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Pushover Analysis of G+5 Reinforced Concrete Building in Basrah

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Abstract- Engineers in Basrah city in the south of Iraq like the engineers in many other cities in the world were not consider seismic forces in the design of the city buildings. It was believed that Basrah is not prone to earthquakes. Recent seismological studies showed that the city is near to an active fault with a high damage intensity in addition, the alluvial thick layer of the city soil is susceptible to liquefaction during an earthquakes. Hence the seismic evaluation of the existing buildings gains an increased attention and become a public demand. In this work a nonlinear static analysis (Pushover analysis) based on ATC40 capacity spectrum method is employed to analyze an existing G+5 stories reinforced concrete building. The building is analyzed in three cases, (regular, irregular in plan and irregular in height). The seismic coefficients of the design earthquake used in the analysis are based on the UBC97 code. Results showed that the building in all its three cases is over designed and its performance during the design earthquake is a little beyond its elastic limit. All plastic hinges developed in the building are in performance level less than immediate occupancy. Also the building showed a weak beam strong column behavior. Thus the building expected to be safe during any earthquake less or equal to the design one.
Keywords:- nonlinear static analysis, pushover analysis, performance levels, RC buildings, plastic hinges

I. INTRODUCTION

Most of the buildings in south of Iraq including Basrah city were designed for gravity loads only and no seismic forces were considered for many reasons, one of them is that the area was considered not prone to seismic activities as no previous earthquakes felt and no seismology stations were exist to record seismic activities. Another reason is that no legislations that mandate the inclusion of seismic forces in the design of buildings, however the first Iraqi seismic code[1] was published in 1997 but it was neither include a probabilistic seismic hazard assessment for Iraq[2,3] nor mandate the inclusion of a defined seismic forces in buildings. Recent seismological studies in Iraq showed that the Iraqi-Iranian border zone is a seismically active area as it present part of the convergent plate between the Arabian, Anatolian and Iranian plates [4,5]. Abdulnaby et al 2016 [6] showed that the Badra-Amara fault which is started about 180km to the north of Basrah and extended to Badra (north of Kut province) as shown in figure 1 is an active fault and it is part of a seismic zone of major damage with intensity of VIII (Modified Mercaly magnitudes). The soil in the south of Iraq is thick alluvial sediments and can be susceptible to liquefaction during an earthquake shaking[5]. The new Iraqi seismic code [7] was released in 2017 which is based on the probabilistic seismic hazard assessments (PSHA) for Iraq, but still it is not yet mandated. On November 12th 2017 people in all of Basrah and other provinces in south of Iraqfelt the ground shaking from an earthquake at the Iraqi-Iranian border to the north of Diyala city (about 500km from Basrah), people in multistory buildings spend that night in the streets afraid from aftershock earthquakes. This event changed the idea of engineers and landlords in Basrah toward seismic design of new buildings and performance evaluation of existing buildings.

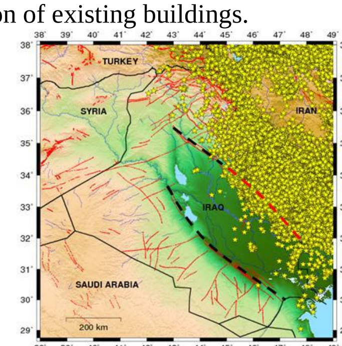


Figure 1: Seismicity of Iraq and adjacent areas taken from the IranianRecords of Seismic Catalogue IRSC (from 1/1/2006 to 1/10/2014)

II. PUSHOVER ANALYSIS

Even though nonlinear time history analysis is the most comprehensive method for structural analysis and seismic evaluation of existing structures, but its complication and longtime requirement are limited its use[8].The simplicity of nonlinear static analysis procedure (pushover analysis) and its proved ability for performance evaluation of existing structures to seismic loads gave it the superiority for use especially with low to moderately high buildings [9,10,11] which is the case in the area considered in this work. The nonlinear static analysis can predict the degradation in the structure stiffness, the formation and locations of plastic hinges with the increase of the lateral loads, identify members likely to reach critical states during an earthquake and finally evaluate the overall performance of the building to the considered earthquake [12]. In pushover analysis the structure under permanent vertical load is subjected to incrementally increasing lateral forces with a predefined invariant height-wise distribution until a target displacement is reached or the structure become unstable. The lateral load distributions used in pushover analysis are usually proportional to the height raised to the power of k (where k can be between 0 for uniform load distribution, 1 for triangular load distribution and 2 for parabolic distribution). FEMA356 [13] requires k to be based on the time period of the structure T (k = 1 for T less or equal 0.5 seconds, k = 2 for T greater or equal 2.5 seconds and interpolated for intermediate values). ATC40 [14] requires at least two different load patterns to be used in the pushover analysis and result envelope to be used. A plot of total lateral load (base shear) with a roof displacement is then drawn which represent the capacity curve of the structure (pushover curve). The intersection of the capacity curve with the demand on the structure gives the performance point of the structure (in base shear vs roof displacement) to the considered earthquake. FEMA356 and modified FEMA440 [15]use a displacement coefficient method in which the target displacement can be calculated based on different factors. While ATC40 applies the response spectrum method which starts with the 5% damped elastic spectrum (for concrete buildings) and continue until the final reduced spectrum as shown in figure 2.

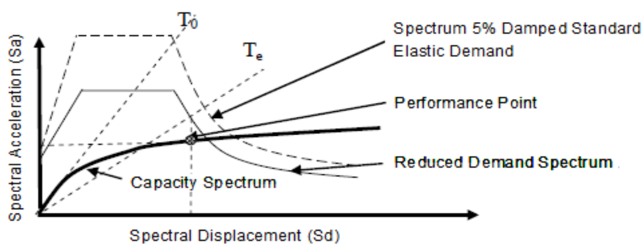


Figure 2: Determination of performance point according to capacity spectrum method.

In this study, the pushover analysis based on ATC40 is used to evaluate an existing reinforced concrete typical structure in the area according to the design seismicity in Basrah. Three cases of the building are analyzed (regular, irregular in plan and irregular in height). For more verification of the results a comparison with the FEMA356, FEMA440 displacement coefficient methods and FEMA440 spectrum method are done. SAP2000 V18 program [16] is implemented for the analysis. Default plastic hinge description and the FEMA356 performance levels shown in figure 3 are used in the analysis.

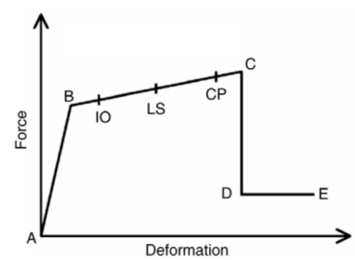
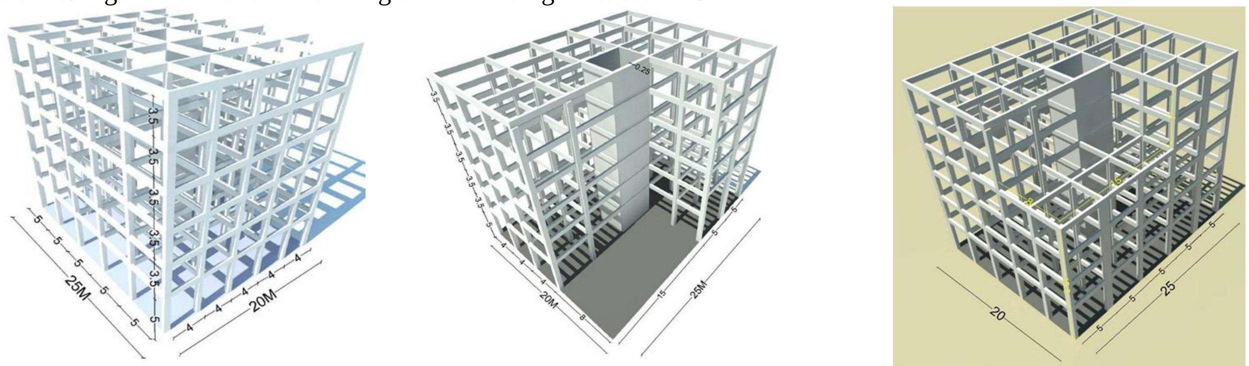


Figure 3: Force-deformation relationship for a typical plastic hinge.

III. BUILDING MODELING AND DESCRIPTION OF MATERIALS

3.1. Buildings Details

The regular building has 5 bays at 4m center to center in X-direction and 5 bays at 5m center to center in Y-direction (20 x 25m plan area). It has 6 stories, the height of the ground one is 5 meters and all the others have a height of 3.5 meters. However changing the stories height is assumed vertical irregularity, but in the present work we assume it regular to differentiate it from setback irregularity. The irregular building in plan has the same spacing as the regular building but 2 bays in X-direction and 3 bays in Y-direction are removed. The irregular building in height also has the same spacing and dimensions, but 2 bays in X-direction and 3 bays in Y-direction are removed only from the last two stories. Figure 4 shows the modeling of the building in its 3 cases.



a- Regular building b- irregular building in plan c- irregular building in height

Figure 4: Buildings Dimensions

The details of the buildings members in dimensions and reinforcements are given in table 1.

Table 1: Structural Members Details

Member	Dimension (cm)	Longitudinal Reinforcement
Beams (all)	30*60	6 #7 bars
Exterior Columns	40*70	10 # 8 bars
Internal column	50*50	8 # 8 bars

All slabs are 200mm thick; the rigid diaphragm option in the program is used to represent the slabs action. The foundation of the building is a raft with 80cm thickness (assumed fixed base in the modeling of the structures). Shear walls are not included in this work. Gravity load on the buildings are in addition to the self-weight a live load of $1.5kN/m^2$ uniformly distributed on the roof and $4.5kN/m^2$ on the other floors. In pushover analysis all the dead load plus 25% of the live load are assumed permanent on the buildings.

3.2. Material Properties

The material model used for the concrete is the Mander's model[17,18] as shown in figure 5. For steel reinforcement the Chai's strain hardening model [19] shown in figure 6 is used. The properties of steel and concrete used in this work are given in table 2.

Table 2: Material properties used in the analysis

Material	Property	Value
Steel reinforcement	Yield stress fy	420 MPa
	Modulus of Elasticity Es	200 GPa
	Tensile strength fsu	650 MPa
	Nominal Yield Strain εy	0.0021
	Ultimate Tensile Strain εsb	0.12
	Reduced Ultimate Tensile Strain εsu	0.087
	On Set Strain Hardening εsh	0.0115
	Poisson's Ratio	0.3
Concrete	Unconfined Compressive Strength fco	35 MPa
	Unconfined Compressive Strain at the Maximum Stress εco	0.002
	Unconfined Ultimate Compressive (Spalling) Strain εsp	0.005
	Poisson's Ratio	0.2
	Modulus of Elasticity Ec	30 GPa

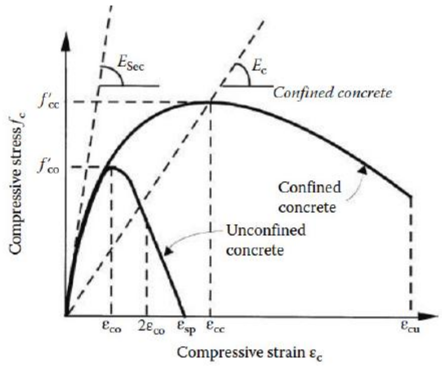


Figure 5: Stress-strain curve of concrete – Mander model

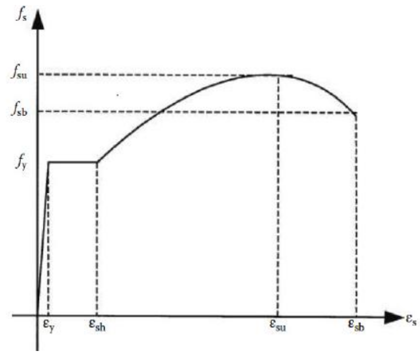


Figure 6: Stress-strain curve for steel reinforcement – Chai strain hardening model

IV. RESULTS AND DISCUSSION

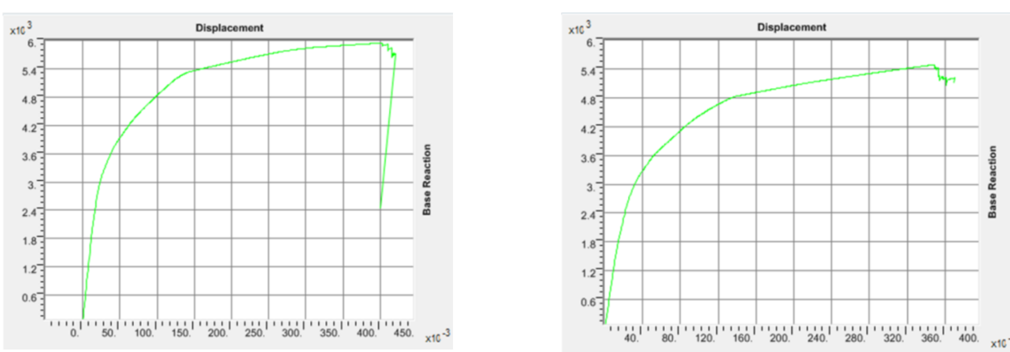
A pushover analysis based on ATC40 spectrum method is applied on the three buildings to evaluate their performance for a design earthquake in Basrah city. The design earthquake is calculated according to the uniform building code UBC97 [20] seismic coefficients for Basrah (C_a = 0.28 and C_v= 0.4).A free vibration analysis of the three buildings gave a time period T of 0.574 second, 0.546 second and 0.522 second for the regular, irregular in plan and irregular in height buildings respectively.Concentrated plasticity are used in the analysis in which the default plastic hinge built in the SAP2000 program are assigned at the beginning and end of each beam (M2 hinge) and column (P-M2-M3 hinge).

Base shear, roof displacement, equivalent damping, number and performance level of plastic hinges at the performance point of each building in both X and Y directions are given in table 3.

Table 3: Results of analysis according to ATC40 spectrum method for the three buildings

building type	Direction	Base shear in (kN)	Displacement at performance point in (cm)	equivalent damping (ζ) %	Number of plastic hinges in			Total number of plastic hinges
					B-IO	IO - LS	LS - CP	
Regular	X	3967.02	5.1	20	146	0	0	146
	Y	3697.56	5.7	20	140	0	0	140
Irregular in plan	X	3140.96	5.6	20	118	0	0	118
	Y	2990.22	5.6	20	115	0	0	115
Irregular in height	X	3805.49	4.4	20	126	0	0	126
	Y	3870.5	5.9	18	142	0	0	142

Figure 7 shows the pushover curves in X and Y directions for the regular building

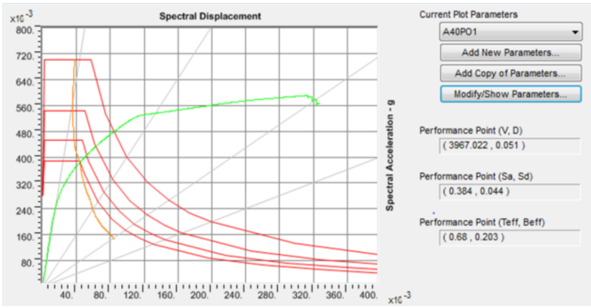


a- pushover curve in X direction

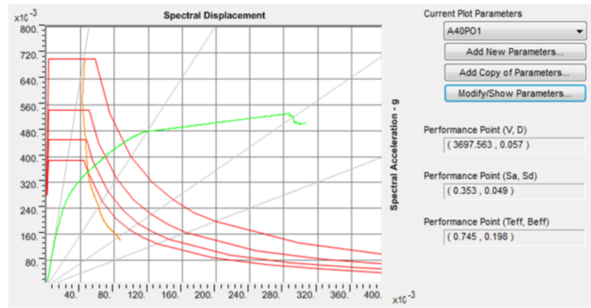
b- pushover curve in Y direction

Figure 7: pushover curve for regular building a- in X- direction and b- in Y- direction

The performance points of the regular building in X and Y directions are shown in figure 8.



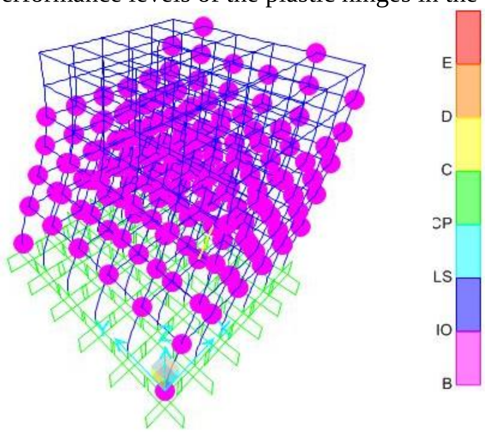
a- X- direction



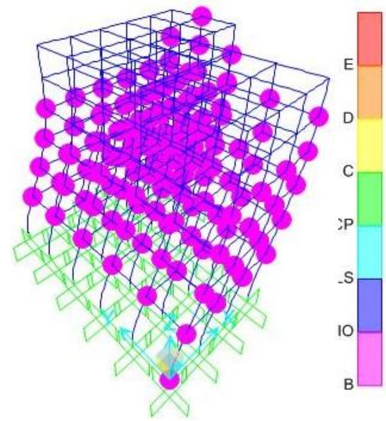
b- Y- direction

Figure 8: Performance points for regular Building a- in X-direction and b- in Y- direction

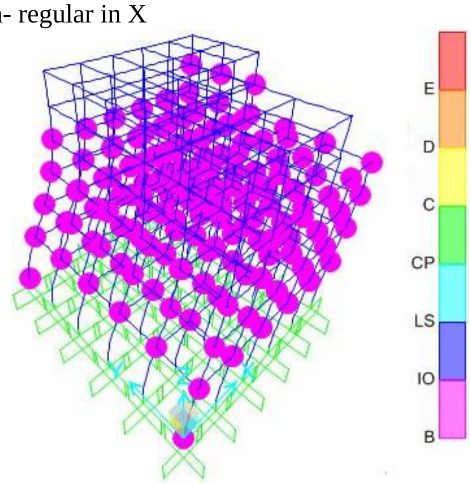
Performance levels of the plastic hinges in the three buildings in X directions are given in figure 9.



a- regular in X



b- irregular in plan in X



c- irregular in height in X

Figure 9: Plastic hinges performance levels at the performance point for the three buildings in X direction

Stories lateral displacements and drifts for the three buildings in both directions at the performance points are given in figures 10 and 11 respectively.

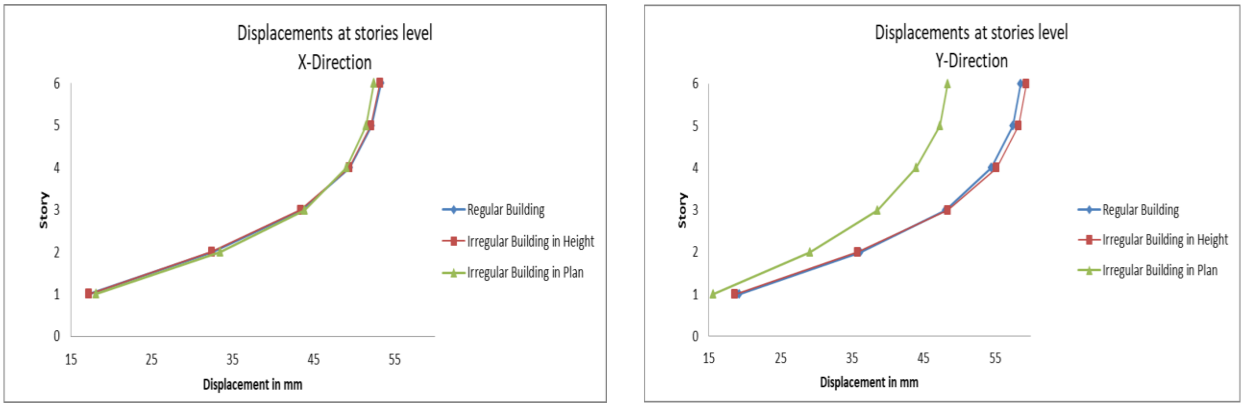


Figure 10: Lateral displacements at stories levels at the performance point

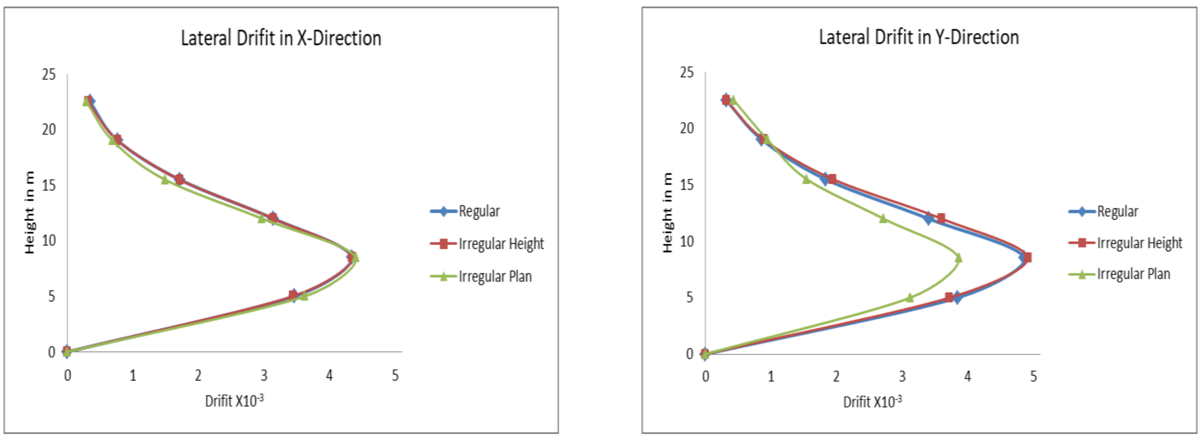


Figure 11: Inter-story drift at the performance point

Results clearly show that all the buildings perform very well (nearly elastic) during the design earthquake which indicate that the buildings are over designed. All the plastic hinges are in performance level below the immediate occupancy level shown in table 3 and figure 12 (the maximum inter-story drift is about 0.5% which is less than 1% specified for immediate occupancy level). As all the buildings are behave in nearly elastic manner, no big difference between their behaviors except the irregular in plan building show less displacements and drifts in Y direction than the other buildings. The maximum structural drift which is the roof displacement divided by the total height of the building is also below the immediate occupancy limit for concrete structures specified by ATC40 which of 1%. All the buildings showed weak beams strong columns structural behavior.

V. CONCLUSINS

The following conclusions can be drawn from the results of analysis:-

1- The three buildings analyzed showed an over design behavior and expected to perform well (approximately linearly) when subjected to an earthquake less or equal to the design one.

2- Irregularity in the building doesn't affect the analysis results in terms of inter-story drift, structural drift or performance level since the stresses are close the elastic limit.

3- The building with plan irregularity showed better performance in Y direction compared to other cases.

4- South of Iraq in general and Basrah in special are no more out of seismic belt, recent studies showed that it is near to an active fault in addition to its alluvial soil that is susceptible to liquefaction requires the inclusion of seismic forces in the analysis and design of buildings in the area.

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