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THE COMPARISON OF SEISMIC RESISTANCE OF BUILDINGS DESIGNED BY TWO CODES

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Abstract

Recently the evaluation of seismic performance of existing buildings has received a great attention. Since The Sudan has low to moderate seismicity most of existing buildings were designed only for gravity load. The objective of this paper is to assess the seismic performance of existing RC buildings in The Sudan. Four typical buildings were investigated using pushover analysis according to ATC-40. They were designed according to the Regulations for earthquake-resistant design of buildings in Egypt (ESEE) and International Building Code (IBC2012). Results showed that the buildings designed considering by ESEE and IBC2012 loads were found adequate and satisfies the Immediate Occupancy (IO) acceptance criteria according to ATC-40. The comparison of the pushover curve shows that the stiffness of frames is larger when using ESEE Regulations compared to the IBC2012 design. This means that ESEE design procedure provides a greater capability to resist seismic load than the IBC2012 design.

Keywords: Pushover Analysis; Seismic Capacity; The Sudan; Assessement; RC Buildings

1. Introduction

The Sudan is not free from earthquakes. It has experienced many earthquakes during the recent history, and the previous studies in this field demonstrated this argument [1]. Most of existing buildings in The Sudan do not meet the current design standards due to design shortage or construction shortcomings. There are various reasons such as there is no seismic code in The Sudan. Therefore, existing buildings should be evaluated regarding their capacity for resisting expected seismic effects. To estimate seismic demands for a building, the structural engineering profession is now using the non-linear static procedure, known as pushover analysis. It is a commonly used technique, which provides acceptable results [2].

Pushover analysis is a series of incremental static analysis carried out to develop a capacity curve for the building. This procedure needs the execution of a nonlinear static analysis of the structure that allows the monitoring of the progressive yielding of the structure component [3].

The building is subjected to a lateral load. The load magnitude increases until the building reaches the targeted displacement. This target displacement is determined to represent the top displacement when the building is subjected to design level ground excitation. Pushover analysis produces a pushover curve or capacity curve that presents the relationship between the base shear (V) and roof displacement (Δ). The Pushover curve depends on the strength and deformation capacities of the structure and describes how the structure behaves beyond the elastic limit [4].

Many researchers have conducted studies in this area such as [5-9]. These studies were conducted to investigate the performance of samples of existing RC buildings in the Sudan.

2. Evaluation of Seismic Performance of Existing Buildings

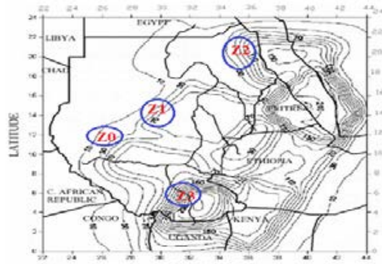
Most buildings and structures in the Sudan have not yet been designed and constructed in compliance with earthquake provisions or given any consideration for earthquake effect. Therefore, two existing codes will be used to evaluate seismic loads in order to perform the seismic performance of chosen buildings.

2.1. Earthquake loads

The earthquake loads are calculated following the rules which are given in the IBC 2012 [10], and the Regulations for earthquake-resistant design of buildings in Egypt, 1988. These regulations have been prepared by the Egyptian Society for Earthquake Engineering (ESEE) [11]

2.2. Seismic map for the sudan

In 2010, Sobaih and Hassaballa have developed new seismic maps for the Sudan, as shown in Fig.1 [12].

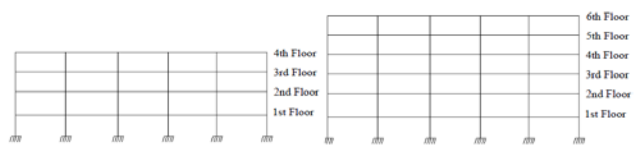


Zone	Z0	Z1	Z2	Z3
PGA	0.03	0.08	0.11	0.26

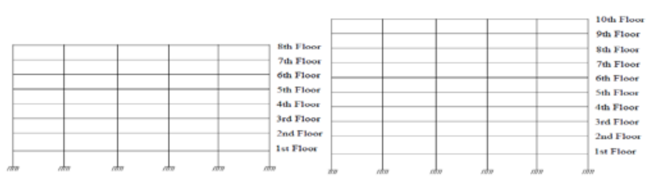
Fig. 1 – Seismic hazard map of the Sudan [12]

3. Description of the Buildings and Modeling

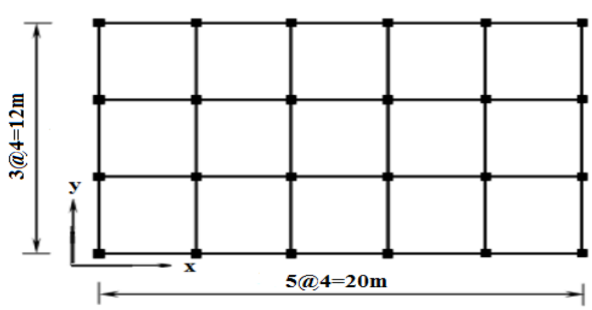
Four cases of existing RC buildings with 4, 6, 8 and 10 stories are considered for study as shown in Fig.2. The buildings are composed of moment resisting RC frames, situated in zone 3. The structure members are made of in-situ reinforced concrete. The main dimensions in plan are 20 meters in the X direction and 12 meters in the Y direction. The typical bay width and storey height of the four models are 4.0 and 3.0 meters, respectively and the ground floor height is 3.5 meters. Columns and beams sizes can be found in Ref [13].The columns are assumed to be fixed at the base. The building is analyzed and designed as per seismic provisions provided by ESEE using BS 8110 British Standard [14] and IBC2012 using ACI [15] .The general finite element package SAP 2000 (Version.14) [16] has been used for the analyses. A two-dimensional model of each structure has been created to undertake the nonlinear analysis. Beams and columns are modeled as nonlinear frame elements. SAP2000 provides default hinge properties and recommends M3 hinges for columns and M3 hinges for beams as described in FEMA 356 [17].



(a)Side elevation of 4 Stories Building (b) Side elevation of 6 Stories Building



(c)Side elevation of 8 Stories Building (d) Side elevation of 10 Stories Building



(e) Plan

Fig. 2 – Dimensions of the studied buildings

4. Pushover Analysis

The static pushover analysis is becoming a popular tool for seismic performance evaluation of existing and new structures. The expectation is that the pushover analysis will provide adequate information on seismic demands imposed by the design ground motion on the structural system and its components. The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces.

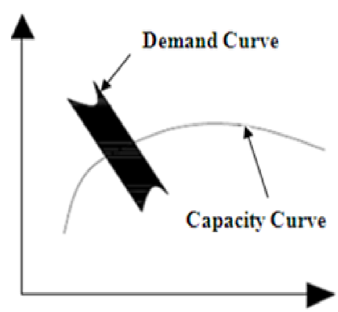
4.1. Seismic Demand and Performance Point

The performance point is the point where the capacity curve crosses the demand curve according to ATC-40 [18] .Two main approaches are used to evaluate the performance point (maximum inelastic displacement of the structure), Capacity-Spectrum Method of ATC-40 and Coefficient Method of FEMA 356.

In the present study the Capacity-Spectrum Method is more suitable for the evaluation task. ATC-40 [18] explains the process and presents the performance levels of buildings.

4.2 Pushover output

The main output of a pushover analysis is in terms of response demand versus capacity. If the demand curve intersects the capacity envelope near the elastic range, Fig.3 (a)**,** then the structure has a good resistance. If the demand curve intersects the capacity curve with little reserve of strength and deformation capacity, Fig.3 (b), then it can be concluded that the structure will behave poorly during the imposed seismic excitation and need to be retrofitted to avoid future major damage or collapse [19].



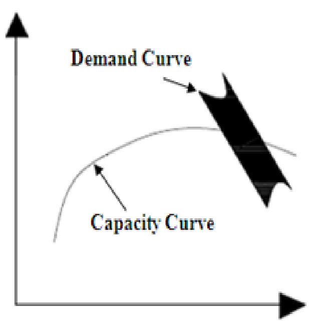


Fig. 3(a) – Safe design Fig. 3(b) – Unsafe design [19]

5. Results and Discussion

This part presents the results of Analysis and Design of considered RC buildings. It also provides a through comparison between the IBC2012 code and the ESEE regulations so as to decide which code produces more vulnerable buildings. Fig.4 shows the labels of columns.

5.1 Beams sections design

The section properties resulting from using the IBC2012 and ESEE codes have the same cross-sections and reinforcement for beams. All beams are 500*300 with 8 Φ16 reinforcement.

5.2 Columns sections design

Tables 1 to 4 show the cross-sections and reinforcing bars of members of 4 and 6 stories buildings according to IBC 2012 and ESEE codes. Results for 8 and 10 stories buildings can be found in Ref.

[13].

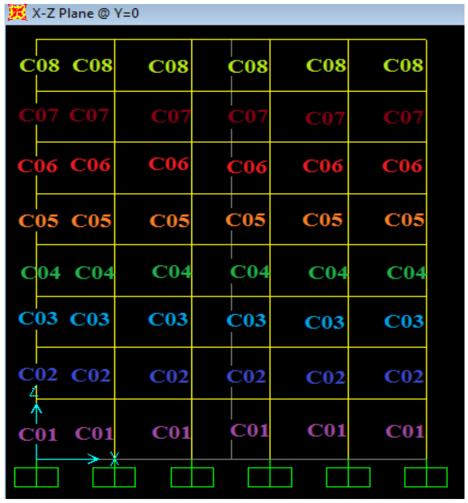


Fig.4– Label of columns

Table 1 – Section properties in 4-stories building using ESEE code

Column No.	4-Stories Case Study			
	Without Seismic Loads		With Seismic Loads by ESEE and designed using BSI	
	Section (mm)	Reinf.	Section (mm)	Reinf.
C01	400x300	10 Φ 16	550x300	12 Φ 16
C02	400x300	8 Φ 16	500x300	12 Φ 16
C03	300x300	8 Φ 16	450x300	10 Φ 16
C04	300x300	8 Φ 16	350x300	8 Φ 16

Table 2 – Section properties in 4-stories building using IBC2012 code.

Column No.	4- Stories Case Study			
	Without Seismic Loads		With Seismic Loads by IBC2012 and designed using ACI	
	Section (mm)	Reinf.	Section (mm)	Reinf.
C01	400x300	10 Φ 16	450x300	12 Φ 16
C02	400x300	8 Φ 16	400x300	10 Φ 16
C03	300x300	8 Φ 16	350x300	8 Φ 16
C04	300x300	8 Φ 16	300x300	8 Φ 16

Table 3 – Section properties in 6-stories building using ESEE code

Column No.	6- Stories Case Study			
	Without Seismic Loads		With Seismic Loads by ESEE and designed using BSI	
	Section (mm)	Reinf.	Section (mm)	Reinf.
C01	500x300	12Φ 16	750x300	16 Φ 16
C02	400x300	10 Φ 16	600x300	12 Φ 16
C03	400x300	10 Φ 16	600x300	12 Φ 16
C04	300x300	8 Φ 16	550x300	12 Φ 16
C05	300x300	8 Φ 16	450x300	10 Φ 16
C06	300x300	8 Φ 16	350x300	8 Φ 16

Table 4 – Section properties in 6-stories building using IBC2012 code.

Column No.	6- Stories Case Study			
	Without Seismic Loads		With Seismic Loads by IBC2012 and designed using ACI	
	Section (mm)	Reinf.	Section (mm)	Reinf.
C01	500x300	12Φ 16	600x300	14 Φ 16
C02	400x300	10 Φ 16	500x300	10 Φ 16
C03	400x300	10 Φ 16	500x300	10 Φ 16
C04	300x300	8 Φ 16	450x300	10 Φ 16
C05	300x300	8 Φ 16	450x300	10 Φ 16
C06	300x300	8 Φ 16	350x300	8 Φ 16

5.3 Pushover curves

The lateral capacity of the structures can be represented by a curve, which is plotted after applying the nonlinear static pushover analysis procedure. This curve is the relation between base shear which expresses the acting force on the structure, and roof displacement which expresses the lateral capacity of the structure. The pushover analysis using SAP2000 is achieved by using displacement control strategy for all RC frames.

The resulting pushover curves will be in terms of Base Shear – Roof Displacement (V-Δ). The slope of the pushover curves is gradually changed with increase of the lateral displacement of the building. This is due to the progressive formation of plastic hinges in beams and columns throughout the structure.

5.3.1. Pushover curves using IBC2012 loads

The plastic deformation in the four buildings, i.e. the five points values, A-B-C-D- E, as shown in Fig.5, can be obtained after the SAP2000 analysis. The range AB is elastic range, B to IO is the range of immediate occupancy, IO to LS is the range of life safety and LS to CP is the range of collapse prevention. If all the hinges are within the CP limit then the structure is said to be safe. However, depending upon the importance of structure the hinges after IO range may also need to be retrofitted [20]. Fig.6 shows the FEMA-356 combined pushover curves for the considered RC buildings heights 4, 6, 8 and 10 stories. This figure shows that the 10 storey building has the larger displacement.

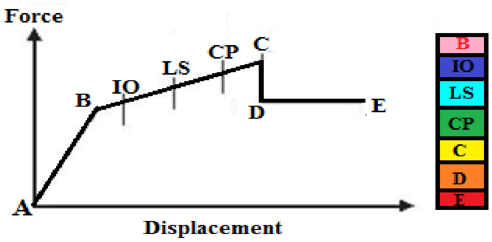


Fig.5– Different stages of plastic hinges [21]

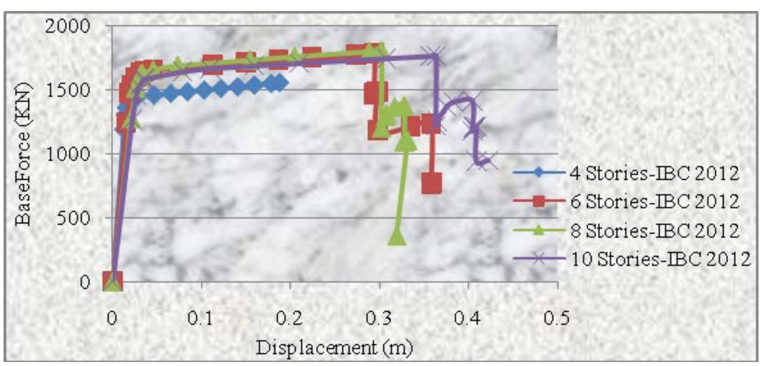


Fig.6– Combined pushover curves for the four buildings using IBC2012

5.3.2. Pushover curves using ESEE loads

Similar to the IBC2012 procedure, Fig. 7 shows the FEMA-356 pushover combined curves for the considered RC buildings heights 4, 6, 8 and 10 stories. One can notice also that the 10 storey building has the larger base shear, displacement and consequently a larger target displacement.

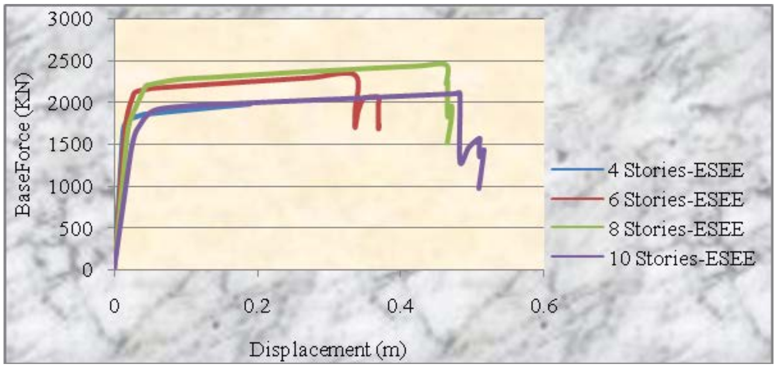


Fig.7– Combined pushover curves for the four buildings using ESEE

Figs. 8 to 11 show the differences between each building using the IBC2012 code with its identical case using the ESEE regulations.

From the comparison of the 4-stories with its identical case in the ESEE regulations as shown in Fig.8, we can notice that there are obvious differences in values between the two codes. The ESEE regulations gives mush larger base shear, but they are similar to each other in terms of total displacement.

From the comparison of the 6-stories as shown in Fig.9, it is clear that the base shear gap between the two models is smaller compared to 4-storey model. On the other hand, the ESEE loading code gives larger total displacement than the IBC2012.

From Fig.10, one can notice from the comparison of 8-Stories model that the ESEE gives higher base shear with much larger total displacement.

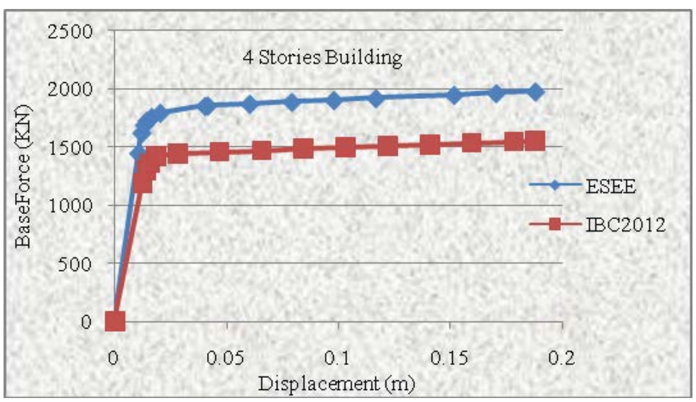


Fig.8– Pushover curves for 4-stories building using IBC2012 and ESEE

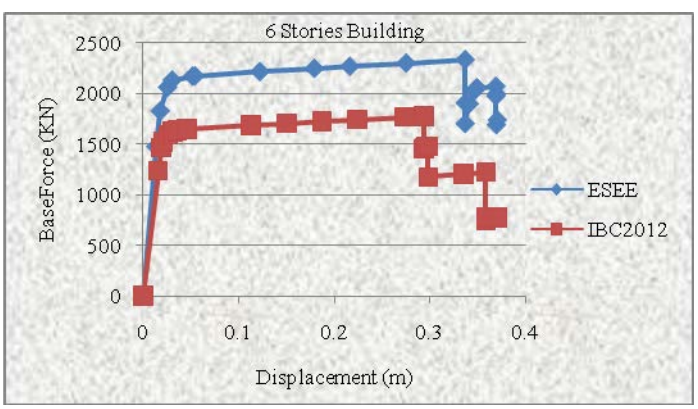


Fig.9– Pushover curves for 6-stories building using IBC2012 and ESEE

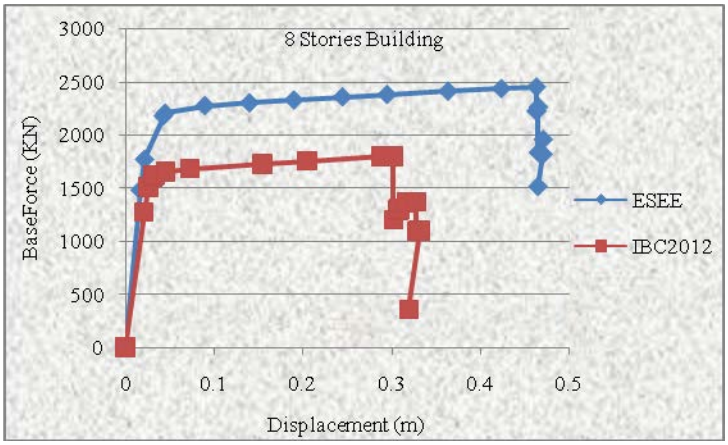


Fig.10– Pushover curves for 8-stories building using IBC2012 and ESEE

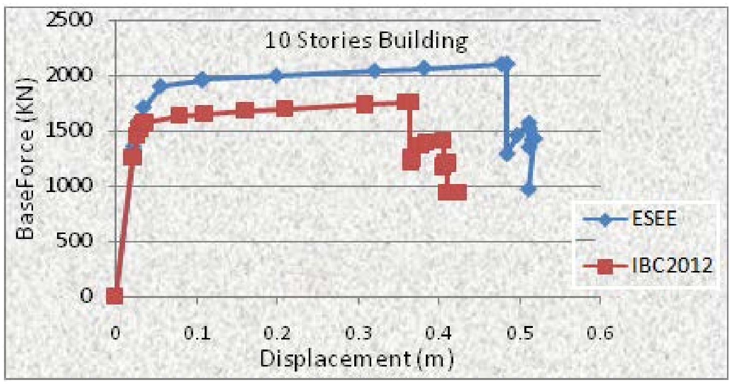


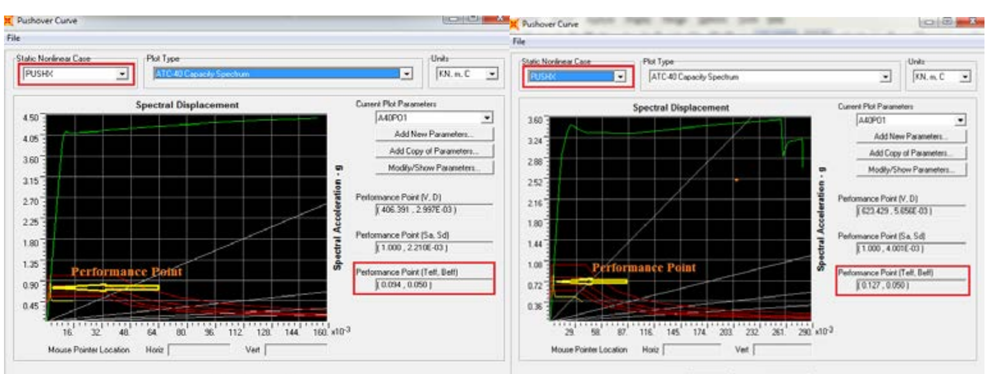
Fig.11– Pushover curves for 10-stories building using IBC2012 and ESEE

Moreover, from Fig.11, it is clear that the comparison of 10-stories model is similar to 6-stories model.

As a result, it is clear that the ESEE-designed buildings were stronger than the IBC2012 buildings, because as the loads increase there is a proportional increase in cross sections and reinforcement.

5.3.3. Performance Point According to ESEE

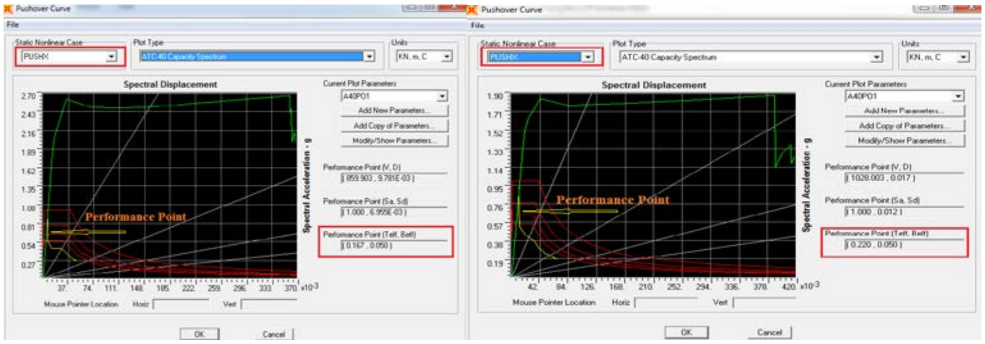
The resulting performance points for the four buildings are shown in Fig.12 and Fig.13 for 4, 6, 8 and 10 stories building, respectively. From the following figures the performance point, i.e., the point at which capacity curve and demand curve intersects is near to the event point B shown in Fig.5 in all the figures.



(a) 4 stories

(b) 6 stories

Fig.12– Performance point of 4 and 6 stories building using ESEE

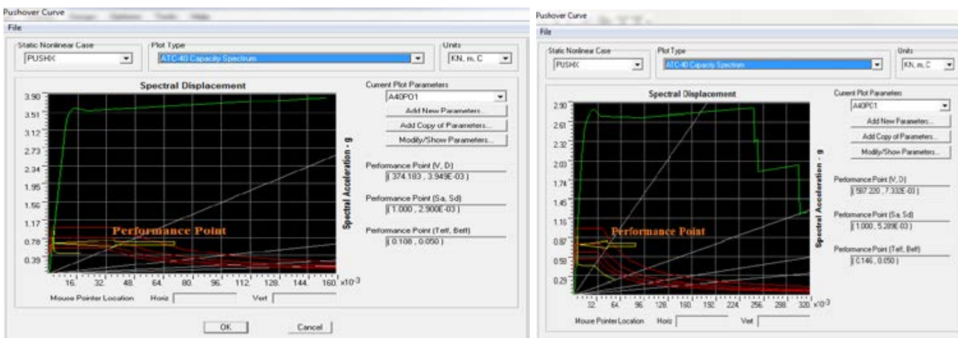


(a) 8 stories (b) 10 stories

Fig.13– Performance point of 8 and 10 stories building using ESEE

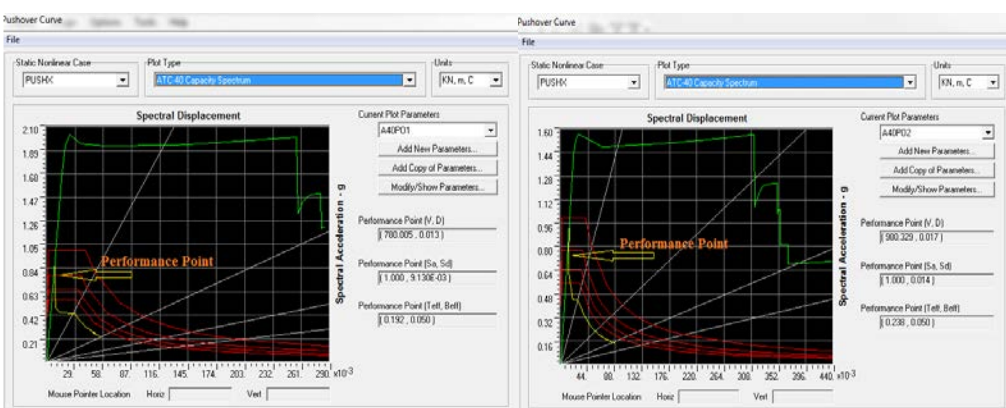
5.3.4. Performance Point According to IBC2012

Similarly, the IBC2012 demand- capacity curves for the four buildings are shown in Fig.14 and Fig.15. for 4, 6 8 and 10 stories building , respectively.



(a) 4 stories (b) 6 stories

Fig.14– Performance point of 4 and 6 stories building using IBC2012

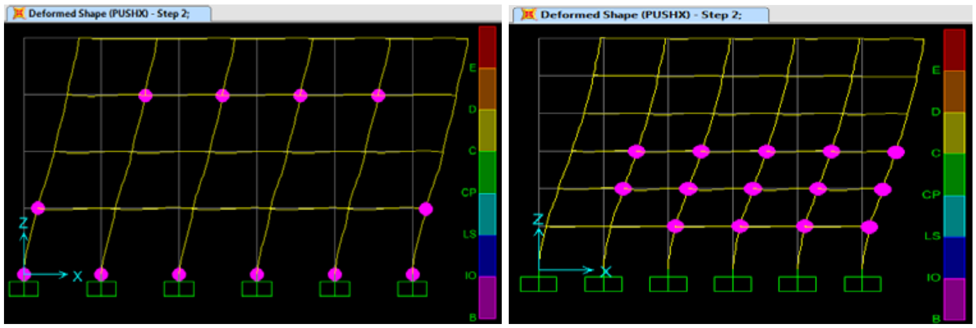


(a) 8 stories (b) 10 stories

Fig.15– Performance point of 8 and 10 stories building using IBC2012

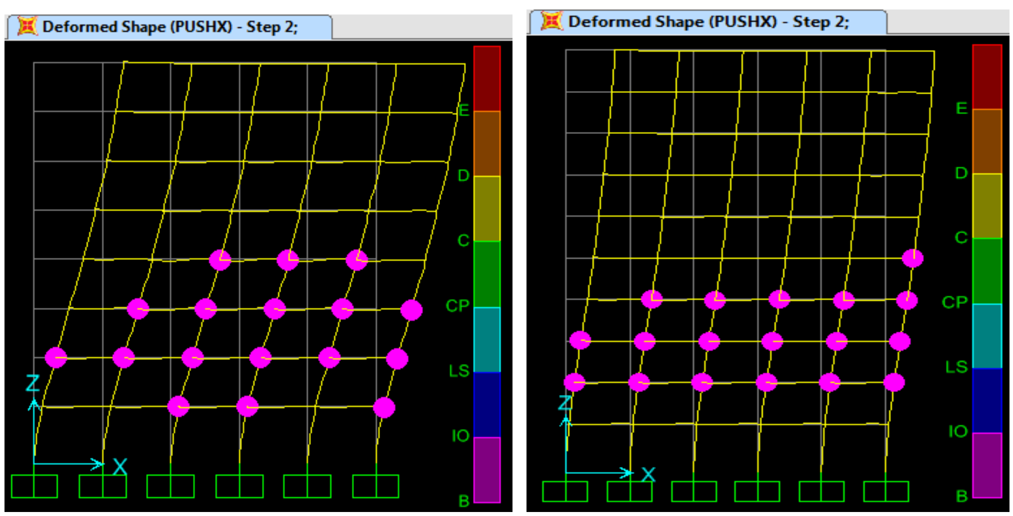
5.3.5. Plastic hinges distribution using IBC2012 loads

Plastic hinge formation starts with beam ends and at top columns of lower stories, then consecutively to upper stories and continue with yielding of interior intermediate columns in the upper stories. But since yielding occurs at events B and IO respectively, the amount of damage in the four buildings will be limited. Figs. 16 and 17 show the plastic hinges distribution of considered RC buildings 4, 6, 8 and 10 stories.



(a) 4 stories (b) 6 stories

Fig.16– Distribution of hinges in 4 and 6 stories building using IBC2012



(b) 8 stories (a) 10 stories

Fig.17– Distribution of hinges in 8 and 10 stories building using IBC2012

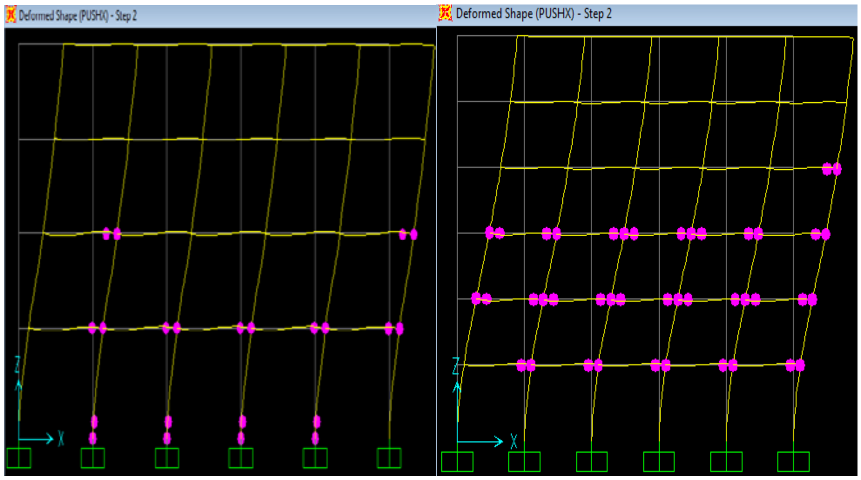
For the 4-stories building, it was found that most of plastic hinges occurred in the columns, which do not satisfy the weak beam - strong column criteria. Moreover, these plastic hinges were located at the first and fourth levels.

From distribution of hinges for 6-stories building, it can be noticed that the plastic hinges were located at the first, second and third levels. Also, most of plastic hinges occurred in the beam column connections, which do not satisfy the weak beam -strong column criteria.

Finally, from distribution of hinges for 8-stories the plastic hinges were located at the first, second, third and fourth levels and for 10-stories buildings, it can be noticed that the plastic hinges were located at the second, third fourth, and fifth levels . Also, most of plastic hinges occurred in the beam column connections, which do not satisfy the weak beam -strong column criteria.

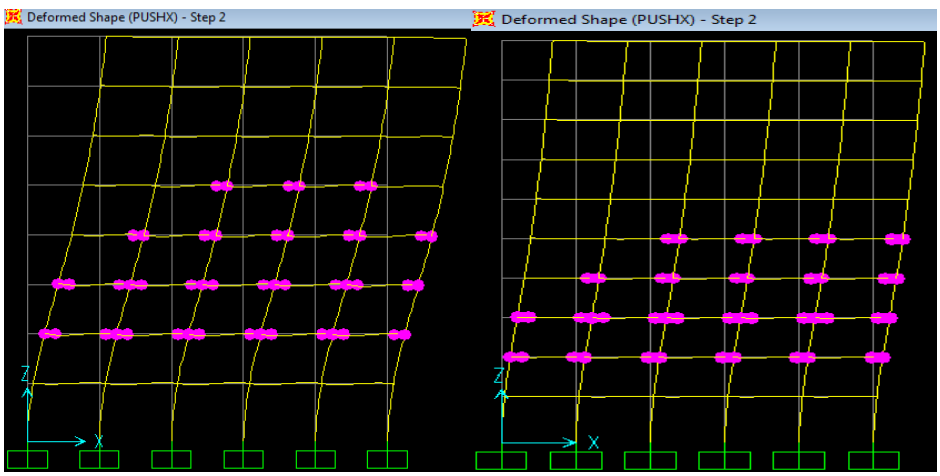
5.3.6. Plastic hinges distribution using ESEE loads

Similarly, using the ESEE Loading code, Figs. 18 and 19 show the plastic hinges distribution of the considered RC buildings with 4, 6, 8 and 10 stories.



(a) 4 stories (b) 6 stories

Fig.18– Distribution of hinges in 4 and 6 stories building using ESEE



(a) 8 stories (b) 10 stories

Fig.19– Distribution of hinges in 8 and 10 stories building using ESEE

Similar to the IBC2012, it was found for the ESEE designed 4-stories building that most of plastic hinges occurred in the beams, which satisfy the weak beam -strong column criteria.

From distribution of hinges for 6-stories, it can be noticed that the plastic hinges were located at the second, third and fourth floors. Also, most of plastic hinges occurred in the beams, which satisfy the weak beam - strong column criteria .These indicate that the ESEE building will sustain the earthquake loads longer than the IBC2012 code.

At last, from distribution of hinges for 8-stories and 10-stories buildings, it can be noticed that the plastic hinges were located at the third, fourth and fifth levels. Also, most of plastic hinges occurred in the beams, which satisfy the weak beam - strong column criteria.

6. Summary and Conclusion

Static pushover analysis is an attempt by the structural engineers to evaluate the real strength of the structure. This method of analysis promises to be a useful and effective tool for performance-based design of structure. Four existing RC buildings in The Sudan have been analyzed by this method and results have been compared in terms of base shear, displacement and plastic hinge pattern. From this study many conclusions can be drawn. The main concluding remarks are listed as follows:

1-Pushover analysis has been found relatively simple and evaluates the performance of the building close to more realistic behavior.

2- Pushover analysis can identify weak elements by predicting the failure mechanism and account for the redistribution of forces during progressive yielding. It may help engineers take action for rehabilitation work.

3-The results show that the design by ESEE and IBC 2012 are found adequate.

4- The buildings that were designed according to ESEE and IBC2012 are satisfactory. The performance point location is at IO (Immediate Occupancy) level. It means that the design satisfies pushover analysis according to ATC -40.

5- From distribution of hinges obtained from IBC2012 and ESEE, it can be noticed that most of plastic hinges obtained from ESEE occurred in the beams, which satisfies the weak beam - strong column criteria .These indicate that the building which is designed by the ESEE code will sustain the earthquake loads longer than the IBC2012 code. Therefore, a structural engineer should consider the ESEE code in designing buildings in The Sudan.

6. From demand capacity curve according to IBC 2012 and ESEE it is concluded that all the demand curves intersects the capacity curves near the event point B. Therefore, it can be concluded that the safety margin against collapse is high and there are sufficient strength and displacement reserves.

7. In all buildings the demand curve intersects the capacity envelope near the elastic range, then the structure has a good resistance.

7. References

[1] Jamal, A, et .al.(1997) Seismic hazard assessment and zoning of Sudan . Sudan Engineering Society Journal, Volume 44, 34-51.

[2] Martino, R., Spacone, E., and Kingsley, G. (2000) Nonlinear Pushover Analysis of RC Structures, Advanced Technology in Structural Engineering, 1-8.

[3] Giannopoulos, P. I. (2009) Seismic Assessment of RC Building according to FEMA 356 and Euro code 8, in Proceedings, 16th Conference on Concrete, 2009, TEE, ETEK.

[4] Vijayakumar, D. L., (2012) . Pushover Analysis of Existing Reinforced Concrete Framed Structures, European Journal of Scientific Research, Vol.71, 195-202.

[5] Sobaih.M, Ismaeil .M.(2012) A Proposed Methodology for Seismic Evaluation and Strengthening of Existing School Buildings in The Sudan, Paper No. 0571 , in Proceedings, 15th WCEE, 28–30 September, 2012. Lisbon, Portugal.

[6] Ismaeil, M. A. , Hassaballa , A. E., Sobaih.M.(2013) Assessment of Seismic Performance and Strengthening of RC Existing Residencial Buildings in the Sudan , International Journal of Engineering Research & Technology (IJERT) , Volume 2, 442-450.

[7] Hassaballa, A. E., Ismaeil, M. A.(2013) Seismic Retrofitting of a RC Building by Adding Steel Plate Shear Walls , IOSR Journal of Mechanical and Civil Engineering (JOSR-JMCE), Volume 7 , 49-62.

[8] Ismaeil, M. A. (2014) Pushover Analysis of Existing 3 Stories RC Flat Slab Building in the Sudan, Paper No.5092, in Proceedings, International Conference, November, 2014, Pattaya, Thailand.

[9] Ismaeil. M., Hassaballa A. , Alzeadc A. , Adamd .M. (2014) Pushover Analysis of Existing 4 Storey RC Flat Slab Building , International Journal of Sciences: Basic and Applied Research (IJSBAR), Volume 16 , 242-257.

[10] IBC2012, International Building Code, International Code Council, (2012).

[11] ESEE. , (1988) Egyptian Society for Earthquake Engineering ,Regulations for Earthquake-Resistance Design of Buildings in Egypt. Cairo. Egypt

[12] Sobaih, M. , Hassabala .A.(2010) Probabilistic Seismic Hazard Assessment for The Sudan, Paper No. 1332 , in Proceedings, 2nd European Conference on Earthquake Engineering and Seismology , 12–17 October, 2010, Ohird , Republic of Macedonia .

[13] Ismaeil, M. A. (2015) Seismic Capacity Assesment of Existing RC Building in the Sudan by Using Pushover Analysis. PhD. Thesis, Faculty of Engineering, Department of Structural Engineering, Cairo University, Giza, Egypt.

[14] BS 8110. (1997). The Structural Use of Concrete, British Standard Institution, London.

[15] ACI Committee 318.(2008) Building Code Requirements for Structural Concrete and Commentary. ACI 318-08, American Concrete Institute, Farmington Hills, MI.

[16] CSI. SAP2000 V-14. (2010) Integrated finite element analysis and design of structures basic analysis reference manual. Berkeley (CA, USA).

[17] Federal Emergency Management Agency, FEMA-356. (2000) Prestandard and Commentary for Seismic Rehabilitation of Buildings, Washington, D.C., USA.

[18] Applied Technology Council (ATC). (1996) Seismic Evaluation and Retrofit of Concrete Buildings, volumes 1 and 2, Report No. ATC-40, Redwood City, CA.

[19] Poluraju P., Nageswara Rao P. V. S. (2011) Pushover analysis of reinforced concrete frame structure using SAP 2000, International Journal of Earth Sciences and Engineering,, Volume 04, No 06 SPL, 684-690.

[20] Maske .A.A, Nikhil A. M , Preeti P. S. (2014) Pushover Analysis of Reinforced Concred Frame Structures: A case Study, International Journal of Advanced Technology in Engineering and Science, Volume No.02, 118-128.