Evaluation of Ductility Factors for MDOF Systems in Special Steel Moment Resisting Frames

철골 연성 모멘트 골조에 대한 다자유도 시스템의 연성계수 평가

강 철 규*   한 영 철**

Kang, Cheol-Kyu   Han, Young-Cheol

국문요약

연성 계수는 반응수정계수(R)의 핵심구성요소로서 내진설계에서 중요한 역할을 하는 계수이다. 본 연구에서의 연성계수($R_{\mu,MDOF}$)는 단자유도 구조물의 연성계수(R_{μ})에 다자유도 보정계수(R_M)를 곱하여 평가하였다. 단자유도 시스템의 연성계수는 지진하중을 받는 단자유도 구조물의 범위 연성요구도와 주기에 따른 비선형 동적해석으로부터 산정하였다. 다자유도 시스템의 영향을 고려하기 위한 다자유도 보정계수(R_M)는 기존의 연구에 근거하여 제시하였다. 철골 연성 모멘트 골조의 연성계수를 평가하기 위하여, 구조물의 층수, 골조시스템(외곽골조, 분배골조), 붕괴 메카니즘(강-기둥 약-보, 약-기둥 강-보), 토질조건 및 지진구역을 변수로 하여 총 108개의 예제 구조물을 설계하였다. 구조물의 층수, 붕괴 메카니즘 및 토질조건은 연성계수에 큰 영향을 미치는 반면, 골조 시스템 및 지진구역은 연성계수에 영향을 미치지 않는 것으로 나타났다.

주요어 : 철골 연성모멘트 골조, 연성계수, 반응수정계수, 다자유도 보정계수.

ABSTRACT

Ductiluty factor has played an important role in seismic design as it is key component of response modification factor(R). In this stuty, ductility factors($R_{\mu,MDOF}$) are calculated by multiplying ductility factor for SDOF systems(R_{μ}) and MDOF modification factors(R_M). Ductility factors(R_{μ}) for SDOF systems are computed from nonlinear dynamic analysis undergoing different level of displacement ductiluty demands and period when subjected to a large number of recorded earthquake ground motions. The MDOF modification factors(R_M) are proposed to account for the MDOF systems, based on previous studies. A total of 108 prototype steel frames are designed to investigate the ductility factors considering the number of stories(4, 8 and 16-stories), framing system(Perimeter Frames, PF and Distributed Frames, DF), failure mechanism(Strong-Column Weak-Beam, SCWB and Weak-Column Strong-Beam, WCSB), soil profiles(S_A, S_C and S_E in UBC 1997) and seismic zone factors(Z=0.075, 0.2 and 0.4 in UBC 1997). It is shown that the number of stories, failure mechanisms (SCWB, WCSB), and soil profiles have great influence on the ductility factors, however, the structural system(Perimeter frames, Distributed frames), and seismic zones have no influence on the ductility factors.

Key words : special steel moment resisting frames, ductility factor, response modification factor. MDOF modification factor

1. Introduction

It is well known that the response modification factor takes account for ductility, over-strength, redundancy and damping of the structural systems. However, several researchers, including Project ATC 19[1] and 34[2], have expressed their concerns about the lack of rationality in the response modification factors currently specified in seismic design codes. Therefore, it is necessary to re-evaluate the response modification factors in seismic design. Ductility factor has played an important role in seismic design as it is key component of response modification factor(R).

The main objective of this paper is to evaluate the ductility factors for special steel moment-resisting frames. The ductility factors for special steel moment-resisting frames($R_{\mu,MDOF}$) are calculated by multiplying ductility factor for SDOF systems(R_{μ}) and MDOF modification factors(R_M). Ductility factors(R_{μ}) are computed for elastic perfectly plastic SDOF systems undergoing different level of inelastic deformation and period when subjected to a large number of recorded earthquake ground motions. Based on the results of regression analysis, simplified expressions are proposed to compute the ductility factors. The MDOF modification factors(R_M) are also proposed to account for the MDOF systems, based on previous studies. A total of 108 prototype steel frames are designed to investigate the ductility factors considering the number of stories(4, 8 and 16-stories), framing system(Perimeter Frames, PF and Distributed Frames, DF), failure mechanism (Strong-Column Weak-Beam, SCWB and Weak-Column Strong-Beam, WCSB), soil profiles(S_A, S_C and S_E in

UBC 1997) and seismic zone factors(Z=0.075, 0.2 and 0.4 in UBC 1997). The effects of these design parameters on ductility factors for special steel moment resisting frames($R_{\mu,MDOF}$) are investigated.

2. Ductility Factor and Response Modification Factor

2.1 Components of Response Modification Factor

In the mid-1980s, data from experimental research at the University of California at Berkeley were used to develop base shear-roof displacement relationships for steel braced frames and a draft formulation for the response modification factor. Using these data, the Berkeley researchers proposed splitting R into three factors that account for contributions from ductility, reserve strength and viscous damping, as follows :

$$R = R_\mu R_s R_\xi \qquad (1)$$

In this expression R_μ is the ductility factor, R_s is the strength factor, and R_ξ is the damping factor.[1]

Recent studies, including those in the companion Project ATC-34, support a new formulation for R; that is, a formulation in which R is expressed as the product of three factors:

$$R = R_\mu R_s R_R \qquad (2)$$

where R_μ is the period-dependent ductility factor, R_s is the period-dependent strength factor, and R_R is the redundancy factor.[1],[2]

2.2 Definition of Ductility Factor

The ductility factor (i.e., the reduction in strength demand),R_μ, is defined as the ratio of the elastic strength demand to the inelastic strength demand,

$$R_\mu = \frac{F_y(\mu = 1)}{F_y(\mu = \mu_i)} \qquad (3)$$

where $F_y(\mu = 1)$ is the lateral strength required to avoid yielding in the system under a given motion and $F_y(\mu = \mu_i)$ is the lateral strength required to maintain the displacement ductility ratio demand,μ, less than or equal to a pre-determined target ductility ratio, μ_i, under the same ground motion.[3],[4]

Equation (1) can be rewritten as

$$R_\mu = \frac{C_y(\mu = 1)}{C_y(\mu = \mu_i)} \qquad (4)$$

where $C_y(\mu = 1)$ is seismic coefficient (yield strength divided by the weight of the structure) required to avoid yielding; and $C_y(\mu = \mu_i)$ is minimum seismic coefficient required to control the displacement ductility demand to μ_i.

3. Ductility Factor for SDOF Systems

3.1 Earthquake Ground Motions and Nonlinear Analysis

It is necessary to get a number of earthquake ground motions to evaluate the ductility factors systematically for SDOF systems. In this study, an effort was made to consider a relatively large number of recorded ground motion to study the effects of the variability of the characteristics of ground motions on ductility factors. A group of 1,860 ground motions recorded on a wide range of soil conditions during 47 different earthquakes was considered. Complete listing of earthquake ground motions can be found in Kang C. K.(2003).[5] All of the selected records represent free-field conditions, basement and ground level.

Based on the local site conditions at the recording station, ground motions were classified into four groups according to average shear wave velocity,$\overline{v_s}$, as follows.

(a) Site AB (Rock Site) : $\overline{v_s} \geq 760\,m/s$ (192 ground motions)

(b) Site C (Dense Soil) : $360\,m/s \leq \overline{v_s} < 760\,m/s$ (554 ground motions)

(c) Site D (Stiff Soil) : $180\,m/s \leq \overline{v_s} < 360\,m/s$ (892 ground motions)

(d) Site E (Soft Soil) : $\overline{v_s} < 180\,m/s$ (222 ground motions)

In Fig 1, the distribution of earthquake ground motions comprising the data-set with regard to epicentral distance, peak ground acceleration and site classification are shown. The figures demonstrate that the data, except site E(soft soil), is well-distributed with respect to all three parameters, hence results of analysis will not have significant bias.

(a) Site AB(Rock Site)

(b) Site C(Dense Soil)

(c) Site D(Stiff Soil)
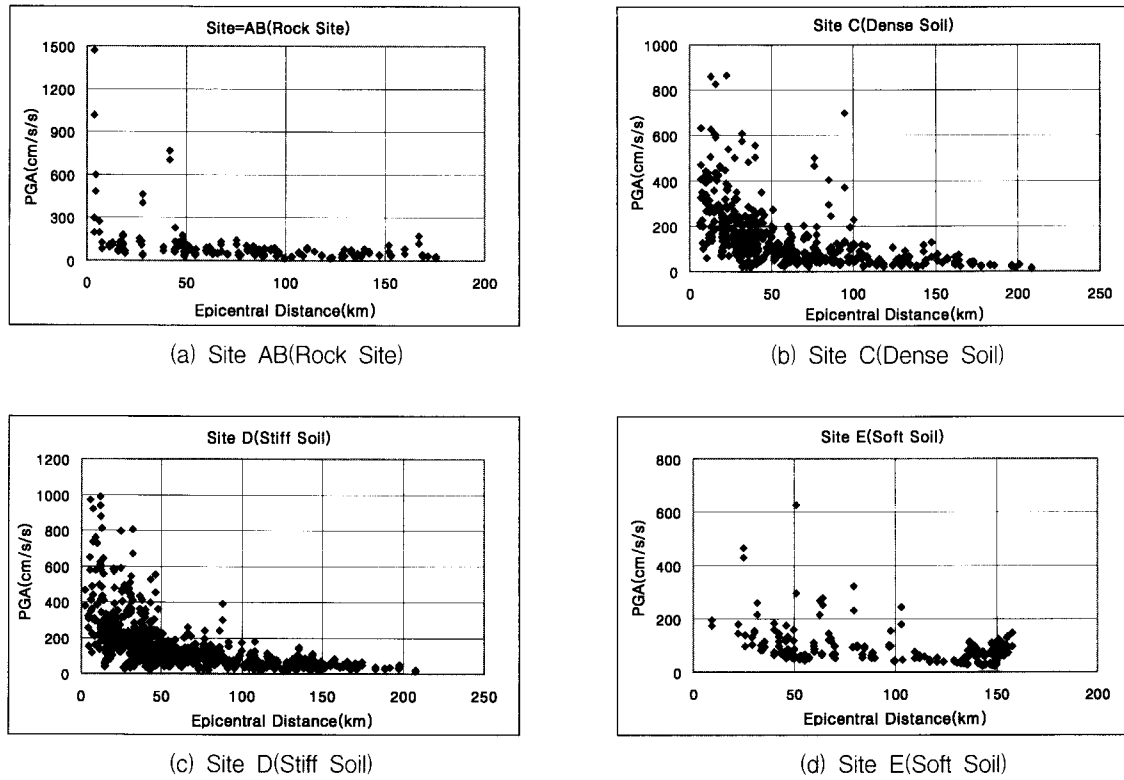

(d) Site E(Soft Soil)

Fig 1 Distribution of earthquake ground motions

Nonlinear time history analysis were carried out on SDOF systems to compute the ductility factors. BISPEC[6] was used to peform the dynamic analysis. The following values of target ductilities are selected for this study : 1(elastic), 2, 3, 4, 5 and 6. For each earthquake record and each target ductility, the inelastic response spectrum are computed for a set of 60 discrete periods ranging from 0.05 to 3.0 seconds. Considering the large number of records, ductilities, and periods of vibration and the large computational effort involved in calculating constant displacement ductility inelastic spectrum through iteration, this study is limited to SDOF systems that have a elastic perfectly plastic behavior and constant damping coefficient corresponding to a damping ratio ξ of 5% based on elastic properties.

3.2 Regression Analysis

The paper resulted in the ductility factor depends strongly on the target displacement ductility ratio(μ) and period(T). For practical purposes, a simplified expression is desired to consider the ductility factor (R_μ)-displacement ductility ratio(μ)-period(T) relationship for each site condition. A study has been carried out on all data set to formulate regression equations representing the ductility factor(R_μ) for

elasto-plastic SDOF systems with 5% critical damping. The approximate ductility factor(R_μ) was suggested by

$$R_\mu = 1 + \frac{T}{\phi} \tag{5}$$

where ϕ is a function of displacement ductility ratio(μ), period(T) and the site condition.

Several forms of the function for ϕ were considered, and regression analysis was conducted for each site condition separately in order to fit the function ϕ to the data obtained from nonlinear time-history analysis. For each site condition, the functions ϕ that fit best mean ductility factors and satisfy the above mentioned conditions were given as follows.

For site AB(Rock site),

$$\phi = \frac{1}{4 + 16\,(LN\mu)} + \frac{0.92\,T}{\mu - 1} \tag{6}$$

For site C(Dense soil),

$$\phi = \frac{1}{8 + 9\,(LN\mu)} + \frac{0.83\,T}{\mu - 1} \tag{7}$$

For site D(Stiff soil),

(a) Site AB, μ=3

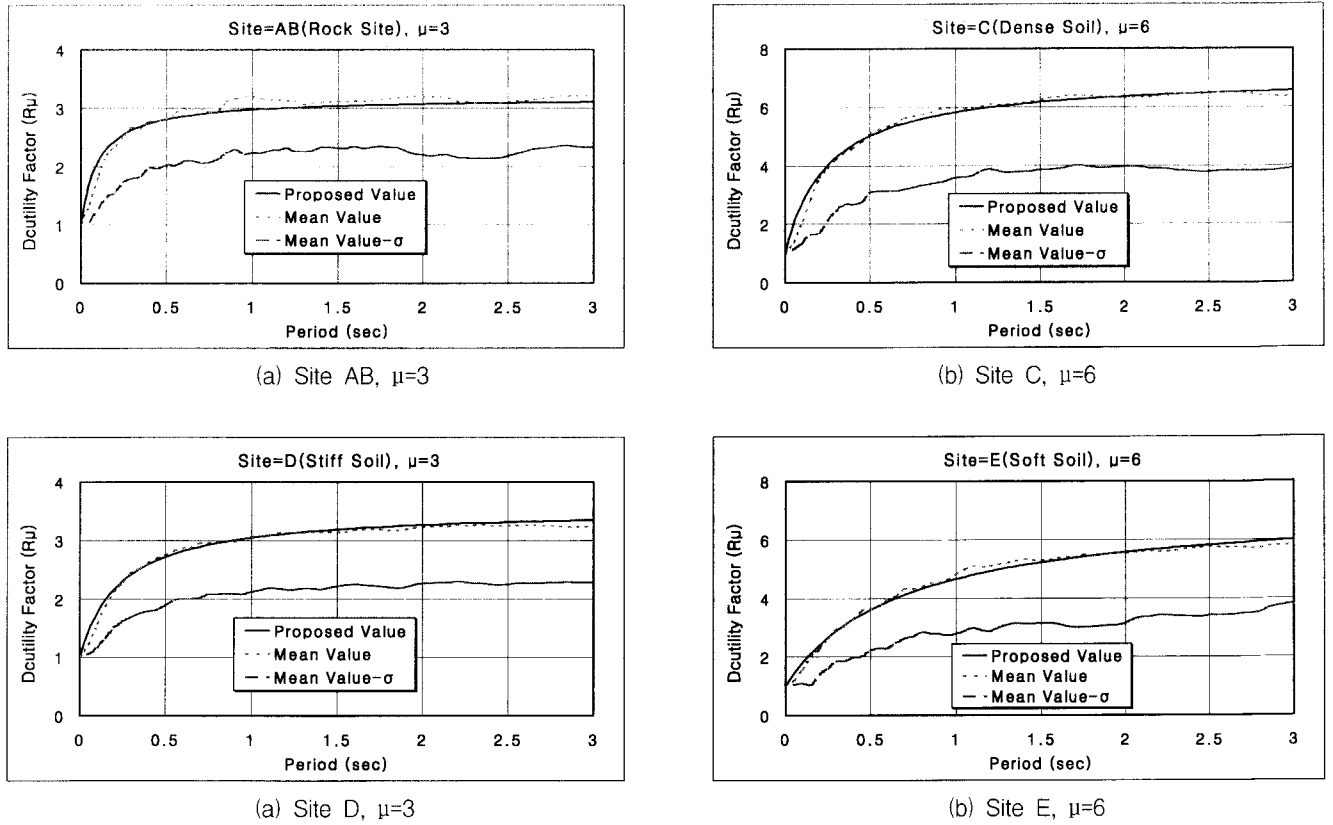(b) Site C, μ=6

(a) Site D, μ=3

(b) Site E, μ=6

Fig 2 Mean and proposed ductility factors for SDOF systems

$$\phi = \frac{1}{3 + 7\,(LN\mu)} + \frac{0.79\,T}{\mu - 1} \tag{8}$$

For site E(Soft soil),

$$\phi = \frac{1}{2 + 4\,(LN\mu)} + \frac{0.82\,T}{\mu - 1} \tag{9}$$

A comparison between mean ductility factors computed for systems subjected to ground motions recorded on each site condition with those computed using proposed equations is shown in Fig 2. In these figures, bottom lines present the mean value minus standard deviation(σ). It can be seen that the use of these simple equations leads to very good approximations of mean ductility factors due to inelastic behavior.

4. Ductility Factor for MDOF Systems

4.1 Modifications for MDOF Systems

The ductility factors(R_μ) previously discussed can be used for the design of structures which can be approximately modeled like a SDOF system. However, most structures need to be modeled as multi-degree-of-freedom(MDOF) systems and have a much more complex behavior than SDOF systems, particularly in the nonlinear range. Thus, ductility factor for SDOF systems(R_μ) need to be modified for the design of MDOF structures. In this paper, the MDOF modification factor(R_M) is proposed to account for the MDOF systems, based on previous studies(Nassar and Krawinkler[7], Miranda[8]).

The modification factor(R_M) is defined as follows ;

$$R_M = \frac{R_{\mu,MDOF}}{R_{\mu,SDOF}} = \frac{V_{y}(\mu=1)/V_{y}(\mu=\mu_i)}{F_{y}(\mu=1)/F_{y}(\mu=\mu_i)} = \frac{F_{y,SDOF}}{V_{y,MDOF}} \tag{10}$$

where $R_{\mu,MDOF}$ is the ratio of the lateral yielding strength required in the MDOF structure to remain elastic to $V_{y,MDOF}$ which is the lateral yielding strength required in the MDOF structure to avoid story displacement ductility demands larger than the maximum tolerable story displacement ductility ratio μ_i ; and $R_{\mu,SDOF}$ is equal to the previously defined R_μ factor.

Fig 3 shows schematically the modification factor R_M to account for the MDOF effect.
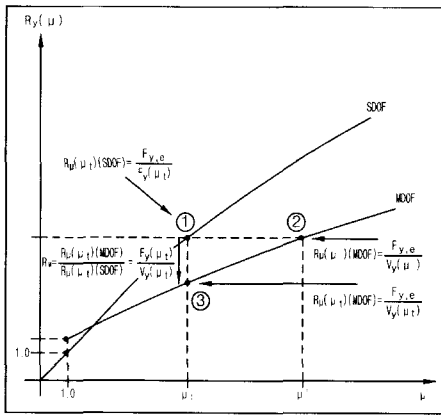
Fig 3 R_μ- μ relationship for SDOF and MDOF systems[7]

4.2 Previous Studies of MDOF Effects

(1) Nassar and Krawinkler (1991)[7]

This study was intended to provide some of the answers needed to assess strength demands for inelastic MDOF systems for comparison with their SDOF counterparts. The focus is on a statistical evaluation of systems that are regular from the perspective of elastic dynamic behavior. The three models were used in this studies. The "beam hinge" (strong-column weak-beam) model, referred to as SCWB model from here on, represents structures in which plastic hinges will form on beams only(as well as supports). The "column hinge"(weak-column strong-beam) model, referred to as WCSB model from here on, represents structures in which plastic hinges will form in columns only. The "weak story" model, referred to as WS model from here on, represents structures in which plastic hinges will form in columns of the first story only. This model represents the behavior of frames with a strength (not stiffness) discontinuity in the first story.

The structures with 2, 5, 10, 20, 30 and 40 stories (story height $h = 3,600$ mm), ranging in period from $T=0.217$ to 2.051 sec, were studied. A bilinear moment-rotation(M-Θ) hysteresis model with strain hardening ratios $\alpha=0$, 2 and 10% is assumed at each plastic hinge location.

(2) Miranda (1997)[8]

In this study, three reinforced-concrete SMRSF 8, 12 and 16 stories were designed according to a strong-column weak-beam philosophy and were subjected to three ground motions with a variable amplitude until maximum story displacement ductilities of 3, 4 and 5 were produced and until the

buildings remain totally elastic. Ductility factors for equivalent SDOF models of the buildings undergoing the same levels of displacement ductility demands when subjected to the same records were also computed. The equivalent SDOF systems had a period of vibration equal to the fundamental period of vibration of the MDOF structures.

4.3 Regression Analysis for RM Factors

In this study, based on the above mentioned previous studies, the simplified expression is proposed for modification factor(R_M) to account for the MDOF effects. It is known that the modification factor(R_M) decreases with increasing story displacement ductility ratio(μ) and periods(T). The following equation is proposed for modification factor(R_M) in SCWB and WCSB models. In these expressions, the strain hardening effects are not considered.

(1) SCWB Models

For $T \leq 0.75s$, $R_M = 1$ (11)

For $T > 0.75s$, $R_M = 1.24 \times \text{EXP}\{-0.1[LN(\mu)+2]\,T\}$ (12)

(2) WCSB Models

For $T \leq 0.2s$, $R_M = 1$ (13)

For $T > 0.2s$, $R_M = \dfrac{0.8\mu^{-0.25}}{T^{0.15[LN(\mu)+1]}}$ (14)

where T and μ are the period and the story displacement ductility demand in the MDOF structure, respectively.

Some of the proposed and previous modification factor(R_M) are shown in Fig 4. As shown in this figure, proposed equations provide a good estimation of previous studies.

4.4 Estimation of Ductility Factors

In this study, ductility factors for MDOF systems are estimated by the product of R_μ and R_M, as follows.

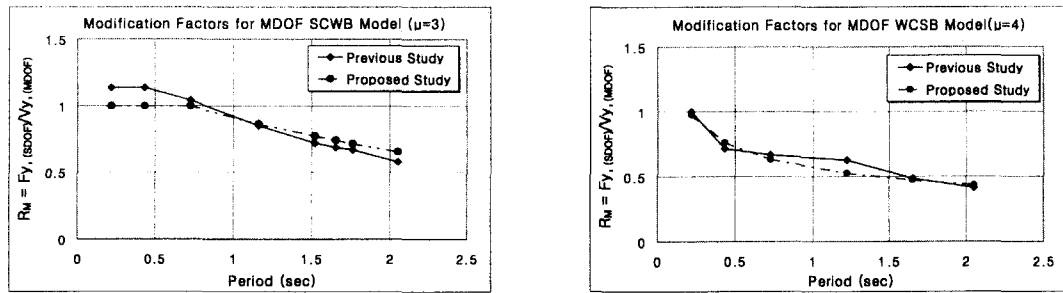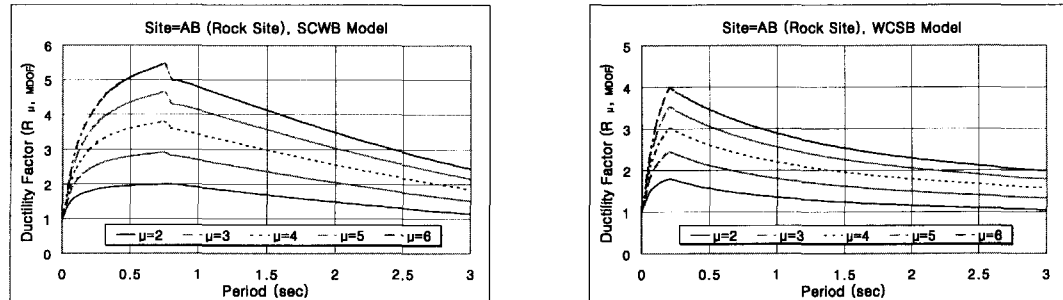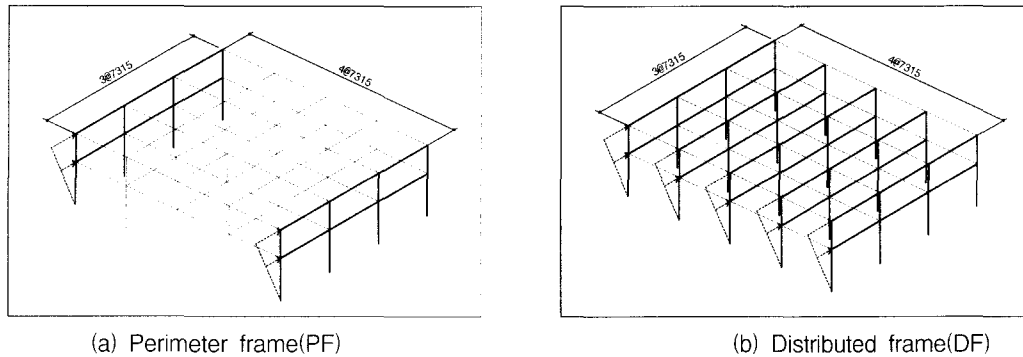$$R_{\mu,MDOF} = R_\mu \times R_M \quad (15)$$

Fig 4 Some of the proposed and previous modification factors

(a) SCWB model   (b) WCSB model

Fig 5 Proposed ductility factors for MDOF systems in Site AB(rock site)

(a) Perimeter frame(PF)   (b) Distributed frame(DF)

Fig 6 Prototype structures

where R_μ is the site-dependent ductility factors for SDOF system and R_M is the structural model dependent modification factors to account for the MDOF effects.

The ductility factors for site AB(rock site) in MDOF systems($R_{\mu,MDOF}$) are shown in Fig 5. As shown in Fig 5, the ductility factors for SCWB model decrease linearly in T>0.75s range, but on the other hand, those of WCSB model decrease dramatically in T>0.2s range.

5. Application of Special Steel Moment Resisting Frames

5.1 Design of Prototype Structures

A series of prototype steel frames are designed to

investigate the ductility factors. Each frame is designed and detailed in accordance with minimum UBC standards(*Uniform Building Code*, 1997)[9] and LRFD (*Load and Resistance Factor Design, American Institute of Steel Structures*, 1994).[10]

The frames are 4, 8 and 16 stories tall and are symmetric and regular with the floor plan and geometry as illustrated in Fig 6. All structures have a 3-bay by 4-bay plan with bay dimensions of 7,315 mm by 7,315 mm. The story height is 5,486 mm for the bottom story and 3,658 mm for all others. Only behavior in the 3-bay direction is investigated. Models are developed based on the *1997 UBC* code for two structural framing systems: perimeter frame(PF) and distributed frame(DF). For the perimeter frame(PF) model, the lateral loads are resisted entirely by the perimeter frames. For the

distributed frame(DF) model, the lateral loads are resisted by all frames in the 3-bay direction. The dead load is 4.8 kN/m^2 on all levels. The design live load is 2.4 kN/m^2 for the floors and $1.2 kN/m^2$ on the roof.

Research has historically focused on beam hinge, that is, strong-column weak-beam(SCWB) steel frames, because they have great ductility than column hinge, that is, weak-column strong-beam (WCSB) frames. The SCWB joints, one of the following relationships shall be satisfied for special moment resisting frames and are assured by *Uniform Building Code*(UBC 1997).

$$\frac{\Sigma Z_c (F_{yc} - P_{uc}/A_g)}{\Sigma Z_b F_{yb}} \geq 1.0 \tag{16}$$

$$\frac{\Sigma Z_c (F_{yc} - P_{uc}/A_g)}{V_n d_b H/(H - d_b)} \geq 1.0 \tag{17}$$

where

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 beams framing into the connection

H = Average of the story heights above and below the joint

However, it is sometimes uneconomical or impractical to obtain SCWB behavior at every joint. Consequently, the *Uniform Building Code*(UBC 1997) and the *National Earthquake Hazard Reduction Program*(NEHRP 1997)[11] permit the use of WCSB joints under specific conditions. In any of the following cases, the strength of the joint need not satisfy Eq. (16) or (17).

- Columns with $P_{uc} < 0.3 F_{yc} A_g$.
- Columns in any story that has a ratio of design shear strength to design force 50% greater than the story above.
- Any column not included in the design to

resist the required seismic shears, but included in the design to resist axial overturning forces.

A basic SCWB steel frame with all joints except the top story satisfying the SCWB provisions(Eq, 16), a basic WCSB steel frame with all joints satisfying *exception 8.6.a of 1997 UBC paragraph 2211. 4 (columns with* $P_{uc} < 0.3 F_{yc} A_g$) and several alternative frames are designed for each of the three building heights.

A total of 108 frames are designed for the following permutations:

- Structures with 4, 8 and 16 stories.
- SCWB and WCSB failure mechanisms.
- Perimeter frames(PF) and Distributed frames(DF).
- Site categories with S_A, S_C and S_E.
- Seismic zone factors with Z=0.075(Z1), 0.2(Z2B) and 0.4(Z4).

5.2 Evaluation of Displacement Ductility Ratio(μ)

The ductility ratios(μ) can be computed at the system, story, and element levels. At the system and story levels, the ductility ratio is normally expressed in terms of the displacement ductility ratio. For the purposes of this study, displacement ductility ratio at the system level is used to determine the ductility factor.

Nonlinear static analysis(also termed *pushover* analysis) was used to estimate the displacement ductility ratio(μ). The nonlinear static analysis of these frames has been accomplished with the DRAIN-2D+ computer program(Keh-Chyuan Tsai and Jeng-Wei Li, 1994).[12] The DRAIN-2D+ beam-column element(element 2) with 1% strain hardening is the primary element used in these analyses. Panel zone yielding and deformation are not considered. Further, the stiffness and resistance of the slab are not included. The procedure used to estimate the strength of a building is straightforward, but requires the analyst to select a limiting state of response. Typical limiting responses include maximum interstory drift and maximum plastic hinge rotation. There is no strict story drift limit for steel frames. Practical drift limit for *Life Safety* and *Collapse Prevention* performance might be 0.02 and 0.04, respectively(*FEMA 274*, 1997).[13] In this study,

the drift limit is assumed 0.04 at any story.

6. Results and Discussion

6.1 Evaluation of Ductility Factor($R_{\mu,MDOF}$)

The ductility factors for MDOF systems, $R_{\mu,MDOF}$ are evaluated by the product of R_μ and R_M factor as follows.

$$R_{\mu,MDOF} = R_\mu \times R_M \qquad (18)$$

where, R_μ is the site dependent ductility factor for SDOF system, and R_M is the structural model dependent modification factor to account for the MDOF effects.

For example, the ductility factor($R_{\mu,MDOF}$) for a 16-story SCWB distributed frames(DF) is estimated as follows, where soil profile is S_C and seismic zone factor is 0.2(No.42 in Table 1).

From nonlinear static analysis, the displacement ductility ratio(μ) is 2.47, and period(T) is 1.847 sec. The ductility factor(R_μ) for SDOF system is calculated by Eq. (5) as follows.

$$R_\mu = 1 + \frac{T}{\phi} = 1 + \frac{1.847}{1.105} = 2.67 \qquad (19)$$

where the function ϕ is computed by Eq. (7) for Site C as follows.

$$\phi = \frac{1}{8 + 9\,(LN\mu)} + \frac{0.83\,T}{\mu - 1}$$

$$= \frac{1}{8 + 9\,(LN2.47)} + \frac{0.83 \times 1.847}{2.47 - 1} = 1.105$$

$$(20)$$

The modification factor(R_M) to account for the MDOF effects is calculated from Eq. (12) as follows.

$$R_M = 1.24 \times EXP\{-0.1[LN(\mu) + 2]\,T\}$$

$$= 1.24 \times EXP\{-0.1[LN(2.47) + 2] \times 1.847\} = 0.725$$

$$(21)$$

The ductility factor for the example frame($R_{\mu,MDOF}$) is computed as follows.

$$R_{\mu,MDOF} = R_\mu \times R_M = 2.67 \times 0.725 = 1.94 \qquad (22)$$

Table 1 Ductility Factor for Prototype Structures

No	Notation SCWB-PF	$R_{\mu,MOOF}$	No	Notation SCWB-DF	$R_{\mu,MOOF}$	No	Notation WCSB-PF	$R_{\mu,MOOF}$	No	Notation WCSB-DF	$R_{\mu,MOOF}$
1	4-Sa-0.075	2.38	28	4-Sa-0.075	2.84	55	4-Sa-0.075	1.44	82	4-Sa-0.075	1.45
2	8-Sa-0.075	2.36	29	8-Sa-0.075	2.48	56	8-Sa-0.075	1.30	83	8-Sa-0.075	1.08
3	16-Sa-0.075	1.69	30	16-Sa-0.075	1.97	57	16-Sa-0.075	1.00	84	16-Sa-0.075	1.00
4	4-Sa-0.2	3.08	31	4-Sa-0.2	2.85	58	4-Sa-0.2	1.51	85	4-Sa-0.2	1.46
5	8-Sa-0.2	2.50	32	8-Sa-0.2	2.48	59	8-Sa-0.2	1.26	86	8-Sa-0.2	1.08
6	16-Sa-0.2	1.85	33	16-Sa-0.2	1.98	60	16-Sa-0.2	1.00	87	16-Sa-0.2	1.00
7	4-Sa-0.4	2.57	34	4-Sa-0.4	2.85	61	4-Sa-0.4	1.53	88	4-Sa-0.4	1.46
8	8-Sa-0.4	2.99	35	8-Sa-0.4	2.53	62	8-Sa-0.4	1.20	89	8-Sa-0.4	1.12
9	16-Sa-0.4	2.48	36	16-Sa-0.4	1.87	63	16-Sa-0.4	1.13	90	16-Sa-0.4	1.00
10	4-Sc-0.075	2.64	37	4-Sc-0.075	2.97	64	4-Sc-0.075	1.55	91	4-Sc-0.075	1.53
11	8-Sc-0.075	2.49	38	8-Sc-0.075	2.62	65	8-Sc-0.075	1.24	92	8-Sc-0.075	1.12
12	16-Sc-0.075	1.92	39	16-Sc-0.075	2.09	66	16-Sc-0.075	1.00	93	16-Sc-0.075	1.00
13	4-Sc-0.2	2.68	40	4-Sc-0.2	2.97	67	4-Sc-0.2	1.74	94	4-Sc-0.2	1.53
14	8-Sc-0.2	2.73	41	8-Sc-0.2	2.67	68	8-Sc-0.2	1.21	95	8-Sc-0.2	1.19
15	16-Sc-0.2	2.36	42	16-Sc-0.2	1.94	69	16-Sc-0.2	1.00	96	16-Sc-0.2	1.00
16	4-Sc-0.4	2.56	43	4-Sc-0.4	2.59	70	4-Sc-0.4	1.68	97	4-Sc-0.4	1.61
17	8-Sc-0.4	2.57	44	8-Sc-0.4	2.44	71	8-Sc-0.4	1.38	98	8-Sc-0.4	1.15
18	16-Sc-0.4	2.41	45	16-Sc-0.4	2.01	72	16-Sc-0.4	1.00	99	16-Sc-0.4	1.03
19	4-Se-0.075	2.12	46	4-Se-0.075	2.54	73	4-Se-0.075	1.43	100	4-Se-0.075	1.39
20	8-Se-0.075	2.28	47	8-Se-0.075	2.36	74	8-Se-0.075	1.20	101	8-Se-0.075	1.11
21	16-Se-0.075	1.84	48	16-Se-0.075	1.93	75	16-Se-0.075	1.00	102	16-Se-0.075	1.00
22	4-Se-0.2	2.46	49	4-Se-0.2	2.21	76	4-Se-0.2	1.48	103	4-Se-0.2	1.41
23	8-Se-0.2	2.22	50	8-Se-0.2	2.32	77	8-Se-0.2	1.26	104	8-Se-0.2	1.13
24	16-Se-0.2	2.40	51	16-Se-0.2	1.76	78	16-Se-0.2	1.06	105	16-Se-0.2	1.02
25	4-Se-0.4	2.52	52	4-Se-0.4	2.15	79	4-Se-0.4	1.52	106	4-Se-0.4	1.44
26	8-Se-0.4	2.03	53	8-Se-0.4	2.25	80	8-Se-0.4	1.27	107	8-Se-0.4	1.16
27	16-Se-0.4	2.52	54	16-Se-0.4	2.23	81	16-Se-0.4	1.00	108	16-Se-0.4	1.00

The ductility factors($R_{\mu,MDOF}$) for all of the prototype structures are provided in Table 1.

6.2 Effects of Design Parameters

Table 1 provide the ductility factor of prototype structures for all of the SCWB and WCSB models. Some of the effect of different design philosophy on ductility factors for prototype structures is shown in Fig 7 with the number of stories, seismic zone factors and soil profiles. The following observations can be seen from Fig 7 :

- The ductility factors for prototype structures decrease with increasing the number of stories, irrespective of the SCWB and WCSB models.

For SCWB models, this trends may be attributed to modification factor(R_M) which decreases with increasing the number of stories and displacement ductility ratio. For WCSB models, to add to modification factor (R_M), this trends may be attributed to the fact that displacement ductility ratio(μ) decreases with increasing the number of stories.

- The ductility factors for WCSB models are significantly lower than those of SCWB models, regardless of perimeter and distributed frames.

- There are no appreciable difference in ductility factors for perimeter and distributed frames, regardless of SCWB and WCSB models.
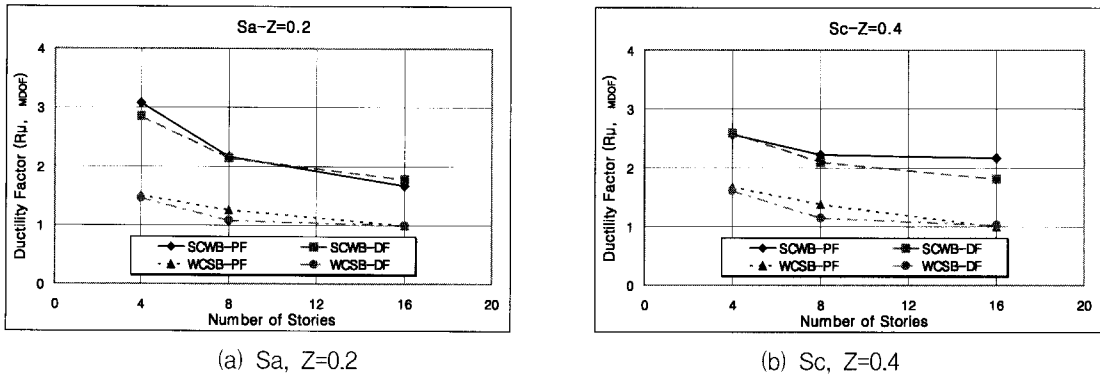

(a) Sa, Z=0.2   (b) Sc, Z=0.4

Fig 7 Some of the effect of different design philosophies on ductility factors

(a) SCWB, PF, Z=0.2   (b) WCSB, DF, Z=0.4
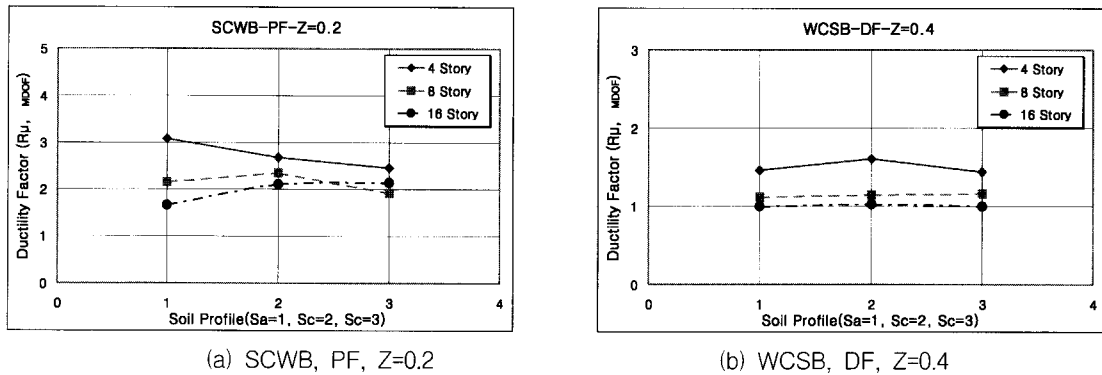
Fig 8 Some of the variations of ductility factors with soil profile

(a) SCWB, DF, Se   (b) WCSB, PF, Sc
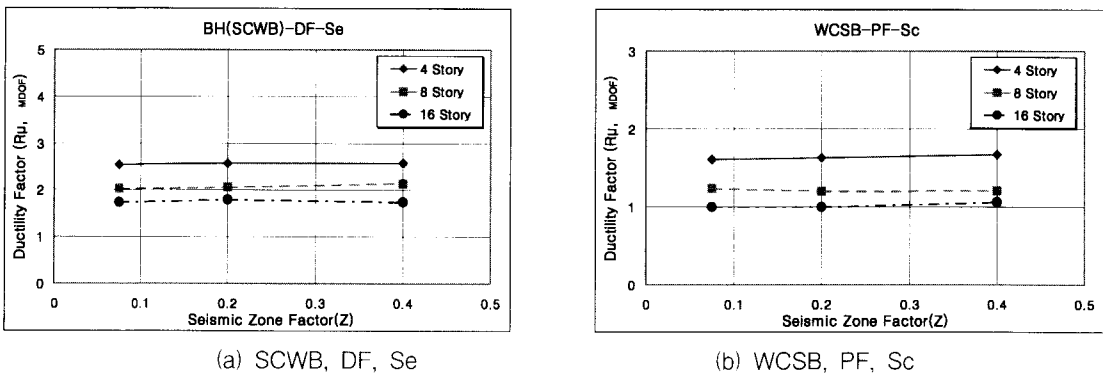
Fig 9 Some of the variations of ductility factors with seismic zone factors

Some of the variations of ductility factors with changes of soil profile are illustrated in Fig 8. As shown in these figures, the soil profiles have great influence on the ductility factors although there are no general trends.

Some of the variations of ductility factors with the change of seismic zone factors are presented in Fig 9. As shown in these figures, the seismic zones have no influence on the ductility factor.

7. Conclusions

The primary purpose of this study was to evaluate the ductility factor for special steel moment resisting frames. The ductility factors for special steel moment-resisting frames($R_{\mu,MDOF}$) were calculated by multiplying ductility factor for SDOF systems(R_μ) and MDOF modification factors(R_M). The following conclusions can be drawn from the results of this study.

- The number of stories, failure mechanisms (SCWB, WCSB), and soil profiles have great influence on the ductility factors for special steel moment resisting frames.
- However, the structural system(Perimeter frame, Distributed frames), and seismic zones have no influence on the ductility factors for special steel moment resisting frames.
- The response modification factor(R) is intended, in part, to account for the ductility of the framing systems. Given that ductility factor is a key component of response modification factor(R), response modification factor(R) should be dependent on design parameters such as number of stories, failure mechanisms(SCWB, WCSB), and soil profiles.

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