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Effect of Earthquake loads on School Buildings in the Kingdom of Saudi Arabia

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Abstract

Background: The designing of the reinforced concrete building for the reduction of the seismic load has significantly gained popularity. Most of the buildings in Saudi Arabia are designed for the gravity load, based on its seismicity level. Objective: The study evaluates the effects of the earthquake load on the RC school building located in Saudi Arabia. Method: An equivalent static analysis technique used to apply the seismic analysis and design method according to Saudi Building Code SBC301 (2007). This design code is used to redesign the chosen school building. The SAP 2000 structural analysis software was used to analyses and study the structure behaviour due to the seismic load. Results: The results of the study provide that the RC school building design in Saudi Arabia is inadequate, and unsafe for the earth quakes. Conclusion: One of the important conclusions in this study is that the designer of the school building in Saudi Arabia should take into consideration the earthquake loads. It also emphasizes on the development of the adequate framework for the implementation of the safe designing of the buildings inclusive of earthquake safety measures.

Keywords: Effect; Saudi Building Code (SBC301-2007); School Building; Seismic; Saudi Arabia.

1. Introduction

It is a well-established fact that Saudi Arabia is located within the small and medium band of earthquakes (Ismaeil, Alhadi, and Alashker, 2017 [1]). Previous researches have demonstrated the fact that there are earthquakes in Saudi Arabia (Fnais et al., 2014 [2]; Alashker, Nazar, and Ismaiel, 2015 [3]). This is also evident from the Arab News reporting of the 63000 earthquakes in the previous 6 years in Saudi Arabia (Arab News, 2018 [4]). This necessitates the consideration of the seismic loads when the buildings are being designed, which have now become part of the development and adoption of a national code and the experienced seismic activity at several regions in the Kingdom. In the past decades, the inclusion of dynamic loads in the design of building in Saudi Arabia was very much limited to important huge structures. A major part of the building industry is designed with focus on the gravity loads only with minor consideration towards the detailing on the accommodation of the lateral loads. Certain rehabilitation of the existing buildings has occurred to sustain the expected performance level. Hakim (2013) further adds that the capacity of the building should be evaluated before rehabilitation work [5].

In recent times, the integration of the reinforced concrete building has gained immense popularity among the researchers (Mahrenholtz et al., 2015 [6]; Gong et al. 2017 [7]). It is because the occurrence of earthquake has increased

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across the region, where it causes movement and vibration under the buildings, causing a sudden release of energy. The Earth moves under buildings randomly during the earthquake. The structure is greatly affected by the lateral movement of the earth that occurred during the earthquake and result in the destruction of many parts of the building based on the instability caused inside the building. Recent researches, along with the historical proofs, and observations in terms of the geological and geophysical characteristics provides that Saudi Arabia is at a significant risk of fall within the regions in the seismic world (Abo El-Wafa ea al. 2015 [8]). Buildings designed to resist the main loads or the gravity loads cannot withstand the lateral loads caused by earthquakes (Pitarka et al., 2015 [9]). Taking the impact of earthquakes during design greatly eliminates the problem of vibrations on buildings (Chopra, 2007 [10]). Consequently, considering the Kingdom vision 2030, the academic performance of the students in the regions needs to be parallel with the international level, emphasizing upon development of more schools (Gelil et al. 2017 [11]). The study is intended to evaluate the impact of earthquakes on the reinforced concrete buildings for schools in Saudi Arabia. This evaluation will help the policy makers in devising a framework for earthquake safety, which can help reduce the effect of loading on the building and, detrimental for the building structure.

2. Modeling and Analysis of RC School Building due to Gravity Loads

2.1. Description of the Building

In this study, the selected building is a typical five stories RC school building with both vertical and horizontal regular geometry. The structural members are made of in-situ reinforced concrete. The overall plan dimensions are 20 m x 18 m. The height of the building is 15.5 m. The beams and the columns cross-section details are present in Table 1. SAP2000 program (2001) is used to analyze the building according to gravity static loading, which is calculated using the Saudi Building Code SBC (2007). Three-dimension frame model with clamped supports with the foundations is used to model the studied school building.

Table 1. The original sections of the studied building's columns and beams

Building	Level	Beams		Columns	
		Dim* (mm)	Reinf*	Dim * (mm)	Reinf **
5 Stories	1st floor -2nd floor	250 x 600	10 Φ 16	250 x 600	12 Φ 16
	3rd floor-4th floor			250 x 500	12 Φ 16
	5th floor			250 x 450	10 Φ 16

Note: * Dim: Dimension (mm); **Reinf: Reinforcement.

2.2. Current Design

In the Kingdom of Saudi Arabia, they usually do not take the effect of the seismic loads in the design of buildings. In this study one typical building, which was designed using only the dead and live loads, is taken to study our current model including the seismic loads. Dead and live loads are following the equations and tables given in the Saudi Building Code SBC (2007) [12].

2.3. Numerical Model

SAP2000 version 14 (2001) [13] is used for numerical modeling of the study case. The beam element is used to model all of the beams and the columns in the structure. The shell elements are used to model the concrete slabs. The five stories building model is shown in the Figures one through three. Two frames have been selected in direction YZ at X=1.2 m and X=12 m as shown in Figures 4-5. Figures 6 and 7 show the labels of columns and beams of the selected frames, respectively.

3. Modeling and Analysis of RC School Building due to Earthquake Loads

Most of the buildings and structures in the Kingdom of Saudi Arabia are not in compliance with earthquake provisions design or structure and further have not considered the effect of earthquake on its building.

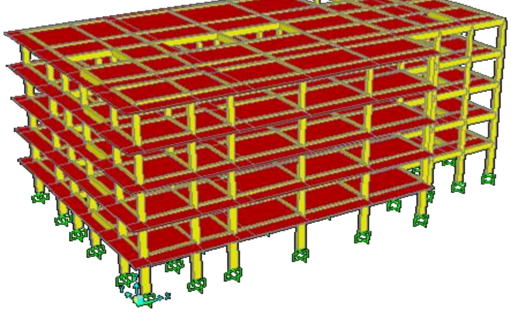

Figure 1. 3D Model of five stories building

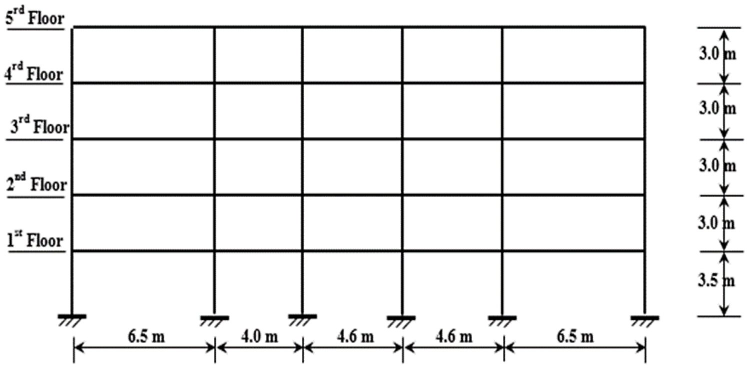

Figure 2. Frame in YZ View of studied building

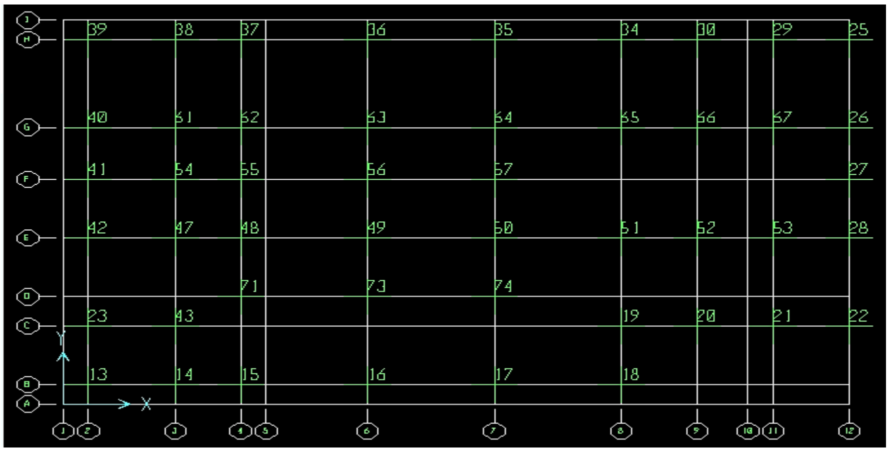

Figure 3. XY Plan of studied building

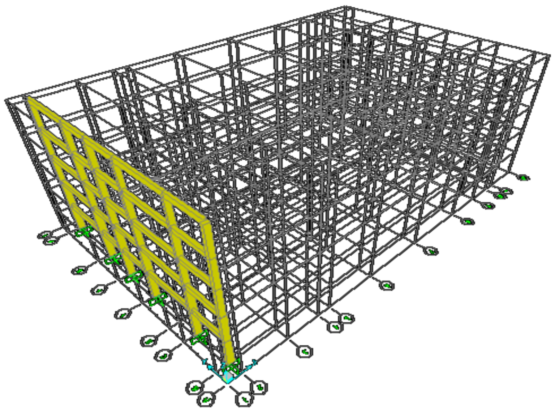

Figure 4. 3D view of the selected frame YZ at X=1.2 m

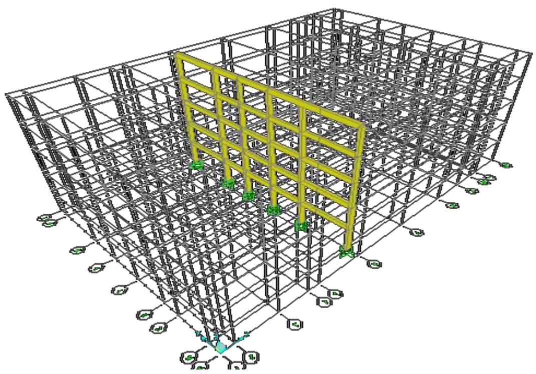

Figure 5. 3D view of the selected frame YZ at X=12 m

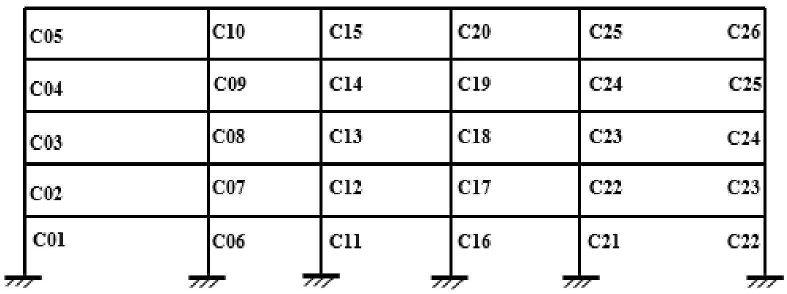

Figure 6. Label of columns for selected frame YZ

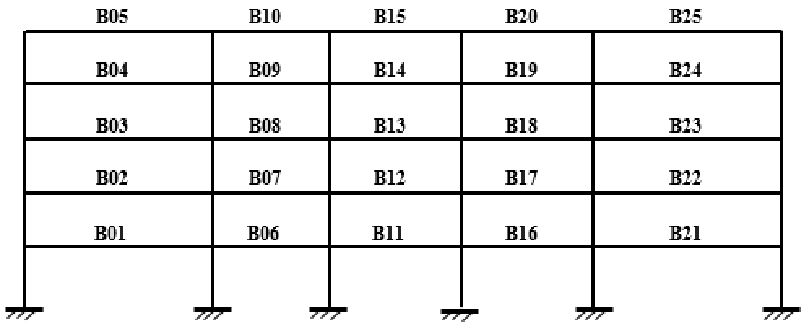

Figure 7. Label of beams for selected frame YZ

The Saudi Building Code (SBC-301) (2007) is used to estimate and calculate the horizontal loads resulting from the impact of earthquakes. The total horizontal shear force resulting from the earthquake is calculated at the building base and then dispersed to each story depending on the height and the gravity loads at each story. The total seismic shear force at the foundation level V is determined by the used code as follows:

$$V = Cs \times W \tag{1}$$

Where; Cs: is the seismic coefficient, W: is the total weight, V: is the base shear.

In the following equation, the seismic design coefficient (Cs) will be determined:

$$Cs = SDs / (R / I) \tag{2}$$

Where; SDs: is the design spectral response acceleration in the short period range, R: is the response modification factor, I: is the occupancy importance factor. The value of the seismic response coefficient (Cs) should not be greater than the following equation:

$$Cs = SD_1 / [T.(R / I)] \tag{3}$$

$$T = 0.1N \tag{4}$$

Where: N = Number of stories. The value of the seismic response coefficient (Cs) will be taken more than:

$$Cs = 0.044 SDs I \tag{5}$$

Where; SD_1 = Design spectral response acceleration at a period of 1 sec, T = Fundamental period of the structure (sec). Design earthquake spectral response acceleration at short periods, SD_S, and at the 1-sec period, SD_1, shall be as follows:

$$SMs = Fa \times Ss \tag{6}$$

$$SM_1 = Fv \times S1 \tag{7}$$

$$SDs = 2/3 \times SMs \tag{8}$$

$$SD_1\ 2/3 \times SM1 \tag{9}$$

Where:

Ss: the maximum spectral response acceleration at short periods

S_1: the maximum spectral response acceleration at a period of 1 sec

F_a: acceleration-based site coefficient

F_V: velocity-based site coefficient

SMs: the maximum spectral response acceleration at short periods adjusted for site class

SM_1: the maximum spectral response acceleration at a period of 1 sec. adjusted for site class

SDs: the design spectral response acceleration at short periods

SD_1: the design spectral response acceleration at a period of 1 sec.

3.1. Vertical Distribution of Base Force

The distribution of the resulting horizontal forces due to the earthquakes as a horizontal concentrated force at each story level by using the following formula in the used Saudi Code:

$$F_x = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} V \tag{10}$$

Where; F_x: is the applied lateral force at level 'x', w: is the story weight, h: is the story height, V: is the design base shear, n: is the number of stories.

The summation of the load times the height for all the story levels is the denominator of the above equation. This load distribution forms a triangular distribution shape where the maximum value is at the highest point where zero value is at the foundation level when k is set equal to unity. According to the story masses at each story height, the lateral loads distribution occurs proportionally to the mass of each story.

k = an exponent related to the structure period as follows;

k = 1, for structures having a period of 0.5 sec or less;

k = 2, for structures having a period of 2.5 sec or more.

3.2. Load Combinations as per SBC301 (2007)

The following load combinations are be considered for the design of the structures, the components, and the foundations, according to the Saudi code SBC-301 section 2.3.

$LC1: 1.2D + 1.0\,E + f1L$

$LC2: 0.9D \pm 1.0E$

Where: $E = \rho\, Q_E + 0.2SDs\, D$, $1.0 \leq \rho \leq 1.5$

$f_1 = 1.0$ for areas occupied as places of public assembly, for live loads in excess of 5.0 kN/m^2, and for parking garage live load.

$f_1 = 0.5$ for other live loads.

SDs = the design spectral response acceleration at the short period range as determined from Section 9.4.4.

Q_E = the effect of horizontal seismic forces.

3.3. Seismic Map for the Jazan City, Kingdom of Saudi Arabia

The Saudi Building Code (SBC-303-2007) provides seismic maps for the Kingdom of Saudi Building. Figures 6 and 7 show the seismic maps for region 6 in which Jazan area lies.

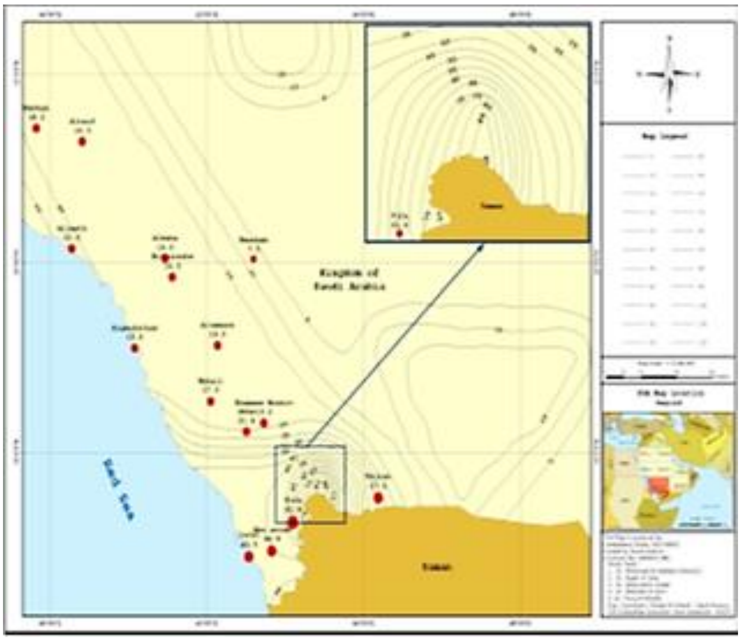

Figure 8. Maximum Considered Earthquake Ground Motion for the Kingdom of 0.2 SEC Spectral Response Acceleration (Ss in %g) (5 Percent of Critical Damping), Site Class B. (Region 6)

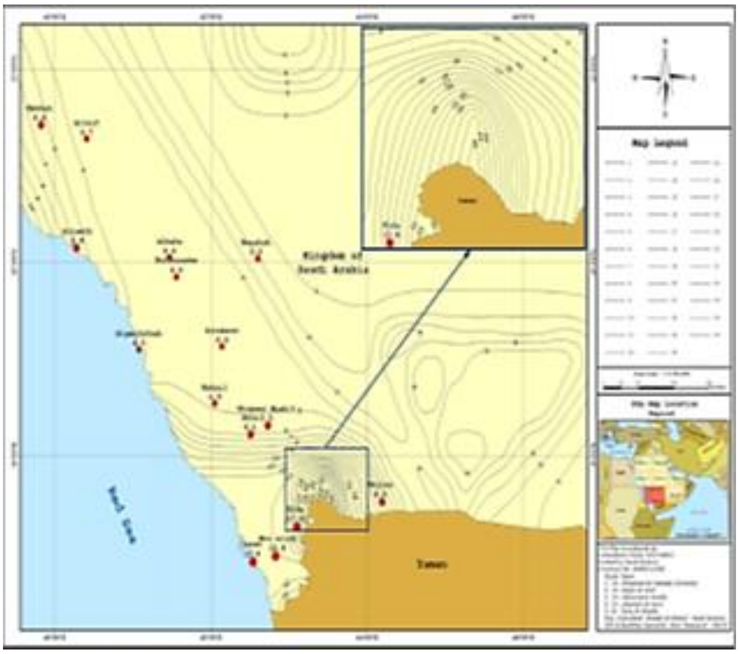

Figure 9. Maximum Considered Earthquake Ground Motion for the Kingdom of 1 SEC Spectral Response Acceleration (S1 in %g) (5 Percent of Critical Damping), Site Class B. (Region 6)

3.3.1. Calculations of Mapped and Design Spectral Response Accelerations for the Jazan City

Using the Saudi Building Code (SBC-301-2007) provisions, the following parameters have been evaluated to be utilized for inputting the data for seismic analysis of the selected model which are noticed from the falls of the Jazan City in region 6. The calculated results of these parameters are as follows:

Table 2 Seismic parameter for Jazan City according to SBC301

City	S_S	S_1	F_a	F_v	S_{MS}	S_{M1}	SDS	SD1	T	R	Cs req	Cs max	Cs
Jazan	0.435	0.124	1.908	3.428	0.83	0.425	0.553	0.283	1.000	2.5	0.221	0.113	0.024

From Table 2 and since SDS< 0.167g and SD1<0.067g, the seismic design category for the three cities is category A (Tables 9.6.a & 9.6.b of SBC301).

R = 2.5 (for ordinary R.C. resisting moment frame)

I = the occupancy importance factor determined in accordance with section 9.5 (SBC-301-2007):

I = 1 (for occupancy category I and II)

A total time of vibration of 10 seconds taken as time interval of 0.025 second was considered for the analysis.

3.4. Base Shear and Seismic Parameters for Jazan City According to SBC301

The seismic parameters shown in Table 2 are calculated according to the mentioned code. The calculated seismic parameters are prepared for entering the data in the seismic analysis program. One of the Saudi Arabia cities is selected for studying the earthquake analysis for the school buildings. The selected building is located in the Jazan city in Asir region, in the south east of the Kingdom of Saudi Arabia, for complete earthquake analysis. This city falls in region 6. Table 3 shows the base shear force and the lateral load values distributed on the building height.

Table 3. Base shear force and the lateral load values distributed on the building height using SBC301.

LEVEL	h_x	W_x	h_x^k	$W_x*h_x^k$	Sum ($W_x*h_x^k$)	($W_x*h_x^k$)/ Sum($W_x*h_x^k$)	V	Final F_x
	m	KN	m	KN.m	KN.m		KN	KN
5th floor	15.5	9986.57	16	159785.12	479355.4	0.333333306	4897.8	1633
4th floor	12.5	9986.57	12.8	127828.096	479355.4	0.266666644	4897.8	1306
3rd floor	9.5	9986.57	9.6	95871.072	479355.4	0.199999983	4897.8	980
2nd floor	6.5	9986.57	6.4	63914.048	479355.4	0.133333322	4897.8	653
1st floor	3.5	9986.57	3.2	31957.024	479355.4	0.066666661	4897.8	327
		49,933	**K=1**	**479355.36**				**4899**

4. Results of Analysis and Design of Considered Building due to Gravity and Earthquake Loads

4.1. Structural Analysis Results due to Gravity Loads

The studied reinforced concrete school building is assumed to be designed using the limit state theory of design using the BSI 8110 [14]. The Information Systems Application on Reinforced Concrete Columns by Mosley and Bungey (1997) [15] was used complete design of the reinforced concrete elements in the used studied school building.

4.1.1. Columns

The axial compression forces and bending moments due to the main load were used for the design of the columns. Table 4 shows the straining actions of some selected columns due to gravity load.

Table 4. Columns internal forces due to the main loads at direction Y-Z @ X=1.2m

Column No.	Output Case	Shear Force (KN)	Bending Moment (KN.m)		Axial Force
			Mx	My	(KN)
C01	1.4DL+1.6LL	2.6	3.04	-5.28	-915.97
C07	1.4DL+1.6LL	7.73	12.48	-12.25	-1153.58
C13	1.4DL+1.6LL	5.81	8.74	-9.84	-687.44
C19	1.4DL+1.6LL	4.87	7.74	-7.85	-347.41
C25	1.4DL+1.6LL	6.12	8.75	-10.84	-242.98

4.1.2. Beams

The straining actions of some selected beams due to main loads are shown in Table 5.

Table 5. Beams internal forces main loads at direction Y- Z@X=1.2m

Beam No.	Moment 3-3 (KN.m)		Shear (KN)
	Start	End	
B01	-45.10	-15.74	-17.23
B07	-58.72	-65.07	94.93
B13	-23.02	-31.06	11.3
B19	15.77	-28.02	21.75
B25	-28.11	9.69	-20.61

4.2. Design Details of the School Building Structural Members due to Main Loads

4.2.1. Columns Design

The design of columns was performed using the ISACOL computer program (1999). Figure 1 shows the design of one the columns using the ISACOL program and the program main window is shown as well. The comparison of the original design and the present design of the reinforced concrete structural members of school building is shown in table 6 [16-19].

Table 6. Design of some selected columns before adding seismic loads

Column No.	Original design (Gravity Loads Only)		Present design (Gravity Loads Only)	
	Dimensions	Reinforcement	Dimensions	Reinforcement
C01	250 X 600	12 Φ 16	250 X 600	10 Φ 16
C07	250 X 600	12 Φ 16	250 X 500	10 Φ 16
C013	250 X 500	12 Φ 16	250 X 500	10 Φ 16
C019	250 X 500	12 Φ 16	250 X 450	10 Φ 16
C025	250 X 450	10 Φ 16	250 X 400	8 Φ 16

4.2.2. Beams Design

The structural analysis is made for the beams to get the internal forces due to the main loads. The existing design is checked using the British Standards 8110 (1997). It has been found that the existing design is adequate.

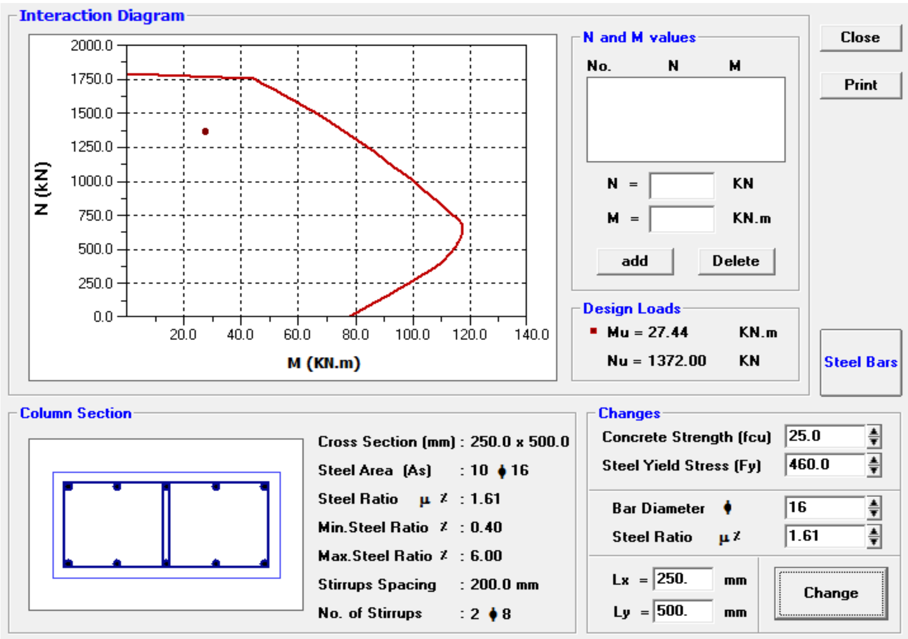

Figure 10. Design of the column no. C01 using the ISACOL program

5. Results due to Gravity and Earthquake Loads

5.1. Structural Elements Internal Forces due to both the Main and the Earthquake Loads

5.1.1 Columns

The columns were designed to resist axial compression forces and bending moments due to gravity and earthquake loads. Tables 7 and 8 show the straining actions of some columns.

5.1.2. Beams

Table 9 shows the internal forces of some selected beams due to load case Group-X (earthquake loads in the x-direction.

5.2. Design of the Structural Elements due to Both the Main and Earthquake Loads

The design of columns has been performed using the computer program ISACOL. Figure 11 shows the ISACOL program results for column No. C07. The seismic load was added to the columns, the analysis and design of some chosen columns were given in Tables10 and 11.

Table 7. Internal forces of some selected columns due to gravity and earthquake loads at direction Y-Z @X=1.2m

Column No.	Output Case	Shear Force	Bending Moment (KN.m)		Axial Force
		(KN)	Mx-Start	My	(KN)
C01	Group-X*	79.67	168.09	86.87	-916.2
C07	Group-X	70.56	114.76	-111.03	-1153.84
C13	Group-X	64.17	99.35	-105.99	-687.66
C19	Group-X	45.63	65.95	-80.08	-347.7
C25	Group-X	30.11	41.61	-54.61	-243.13

* Group –X: earthquake load is in the X-direction

Table 8. Internal forces of some selected columns due to gravity and earthquake loads at direction Y-Z@X=14.4 m

Column No.	Output Case	Shear Force (KN)	Bending Moment (KN.m)		Axial Force (KN)
			Mx	My	
C01	Group-X	92.35	180.87	-114.66	-2105.39
C07	Group-X	97.89	157.14	-156.18	-1984.32
C13	Group-X	80.85	125.38	-133.35	-708.83
C19	Group-X	64.58	97.59	-109.06	-491.53
C25	Group-X	43.82	63.45	-76.77	-401.65

Table 9. Internal forces of some selected beams at direction Y-Z@X=1.2m

Beam No.	Moment 3-3 (KN.m)		Shear (KN)
	Start	End	
B01	-45.1	-15.73	-17.23
B07	-58.31	-65.07	94.93
B13	-22.98	-31.07	11.31
B19	15.77	-27.92	21.72
B25	-28.1	9.69	-20.6

Table 10. Design of some selected columns after adding seismic loads at direction Y-Z @ X=1.2m

Column No.	Original design (Without Seismic Loads)		Including seismic loads	
	Dimensions	Reinforcement	Dimensions	Reinforcement
C01	250 X 600	12 Φ 16	250 X 700	12 Φ 16
C07	250 X 600	12 Φ 16	250 X 750	14Φ 16
C13	250 X 500	12 Φ 16	250 X 700	12 Φ 16
C19	250 X 500	12 Φ 16	250 X 650	10 Φ 16
C25	250X450	10 Φ 16	250X500	10 Φ 16

Table 11. Design of some selected columns after adding seismic loads at direction Y-Z @ X=12 m

Column No.	Original design (Without Seismic Loads)		Including seismic loads	
	Dimensions	Reinforcement	Dimensions	Reinforcement
C01	250 X 600	12 Φ 16	250 X 950	16 Φ 16
C07	250 X 600	12 Φ 16	250 X 1000	18Φ 16
C13	250 X 500	12 Φ 16	250 X 850	16 Φ 16
C19	250 X 500	12 Φ 16	250 X 750	14 Φ 16
C25	250X450	10 Φ 16	250X5०0	10 Φ 16

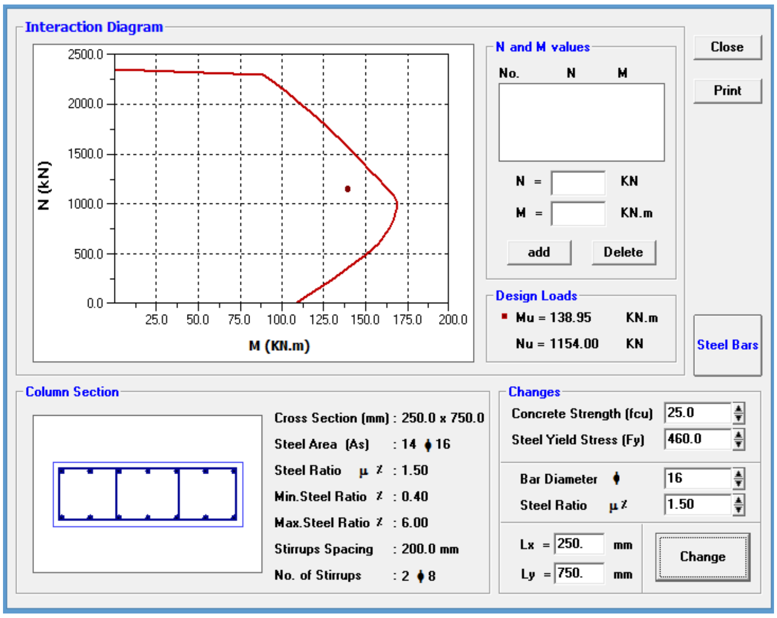

Figure 11. Design of the column no. C07 using the ISACOL program at direction Y-Z @ X=1.2m

6. Conclusion

The RC school building located in Saudi Arabia reprinted by Jazan city is studied in this paper under the effect of both of the gravity loads and the seismic loads. First the structural analysis and design of the studied RC school building due to the gravity loads was done. The earthquake load in two directions XX and YY was applied to the studied RC building after the analysis and design due the gravity loads. The present results have depicted that are slight changes in the values of the bending moments and shear forces on the beams before and after considering earthquake loads (load case Group-X) as shown in Tables 5 and 9. The values of the bending moments and shear forces in the columns due to seismic loads are nearly more than ten times that due to gravity loads as shown in Tables 4 and 7. The values of the axial forces on the columns due to seismic loads are approximately similar to that for gravity loads as shown in Tables 4 and 7. The presented results in this paper shows that the RC schools buildings located in Jazan city in Kingdom of Saudi Arabia is not safe to sustain the earthquake if it occurs, as shown in the presented results.

The present study has presented the seismic loads effect on the RC school buildings in Jazan city in Saudi Arabia. Because of many reasons, most of the buildings in Jazan city and Saudi Arabia in general are not designed to sustain the earthquake load. The earthquake information and maps show that The Saudi Arabia may be considered in the moderate area of earthquake. This paper introduces a simple method from which the seismic resistance of the RC school buildings can be predicted. The obtained results emphasize that some of the school buildings in Jazan city in Saudi Arabia are not designed to sustain seismic loads. The existing RC school buildings in Jazan city in Saudi Arabia will not be able to carry and severe the earthquake if it supposed to happen.

7. Funding and Acknowledgements

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8. Conflicts of Interest

The authors declare no conflict of interest.

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