Journal of Engineering Research and Reports

5(4): 1-14, 2019; Article no.JERR.49680

Strengthening Methods of the Existing Reinforced Concrete School Buildings in Medina, Saudi Arabia

Mohamed Laissy[1*] and Mohammed Ismaeila[2]

[1]Civil Engineering Department, Collage of Engineering, Prince Mugrin University, Medina, Postal code 20012, KSA.
[2]Prince Mugrin University, Almadinah, KSA.

Authors' contributions

This work was carried out in collaboration between both authors. They designed the work, wrote the protocol and created the model of the building. Author ML supervised the work, managed the literature searches, performed statistical analyses procedures, interpreted the results and revised of the final paper thoroughly. Author MI calculated the data of the building with and without shear walls and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2019/v5i416933
Editor(s):
(1) Dr. Ahmed Bdour, Professor, Water Resources and Environmental Engineering, Department of Civil Engineering, The Hashemite University, Jordan.
Reviewers:
(1) J. Dario Aristizabal-Ochoa, Civil Engineering, National University of Colombia, Colombia.
(2) Xinlei Yang, Tianjin Chengjian University, China.
Complete Peer review History: http://www.sdiarticle3.com/review-history/49680

Original Research Article

Received 30 March 2019
Accepted 13 June 2019
Published 18 June 2019

ABSTRACT

Nowadays, evaluation of the seismic performance of existing buildings has received great attention. This paper was carried out to study the effect of strengthening the existing reinforced concrete (RC) school buildings in Medina, Saudi Arabia through assessing the seismic performance and retrofitting where seismic analysis and design were done using equivalent static analysis method according to Saudi Building Code (SBC 301) and SAP2000 software.
A Typical five-story RC school building designed according to the SBC301 has been investigated in a comparative study to determine the suitable strengthening methods such as RC shear walls and steel X-bracing methods. The results revealed that the current design of RC school buildings located in Medina was unsafe, inadequate, and unsatisfied to mitigate seismic loads. Moreover, adding steel X-bracing and RC shear walls represent a suitable strategy to reduce their seismic vulnerability.

Keywords: Steel X-bracing; Saudi Building Code (SBC301-2007); school building; RC shear walls; Medina.

**Corresponding author: Email: laissy99@yahoo.com, m.laissy@upm.edu.sa;*

1. INTRODUCTION

Buildings are normally constructed to resist gravity; many traditional systems of construction are not inherently resistant to horizontal forces although most damaging effects on buildings caused by lateral movements disturbing the stability of the structure, leading to topple or to collapse sideways, thus design for earthquakes consists largely of solving the problem of building vibrations [1] .

Kingdom of Saudi Arabia has experienced many earthquakes during the recent history confirming many previous studies demonstrating that the kingdom is not free from earthquakes [2], so fortifying essential buildings became an urgent requirement considering the choice of the fortifying plan, which is affected by the significance of the building, the fortifying cost as well as accessible innovation [3].

Schools play vital roles in community; they represent places for students to learn social gatherings, theatre and, sports, also school buildings play an important role in responding to and recovering from natural disasters like earthquake, hurricane or flood, schools can serve as emergency shelters and, as such, can be used to house, feed and care for the local population [1-3].

This paper trying to examine the seismic retrofitting of a typical school building in Medina aiming to improve the building's performance in future earthquakes through adding RC shear walls which is one of the most common structure-level retrofitting methods used to strengthen existing structures.

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

2.1 Description of the Chosen Building

The studied building is a typical five stories RC school building of both vertical and horizontal regular geometry. The structure members are made of in-situ reinforced concrete. The overall plan dimension is 36.5m X 30.5m. The height of the building is 17.6 m. The cross-section of beams and columns showed in Table 1. The structure system is a moment resisting RC frame with solid slab system, 125 mm thickness, situated in the seismic zone in Medina. The analysis of the building carried out using SAP2000 FEA program [4] due to vertical static loading and earthquake loading per the Saudi Building Code (SBC) [5]. The building modeled as 3D frames with fixed supports at the foundation level. Table 1 shows the sections of columns and beams of the studied building.

2.2 Current Design

It is a common practice in Saudi Arabia to design buildings without consideration of seismic loads; therefore, the considered building was studied first under the effect of gravity loads and without consideration of seismic loads to check the current design where dead and live loads are following the equations and tables given in the (SBC).

2.3 Numerical Model

Numerical models for the studied building were prepared using SAP2000 version 14 (2001) where beams and columns were modeled as beam elements while walls were modeled with shell elements. Figs. 1 to 3 shows the model of the five stories RC building.

This part presents the results of the analysis of considered RC buildings due to gravity loads where two frames selected in each direction X and Y as shown in Figs. 4 to 7 for columns and beams and Figs. 8 to 11 shows the label of columns and beams of the selected frames.

2.4 Straining Action of Some Columns and Beams Due to Gravity Loads

The moments, shear and axial forces in the columns and beams for the selected frames obtained from gravity loads are shown in Tables 2 and 3.

Table 1. Sections of columns and beams of the studied building

Building	Beams mm	Level	Columns mm
5 Stories	600*300	First and 2nd floor	600*300
		3rd floor and 4th floor	500*300
		5th floor	400*300

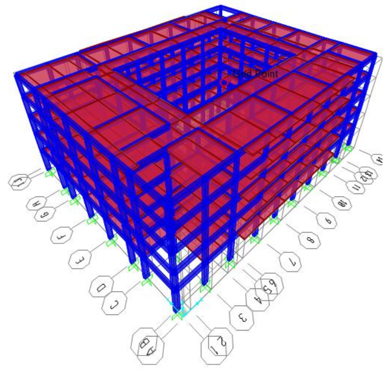

Fig. 1. 3D Model of five stories building

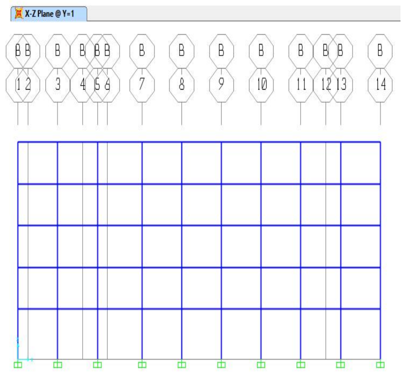

Fig. 2. YZ View of studied building

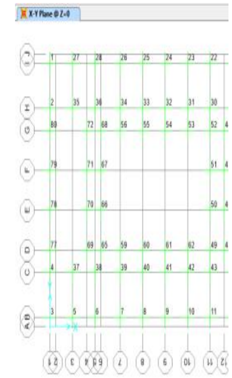

Fig. 3. XY Plan of studied building

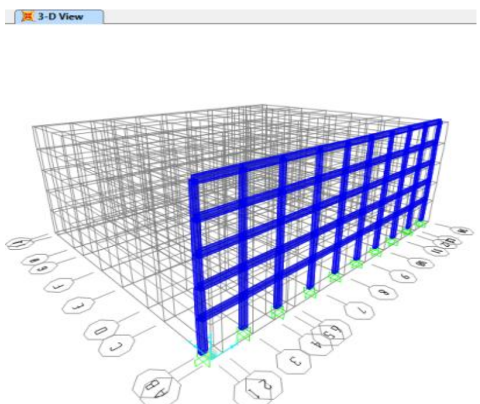

Fig. 4. 3D view of the selected frame XZ at Y=1

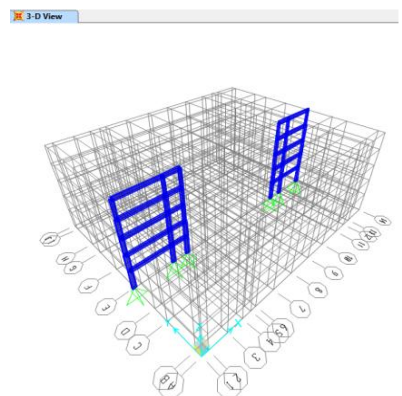

Fig. 5. 3D view of the selected frame XZ at Y=13

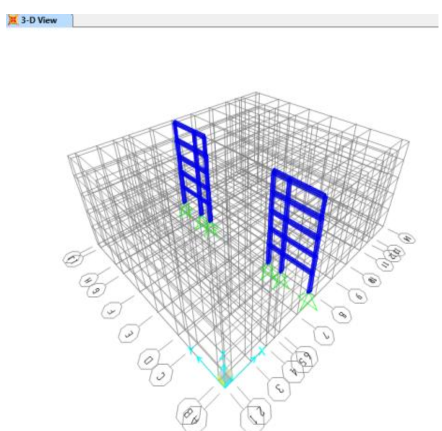

Fig. 6. 3D view of the selected frame YZ at X=16.5

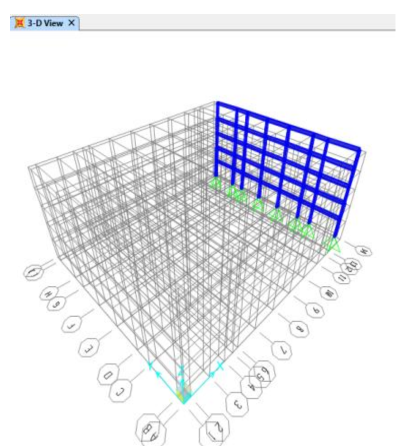

Fig. 7. 3D view of the selected frame YZ at X=36.5

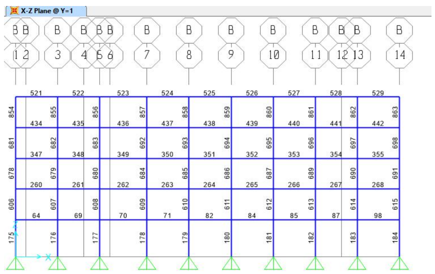

Fig. 8. Label of columns and beams for selected frame XZ

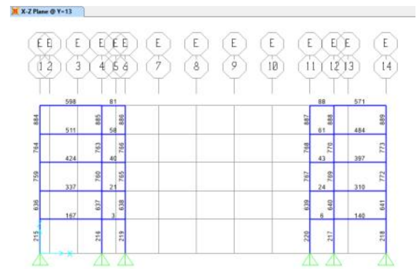

Fig. 9. Label of columns and beams for selected frame XZ

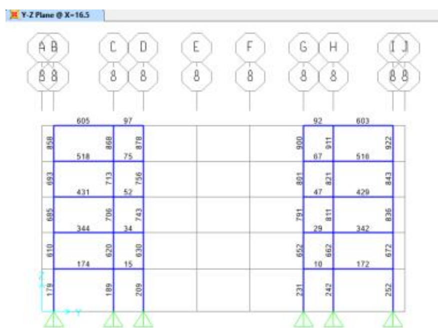

Fig. 10. Label of columns and beams for selected frame YZ

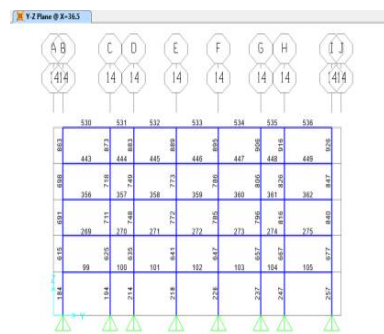

Fig. 11. Label of columns and beams for selected frame YZ

2.4.1 Columns

Table 2. The Straining action of some Columns in the selected frames

Column no.	Moment 3-3		Shear	Axial
	Start	End		
214	0	-25.03	6.95	1141.96
748	32.51	-36.71	23.07	667.11
883	34.39	-44.76	26.38	195.1
237	0	-25.21	7	1104.88
216	0	-55.54	15.43	2004.86
217	0	38.66	10.74	1844.97

2.4.2 Beams

Table 3. The Straining action of some Columns in the selected frames

Beam No.	Moment 3-3		shear
	Start	End	
527	6.35	34.07	33.91
523	47.02	35.92	80.57
167	-149.35	-138.39	133.14
140	-99.45	73.94	119.84
174	-32.62	-40.44	50.29
605	-11.37	-34.26	38.30
172	-40.52	-32.56	50.32

2.5 Results of Design of Structural Elements due to Gravity and Earthquake Loads

The design of columns performed using the computer program ISACOL. Fig. 12 shows the ISACOL program results for column No. 214.

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

Most buildings and structures in the Kingdom of Saudi Arabia were neither designed nor constructed in compliance with earthquake provisions or given any consideration for earthquake effect.

The horizontal seismic loads are defined according to Saudi Building Code (SBC-301) (2007) as 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.

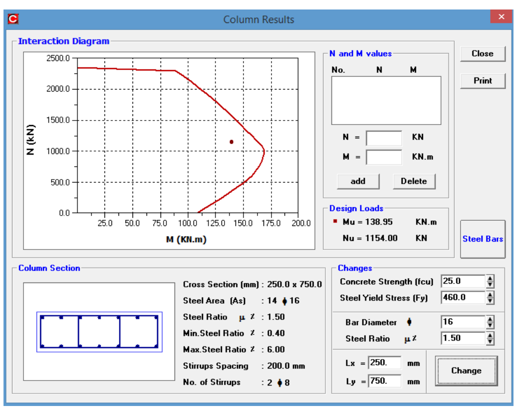

Fig.12. The ISACOL program results for column No. 214

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:

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

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

where

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

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

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:

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

$$SM_1 = Fv*S_1 \tag{7}$$

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

$$SD_1 = 2/3*SM_1 \tag{9}$$

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 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):

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

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 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 [6-10].

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_1L
0.9D ± 1.0E

Where E = ρ Q_E + 0.2SDs D, where 1.0 ≤ ρ ≤ 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.
Q_E = the effect of horizontal seismic forces.

3.3 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 4 were calculated to be used as input data for seismic analysis of the selected model noting that Medina falls in region 3.

3.4 Results of Analysis of Structural Elements due to Gravity and Earthquake Loads Straining action of some Columns and Beams due to Gravity and Earthquake Loads

The moments in the columns and beams for the selected frames obtained from gravity and earthquake loads are shown in Tables 6 to 9.

Table 4. Seismic parameters for Abha city according to SBC301

SS	S1	Fa	Fv
0.251	0.073	1.6	2.4
SMs	SM1	SDs	SD1
0.406	0.175	0.271	0.116
T	R	Cs req	Cs max
1	2.5	0.1084	0.0464
Cs min	W	V	
0.012	55.260	6410	
Take Cs= 0.0464			

Table 5 Shows the results of the base shear and the lateral load distribution with height "Calculation of base shear and lateral load distribution with height according to SBC301"

Level	hx	Wx	hx^k	Wx*hx^k	Sum (Wx*hx^k)	(Wx*hx^k)/ Sum(Wx*hx^k)	V	Final F_x
	m	kn	m	kn.m	kn.m		kn	KN
5^{th} floor	15.6	10627	15.6	165781.2	517746	0.320197935	6410.2	2052.5
4^{th} floor	12.6	10627	12.6	133900.2	517746	0.258621409	6410.2	1657.8
3^{rd} floor	9.6	10627	9.6	102019.2	517746	0.197044883	6410.2	1263.1
2^{nd} floor	6.6	10627	6.6	70138.2	517746	0.135468357	6410.2	868.4
1^{st} floor	3.6	12752	3.6	45907.2	517746	0.088667416	6410.2	568.4
		55,260	K=1	517746				6410.2

3.4.1 The Straining action of some Columns & beams in the selected frames (Group X)

3.4.1.1 Columns

Table 6. The Straining action of some columns in the selected frames (Group X)

Column no.	Moment 3-3		Shear	Axial
	Start	End		
214	0	-182.8	50.8	1151.3
748	59.5	-76.5	45.3	679.3
883	35.9	-47.1	27.7	204.1
237	0	-207.8	57.7	1136.1
216	0	-285.92	79.42	2024.63
217	0	-242.97	67.49	1861.33

3.4.1.2 Beams

Table 7. The Straining action of some beams in the selected frames (Group X)

Beam no.	Moment 3-3		Shear
	Start	End	
527	-11.03	-34.84	37.01
523	-50.47	-36.86	-85.45
167	-209.16	-138.73	137.13
140	-99.55	-174.17	119.87
174	-41.46	41.76	56.91
605	-21.07	-34.65	41.25
172	-41.82	-41.42	56.93

3.4.2 The Straining action of some Columns & beams in the selected frames (Group Y)

3.4.2.1 Columns

Table 8. The straining action of some columns in the selected frames (Group Y)

Column no.	Moment 3-3		Shear	Axial
	Start	End		
214	0	-38.2	10.6	1238.5
748	32.1	-36.7	22.9	676.3
883	35.9	-47.1	27.7	204.2
237	0	-24.4	6.8	1113.4
216	0	-55.19	15.33	2024.63
217	0	37.69	10.47	1861.33

3.4.2.2 Beams

Table 9. The Straining action of some beams in the selected frames (Group Y)

Beam No.	Moment 3-3		Shear
	Start	End	
527	-11.03	-34.84	37.01
167	-149.21	-138.73	133.21
140	-99.55	-73.96	119.87
174	-156.69	180.35	108.40
605	-22.26	-34.65	41.2
172	-219.06	122.92	110.38

3.5 Results of Design of Structural Elements due to Gravity and Earthquake Loads

The design of columns was performed using the computer program ISACOL. Fig. 13 shows the ISACOL program results for column No. 214.

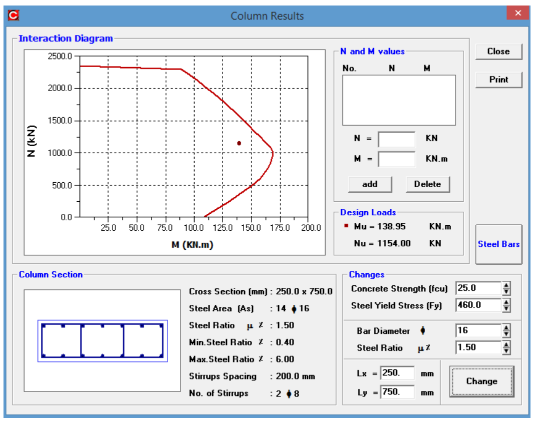

Fig.13. ISACOL program results for column No. 214

4. 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.

4.1 Modeling of Concrete Shear Walls

The concrete shear walls can be modeled using full shell elements and isotropic material. The lateral force resisting system consists of moment resisting frames with concrete shear walls. The studied building is analysed for gravity and seismic loads as previously explained, i.e., using SAP2000 structural analysis software package. Reinforced concrete walls with thicknesses of 200 mm were chosen for this case study. We selected two frames in each direction X and Y as shown in Figs. 14 to 17.

4.2 Results of Analysis of Considered Building Due to Gravity Earthquake Loads after Strengthening by Adding RC Shear Walls

This part presents the results of Analysis and Design of considered RC buildings due to gravity earthquake loads after strengthening by Adding RC Shear Walls.

4.2.1 Straining action of some columns and beams due to gravity and earthquake loads after strengthening by adding RC shear walls

The moments in the columns and beams for the selected frames obtained from gravity and earthquake loads after strengthening by Adding RC Shear Walls are shown in Tables 10 to 13.

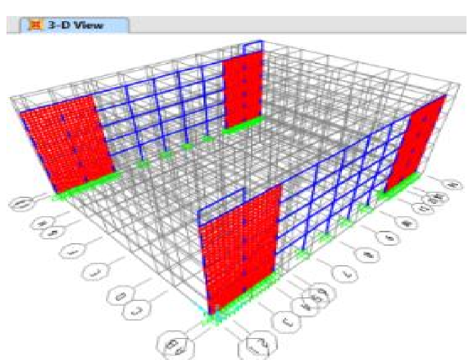

Fig. 14. Modelling of shear wall in direction XZ at Y=1, 29.5

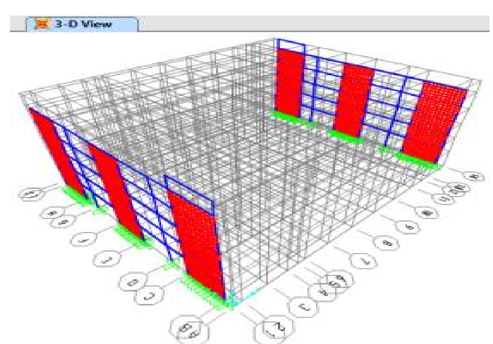

Fig. 15. Modelling of shear wall in direction YZ at X= 0, 36.5

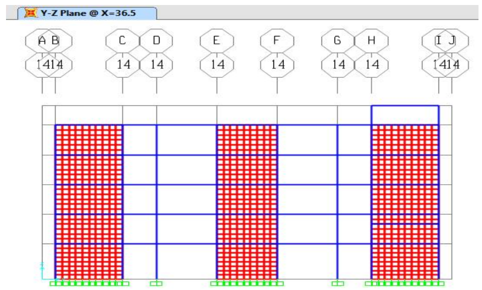

Fig. 16. Modelling of shear wall in direction YZ

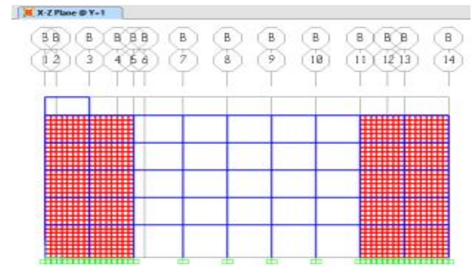

Fig. 17. Modelling of shear wall in direction XZ

4.2.1.1 Columns

Table 10. The Straining action of some columns in the selected frames (Group X)

Column No.	Moment 3-3		Shear	Axial
	Start	End		
214	31.6	-46.2	21	1049.9
748	51.7	-58.3	36.7	586.5
883	55.16	-74.4	43.2	171.1
237	32.1	-46.13	21.2	1053.3
216	41.88	-66.81	29.74	2053.75
217	-19.99	42.01	17.22	1817.06

4.2.1.2 Beams

Table 11. The straining action of some beams in the selected frames (Group X)

Beam No.	Moment 3-3		Shear
	Start	End	
101	-40.73	-66.07	78.35
103	-66.14	-40.64	-78.39
358	-30.12	-74.05	82.92
360	-74.41	-29.56	-83.16
532	-14.15	-69.46	75.46
534	-69.59	-14.33	-75.62
167	-169.95	-176.88	156.67
140	-109.96	-121.49	122.87
174	-90.01	-71.99	110.58
605	-75.51	-46.83	103.52
172	-71.82	-90.15	110.66

4.2.2 The Straining action of some Columns & beams in the selected frames (Group Y)

4.2.2.1 Columns

Table 12. The Straining action of some columns in the selected frames (Group Y)

Column No.	Moment 3-3		Shear	Axial
	Start	End		
214	22.34	-46.24	19.1	1073.1
748	51.7	-58.3	36.7	604.6
883	55.2	-74.4	43.2	171.1
237	22.2	-46.13	18.9	1053.3
216	32.17	-66.81	27.5	2053.75
217	-19.99	42.01	17.22	1817.06

4.2.2.2 Beams

Table 13. The Straining action of some beams in the selected frames (Group Y)

Beam No.	Moment 3-3		Shear
	Start	End	
527	-30.89	-87.78	107.5
523	-80.21	-60.37	91.87
167	-169.95	-176.88	156.67
140	-109.96	-121.49	122.87
174	-90.01	-71.99	110.58
603	-75.51	-46.83	103.52
172	-71.82	-90.15	110.66

4.3 Results of Design of Structural Elements due to Gravity and Earthquake Loads after Strengthening by Adding RC Shear Walls

The design of columns was performed using the computer program ISACOL. Fig. 18 shows the ISACOL program results for column No. 214. after strengthening by Adding RC Shear Walls.

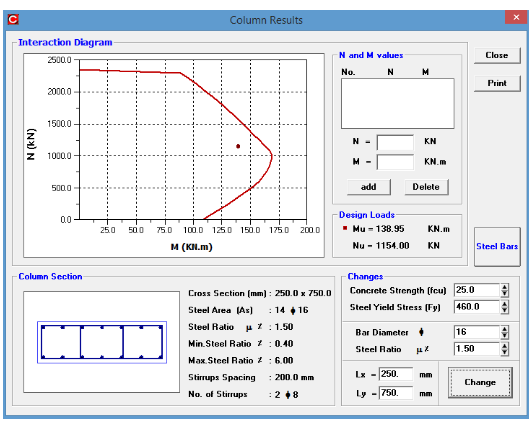

Fig.18. The ISACOL program results for column No. 214.

5. 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.

5.1 Strengthening Method

The lateral force resisting system consists of moment resisting frames with steel bracing. The studied building analyzed for gravity and seismic loads as previously explained, i.e., using SAP2000 structural analysis software package. Steel bracing was chosen for this case study. Two frames in each direction X and Y as shown in Figs. 19 and 20.

5.2 Results of Analysis of Considered Building Due to Gravity Earthquake Loads after Strengthening by Adding Steel Bracing

This part presents the results of Analysis and Design of considered RC buildings due to gravity earthquake loads after strengthening by Adding RC Shear Walls.

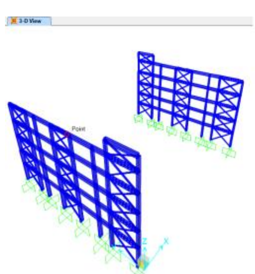

Fig. 19. Modelling of steel bracing in direction XZ at Y=1, 29.5

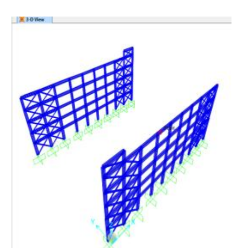

Fig. 20. Modelling of steel bracing in direction YZ at X= 0, 36.5

5.2.1 Straining action of some columns and beams due to gravity and earthquake loads after strengthening by Adding Steel Bracing

The moments in the columns and beams for the selected frames obtained from gravity and earthquake loads after strengthening by Adding Steel Bracing shown in Tables 14 to 17.

5.2.1.1 Columns

Table 14. The Straining action of some columns in the selected frames (Group X)

Column No.	Moment 3-3		Shear	Axial
	Start	End		
214	96.9	-73	47.2	-1125.5
748	66.4	-74.6	46.9	-654.5
883	57.4	-77.7	45	-188.7
237	101.8	-75.2	49.2	-1152.9
216	-119.9	-118.2	66.2	-2103.3
217	91.7	-60.3	42.2	-1873.5

5.2.1.2 Beams

Table 15. The Straining action of some beams in the selected frames (Group X)

Beam No.	Moment 3-3		Shear
	Start	End	
527	-42.3	-86.4	96.1
523	-61.9	-83.2	99.5
167	-186.9	-177.6	163.1
140	-118.4	-142.9	128.6
174	-90	-71.9	-110.6
605	-75.6	-46.4	-103.6
172	-71.8	-90.2	110.7

5.2.2.2 The Straining action of some Columns & Beams in the Selected Frames (Group Y)

5.2.2.1 Columns

Table 16. The Straining action of some columns in the selected frames (Group Y)

Column No.	Moment 3-3		Shear	Axial
	Start	End		
214	22.7	-46.3	19.17	-1200.4
748	52.6	-59.2	37.2	-684.9
883	57.4	-77.7	45	-188.7
237	22.4	-46.2	19.1	-1152.9
216	34.2	-70.5	29.1	-2103.3
217	-21.2	45.2	-18.5	-1873.5

5.2.2.2 Beams

Table 17. The Straining action of some beams in the selected frames (Group Y)

Beam No.	Moment 3-3		Shear
	Start	End	
527	33	-66.6	94.8
523	-61.9	-73.2	99.5
167	-177.5	-177.6	163.1
140	-118.4	-118.9	128.6
174	-112.6	-71.9	-114.8
605	-75.6	-46.4	-103.6
172	-107.2	-90.2	110.7

5.2.3 Results of design of structural elements due to gravity and earthquake loads after adding RC shear wall

The design of columns was performed using the computer program ISACOL. Fig. 21 shows the ISACOL program results for column No. 214.

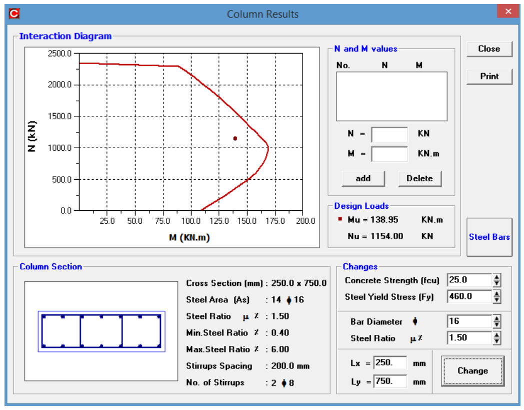

Fig. 21. The ISACOL program results for column No. 214.

6. RESULTS AND DISCUSSION

This part is focusing on the results, discussion and, comparison between the results of the analysis of studied building before and after strengthening.

Tables 18 and 19 show the results of selected beams and columns to represents part of the whole results mentioned before.

Table 18. Comparison between the Bending Moments at Selected Columns Due to load case (Group-X)-KN.m

Columns no.	Gravity	Seismic	Strengthening (Shear Walls)	Strengthening (Steel Bracing)
	KN.m	KN.m	KN.m	KN.m
214	25.03	182.8	46.2	73
237	25.21	207.8	46.13	75.2
216	55.54	285.92	66.81	118.2
217	38.66	242.97	42.01	60.3

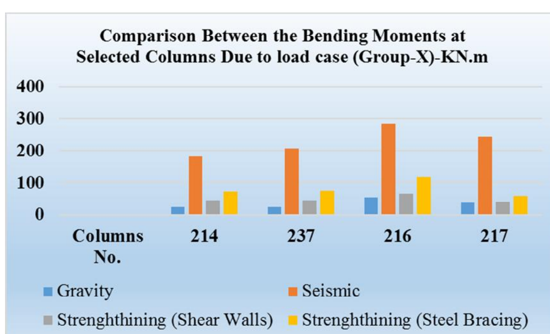

Fig. 22. Comparison between the Bending Moments at Selected Columns Due to load case (Group-X)-KN.m

Table 19. Comparison between the Shear Forces at Selected Columns Due to load case (Group-X)-KN

Columns No.	Gravity	Seismic	Strengthening (Shear walls)	Strengthening (Steel bracing)
	KN	KN	KN	KN
214	6.95	50.8	21	47.2
237	7	57.7	21.2	49.2
216	15.43	79.42	29.74	66.2
217	10.74	67.49	17.22	42.2

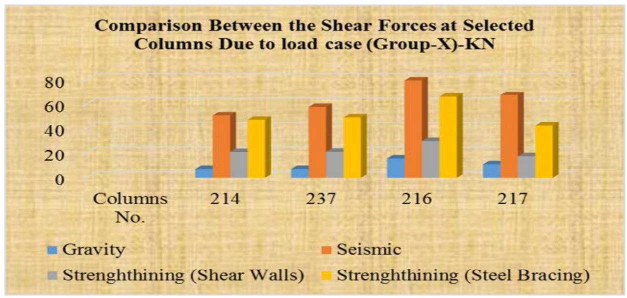

Fig. 23. Comparison between the Shear Forces at Selected Columns Due to load case (Group-X)-KN

6.1 Design of Some Selected Columns

Fig. 24 to 26 shows the ISACOL program results for the selected column design according to the gravity loads, gravity loads and seismic loads and gravity loads and seismic loads after strengthening using the RC shear walls.

Fig. 24. Design of Selected Column Due to gravity loads

Fig. 25. Design of Selected Column Due to gravity and seismic loads

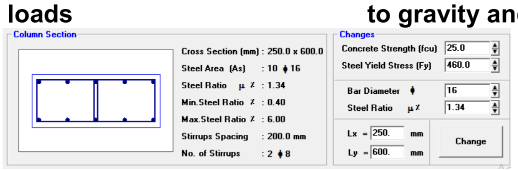

Fig. 26. Design of Selected Column Due to gravity loads& seismic loads after strengthening adding RC shear walls

7. CONCLUSIONS

One of the most difficult problems of strengthening existing buildings is to find the adequate solution that satisfy both economic and technical aspects. This study presents the seismic resistance of RC school building in Medina and proposes simple procedures to check their seismic resistance and retrofit- The following conclusions are obtained from the obtained results:

(1) The current design of most RC school buildings in Medina the SBC301 does not consider earthquake loads.
(2) A proposed methodology was presented to evaluate the seismic resistance of existing RC school building in Medina.
(3) Two strengthening techniques for existing RC school building in Medina is presented.
(4) With the use of RC shear walls inserted in the building reductions of bending

moments in the columns and beams were observed.

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

(6) The results which come from strengthening by adding RC shear walls have been better strengthening than by adding steel X-braces.

(7) Optimal locations of both shear walls and steel X-bracings in the framed system are critically important to reduce the lateral forces.

(8) The X technique to enhance the seismic performance or strengthen the structures proved that RC shear walls actually represent a suitable strategy to reduce the seismic vulnerability of RC school buildings.

FUNDING

The research is not funded through any source.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Saleh Mahmoud A. Attar Evaluation of the seismic performance of a typical school building, Thesis (M.Sc.), King Abdulaziz University; 2003.
2. Ji-Hyun Hwang1, et al. Seismic performance evaluation of reinforced concrete moment framed Low-story school buildings. Journal of the Korea Academia-Industrial cooperation Society. 2013;14(9): 4580-4586. Available:http://dx.doi.org/10.5762/KAIS.2013.14.9.4580
3. Central Public Work Department & Indian Building Congress in Association with Indian Institute of Technology Handbook on Seismic retrofit of Buildings, Madras, India; 2007.
4. SAP 2000. Three Dimensional Static and Dynamic Finite Element Analysis and Design of Structures, Computers and Structures Inc., Berkeley, California, U.S.A; 2001.
5. Saudi Building Code SBC-301. Loads and Forces Requirements, Saudi Buildings Code National Committee; 2007.
6. Sobaih M, Ismaeil M. Evaluation of Seismic Performance of Existing RC School buildings in Abha City, Saudi Arabia, Presented to the 16th European Conference on Earthquake Engineering, Thessaloniki, Greece; 2018.
7. Sobaih M, Ismaeil M. A proposed methodology for seismic evaluation and strengthening of existing school buildings in Sudan. Proceedings of 15th WCEE, Lisbon, Portugal; 2012.
8. Otani S. Earthquake resistant design of reinforced concrete buildings. Journal of Advanced Concrete Technology. 2003; 2(1): 3-24.
9. IBC 2012. International building code. International Code Council; 2012.
10. Al-Haddad M, Siddiqi GH, Al-Zaid R, Arafah A, Necioglu A, et al. A basis for evaluation of seismic hazard and design criteria for Saudi Arabia. Earthquake Spectra. 1994;10(2):231-258.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle3.com/review-history/49680