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PROPOSED METHODOLOGY FOR STRENGTHENING OF EXISTING RC SCHOOL BUILDINGS IN ABHA CITY, SAUDI ARABIA

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ABSTRACT

Saudi Arabia is not free from earthquakes. It has experienced many earthquakes during the recent history, and the previous studies in this field demonstrated this argument Attar (2003). Recently the design of RC buildings to mitigate seismic loads has received a great attention. Since Saudi Arabia has low to moderate seismicity, most of the buildings were designed only for gravity load. This study aims to propose a methodology for the strengthening of existing RC school buildings in Abha city in Saudi Arabia. The seismic analysis and design have been carried out by using equivalent static analysis method according to Saudi Building Code SBC 301 (2007), SAP 2000 structural analysis software (2001), and ASACOL program by Shehata (1999). Typical 5 stories RC school building, designed according to the Saudi Building Code SBC 301 (2007), is investigated. RC shear walls and steel X bracing methods are studied for strengthening RC school structures. These methods of strengthening will become the effective means in the retrofit of RC school buildings. The results revealed that the current design of RC building located in Abha city in Saudi Arabia is unsafe, and inadequate to mitigate seismic loads. A comparative study has been done to choose a suitable strengthening method. An effective method has been proposed by adding steel X bracing and RC shear walls. It has been proved that RC shear walls actually represent a very suitable strategy to reduce the seismic vulnerability of existing RC school buildings.

Keywords: Strengthening; Saudi Building Code SBC301 (2007); School buildings; RC shear walls; Abha city

1. INTRODUCTION

Recent studies, historical evidence, geological and geophysical observations indicate that parts of the Kingdom fall within seismic risk regions. In western Saudi Arabia, a design peak ground acceleration (PGA) ranging from 0.03g to 0.26g for an economic life of 50 years was suggested. Seismic zonation was established with zone numbers 0, 1, 2A, and 2B. Saudi Arabia is not free from earthquakes. It has experienced many earthquakes during the recent history, and the previous studies in this field demonstrated this argument. Most of existing buildings in Saudi Arabia do not meet the current design standards due to design shortage or construction shortcomings. Therefore, buildings should be designed regarding their capacity for resisting expected seismic effects. This paper discusses seismic retrofitting of a typical school building in Abha city, Saudi Arabia which has been designed and constructed without any seismic provisions. Seismic retrofitting is a modification of the structural and /or non-structural components in a building that aims to improve the building's performance in future earthquakes. Adding RC shear 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. In this paper, the seismic retrofitting of existing reinforced concrete RC buildings by means of steel bracing and RC shear walls are examined.

2. MODELING AND ANALYSIS OF RC SCHOOL BUILDINGS DUE TO GRAVITY LOADS

2.1 Description of the Building

The studied building in this paper is a typical five stories RC school building with both vertical and

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horizontal regular geometry. The structural members are made of in-situ reinforced concrete. The overall plan dimensions are 37.2m x 23.6m. The height of the building is 16 m. The cross-section of beams and columns are shown in Table 1.The analysis of the building is carried out using SAP2000 computer program (2001) due to vertical static loading and earthquake loading as per the Saudi Building Code SBC 301 (2007). The building is modeled as 3-D frames with fixed supports at the foundation level.

Table 1. Original sections of columns and beams of the studied building.

Building	Level	Beams		Columns	
		Dim* (mm)	Reinf*	Dim* (mm)	Reinf*
5 Stories	1st floor -2nd floor	250x600	10 Φ 16	250x600	12 Φ 16
	3rd floor-4th floor			250x500	12 Φ 16
	5th floor			250x450	10 Φ 16

Where:
* Dim: Dimension (mm)
*Reinf: Reinforcement

2.2 Current Design

It is a common practice in The Kingdom of Saudi Arabia to design buildings without any consideration of seismic loads. Therefore, the considered typical building has been studied first under the effect of gravity loads and without consideration of seismic loads in order to check the current design. Dead and live loads are following the equations and tables given in the Saudi Building Code.

2.3 Numerical Model

Numerical models for the studied case has been prepared using SAP2000 version 14 (2001). Beams and columns are modeled as beam elements while walls are modeled with shell elements. Figures 1 to 3 show the model of the five stories RC building.

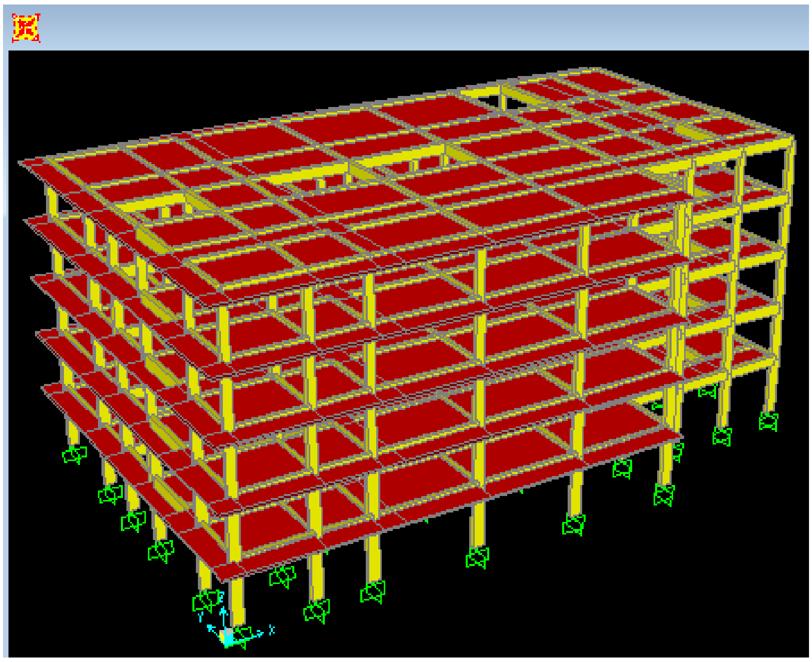


Figure 1. 3D Model of five stories building

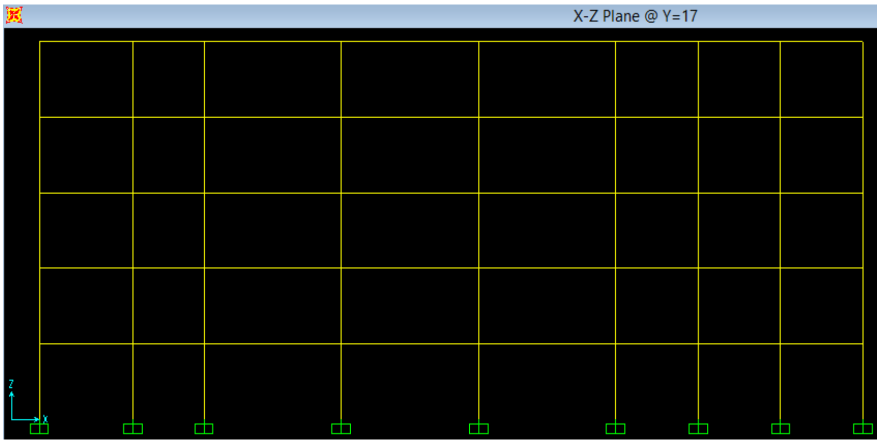


Figure 2. YZ View of studied building

Two frames in direction YZ at X=1.2 m and X=14.4 m have been selected as shown in Figures 4 and 5. Figures 6 and 7 show the labels of columns and beams of the selected frames, respectively.

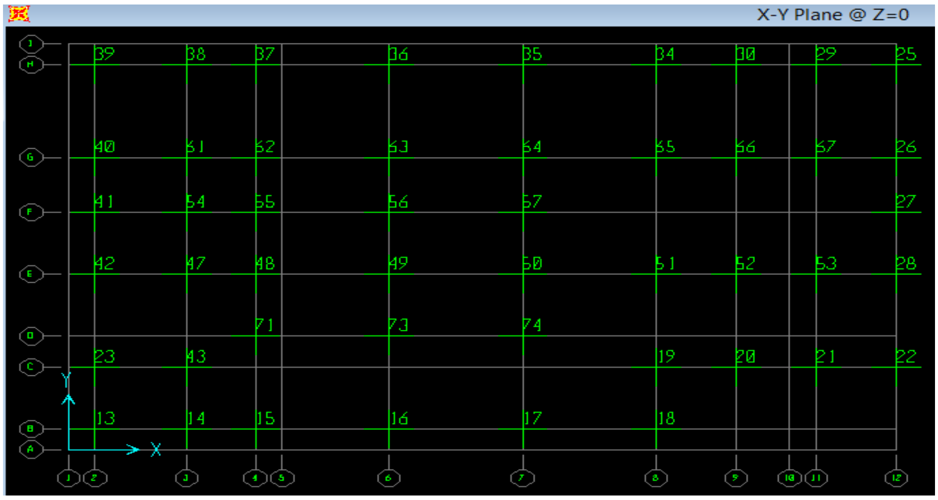


Figure 3. XY Plan of studied building

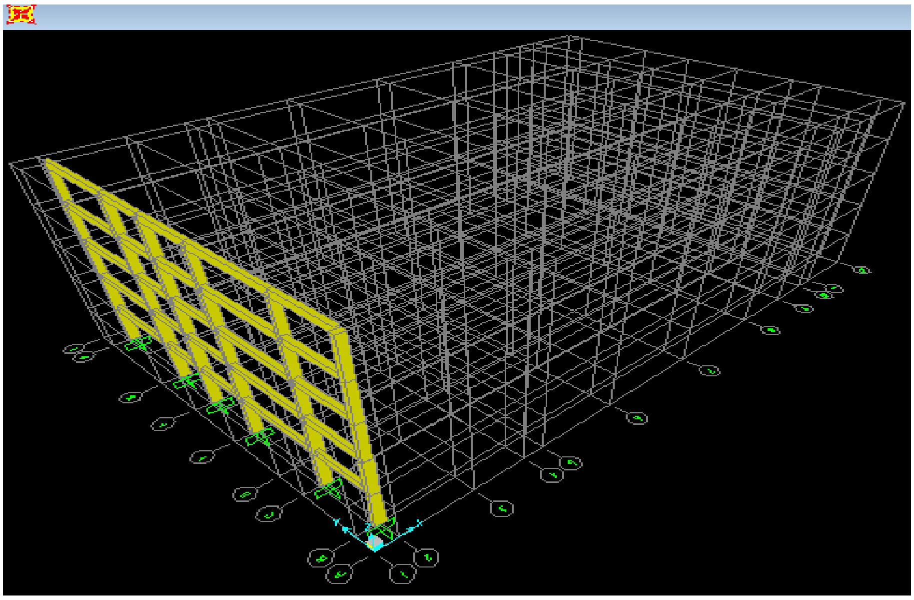


Figure 4. 3D view of the selected frame YZ at X=1.2 m

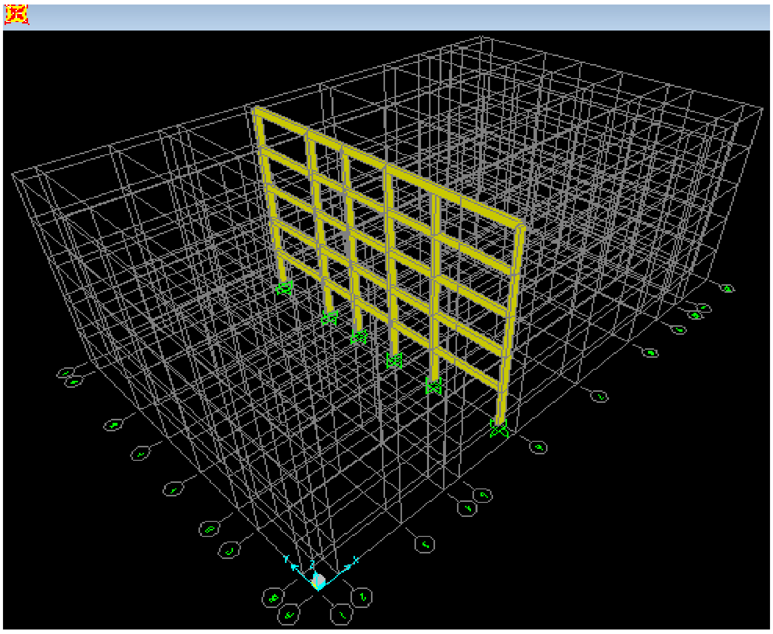


Figure 5. 3D view of the selected frame YZ at X=14.4 m

The chosen building has been checked against earthquake loads as per the Saudi building Code. It has been found that the chosen building is not safe to resist earthquake load as presented in Sobaih and Ismaeil (2018).

3. SEISMIC STRENGTHENING OF RC SCHOOL BUILDING BY ADDING RC SHEAR WALLS

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 of reinforced concrete or steel plates.

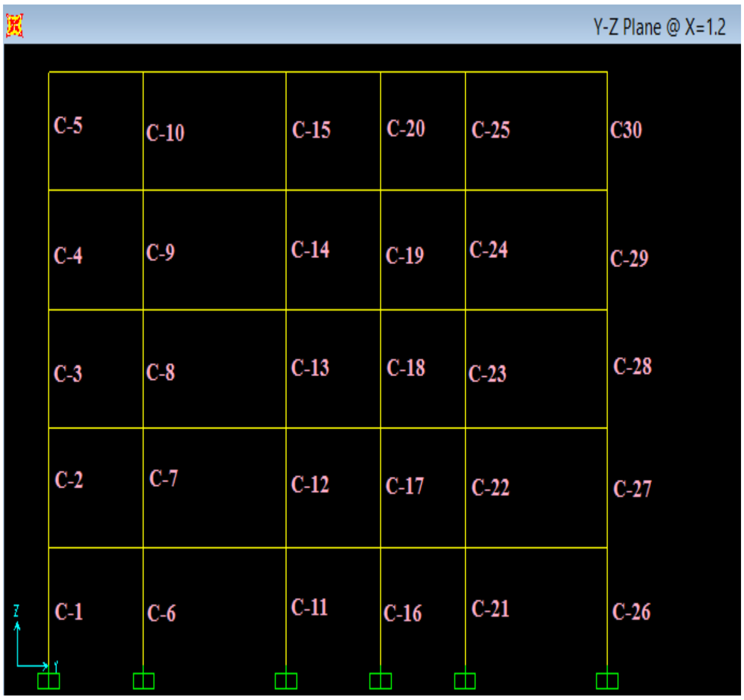


Figure 6. Label of columns for selected frame YZ

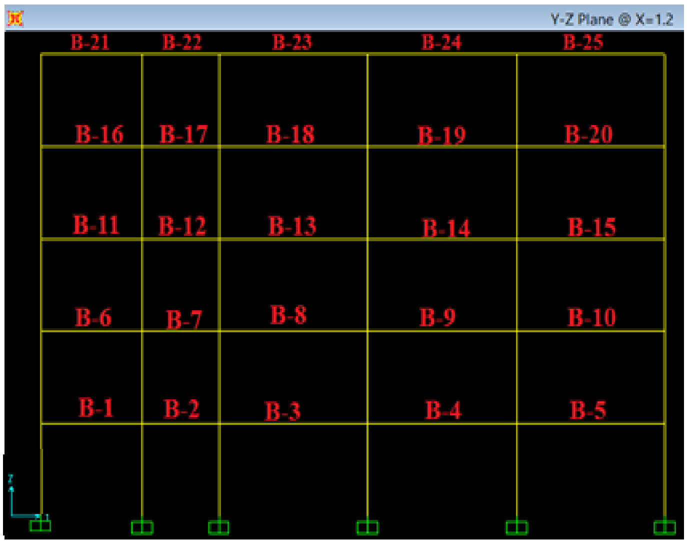


Figure 7. Label of beams for selected frame YZ

3.1 Modeling of Concrete Shear Walls

The concrete shear walls can be modeled using full shell elements with an isotropic material. The lateral force resisting system consists of moment resisting frames with concrete shear walls. The studied building is analyzed for gravity and seismic loads as previously explained, i.e., using SAP2000 structural analysis software package (2001). Reinforced concrete walls with thicknesses of 20 cm have been chosen for this case study. We selected two frames in each direction X and Y as shown in Figures 8 to 11.

3.2 Results of Analysis and Design of Considered Building After Strengthening by Adding RC Shear Walls

The reinforced concrete sections were designed according to the, BS 8110 (1997) using the limit state design method by Mosley and Bungey (1997). The design of columns has been performed using a computer program called ISACOL by Shehata (1999) Figures 12 and 13 show the main window of ISACOL program and sample of a column design.

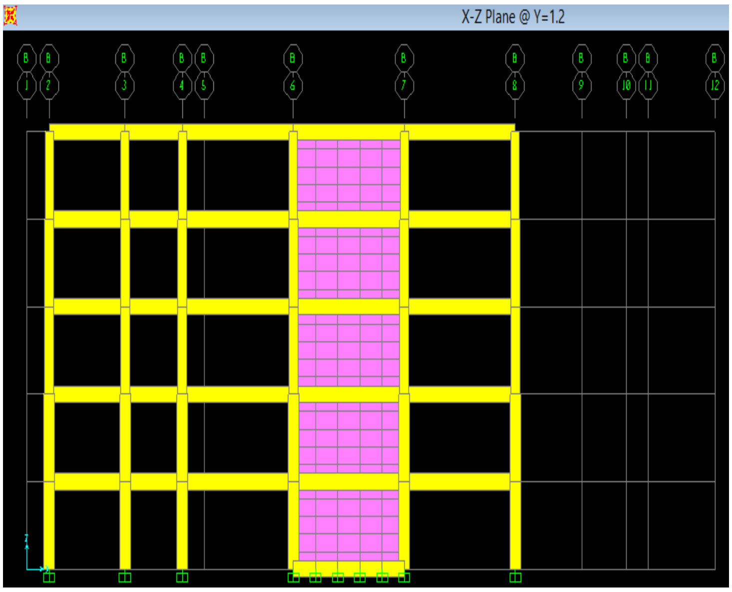


Figure 8. Modeling of shear wall in direction XZ at Y=1.2 m

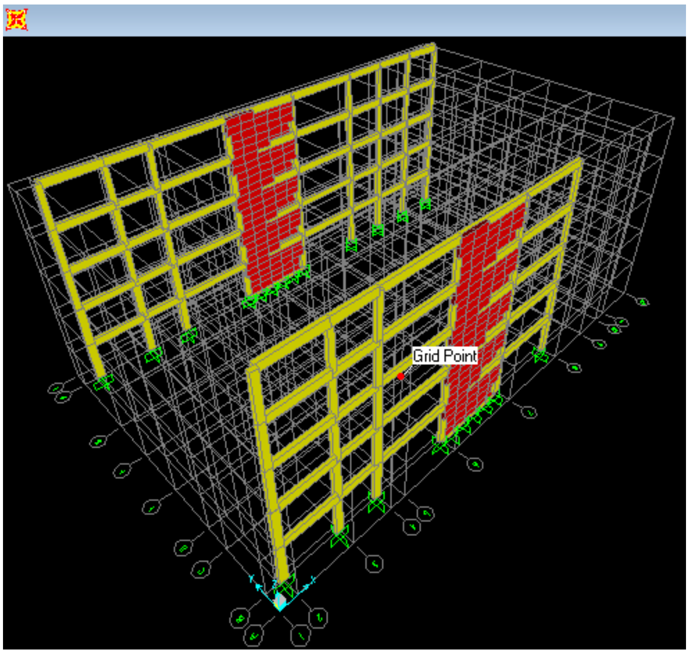


Figure 9. 3D view of shear wall in direction XZ

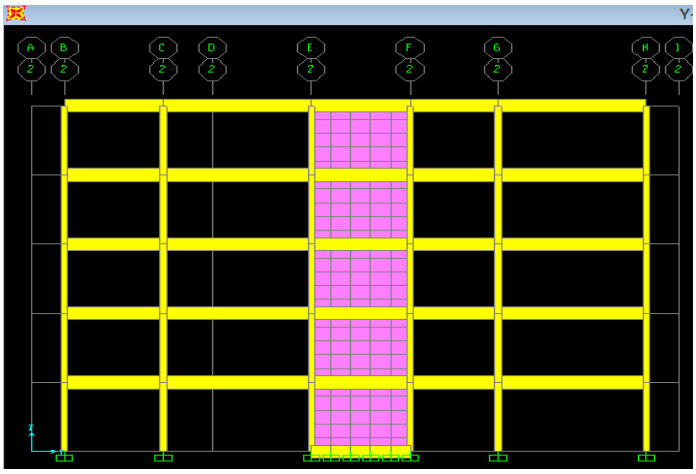


Figure 10. Modeling of shear wall in direction YZ at X=1.2 m

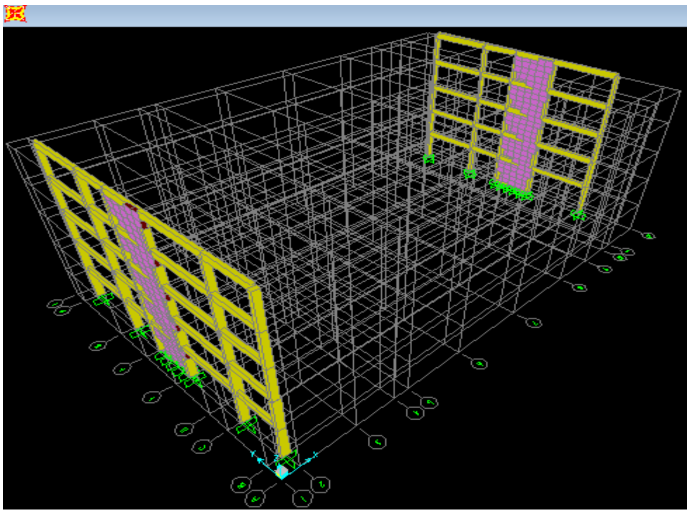


Figure 11. 3D view of shear wall in direction YZ

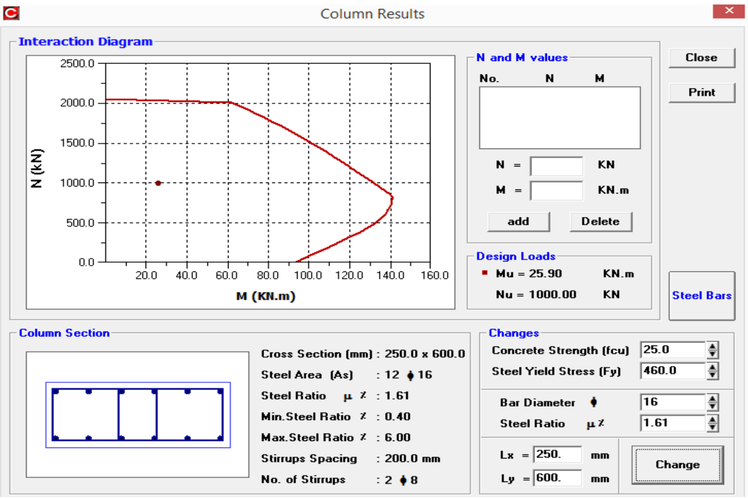


Figure 12. ISACOL program results for C-7.

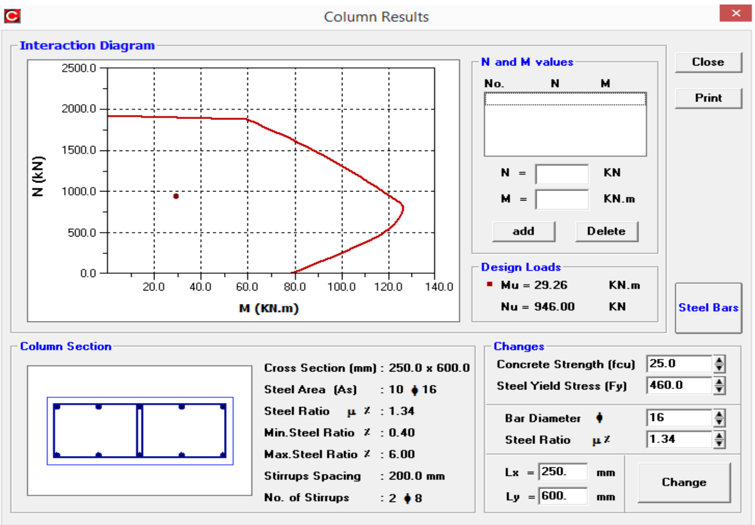


Figure 13. ISACOL program results for C-1.

3.3 Comparison between original and retrofitted design in Direction Y-Z @ X = 1.2 & Y = 14.4.

Tables 2 and 3 show the design results for some columns after retrofitting due to earthquake forces in direction x-x.

Table 2. Design of some selected columns after strengthening by adding RC shear walls at direction Y-Z @ X=1.2 m

Column No.	**Original design (Without Seismic Loads)**		**Including seismic loads**		**After strengthening by Adding RC shear walls**	
	Dim*	**Reinf***	**Dim***	**Reinf***	**Dim***	**Reinf***
C-1	250 X 600	12 Φ 16	250 X 700	12 Φ 16	250 X 600	10 Φ 16
C-7	250 X 600	12 Φ 16	250 X 750	14Φ 16	250 X 600	12 Φ 16
C-13	250 X 500	12 Φ 16	250 X 700	12 Φ 16	250 X 500	10 Φ 16
C-19	250 X 500	12 Φ 16	250 X 650	10 Φ 16	250 X 500	10 Φ 16
C-25	250 X 450	10 Φ 16	250 X 500	10 Φ 16	250 X 450	8 Φ 16

Table 3. Design of some selected columns after strengthening by adding RC shear walls at direction Y-Z @ X=14.4 m

Column No.	Original design (Without Seismic Loads)		Including seismic loads		after strengthening by Adding RC shear walls	
	Dim*	Reinf*	Dim*	Reinf*	Dim*	Reinf*
C-1	250 X 600	12 Φ 16	250 X 9500	16 Φ 16	250 X 600	10 Φ 16
C-7	250 X 600	12 Φ 16	250 X 1000	18Φ 16	250 X 600	12 Φ 16
C-13	250 X 500	12 Φ 16	250 X 850	16 Φ 16	250 X 500	10 Φ 16
C-19	250 X 500	12 Φ 16	250 X 750	14 Φ 16	250 X 500	10 Φ 16
C-25	250X450	10 Φ 16	250X550	10 Φ 16	250X450	8 Φ 16

4. SEISMIC STRENGTHENING OF RC SCHOOL BUILDING BY ADDING X STEEL BRACING

This part presents the modeling and analysis of RC school buildings due to gravity and earthquake loads after strengthening by adding steel bracing with 2L 150*100*12*12.

4.1 Strengthening Method

The lateral force resisting system consists of moment resisting frames with steel bracing. The studied building is analyzed for gravity and seismic loads as previously explained, i.e., using SAP2000 structural analysis software package. Steel bracing have been chosen for this case study. Two frames in each direction X and Y as shown in Figures 14 to 17.

4.2 RESULTS OF ANALYSIS OF STRUCTURAL ELEMENTS AFTER STRENGTHENING BY ADDING X STEEL BRACING

Figures 18 to 20 show the design of some columns after strengthening by adding X steel bracing while Tables 4 and 5 show the design results for some columns after retrofitting due to earthquake forces in direction x-x

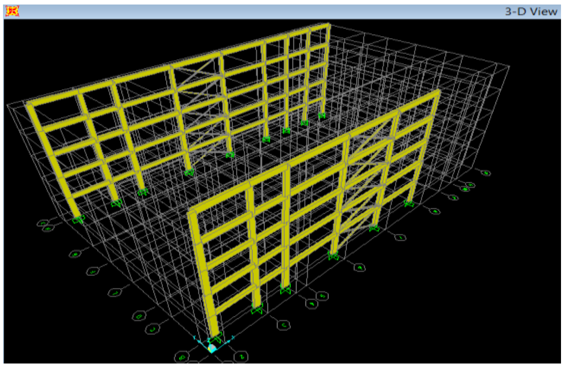


Figure 14. 3D view of steel bracing in direction XZ

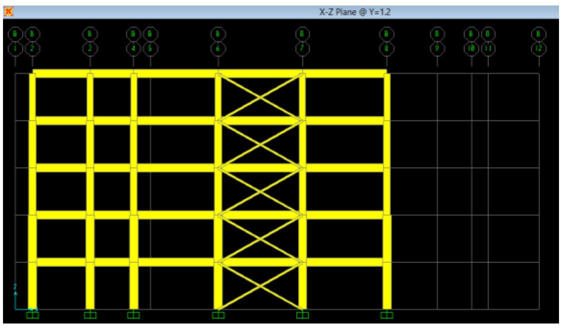


Figure 15. Modeling of steel bracing in direction XZ at Y=1.2 m

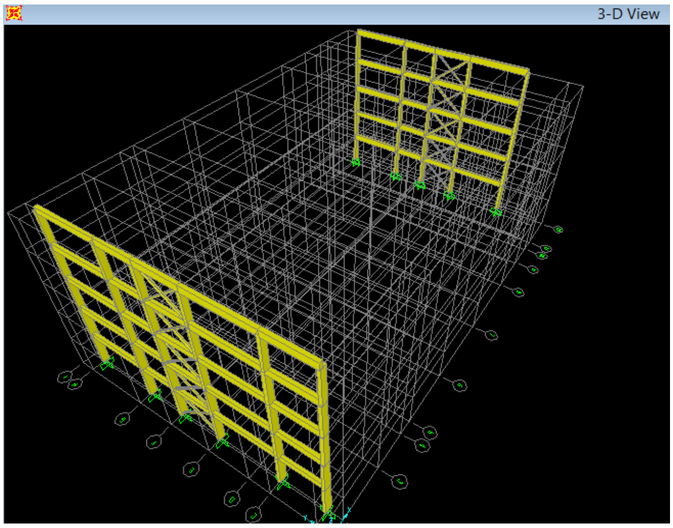


Figure 16. 3D view of steel bracing in direction YZ

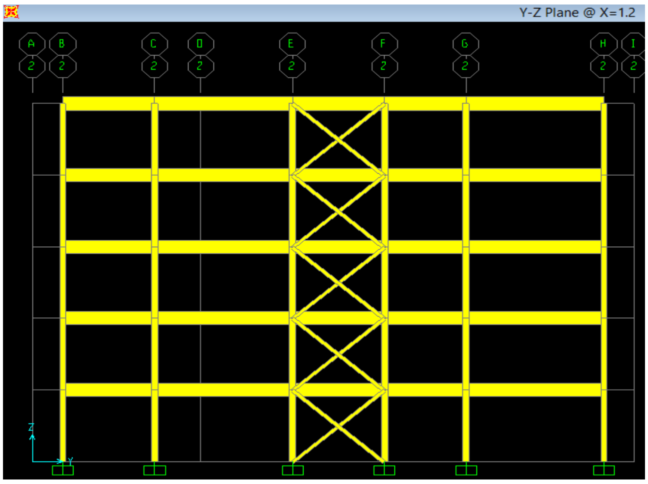


Figure 17. Modeling of steel bracing in direction YZ at X=1.2 m

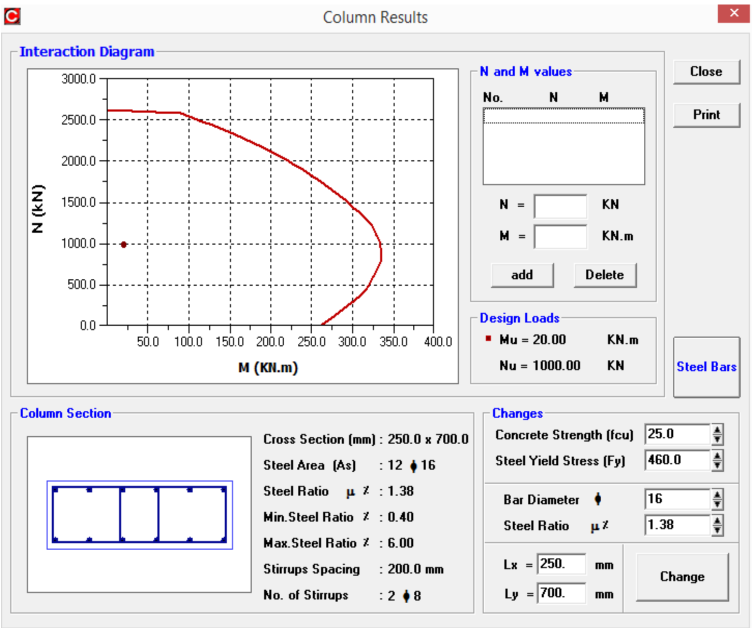


Figure18. ISACOL program results for C-7 after strengthening by adding X steel bracing,

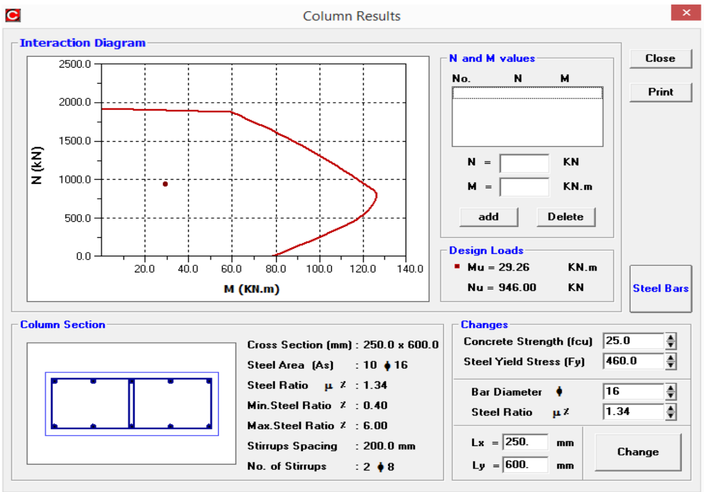
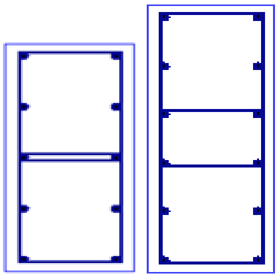


Figure 19. ISACOL program results for C-1 after strengthening by adding X steel bracing



250*600 250*700
10 Φ 16 12 Φ 16
Figure20. Design of columns C-1 and C-7 after strengthening by adding X steel bracing

Table 4. Design of some selected columns after strengthening by adding X Steel bracing direction Y-Z @ X=1.2 m

Column No.	Original design (Without Seismic Loads)		Including seismic loads		after Strengthening by Adding X Steel Bracing	
	Dim*	**Reinf***	**Dim***	**Reinf***	**Dim***	**Reinf***
C-1	250 X 600	12 Φ 16	250 X 700	12 Φ 16	250 X 600	10 Φ 16
C-7	250 X 600	12 Φ 16	250 X 750	14Φ 16	250 X 700	12 Φ 16
C-13	250 X 500	12 Φ 16	250 X 700	12 Φ 16	250 X 500	10 Φ 16
C-19	250 X 500	12 Φ 16	250 X 650	10 Φ 16	250 X 500	10 Φ 16
C-25	250X450	10 Φ 16	250 X 500	10 Φ 16	250 X 450	8 Φ 16

Table 5. Design of some selected columns after strengthening by adding X steel bracing at direction Y-Z @ X=14.4 m

Column No.	Original design (Without Seismic Loads)		Including seismic loads		after Strengthening by Adding X Steel Bracing	
	Dim*	**Reinf***	**Dim***	**Reinf***	**Dim***	**Reinf***
C-1	250 X 600	12 Φ 16	250 X 9500	16 Φ 16	250 X 600	10 Φ 16
C-7	250 X 600	12 Φ 16	250 X 1000	18Φ 16	250 X 600	12 Φ 16
C-13	250 X 500	12 Φ 16	250 X 850	16 Φ 16	250 X 500	10 Φ 16
C-19	250 X 500	12 Φ 16	250 X 750	14 Φ 16	250 X 500	10 Φ 16
C-25	250X450	10 Φ 16	250X550	10 Φ 16	250X450	8 Φ 16

6. CONCLUSION

One of the most difficult problems of strengthening of existing buildings is how to find the adequate solution that satisfies both economic and technical aspects. This study presents an approach to investigate the seismic resistance of RC school building in Abha city, Saudi Arabia. The present paper proposes a simple procedure to check the seismic resistance and retrofit of such buildings. The obtained results emphasize the following conclusions:

(1) Current design of RC school building in Abha city, Saudi Arabia does not consider earthquake loads

(2) A proposed methodology has been presented for evaluation of seismic resistance of existing RC school building in Abha city, Saudi Arabia.

(3) A strengthening technique for existing RC school building in Abha city, Saudi Arabia has been presented.

(4) With the use of RC shear walls inserted in the building, a reduction of bending moments in the columns and beams were observed.

(5) Shear walls reduce significant amount of bending moment and shear forces in frame members as compared to other techniques of retrofitting.

(6) The results which come from strengthening by adding RC shear walls have been better than strengthening by adding the X-bracing system

(7) Optimal locations of shear walls and steel bracing in frame system is critically important to reduce the lateral forces.

(8) Steel bracing is a technique to enhance the seismic performance or strengthen the structures. It has been proved that RC shear walls actually represent a very suitable strategy to reduce the seismic the vulnerability of RC school buildings.

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