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EVALUATION OF SEISMIC PERFORMANCE OF EXISTING RC SCHOOL BUILDINGS IN ABHA CITY, SAUDI ARABIA

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ABSTRACT

Recent studies, historical evidence, geological and geophysical observations indicate that parts of the Kingdom of Saudi Arabia 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. 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 such as Attar (2003) and Al-Haddad et al. (1994). Most of existing RC school buildings in Abha city, Saudi Arabia are not designed and built to resist earthquakes. The objective of this paper is to assess the seismic performance of school buildings in Abha city. A typical 5 stories RC school building is investigated. Seismic analysis and design have been carried out by using equivalent static analysis according to Saudi Building Code SBC301 (2007). The chosen building was redesigned by using Saudi Building Code SBC 301 (2007), structural analysis software SAP 2000 (2001), and ISACOL program by Shehata (1999). The results of this paper show that current design of school buildings is unsafe for the current seismicity of Abha city.

Keywords: Evaluation; Saudi Building Code (SBC301-2007); School buildings; Seismic; Abha city

1. INTRODUCTION

The Kingdom of Saudi Arabia lies within low to moderate seismic regions. The seismic load should be considered as an important aspect that needs to be included in the building design. 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. Recently, the development and adoption of a national code and the experienced seismic activity at several regions in the Kingdom necessitate the detailed consideration of seismic loads in the design of all buildings. A major part of the building industry is designed for gravity loads only and poorly detailed to accommodate lateral loads. The existing buildings have to be provided by some rehabilitation to sustain the expected performance level. The capacity of the building should be evaluated before rehabilitation work, Hakim (2013). The evaluation of seismic performance of existing RC buildings has received a great attention in the last decade. An earthquake is the vibration of the earth's surface that follows a sudden release of energy in the crust. During an earthquake, the ground surface moves in all directions. The most damaging effects on buildings are caused by lateral movements which disturb the stability of the structure. Since buildings are normally constructed to resist gravity, many traditional systems of construction are not inherently resistant to horizontal forces. Thus design for earthquakes consists largely of solving the problem of building vibrations. This paper is an attempt to study the effect of seismic loads on RC school buildings in Abha city, Kingdom of Saudi Arabia.

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2. MODELING AND ANALYSIS OF RC SCHOOL BUILDING 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 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 program (2001) due to vertical static loading as per the Saudi Building Code SBC (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 one 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 SBC (2007).

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 shows the model of the five stories RC building.

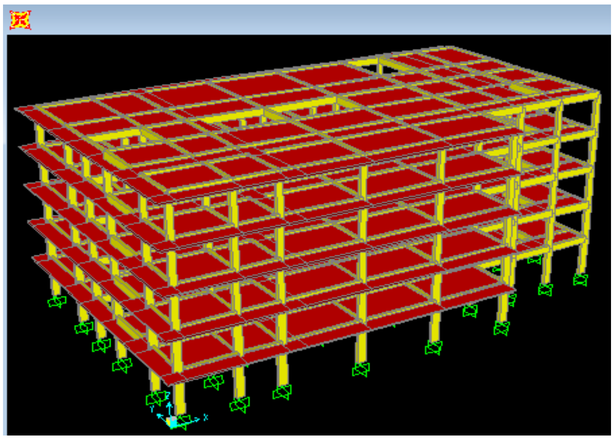

Figure 1. 3D Model of five stories building

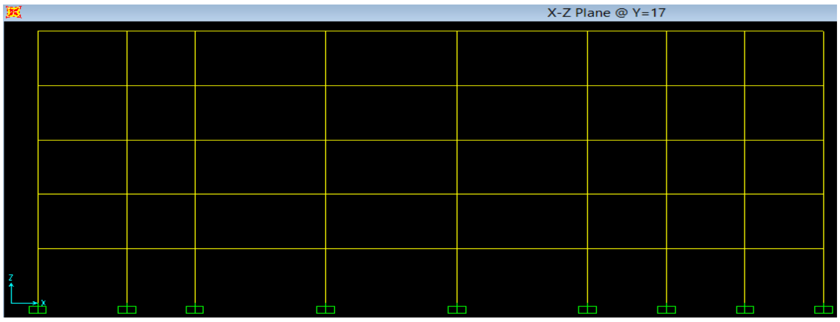

Figure 2. YZ View of studied building

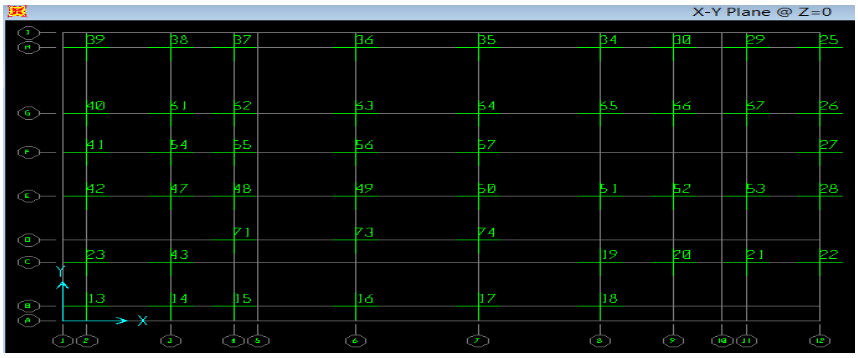

Figure 3. XY Plan of studied building

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

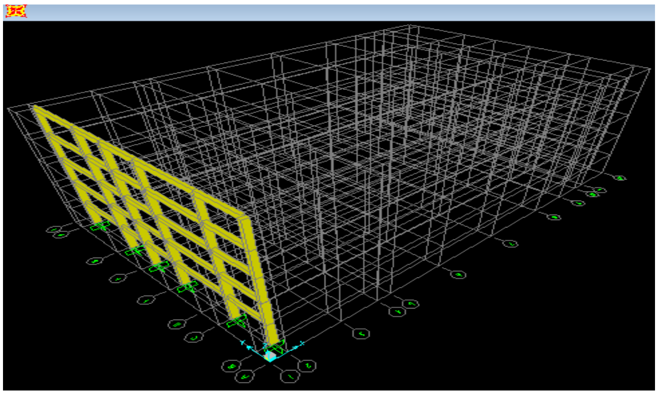

Figure 4. 3D view of the selected frame YZ at X=1.2 m

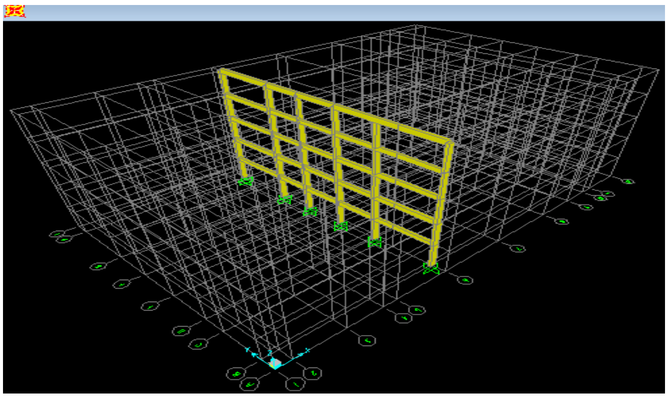

Figure 5. 3D view of the selected frame YZ at X=14.4 m

3. MODELING AND ANALYSIS OF RC SCHOOL BUILDING DUE TO EARTHQUAKE LOADS

Most buildings and structures in the Kingdom of Saudi Arabia have not yet been designed and constructed in compliance with earthquake provisions or given any consideration for earthquake effect.

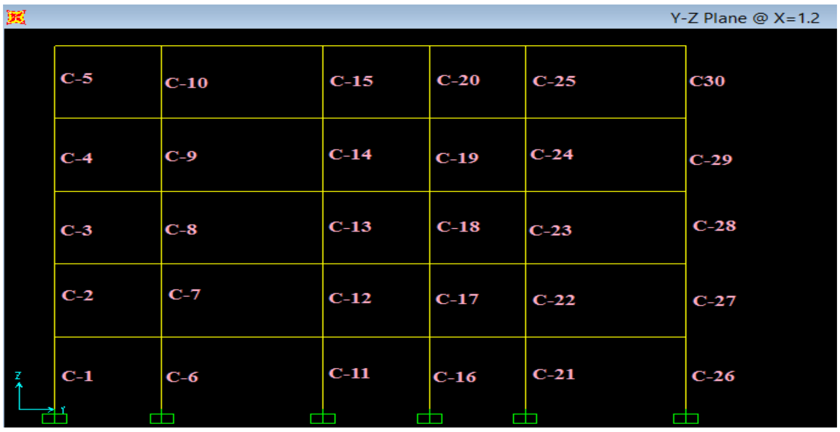

Figure 6. Label of columns for selected frame YZ

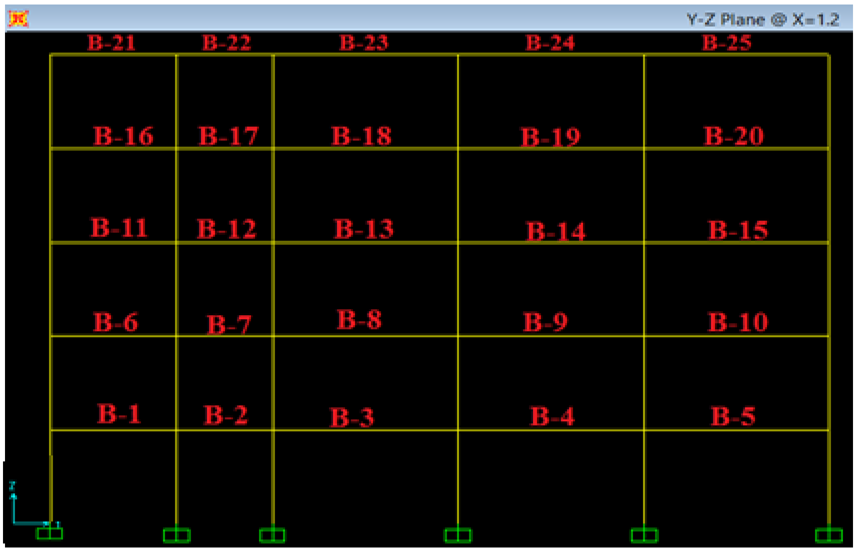

Figure 7. Label of beams for selected frame YZ

The horizontal seismic loads are defined according to Saudi Building Code (SBC-301) (2007). The lateral force effect on the structure can be translated to equivalent lateral force at the base of the structure which can be distributed to different stories. According to Saudi Building Code SBC301 (2007), the total seismic base shear force V is determined as follows:

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

Where: Cs is the seismic coefficient, W is the total weight and V is the base shear. The seismic design coefficient (Cs) shall be determined in accordance with the following equation:

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

Where SDs = Design spectral response acceleration in the short period range
R = Response modification factor

I = Occupancy importance factor
The value of the seismic response coefficient (Cs) need not be greater than the following equation:

$$Cs = SD_1 / [T. (R / I)] \quad (3)$$

$$T = 0.1N \quad (4)$$

Where N = Number of stories
But shall not be taken less than.

$$Cs = 0.044SDs\ I \quad (5)$$

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:

$$SMs= Fa*Ss \quad (6)$$

$$SM_1= Fv*S_1 \quad (7)$$

$$SDs= 2/3*SMs \quad (8)$$

$$SD_1= 2/3*SM_1 \quad (9)$$

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 building is subjected to a lateral load distributed across the height of the building based on the following formula specified by Saudi Building Code SBC301 (2007):

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

Where F_x is the applied lateral force at level 'x', w is the story weight, h is the story height and V is the design base shear, and N is the number of stories. The summation in the denominator is carried through all story levels. This results in an inverted triangular distribution when k is set equal to unity. A uniform lateral load distribution consisting of forces that are proportional to the story masses at each story level.
k = an exponent related to the structure period as follows:
For structures having a period of 0.5 sec or less, k = 1
For structures having a period of 2.5 sec or more, k= 2

3.2 Load Combinations as per SBC301 (2007)

As per SBC-301 section 2.3, the following load combinations should be considered for the design of structures, components, and foundations:

$1.2D + 1.0\,E + f_1 L$

$0.9D \pm 1.0E$

Where:

$E \quad = \quad \rho\, Q_E + 0.2SDs\, D$

Where:

$1.0 \leq \rho \leq 1.5$

$f_1 \quad = \;$ 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.

$f_1 \quad = \;$ 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 Kingdom of Saudi Arabia

The Saudi Building Code SBC 301 (2007) provides seismic maps for the Kingdom of Saudi Arabia, as shown in Figures 8 and 9.

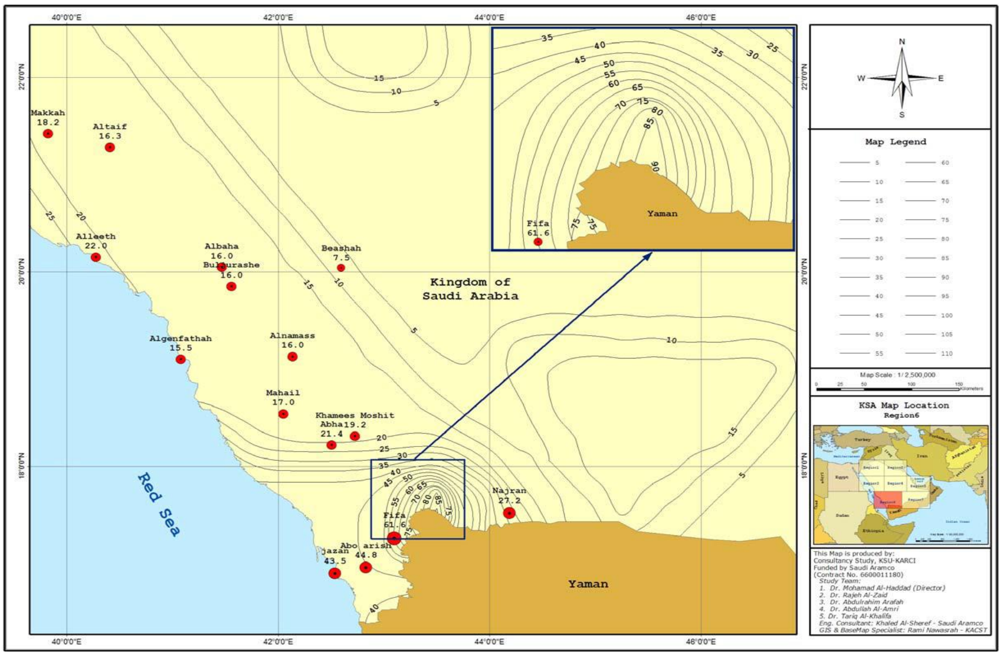

Figure 8. Maximum considered earthquake ground motion for the Kingdom of 0.2 sec. Spectral Response Acceleration (Ss in %g) (5 percent of critical damping), site class B (region 6)

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

Using the Saudi Building Code SBC 301 (2007) provisions, the parameters shown in Table 2 have been calculated to be used as input data for seismic analysis of the selected model noticing that Abha

Table 2. Seismic parameters for Abha city according to SBC301.

S_S	0.214	Fa	1.6
S_1	0.061	Fv	2.4
T	0.5	SMs	0.3424
SDs	0.2294	SM_1	0.1464
SD_1	0.0981	Cs	0.1147
I	1.25	Cs (max.)	0.09809
R	2.5	Cs (min.)	0.0126174
W	49933 KN	V	4897.8281 KN
Take Cs= 0.09809			

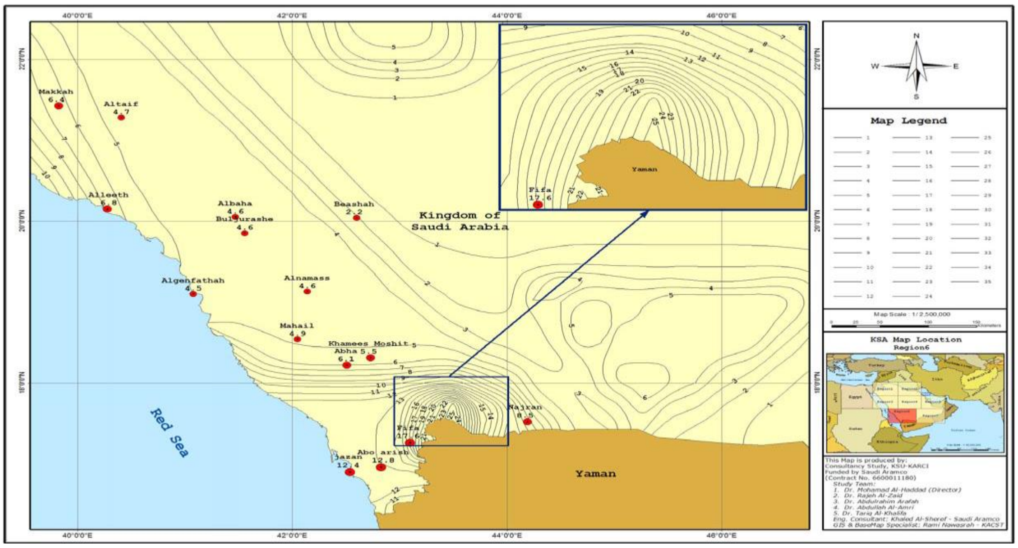

Figure 9. Maximum considered earthquake ground motion for the Kingdom of 1 sec Spectral Response Acceleration (S_1 in %g) (5 percent of critical Damping), site class B (region 6)

the city falls in region 6. Table 3 shows the results of the base shear and the lateral load distribution with height.

Table 3. Calculation of base shear and lateral load distribution with height according to 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	16	9986.57	16	159785.12	479355.4	0.333333306	4897.8	1633
4th floor	12.8	9986.57	12.8	127828.096	479355.4	0.266666644	4897.8	1306
3rd floor	9.6	9986.57	9.6	95871.072	479355.4	0.199999983	4897.8	980
2nd floor	6.4	9986.57	6.4	63914.048	479355.4	0.133333322	4897.8	653
1st floor	3.2	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 Results of Analysis of Structural Elements due to Gravity Loads

The reinforced concrete sections were designed according to the BSI 8110 [7] using the limit state design method by Mosley and Bungey (1997).

4.1.1 Columns

The columns were designed to resist axial compression forces and bending moments due to gravity load. Table 4 shows the straining actions of some selected columns due to gravity load.

4.1.2 Beams

Table 5 shows the straining actions of some selected beams due to gravity loads.

Table 4. Internal forces in some selected columns due to gravity loads at direction Y-Z @ X=1.2m.

Column No.	**Output Case**	**Shear Force (KN)**	**Bending Moment (KN.m)**		**Axial Force**
			Mx	**My**	**(KN)**
C-1	1.4DL+1.6LL	2.6	3.04	-5.28	-915.97
C-7	1.4DL+1.6LL	7.73	12.48	-12.25	-1153.58
C-13	1.4DL+1.6LL	5.81	8.74	-9.84	-687.44
C-19	1.4DL+1.6LL	4.87	7.74	-7.85	-347.41
C-25	1.4DL+1.6LL	6.12	8.75	-10.84	-242.98

Table 5. Internal forces in some selected beams due to gravity loads at direction Y- Z@X=1.2m

Beam No.	**Moment 3-3 (KN.m)** Start	End	**Shear (KN)**
B-1	-45.10	-15.74	-17.23
B-7	-58.72	-65.07	94.93
B-13	-23.02	-31.06	11.3
B-19	15.77	-28.02	21.75
B-25	-28.11	9.69	-20.61

4.2 Results of Design of Structural Elements due to Gravity Loads

4.2.1 Design of columns

The design of columns has been performed using a computer program called ISACOL by Shehata (1999). Figure 10 shows the main window of ISACOL program and sample of a column design. Table 6 shows a comparison of original design and the present design.

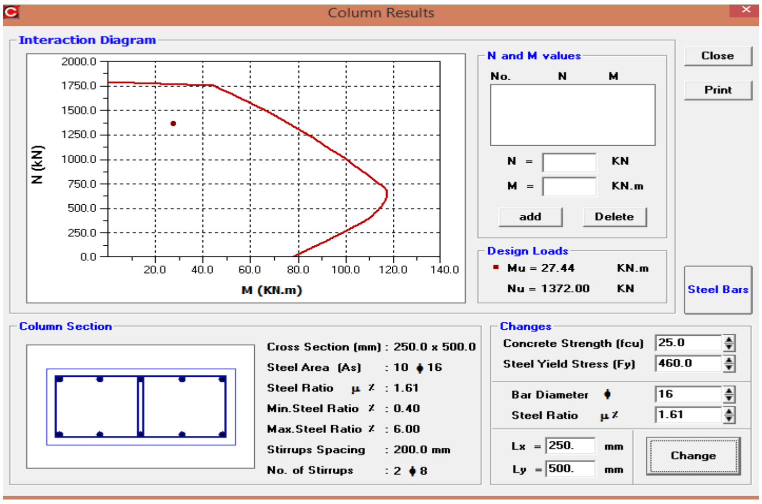

Figure 10. ISACOL program results for column No. C-1

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
C-1	250 X 600	12 Φ 16	250 X 600	10 Φ 16
C-7	250 X 600	12 Φ 16	250 X 500	10 Φ 16
C-13	250 X 500	12 Φ 16	250 X 500	10 Φ 16
C-19	250 X 500	12 Φ 16	250 X 450	10 Φ 16
C-25	250 X 450	10 Φ 16	250 X 400	8 Φ 16

4.2.2 Design of beams

As for the beams, the internal forces due to gravity loads have been calculated first. Then the British Standards 8110 (1997) has been used to check the existing design. It has been found that the existing design is adequate.

5. RESULTS DUE TO GRAVITY AND EARTHQUAKE LOADS

5.1 Results of Analysis of Structural Elements due to Gravity and Earthquake Loads

5.1.1 Columns

The columns were designed to resist axial compression forces and bending moments due to gravity and earthquake loads. Tables7 and 8 show the straining actions of some columns.

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)
C-1	Group-X*	79.67	168.09	86.87	-916.2
C-7	Group-X	70.56	114.76	-111.03	-1153.84
C-13	Group-X	64.17	99.35	-105.99	-687.66
C-19	Group-X	45.63	65.95	-80.08	-347.7
C-25	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=14.4m.

Column No.	Output Case	Shear Force (KN)	Bending Moment (KN.m)		Axial Force (KN)
			Mx	My	
C-1	Group-X	92.35	180.87	-114.66	-2105.39
C-7	Group-X	97.89	157.14	-156.18	-1984.32
C-13	Group-X	80.85	125.38	-133.35	-708.83
C-19	Group-X	64.58	97.59	-109.06	-491.53
C-25	Group-X	43.82	63.45	-76.77	-401.65

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.

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	
B-1	-45.1	-15.73	-17.23
B-7	-58.31	-65.07	94.93
B-13	-22.98	-31.07	11.31
B-19	15.77	-27.92	21.72
B-25	-28.1	9.69	-20.6

5.2 Results of Design of Structural Elements due to Gravity 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. C-7.

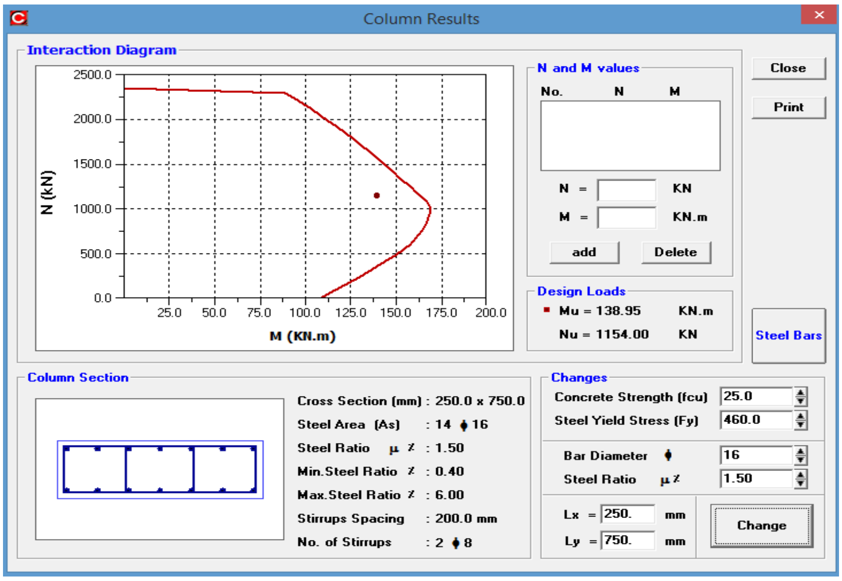

Figure 11. ISACOL program results for column C-7 at direction Y-Z @ X=1.2m

Tables10 and 11 show the design of some columns after adding seismic loads.

6. SUMMARY AND DISCUSSION

This paper provides results of seismic analysis and design of RC School building located in Abha city in Saudi Arabia. The building was analyzed and designed before and after considering earthquake loads applied in two directions; XX and YY. From the results obtained it can be clearly seen that:
1. There 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.
2. 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.
3. 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.
4. As an overall trend, the results showed that the current design of RC school buildings located in Abha city in Kingdom of Saudi Arabia is found unsafe and inadequate to mitigate seismic loads as shown in Tables 10 and 11.

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

Column No.	Original design (Without Seismic Loads)		Including seismic loads	
	Dimensions	**Reinforcement**	**Dimensions**	**Reinforcement**
C-1	250 X 600	12 Φ 16	250 X 700	12 Φ 16
C-7	250 X 600	12 Φ 16	250 X 750	14Φ 16
C-13	250 X 500	12 Φ 16	250 X 700	12 Φ 16
C-19	250 X 500	12 Φ 16	250 X 650	10 Φ 16
C-25	250X450	10 Φ 16	250X500	10 Φ 16

Table 11. Design of some selected columns after adding seismic loads at direction Y-Z @ X=14.4m

Column No.	Original design (Without Seismic Loads)		Including seismic loads	
	Dimensions	**Reinforcement**	**Dimensions**	**Reinforcement**
C-1	250 X 600	12 Φ 16	250 X 950	16 Φ 16
C-7	250 X 600	12 Φ 16	250 X 1000	18Φ 16
C-13	250 X 500	12 Φ 16	250 X 850	16 Φ 16
C-19	250 X 500	12 Φ 16	250 X 750	14 Φ 16
C-25	250X450	10 Φ 16	250X550	10 Φ 16

7. CONCLUSIONS

The present study represents the first attempt to investigate the seismic resistance of school buildings in Abha city in Saudi Arabia. Due to the lack of knowledge about the seismic activity in this country some buildings are designed and constructed without any seismic load consideration. Seismicity of Saudi Arabia 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 some school buildings in the Abha city in Saudi Arabia does not consider earthquake loads.
2-It has been found that the current design of school buildings in the Abha city was unsafe for the current seismicity of the Abha city.

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