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Studying the Effect of Torsional Irregularity on Seismic Response Modification Factor in RC Dual System

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Abstract:

In this research, the effect of torsion due to the irregularity of the reinforced concrete dual system on seismic response factors and building behavior was investigated. As the demands of modern architecture increase, the effects of twisting are amplified, altering the actual earthquake response of a structure. A fifteen-storey 3D building has been modeled using Incremental Dynamic Analysis (IDA) under 20 seismic records that are selected to match the seismological specifications of Syria country. Eleven different scales were used for each seismic record, and a force-displacement curve was derived to determine the necessary parameters and calculate the seismic response modification factor. These values were then compared with the values of the Syrian and American codes, and differences in decreases by 35% were observed relating to the eccentricity ratio 42%. These differences vary according to the eccentricity ratio and torsional effects in these systems. Therefore, it is recommended to use a dimensionless factor that considers the effect of the torsion ratio on the response modification factor instead of using a fixed value for the R factor as stated in the codes.

Keywords: Nonlinear Modeling, Incremental Dynamic Analysis (IDA), Dual Systems, Torsion, Irregularity.

دراسة تأثير الفتل الناتج عن عدم الانتظام على عامل تعديل الاستجابة الزلزالية في الجملة الثنائية الخرسانية المسلحة

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الملّخص:

تم في هذا البحث دراسة تأثير الفتل الناتج عن عدم انتظام الجملة الثنائية الخرسانية المسلحة على عوامل الاستجابة الزلزالية وسلوك المبنى. مع ازدياد متطلبات الهندسة المعمارية الحديثة، تتضخم تأثيرات الفتل، مما يغير الاستجابة الفعلية للزلزال في المبنى. تم نمذجة مبنى ثلاثي الأبعاد مكون من خمسة عشر طابقًا باستخدام التحليل الديناميكي المتزايد (IDA) باستخدام 20 سجلًا زلزالياً تم اختيارها لتعكس المواصفات السيسمولوجية والزلزالية لسوريا. استُخدم إحدى عشر مقياساً مختلفاً لكل سجل زلزالي، وتم اشتقاق منحنى القوة–الإزاحة لتحديد المعلمات الضرورية وحساب عامل تعديل الاستجابة الزلزالية. ثم قورنت هذه القيم مع قيم الكودين السوري والأمريكي، ولوحظ وجود اختلافات في الانخفاض بنسبة 35% وفقاً لنسبة لامركزية 42%. تختلف هذه النسب وفقًا لنسبة اللامركزية وتأثيرات الفتل في هذه الجمل. ولذلك، يوصى باستخدام عامل لابعدي يأخذ في الاعتبار تأثير نسبة الفتل على عامل تعديل الاستجابة بدلاً من استخدام قيمة ثابتة لعامل R كما هو مذكور في الكودات.

الكلمات المفتاحية: التحليل اللاخطي، التحليل الديناميكي المتزايد (IDA)، الجمل الثنائية، الفتل، عدم الانتظام.

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Introduction:

Torsional irregularity in buildings significantly influences their seismic response, particularly in dual systems that combine moment-resisting frames and shear walls. Studies have shown that torsional vibrations, resulting from irregularities, are a primary cause of structural damage during earthquakes, making unsymmetric buildings more vulnerable than symmetric ones. Evaluating the seismic performance of dual reinforced concrete systems under varying levels of torsional irregularity reveals the importance of considering torsion-related factors, such as overstrength and dynamic amplification, in seismic design. Torsional amplification factors, which measure the increased seismic demand caused by torsion, depend on building characteristics and the contribution of non-structural components, making them essential for designing acceleration-sensitive elements in torsional irregular buildings [(Alaa et al, 2022)-(Ulcuango et al, 2024)-(Jain et al, 2022)-(Rashidi et al, 2019)].

The current research has demonstrated that torsional effects can significantly modify the structural response, leading to increased displacement demands and potential structural damage. This is particularly evident when torsional components of earthquakes introduce additional eccentricity, further amplifying the seismic response. Current seismic codes, however, may be unconservative in their treatment of torsional irregularity, necessitating the development of improved models and equations to enhance the accuracy of seismic design provisions. Simplified procedures such as elastic response spectrum analysis and pushover analysis can capture torsional amplification, but these methods often require adjustments for inelastic systems to accurately represent real-world structural behavior [(Alaa et al, 2022),)-(Jain et al, 2022)-(Ouazir et al, 2024)].

Several studies have investigated the response modification factor (R) for dual systems under torsional irregularity. (Nasser et al, 2020)found significant discrepancies between R-values obtained through nonlinear static analysis (NSP) and those provided in Syrian Arab Code, indicating that code-specified values may not always reflect actual structural behavior. Similarly, (Abou-Elfath et al, 2018)showed that R factor is highly sensitive to both the number of floors and floor height, with taller frames exhibiting lower R-values. These findings highlight the need to refine existing seismic codes to account for variations in torsional response and building configurations.

Further studies have analyzed the relationship between torsional irregularity and seismic demand across different structural configurations. (Patil et al, 2019) conducted a comparative study of regular and irregular buildings, observing that irregularity leads to increased displacements, deflections, storey shear forces, and total base shear.(Naganur and Vijaykumar, 2018) evaluated torsional irregularity in high-rise reinforced concrete buildings using response spectrum analysis, emphasizing the need to accurately estimate base shear and displacement demands. Additionally, (Hussein et al, 2019)used a nonlinear sequential push method to determine the response modification factor for different levels of irregularity, concluding that buildings with severe irregularity experience faster formation of plastic hinges and greater structural damage.

design approaches for earthquake-resistant structures.

1. Research Objectives

The objective of this study is to investigate the effects of torsional irregularity on the seismic behavior of reinforced concrete buildings, addressing a critical gap in existing researches where the impact of torsion on seismic response factors in nonlinear 3D models has not been explicitly considered. Despite extensive earthquake damage reports confirming that irregular buildings experience greater damage than regular ones—often due to torsional effects leading to structural collapse—current seismic design approaches may not fully account for this behavior. To bridge this gap, this study employs incremental dynamic analysis (IDA) on a 3D model subjected to torsional effects, utilizing a comprehensive set of twenty seismic records. The key objectives include evaluating the actual seismic response of reinforced concrete buildings under torsional loading, analyzing the effect of torsion on the seismic response modification factor and its dependency on contribution ratios, and comparing the resulting R-values with those specified in seismic codes such as Syrian Arab Code(SAC). and American code ASCE. based on the findings of this study, potential modifications to existing code provisions will be proposed to enhance their accuracy in accounting for torsional effects in seismic design.

2. Methodology:

In order to study the effect of torsional irregularity on the response modification factor, a parametric study was performed on a 15-story concrete building with dual system (shear wall and intermediate moment resisting frame (IMRF)), under the effect of 20 seismic records selected according to the geological and seismic nature of the studied region (Syria), using 11 different scales

To address these challenges, researchers have proposed updated models and provisions that had better account for torsional irregularity in seismic design. Incremental Dynamic Analysis (IDA) and fragility curves have been used to quantify the probability of structures reaching different performance levels, such as immediate occupancy, life safety, and collapse prevention, under varying degrees of torsional irregularity. Additionally, second-order effects, such as instantaneous load eccentricities, have been identified as significant contributors to underestimating seismic displacement demands, particularly in symmetrical systems [(Hong et al, 2012)-(Erduran et al, 2011)-(Emrah et al, 2010)].

A broader perspective on seismic irregularity research includes findings from (De Stefano and Pintucchi, 2002) who categorized studies into three key areas: the effects of plane irregularity through single-storey and multi-storey models, passive control strategies to mitigate torsional effects, and irregularities in vertical configurations. Earlier work by (Chopra and Goel, 1991) assessed the impact of irregularity on code-designed buildings, establishing the extent to which flexural requirements in seismic codes capture these effects. These historical studies provide a foundation for modern research efforts in refining seismic design methodologies to enhance the resilience of buildings with irregular configurations.

In conclusion, torsional irregularity significantly affects the seismic response modification factor in dual systems. The current research has demonstrated that irregular configurations amplify displacement demands, increase structural damage, and may not be fully accounted for in current seismic codes. By integrating nonlinear dynamic analysis methods such as IDA, refining response modification factor calculations, and updating code provisions based on empirical data, researchers and engineers can develop more accurate and resilient eccentricity by the amplification factor Ax. Equation (1) can be used for torsional irregularity and Equation (2) for severe torsional irregularity [21, 22].

$$1 \leq A_x = \left[\frac{\delta max}{1.4\,\delta av}\right]^2 = \frac{\eta}{1.4} \leq 3 \qquad \textbf{(1)}$$

$$1 \leq A_x = \left[\frac{\delta max}{1.4\,\delta av}\right]^2 = \frac{\eta}{1.4} \leq 3 \qquad \textbf{(2)}$$

3. 2 Response Modification Factor:

To simplify the structural design process, it has been proposed to incorporate the response modification factor (R) into the calculation of the base shear force, allowing static elastic analysis to be sufficient for the design of most structures. The R factor plays a fundamental role in seismic design, as it enables the reduction of seismic loads by accounting for a structure's inherent overstrength and energy dissipation capacity (ductility)—a concept widely recognized in international seismic codes. This factor reflects the combined effects of overstrength and ductility through the dynamic behavior factor (R), which depends on several parameters, including the required performance level, structural system type, construction materials, reinforcement detailing, fundamental structural role, and the influence of higher deformation modes. The R factor essentially quantifies the expected level of inelasticity within a structural system during an earthquake. The National Earthquake Hazards Reduction Program (NEHRP, 1988) defines it as "a factor intended to take into account both the damping and the inherent ductility of structural systems at displacements large enough to approach the maximum displacement of the structure." By incorporating R, seismic response analysis becomes more representative of real structural behavior for each seismic record. In addition, the force-displacement curves were plotted using nonlinear Incremental Dynamic Analysis (IDA), the necessary parameters were determined, the seismic response modification factor was calculated, and these values were compared with the values of Syrian Arabic code and American code. It was proposed to use a non-dimensional factor that takes into account the effect of the contribution ratio and torsion on the response modification factor, and not to use a fixed value for R-factor as stated in the codes, the proposed finite element analysis was performed by ABAQUS software package (2019).

3. 1 Irregularities and Torsional Irregularity Ratio:

According to ASCE/SEI 7-22 code, building irregularities are classified into two main categories: horizontal and vertical irregularities. Horizontal irregularities include torsional irregularity, reentrant corner irregularity, diaphragm discontinuity irregularity, out-of-plane offset irregularity, and nonparallel systems irregularity. Vertical irregularities encompass stiffness irregularity (soft story), vertical geometric irregularity, in-plane discontinuity in vertical elements resisting lateral force, and strength irregularity (weak story).

The Torsional Irregularity Ratio (TIR), as defined in ASCE/SEI 7-22, is calculated for each story and for each accidental torsion case. The TIR for the entire building is determined as the maximum value obtained from the computations performed for each story and in each direction.

Torsional irregularity is considered when the ratio of the maximum to the average storey drift is greater than 1.2. For severe torsional irregularity, this ratio is considered to be 1.4. The analysis should be performed by multiplying the emergency static and dynamic methods to assess its seismic performance. The building was designed as a dual system, incorporating intermediate moment-resistant frames (IMRF) and shear walls. The material properties used in the analysis were Fy = 400 MPa for longitudinal reinforcement, Fys = 240 MPa for shear reinforcement, and f'c = 30 MPa for concrete. The design of beams, columns, and shear walls followed the requirements of Syrian Arab Code, ASCE 7-16, and ACI 318-8 using ETABS. The dimensions of the structural elements are provided in Table 1. The applied loads included a dead load (DL) of 2 kN/m² and a live load (LL) of 3 kN/m².

Table (1) Member's cross-sections (Dimensions in cm)

Columns	Corner	Inter	Edge
Story No 1-5	50*50	70*70	55*55
Story No 6-10	45*45	65*65	50*50
Story No 11-15	40*40	60*60	45*45
Beams	30*60		
Slabs(Solid)	t=14		
Shear walls	Story No 1-5, thickness=40 Story No 6-10, thickness=30 Story No 11-15, thickness=25		
Spans	4.5 m		

The numerical model was developed using finite element methods(ABAQUS) as shown in Figure 1, where beams and columns were modeled with B31 (beam elements), allowing transverse shear deformations, while shear walls and slabs were modeled using S4R shell element as shown in Figure 2. The longitudinal and transverse reinforcement was represented using rebar elements. The material behavior of steel was defined as elastic-perfectly plastic, while the concrete material was also assumed to follow an elastic-perfectly plastic model. The self-weight of under earthquake loading, ensuring consistency with modern seismic design principles.

Syrian Arab Code provides specific values for the response modification factor R in Appendix No. (2), (2020), where tables define R values for different structural systems based on the type of elements resisting horizontal forces. Table (3-6) presents the R values according to the lateral force-resisting system, derived from Uniform Building Code (UBC-97). According to this table, the response modification factor for a dual system with intermediate moment-resisting frames is R = 6.5. However, based on the simplified table for Syrian Arab Republic, the R values for the same system range between R = 5.5 and R = 5, varying linearly according to the percentage of the frame's contribution to resisting the base shear forces.

3. 3 Incremental Dynamic Analysis:

Incremental Dynamic Analysis (IDA) is a nonlinear dynamic analysis method to estimate the seismic performance of structures more comprehensively by subjecting the studied model to a set of ground motion records using a series of nonlinear dynamic analyses, Each of these is measured at multiple levels of intensity. This requires expanding the scope of each record appropriately to cover the full range of structural response, starting from elasticity, to yielding, and finally collapse (covering the linear and nonlinear domain), in proportion to the seismicity of the studied building area. Then the results of this analysis are presented as IDA curves that represent response curves (relationship of inter storey drift or maximum displacement with base shear) which provide a general estimate of the structure's performance.

3. 4 Modeling and Analysis of RC Building:

A 15-story reinforced concrete (RC) building with a story height of 3.5 meters was analyzed using both

Figure (1) a)-Plan b)- 3D model for studied building.

The seismic analysis was conducted in two stages: (1) Static analysis for permanent loads and (2) Dynamic analysis for seismic loads using a nonlinear time-history analysis (NTHA). Ground motion records were applied through an input file, where each seismic record was defined with its X- and Y-direction components. A Python script was developed to automate the scaling of ground motions and extract the necessary results.

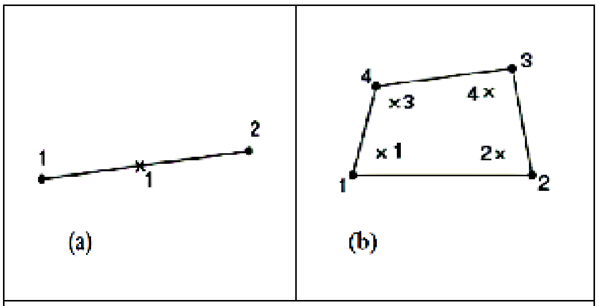
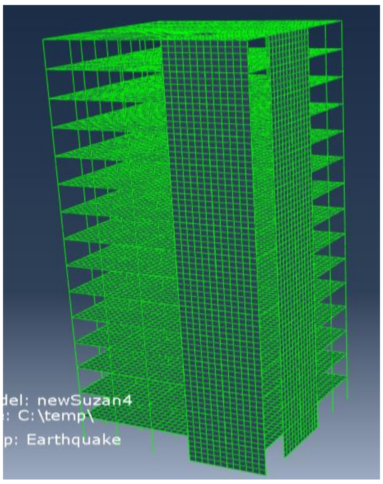


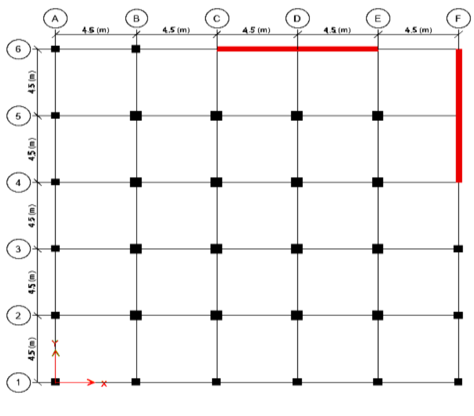
Figure (2) a)-Member B31 – b)- Shell element S4R, [20]..

To evaluate the incremental dynamic analysis (IDA), a set of twenty seismic records was selected, following previous studies (Shome and Cornell, 1999), which suggested that 10 to 20 records are sufficient for accurate seismic assessment of medium-rise buildings (Table 2). According to the seismicity of the studied building area (the whole of Syria, which is considered geologically and seismically diverse in terms of intensity, proximity and distance from the fault and the geological and seismological nature of the region, due to the lack of accurate data or seismic records for specific areas in Syria, so global and neighboring seismic records (Turkey, Iran) were used).Each record was scaled at ten intensity levels ranging from very low to very high (0.2, 0.5, 1, 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3, and 3.25)*g. These scaled records covered both the elastic and plastic behavior ranges of the building. The main objective of this method was to determine the structural elements was incorporated using a gravity value of 9810 mm/sec² and a concrete density of 2.4e-9 ton/mm³. Live and dead loads were applied as distributed masses.

The building was intentionally designed with unsymmetrical walls, where the shear walls were strategically placed to induce significant torsional effects due to horizontal irregularity, resulting in an eccentricity of e = 42%,. The frames contributed 39.6% of the seismic shear force in the X-direction, while the shear walls carried 60.4%. In the Y-direction, the frames contributed 37.3%, while the walls carried 62.7%.



a)



b)

A Python script was written to automate the seismic analysis in ABAQUS, incorporating all seismic records along with their corresponding intensity scales. The response modification factor (R) was then calculated by analyzing the IDA curves, which plotted shear force against maximum displacement for all seismic records and scales. The average, minimum, and maximum IDA curves were derived, allowing for a comprehensive comparison of the response modification factor (R) values across different seismic scenarios.

4 Results and Discussion:

4.1 Contribution ratio:

The maximum displacement and shear forces were calculated for each scale of the studied records, as detailed in Tables 3 and 4, with an example provided for the Northridge LA-Chalon record. Additionally, the contribution ratios in both directions were determined for all twenty records, as shown in Table 5. The capacity curves (IDA curves) were plotted to illustrate the relationship between the maximum shear force and the maximum top-story displacement for each seismic record scale in the X and Y directions (Figures 3 and 4). The data in Tables 5 reveal that the the building's response under varying seismic intensities. More than 440 nonlinear dynamic analyses were conducted, and the base shear versus maximum displacement curves were plotted.

Table (2) The seismic records.

No.	Earthquake	Date	Station	Magnitude	Fault Distance(km)	PGA(g)
1	Duzce, Turkey	/12/11 1999	Lamont 1061	7.1	15.6	0.131 0.101
2	Hollister	1986/26/1	SAGO South -	5.5	-	0.086 0.044
3	Imperial Valley	/15/10 1979	Parachute Test Site	6.5	14.2	0.206 0.113
4	Imperial Valley	/15/10 1979	Cerro Prieto	6.5	26.5	0.168 0.157
5	Imperial Valley	/15/10 1979	Superstition Mtn	6.5	26	0.202 0.111
6	Kern County	1952/21/7	Taft Lincoln	7.4	41	0.180 0.159
7	Livermore	1980/24/1	CSUH	5.8	31	0.065 0.057
8	Loma Prieta	/18/10 1989	Anderson Dam	6.9	21.4	0.239 0.078
9	Loma Prieta	/18/10 1989	Coyote Lake Dam	6.9	22.3	0.485 0.179
10	Loma Prieta	/18/10 1989	Hayward-BART Sta	6.9	58.9	0.160 0.156
11	Morgan Hill	1984/24/4	Corralitos	6.2	22.7	0.110 0.081
12	N. Palm Springs	1986/8/7	Cranston Forest	6	35.3	0.175 0.130
13	Northridge	1994/17/1	Featherly Park	6.7	84.2	0.104 0.100
14	Northridge	1994/17/1	LA-Baldwin	6.7	31.7	0.215 0.183
15	Tabas, Iran	91978/16/	Boshrooyeh	7.4	50	0.106 0.085
16	Northridge	1994/17/1	LA-Chalon Rd	6.7	23.7	0.082 0.058
17	San Fernand	1971/9/2	Palmdale Fire	6.6	25.4	0.151 0.112
18	Trinidad,	1980/8/11	Rio Dell Overpass	7.2	-	0.157 0.135
19	Victoria,	1980/9/6	Cerro Prieto	6.4	-	0.645 0.633
20	Westmorland	1981/26/4	Parachute Test Site	5.8	-	0.232 0.149

47.48235	0.31548495	82645
51.79892	0.34094394	87423
56.1155	0.36572853	93521

Table (5) Maximum displacements and shear force for each scale in the X and Y directions.

V_Xw-kN	V_Xf-kN	Fco	Wco
157928	136941	0.48	0.52
93634	8026	0.46	0.54
29340	23579	0.45	0.55
45584	24026	0.35	0.65
52061	24177	0.32	0.68
56349	26968	0.32	0.68
59239	26352	0.31	0.69
61504	27885	0.31	0.69
62193	27999	0.31	0.69
63072	27846	0.31	0.69
64345	27844	0.30	0.70
V_Yw-kN	V_Yf-kN	Fco	Wco
1521	167661	0.39	0.61
1282.3	937.02	0.42	0.58
24125	19743	0.45	0.55
27039	29458	0.52	0.48
30465	31339	0.51	0.49
35811	30863	0.46	0.54
39742	30873	0.44	0.56
61504	27885	0.36	0.80
40493	42152	0.51	0.49
46020	41403	0.47	0.53
51055	42466	0.45	0.55

Where: Fco : frame contribution ratio from total contribution ratios varied within the same model depending on the seismic record, as well as within the same record based on intensity scale changes. Notably, significant variations in contribution ratios were observed under dynamic seismic loading, with differences reaching up to 35% in each direction.

Northridge LA-Chalon

Table (3) The maximum displacement values with maximum shear force in the X direction.

PGA_X	Max Dis-X(m)	Shear Force-x(kN)
2.441025	0.01123101	14093.6
6.1029919	0.010792141	1738.94
12.205984	0.11617171	52919
18.308976	0.15874389	69610
21.360472	0.17765506	76238
24.411968	0.19573241	83317
27.463464	0.21214906	85591
30.514959	0.22793183	89389
33.566455	0.24141748	90192
36.617951	0.25155936	90918
39.669447	0.25852658	92189

Table (4) The maximum displacement values with maximum shear force in the Y direction.

PGAy	MAX Dis-Y(m)	Shear Force-y(kN)
3.453214	0.0070124	12933.6
8.633154	0.0310215	22193.2
17.26631	0.12990967	43868
25.89946	0.1639779	56497
30.21604	0.19717919	61804
34.53262	0.22600553	66674
38.84919	0.25547941	70615
43.16577	0.28503129	77187

content of each record. However, in most cases, the building entered the plastic stage at nearly the same displacement, albeit with different corresponding shear force values. These curves further illustrate how the seismic response of the structure is influenced by both the intensity and frequency characteristics of the applied ground motion.

4.2. IDA curves:

The IDA curves representing the relationship of the shear forces in the studied analysis with the maximum displacement of the top storey of each scale of the studied seismic record in the X, Y directions were grouped into one figure and then the average curve of each direction and the maximum and minimum curve were plotted, see Figures (5).

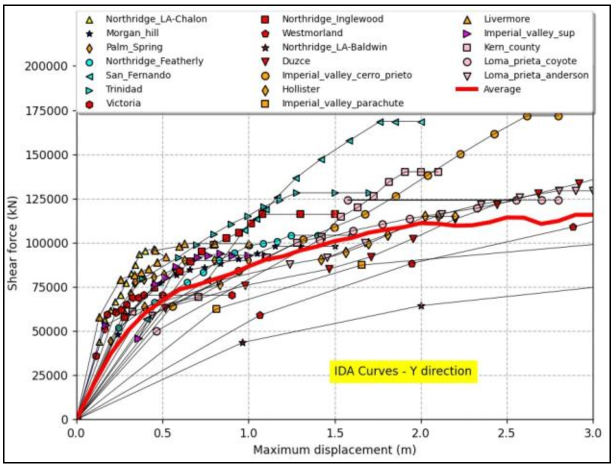


Figure (5) Y-direction average IDA curve.

Each curve represents the response of the building under a seismic record with eleven points (point for each scale), so we plotted twenty curve then we calculated the average and minimum and maximum value and plotted the resulting curves to determine response modification factor, noticed that the curves give horizotal line at the end of the analysis, confirming that the building was collapse.

4.3 Response Modification Factor (R):

shear force.

Wco : shear wall contribution ratio from total shear force.

$V_X w$: Shear force by direction X for shear wall.

V_{Xf} : Shear force by direction X for frame.

V_Y: Shear force by direction Y for shear wall.

$V_{Y\,f}$: Shear force by direction Y for frame.

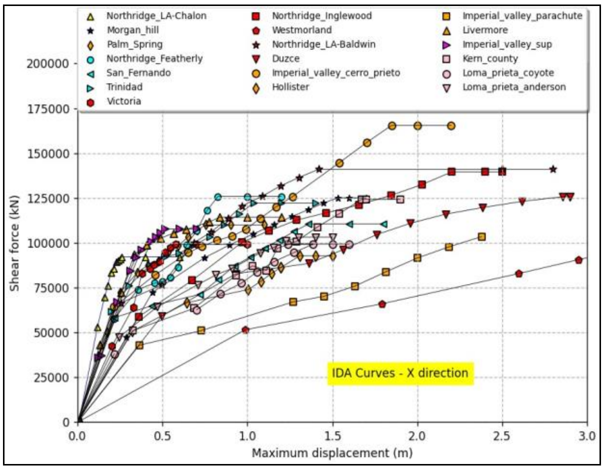


Figure (3) X-direction IDA curves (shear force-maximum displacement) for the twenty seismic records.

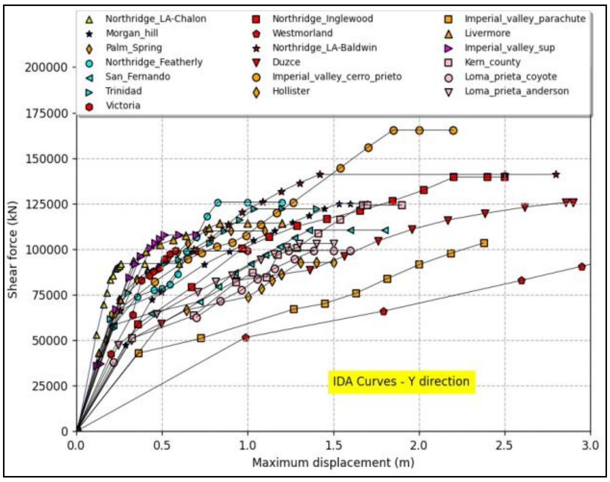


Figure (4) Y-direction IDA curves (shear force-maximum displacement) for the twenty seismic records.

From the previously analyzed curves, it is evident that the building reached a state of collapse under the selected seismic records, with displacement values varying based on the intensity and frequency

The Response Modification Factor (R) was calculated and compared with the values specified in Syrian Arab Code and American Code (ASCE/SEI 7-22). The response modification factor is typically defined as the ratio of the base shear of a structure at a specific performance level to the base shear obtained from an elastic analysis.

Using the Incremental Dynamic Analysis (IDA) curves as shown in Figures 4, 5 and 6, R-factor was determined based on the average, maximum, and minimum response curves. Specifically, the base shear at collapse (identified as the last point before the curve flattens) was divided by the base shear obtained from the elastic analysis at the allowable elastic design drift. The maximum response modification factor (R_{max}) was computed using the following equation:

$$R_{max}= (PGA_{collapse}/ PGA_{yield})*(V_{collapse} /V_{yield}) \quad \textbf{......(1)}$$

where: $V_{collapse}$ is the maximum shear force before collapse, and V_{yield} is the shear force at the yield point.

Additionally, the design response modification factor (R_d), which represents the value adopted in seismic design codes, was determined based on the design-level earthquake, typically set at two-thirds of the maximum considered earthquake. The design value was calculated as follows:

$$R_d= (PGA_{design}/ PGA_{yield})* (V_{design}/V_{yield}) \quad ..... \quad \textbf{(2)}$$

The elastic shear strength (V_d) was evaluated at an inter-story drift ratio of 0.02, in accordance with ASCE/SEI 7-22 provisions. The acceptable drift ratio, as specified in ASCE/SEI 7-22, ranges from 0.007 to 0.025 depending on the building's risk category and construction type. Table 6 presents the computed values of the maximum and design response modification factors for the analyzed model, considering the effect of eccentricity (e=42%) induced by torsional effects.

Table (6) The values of maximum and design response modification factor R.

		R_X	R_Y
Av.curve	R_{max}	2	1.898
	R_{design}	1.576	1.393
Max.curve	R_{max}	3.132	1.906
	R_{design}	2.358	1.444
Min.curve	R_{max}	4.4	3.765
	R_{design}	3.47	2.2

The results of the differences in the value of the design response modification factor for the studied model and the values given in the codes were calculated according to the following table:

Table (7)The differences in the calculated response modification factor and code values

		Δ_{RX} %	Δ_{RY} %
Syrian Arab Code	5.26	70	73.5
ASCE7-16	6	73.3	76.8
UBC97	6.5	75.75	78.5

A comparison of the response modification factors (R) obtained from Incremental Dynamic Analysis (IDA) and those specified in various seismic design codes revealed that results for the model gave a decrease in the value of the response modification factor under severe torsion with percentages ranging from 78.5%-70% from the values in Syrian Arabic code and other international codes as shown in Figure (6).

5. Conclusion

This study investigated the effect of torsional irregularity on the seismic response modification factor (R) in dual reinforced concrete systems. Using Incremental Dynamic Analysis (IDA) on a 15-story structure subjected to 20 seismic records, the current research evaluated how torsional effects influence structural behavior and seismic performance. The results demonstrated significant variations in R-factor based on eccentricity levels, with reductions of up to 22% compared to values prescribed by international seismic codes. This discrepancy highlights the need to reconsider current design assumptions regarding torsional irregularity and seismic response. The findings emphasize that a fixed R-value, as currently used in many seismic codes, does not adequately account for the influence of torsional effects, necessitating the introduction of an adjustment factor.

The following conclusions can be drawn:

- Static contribution ratios cannot be reliably used to determine the response modification factor (R), as no clear relationship was observed between these ratios and R-value.
- Contribution ratios derived from linear analysis do not accurately reflect the structure's behavior under seismic loading.
- The IDA results indicated that the response modification factor was up to 78% lower than the values prescribed by international codes when torsional effects were present. Therefore, lower R-values should be considered when significant torsional irregularity exists.
- The response modification factor is not a constant value for all structures with the same lateral load-resisting system, as assumed by many design codes. Instead, it varies based on the system type, structural combination, and degree of geometric torsional irregularity.

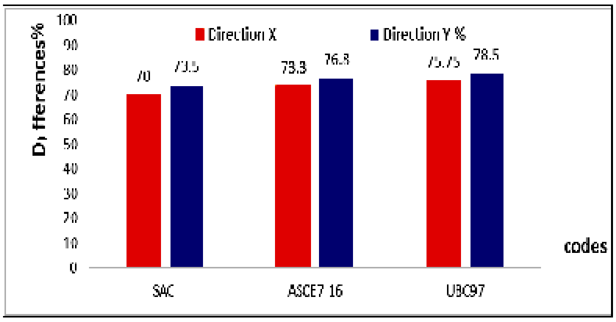


Figure (6) Differences in the values of the two-way response modification factor

According to Annex 2 of Syrian Arab Code, Table (2-4) provides R-values for commonly used structural systems, and for local intermediate moment frames with reinforced concrete shear walls, considering a frame contribution ratio of 78%, the code specifies R=5.26. In contrast, the American code (ASCE 7-16) prescribes R=6, while the Uniform Building Code (UBC 97) assigns R=6.5, resulting in a range of 5 to 6.5. However, the IDA-derived R-values varied between 1.4 and 4.4, indicating that the factors calculated through IDA are generally lower than those specified in international seismic codes. Notably, the minimum R-values obtained from IDA were lower than those prescribed by UBC 97 and ASCE 7-16, suggesting a potential overestimation of structural performance in these codes. Conversely, Syrian Arab Code provided a more conservative estimate, aligning more closely with the lower bound of the IDA results. To account for torsional effects, it is proposed that the response modification factor (R) be adjusted using a dimensionless reduction factor (α), where α<1. Initial values for this reduction factor were suggested based on the study's findings, but further research involving additional structural models is necessary to validate this approach and establish a more precise value for α.

structures with varying degrees of torsional irregularity. Additional models with different structural configurations, eccentricity values, and lateral load-resisting systems should be analyzed to establish a more accurate and widely applicable adjustment factor. Moreover, experimental validation through shake table testing and full-scale structural simulations would provide deeper insights into the influence of torsional effects on seismic performance, ultimately leading to improved seismic design guidelines in international codes.

- To address torsional effects, it is proposed to introduce an adjustment factor (α) for the response modification factor (R), where $\alpha<1$. This factor should be related to the building's torsion ratio (eccentricity).
- For the studied case, an eccentricity of 42% resulted in a recommended reduction factor of $\alpha=0.28$.
- The torsional irregularity factor (Ax) directly affects base shear, with an increase in eccentricity leading to higher base shear forces and, consequently, a reduction in the R-value.

Further studies should be conducted to refine the evaluation of the response modification factor for

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