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Assessment of Seismic Performance and Strengthening of RC Existing Residual Buildings in the Sudan

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Abstract

The evaluation of seismic performance of existing buildings has received a great attention in the last decade. A common engineering practice in Sudan is not to consider earthquake effects in the design of all buildings. Therefore, all types of buildings in the Sudan are not earthquake-resistant. The objective of this paper is to assess the seismic performance of existing residual buildings in the Sudan. One case study has been chosen for this purpose. The evaluation has proved that the columns of four-story residual buildings are not seismically safe. A comparative study has been conducted to choose a suitable strengthening method. An effective method has been proposed by adding RC shear walls. Three cases of same positions for the shear walls with thicknesses of 20 cm, 15 cm and 10 cm have been examined. It has been proved that RC wall with 15 cm thickness is suitable strategy for this case to reduce the seismic vulnerability of exiting (RC) buildings in the Sudan.

Keywords: Assessment; Strengthening; RC residual buildings; Seismic; Sudan

1. INTRODUCTION

Seismic Analysis is a subset of structural analysis and is the calculation of the response of a building structure to earthquakes. It is a part of the process of structural design, earthquake engineering or structural assessment and retrofit in regions where earthquakes are prevalent.
Sudan and its vicinity, which spans several countries, have diverse geologic and tectonic structure. So that 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. This paper is an attempt to study the effect of seismic loading on residual buildings in the Sudan.

2. DESCRIPTION OF STUDY CASE

The case performed in this study is a typical four-story model for residual building in the Sudan .The buildings are comprised of a reinforced concrete structural frame. The structure members are made of insitu reinforced concrete .The overall plan dimension is 20 x 17.5 m. Height of the building is 12 m .The floor is a flat slab system. Figures 1- 4 show detailed information of the structural and architectural layout.

3. CURRENT DESIGN

It is a common practice in the Sudan to design buildings without any consideration of seismic loads. Therefore, the residual building has been studied first under the effect of gravity loads only without consideration of seismic loads in order to check the current design. Dead and live loads are following the rules given in the (BS 8110, 1997).

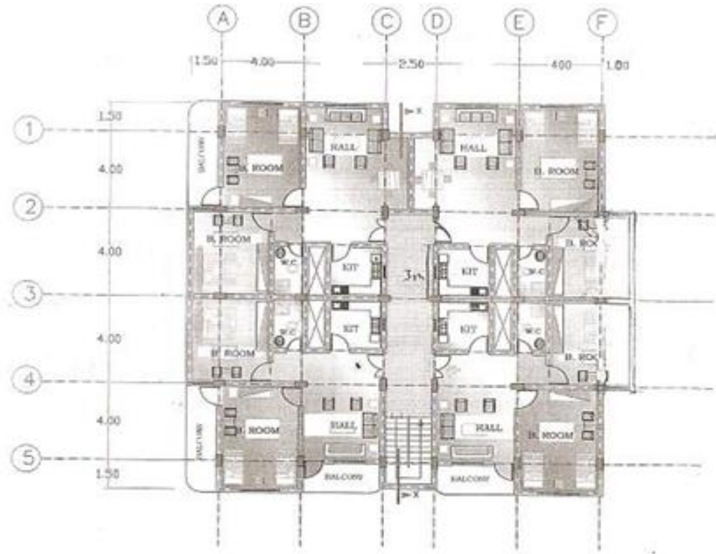

Figure 1. Plan of residual buildings considered

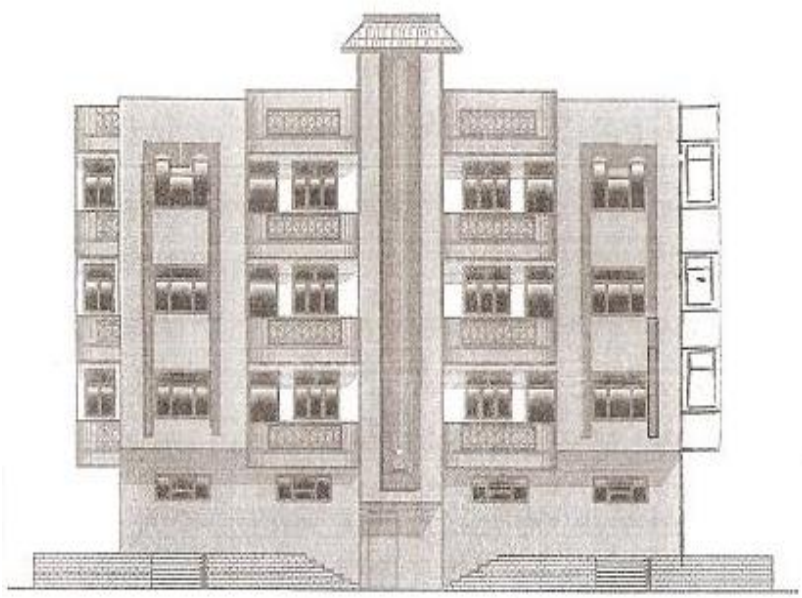

Figure 2: South Elevation

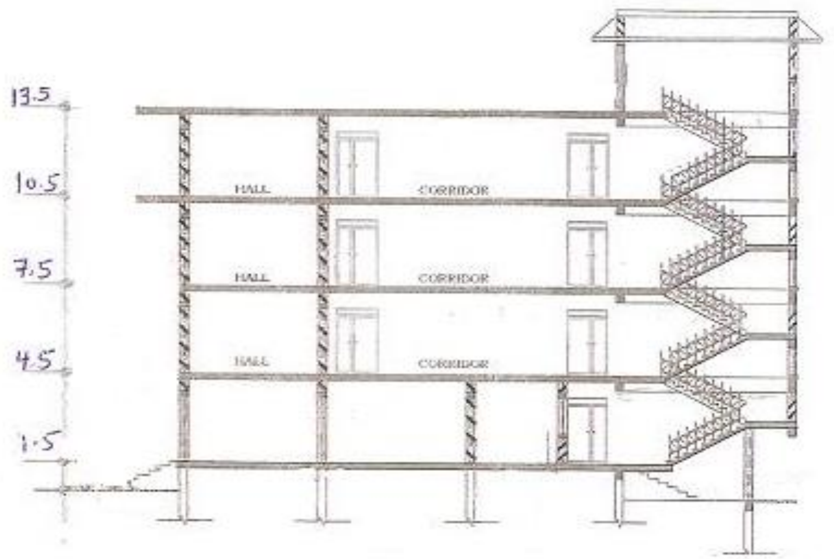

Figure 3: Section x-x

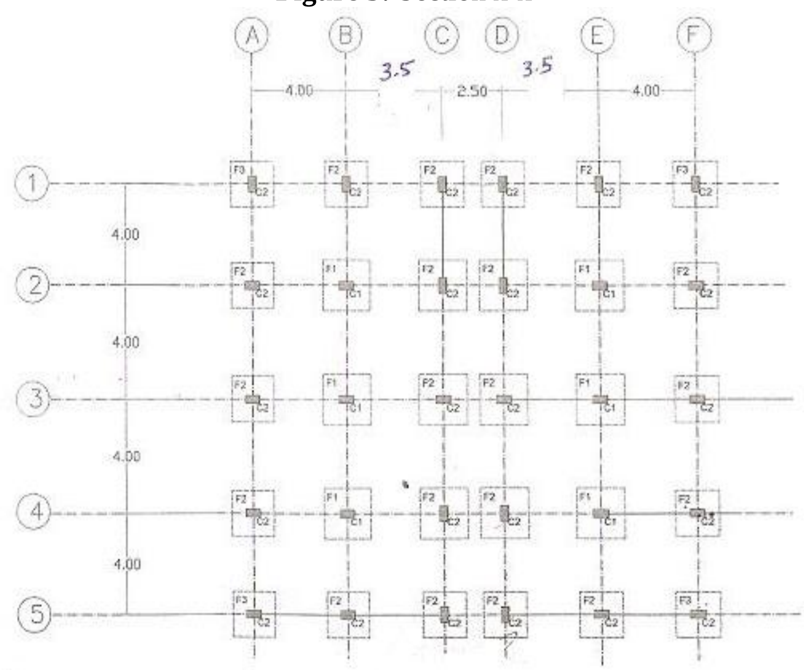

Figure 4: Foundations and columns plan

3.1 Numerical model

Numerical models for the case has been prepared using SAP2000 version 14 (Computers and Structures, 2011) Beams and columns are modeled as frame elements while walls and slabs are modeled as shell elements.

In this paper the seismic performance of the considered residual building will be evaluated using the Linear static analysis procedure . This procedure uses a simple estimate of the structure's fundamental period and the anticipated maximum ground acceleration together with other relevant factors to determine a maximum base shear. Horizontal loading equivalent to this shear is then distributed in some prescribed manner throughout the height of the building to allow a static analysis of the structure. This method is simple and rapid .

Figure5 shows the models for the four-story building. The label of columns is shown in Figure 6.

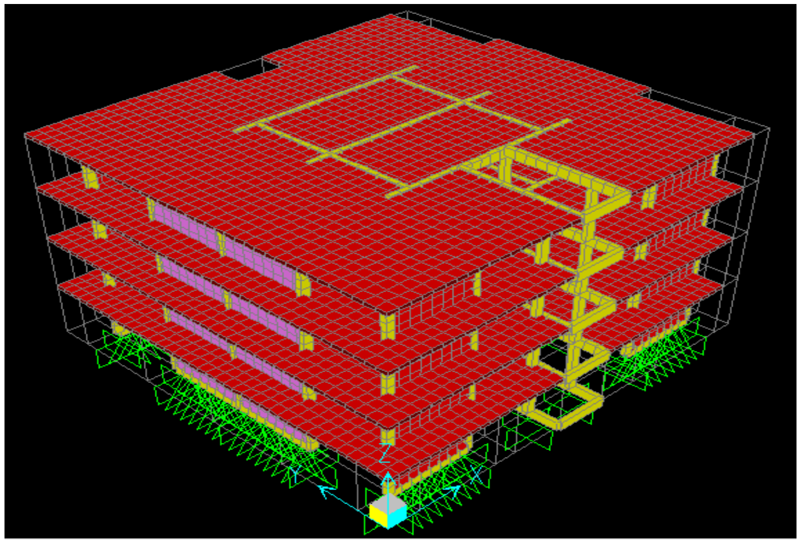

Figure 5: Model of 4-story residual building

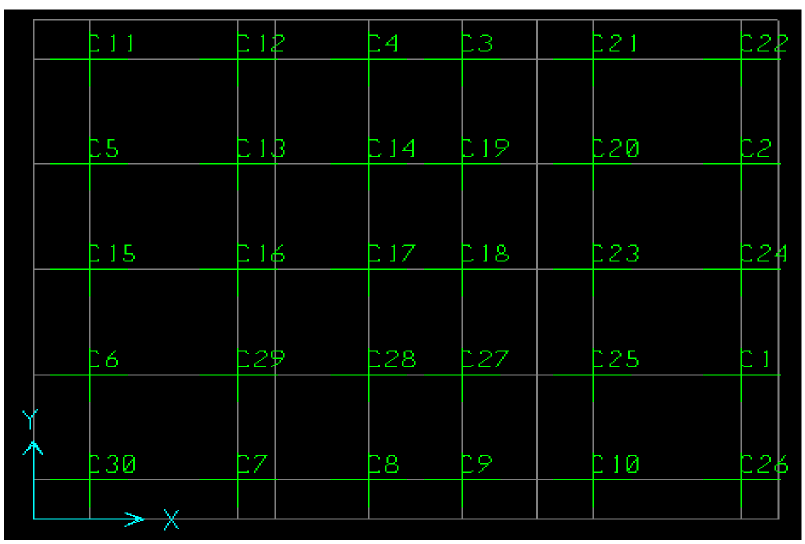

Figure 6: Label of columns

3.2 The modeling assumptions

The following assumptions are considered:

1- The cross section of beam and column members are input according to the original design

2-Rigid diaphragm is assumed

3- Residual Building is modeled as 3-D frames with fixed supports at the foundation level.

4. The columns in all selected models are assumed fixed at the base and supported on isolated footing.

3.3 Check of design for gravity loads

The internal forces obtained from the computer analysis program SAP2000 are used to design the reinforced concrete sections of the structural elements of the residual building using the (BS 8110 , 1997) using the limit state design method (Mosley and Bungey, 1997). It has been found that the existing design of columns under the effect of gravity loads is adequate for the study case. As for the design of columns a computer program called ISACOL (Shehata, 1999) has been used. The paper studied ten columns from thirty for the evaluation.

Table 1shows the Straining action for the ten columns due to gravity load and Table 2 shows the present design compared with the original design of critical columns for the studied case. It is clear that the original design of these columns exceeds the present design which means that it is satisfactory for gravity loads.

It is worthy to mention that internal forces in beams of the study case have been calculated under gravity loads. Then the (BS 8110 , 1997) has been used to check the existing design. It has been found that the existing design is adequate for the case.

Table 1. Straining action for the ten columns due to gravity load

ORIGINAL				
Column No	**Case**	**N**	**Mx**	**My**
C05	ULTIMATE	1819.32	-0.47	6.25
C06	ULTIMATE	1823.8	-0.23	5.75
C13	ULTIMATE	1966.4	-0.78	5.68
C15	ULTIMATE	1816.35	-0.34	5.73
C16	ULTIMATE	2002.41	-0.26	5.57
C20	ULTIMATE	1998.13	-0.79	6.24
C21	ULTIMATE	1777.94	0.97	2.52
C23	ULTIMATE	2021.05	-0.24	1.88
C25	ULTIMATE	1977.63	-0.32	7.19
C29	ULTIMATE	1947.29	-0.36	1.04

3.3.1Design of some columns due to gravity loads only:

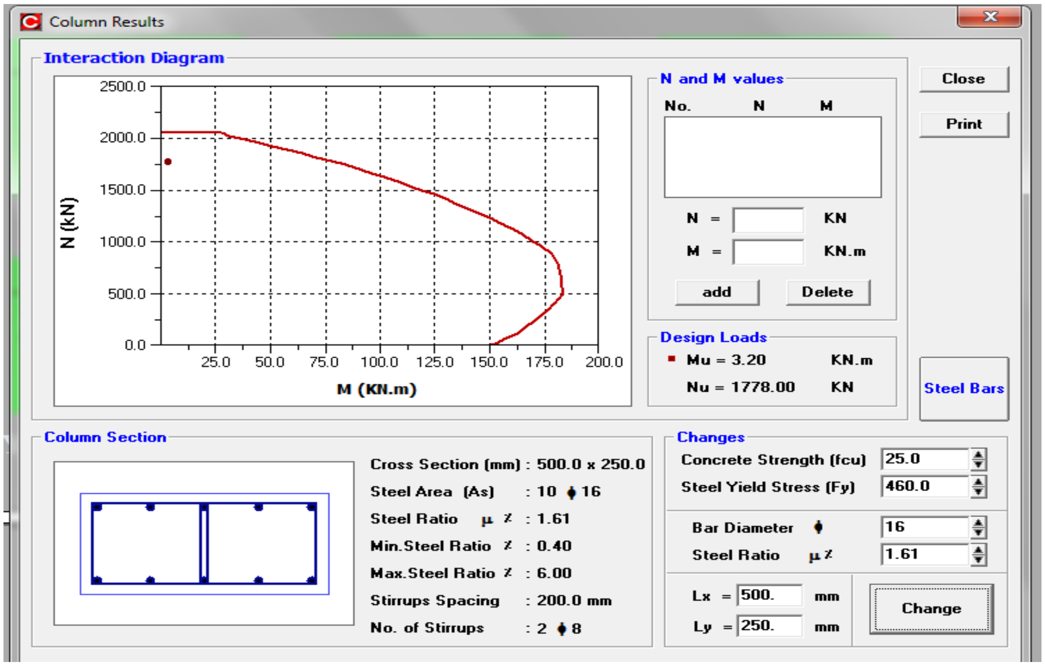

Figure 7. ISACOL Program result for Design of Column No, C21due to gravity loads

Table 2. Comparison Between Original and Present Design For Gravity Loads

Column No.	4-Story Case Study			
	Original Design		Present Design	
	Section*	Reinf.	Section*	Reinf.
C05	250x500	10 Φ 16	250x500	10 Φ 16
C06	250x500	10 Φ 16	250x500	10 Φ 16
C13	250x500	10 Φ 16	250x500	10 Φ 16
C15	250x500	10 Φ 16	250x500	10 Φ 16
C16	250x500	10 Φ 16	250x500	10 Φ 16
C20	250x500	10 Φ 16	250x500	10 Φ 16
C21	250x500	10 Φ 16	250x500	10 Φ 16
C23	250x500	10 Φ 16	250x500	10 Φ 16
C25	250x500	10 Φ 16	250x500	10 Φ 16
C29	250x500	10 Φ 16	250x500	10 Φ 16

* Section dimensions are in mm.

3.4 Check of design considering earthquake and wind loads

The moments obtained from earthquake and wind loads are shown in

Tables 3 and 4. It has been found that the effect of seismic load is much more than the effect of wind load . Fig 8 and 9 show the comparison between moments in columns due to earthquake and wind loads

Table3. The Staining actions (My) due to Wind loads and Seismic loads

Column No.	WIND	SEISMIC
	My	My
C05	*5.68*	*20.24*
C06	5.73	5.73
C13	6.24	26.27
C15	5.75	5.75
C16	7.19	7.19
C20	1.88	21.16
C21	6.25	39.8
C23	1.04	1.27
C25	2.52	2.52
C29	5.57	5.57

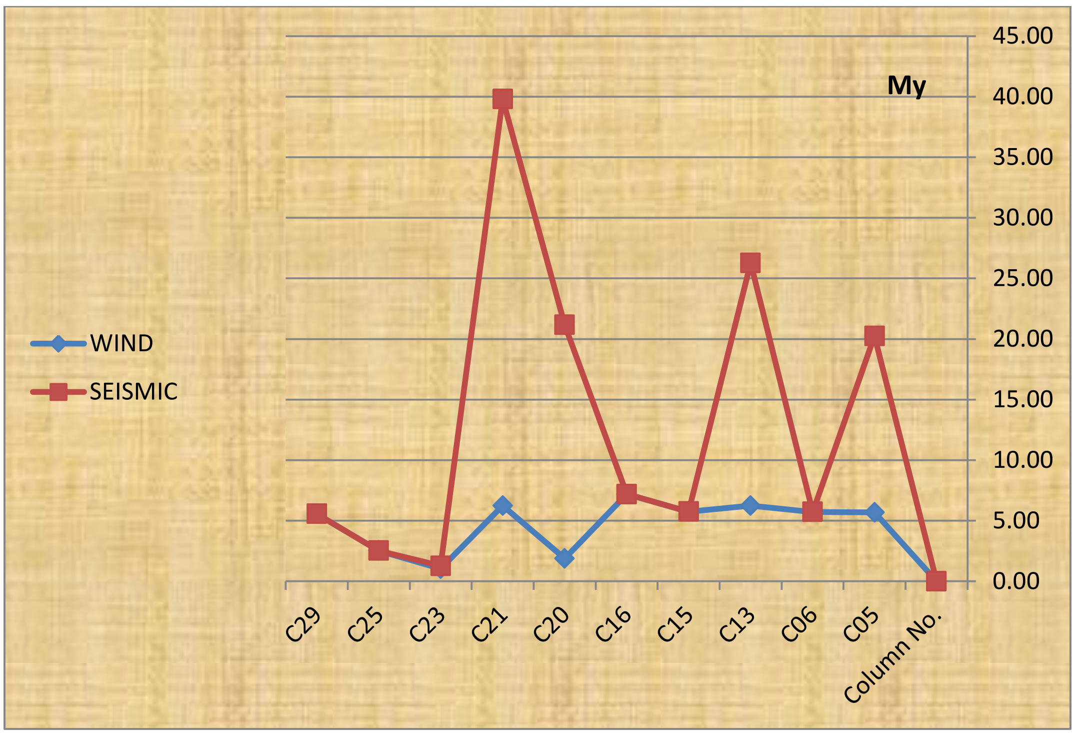

Figure 8. Comparison between My due to Wind loads and My due to Seismic loads

Table 4. The Staining actions (Mx) due to Wind loads and Seismic loads

Column No.	WIND	SEISMIC
	Mx	Mx
C05	*31.45*	*264.36*
C06	31.6	264.52
C13	32.54	285.83
C15	31.19	261.38
C16	32.78	285.58
C20	32.23	305.43
C21	30.79	276.76
C23	32.4	304.11
C25	32.55	306.11
C29	32.82	286.42

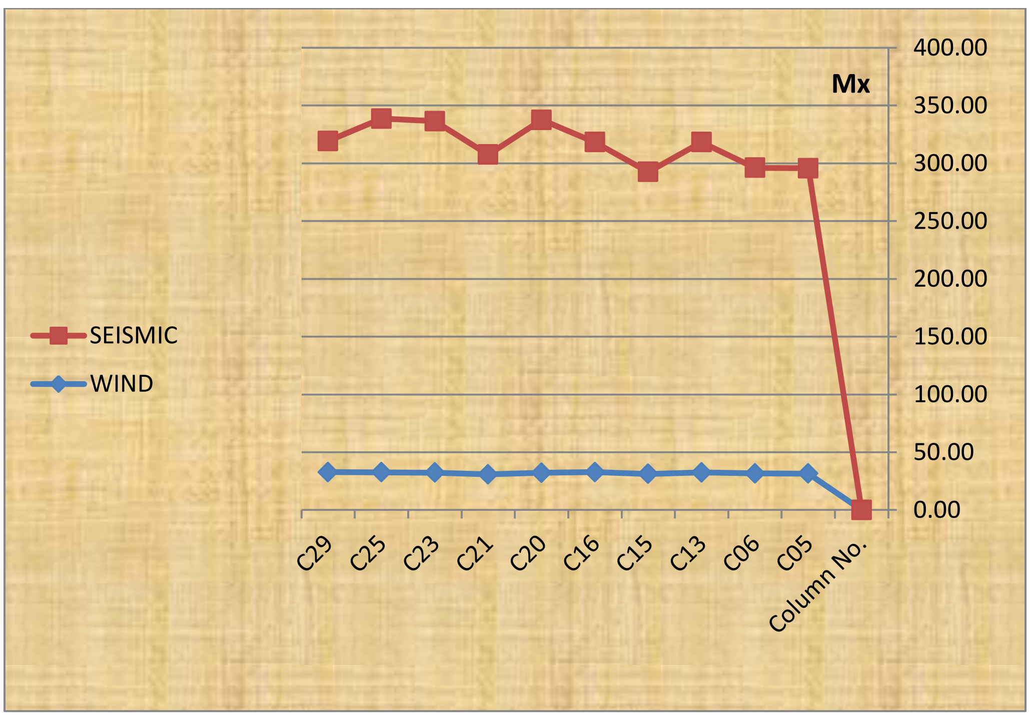

Figure 9. Comparison between Mx due to Wind loads (y) and Mx due to Seismic loads

In all directions the effect of seismic loads is govern so, the paper concentrated in the effect of seismic loads on residual buildings in the Sudan.

3.4.1 Earthquake loads

It is well known that the Sudan has no regulations for the seismic design of buildings. Therefore, in the present paper earthquake loads are calculated following the rules which are given in the Regulations for earthquake resistant design of buildings in Egypt, (ESEE, 1988) [4]. These regulations have been prepared by the Egyptian Society for Earthquake Engineering (ESEE).

In order to apply the ESEE regulations a seismic map for the Sudan is required to determine the site seismicity factor. In 2009, Hassaballaet. al. developed a new seismic hazard maps and seismic zoning map for the Sudan (Hassaballa et al , 2009) [5] , as shown in Fig.11.

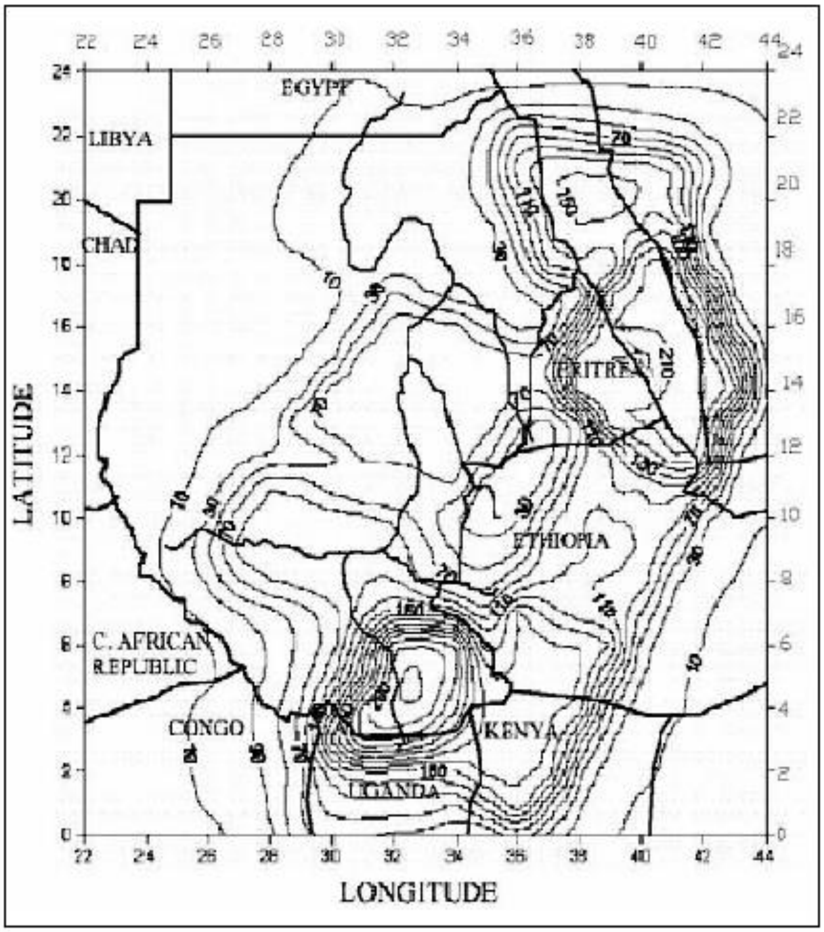

Figure 10. Seismic Hazard Map of The Sudan (Hassaballa et al , 2009).

3.4.1.1 Calculation of base shear

The total weight is given by:

$$Wi = Di + PLi \quad (1)$$

Where, p is the incidence factor and is equal to p = 0.25 . After analysis for gravity loads, the total floor weight will be as follows:

=29580 + 0.25 X 2812 = 30283 KN

The equivalent lateral force procedure of (ESEE 1988) was used to calculate the design base shear. The resulting seismic coefficient, Cs, was determined to be 0.125 and the corresponding base shear was approximately 3785 KN from:

$$V = Cs*Wt \tag{2}$$

3.4.1.2Distribution of horizontal seismic force

The period of the building is the same in both directions. Hence, the load in the E-W direction are the same as those for the N-S direction as shown Fig 18.

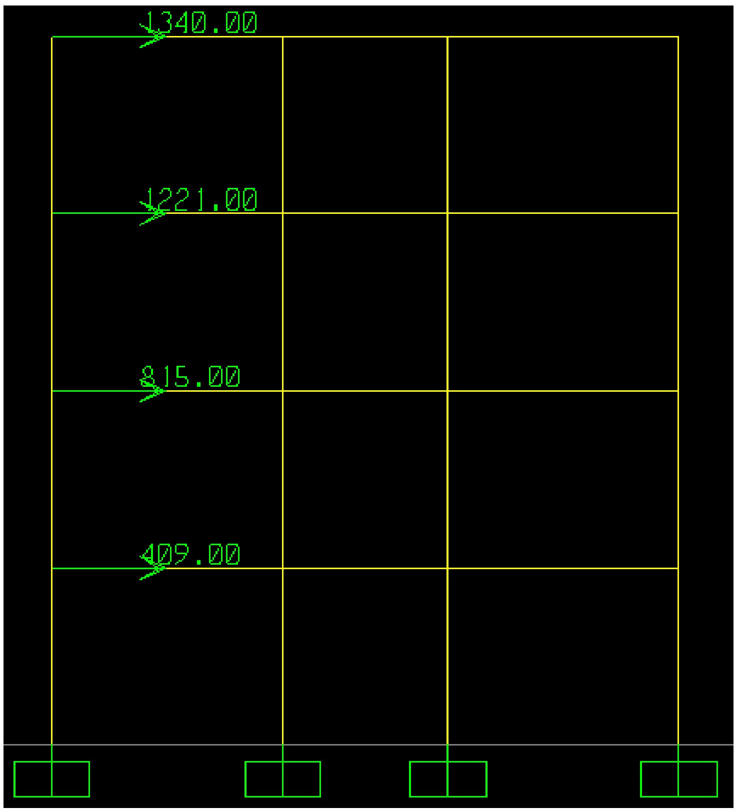

Figure 11. Distribution of horizontal seismic force

3.4.2 Check of Seismic design for study case

Numerical analysis for the study case has been performed using SAP2000 (Computers and Structures) [3] and the reinforced concrete columns are designed according to the (BS 8110 , 1997) [2] using the limit state design method (Mosley and Bungey, 1997) [6].

Table 5 and 6 show the Straining action (moments) for the ten columns due to seismic load, and the seismic design compared with the original design of that columns which are chosen respectively. It is clear that most of columns are unsafe due to seismic loads. Therefore, a strengthening scheme is needed for the residual building in order to resist earthquake forces.

Table 5. Straining action for the same ten columns due to seismic load

Column No.	Case	Step Type	N	Mx	My
C05	*ENVEQX*	*Max*	*1819.32*	*264.36*	*20.24*
C06	ENVEQX	Max	1823.8	264.52	5.73
C13	ENVEQX	Max	1966.4	285.83	26.27
C15	ENVEQX	Max	1816.35	261.38	5.75
C16	ENVEQX	Max	2002.41	285.58	7.19
C20	ENVEQX	Max	1998.13	305.43	21.16
C21	ENVEQX	Max	1777.94	276.76	39.8
C23	ENVEQX	Max	2021.05	304.11	1.27
C25	ENVEQX	Max	1977.63	306.11	2.52
C29	ENVEQX	Max	1947.29	286.42	5.57

3.4.2.1 Design of some columns due to gravity and seismic load

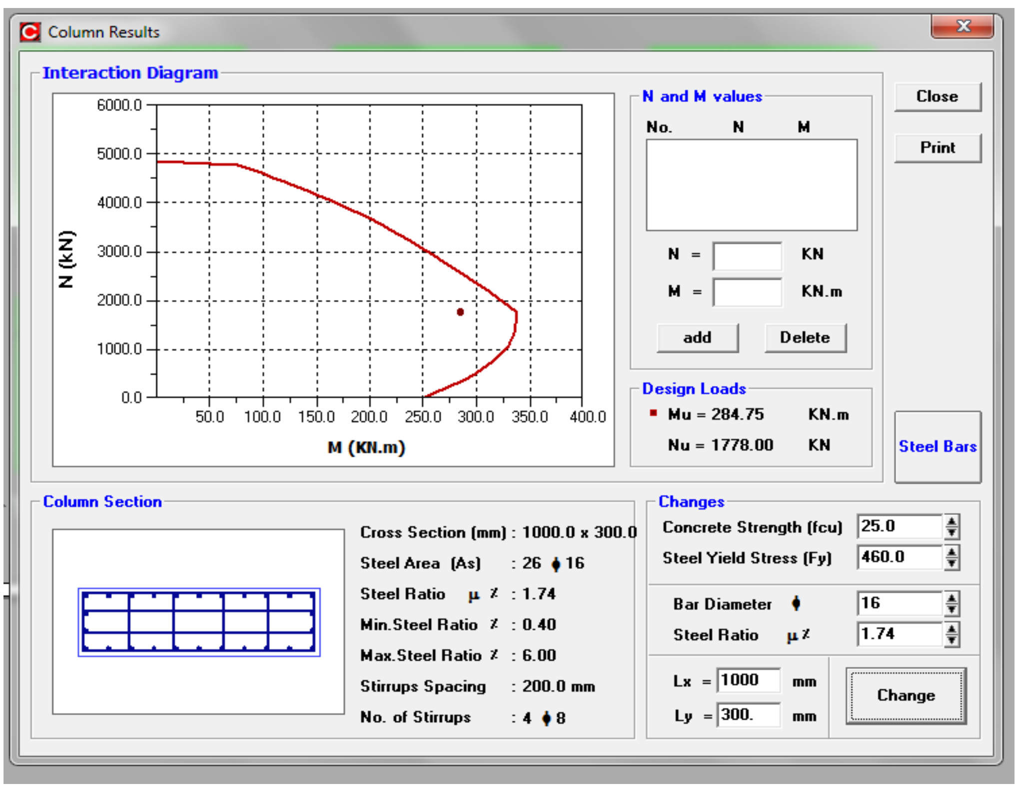

Figure 12.ISACOL Program result for Design of Column No, C21 due to seismic loads

Table 6. Comparison between Original and Present Design Including Seismic Loads

Column No.	Original Design		Present Design	
	Section*	Reinf.	Section*	Reinf.
C05	250x500	10 Φ 16	300x1000	20 Φ 16
C06	250x500	10 Φ 16	300x1000	20 Φ 16
C13	250x500	10 Φ 16	300x1000	22 Φ 16
C15	250x500	10 Φ 16	300x1000	20 Φ 16
C16	250x500	10 Φ 16	300x1000	22 Φ 16
C20	250x500	10 Φ 16	300x1100	26 Φ 16
C21	250x500	10 Φ 16	300x1000	20Φ 16
C23	250x500	10 Φ 16	300x1100	26 Φ 16
C25	250x500	10 Φ 16	300x1100	24 Φ 16

* Section dimensions are in mm.

4. PROPOSED STRENGTHENING METHOD

There are different methods for seismic strengthening of existing buildings. However, social and economic conditions should be considered to choose the appropriate method. Adding structural walls is one of the most common structure-level retrofitting methods to strengthen existing structures. This approach is effective for controlling global lateral drifts and for reducing damage in frame members. Structural walls may be either reinforced concrete or steel plate.

4.1 Modeling Reinforced Concrete Shear Walls (RCSW)

The Reinforced Concrete Shear Walls (RCSW)can be modeled using full shell elements and isotropic material. It is suggested that the wall panel be modeled using at least 16 shell elements (4x4 mesh) per panel (Abolhassan, 2001).The lateral force resisting system consists of moment resisting frames with RC Shear Walls . The residual building of the study case was analyzed and designed for gravity and seismic loads as previously explained, i.e., using SAP2000 structural analysis software package (Computers and Structures) , British standard code (BS 8110 , 1997) , and ESEE -Regulations ((ESEE , 1988).

4.1 Comparative Study

Three cases of same positions for the shear walls have been examined. Reinforced concrete walls with thicknesses of 20 cm , 15 cm and 10 cm as shown in Figures 13-16

The following results have been obtained:

1- For the two cases and using the shear walls of concrete, with different showed that all the columns in both directions x and y are safe, as shown in Table 4.
2- For economy, Reinforced concrete wall with thicknesses of 15 cm have been chosen for this case study.

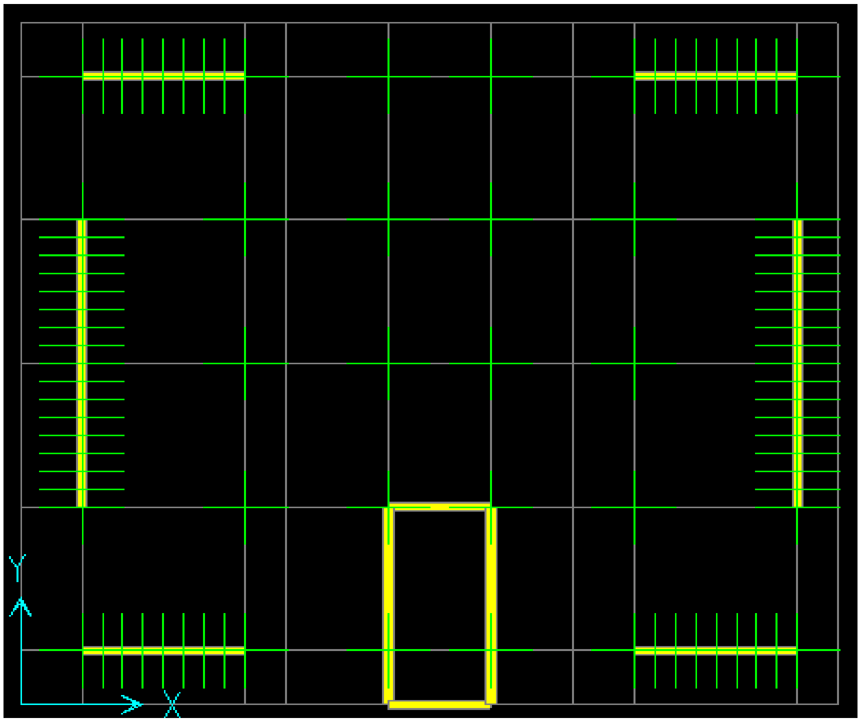

Figure 13. The RCshear wall positions

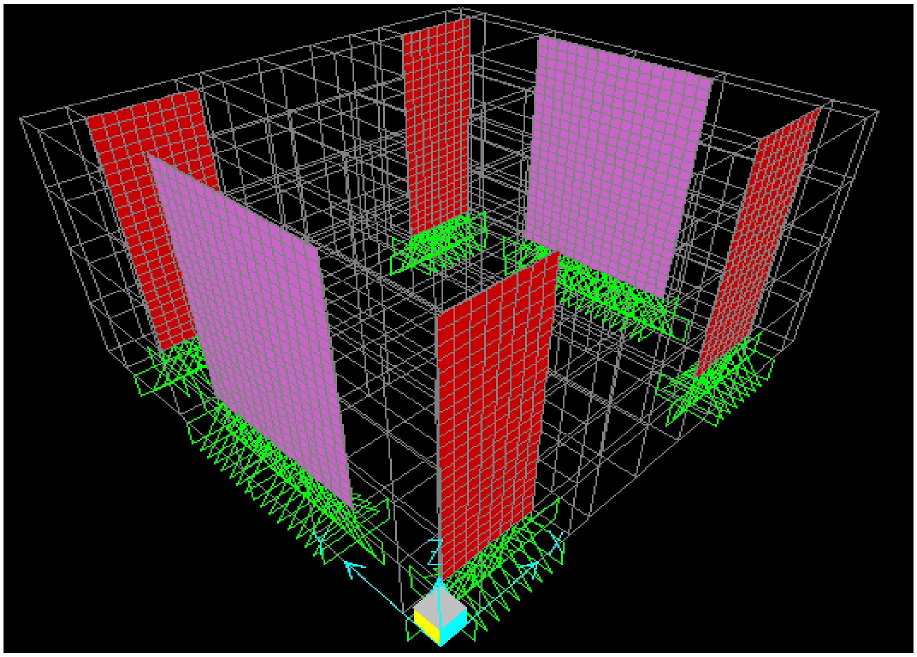

Figure 14. Modeling of shear wall in both directions x and y

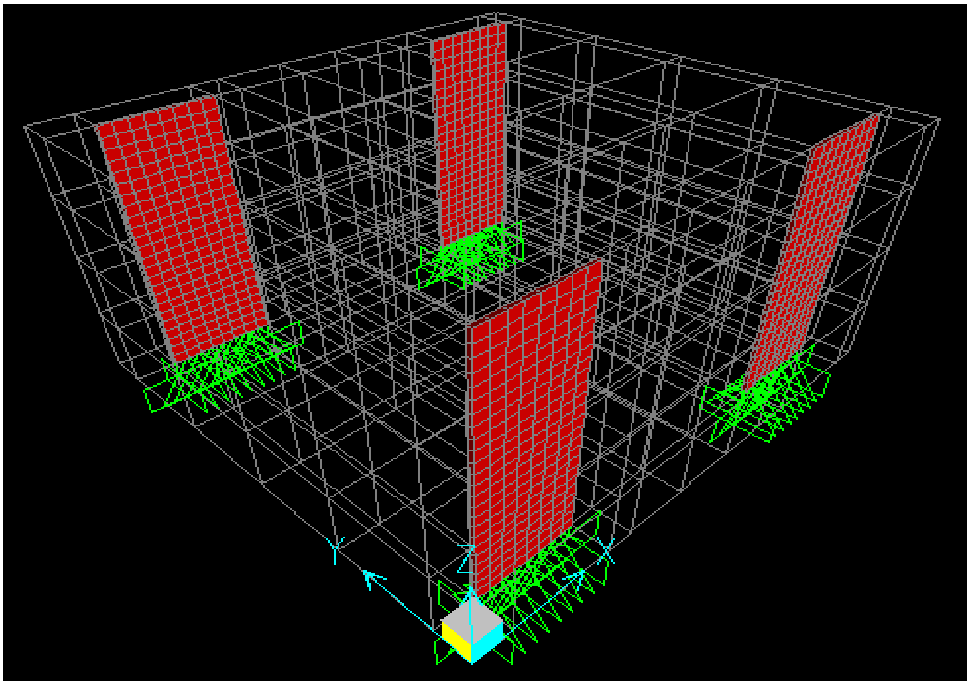

Figure 15. Modeling of shear wall in x direction

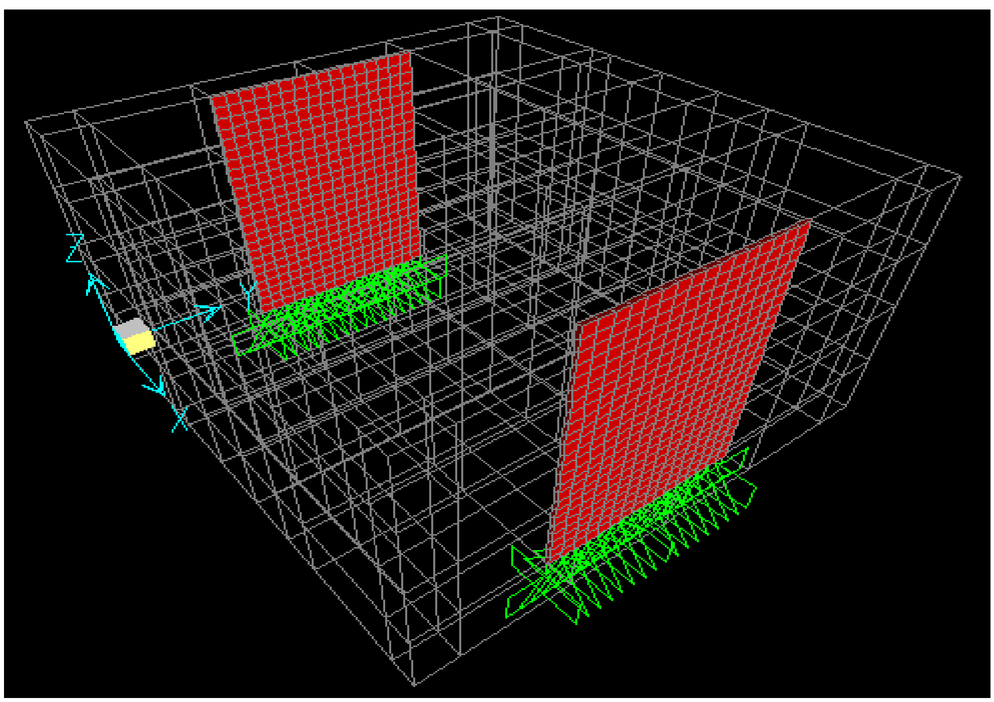

Figure 16. Modeling of shear wall in y directions

Table. 7 shows straining action for the ten columns that which are chosen due to seismic load before and after strengthening. It has been found that all columns in the study case became safe after strengthening.

Table.7Straining action for the ten columns that which are chosen due to seismic load before and after strengthening.

Column No.	**Original**	**Columns**	**Shear wall 0.2**	**Shear wall 0.15**	**Shear wall 0.1**
	Mx	**Mx**	**Mx**	**Mx**	**Mx**
C05	-0.47	*264.36*	18.7	22.06	*27.81*
C06	-0.23	264.52	13.63	16.36	21.14
C13	-0.78	285.83	5.27	6.56	8.95
C15	-0.34	261.38	13.89	16.49	21.37
C16	-0.26	285.58	4.87	6.22	8.74
C20	-0.79	305.43	5.42	6.78	9.29
C21	0.97	276.76	13.55	13.51	13.68
C23	-0.24	304.11	5.02	6.42	9.01
C25	-0.32	306.11	4.83	6.27	8.88
C29	-0.36	286.42	4.57	5.97	8.52

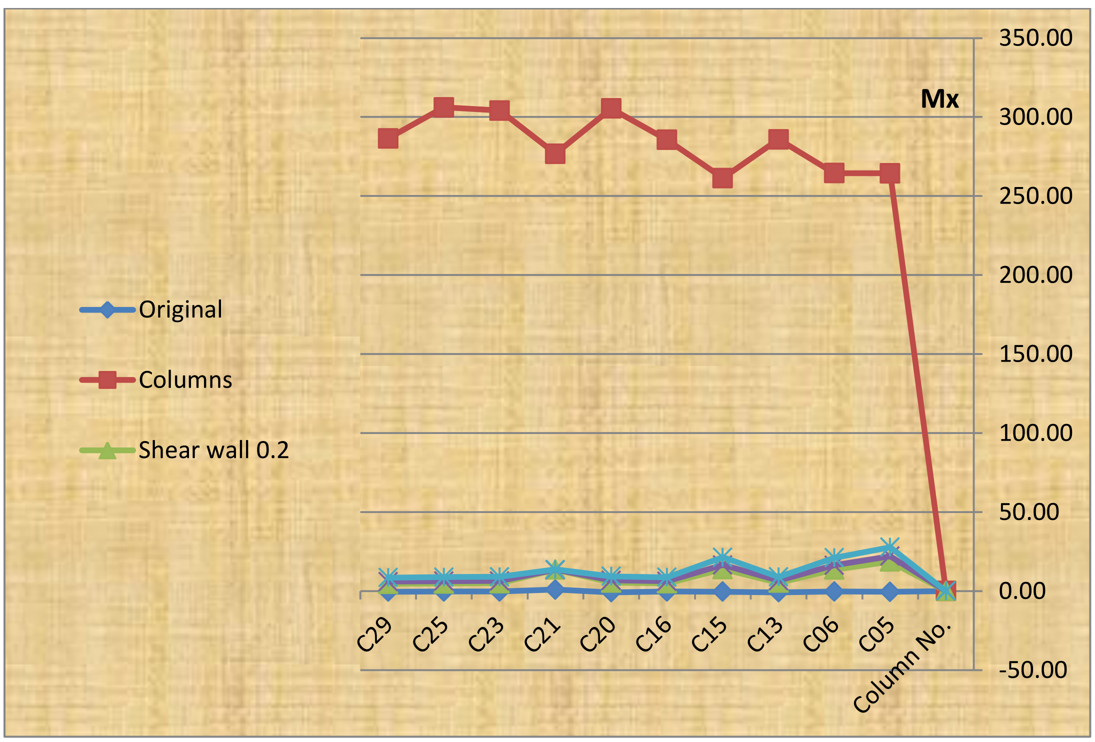

Figure 17. Straining action for the ten columns which are chosen due to seismic load before and after strengthening.

Table 4: Comparison between Original and Strengthened Design for Study Case

Column No.	Seismic Loads in direction (x) and direction (y)			
	Original Design		After Strengthening	
	Section (mm)	Reinf.	Section (mm)	Reinf.
C05	250x500	10 Φ 16	250x500	10 Φ 16
C06	250x500	10 Φ 16	250x500	10 Φ 16
C13	250x500	10 Φ 16	250x500	10 Φ 16
C15	250x500	10 Φ 16	250x500	10 Φ 16
C16	250x500	10 Φ 16	250x500	10 Φ 16
C20	250x500	10 Φ 16	250x500	10 Φ 16
C21	250x500	10 Φ 16	250x500	10 Φ 16
C23	250x500	10 Φ 16	250x500	10 Φ 16
C25	250x500	10 Φ 16	250x500	10 Φ 16
C29	250x500	10 Φ 16	250x500	10 Φ 16

5. CONCLUSIONS

The present study represents the first attempt to investigate the seismic resistance of residual buildings in the Sudan. Due to the lack of knowledge about the seismic activity in this country buildings are designed and constructed without any seismic load consideration. Seismicity of The Sudan may be considered as moderate. Hence, all buildings should be checked against earthquake resistance. The present paper proposes a simple procedure to check the seismic resistance of such buildings.

The obtained results emphasize the following conclusions:

1- Current design of residual buildings in the Sudan does not consider earthquake loads.
2- It has been found that the current design of residual buildings in the Sudan is not safe for the current seismicity of the Sudan.
3- A proposed methodology has been presented for evaluation of seismic resistance of existing residual buildings in the Sudan.
4- A strengthening technique for existing residual buildings in the Sudan has been presented. It has been proved that RC walls with 15 cm thickness is suitable strategy for this case to reduce the seismic vulnerability of exiting (RC) buildings in the Sudan.

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