IOP Conf. Series: Materials Science and Engineering **884** (2020) 012029 doi:10.1088/1757-899X/884/1/012029

Effects of the intensity of design live load on the seismic design modification factors of reinforced concrete frames

S C Alih[1*], M Vafaei[2], M Alhariri[2] and I Ghanim[2]
[1] Institute of noise and vibration, School of Civil Engineering, Universiti Teknologi Malaysia, Johor, Malaysia
[2] School of Civil Engineering, Universiti Teknologi Malaysia, Johor, Malaysia

[*]Corresponding author e-mail: sophiacalih@utm.my

Abstract. Seismic design modification factors that include the response modification factor (R), the overstrength factor (Ω), and the displacement amplification factor (C_d) play a significant role in the seismic design of structures. The recommended values for these factors in seismic design codes are empirical and do not account for the differences in the intensity of the design live load in structures. This study investigates the change in the value of these factors as a result of the change in the intensity of the design live load. For this purpose, eighteen reinforced concrete frames with the different number of stories and ductility classes were designed and analyzed. Nonlinear static analysis was used to calculate the capacity curve of frames and their seismic response modification factors. Results indicated that the values of Ω and C_d for both low and high-ductile reinforced concrete frames decreased slightly as the intensity of design live load increased. An increase in the intensity of the design live load increased the R-factor in the high-ductile RC frames.

1. Introduction

The seismic design of structures requires an accurate estimation of seismic actions. During a seismic event, lateral forces and displacements of a structure can be estimated with a good accuracy through a nonlinear analysis. However, since the nonlinear analysis is complex and time consuming many seismic codes recommend a linear analysis which has been modified by some factors in order to estimate the real response of structures. These factors that are known as seismic design modification factors include the response modification factor (R) which is also referred to as behavior factor in Eurocode 8, the overstrength factor (Ω), and the displacement amplification factor (C_d). In seismic codes, the values of these factors are often selected empirically using the observed structural behavior during past seismic events. In addition, seismic design codes do not provide the values of seismic design modification factors for all types of structural systems. Therefore, many researchers have tried to quantify these factors for different types of the structural system. For example, Vafaei and Alih [1] studied the seismic performance of three Air Traffic Control towers ATC with dual concrete core lateral load resisting system. They performed nonlinear time history analysis and concluded that the response modification factor adopted by the seismic design code did not provide a uniform safety margin for all ATC towers. They reported that the shorter tower had significantly a larger response modification factor when compared with the tallest one. Keykhosravi & Aghayari [2] studied the response modification factors of reinforced concrete frames equipped with chevron steel-bracing system and steel-slit dampers (SSD). The results revealed that the R-value of reinforced concrete

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

frames equipped with the dampers was significantly larger than the other systems and the R-factor decreased as the height of frames increased. Mahmoudi and Zaree [3] tried to calculate the response modification factors of buckling-restrained braced frames (BRBFs) used for rehabilitation of steel frames. The results showed that the response modification factor had a large value and ranged from 8 to 22. In another study, Mwafy [4] assessed seismic design response factors of 20 to 60-stories concrete wall buildings through pushover and nonlinear dynamic analysis. It was concluded that the code-recommended values for seismic response modification factors were conservative. Menegon et al. [5]evaluated the value of the overstrength factor of the low ductile reinforced concrete walls. The archetype models included structures with rectangular walls and box-shaped cores selected from actual case study buildings in Australia. They concluded that box-shaped cores had a lager overstrength factor. Taieb and Sofiane [6]reviewed the methods proposed by seismic codes for investigating the overstrength factor and ductility in reinforced concrete structures. The studied models included frames and shear walls. It was reported that the overstrength factor increased as the ductility increased. Response modification factors of Steel Fiber Reinforced Concrete (SFRC) segmental tunnels was investigated by Jamshidi Avanaki [7]. It was reported that micro fibers had a greater influence than the macro fibers in increasing the R-factor. In addition, an R-factor ranging from 2.55 to 2.84 was derived for the different mixture of SFRC segmental tunnels. Zahrai et al. [8] worked on response modification factors of concrete bridges with different bearing conditions. They concluded that the code-prescribed R-factors were conservative for typical bridges with elastomeric rubber bearings. Zhou et al. [9] studied numerically the seismic force modification factors of hybrid light wood frame structures connected to a stiff core. Results indicated that a R-factor larger than the lower value of the two sub-systems could be selected for the seismic design of the structure.

It can be seen through the literate review that many studies have been performed in order to quantify the seismic design modification factors of different structural systems. This study investigates to what extent the intensity of design live load influences the seismic design modification factors of low and high ductile reinforced concrete frames. Such study is of great interest because the values given by the seismic codes for the seismic design modification factors of structures do not account for the differences in the intensity of the design live load.

2. Selected RC Frames

In this study 18 reinforced concrete frames were analyzed. The reinforced concrete frames were categorized into low ductility and high ductility frames in accordance with the specifications of ACI 318 [10]. The frames of each ductility class had 3, 5 and 7 stories with four identical spans each of which with 4 m length. The selected RC frames are shown in Figure 1. The height of the first story in all frames is 3.5 m and the height of the remaining stories is 3 m. The compressive strength of concrete for all frames is equal to 30 MPa. The yield strength of reinforcing bars is 400 MPa. All frames were designed for the dead load of 6 kN/m2 at roof level and 5 kN/m2 in other stories. The intensity of live load at roof level was constant for all frames and equaled 1.5 kN/m2. However, three different intensities of live load were selected for the design of each frame. The live load intensities were 2.5 kN/m2, 5 kN/m2, and 7.5 kN/m2. Calculation of seismic loads of frames was based on the equivalent lateral force approach proposed by ASCE 7-16 [11]. The seismic response modification factors of low ductile RC frames as per the recommendation of AISC 7-16 were R=3, Ω=3, and C_d=2.5. For high ductility class frames, these factors equaled R=8, Ω=3, and C_d=5.5. Design load combinations were also selected based on the recommendation of ASCE 7-16 [11]. In order to provide an unbiased comparison, the demand to capacity ratio (D/C) was kept within the range of 0.7 to 1 for the structural elements of all frames. Structural elements were designed using the ACI 318 [10]. For the sake of brevity, only some of the obtained results for the sizes of beams and columns have been presented in this paper. For example, table 1 summarizes the reinforcement ratios and the sizes of beams and columns for the low ductile 3-story reinforced concrete frame designed for the live load intensity of 7.5 kN/m2. Table 2 summarizes the same results for the high ductile 3-story reinforced concrete frame.

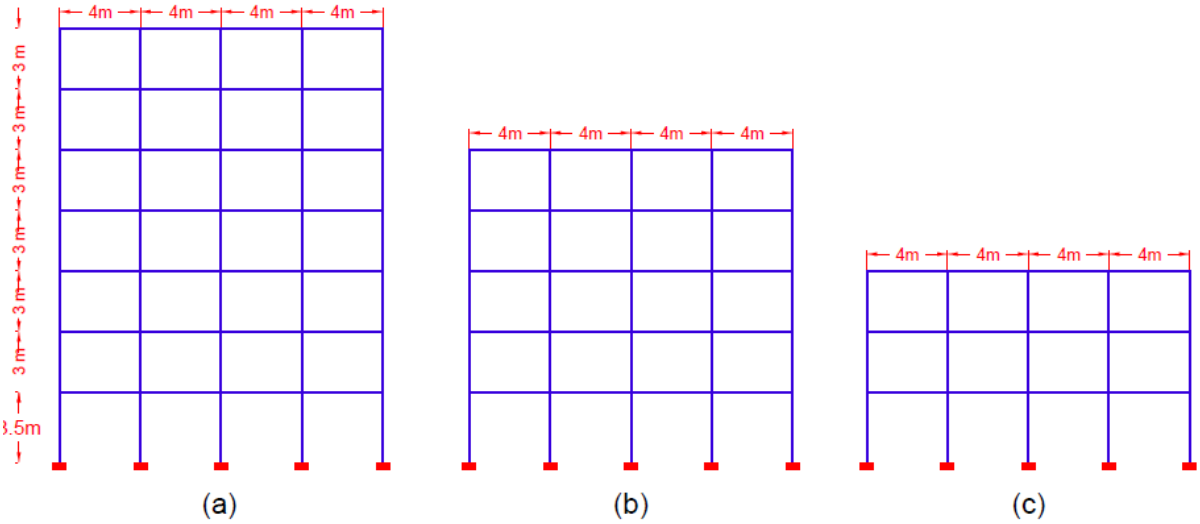


Figure 1. Elevation view of investigated structures. (a) 7-story building (b) 5-story building (c) 3-story building.

Table 1. Reinforcement ratios and sizes of beams and columns of low ductile RC frame for the live load intensity of 7.5 kN/m^2.

Story	Columns				Beams			
	External (cm)	Reinf. ratio (%)	Internal (cm)	Reinf. ratio (%)	External (cm)	Reinf. Ratio (%) (top/bot.)	Internal (cm)	Reinf. Ratio (%) (top/bot.)
1	45*45	2.25	45*45	2.25	25*50	1.18/0.71	25*50	1.11/0.59
2	40*40	1.51	40*40	1.91	25*45	1.3/0.66	25*45	1.24/0.61
3	35*35	1.51	35*35	1.51	25*40	0.9/0.39	25*40	0.83/0.30

Table 2. Reinforcement ratios and sizes of beams and columns of high ductile RC frame for the live load intensity of 7.5 kN/m^2.

Story	Columns				Beams			
	External (cm)	Reinf. ratio (%)	Internal (cm)	Reinf. ratio (%)	External (cm)	Reinf. Ratio (%) (top/bot.)	Internal (cm)	Reinf. Ratio (%) (top/bot.)
1	40*40	1.16	40*40	1.16	30*35	1.44/1.03	30*35	1.39/1.02
2	35*35	1.11	35*35	1.97	30*35	1.41/1.03	30*35	1.35/1.02
3	30*30	2.68	35*35	1.51	30*35	0.91/0.42	30*35	0.86/0.41

IOP Conf. Series: Materials Science and Engineering **884** (2020) 012029 doi:10.1088/1757-899X/884/1/012029

3. Calculation of seismic response modification factors

In this study, pushover analysis was employed in order to calculate the capacity curves of designed reinforced concrete frames. In the pushover analysis, two different lateral load patterns were used. The first load pattern followed the shape of the first natural mode of each frame and the second load pattern was proportional to the product of the mass matrix of each floor. Nonlinear response of beams and columns was simulated through the lumped plasticity model [12][13]. Plastic hinges were assigned to both ends of beams and columns. The moment-rotation relationships of plastic hinges were calculated based on the cross-sectional properties of structural elements together with the values given in the ASCE 41[14]for the rotational capacities and acceptance criteria of concrete beams and columns. In order to calculate the seismic response modification factors of frames, at first, the capacity curves of all frames were idealized using the bilinear representation proposed by FEMA 356 [15]. As it is shown in figure 2 this method employs the equal energy approach in which the enclosed area above (see A1 in Figure 2) and below (see A2 in Figure 2) the bilinear curve should be equal.

The seismic response modification factors were extracted from the idealized capacity curves using the following equations:

$$\Omega = \frac{F_y}{F_d} \tag{1}$$

$$C_d = \frac{\Delta_u}{\Delta_d} \tag{2}$$

$$R = R_\mu . \Omega \tag{3}$$

$$\mu = \frac{\Delta_u}{\Delta_y} \tag{4}$$

$$if\ T < 0.5\ sec.\ \ then\ \ R_\mu = \mu \tag{5}$$

$$if\ T > 1.0\ sec.\ \ then\ \ R_\mu = \mu . \Omega \tag{6}$$

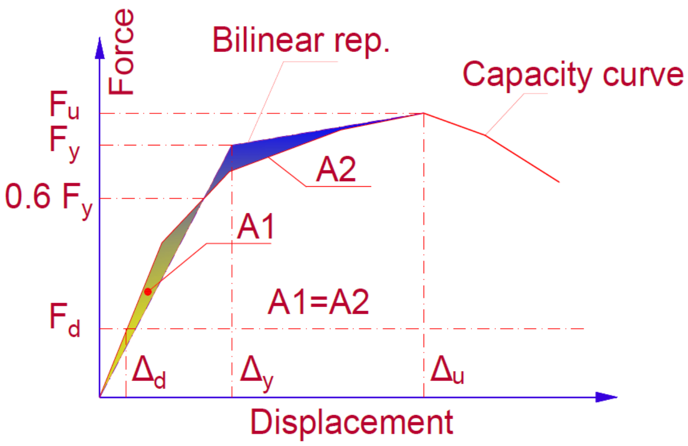


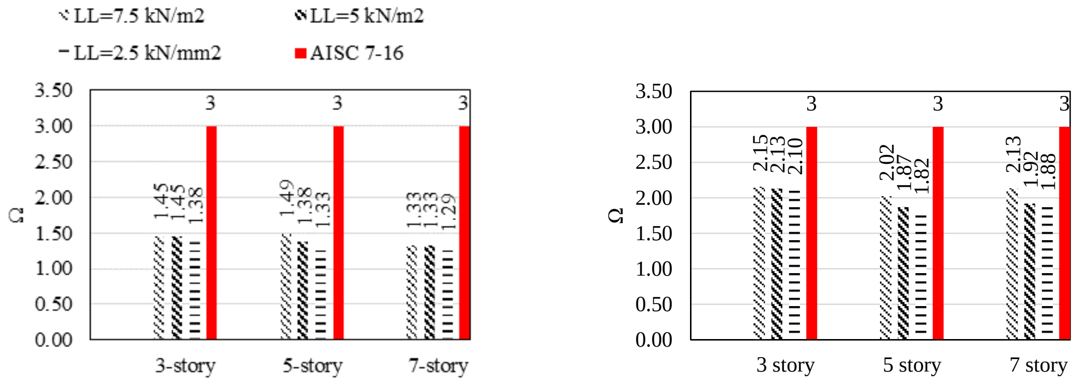
Figure 2. Bilinear representation of capacity curve.

In this equations, F_y and F_u show the effective yield and ultimate strength of the frame and Δ_y and Δ_u represent their corresponding displacements, respectively. Moreover, F_d is the design base shear of the frame and Δ_d is its corresponding displacement at roof level.

IOP Conf. Series: Materials Science and Engineering **884** (2020) 012029 doi:10.1088/1757-899X/884/1/012029

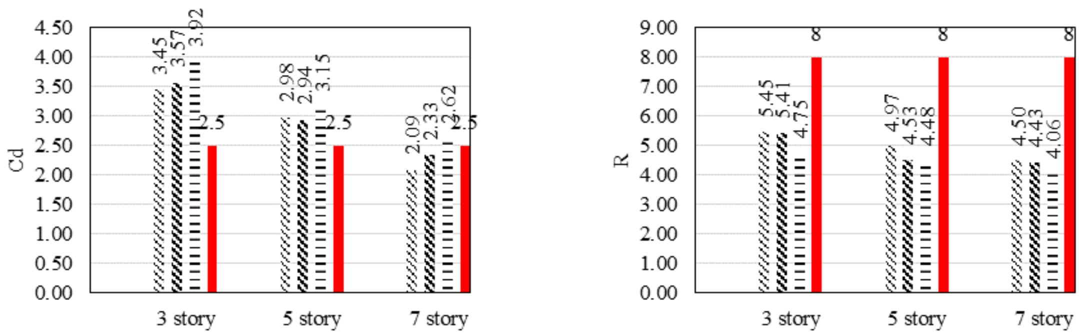
4. Results and discussions

Figures 3, 4, and 5 display the obtained results for the seismic response modification factors of RC frames. As can be seen from figure 3, the calculated overstrength factors for all frames are less than the value given by the design code. This is mainly because unlike current study seismic codes consider the effects of infill walls, soil-structure interaction, and redundancy. It can also be seen from figure 3 that for low and high ductile frames the value of overstrength factor decreases slightly as the intensity of design live load decreases. On the other hand, as it can be seen from figure 4, increase in the intensity of design live load has led to a slight decrease in the value of displacement amplification factors of low and high ductile frames. It is also evident that the calculated displacement amplification factors for shorter frames are larger than the values recommended by the design seismic code. It is also shown in figure 5 that increase in the intensity of design live load has slightly increased the values of R-factor in high ductile RC frames. Considering this observation that the change in the values of seismic design response modification factors is insignificant it can be concluded that the recommended values by the seismic code can be safely used for any intensity of design live load.



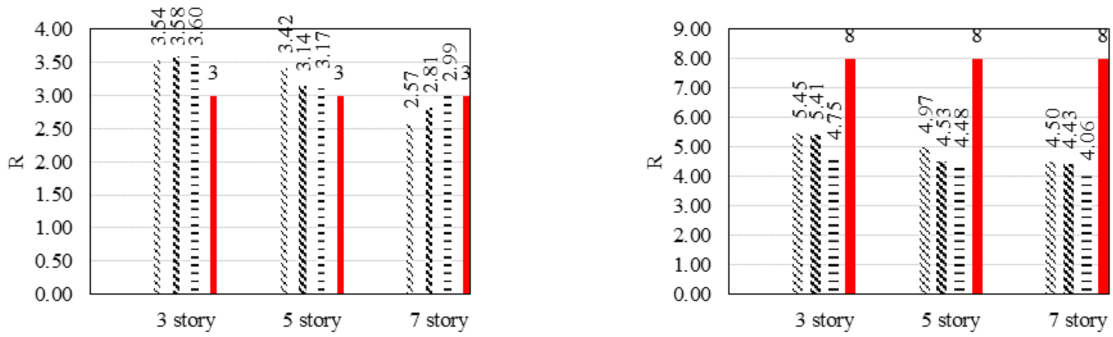
(a) (b)

Figure 3. Calculated overstrength factors (a) low ductile frames (b) high-ductile frames.



(a) (b)

Figure 4. Calculated displacement amplification factors (a) low ductile frames (b) high-ductile frames.



(a) (b)

Figure 5. Calculated response modification factors (a) low ductile frames (b) high-ductile frames.

5. Conclusion

This study investigated the effect of change in the intensity of design live load on the seismic design modification factors of low and high ductile reinforced concrete frames. Totally 18 reinforced concrete frames with different live load intensities and ductility classes were designed according to specifications of ACI 318 and AISC 7-16. The frames were subjected to pushover analysis, and their capacity curves were obtained. Then, by using the proposed approach in FEMA 356, the capacity curves were idealized to a bilinear representation. Finally, the seismic design modification factors were extracted from the idealized curves. Results indicated that change in the seismic design modification factors as a result of different intensities of deign live load was insignificant. Therefore, it was concluded that the recommended values by seismic codes could be safely employed for different intensities of design live load.

Acknowledgments

This study was funded by the Ministry of Higher Education of Malaysia through the RUG votes of 17H80 and 19H36 which are acknowledged.

References

[1] Vafaei M and Alih S C 2016 Assessment of seismic design response factors of air traffic control towers *Bull. Earthq. Eng.* **14** 3441–61
[2] Keykhosravi A and Aghayari R 2017 Evaluating response modification factor (R) of reinforced concrete frames with chevron brace equipped with steel slit damper *KSCE J. Civ. Eng.* **21** 1417–23
[3] Mahmoudi M and Zaree M 2013 Determination the Response Modification Factors of Buckling Restrained Braced Frames *Procedia Eng.* **54** 222–31
[4] Mwafy A 2011 Assessment of seismic design response factors of concrete wall buildings *Earthq. Eng. Eng. Vib.* **10** 115–27
[5] Menegon S J, Tsang H H, Wilson J L and Lam N 2015 Overstrength and ductility of limited ductile RC walls: from the design engineers perspective *Proceedings of the Tenth Pacific Conference on Earthquake EngineeringBuilding an Earthquake-Resilient Pacific* (Sydney) pp 183–92
[6] Taïeb B and Sofiane B 2014 Accounting for ductility and overstrength in seismic design of reinforced concrete structures *Proceedings of the 9th International Conference on Structural Dynamics, EURODYN 2014* vol 2014-Janua (Porto) pp 311–4
[7] Jamshidi Avanaki M 2019 Response modification factors for seismic design of steel Fiber Reinforced Concrete segmental tunnels *Constr. Build. Mater.* **211** 1042–9
[8] Zahrai S M A P 2019 Response modification factors of concrete bridges with different bearing

conditions *Earthquakes Struct.* **16** 185–96
[9] Zhou L, Chui Y-H and Ni C 2019 Numerical study on seismic force modification factors of hybrid light wood frame structures connected to a stiff core *Eng. Struct.* **183** 874–82
[10] ACI 318, *Building Code Requirements for Structural Concrete (ACI 318–14) and Commentary on Building Code Requirements for Structural Concrete (ACI 318R-14)* American Concrete Institute (Farmington Hills)
[11] ASCE/SEI 7-10,*Minimum Design Loads for Buildings and Other Structures*,American Society of Civil Engineers (Reston, Virginia)
[12] Vafaei M, Alih S C and Fallah A 2019 The accuracy of the lumped plasticity model for estimating nonlinear behavior of reinforced concrete frames under gradually increasing vertical loads *Struct. Concr.* suco.201800357
[13] Vafaei M, bin Adnan A and Yadollahi M 2011 Seismic Damage Detection Using Pushover Analysis *Adv. Mater. Res.* **255**–**260** 2496–9
[14] ASCE/SEI 41-13 *: Seismic Evaluation and Retrofit of Existing Buildings, American Society of Civil Engineers* (Reston, Virginia)
[15] FEMA 356 *Prestandard And Commentary For The Seismic Rehabilitation Of Building*. Federal Emergency Management Agency (Washington, DC)