Performance Based Behavior of Reinforced Concrete Frames Designed According to Iraqi Seismic Code

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ABSTRACT

The objectives of this study was to develop and document a method for accurately assessing building system performance and response parameters for use in seismic design for typical reinforced concrete (RC) moment-resisting frames (MRFs), then compare the R factor derived with the values stated in the Iraqi seismic code of practice. The effect of the following parameters on the archetype models has studied: number of stories, bay width, the building stiffness represent by f'c, Seismic design category. The results indicate that the general trend in increasing the bay width to increase the value of seismic performance factors is to increase. While the value of seismic performance factors decreased when increasing the building height.

Keywords:

1. Introduction

There are many natural hazards in the world and earthquakes can be considered as one of the most destructive natural hazards that cause a severe social and economic impact. One of the major design requirements is to know the potential hazard of future earthquake events. So for this purpose, detailed investigations and studies for the definition of seismic hazard level of a given site are necessary.

In the years gone by, the earthquake engineering community has been reassessing its procedures, in the wake of devastating earthquakes which caused extensive damage. These procedures involve rating the seismic force demands on the structure. Conventional seismic design in codes of practice is entirely force-based, with a final check on structural displacements. The seismic design follows the same procedure, except the fact that inelastic deformations may be utilized to absorb certain levels of energy. This leads to the creation of the Response modification factor. While the concept of R factor or also commonly known as Force Reduction Factor has appeared as a single most important number, representing the capability of the structure to dissipate energy through inelastic behavior.

Tectonically Iraq is located on the northern portion of the Arabian Plate, surrounded in the northern and eastern boundaries by the Bitlis - Zagros Fold and Thrust Belt, in which the convergent tectonic boundary between the Arabian and Eurasian plates produces a strong earthquake activity.

The remainder of Iraq is mainly situated within the Arabian Plate, far from the major boundaries of the plate, [1]. Alsinawi & Ghalib (1975c) presented the first seismic zoning map for Iraq where Iraq was divided into five intensity regions ranging between V- IX on the MM scale, [2].

The primary objective of this study is to establish and document a recommended methodology for reliably quantifying building system performance and response parameters for use in seismic design for typical reinforced concrete (RC) moment-resisting frames (MRFs) which exist in Iraq

2. Previous Studies

The proposed push-over analysis procedure is also an effective tool for the performance-based seismic design of new steel moment-frame buildings [3]. the response modification factor formulation was discovered. The formulation's goal was to establish a technical foundation for the R values used in seismic codes and guidelines. R was divided into three categories: reserve strength (Rs), ductility (Rm), and redundancy (Rd) (RR). The impacts of plan and vertical irregularity on building response were not taken into account in the formulation. where it turned out the strength of buildings varies greatly depending on the type of building, its height, and its seismic zone. Factors of strength Values must account for these differences, and the impact of higher-mode effects must be investigated further [4]. Then it was developed a way for determining the response modification factor. The proposed methodology allows to determine the maximum response modification factor for a building of desired probabilistic performance objective. The methodology is used to determine the response modification factors of special moment resisting perimeter frames for three probabilistic performance objectives. According to the results obtained from the example buildings, the force-based design method may develop SMRPFs that satisfy the three probabilistic performance targets by employing the proposed response modification factor expressions. As a result, they were able to come to the conclusion that the proposed response modification factor expressions can effectively turn the force-based design approach into a direct probabilistic performance-based design procedure [5].

in 2020 studied the effect of friction dampers on response modification factor (R) in steel structures concerning traditional and advanced methods of nonlinear static analysis. In general, they found that the two concepts are affecting the R factor: strength and ductility.

When the damper was used, the average response modification factor for the structures increased from 22.8 to 110.1%. The dampers with different slip loads and a variable number of dampers in each story were studied. The researchers concluded a new (Rd) proposed for the R factor of structures along with a friction damper: slip force, the number of stories, and the bay of equipped with damper. In the obtained results, several equations of the response modulation factor were presented to evaluate and predict the behavior of steel structures along with friction dampers [6].

3. Seismic Performance Factors

Development of the seismic design of buildings through history will be presented briefly. Then the behavior of the structures will be listed in general for earthquakes and tacitly talk simply about the behavior of the Seismic Force-Resisting System that was used in the present thesis. The analysis procedure adopted in seismic design and methods of calculating of the seismic performance factors and the seismic performance levels will be mentioned.

Efforts to construct buildings that can safely resist seismic events in the modern era have just passed 100 years which can be divided into three periods. The first uses a predetermined percentage of the building's weight as an applied load, while the second uses variants of the Eq. V= ZKCW, which relates seismic base shear (V) to a seismic zone factor (Z), building period (C), building weight (W), and building system type (W) (K). To compute equivalent lateral forces on the structure, the most recent approach uses site-specific ground motion maps, building period, important factors, site (soil) variables, and 'Response Modification Factors (R). In the 2018 International Building Code - IBC (ICC, 2018) [7], three seismic design elements, namely response modification factor (R), deflection amplification factor (Cd), and system over-strength factor ('Ωo), are employed to derive the nonlinear response from their linear equivalents. As it has been proposed to break the R factor into discrete behavioral component components since the mid-1980s. Period-dependent strength factor (Rs), period-dependent ductility factor (R), and redundancy factor (RR) are some of the presented suggestions [8].

The Methodology adheres to the ASCE/SEI 7-16 definitions of seismic performance elements and the underlying nonlinear static analysis (pushover) ideas specified in the Commentary to the NEHRP Recommended Provisions.

The seismic performance factors are explained and illustrated in Fig. 1, as well as how they are used in the Methodology. Eq.s, which are dimensionless ratios of force, acceleration, or displacement, are used to define parameters.

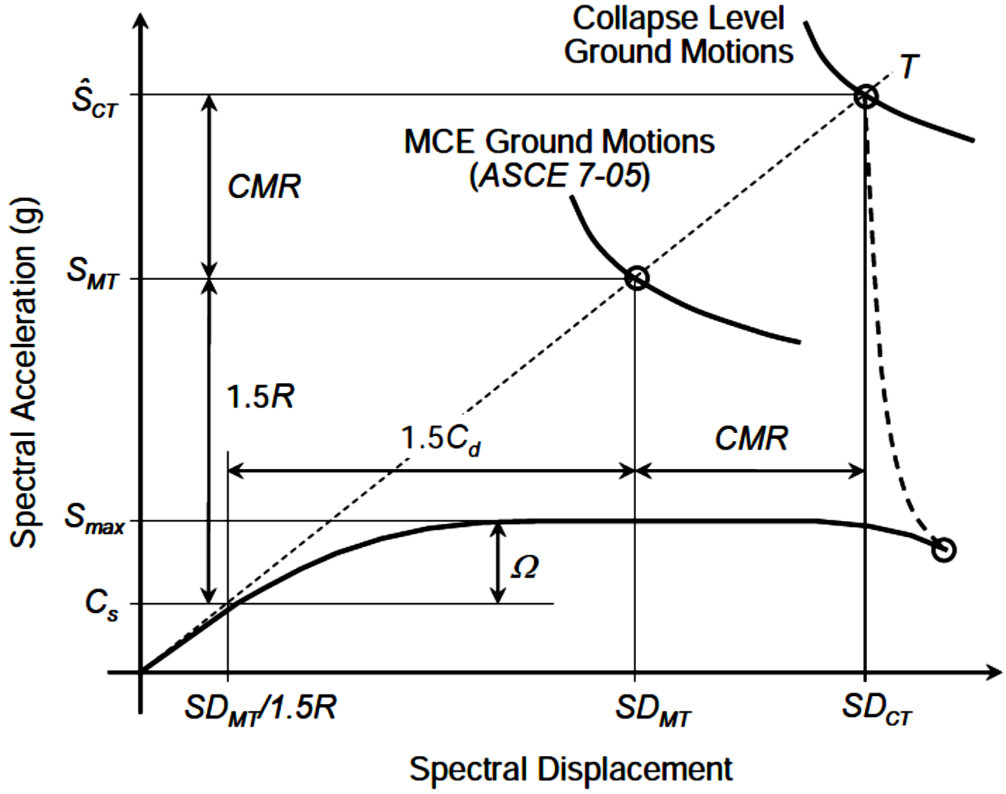

Fig. 1: Illustration seismic performance factors as defined in FEMA-P695 [9]

This section will illustrate how to use Eq.s 1 to 3 get the response modification factor, R factor, system over-strength factor, Ω o, and deflection amplification factor, Cd.

The R factor is 1.5 times the MCE spectral acceleration to the seismic response coefficient, which is the design level acceleration as described in Eq 1.

$$1.5R = \frac{S_{MT}}{C_s} \quad (1)$$

Where: S_{MT} is the Maximum considered earthquake (MCE) spectral acceleration at the period of the system, *T*.

C_s is the seismic response coefficient

The over-strength parameter, Ω, is defined as the maximum strength ratio of the fully-yielded system, *Smax* to the seismic response coefficient, *Cs* as defined in Eq. 2

$$\Omega = \frac{S_{max}}{C_s} \quad (2)$$

The displacement corresponding to the design seismic response coefficient, C_s, is 1.5Cd times the displacement corresponding to the inelastic system displacement at the MCE level. And if it's set to the MCE elastic system displacement, SD_{MT}, the Cd factor is effectively renamed the R factor, as defined in Eq. 3

$$C_d = R \tag{3}$$

Designing buildings to behave elastically during ground shaking without any damage may lead to an economically unaccepted project. Consequently, the building structure must undergo damage and then dissipate the energy input from an earthquake. This is achieved by designing the building for only a portion of the elastic seismic forces, Hence, the seismic design balances the acceptable damage and the reduced cost, [10].

Generally, there are three structural damage levels or structural performance levels which are usually depicted as significant for the design of structures, which are, [11] immediate occupancy level (IO), life safety level (LS) and collapse prevention level (CP).

ASCE/ SEI 41-17, FEMA 356, and ATC-40 presented four procedures for seismic analysis, where two of them are linear and the others are nonlinear procedures. These are the Linear Static Procedure (LSP), the Nonlinear Static Procedure (NSP) usually called "pushover analysis", the Linear Dynamic Procedure (LDP), and the Nonlinear Dynamic Procedure (NDP) which is known as nonlinear time history analysis.

Linear methods are suitable for a low level of nonlinearity. Dynamic methods are necessary for irregular tall buildings. The NSP is acceptable for most buildings, however, it needs to be supplemented by an LDP when the mass participation in the first mode is small, [12] [13].

4. Theoretical Work

According to the principles and concepts mentioned above, the methodology used to prepare primary archetype models, considered parameters, applying a gravity and seismic load, and then analyzing these models.

Four main parameters were chosen to study the Performance and calculate the seismic performance factors for moment frame building: bay width, number of stories, building stiffness represented by f'c and Seismic Design Category

Considering typical office occupancies, three basic configurations of reinforced concrete moment frame, archetypes will be adopted which are 6m, 7.5m, and 9m bay widths and unsymmetrical archetype (6 × 7.5) m. Story heights were taken as 15 feet, (≈ 4.5m), for the first story and 13 feet, (≈ 4m), for the upper stories.

Also for each one of the three basic configurations of bay size, three primary archetype heights or number of stories were considered, which are 5, 10, and 15 stories. For each above configuration, two primary concrete strengths were considered, which are normal f'c 25Mpa and higher f'c equal to 40Mpa. All of the above configurations will be assumed to be located in two Iraqi Cities: Najaf and Erbil. In such cases, SDC B, C and D will be expected and a total of 51 archetype models will be investigated, as shown in Tab. 1.

Tab. 1, summary of reinforcement Moment Frame Archetypes Models

Archetypes Models in terms of total number of stories, (n)	Models Name				
	Building in Najaf			Building in Erbil	
	SDC B		SDC C	SDC D	
	25Mpa	40Mpa	25Mpa	25Mpa	40Mpa
Bay width 6 m					
5	N5-6F25B	N5-6F40B	N5-6F25C	E5-6F40D	E5-6F25D

10	N10-6F25B	N10-6F40B	N10-6F25C	E10-6F25D	E10-6F25D
15	N15-6F25B	N15-6F40B	N15-6F25C	E15-6F25D	E15-6F25D
Bay width 7.5 m					
5	N5-7.5F25B	N5-7.5F40B		E5-7.5F25D	E5-7.5F25D
10	N10-7.5F25B	N10-7.5F40B		E10-7.5F25D	E10-7.5F25D
15	N15-7.5F25B	N15-7.5F40B		E15-7.5F25D	E15-7.5F25D
Bay width 9 m					
5	N5-9F25B	N5-9F40B		E5-9F25D	E5-9F25D
10	N10-9F25B	N10-9F40B		E10-9F25D	E10-9F25D
15	N15-9F25B	N15-9F40B		E15-9F25D	E15-9F25D
Un symmetric 6*7.5 m					
5	N5-UF25B	N5-UF40B		E5-UF25D	E5-UF25D
10	N10-UF25B	N10-UF40B		E10-UF25D	E10-UF25D
15	N15-UF25B	N15-UF40B		E15-UF25D	E15-UF25D

Structures, components, and foundations shall be designed so that their design strength equals or exceeds the effects of the factored loads in the following combinations. The combinations of design loads including earthquake effects, according to ASCE/SEI 7-16, ACI 318-14, and Iraqi Seismic Code, for Najaf in Eqs. (4-a,b) and for Erbil in Eqs. (5-a,b)

$$U = 1.242D + 0.5L \pm Q_E \quad (4\text{-a})$$

$$U = 0.857D \pm Q_E \quad (4\text{-b})$$

$$U = 1.305D + 0.5L \pm \rho\ Q_E \quad (5\text{-a})$$

$$U = 0.794D \pm \rho\ Q_E \quad (5\text{-b})$$

Where the design dead load will be taken as an average of 8 kN/m2 while the design floor and roof live loads are 2.4 and 1.0 kN/m2, respectively. All models are analyzed by applying the gravity loads to the building in ETABS after assume all reinforcement area and the estimated preliminary structural element sections, and checked if it works and can resist the loads, where the longitudinal reinforcing rebar of the columns are considered to be not less than 1% nor more than 8% of the concrete gross area.

According to recommendations of FEMA P695, and Haselton and Deierlein (2007) [14], the compression strength is assumed to be between 5ksi ≈ 34.4Mpa to 7ksi ≈ 48.3Mpa, However, in this study, pre-constructed buildings will be evaluated so that a compressive strength equal to 25Mpa will be used. Also, to cover a wider spectrum of buildings, a compressive strength equal to 40Mpa will be used as well

5. Results and Discussion

The obtained results from the pushover analysis of the present study are:The performance point which lies at the intersection of demand and capacity curve according to FEMA P695, it can be found through the spectrum acceleration-spectrum displacement curve. The seismic performance level of the archetype models after applying the seismic load to the building. Calculating the seismic performance factors and all requirements. All of these results were recorded after the pushover analysis in Etabs. The performance point, performance levels, and the required results were obtained from the spectrum acceleration-spectrum displacement curve and base shear-roof displacement curve. Some of archetype models result for the fifty-one models are presented in the following sections.

For the 6m bay width archetype model 5 story and concrete strength 25Mpa in Najaf city with risk category III, so the seismic design category is B, this model had performance point information with base shear is 1195.5kN and displacement is 133.5mm as shown in fig. 2. Fig. 3 shows the seismic design performance for the archetype model and its turn up to match the life safety level. The base shear versus the monitored displacement of the archetype model is shown in Fig 4. Since the maximum displacement (263.6mm) less than 4% from the model height in fig. 4 so the building did not approach the collapse limit as figure in3.

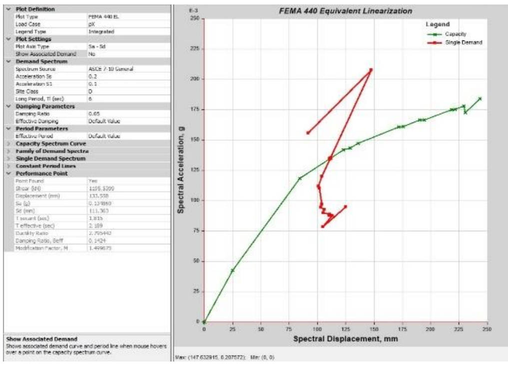

Fig. 2 spectral acceleration- spectral displacement of archetype model N5-6F25B

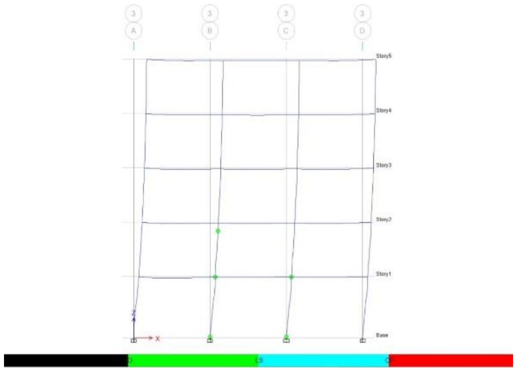

Fig. 3 seismic design performance level of archetype model N5-6F25B

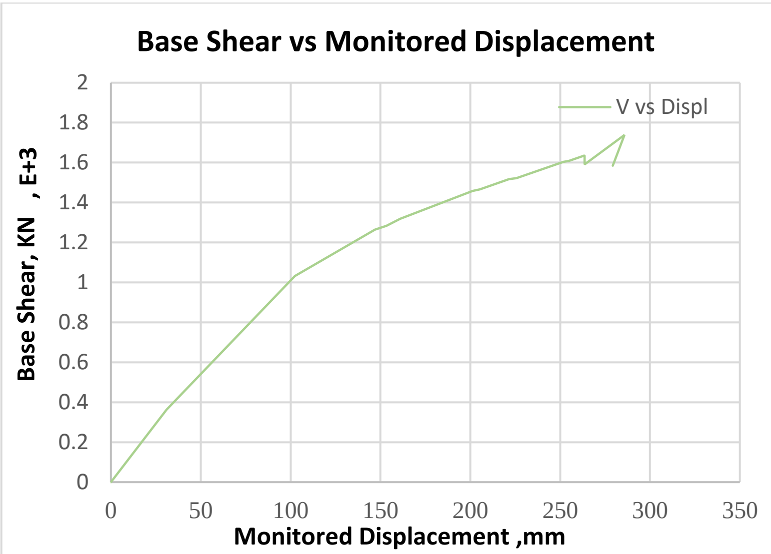

Fig. 4 Base shear-monitored displacement of archetype model N5-6F25B

The hand calculation results are summarized in tab. 2, where Cs is the seismic response coefficient, R is response modification factor, Cd is deflection amplification factor, Ωo is over-strength factor.

Tab. 2 The results summery of seismic performance factors

model	R, Cd	Ωo	model	R, Cd	Ωo
N5-6F25B	1.1667	2.0059	N10-9F40B	0.8805	2.8249
N5-6F25C	1.434		E10-9F40D	1.2875	2.923
E5-6F25D	1.7025	2.213	N10-UF25Bx	0.9083	2.7236
N5-6F40B	1.08	1.809	N10-UF25By	0.8025	2.9104
E5-6F40D	1.5751	1.9096	E10-UF25Dx	1.4103	2.6817
N5-7.5F25B	1.4235	2.9745	E10-UF25Dy	1.2698	2.9703
E5-7.5F25D	1.887	2.7881	N10-UF40Bx	0.8655	2.5684
N5-7.5F40B	1.2615	2.8485	N10-UF40By	0.783	2.9756
E5-7.5F40D	1.8404	2.9063	E10-UF40Dx	1.3046	2.5773
N5-9F25B	1.4963	1.5784	E10-UF40Dy	1.2416	2.9201
E5-9F25D	2.0951	1.7865	N15-6F25B	0.6555	1.179
N5-9F40B	1.4025	2.9655	N15-6F25C	0.8127	2.818
E5-9F40D	1.996	2.9802	E15-6F25D	0.9198	1.2764
N5-UF25Bx	1.2683	2.583	N15-6F40B	0.5745	1.7089
N5-UF25By	1.2353	2.7241	E15-6F40D	0.8378	1.9273
E5-UF25Dx	2.8725	2.8384	N15-7.5F25B	0.7208	2.2343
E5-UF25Dy	2.122	2.8521	E15-7.5F25D	1.0393	2.0948
N5-UF40Bx	1.1271	2.2635	N15-7.5F40B	0.5858	2.9768
N5-UF40By	1.0253	2.8395	E15-7.5F40D	0.9875	2.9748
E5-UF40Dx	1.8896	2.2346	N15-9F25B	0.9008	2.4829
E5-UF40Dy	1.7228	2.6158	E15-9F25D	1.2554	2.8364
N10-6F25B	0.6855	2.3771	N15-9F40B	0.6428	2.6415
N10-6F25C	1.006	2.928	E15-9F40D	1.0164	2.9664
E10-6F25D	1.2186	2.5557	N15-UF25Bx	0.7298	2.8013

N10-6F40B	0.678	2.2196	N15-UF25By	0.6795	2.9115
E10-6F40D	1.0459	2.3114	E15-UF25Dx	0.9395	2.5429
N10-7.5F25B	0.945	2.4908	E15-UF25Dy	0.9284	2.9427
E10-7.5F25D	1.2416	2.5547	N15-UF40Bx	0.7058	2.8271
N10-7.5F40B	0.8303	2.1668	N15-UF40By	0.642	2.7281
E10-7.5F40D	1.0781	2.3843	E15-UF40Dx	0.9198	2.1795
N10-9F25B	0.9855	1.7089	E15-UF40Dy	0.8975	2.8836
E10-9F25D	1.3401	2.9693			

The results of seismic performance factors were discussed according to four parameters. Some of them will be discussed below:

Fifty-one archetype models will be divided according to the effect of the number of stories into four groups which Each group differs among themselves in the number of story group 1 contains models in Najaf city with f'c 25Mpa, group 2 contains models in Najaf city with f'c 40Mpa, group3 have all models in Erbil city with f'c 25Mpa, group 4 have models in Erbil city with f'c 40Mpa. The main results of group 1 and 2 are shown in Fig 5 to Fig. 6.

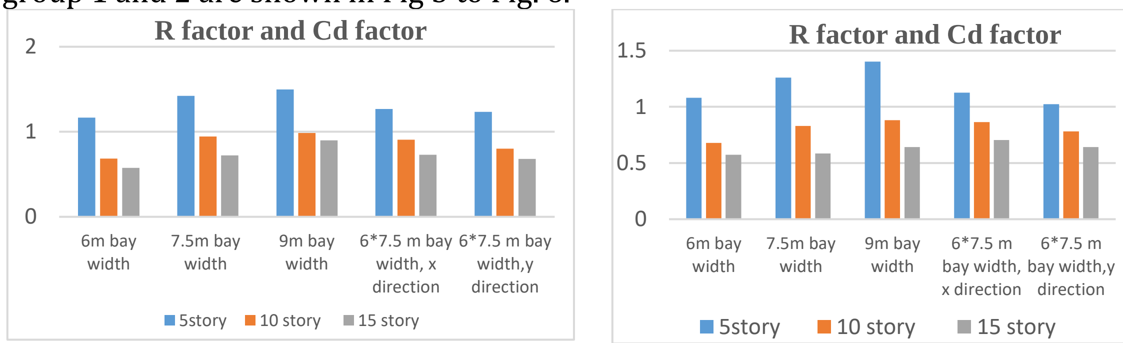

Fig. 5 Number of story effect on the response modification factor and deflection amplification factor for group 1 and 2

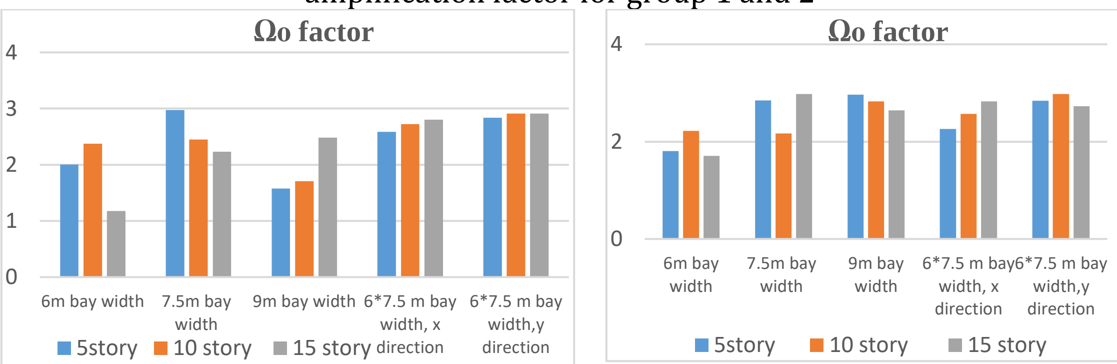

Fig. 6 Number of story effect on over-strength factor for group1 and 2

Fifty-one archetype models will be divided according to the effect of bay width into four groups which Each group differs among themselves in the bay width, group 1 contains models in Najaf city with f'c 25Mpa, group 2 contains models in Najaf city with f'c 40Mpa, group3 have all models in Erbil city with f'c 25Mpa, group 4 have models in Erbil city with f'c 40Mpa. The main results of group 3 and 4 are shown in Figs. 7 and 8.

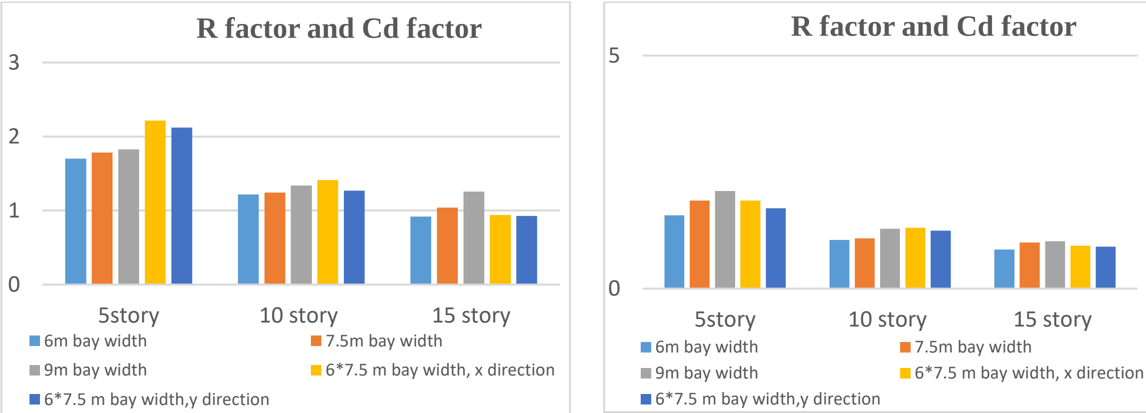

Fig. 7 Bay width effect on the response modification factor and deflection amplification factor for group3 and 4

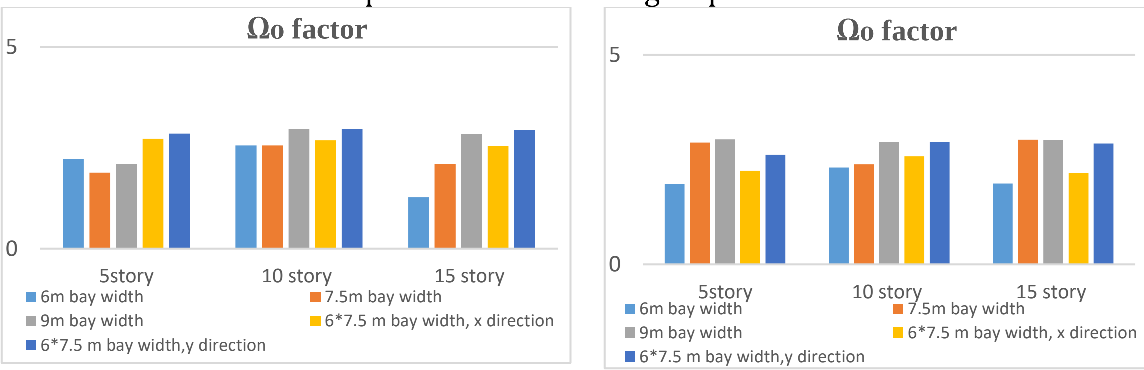

Fig. 8 Bay width effect on over-strength factor for group4

Fifty-one archetype models will be divided according to the effect of stories number into three groups which Each group differs among themselves in the number of stories, group 1 contains models with 5 story buildings, group 2 contains models with 10 story buildings, group3 have all models with 15 story buildings. The main results of group 1 are shown in Figs. 9 and 10.

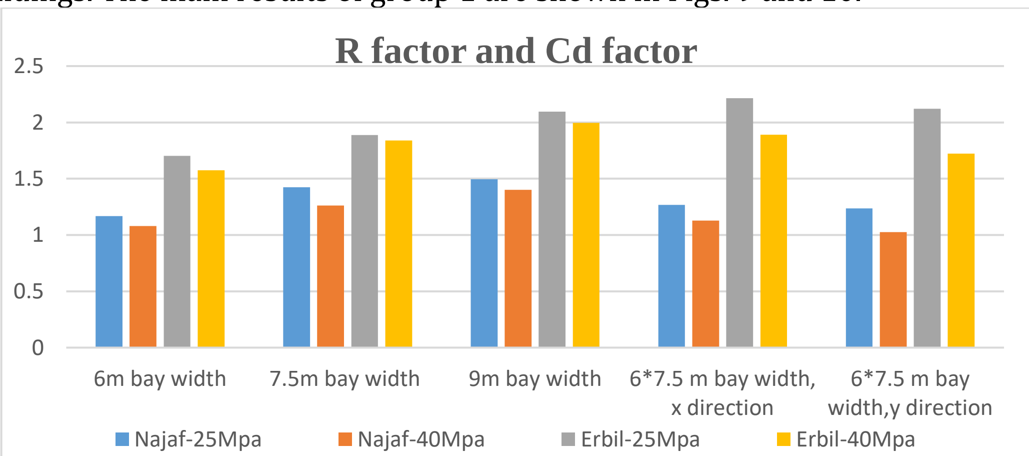

Fig. 9 Building stiffness effect on the response modification factor and deflection amplification factor for group1

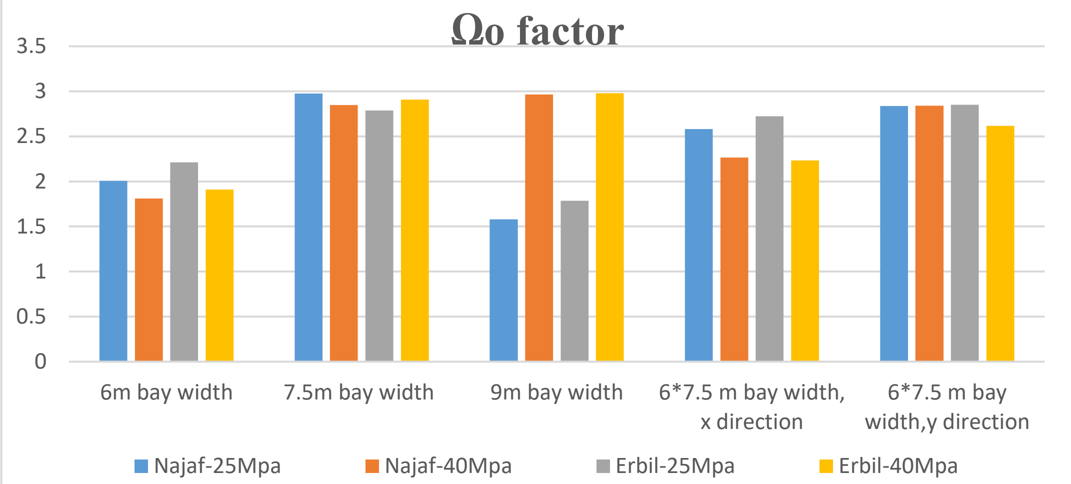

Fig. 10 Building stiffness effect on over-strength factor for group1

Fifty-one archetype models will be divided according to the seismic design category effect into three groups which Each group differs among themselves in the seismic design category, group 1 contains models with 5 story buildings, group 2 contains models with 10 story buildings, group3 have all models with 15 story buildings. The main results of group 2 shown in Figs.11and 12

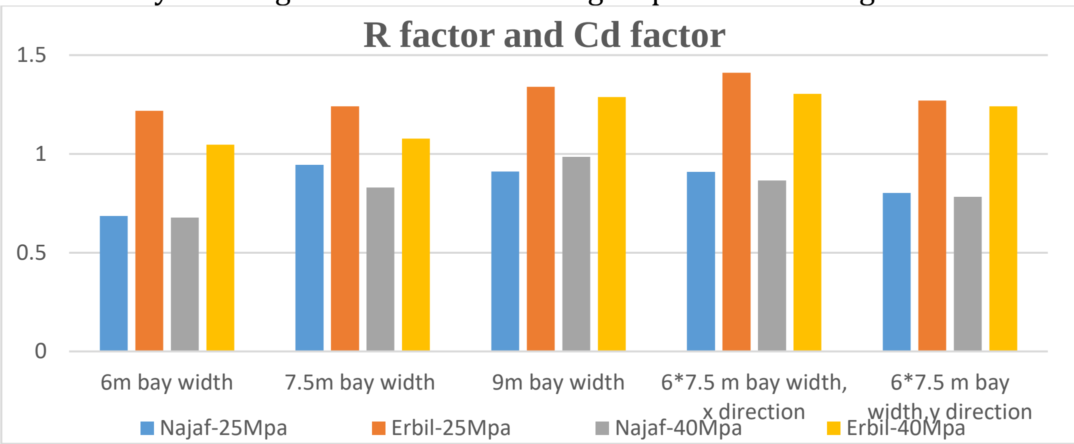

Fig. 11 SDC effect on the response modification factor and deflection amplification factor for group2

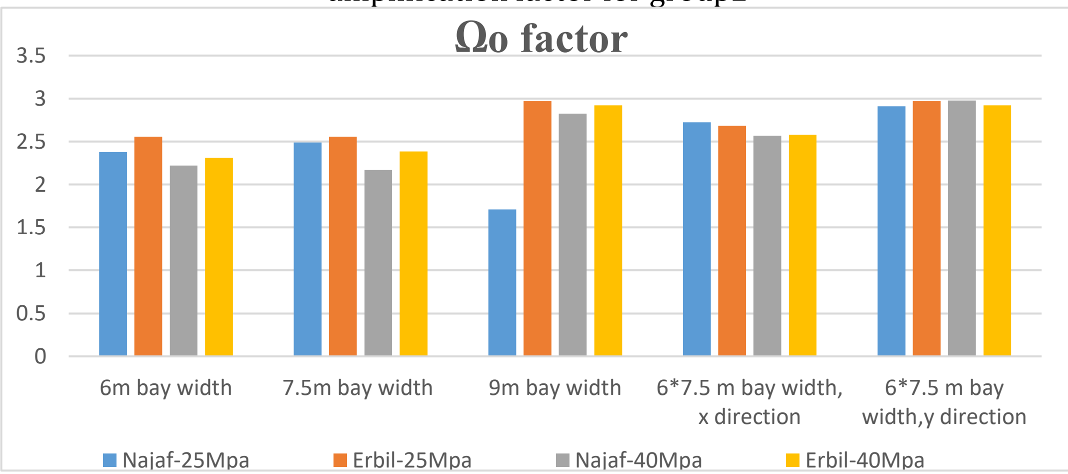

Fig. 12 SDC effect on over-strength factor for group2

6. Conclusions

From the presented study in which fifty-one archetype models were analyzed by using the ETABS the following main conclusions can be summarized: The archetype models in Erbil city for special moment-resisting frame system are didn't approach the collapse limit and the seismic performance factors in the Iraqi seismic code can be accepted for these cities. Intermediate and ordinary moment-resisting frame system for archetype models in Najaf city with seismic design category C are did not approach the collapse limit and the seismic performance factors in Iraqi seismic code can be accepted for this city and the surrounding areas that are under the same seismic influence in the seismic map.

Increasing the building height nearly three times higher than its original height (number of stories) and increasing the building bay width 1.5 times higher than its original bay width leads to get lower response modification factor and deflection amplification factor with percentage decreases from 37.4% to 67.3% and from 10% to 43.7%, respectively. Increasing the building concrete strength 1.6 times higher than its original strength leads to get lower response modification factor and deflection amplification factor with the percentage decreasing from 1.1% to 12% for Najaf and 7.5% to 14.2% for Erbil. response modification factor and deflection amplification factor directly proportional with the increasing of archetype seismic design category, since the percentage increasing from 29.8% to 77.7% for symmetric archetype and 28.7% to 126.4% for unsymmetrical models.

The value of over strength factor is unstable with the four studied parameters changes.

Adding an ordinary moment-resisting frame to the Iraqi seismic code with the seismic performance factors as recommend in ASCE7-16.

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