Egyptian Code Seismic Load Design Provisions for Moment Resisting Frames

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Abstract. The occurrence of any seismic activity can impact the robustness of the structure as well as the human lives, the Egyptian code of practice of seismic loads is mainly concerned about maintaining the safety and the structural integrity of the structures. In this study an estimation of the strength reduction factor of the different seismic zones in Egypt is to be implemented. Moreover, the probabilistic seismic hazard map of Egypt is also evaluated to test the soundness of the currently used seismic zones map in Egypt.

1 Introduction

According to the Egyptian code of practice Egypt is to be categorized into 6 seismic zones (Zone 1, 2, 3, 4, 5A and 5B). The main objective of this paper is to study the variation of the response modification factor determined by the Egyptian code of practice due to the change in seismic zones, 2 analytical models are to be implemented via SAP 2000 software using pushover nonlinear static analysis on a 2 storey building and 3 storey building respectively.

The analysis predominantly depend on the application of the base shear generated according to the Egyptian code of practice for each seismic zone on the 2 storey 2D frame and the 3 storey 2D frame respectively. Moreover, applying the pushover analysis to know the capacity of the structure.

2 Response Modification Factor

According to (Uang 1991; Whittaker et al. 1987), the main three properties that influencing Response Modification Factor are ductility, overstrength, and redundancy factor. Beginning from USA at Berkeley city in the University of California, perform an experimental work was performed to understand and capture the seismic behavior of steel braced frames structure buildings through their seismic response. Submitting the base shear - roof displacement relationships timed to the maximum base shear of each earthquake and each model, using those data to plot the base shear versus roof displacement relationship (pushover curve) for each and every model, using the acceleration-response history of the earthquake platform to generate the elastic

H. Rodrigues et al. (eds.), *Facing the Challenges in Structural Engineering*,
Sustainable Civil Infrastructures, DOI 10.1007/978-3-319-61914-9_8

acceleration response spectrum. Moreover, using results data, the researchers in the Applied Technology Council (ATC 40) in 1996 described R as the product of three factors that accounted for ductility, reserve strength, and viscous damping through the following equation: ([Eq. 2.1, ATC40, 1996])

$$R = R_{\mu} \cdot R_{s} \cdot R_{\xi}R = R_{\mu} \cdot R_{s} \cdot R_{\xi} \tag{2.1}$$

Where:
$R_{\mu}R_{\mu}$: Ductility reduction factor.
$R_{s}R_{s}$: Overstrength factor.
$R_{\xi}R_{\xi}$: Damping factor.

The three factors $R_{\mu}R_{\mu}$, $R_{s}R_{s}$, and R_{ξ} take account of many characteristics of the structure energy absorption and dissipation through undergoing plastic deformations, redistribution of internal forces in the inelastic range, and damping of the structure through the supplemental viscous damping devices.

2.1 Overstrength Factor (Rs)

The overstrength factor is a characteristic, which reflects the collapse prevention ability of the structures, and represented as a factor, which illustrate that the real strength is more likely to be higher than the design strength of the structure as the ratio between the yield force Vy to the design force Vd. ([Eq. 2.1.1, ATC40, 1996])

$$R_{s} = \frac{V_{y}}{V_{d}} \tag{2.1.1}$$

2.2 Ductility Reduction Factor (Rμ)

The ductility reduction factor according to the work of (Newmark et al. 1973) is a characteristic, which reflects the capacity of structures from dissipate hysteretic energy through undergoing plastic deformations with acceptable loss in stiffness, and represented as a factor that reduces the elastic force demand to the level of idealized yield strength of the structure as the ratio between the elastic collapse forces Ve to the actual yield one Vy as shown in Fig. 1.

This factor depends on a characteristic of the structure that is called the Ductility factor μ, which defined as the ability of the structure to undergo large plastic deformations without significant loss of strength. It can be mathematically presented as the ratio between the maximum ultimate deformation Δu at an assumed collapse point to the yield deformation Δy.

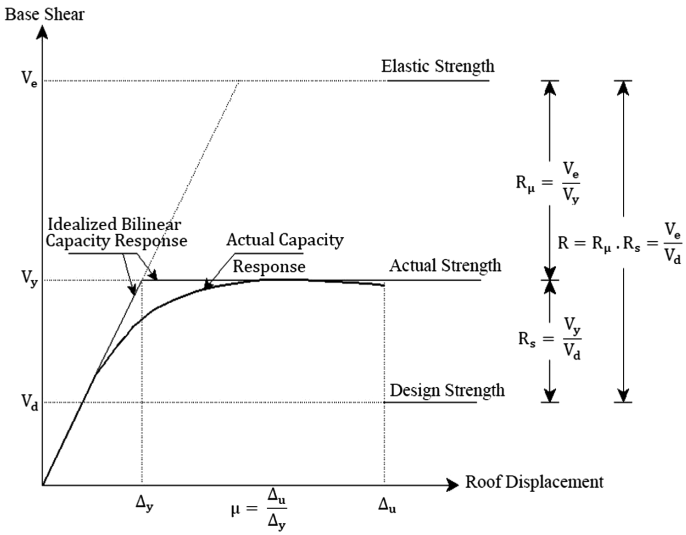

Fig. 1. Base shear V - Roof displacement Δ relationship showing response modification factor R components ductility reduction factor Rμ and overstrength factor Rs.

3 Validation Process

An experimentally obtained pushover curves of a 0.25 size RC frame models from (Paul et al. 2011) with and without infill wall and steel bracing have been used to calibrate the non-linear analytical model of the frame. The pushover testing has been carried out on three non-ductile frame models namely bare frame (BF), infilled frame (INF) and a steel braced (SBF) frame under quasi-static condition. The non-linear analytical model is further extending for the seismic evaluation and retrofitting of a 4-storied 2D frames using infill wall and steel bracing. In this context; firstly a 4-storied 2D RC frame structure has been analyzed and designed using different versions of IS: 456 and IS: 1893. Re-evaluation of these frames has been carried out to with masonry infill and steel bracing as retrofitting scheme using pushover analysis. The different pushover parameters of the frames before and after retrofitting have been compared.

4 Analytical Model

For the required analysis of a moment resisting frame a 2D model is to be implemented via SAP 2000 software (Computers and Structures Inc. 2016) of a 2 storey with 2 bays intermediate frame and a 3 storey with 3 bays frame as shown in Figs. 2 and 3.

The undermentioned 2D frames are designed according to the Egyptian code of practice ECP201and ECP203, in order to calculate gravity and seismic loads on the following buildings in given seismic zones accordingly.

The beams’ dimensions are to be 300 mm * 650 mm and the columns’ dimensions are to be 600 mm * 600 mm in all the moment resisting frames (2 storey and 3 storey).

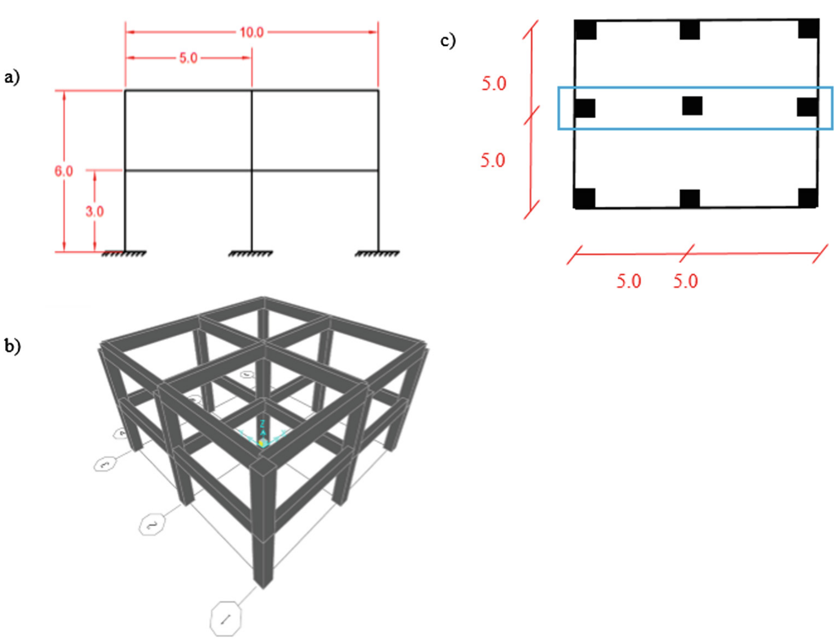

Fig. 2. For the 2 storey building (a) Elevation. (b) Plan. (c) Isometric view.

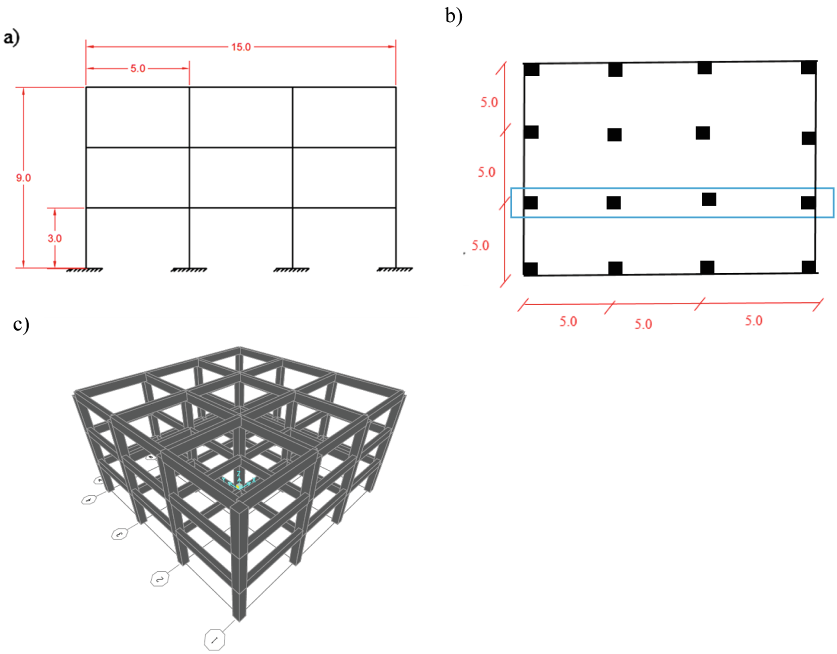

Fig. 3. For the 3 storey building (a) Elevation. (b) Plan. (c) Isometric view.

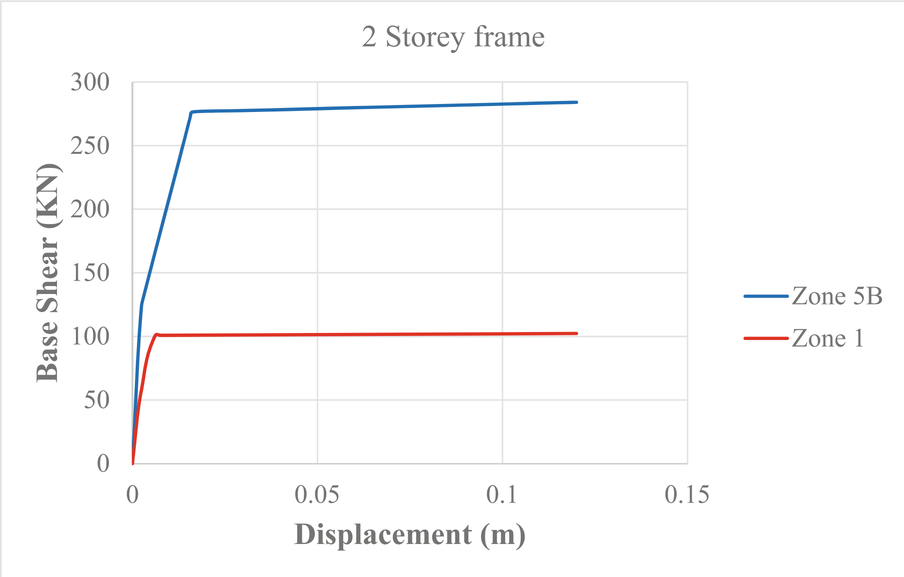

Fig. 4. Static pushover curve for 2 Storey frame in seismic zone 1 and zone 5B

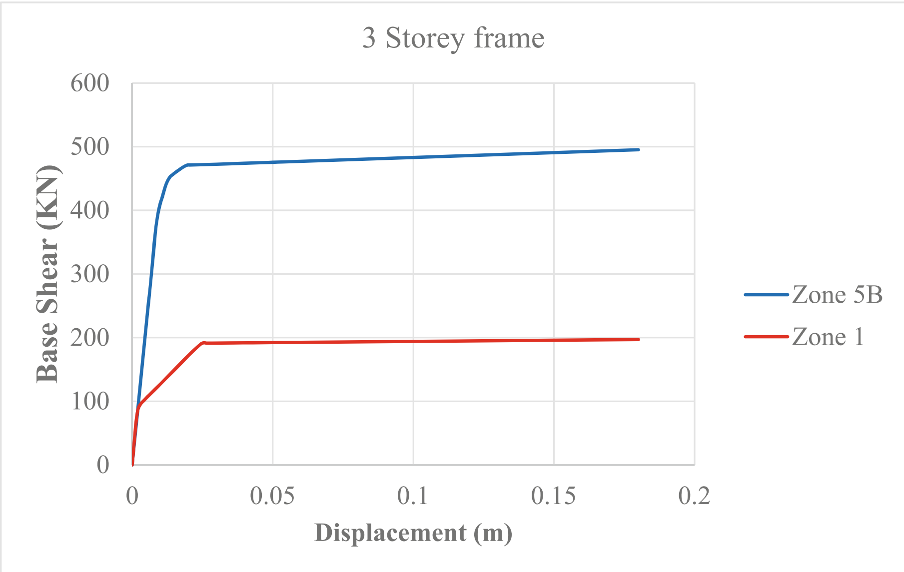

Fig. 5. Static pushover curve for 2 Storey frame in seismic zone 1 and zone 5B

The materials used in the design of systems members are concrete (confined and unconfined), which has a unit weight of 2.5 t/m^3, a characteristic strength of 30 MPa, and Poisson's ratio of 0.20. Yield strength of 360 MPa, and ultimate strength of 520 MPa (high grade steel).

For a given 2D frame the Live load = 3000 N, thickness of slab = 0.2 m, Floor covering = 2000 N.

5 Results

The 2 storey frame model plan dimensions are 10 m × 10 m as shown in Fig. 2 resting on dense sand soil which is to be located in seismic zones 1, 2, 3, 4, 5A and 5B. As for the 3 storey frame model the plan dimensions are 15 m × 15 m as shown also in Fig. 2 resting on dense sand soil which is also to be located in seismic zones 1, 2, 3, 4, 5A and 5B respectively. While the elevations of both frames are illustrated in Fig. 3, consisting of a storey height of 3 m and a fixed end supports.

Primarily the model is prepared, afterwards a nonlinear static pushover analysis is to be performed on each model in order to generate the static pushover curve of the structure, from Table 1 the design base shear according to the Egyptian code of seismic load are calculated for each frame in each zone. Afterwards, nonlinear static pushover analysis under incremental lateral displacement controlled loading were performed on the 2 storey and the 3 storey moment resisting frames. Plastic hinge properties were assigned to concrete beam and column sections as per FEMA 356.

Table 1. Base shear for 2 storey and 3 storey buildings in different seismic zones in Egypt.

	Fb (Base shear according to ECP) for **2 storey** building in KN	Fb (Base shear according to ECP) for **3 storey** building in KN
Zone 1	84.8	161.339
Zone 2	106	201.673
Zone 3	127.2	242.008
Zone 4	169.6	322.667
Zone 5A	212	403.346
Zone 5B	254.5	484.016

From Table 1 it is noticed that the magnitude of the base shear described by the Egyptian code increases radically for the same structure through the different seismic zones, for the 2 storey and the 3 storey frame the base shear gradually increase from seismic zone 1 (low seismicity) to zone 5B (higher seismicity) as shown in Fig. 27 according to Egyptian seismic map.

For the 2 storey frame the base shear increases by 201% from zone 1 to zone 5B, and for the 3 storey frame the base shear increases also by 200%, which is predicted to have a direct influence on the strength reduction factor (R).

From Tables 2 and 3 it is observed that the variation in the strength reduction factor is noticeable, for the 2 storey and the 3 storey frames the strength reduction factor (R) values decrease gradually from seismic zone 1 to the seismic zone 5B as per noticed.

Table 2. Response modification factor for 2 storey building in different seismic zones in Egypt.

2 storey moment resisting frame							
	Vy (KN)	Vd (KN)	Δu (mm)	Δy (mm)	Rμ	Ω	R
Zone 1	102	84.8	120	28	4.285	1.202	5.154
Zone 2	118	106	119	26	4.576	1.113	5.095
Zone 3	140	127.2	120	26	4.615	1.100	5.079
Zone 4	180	169.6	120	26	4.615	1.061	4.898
Zone 5A	257	212	120	30	4.001	1.212	4.849
Zone 5B	285	254.5	120	28	4.285	1.119	4.799
						Average =	4.979

In the case of the 2 storey frame, the calculated strength reduction factor has decreased by 3.3% from zone 1 to zone 5B, correspondingly the 3 storey frame' strength reduction factor has decreased similarly by 8% from zone 1 to zone 5 B.

Moreover, the illustration from Fig. 6 shows the variation of (R) between the 2 storey frame and the 3 storey frame, as the relation between the structure height and the (R) is apparent. The strength reduction values decrease with the increase in the structure' height.

The static pushover curve of the 2 storey frame in seismic zone 1 has a maximum base shear (Vy) from Table 2 of 84800 N while in seismic zone 5B has Vy of 254500 N which has also incremented by 171.56%. Which leads us to the conclusion that the Response modification factor would be directly impacted due to the change in seismic zones, as per noticed in Table 2 as well the response modification factor (R) for the 2 storey frame in seismic zone 1 is 6.71 and in seismic zone 5B is 2.93 which has exponentially decreased by 56.33%, as for the 3 storey frame the response modification factor (R) from Table 3 in seismic zone 1 is 6.3 while in seismic zone 5b is 2.07 which has similarly decreased by 67.14%.

Correspondingly it has been noticed that the Response modification factor for the same structure decreases gradually from seismic zone 1 to seismic zone 5B, taking into consideration that the Response modification factor for the 2 storey frame is higher than

Table 3. Response modification factor for 3 storey building in different seismic zones in Egypt.

3 storey moment resisting frame							
	Vy (KN)	Vd (KN)	Δu (mm)	Δy (mm)	Rμ	Ω	R
Zone 1	193	161.339	180	42	4.285	1.196	5.126
Zone 2	228	201.673	180	40	4.500	1.130	5.087
Zone 3	282	242.008	180	42	4.285	1.165	4.993
Zone 4	353	322.667	180	41	4.390	1.094	4.802
Zone 5A	420	403.346	180	40	4.500	1.041	4.685
Zone 5B	499	484.016	180	40	4.500	1.030	4.639
						Average =	4.889

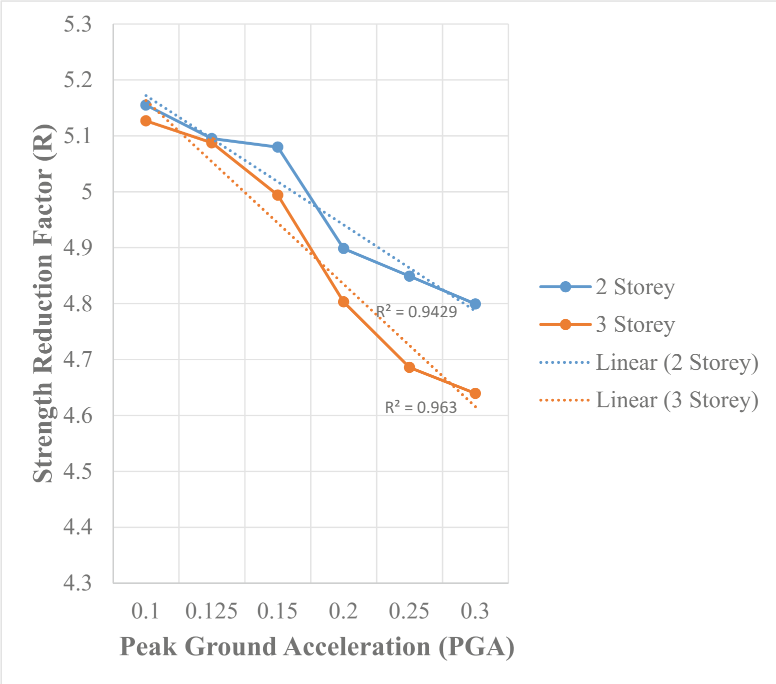

Fig. 6. Response modification factor R relationship with peak ground acceleration PGA.

the response modification factor of the 3 storey frame in the same seismic zone as shown in Fig. 6 which is rational due to the change in the ductility factor (Rμ) between each structure.

The ductility factor (Rμ) for the 2 storey frame in seismic zone 1 is 5.7 from Table 2, while for the 3 storey frame in the same seismic zone is 5.53 from Table 3.

Figures 4 and 5 shows the static pushover curve between 2 storey frames the first one in Fig. 5 is in seismic zone 1 and the latter one is seismic zone 5 B, it is observed

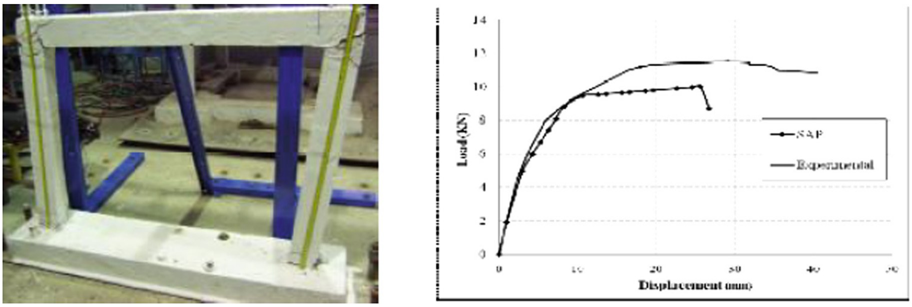

Fig. 7. Shows the BF model after pushover testing and its pushover curves

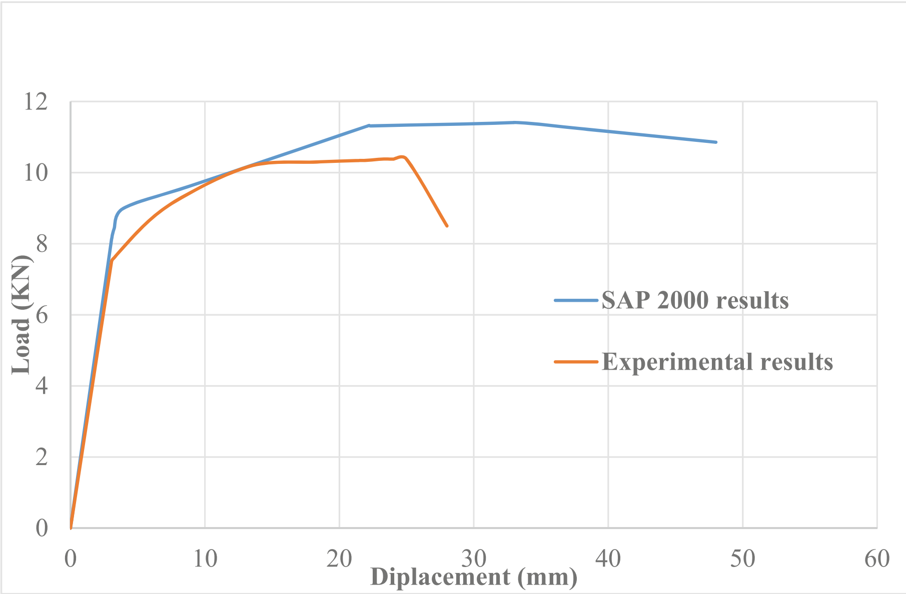

Fig. 8. Shows the static pushover curve generated from the SAP 2000 software and the formation of the first plastic hinge.

that the the yield deformation Δy of the frame in seismic zone 1 is 41 mm while in seismic zone 5B is 91 mm which has increased by 121% (Figs. 7 and 8).

6 Conclusions

A total number of 12 2D moment resisting frames has been analyzed via SAP 2000 software to comply with the provisions and considerations of the Egyptian seismic code in the 6 different seismic zones in Egypt.

As per noticed the response modification factor decreases with respect to the seismic zone, for seismic zone 1 has higher response modification factor than seismic zone 5B for the same structure. Which indicates that the more the seismic hazard within the seismic zone the less the response modification factor would be.

Also the 2 storey 2D frame has higher response modification factor than the 3 storey 2D frame, in that regard according to the design based on the Egyptian seismic code the base shear force increases noticeably from the 2 storey frame than 3 storey frame within in the same seismic zone.

The observations mentioned above calls for the seismic Egyptian provision code to take into consideration the variation of the response modification factor. Correspondingly the moment resisting frames with high response modification factor (R) do perform better under the application of lateral loads, with a less likely of a brittle failure than the frames with less (R).

Acknowledgement. I would like to express my deepest gratitude and appreciation for the Civil Engineering program at the German University in Cairo for providing me with the support and the facilities throughout my work on this research.

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