Responsible Design and Delivery of the Constructed Project
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CASE STUDY OF SEISMIC EVALUATION AND STRENGTHENING OF EXISTING LOW-RISE REINFORCED CONCRETE BUILDING

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All new buildings nowadays have to be designed and executed to overcome any imposed type of loading (lateral/vertical). On a universal scale, the stock of buildings built before 1980's is believed to be many times more than the number of newer buildings in most urban cities. In Beirut, as an example, a large proportion of Reinforced Concrete (RC) structures were constructed in the absence of mandatory earthquake design requirements, and unquestionably recognized as the type of construction most vulnerable to earthquakes. The performed research focused on how to evaluate the status of old building and how to design and execute the convenient seismic strengthening schemes. A case study has been selected to implement the evaluation process and design proposals. Conventional seismic upgrading technique has been assessed like the addition of shear walls in addition to more innovative approach which is the installation of steel bracing system. The strengthening schemes proposed aimed to create an ideal harmonization of the technical, economic and social aspects of the issue in hand. Analysis of the three structural systems (existing, modified with shear walls and with bracing systems) has been performed using the ETABS software including static equivalent, dynamic and pushover analyses. The research sorted out with a comparison between the systems based on different structural criteria followed by general recommendations and suggestions.

Keywords: Earthquake, Retrofitting, Rehabilitation, Shear walls, Steel braces, Lateral displacement.

1 INTRODUCTION

A remarkable seismic activity is carefully observed in Lebanon and the Region revealing the need for seismic assessment and strengthening for all new and some existing construction projects. Specialists keep sending alerts for many old low-rise buildings in Lebanon. Those buildings, more than 50% of Beirut Reinforced Concrete structures, are constructed in the absence of mandatory earthquake design requirements and conclusively vulnerable to earthquakes. The Lebanese Government imposed many regulations concerning the seismic activity and the needed considerations in the structural design, execution or modification of new or existing buildings. It refers to the seismic hazard level specified in the Decree 7964 dated April 7, 2012 which considers the national territory as one seismic zone. The requirements of the present Standard apply equally to new and some existing structures such as power plants, electrical substations, pumping and water treatment stations, water tanks of a capacity greater than 1000m^3, educational occupancies, hospitals and health centers, fire stations public buildings and civil works and structures including large cantilevers or deep foundations (NL-135:2012).

The main challenge remains to assess and choose the best seismic strengthening techniques that are technically, economically and socially acceptable. The most common process to start is to set a screening criteria, then proceeding to the evaluation and ending up with applying the convenient seismic strengthening design (Cheung *et al.* 2004). In screening, buildings are classified as high, medium or low need for rehabilitation. The evaluation process takes place accordingly for the "high need" classified structures at first; it identifies the susceptibility of the structural components to seismic loads where the building performance is described in terms of safety during and after the event. Strengthening becomes urgent if the evaluation shows that the building does not meet the minimum requirements up to the existing code. This means that it could be subject to local or even full collapse during any seismic event. (Hakim 2016).

2 CASE STUDY CONFIGURATION

In this paper, the three steps process are applied to a representative case study in Beirut: "The Beirut Arab University (BAU), Block C", (Figure 1), denoting a suitable application for this process.

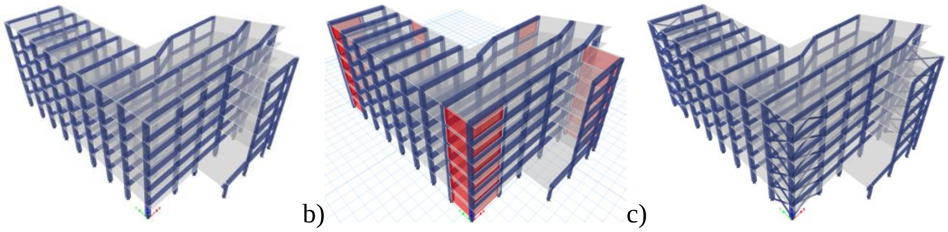
It is a university complex located in the heart of Beirut, built five decades ago, and serving more than 1000 students and staff members. It consists of a five-story Reinforced Concrete structure with inter-story heights ranging from 3.5m to 4.0m and a total height of 23.5m at the top roof. The BAU main building was structurally designed in the late 1950s. The construction works were done in 1958 with the absence of any seismic codes or requirements. The structural system is a "simple beam-column" system known also as Gravity Load Design (GLD) framing system. The load's path in GLD is transmitted from slabs to beams then to columns. Gravity Loads applied to this kind of structural systems will not transmit considerable moments to the columns.

A full structural investigation of the building confirms the efficiency of the as-built structure in terms of material type/performance and the soil/foundation types under gravity loads. Yet, the 3D numerical modeling evaluation endorses the vulnerability of this structure to seismic loads. The Lebanese Decree 7964 automatically screens this building as "High Need" for seismic strengthening. Therefore, two strengthening schemes are proposed, evaluated, designed and compared which are the addition of shear walls and the addition of bracing system.

Figure 1. Beirut Arab University Block C eastern facade.

3 ANALYSIS

ETABS 15.2.0 Modeling software is used to perform the Static Equivalent, dynamic and pushover analyses according to the below design criteria. Three prototypes, as shown in Figure 2, are considered:



a) b) c)

Figure 2. ETABS 3D Views of a) Existing structure, b) Existing structure with addition of edge shear walls, c) Existing structure with addition of edge steel braces.

- The material input for the model of Figure 2.a. is based on set of standard tests performed on existing structural elements; ASTM C39 for the evaluation of concrete compressive strength (f'_c) and ASTM A-370 for evaluation of the steel bars yielding stress. (f_y)
- The concrete compressive strength (f'_c) is at minimum 20 MPa for most of the cored samples.
- The Mild Steel Reinforcement found with 14mm and 16mm plain diameter has a yielding stress (f_y) near 260 MPa.
- The added shear walls and steel braces (Figure 2.b and 2.c) are designed with the following material parameters; (f'_c=30 MPa) and grade 40/60 high strength steel with (f_y = 420MPa).
- The Gravity Loads are assigned according to ASCE/SEI 7-05 (ASCE 2006) (Self-weight, Super Imposed Dead Loads = 5.0 KN/m^2 and Live Loads = 5.0 KN/m^2).
- Seismic Loads are assigned according to UBC 97 (ICBO 1997) (Seismic Zone: 3, Soil Type: C).
- The design of 25cm thickness shear walls considers the existing columns as boundary members. They are vertically continious, joined to the existing frames and fixed to the foundation. The implantation of these walls causes closure of some exterior bays as shown in Figure 3. (Grids: A-2-3, 2-A-B, F-1-2, 5-E-G, C-8-9, A-10-11, 11-A-B).
- The added braces have compact and non-slender steel sections. They are concentric X-Braces (25cm diamater and 1cm thickness) placed in the same location of the added shear walls (Figure 3). The newly introduced system utilizes the strength of existing column-beam connections. Noting that, braces are pin connected to the column-beam joint and require simple and clean connections.

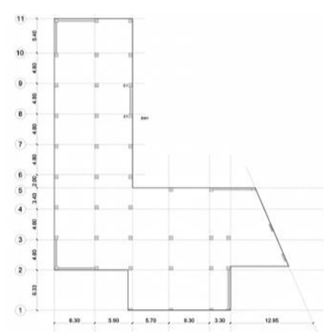


Figure 3. Plan view of BAU typical floor modified with shear walls.

4 RESULTS

4.1 Drift

Drift values are checked for the three models of Figure 3. The proposed check by UBC 97 (ICBO 1997) code evaluates the maximum inelastic response displacement, ΔM, of the structure caused by the Design Basis Ground Motion (see Eq.1). Table 1 includes results on roof floor where the modified structure with shear walls and steel braces show satisfactory results in compare to those of the existing structural system.

$$\Delta M = 0.7\,R\,\Delta S \leq 0.02 \times H_s \tag{1}$$

Where **R**, **ΔS** and $\mathbf{H_S}$ denote respectively the over strength factor, the total story drift, and the total story height. The overstrength factor is defined as numerical coefficient representative of the inherent overstrength and global ductility capacity of lateral force resisting systems. In the three cases, R is set to 5.5. The assumption considers the basic structural system as Building Frame System where lateral forces are resisted by shear walls or steel braces. (ICBO 1997).

Table 1. Interstory drift results – roof floor.

	Story	**Direction**	$\Delta S/H_S$	$0.7*R*(\Delta S/H_S)$	**Status**
Existing Structure	Roof	X	0.007202	0.0277277	NOT Adequate
	Roof	Y	0.019853	0.0764341	NOT Adequate
	Roof	X	0.004735	0.0182298	Adequate
	Roof	Y	0.018177	0.0699815	NOT Adequate
	Roof	X	0.062028	0.2388078	NOT Adequate
	Roof	Y	0.060738	0.2338413	NOT Adequate
Existing structure with Shear Walls	Roof	X	0.000541	0.0020829	Adequate
	Roof	Y	0.000192	0.0007392	Adequate
	Roof	X	0.000392	0.0015092	Adequate
	Roof	Y	0.000136	0.0005236	Adequate
	Roof	X	0.000296	0.0011396	Adequate
	Roof	Y	0.001008	0.0038808	Adequate
Existing structure with Steel Braces	Roof	X	0.000541	0.0020829	Adequate
	Roof	Y	0.000192	0.0007392	Adequate
	Roof	X	0.000392	0.0015092	Adequate
	Roof	Y	0.000136	0.0005236	Adequate
	Roof	X	0.000296	0.0011396	Adequate
	Roof	Y	0.001008	0.0038808	Adequate

4.2 Lateral Displacement

Lateral displacement of the structure cannot exceed the $\frac{H}{500} = 47mm$ conservative limiting value. As such, H is the total height of the building (23.5 m). Graphs in Figure 4 show that the existing structure's lateral displacement values exceeds the allowable. Whereas, values of lateral displacement in the two modified structural system remains less than 47mm.

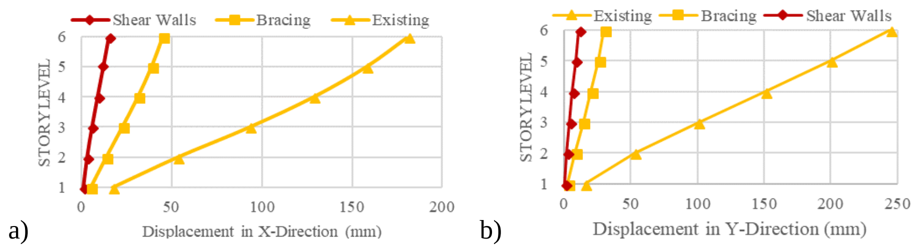


Figure 4. Horizontal displacement of the 3 models at different stories for both earthquake forces directions a) X-Direction b) Y-Direction.

4.3 Performance Based Check

Performance Based Check is done through the pushover analysis where beams and columns are modeled with concentrated plastic hinges at the column and beam faces, respectively. The beams have only main moment hinges whereas columns have axial load and biaxial moment (PMM) hinges. It is performed in presence of gravity loads, with monotonically increasing lateral loads until reaching maximum force value. These loads are distributed according to the ASCE requirements independently in the X and Y directions. The Performance Based curve deduced form the analysis is shown in figure 5 and denotes the following results.

- The as-built structure illustrates the lower stiffness and strength values between the three models in the elastic phase (54735 kN/m and 5000 kN).
- The bracing system has higher stiffness and strength (140882KN/m and 5500 kN).
- The shear walls system offers the largest stiffness, 4.5 times higher than the bracing system, and largest strength values with (511339 KN/m and 11000 kN)
- The ductility of the system is undesirably affected when shear walls are applied. Yet, it is highly enhanced in the bracing system alternative (the curve extends largely).
- To be noted that the Y-direction forces curves show similar behavior for the three models.

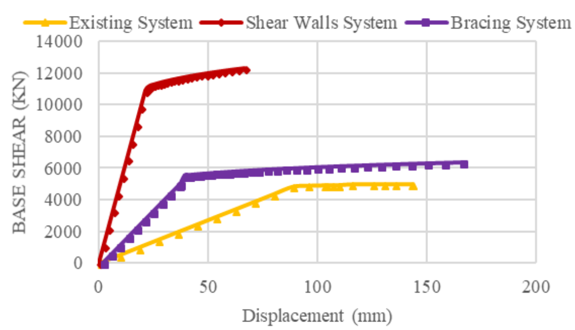


Figure 5. Base Shear versus Displacement for X-Direction earthquake forces.

4.4 Foundation

A test pit under the column on grid A-11 (Figure 3) shows a 230x230x70 cm spread footing.

- Using the Autodesk Robot software, the status of this foundation is evaluated.

- It shows that a failure is expected in both strengthening schemes: soil pressure is greater than the allowable soil bearing capacity (360 kPa).
- In the case of bracing system, a simple footing modification is required (e.g. increase of footing's area by 20%).
- In the case of shear walls system, strip footing should be implanted.

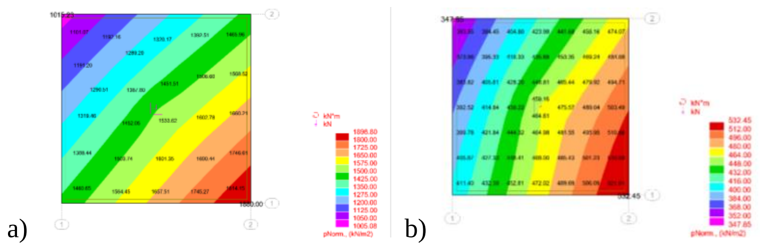


Figure 6. Soil Pressure below footing of Column (A-11) a) Shear Walls system, b) Bracing system.

5 CONCLUSION

The comparison between the shear walls system and steel braces system shows that both of them provide the desired seismic performance. For any earthquake event, similar to that simulated according to the Lebanese Norms and UBC 97 (ICBO 1997) code, the considered case study should show acceptable drift, stiffness and strength values.

However, the addition of steel braces to the existing structure provides a better ductility than the shear walls addition system and requires a minor modification for the foundation scheme. The bracing system provides an easier construction process and it is aesthetically acceptable if matched with the general architecture of the building.

In conclusion, the seismic evaluation of the Beirut Arab University main building confirms that an implementation of steel braces on the edge bays of the building could achieve an adequate seismic strength. Hence, it should prevent any collapse or significant damage during earthquakes.

6 GENERAL RECOMMENDATIONS

(i) The seismic evaluation of every old building is an urgent need in Beirut. The case study evaluated in this paper is a prototype of the majority of Beirut old buildings.

(ii) A national strategy should be adopted to find solutions against the high threats of earthquakes in Lebanon.

(iii) Strong, fair and sustained strategy could be summarized in the 3 steps process adopted in this research: Screening, Evaluation and the strengthening application.

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