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Seismic Analysis and Design of a Multi-Storey Building Located in Haql City, KSA

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ABSTRACT

Recently the design of RC building to mitigate seismic loads has received great attention. Since Saudi Arabia has low to moderate seismicity, most of the buildings were designed only for gravity load. The objective of this paper is to analysis design RC building located in the most active seismic zone region in Saudi Arabia to mitigate seismic loads. A multi-story reinforced concrete building, in Haql city, was seismically analyzed and designed using the Equivalent Lateral Force Procedure with the aid of SAP200 software. The chosen buildings which were Ordinary Moment Resisting Frame (OMR), was analyzed and designed by using SBC 301 (2007) Saudi Building Code [1], SAP2000 (structural analysis software) [2] and ISACOL "Information Systems Application on Reinforced Concrete Columns" [3]. The results showed that the current design of RC buildings located in the most active seismic zone region in Saudi Arabia, Haql city was found unsafe, inadequate and unsatisfied to mitigate seismic loads.

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1. Introduction

Haql is a town in the northwest of Saudi Arabia near the head of the Gulf of Aqaba, adjacent to Aqaba across the Jordanian border. The coasts of Egypt, Israel, and Jordan, can be seen from Haql. Haql city is located in the most active seismic zone region of the Kingdom of Saudi Arabia where there is a complicated geological structure and tectonics. This paper is an attempt to study the effect of seismic loads on RC residential buildings located in the most active seismic zone region of the Kingdom of Saudi Arabia. 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 the existing buildings in Saudi Arabia do not meet the current design standards due to design shortage or construction shortcomings.

The last major event was the 1995 Haql earthquake in the Gulf of Aqaba (magnitude 7.3) which caused significant damage on both sides of the Gulf and was felt hundreds of kilometers away. As far as Saudi Arabia is concerned, the most active area is along the Gulf of Aqaba (Dead Sea transform fault). On 19 May 2009, 19 earthquakes of M4.0 or greater took place in the volcanic area of Harrat Lunayyir to the north of Yanbu, including an M5.4 event that caused minor damage to structures [4]. The 1995 Gulf of Aqaba earthquake (also known as Nuweiba earthquake) occurred on November 22 at 06:15 local time (04:15 UTC) and registered 7.3 on the moment magnitude scale. The epicenter was located in the central segment of the Gulf of Aqaba. The earthquake occurred along the Dead Sea Transform (DST) fault system, an active tectonic plate boundary with seismicity that is characterized by long-running quiescent periods with occasional large and damaging earthquakes, along with intermittent earthquake swarms. It was the strongest tectonic event in the area for many decades and caused injuries, damage, and deaths throughout the Levant and is also thought to have remotely triggered a series of small to moderate earthquakes 500 kilometers (310 miles) to the north of the epicenter. In the aftermath of the quake, several field investigations set out to determine the extent of any surface faulting, and the distribution of aftershocks was analyzed. Areas affected: Egypt, Israel, Jordan and Saudi Arabia as shown in Figure 1[4]. 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 [5]. 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 the 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 the expected seismic effects. The seismic hazard analysis for the Kingdom was performed [6,7]. Seismograph stations of the Saudi National Seismic Network as shown in Figure 2 [8], was developed for the Kingdom based on the peak ground acceleration, PGA, values calculated for 50 years service lifetime with 10% probability of being exceeded.

Fig. 1. 1995 Gulf of Aqaba earthquake [4].

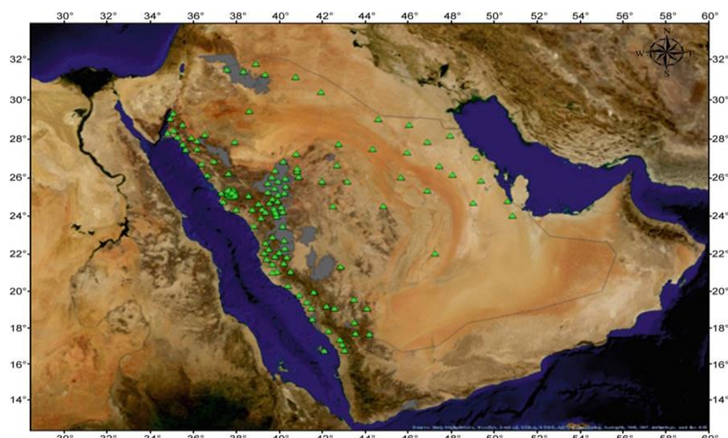


Fig. 2. Seismograph stations of the Saudi National Seismic Network [8].

2. Description and Model of the Building

A six-story residential building with plan and elevations as shown in Figures 3 to 6 is considered for the study. The building is composed of moment resisting RC frame with solid slab, 140mm thickness, situated in the most active seismic zone region of the Kingdom of Saudi Arabia. The structure members are made of in-situ reinforced concrete. The overall plan of the building is square with dimensions 14.5x15m as shown in Figure 3. The height of the building is 16 m, and story height for each floor is 3.2 m. Columns and beams sizes are shown in Table 1. The building is approximately symmetric in both directions. The plan and some frames of the studied building as shown in Figures 3 to 5. Beams and columns have been modeled as frame elements while the in-plane rigidity of the slab is simulated using rigid diaphragm action. The columns are assumed to be fixed at the base. The building is analyzed.

As per seismic provisions provided by SBC 301-2007.

Table 1
The cross-section of beams and columns.

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

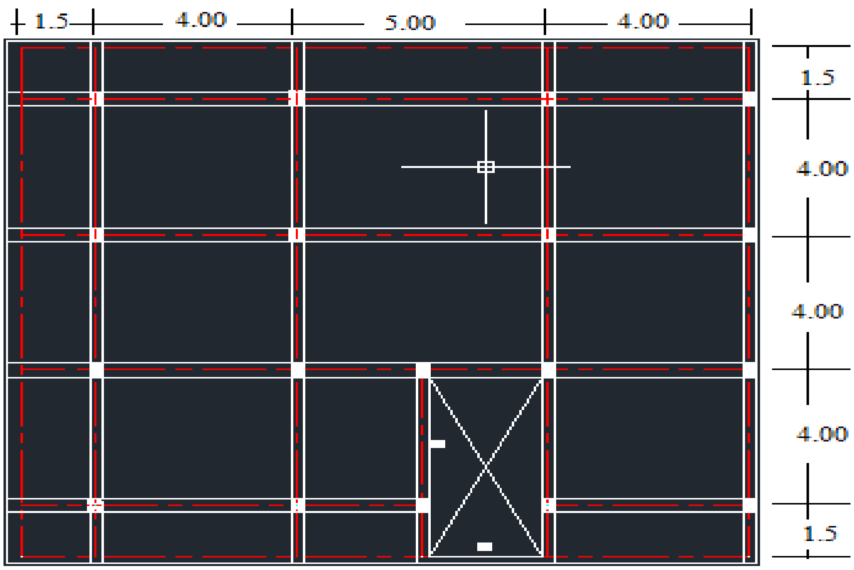


Fig. 3. Architectural plan of the studied building.

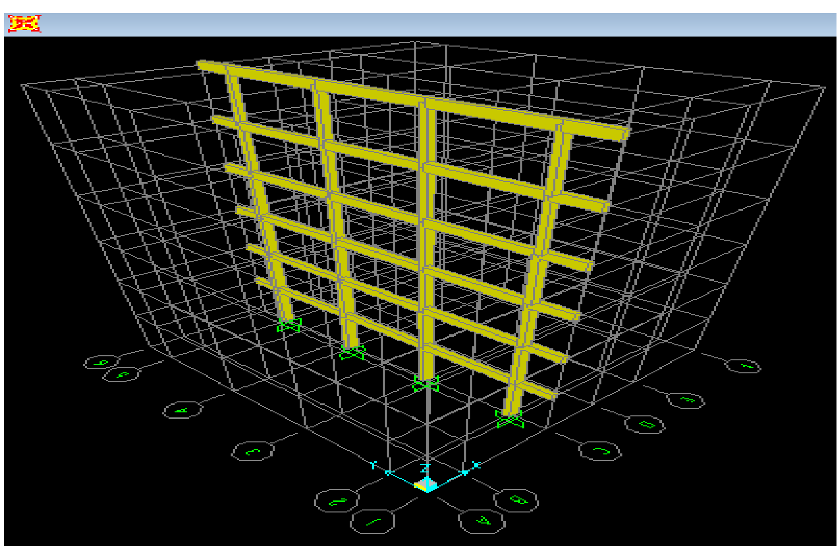


Fig. 4. YZ elevation @ X=5.5 m of the studied building.

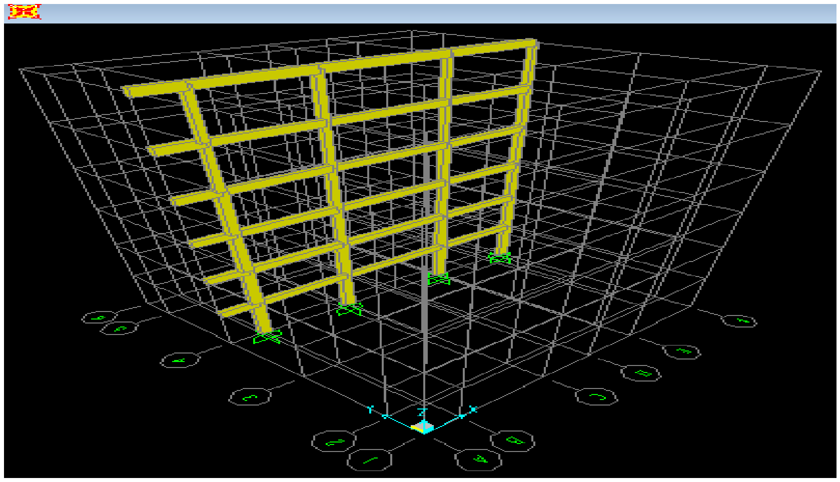


Fig. 5. XZ elevation @ Y=9.5 m of the studied building.

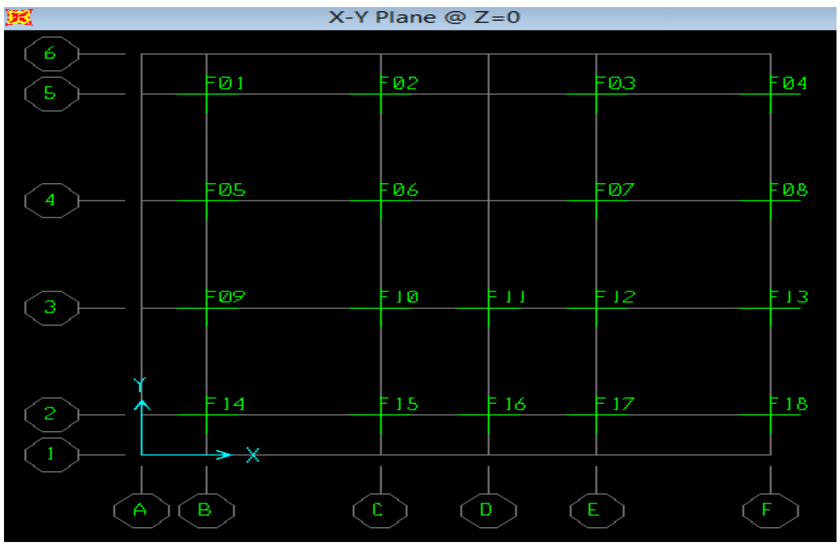


Fig. 6. XY Plan of studied building.

3. 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 case study 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 SBC-301-2007(Saudi Arabia) and second under the effect of seismic loads.

4. Modeling and Analysis of RC Residential Buildings due to Earthquake Loads (Equivalent Static Method as per SBC-303-2007)

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.

The horizontal seismic loads are defined according to Saudi Buildings Code (SBC-303-2007). 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 Buildings Code (SBC-303-2007), 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 by 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 determined

The value of the seismic response coefficient, (Cs), need not be greater than the following equation:

$$Cs = SD1 / [T. (R / I)] \tag{3}$$

However, shall not be taken less than:

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

Where N = Number of stories

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

Where, SDS = 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, SDS, and at the 1-sec period, SD1, shall be as follows.

$$SMS= Fa*SS \tag{6}$$

$$SM1= Fv*S1 \tag{7}$$

$$SDS= 2/3*SMS \tag{8}$$

$$SD1= 2/3*SM1 \tag{9}$$

Where:

SS: the maximum spectral response acceleration at short periods

S1: the maximum spectral response acceleration at a period of 1 sec

Fa: acceleration-based site coefficient

Fv: velocity-based site coefficient

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

SM1: the maximum spectral response acceleration at a period of 1 sec adjusted for site class

SDS: the design spectral response acceleration at short periods

SD1: the design spectral response acceleration at a period of 1 sec

5. Vertical Distribution of Base Force

The buildings are subjected to a lateral load distributed across the height of the buildings based on the following formula specified by Saudi Buildings Code (SBC-303-2007):

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

Where *Fx* 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

6. LOAD COMBINATIONS AS PER SBC-303-2007

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

1.4 (D + F)
1.2 (D + F + T) + 1.6 (L + H) + 0.5 (Lr or R)
1.2 D + 1.6 (Lr) + (f1L)
1.2D + f1L + 0.5 (Lr)
1.2D + 1.0 E + f1L
0.9D ± 1.0E
Where:
E = ρQE + 0.2SDSD
1.0 ≤ ρ ≤ 1.5
f1 = 1.0 for areas occupied as places of public assembly, for live loads more than 5.0 kN/m2, and for parking garage live load.

f1 = 0.5 for other live loads.
SDS = the design spectral response acceleration in the short period range as determined from Section.
QE = the effect of horizontal seismic (earthquake-induced) forces.
Table 6.1 shows the design parameters taken from both codes for analysis of buildings.

7. Seismic Map for the Kingdom of Saudi Arabia

The Saudi Buildings Code (SBC-303-2007) provides seismic maps for the Kingdom of Saudi Buildings, as shown in Figures 7 and 8.

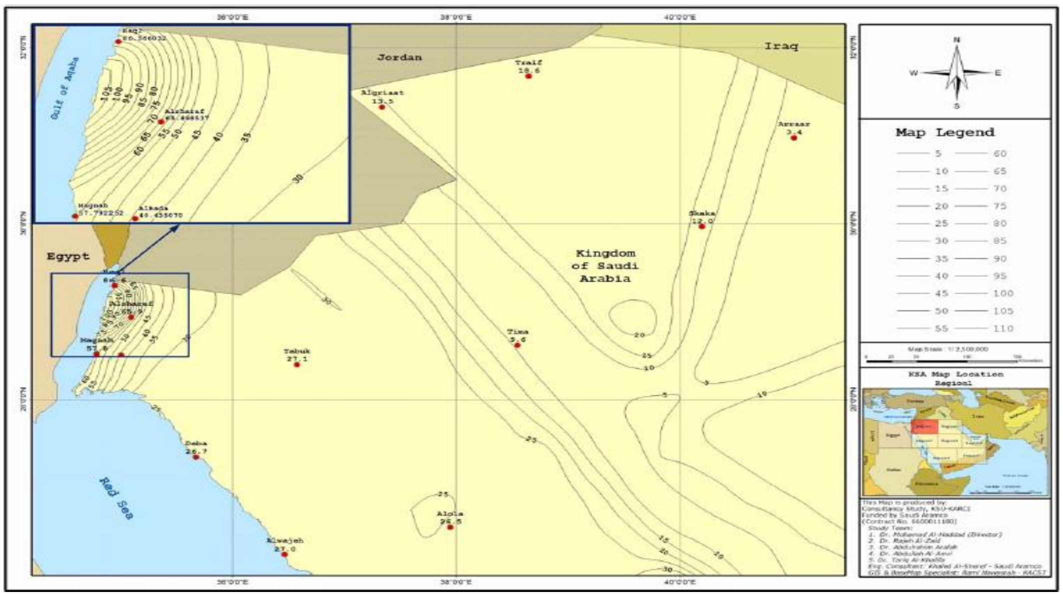


Fig. 7. Maximum Considered Earthquake Ground Motion for the Kingdom of 1 SEC Spectral Response Acceleration (S1 in %g) (5 Percent of Critical Damping), Site Class B. (Region 1) [1].

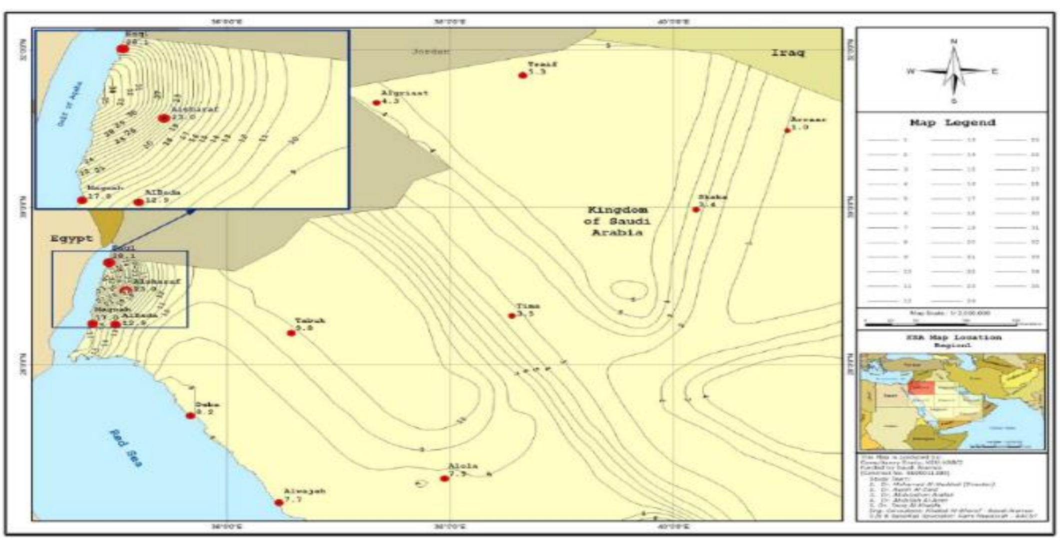


Fig. 8. Maximum Considered Earthquake Ground Motion for the Kingdom of 0.2 SEC Spectral Response Acceleration (Ss in %g) (5 Percent of Critical Damping), Site Class B. (Region 1) [1].

8. Mapped acceleration parameters

The design parameters that are used in the equivalent static method are illustrated as follows: The parameters Ss and S1 shall be determined from the 0.2 and 1-second spectral response accelerations shown on country maps

Where S1 is less than or equal to 0.04 and Ss is less than or equal 0.15, the structure is permitted to be assigned to seismic design category A So,

S1= the mapped spectral accelerations for a 1- second period

Ss= the mapped spectral accelerations for a short period.

- ❖ On lack of a map of spectral accelerations of S1 and SS, the following can be assumed: S1= 1.25 Z, Ss= 2.5 Z (amendment no. 3 to SI 413 (2009)) or from maps as shown in Figures 7 and 8.

9. The Results and Discussions

Figures 9 and 10 show the label of columns and beams of the selected frames.

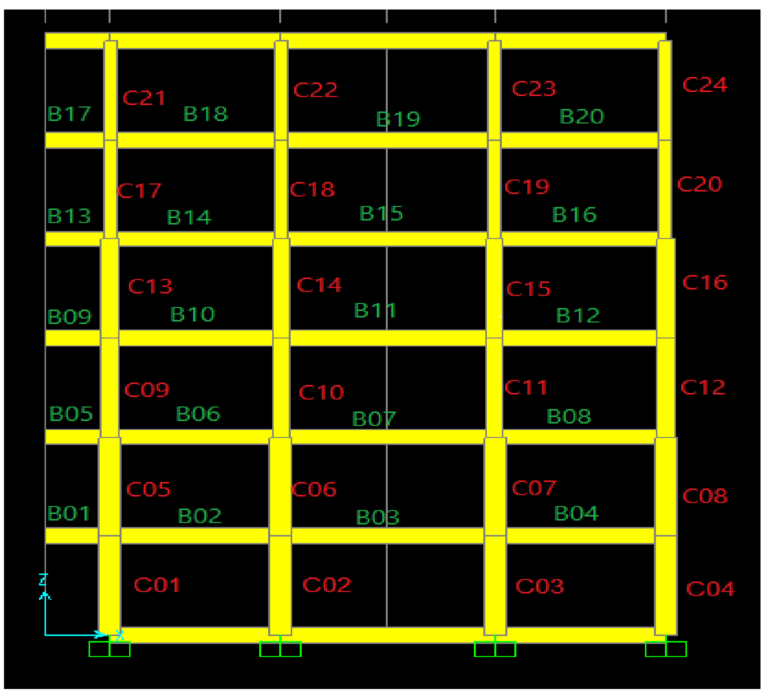


Fig. 9. The label of beams and columns in direction XZ@Y=9.5 m.

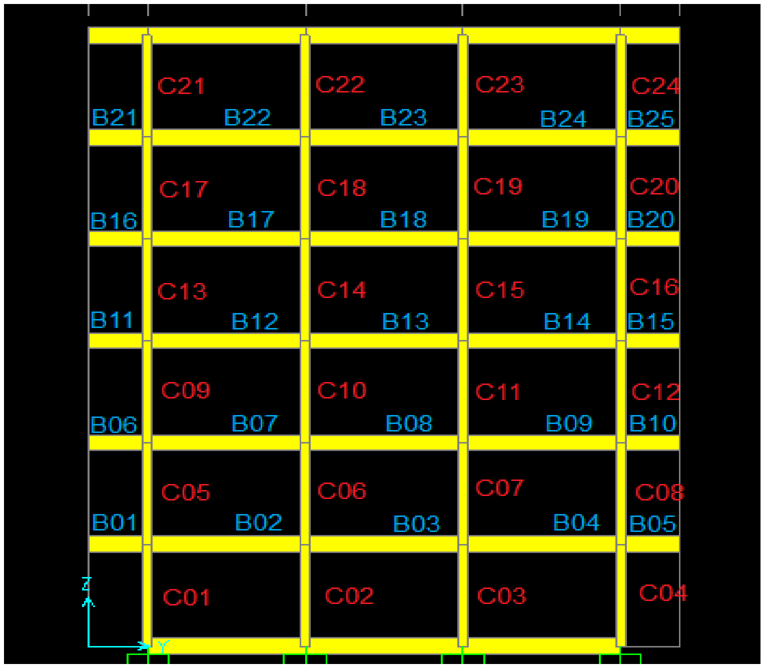


Fig. 10. The label of beams and columns in direction YZ@X= 5.5 m.

9.1. Results of analysis of considered buildings due to gravity loads

This part presents the results of analysis and design of considered RC buildings due to gravity loads. We selected one frame in each direction X and Y as shown in figures 9 and 10 for columns and beams.

1. Beams

Table 2 shows the Straining action of some beams in the selected frames at direction YZ @ X = 5.5

Table 2
The Straining action of some beams in the selected frames at direction YZ @ X = 5.5**.**

Direction Y-Z @ X=5.5			
Load Case Ultimate (1.4DL+1.6LL)			
Beam No.	SHEAR	MOMENT 3-3 (KN.m)	
	KN	END	START
B-03	-9.81	0.24	-6,81
B-09	21.7	-29.54	-1.62
B-11	-11.91	4.5	-10.15
B-17	21.42	-29.11	-1.61
B-19	-13.16	7.37	-12.3

2. Columns

Tables 3 shows the Straining action of some columns in the selected frames at direction YZ @ X = 5.5

Table 3
The Straining action of some columns in the selected frames at direction YZ @ X = 5.5.

Direction Y-Z @ X=5.5				
Load Case Ultimate (1.4DL+1.6LL)				
Column No.	AXIAL	SHEAR	MOMENT 3-3 (KN.m)	
		KN	END	START
C-01	-907.8	-0.61	-0.62	-2.57
C-03	-1307.75	-10.94	21.51	-13.51
C-09	-586.33	0.56	-1.46	-0.33
C-11	-855.93	-15.98	26.44	-24.68
C-17	-285.18	0.63	-1.17	0.84
C-19	-421.77	-11.1	18.29	-17.22

9.2. Results of analysis of considered buildings due to seismic loads

This part presents the results of analysis and design of considered RC buildings due to seismic loads. Using the Saudi Buildings Code (SBC-301-2007) provisions, the following parameters have been calculated to be used as input data for seismic analysis of the selected model with notice that the Haql City falls in region 6. The calculated results of these parameters are as follows:

Table 4
The seismic parameter for Haql City according to SBC301.

SDS	0.14	**CS =**	0.0714
SD1	0.04	**CS (max.) =**	0.0678
I	1.00	**CS(min.) =**	0.0057
R	2.00		
W=	812.0 KN	**V=**	55.1 TON
Take CS= 0.678			

Table 5
Calculation of Base Shear and lateral load distribution with height.

Story	W (ton)	h (m)	w*h	cv	Fx (TON)
Sixth Floor	16.66	21	350	0.015	0.9
Fifth Floor	142.67	18	2568	0.114	6.3
Fourth Floor	268.69	15	4030	0.179	9.8
Third Floor	394.70	12	4736	0.210	11.6
Second Floor	520.72	9	4686	0.208	11.4
First Floor	646.73	6	3880	0.172	9.5
Ground Floor	772.75	3	2318	0.103	5.7
		SUM(W*H)	22570	SUM FX	55.1

1. Beams

Tables 6 shows the Straining action of some beams in the selected frames at direction YZ @ X = 5.5 m due to load case Group-Y

Table 6
The Straining action of some beams in the selected frames at direction YZ @ X = 5.5 m due to load case Group-Y.

Direction Y-Z @ X=5.5 m			
Load case: GroupY			
Beam No.	SHEAR KN	MOMENT 3-3 (KN.m) END	START
B-03	53.39	-93.73	90.13
B-09	22.07	-30.12	-1.65
B-11	49.02	-86.03	82.88
B-17	21.78	-29.68	-1.64
B-19	32.05	-52.51	49.84

Where:

Load Case Group-Y is load combination included seismic loads at Y direction.

Load Case Ultimate is load combination included dead and live loads only

2. Columns

Tables 7 shows the Straining action of some columns in the selected frames at direction YZ @ X = 5.5 m

Table 7
The Straining action of some Columns in the selected frames at direction YZ @ X = 5.5 m due to load case Group-Y.

Direction Y-Z @ X=5.5				
Load Case: GroupY				
Column No.	AXIAL	SHEAR KN	MOMENT 3-3 (KN.m) END	START
C-01	-922.95	1.23	-2.68	-2.62
C-03	-1331.32	-11.18	21.93	-13.8
C-09	-596.12	1.74	-3.28	2.3
C-11	-871.43	-18.32	27.01	-25.21
C-17	-289.96	0.74	-1.33	1.04
C-19	-429.44	-11.33	18.68	-17.59

10. Design of structural elements against gravity loads

The reinforced concrete sections were designed according to the BSI 8110 [9] using the limit state design method (Mosley and Bungey, 1997) [10].

10.1. Design of columns

(a) Calculation of internal forces in columns

The columns were designed to resist axial compression forces and bending moment due to gravity load. The design forces in columns obtained from the computer analysis program SAP2000 are shown in Table 8.

***Direction YZ@X=5.5**

Table 8
Internal forces in columns due to gravity loads.

Column No.	Output Case	Shear Force (KN)	Bending Moment (KN.m)	Axial Force (KN)
C04	1.4DL+1.6LL	11.26	13.99	1372.02
C03	1.4DL+1.6LL	10.94	13.51	1307.75
C02	1.4DL+1.6LL	1.64	3.78	997.52
C01	1.4DL+1.6LL	-0.61	2.57	907.80

(b) Design of columns *before* adding seismic loads

*** Direction YX@X=5.5**

The design of columns has been performed using a computer program called ISACOL [5]. Figures 11 and 13 show the main window of ISACOL program and sample of column design.

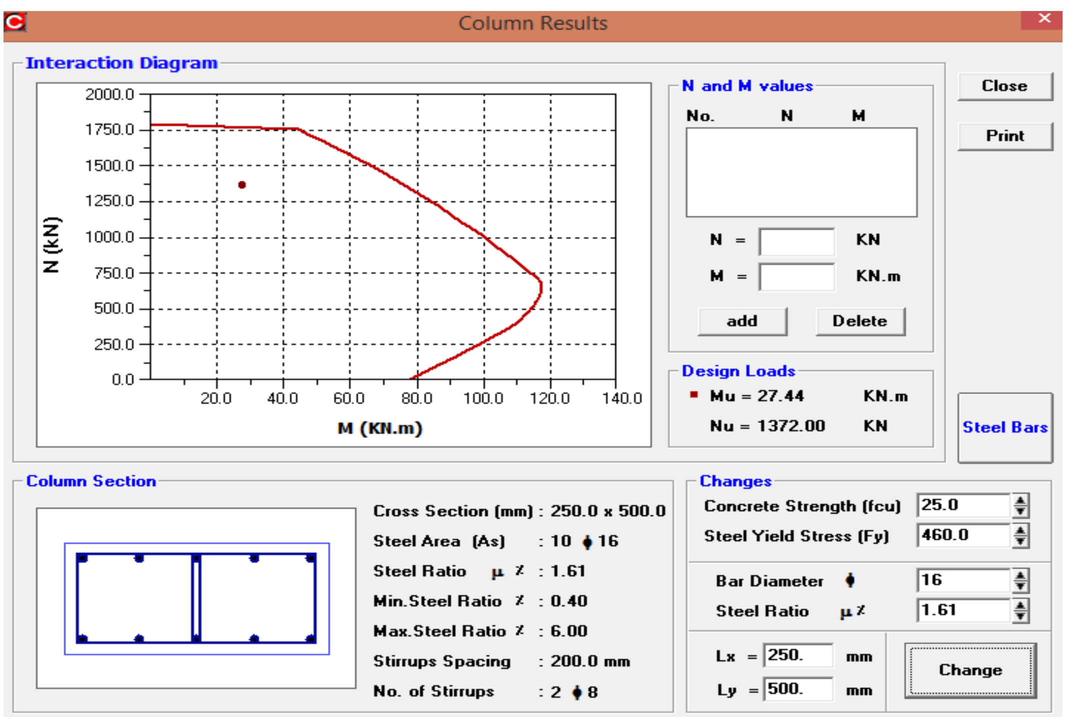
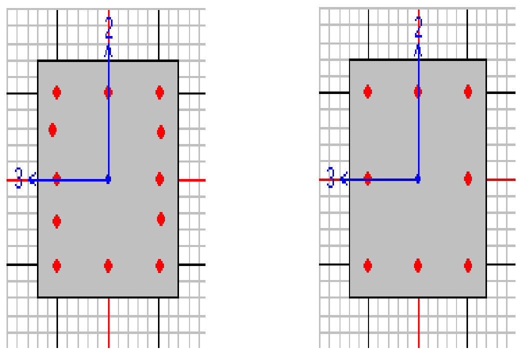


Fig. 11. ISACOL program results for C40 [3].

Table 9
Design of columns before adding seismic Loads.

Column No.	Original design		Present design	
	Dimensions	Reinforcement	Dimensions	Reinforcement
C04	250 X 500	12 Φ 16	250 X 500	10 Φ 16
C03	250 X 500	12 Φ 16	250 X 500	10 Φ 16
C02	250 X 500	12 Φ 16	250 X 500	10 Φ 16
C01	250 X 500	12 Φ 16	250 X 500	10 Φ 16



250*500 12 Φ 16 250*500 10 Φ 16

Fig. 12. Design of some columns before adding seismic Loads.

10.2. Design of beams

As for the beams, the internal forces due to gravity loads have been calculated first. Then the BSI [9], has been used to check the existing design. It has been found that the existing design is adequate.

11. Design of structural elements against gravity loads and earthquake loads

The reinforced concrete sections were designed according to the BSI 8110 [9] using the limit state design method (Mosley and Bungey, 1997) [10].

11.1. Design of columns

(a) Calculation of internal forces in columns

The columns were designed to resist seismic and gravity load. The design forces in columns obtained from the computer analysis program SAP2000 are shown in Table 10.

*** Direction YZ@X=5.5 m**

Table 10
Internal forces in columns due to seismic loads.

Column No.	Output Case	Shear Force (KN)	Bending Moment (KN.m)	Axial Force (KN)
C04	GROUPX	159.27	298.95	1397.14
C03	GROUPX	137.69	256.36	1331.32
C02	GROUPX	125.60	223.55	1041.80
C01	GROUPX	96.96	173.70	922.95

(b) Design of columns *after* adding seismic loads

The design of columns has been performed using a computer program called ISACOL [3]. Figures 12 and 14 show the design of some columns before and after adding seismic loads.

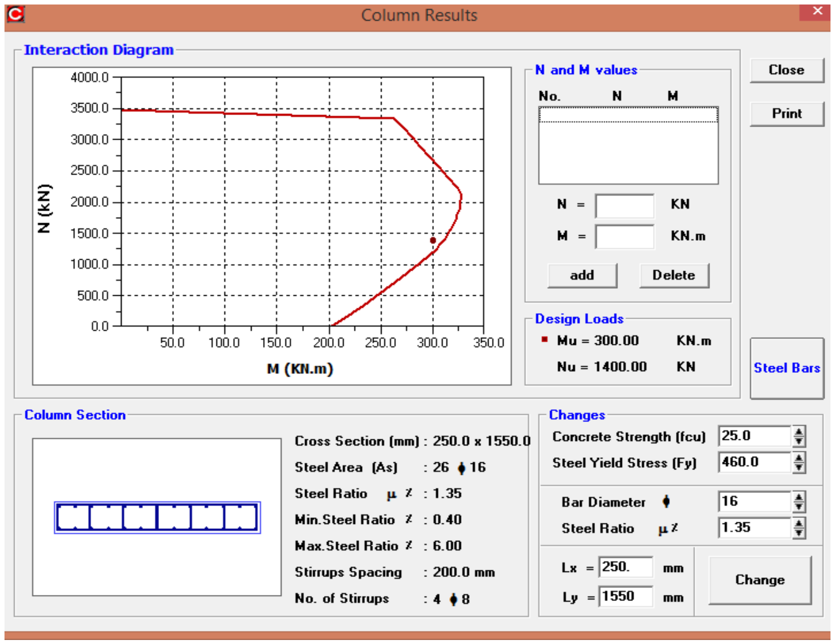
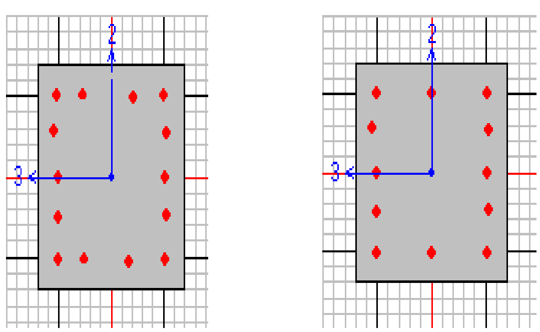


Fig. 13. ISACOL program results for C04 [3].

Table 11. Shows the design of columns after adding seismic loads.

Table 11
Design of columns after adding seismic loads-direction (y).

Column No.	Original design		Including seismic loads	
	Dimensions	Reinforcement	Dimensions	Reinforcement
C04	250 X 500	10 Φ 16	250*1550	18 Φ 20
C03	250 X 500	10 Φ 16	250*1250	14 Φ 20
C02	250 X 500	10 Φ 16	250*1200	14 Φ 20
C01	250 X 500	10 Φ 16	250*850	12 Φ 20



250*1200 14 Φ 20

250*850 12 Φ 20

Fig.14. Design of some columns after adding seismic loads

12. Conclusion

This paper provides a set of seismic analysis and design of RC buildings located in the most active seismic zone region 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 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 as shown in Tables 2 and 6. There is an increase in some internal beams, such as B-3, B-11, and B-19.

2. The values of the bending moments and shear forces on the columns due to seismic loads are nearly five times that due to gravity loads as shown in Tables 8 and 10.

3. The values of the axial forces on the columns due to seismic loads are approximately similar to gravity loads as shown in Tables 8 and 10.

4. As an overall trend the results showed that the current design of RC buildings located in the most active seismic zone region of the Kingdom of Saudi Arabia, Haql city were found unsafe, inadequate and unsatisfied to mitigate seismic loads.

The present study represents the first attempt to investigate the seismic resistance of residual buildings in Haql 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 residual buildings in Saudi Arabia does not consider earthquake loads.
2- It has been found that the current design of residual buildings in the Haql city is unsafe for the current seismicity of the Haql city.

Acknowledgments

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