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Seismic Assessment of Asymmetrical Existing RC Building in South of Iraq by Nonlinear Time History Analysis

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Abstract

The research aim is to assess the seismic performance of an asymmetrical RC building using NTHA. The building was built in the southern Iraqi city of Basra. Southern Iraq is categorized as a low seismic region in ISC1997, however, the current ISC2017 has been updated and contains specific seismic requirements to be applied for the construction of new buildings, prompting the need to assess the state of existing buildings concerning these new requirements. The case study is irregular in plan floors and vertically, causing it more vulnerable to severe deformations and damage than buildings with regular plan floors. The analysis is based on the ISC2017 in the design of the RSC and the modern US standard code ASCE7-16 in the selection of GMs.

Keywords: seismic assessment, nonlinear time history analysis, torsional irregularity.

Nomenclature

The notations applied in this paper are provided in Table1.

Table 1 The list of notations used in this paper

Symbol	Description
RC	reinforced concrete
G+10	ground floor and 10 storeys
THA	time history analysis
NTHA	nonlinear time history analysis
GMs	ground motion records
RSC	response spectrum curve
RSA	response spectrum analysis
ESA	Equivalent static analysis
LS	Life Safety
CP	Collapse Prevention
IO	Immediate Occupancy
FRAs	Floor Rotation Angles
TIRs	Torsional Irregularity Ratios
SDRs	Story Drift Ratios
ISC2017	Iraqi seismic code-2017

1. Introduction

Architectural features, geographical conditions, and functional requirements all contribute to asymmetrical buildings' international popularity. The overall size, shape, and geometry of a structure, as well as how seismic forces are transmitted into the ground, all have an impact on how it reacts to an earthquake **[1]**. The structural system's asymmetry is the main cause of torsion under seismic loads. Torsion effects in structures are inescapable, and they are the core issue in the structure. Most seismic codes recommend reducing the impacts of torsion by increasing the strength of parts on the weak side of the building or decreasing the strength of those on the strong side. G+10 storey RC building, studied in this paper, is representative of modern building type constructed in Basra City in the south of Iraq, which is irregular in plan floors and vertically. To investigate that, an existing RC building with shear walls and irregularities in-plane and height is analyzed using the NTHA and 11 different GMs scaled to match the RSC of Basrah city, Iraq. Nonlinear dynamic analysis is increased in popularity among practitioners, due often to advances in simulation and computing capabilities, as well as the increased usage of performance-based seismic design techniques. The NTHA method is considered the only one that captures the realistic response of buildings to earthquake loads. It is carried out by using a set of real or artificially generated GMs to provide an approximation of a structure's predicted seismic performance **[2]**. However, NTHA is very sensitive to the nonlinear properties of structural materials, and the results vary substantially depending on the GMs selected **[3]**. The Iraqi seismic code 1997 **[4]** classified southern Iraq as a low seismic area, but the new code 2017 has been updated to enhance seismic activity based on seismic activities in Iraq in general and research that predict an increase in seismic activity. Buildings that were built before their most recent update must have their seismic performance analyzed to assure their safety.

2.Litruture Review

Buildings with irregular plan floors are more sensitive to major deformations and damage if exposed to strong GMs than those with regular plan floors. It is caused by the extra torsional forces caused by the existing eccentricity between the centers of mass and stiffness of the resisting components **[5]**.

Shear walls are effective in resisting lateral loads caused by earthquakes. It reduces the fundamental natural period, the percentage of reinforcements in the columns, and increases the building's lateral stiffness **[6]**.

A study of multi-story structures designed using the IBC 2009 and ACI 318-2014 codes, and the NTHA method, using a set of near-source scaled seismic records, illustrates that the code's provisions still need to be improved, particularly in terms of analyzing the effects of significant vertical ground motion caused by near-source earthquakes **[7]**.

The irregular masonry infill wall elevation distribution affects seismic response behavior. Three RC structures are modeled with the ETABS program and analyzed with RSA and NTHA. The fundamental period of the model has shown a reduction trend when adding infill walls, and it increased in the model with a soft story in comparison to the entire infilled one **[8]**.

NTHA evaluated the seismic performance of two six-story RC buildings, one with and one without a shear wall, using the International Building Code (IBC2012), the Unified Building Code (UBC1997), and ISC2017. It is founded IBC2012 produced the most conservative results. The ISC2017 significantly over the elastic level, UBC1997 above the IO level, and IBC2012 near the CP level. Buildings without shear walls are more vulnerable to earthquakes, according to IBC2012 and UBC1997 **[9]**.

Qatar is frequently assumed to have low seismic activity, but recent earthquakes have proven it is not immune to earthquakes. Low and midrise RC buildings were examined for wind and seismic loads using the ACI and ASCE standards, as well as the accelerations from the 2014 Qatar construction standards update. Seismic loads are found to be more critical than wind loads, and lateral movements of buildings under seismic loads are greater than those under wind loads. During earthquakes, nearby buildings may collide if the movement connections are only designed to resist wind or heat stresses **[10]**.

The seismic performance of an existing G+10 Stories RC Shear Wall building is investigated using nonlinear static (Pushover) analysis and NTHA. The results show that the Pushover method underestimates the expected seismic effect of the building by 35.49 percent for the total number of plastic hinges, 40.7 percent for the target displacement, and 40 percent for the overall drift, but the base shears are roughly comparable in both methods. Both techniques predict that the predicted building performance will be at the IO level, which means that it will resist the design earthquake with little reparable damage **[11]**.

3.Building Description and Modeling

The case study is G+10, RC dual system building with shear walls, which is designed in 2011 to be a private hospital, and then the design was modified to a five stars hotel. The architecture design of the building includes irregularities in-plane and height as shown in **Fig.1. (a)**. The three-dimensional building is modeled in SAP200 (Computers & Structures, Inc.). The plan of building ground floor is illustrated in **Fig.1. (b)**, and the three corners of the building are used as control points in the calculation of the results; they are labeled as corner 1 (Cr1), corner 2 (Cr2), and corner 3 (Cr3). Due to these irregularities, the NTHA is the most accurate method to be used **[12]**.

The total height of the building is 48m. The first-floor height is 5.5m, the third, fifth, and eight storeys are 5m while the other floor heights are 4m. The beams and columns are modeled as frame elements, the slabs are modeled as shell elements, the shear walls are modeled as multi-layered shell elements and the building is assumed fixed at the foundation level. The partitions are not considered in the analysis because they reduced Tn and provided a low response as compared to the bare frame model. As a result, so, it’s neglected for simplicity **[8]**. At the beginning and end of each beam (5% and 95% of the length) plastic hinges of the type [Moment (M3) and Shear (V2)] are assigned. In the columns, plastic hinges of the type (P-M1-M2) (combined axial with a moment in two directions) and Torsion (T) are assigned at (5% and 95% of the length). Slabs are assumed linear materials, which operate as a rigid diaphragm in each floor level to transfer lateral forces caused by seismic loads to the columns. Finally, shear walls nonlinearity is proposed as a multi-layer shell element model based on composite material mechanics principles. A multi-layer shell element model is composed of variable thickness and different material properties are assigned to various levels. This indicates that the reinforcing rebars were smeared into one or more layers **[13]**.

The gravity load on the building include the self-weight, and alive load of (5 KN/m2) for 2nd floor (restaurant floor) and (3 KN/m2) for remaining floors including the roof. The load cases are Dead Load (DL), Live Load (LD), and the seismic load which is represented by the time history function that has acceleration load type and a scale factor of 9.81. The effect of DL is combined with 25% of the LL.

The building's real material properties were examined using non-destructive testing especially to determine the compressive strength of columns, and the results are matched to design values. The material properties which are applied in the model are given in **Table 2**, he Mander model **[14]** for concrete and Chai’s model for steel are used **[15]**. For beams, the section building members are (250x550), (300x550), (500x500), and (600x550); for columns, the section building members are (300x1000), (400x1000), (800x800), (700x700), and (600x600); and for shear walls, the wall thicknessing is all 300 mm. Details were excluded due to space constraints. The structural elements are modeled to represent existing building frame by section dimensions, longitudinal reinforcement, and confining reinforcement, to reach the optimum possible accuracy of the building behavior.

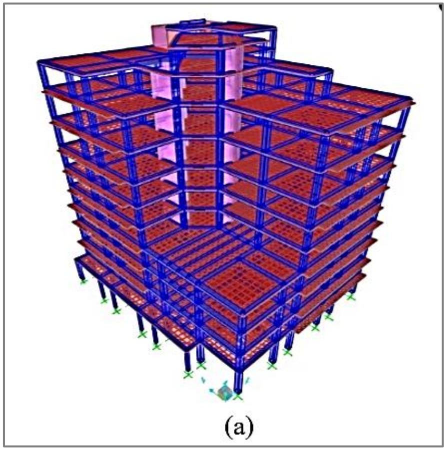

Fig.1 (a) the perspective view of the building

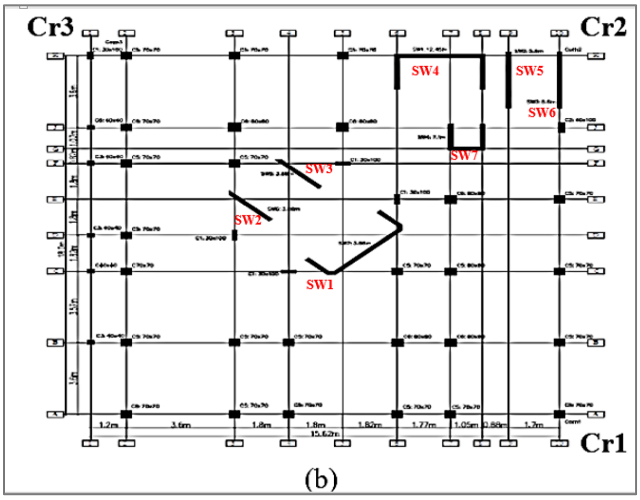

Fig.1 (b) the layout of the columns and shear walls (SW) is depicted on the structure's ground floor plan.

Table 2 Material properties

SN	Property	Amount
Concrete	Cylinder compression strength (Mpa)	35
	Poisson ratio	0.2
	Unit weight of concrete (ρ_c) (kN/m^3)	24
	The elasticity modulus of concrete (E_c)* (Mpa)	27.8056x10^3
Steel	Yield Stress (Mpa)	420
	Poisson ratio	0.2
	The elasticity modulus of steel (E_c) (Mpa)	2x10^5

* ASCI318-19 / 19.2.2.1, normal weight concrete.[2]

4. GMs and RSC

The analysis is performed by 11 GM real records which are selected by PEER online tool based on Basrah RSC, as shown in **Table 3.** The records are available in online databases [PEERNGA-West2]) (https://ngawest2.berkeley.edu). The GMs have different magnitudes and intensities. To be used for analysis it should be scaled to the Basrah level of earthquakes. The spectrum matchings method is used to scale the selected GMs. The RSC of Basrah is done based on the current Iraqi seismic code ISC2017 **[16]** as shown in **Fig.2.** Each of the 11 GMs is scaled using SeismoMatch 2021, a computer software program. **Fig.2(b)** is shown the scaling of record GM10. The GMs are applied either in X-direction and in Y-direction. The geometric nonlinearity is conducted in analysis by the P-delta effect is an option provided in SAP2000 program.

Table 3 The selected GM Records from PEER database

GMs	Earthquake	Year	Station	Mag.
1	Iwate, Japan	2008	Machimukai Town	6.9
2	Iwate, Japan	2008	Kurihara City	6.9
3	Iwate, Japan	2008	Semine Kurihara City	6.9
4	Landers	1992	Joshua Tree	7.28
5	Northridge-01	1994	Sunland - Mt Gleason Ave	6.69
6	Chuetsu-oki, Japan	2007	Yamakoshi Takezawa Nagaoka	6.8
7	Manjil, Iran	1990	Abbar	7.37
8	Iwate, Japan	2008	Tamati Ono	6.9
9	Duzce_ Turkey	1999	Lamont 362	7.14
10	Loma Prieta	1989	Coyote Lake Dam- Southwest Abutment	6.93
11	Iwate, Japan	2008	Yuzawa Town	6.9

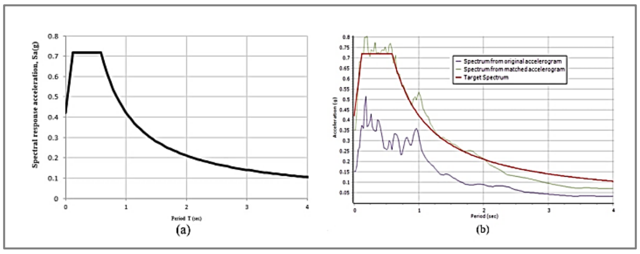

Fig.2 (a) Basrah RSC based on ISC-2017 **(b)** GM10 matching with Basrah RSC

5. Outcomes of Analysis

5.1. TIR

TIR is used to determine existing torsional behavior but does not accurately reflect torsional behavior **[17]**. It is defined by ASCE7 used to assess whether or not a horizontal irregularity exists **[18]**. Horizontal irregularity exists when the TIR is greater than 1.2, and extreme torsional irregularity exists when it is greater than 1.4 ASCE7-16 **[19]**. The term "extreme torsional irregularity" was not specified in previous codes, but due to the importance of the issue, the topic is now clarified in considerable detail **[20]**. TIR evaluation, as shown in **Equ.1.** and **Fig.3.(a)**

$$TIR = \frac{\delta_{max}}{\delta_{ave}} \qquad (1)$$

Where :

$\delta_{\max}$ = maximum displacemen at level x
δ_{ave} = the average of the displacements at the extreme points of the structure at level x.

5.2. FRA

The FRA (θ) closely reflects the torsional behavior of buildings and is considered to be a direct representation of torsional compatibility with the torsional irregularity coefficient (TIR) **[17]**. θ evaluation, as shown in **Equ.2.** and **Fig.3.(b).**

$$\theta = \frac{\delta_A - \delta_B}{L} \quad \text{radian} \qquad (2)$$

Where :

δ_A = displacement at control node A at level x .
δ_B = displacement at control node B at level x .
L = the distance between A and B at level x.

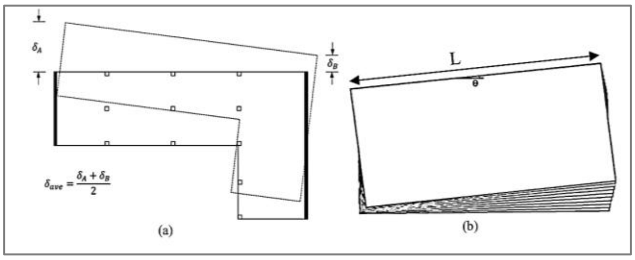

Fig.3 definition of **(a)** TIR (ASCE7-16)**[9]**, **(b)** storey angular rotation **[17]**

5.3. SDR

The Drift "shall be computed as the largest difference of the deflections of vertically aligned points at the top and bottom of the story under consideration along any of the edges of the structure" **[19]**. The floors were modeled as rigid diaphragms, and the displacement was taken into account as deflection. The displacement of nodes at Cr1 is showed the highest values compared with Cr2 and Cr3, due to the influence of the stiffness and position of shear walls. The displacements were taken as absolute values. SDR is the floor drift divided at its height, as shown in **Equ.3.** The SDR can have an affect on structural elements, nonstructural elements, and surrounding structures, and the effect increases in proportion to the irregularity of the building **[21]**.

$$\mathrm{SDR} = \frac{\Delta_i}{h_i} \qquad (3)$$

Where;

$\Delta_i =$ story drift, it is the difference between two successive stories displacement at the same time.
$h_i =$ story height.

6. Results and Discussion

6.1. Displacement and SDRs

Fig.4 show the average of results for displacements and SDRs for the 11 GMs analyses in directions X and Y. The values of displacements and SDRs in the Y-direction are higher than in the X-direction, indicating the building stiffness is greater in the Y-direction. According to the SDRs, the middle level is more vulnerable to seismic load than the upper and lower floors. According to the case study, the allowable SDR is ($4x10^{-2}$) based on ASCE7-16, and as shown in Fig.4 (b), the SDRs of the building in directions X and Y are significantly lower than the allowable limit.

6.2. TIR and FRA

Fig.5. show the average TIRs and FRAs of the 11 GMs analyses in X and Y directions. The TIRs in directions X and Y are more than 1.4, which reflects the extreme horizontal irregularity illustrated in **Fig.5.(b)**. The TIRs and FRAs in the Y-direction are more than in the X-direction, indicating that the building has a higher torsion stiffness in the X-direction. The FRAs indicated a high torsional response, especially in the upper floor as shown in Fig.5(a).

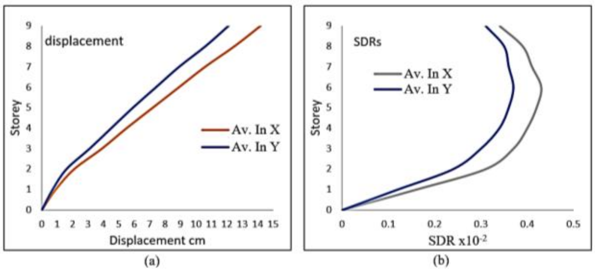

Fig.4 (a) Displacements **(b)** SDRs, in directions X and Y

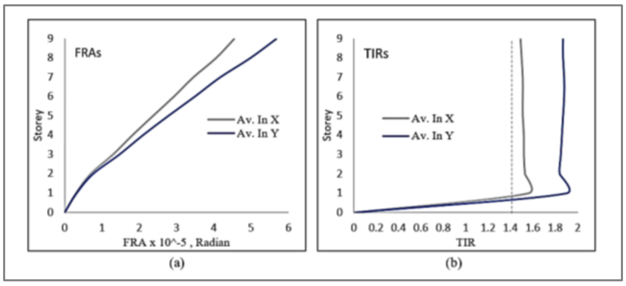

Fig.5 (a) FRA **(b)** TIR, in directions X and Y

6.3. Plastic Hinge Formation

As shown in Tables (4) and (5), as well as Fig.6.(a), the plastic hinge of state (IO-LS) is formed only in beam elements of type M3, which explains the building response under the weak beam strong column rule (the required behavior), and the beams begin yielding by bending. The average number of plastic hinges in the X-direction is greater than in the Y-direction, explain the Y-direction is stiffer than the X-direction. Plastic hinges are mostly found in coupling beams, which are beams that joins two shear walls, as illustrated in Fig.6 (a)

Table 4 average of plastic hinge number, in X-direction

State (A-IO)			
M3	V2	PMM	T
1469.27	1492	591.91	591.91
State (IO-LS)			
22.73	0	0	0

Table 5 average of plastic hinge number, in Y-direction

State (A-IO)			
M3	V2	PMM	T
1489.82	1492	592	592
State (IO-LS)			
2.18	0	0	0

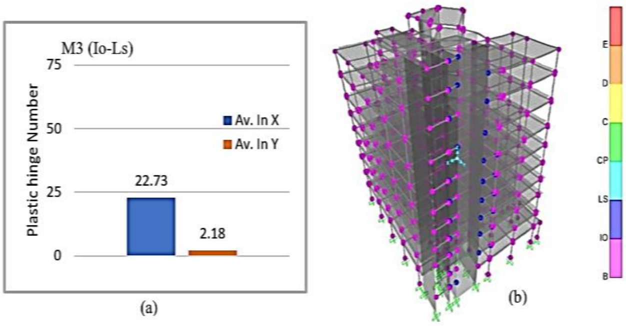

Fig.6 (a) average number of Plastic hinge number of type (M3) and state (IO-LS), in directions X and Y, **(b)** perspective view shown the locations of Plastic hinges formation, the record GM7.

6.4. Shear Wall Stresses

The stresses at the shear walls from the GMs analysis do not exceed the yield stresses in each reinforcing layers and concrete layer, showing the building's high stiffness. Fig.7 depicts the stress in the shear wall layer at the record GM11.

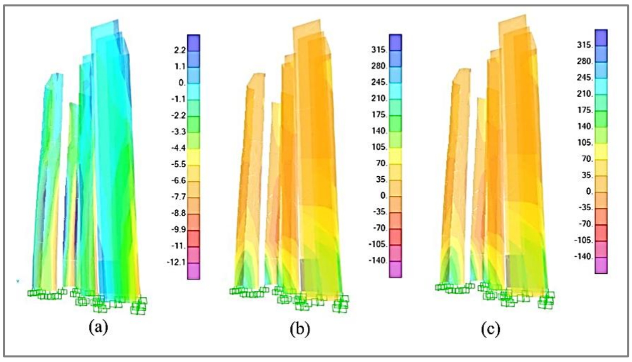

Fig.7 Stress at shear wall layers at GM11 at time step 29.76 sec in **(a)** concrete layer, **(b)** top reinforcement layer, **(c)** bottom reinforcement layer

Conclusions

In this study, NTHA is used for seismic evaluation of an existing RC building with irregularities in height and plan. The following conclusions can be drawn from the case study analysis results:

1. The Y-direction stiffness of the building is greater than the X-direction stiffness, as shown by displacements, SDRs, and plastic hinge number. The building has a high torsional stiffness in the X direction, as shown by the calculation of FRAs and TIRs.
2. The SDRs of the building in directions X and Y are significantly lower than the allowable limit.
3. The shear walls in the building have no yielding reinforcement and concrete layers, reflecting an accepted response during selected GMs.
4. The building's behavior follows the weak beam, strong column rule.
5. The position of plastic hinges is primarily formed in coupling beams that link shear walls.

From the foregoing, it is suggested that building retrofitting is for the coupling beams to limit the number of plastic hinges created during earthquakes.

The study highlighted the significance of reassessing structures built in accordance with previous versions of seismic codes in order to assure their behavior during earthquakes.

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