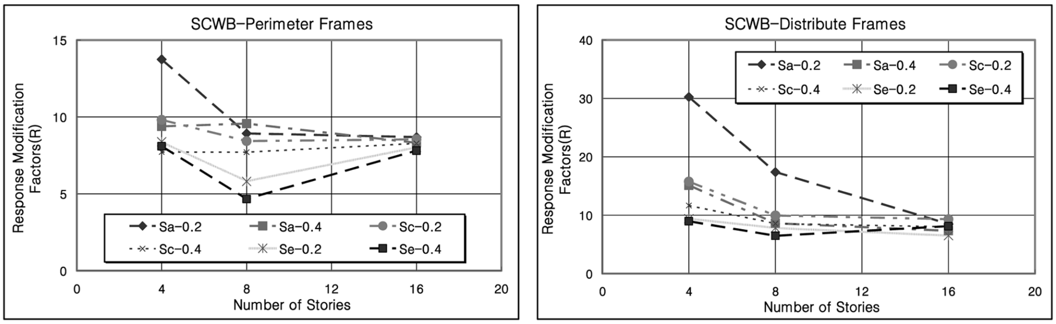
Figs. 10 and 11 show the variations of strength (R_S) and response modification factors (R) with the number of stories for WCSB models. From these figures, the following observations are made for WCSB models.

- The variation of the strength (R_s) and response modification(R) factors with the number stories are affected by whether the member sizes are controlled by strength criteria, drift (stiffness) criteria or exception criteria. As shown in Figs. 10 and 11, the variation of these factors with the number of



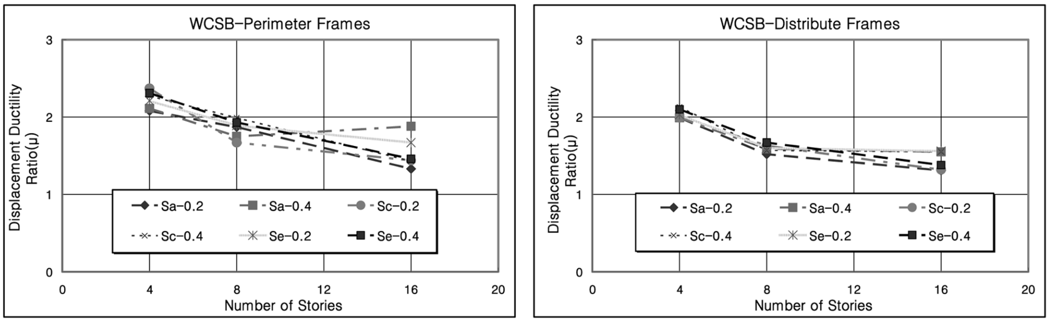
(a) SCWB-Perimeter Frames (b) SCWB-Distributed Frames

Fig. 6 Variations of Rs factors with the number of stories for SCWB models



(a) SCWB-Perimeter Frames (b) SCWB-Distributed Frames

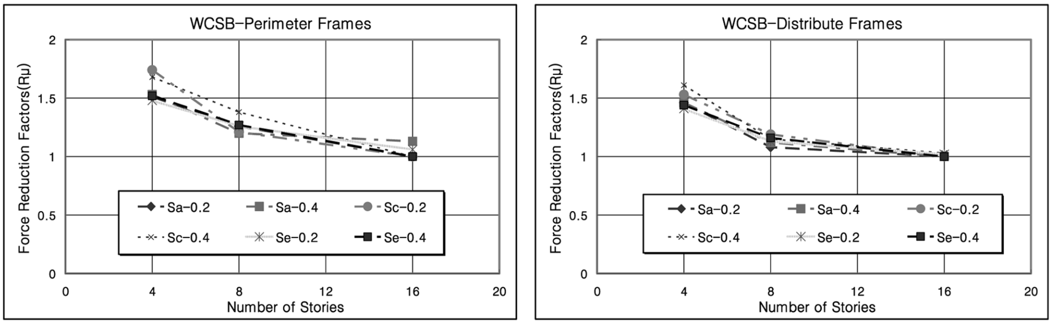
Fig. 7 Variations of R factors with the number of stories for SCWB models



(a) WCSB-Perimeter Frames (b) WCSB-Distributed Frames

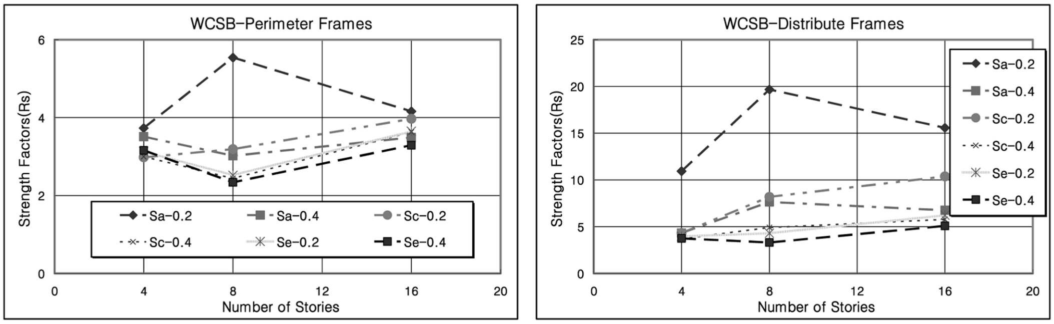
Fig. 8 Variations of displacement ductility ratio (μ) with the number of stories

stories are prominent when member sizes are controlled by *exception criteria* to meet the WCSB, for instance, seismic zone factor is $Z = 0.2$. This exception requirement plays a great role in the determination of cress-sectional sizes and gives rise to a great strength factor, especially in lower seismic zones, rock sites and high-rise buildings.



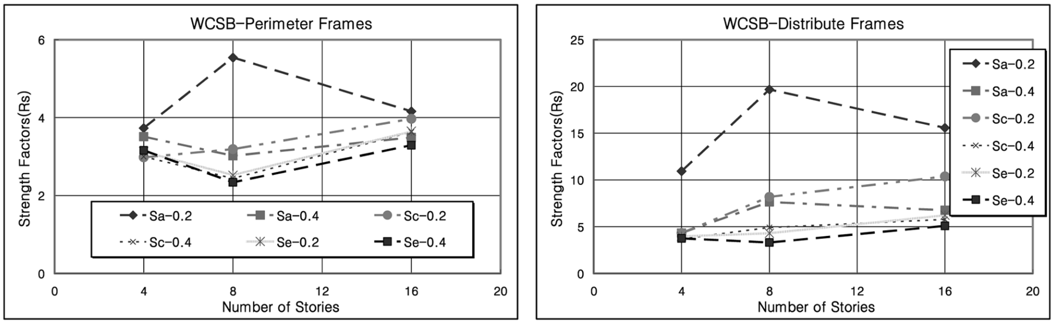
(a) WCSB-Perimeter Frames (b) WCSB-Distributed Frames

Fig. 9 Variations of R_{μ} factors with the number of stories for WCSB models



(a) WCSB-Perimeter Frames (b) WCSB-Distributed Frames

Fig. 10 Variations of Rs factors with the number of stories for WCSB models

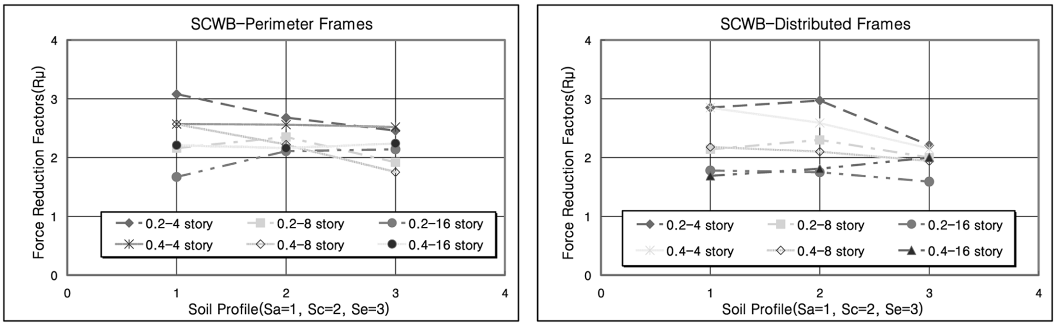


(a) WCSB-Perimeter Frames (b) WCSB-Distributed Frames

Fig. 11 Variations of R factors with the number of stories for WCSB models

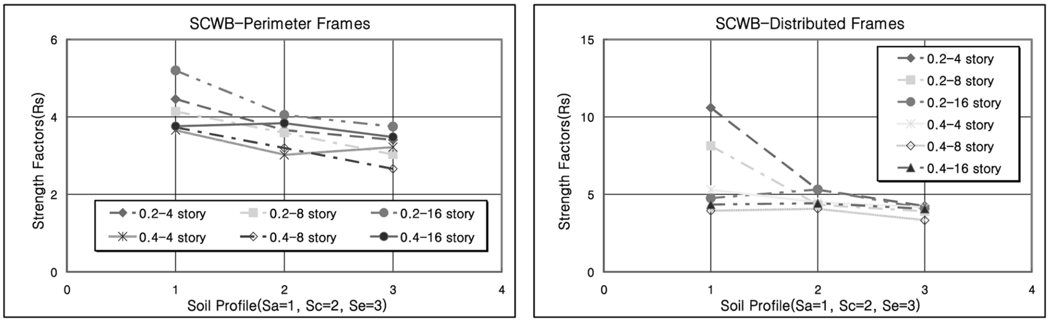
4.2 Soil profile

From Figs. 12 to 14 illustrate the variations of force reduction (R_{μ}), strength (R_s) and response modification factors (R) with the soil profiles for SCWB models. The results in Fig. 12 through 14 show general trends that can be summarized as follows.



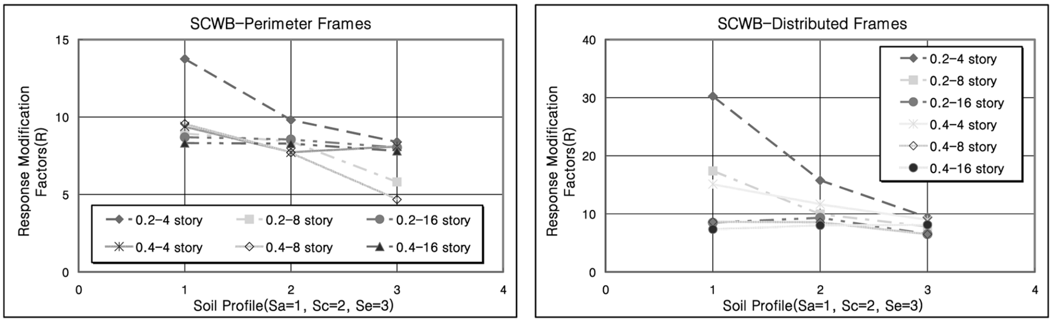
(a) SCWB-Perimeter Frames (b) SCWB-Distributed Frames

Fig. 12 Variations of R_μ factors with the soil profiles for SCWB models



(a) SCWB-Perimeter Frames (b) SCWB-Distributed Frames

Fig. 13 Variations of Rs factors with the soil profiles for SCWB models



(a) SCWB-Perimeter Frames (b) SCWB-Distributed Frames

Fig. 14 Variations of R factors with the soil profiles for SCWB models

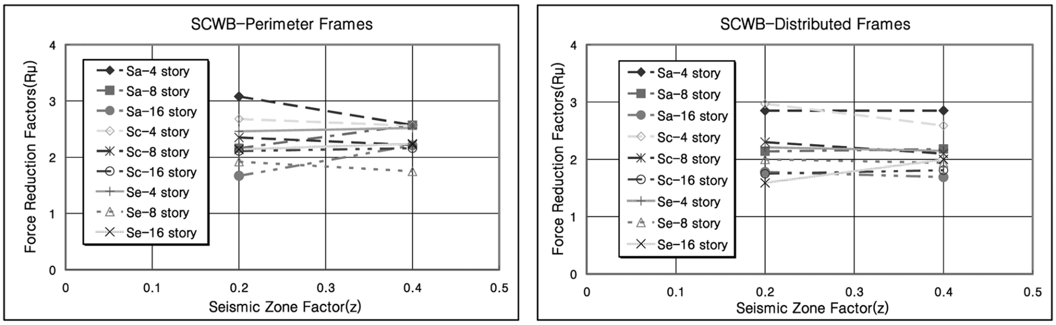
- The soil profile has a small effect on the force reduction factors (R_μ), although there are no general trends.
- However, the soil profiles have a great influence on the strength (R_s) and response modification factors (R). The variations of strength and response modification factors with the soil profiles are

more significant in lower seismic zones as compared to higher seismic zones.
- In comparison of perimeter and distributed frames, the variations of strength and response modification factors with the soil profiles for distributed frames are more remarkable than perimeter frames.

For WCSB models, it is showed that the variations of force reduction, strength and response modification factors with soil profiles seem to follow a similar pattern as the SCWB models.

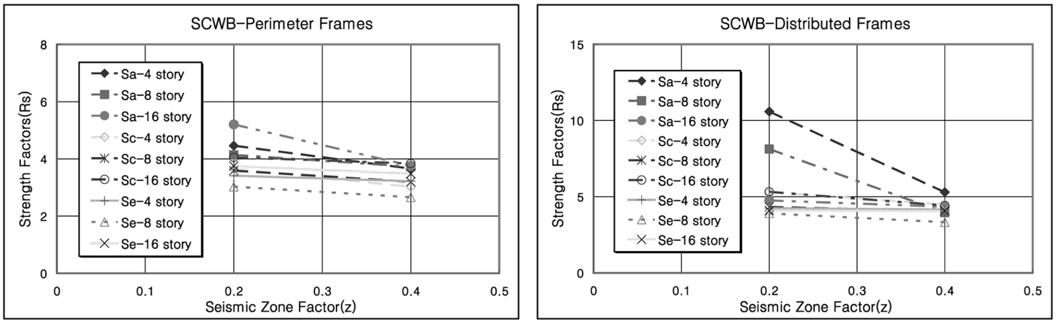
4.3 Seismic zone

From Figs. 15 to 17 show the variations of force reduction (R_{μ}), strength (R_s) and response modification factors (R) with the seismic zone factors for SCWB models. The results in Fig. 15 through 17 show general trends that can be summarized as follows.
- The seismic zone has a small effect on the force reduction factors (R_{μ}), although there are no general trends.
- However, the seismic zone has a great influence on the strength (R_s) and response modification factors (R). The variations of strength and response modification factors with the seismic zone factors are more prominent in rock sites (Site S_a) as compared to soft sites (Site S_e).
- In comparison of perimeter and distributed frames, the variations of strength and response modification



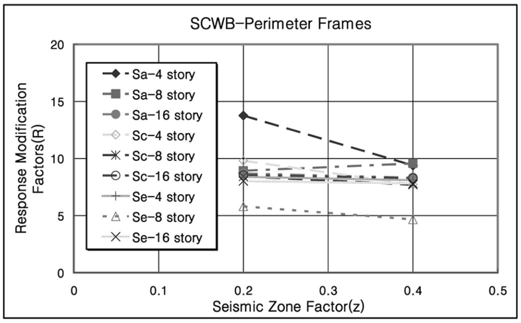
(a) SCWB-Perimeter Frames (b) SCWB-Distributed Frames

Fig. 15 Variations of R_{μ} factors with the seismic zone factors for SCWB models

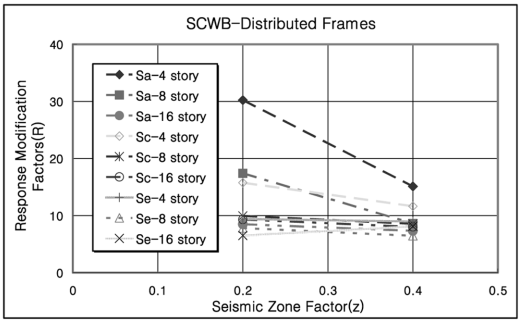


(a) SCWB-Perimeter Frames (b) SCWB-Distributed Frames

Fig. 16 Variations of Rs factors with the seismic zone factors for SCWB models



(a) SCWB-Perimeter Frames



(b) SCWB-Distributed Frames

Fig. 17 Variations of R factors with the seismic zone factors for SCWB models

factors with the seismic zone for distributed frames are more remarkable than perimeter frames.

For WCSB models, it is investigated the variations of force reduction, strength and response modification factors with seismic zone factors seem to follow a similar pattern as the SCWB models.

4.4 Different design philosophies

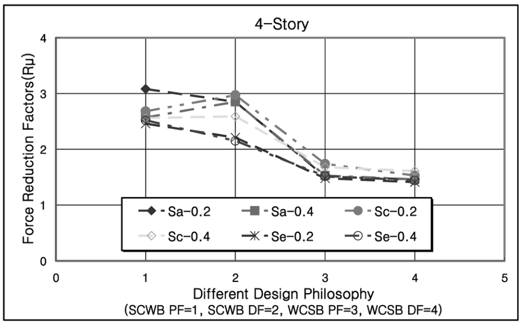
Fig. 18 shows the variations of force reduction (R_μ), strength (R_s) and response modification factors (R) with the different design philosophy for 4 and 16 stories. The following observations are made from these figures.

- As shown in Fig. 18 (a) and 18 (b), the force reduction factors (R_μ) of the WCSB models were significantly lower than those of the SCWB models, regardless of the perimeter and distributed frames. This is attributed to the decrease in the displacement ductility ratio (μ) with the increase in the number of stories, as shown in Fig. 8. In addition, the MDOF effects of WCSB models are more remarkable than those of SCWB models, as shown in Fig. 3.
- As a general rule, the strength factors (R_s) decreases with increasing seismic tributary area. As the seismic tributary area increases, relative to gravity tributary area, lateral forces overwhelm other load cases and members become better optimized for seismic loads alone. Conversely, the strength factor generally increases with increasing gravity tributary area, relative to seismic tributary area, as seismic forces become relatively minor. These effects are apparent in all of the strength factor figures in this study.
- Therefore, as illustrated in Fig. 18 (c) and 18 (d), even though the perimeter(PF) and distributed frame(DF) have the same design level, the strength factors of distributed frames have a great variations compare to those of perimeter frames.

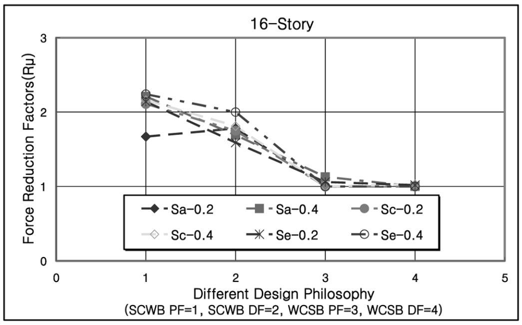
4.5 Design base shear coefficient

The variations of force reduction (R_μ), strength (R_s) and response modification factors (R) with design base shear coefficient (V/W), which imply the seismic design intensity, are shown in Fig. 19. As shown in these figures, the seismic design intensity has great influence on strength (R_s) and response modification factors (R). The following observations are made from Fig. 19.

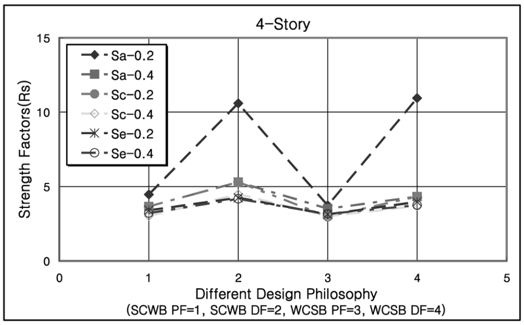
- The variations of force reduction factors with seismic design base shear coefficient (V/W) maintain



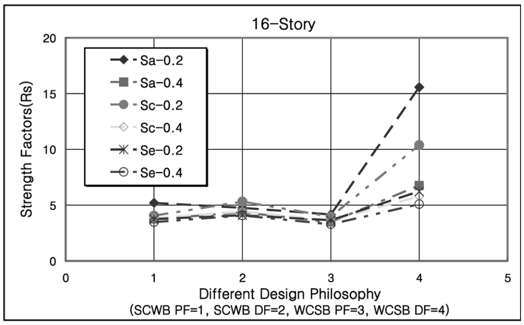
(a) R_μ factor for 4-story



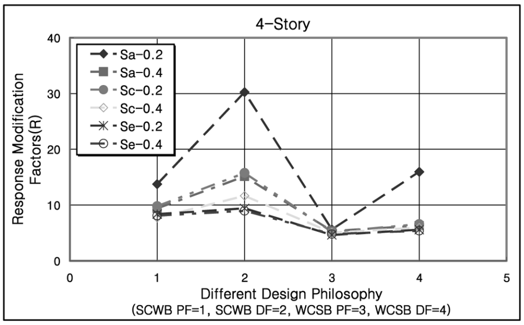
(b) R_μ factor for 16-story



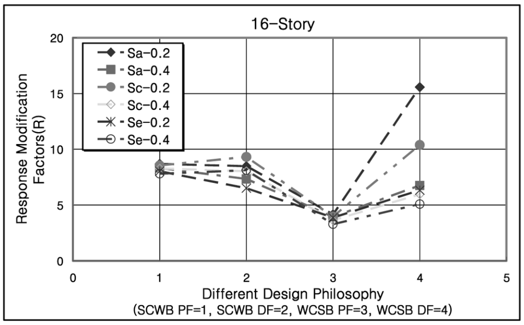
(c) R_s factor for 4-story



(d) R_s factor for 16-story



(e) R factor for 4-story



(f) R factor for 16-story

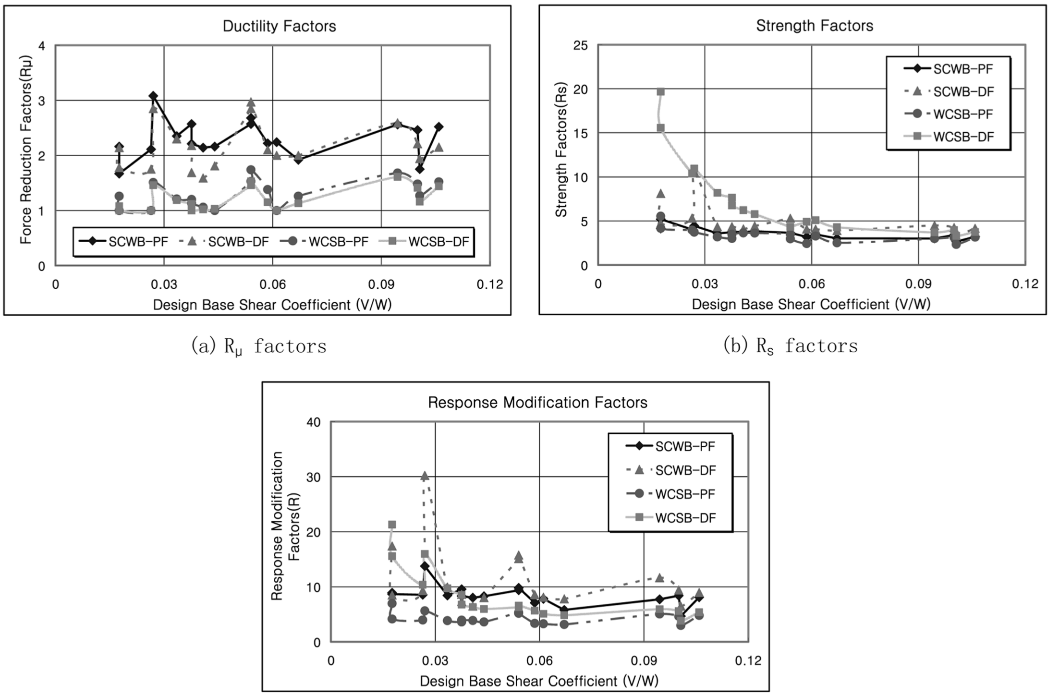
Fig. 18 Variations of R_μ, Rs and R factors with the different design philosophy

uniform value, regardless of the SCWB and WCSB models. Therefore, the seismic design base shear coefficient (V/W) has no influence on force reduction factors (R_μ).

• The more seismic design base shear coefficient (V/W) increases, the more strength (R_s) and response modification factor (R) decreases in lower seismic design intensity ranges. However, the strength (R_s) and response modification factors(R) are approximately constant in higher seismic design base shear coefficient (V/W) ranges.

5. Statistical study

Statistical study is carried out to investigate the role of the force reduction (R_μ) and strength (R_s) factors in response modification (R) factor. Some of the extreme values in lower base shear coefficient



(a) R_μ factors (b) R_s factors

(c)R factors

Fig. 19 Variations of R_μ, Rs and R factors with the design base shear coefficient (V/W)

(V/W) ranges are excluded from statistical study. The statistical study is carried out for the values that base shear coefficients (V/W) are more than 0.03. The following conclusions can be made from Table 3 and Fig. 19.

- The mean values of the force reduction factors (R_μ) are evaluated as 2.51, 2.34, 1.32 and 1.23, for SCWB PF models, SCWB DF models, WCSB PF models and WCSB DF models, respectively. Therefore, it is judge that the WCSB models are insufficient for ductile behavior in all seismic design intensity ranges.
- The mean values of the strength factors (R_s) are evaluated as 3.43, 4.29, 3.10, and 5.16, for SCWB PF models, SCWB DF models, WCSB PF models, and WCSB DF models, respectively. These values are 122.5%, 153.2%, 110.7%, and 184.3% of the assigned value, that is 2.80.
- The mean values of the response modification factors (R) are evaluated as 8.64, 10.2, 4.06, and 6.18, for SCWB PF models, SCWB DF models, WCSB PF models, and WCSB DF models, respectively. These values are 101.7%, 120.0%, 47.8%, and 72.7% of the assigned value, that is 8.50.
- The coefficients of variation of the force reduction (R_μ), strength (R_s), and response modification factors (R) are evaluated from 0.09 to 0.18, from 0.10 to 0.29, and from 0.16 to 0.25, respectively.

6. Conclusions

The force reduction (R_μ), strength (R_s), and response modification (R) factors for special steel moment

Table 3 Statistical study on force reduction, strength and response modification factors

Soil	Zone factor (Z)	Story	Base shear (V/W)	SCWB PF			SCWB DF			WCSB PF			WCSB DF		
				R_μ	R_S	R	R_μ	R_S	R	R_μ	R_S	R	R_μ	R_S	R
Sa	0.4	4	0.0540	2.57	3.66	9.39	2.85	5.30	15.1	1.53	3.51	5.35	1.46	4.32	6.31
		8	0.0376	2.98	3.73	11.1	2.53	3.95	10.0	1.20	3.02	3.62	1.12	7.64	8.55
		16	0.0376	2.48	3.76	9.33	1.87	4.35	8.13	1.13	3.49	3.95	1.00	6.76	6.76
Sc	0.2	4	0.0540	2.68	3.66	9.81	2.97	5.30	15.7	1.74	2.98	5.18	1.53	4.32	6.59
		8	0.0335	2.73	3.59	9.80	2.66	4.33	11.5	1.21	3.19	3.86	1.19	8.19	9.72
	0.4	4	0.0945	2.56	3.02	7.72	2.59	4.49	11.6	1.68	3.00	5.05	1.61	3.70	5.94
		8	0.0586	2.57	3.20	8.23	2.44	4.07	9.92	1.38	2.44	3.37	1.15	4.91	5.66
		16	0.0440	2.40	3.84	9.25	2.00	4.43	8.90	1.00	3.63	3.63	1.03	5.78	5.97
Se	0.2	4	0.1000	2.46	3.41	8.39	2.21	4.25	9.41	1.48	3.13	4.64	1.41	3.97	5.59
		8	0.0671	2.22	3.03	6.73	2.32	3.91	9.07	1.26	2.52	3.17	1.13	4.29	4.84
		16	0.0408	2.40	3.75	9.00	1.76	4.09	7.18	1.06	3.65	3.88	1.02	6.23	6.33
	0.4	4	0.1059	2.52	3.22	8.10	2.15	4.17	8.97	1.52	3.16	4.80	1.44	3.75	5.39
		8	0.1006	2.02	2.66	5.39	2.25	3.33	7.50	1.27	2.34	2.98	1.16	3.31	3.84
		16	0.0611	2.53	3.48	8.78	2.23	4.07	9.07	1.00	3.29	3.29	1.00	5.09	5.09
Mean value				2.51	3.43	8.64	2.34	4.29	10.2	1.32	3.10	4.06	1.23	5.16	6.18
Standard deviation				0.23	0.35	1.41	0.35	0.51	2.56	0.24	0.42	0.82	0.21	1.53	1.46
Coefficient of variation				0.09	0.10	0.16	0.15	0.12	0.25	0.18	0.14	0.20	0.17	0.29	0.24

resisting frames were investigated thorough numerical analysis. The 72 steel moment resisting frames were designed to reflect the influences of design parameters on these factors. The following conclusions can be drawn from the results of these studies.

- The number of stories had a great influence on force reduction, strength and response modification factors. In general, the more stories are increased, the more force reduction, strength, and response modification factors are decreased.
- The soil profile and seismic zone had a small effect on force reduction factors. However, these parameters had a great influence on strength and response modification factors.
- The force reduction factor for the WCSB models were significantly lower than those of SCWB models, regardless of the perimeter and distributed frames.
- The strength factors of distributed frames have a great value compare to those of perimeter frames because of difference of seismic tributary area.
- The seismic design intensity has no effects on force reduction factors. However, this parameter has great influences on strength and response modification factors, especially in lower seismic design intensity ranges.

Notations

A_g = Gross area of a column

P_{uc} = Required axial strength in the column (in compression) ≥ 0

F_{yb} = Specified minimum yield strength of a beam

F_{yc} = Specified minimum yield strength of a column

Z_b = Plastic section modulus of a beam
Z_c = Plastic section modulus of a column
V_n = Nominal strength of the panel zone
d_b = Average overall depth of the beams framed into the connection
H = Average of the story heights above and below the joint

Appendix

- ***MDOF modification factor (R_M)***

1. SCWB Models
(1) For $T \leq 0.075$ sec, $R_M = 1$
(2) For $T > 0.075$ sec, $R_M = 1.24 \times \text{EXP}\{-0.1[LN(\mu) + 2]T\}$

2. WCSB Models
(1) For $T \leq 0.2$ sec, $R_M = 1$
(2) For $T > 0.2$ sec, $R_M = \dfrac{0.8\mu^{-0.25}}{T^{0.15[\ln(\mu)+1]}}$

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