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Stopping the tragedy before it occurs

Protecting Lebanese public schools from upcoming earthquake disasters

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Abstract

Purpose – The purpose of this paper is to offer an assessment of seismic structural vulnerability of a sample of public schools using Lang survey questionnaire. The structural integrity of public schools in Lebanon is a source of deep concern due to their outdated design and deteriorated status, their apparent lack of compliance with seismic design regulations, the unknown status of their safety and stability, their substandard maintenance and their low construction quality. These schools have not undergone any strengthening improvements to enhance their load-carrying capacity or their resistance to earthquake activity.

Design/methodology/approach – This paper is based on survey questionnaire illustrating the seismic risk exposure of public schools in Lebanon. It offers an assessment of seismic structural vulnerability of a sample of public schools using Lang survey questionnaire. It stresses the needs of retrofitting of public school buildings to enhance their functional capacities against future destructive earthquakes.

Findings – The findings of the survey emphasize the seismic structural vulnerability of the majority of public schools in Lebanon and call for deeper assessment and investigation that involve government officials for strengthening and retrofitting of public school buildings as part of holistic disaster risk-reduction strategy to prevent the induced serious risk to children in the event of a devastating earthquake.

Originality/value – This article should alert school administrators, public leaders and government officials regarding the seismic threats and their subsequent effects on the structural safety of public school buildings in Lebanon. The assessment of seismic structural vulnerability has rarely been performed or even discussed in the Lebanese-related literature.

Keywords Lebanon, Disaster risk reduction, Earthquakes, Public schools, Structural vulnerability

Paper type Viewpoint

Introduction

Earthquakes are the most powerful and deadliest natural disasters on earth. They pose a threat to a country's infrastructure, population, economy and social structure. Earthquakes can wipe out communities and destroy a nation's economy, thus precipitating panic, bereaved families and sad stories. Recent earthquakes have shown that the effects of such disasters on ill-prepared nations are long-lasting and devastating. These events often deplete a nation's limited resources and divert its essential budget and financial assets from development and investment to post-disaster recovery, reconstruction and rehabilitation. Earthquakes also disrupt the essential

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services upon which a population relies for daily life. As a result, earthquake disasters can hinder a country's developmental progress and economic growth and can reduce the quality of life of the affected communities (World-Bank, 2000).

Access to free education is a basic human right, and there is a strong impulse to implement such a doctrine in countries worldwide (World_Education_Forum, 2000). However, in the rush to achieve this goal, children have been put at risk. Similar to other critical infrastructure, school buildings are prone to damage and failure in earthquakes. In recent earthquakes, children and teachers have suffered, killed and injured at schools in such disasters (Wisner *et al.*, 2004). When an earthquake hit the Spitak area of northern Armenia during school hours in 1988, many children lost their lives due to the collapse of school buildings. A total of 285 children (out of 302) died at one of these schools. Nearly two-third of the total deaths (25,000) due to this earthquake were children and adolescents. In the 1999 Chi-Chi earthquake, a total of 700 schools were destroyed in Taiwan. The 2001 Gujarat earthquake in India caused damages to more than 11,600 schools (World-Bank, 2000). The 2005 Kashmir earthquake resulted in the collapse of 6,700 schools in the North-West Frontier Province and the collapse of 1,300 schools in Pakistan-administered Kashmir. These collapses resulted in the deaths of 18,000 schoolchildren due to a lack of safety regulations and poorly practiced earthquake drills. The Sichuan earthquake disaster of 2008 in China also killed 5,335 students and left another 546 children disabled due to poor school construction (CNN, 2009). Such repeated tragedy speaks for itself and should not be accepted, underestimated or ignored. Education leaders and community activists must prioritize school safety so that these tragedies can be addressed and prevented. School buildings should be protected from earthquakes to save the lives of children and to function as shelters in post-disaster scenarios. Moreover, safe schools are effective in disseminating disaster risk awareness in their respective communities and could potentially have fundamental roles in building disaster-resistant communities.

In the Long Beach earthquake in 1933, California suffered the collapse of 70 schools. One month after the earthquake, a school earthquake safety law called the Field Act was passed. This legislation required careful design and independently inspected school construction. Since the passing of this law, no student or teacher has been killed or hurt during an earthquake in the state. The recent seismic retrofit of public schools of the Canadian province of British Columbia (BC) has become a leading mitigation program worldwide. First launched in 2004, the School Seismic Mitigation Program is the commitment of BC government to student safety. It is an ongoing program to upgrade the seismic performance of school buildings to resist future destructive earthquakes. Out of 800 evaluated schools, 315 were identified and assessed as seismically high-risk school buildings to be subjected to seismic retrofit by 2015 (Wisner *et al.*, 2004). The cost of this project has been estimated to be $2.8 billion. BC with population size of 4.4 million is comparable to 4.5 million of Lebanon which could be used as a model that the Lebanese Ministry of Education should investigate to run similar program for upgrading the seismic safety of the existing high-risk schools and to enforce the seismic design in future constructed schools. Only a small portion of the 1,290 public schools in Lebanon can be classified as seismically low risk. However, assessment methodologies based on engineering and geological data are needed to identify the high-risk schools. As the great majority of school structures are low-rise buildings. The overall expected cost of assessment, evaluation, analysis and construction involved in public schools seismic retrofit should not exceed $300,000 per school, leading to cumulative retrofit cost of all public schools in Lebanon to a maximum value of $400 million.

Despite successes in California and British Columbia and other locations, school earthquake vulnerability around the world remains high. For example, in Pakistan, 80 per cent of the country's vulnerable schools remain exposed and vulnerable (Revkin, 2008). Lebanon has not yet committed itself to prioritize the structural safety of schools due to more pressing concerns such as wars, sectarian conflicts and political turmoil that appear more urgent than a devastating earthquake that may not occur for decades or longer.

Purpose and importance of this study

There is currently a shortage of literature on earthquake hazard awareness and seismic vulnerability of essential facilities in Lebanon, and there have been no studies focusing on the safety of school buildings and, thus, schoolchildren in the event of an earthquake. The aim of this study was to highlight the seismic structural vulnerability of Lebanese public schools and to alert school administrators and the Lebanese Government officials about the importance of seismic school safety. A comprehensive school retrofitting project is needed as a part of a national disaster risk-reduction strategy to mitigate the effects of earthquakes in Lebanon. Thus, Lebanese Government officials should be persuaded to take the necessary action to improve the conditions of existing schools by mandating seismic-resistant renovations and by investing more resources into efficient earthquake education, preparedness and planning. Also, the article will open the way for more persuasive literatures that address the vulnerability of essential facilities in Lebanon to earthquakes.

Lebanon seismic setting

The geological history and current geological conditions in Lebanon (and its surroundings) provide evidence for the country's vulnerability to earthquakes. Due to government negligence, a lack of public awareness and preparedness, the deterioration of community ties, the overcrowding of coastal cities and a lack of education regarding such hazards, Lebanon is currently unaware of, unprepared for and vulnerable to a major earthquake.

Seismic activity in Lebanon and along the Dead Sea Fault has been observed and documented for more than 2,000 years. Over this period, strong earthquakes have damaged many cities and towns, have destroyed thousands of buildings and have killed hundreds of thousands in the eastern Mediterranean region. Seismic activity in Lebanon has triggered many earthquakes over the past 2,000 years. The most notable and prominent of these instances were the earthquakes of 551 AD, 1202 AD and 1759 AD. These earthquakes have been estimated to reach magnitudes of 7.5 and caused tremendous destruction in the coastal cities of Beirut, Tripoli, Jubail, Saida and Tyre, as well as in the ancient city of Baalbek.

Geologists have shown that Lebanon is covered by seismic fault systems. The Dead Sea Transform is extremely important because it has been responsible for the majority of the seismic activity in the eastern Mediterranean region. This fault originated from interactions and collisions between the African and the Arabian plates. It is the deepest and most powerful fault system in the eastern Mediterranean region, stretching from Ethiopia through Aqaba, Jordan, Lebanon and Syria and continuing north to join the

East Anatolian Fault in Turkey. This fault system has been the origin of several catastrophic earthquakes in Lebanon (Harajli *et al.*, 2002).

The Mount Lebanon Thrust (MLT) is another active major fault that was recently discovered along the coast between Beirut and Enfeh (Elias *et al.*, 2007). A disastrous 7.5 moment magnitude earthquake occurred along this fault on July 9, 551 AD, and destroyed most of the coastal cities of Lebanon. Scientists have suggested that similar earthquakes on the same fault should occur between every 1,500 and 1,750 years. The earthquake of May 20, 1202 AD, which caused severe destruction in Beirut and Damascus, was estimated to have an equivalent moment magnitude of approximately 7.5 (Daëron *et al.*, 2005; Elias *et al.*, 2007). In the year 1759 AD, significant seismic events occurred on October 30 and November 25. The equivalent moment magnitudes of these events were approximately 6.7 and 7.4, respectively (Daëron *et al.*, 2005).

Traditionally, governments in Lebanon have not prioritized earthquake threats, although they are aware of its devastating consequences. As a result, the current perception of earthquake risk for Lebanese people is low and earthquake preparedness is poor. School education programs in Lebanon do not cover any aspects of earthquake disaster awareness or preparedness, and no commitment to seismic hazard reduction has occurred over the past few decades. In addition, mass media (especially televised news outlets) have poorly addressed this issue.

Currently, more than 75 per cent of the Lebanese population lives in regions that are at a moderate-to-high risk of earthquakes, and more than 80 per cent of Lebanese buildings do not meet basic seismic design standards and requirements. Similar conditions are found in schools.

Why should schools be protected against earthquakes?

The earthquakes occurring worldwide since the year 2000 claimed the lives of more than 28,000 children and teachers due to unsafe school buildings (Petal, 2008). It is often the responsibility of schools to teach their students about disaster safety and awareness.

The Lebanese public school system has a substantial responsibility to increase earthquake awareness while strengthening community resilience against disasters. Therefore, schools should seriously consider earthquake threats and should advocate and campaign to promote awareness, preparedness, building safety regulations and community protection. There is a lack of awareness regarding earthquake threats among the majority of school administrators in Lebanon that must be urgently addressed, and this study is a part of an effort aiming to support the role of schools in promoting school building protection to ensure the safety of children in the event of an earthquake and to ensure the continuity of their functioning after a disaster.

Generally, schools can provide education to help citizens prepare for and cope with earthquake disasters. As shown by previous earthquake disasters, children are among the most affected demographics due to damaged, collapsed and disrupted school services. Such disruptions can reduce time in the classroom and can lead to poorer education and, thus, a higher dropout rate.

The majority of public schools in Lebanon are old, unmaintained, located in seismically active locations and unprotected against earthquakes. Government authorities have never taken the initiative to implement the necessary disaster risk-reduction strategies, have failed to strengthen school buildings across Lebanon and have never prioritized safety procedures that could mitigate prospective losses and destruction caused by earthquakes. Recent Ministry of Education officials have admitted their concern regarding school safety during seismic events and issued a warning on the structural integrity and safety of public schools. These officials also requested funds to initiate a plan to increase earthquake-related safety in schools.

The safety of schools begins with rigorous and strict engineering regulations of design and construction which starts with seismic hazard assessment of the site and proper design procedures and construction methods. Safety measures are inexpensive when correctly implemented during the design and construction of new schools. The retrofitting of schools and the implementation of seismic designs in new construction can promote the value of safe buildings in the surrounding community and, consequently, encourage the community to develop further earthquake disaster mitigation. Therefore, school buildings in Lebanon should be assessed and evaluated to ensure their structural integrity in terms of strength and load-carrying capability, and they should be retrofitted to enhance their seismic resistance capabilities. When their structural safety is ensured, Lebanese public schools can function during periods following earthquake disasters. These schools could also support relief efforts and provide shelter to earthquake victims. Thus, educational leaders in Lebanon should work closely with the Ministry of Education officials to make the protection of school buildings and the safety of schoolchildren an urgent priority. Increasing schools' structural resistance to earthquakes will ensure the safety of the children, maintain the functionality of the institutions during and after an earthquake and provide relief facilities for victims.

Seismic structural vulnerability assessment

The assessment of the seismic structural vulnerability of school buildings in Lebanon is of great importance, as it provides government officials with necessary information regarding structural deficiencies that can induce structural damage or collapse of such facilities by earthquake-generated forces. Generally, such assessment requires detailed structural analysis of a multitude of input information on buildings layout, detailing reinforcements and construction material properties. As most of such required and necessary information cannot be easily obtained for old buildings in Lebanon, a quick survey approach can be applied for the purpose of conducting such an assessment. Thus, to achieve this goal, a field trip was performed in the Northern city of Tripoli where the highest concentration of public schools exists in the country with the purpose to get acquainted with the general aspects of plan and elevation configurations of the existing public school facilities. Based on the screening process, nine schools representing the main structural and architectural features that commonly appeared among the majority of the observed schools were visited and surveyed using a questionnaire survey approach (Lang *et al.*, 2009). The questionnaire includes two parts: general information part and structural vulnerability part that have been tested on numerous school buildings in the Central American countries: Guatemala, Nicaragua, El Salvador and Panama.

General information

The statistical summary of the general information of the targeted schools are outlined in Tables I-VII.

Seismic structural vulnerability

The statistical analysis of structural vulnerability of the targeted school buildings provides a first impression about the most common features which have an impact on their structural capabilities to withstand earthquake-generated actions. The objective of the vulnerability assessment is to derive the structural vulnerability index (SVI) of the targeted buildings and to adjust the resulted index with the age factor and the actual state factor to obtain (SVI)*. Such quick assessment procedure is based on 15 questions which are used to assess the structural seismic vulnerability and gives their levels of importance which are dependent on the construction type. Each level of importance is connected to a certain importance factor. SVI is then derived by dividing the sum of importance factors by the number of answered questions. The determined index value can assist engineers with the information needed regarding the resistance capacity of the assessed structure, so they can suggest a strengthening approach to prevent major failure or collapse of buildings during a strong earthquake. Based on the percentages given in Table VIII, the following statements can be derived:

- *Decreased vulnerability (DV)*: Feature that increases vulnerability.
- *Increased vulnerability (IV)*: Features are affected by this feature in a negative way.

Index	Name	*N*	No. of students	No. of staff
S 01	Zahria High School for Girls	3	551	74
S 02	Zahria Middle School for Boys and Girls	4	575	54
S 03	Mina High School for Girls	3	693	72
S 04	Salah Middle School for Girls	4	382	36
S 05	Gazale Middle School for Boys	5	619	51
S 06	Abou Samra Middle School for Girls	3	932	50
S 07	Abou Samra Middle School for Boys	4	802	65
S 08	Haddadeene High School for Girls	4	643	93
S 09	Fadila Middle School for Girls	4	280	30

Table I. Name, number of levels (N) and number of students in the targeted schools

Less than 200	Between 200 and 500	More than 500
0	2	7

Table II. Distribution of students in the targeted schools

New	Recently renovated	Renovation is needed	Decayed
0	3	6	0

Table III. Actual status of targeted school buildings

Less than 10 a	10-20 a	20-40 a	Greater than 40 a
0	0	4	5

Table IV. Building age of the targeted school buildings

The majority of the targeted school buildings have an IV due to the following features:

- buildings are irregular in plan;
- inadequate bracings in both building directions;
- the ratio between the building's length and width > 2.5;
- buildings possess eccentric cores;
- buildings possess a heavy mass at the top or at roof level;
- the existence of strong beams – weak columns;
- no shear walls; and
- the buildings do not possess seismic retrofitting or strengthening measures.

The above commonly observed seismic resistance deficiencies among the existing public school buildings in Lebanon can be understood in the context that the majority of such facilities were built a half century ago where earthquake risk awareness and concerns were completely absent, seismic codes applications were scarce and unavailable and the knowledge of the Lebanese engineers and architects in earthquake-resistant design was inadequate. Even today, the bulk of Lebanese engineers are not aware of the design features that reduce structural vulnerability to earthquakes due to the lack of emphases of engineering programs on such issues. Also, the government has not been helpful in this regard. For instance, decree No 646 (for seismic design regulations in Lebanon) issued in 2005 exempts buildings composed of three floors or less from seismic requirements, including schools and hospitals. Such strange exemption should be reconsidered because it is not based on any consolidated facts or scientific verifications. Actually, it contradicts the observed and documented structural collapse induced by previous earthquakes in Turkey, Iran, China and Haiti.

Therefore, based on the above results, civil engineering programs in Lebanon must emphasize the knowledge of both seismic design and architectural features to enhance seismic design performance capabilities of future engineers. For example, it is not just

Table V.
Type of structural system in the targeted school buildings

Stone masonry	Ordinary RC frames	Seismic frames	Concrete shear wall	Bracing systems
0	9	0	0	0

Table VI.
Building plan configuration of the targeted school buildings

Rectangular	L shape	T shape	U shape	Others
4	2	1	1	1

Table VII.
Maintenance record

Available	Not available
0	9

No.	Item	Yes	No	N/A	Evaluation
1	Is the building irregular in plan?	34	66		DV
2	Are the columns regularly distributed?	66	34		DV
3	Are both building directions adequately braced (RC frames or shear walls)?	0	100		IV
4	Does the ratio between the building's length and width > 2.5?	89	11		IV
5	Does the building possess eccentric cores (staircases or elevators)?	22	78		IV
6	Does the building have a soft storey?	22	78		DV
7	Is the building irregular in elevation caused by setbacks of upper stories?	0	100		DV
8	Does the building have cantilevering upper stories?	11	89		DV
9	Does the building possess a heavy mass at the top or at roof level?	89	11		IV
10	Are pounding effects possible?	11	89		DV
11	Does the building have short columns?	76	22		
12	Are strong beams – weak columns available?	0	100		IV
13	Does the building possess shear walls?	11	89		IV
14	Did the building suffer any significant structural damage in the past?	–	–		
15	Does the building possess seismic retrofitting or strengthening measures?	0	100		IV

Table VIII. Statistical figures of the vulnerability indicators of the targeted schools

sufficient for engineering students to know about structural design procedures of shear walls, but students should be taught more about the behavior of structures with and without shear walls under various loading conditions and how such resisting elements should be distributed and balanced in a building to avoid any additional torsional effects. Also, they should be aware of the effects of architectural features and structural wall elements in controlling and limiting upper stories drift, in providing the maximum resistance efficiency against torsional and shear forces and in preventing the catastrophic pancake effect mode in the event of strong earthquakes.

The lack of seismic retrofitting observed in public school buildings is solely the responsibility of the government. Such neglect is an immediate result of the poor seismic risk awareness among government officials and clearly reflects the absence of any national earthquake mitigation plan to protect and save essential facilities.

The majority of the targeted school buildings have a DV due to the following features:

- columns regularly distributed;
- no soft storey;
- building are regular in elevation;
- building have no cantilevering upper stories; and
- no pounding effect.

The structural vulnerability indices obtained for the targeted schools are shown in Table IX.

Such assessment revealed that public school buildings in Lebanon must undergo serious strengthening procedure to prevent catastrophic collapse during future earthquakes. The majority of these schools share similar architectural and structural features that increase their vulnerability to earthquake lateral and twisting actions.

The cost of such retrofitting in Lebanon depends on the strengthening system used. For example, in case of shear walls strengthening technique, the estimated retrofitting cost (labor and materials) must take into consideration the installation of the foundations, the erection of the walls and the detailed connections between the walls and the existing slabs which can be estimated at $700 per meter, $120 per square meter and $200 per meter for connections, respectively. Assume an eight shear walls of 6 m in length are required for the seismic retrofitting of a three-story school building, then the overall estimated retrofitting cost would be shown in Table X.

Thus, adding the 15 per cent for engineering work, the estimated cost of seismic retrofitting of a typical school in Lebanon by applying shear wall strengthening technique should not exceed a total of $160,000 American dollars. A $35,000 must be added for every additional story for schools that have more than three levels.

In the case of column strengthening, the cost varies with the technique used. For example, jacketing the existing columns with reinforced concrete to improve the strength and the confinement of the existing column by enlarging their sections can cost roughly between $1200 and $1500 per column. The cost includes labor materials and connections with beams/slabs. A typical three-story school has about 30 critical columns per floor that require strengthening which yield to a total of 90 columns with a cumulative cost ranging from $108,000 to $135,000. Therefore, the cost estimation of concrete jacketing is somehow closed to shear wall installation approach. This technique will yield bulky columns that may not fit with the architectural setting of the traditional school environment.

Index	Name	Type	N	AF	ASF	SVI	(SVI)[a]
S 01	Zahria High School for Girls	RC	3	1.05	1.05	8.7	9.60
S 02	Zahria Middle School for Boys and Girls	RC	4	1.10	1.10	9.6	11.6
S 03	Mina High School for Girls	RC	3	1.05	1.10	9.4	10.8
S 04	Salah Middle School for Girls	RC	4	1.10	1.05	9.4	10.8
S 05	Gazale Middle School for Boys	RC	5	1.10	1.10	9.4	11.3
S 06	Abou Samra Middle School for Girls	RC	3	1.10	1.05	10.5	12.1
S 07	Abou Samra Middle School for Boys	RC	4	1.10	1.10	9.8	11.8
S 08	Haddadeene High School for Girls	RC	4	1.05	1.05	9.4	10.8
S 09	Fadila Middle School for Girls	RC	4	1.05	1.10	8.4	9.70

Note: [a] Adjusted (SVI) by taking in consideration the age factor (AF) and the actual state factor (ASF)

Table IX.
SVI and adjusted SVI values by age and actual state factors

Component	Unit cost ($)	No. of units	Estimated cost ($)
Foundation	700/m	60 m	42,000
Wall	120/m^2	480 m^2	57,600
Connection	200/m	200 m	40,000
			139,600

Table X.
Detailed retrofitting cost of a school using shear wall approach

Jacketing columns with steel casing is also an alternative that yields good seismic reinforcement of the columns, and it has been used also in Lebanon. The cost per column varies between $1,800 and $2,200. Based on 90 steel jacketing columns, the cost would be $162,000 and $198,000. Although steel jacketing is more costly, it is far more esthetic and practical.

Wrapping the columns with carbon fiber-reinforced plastic material can also be an option, but at an elevated cost which may cost between $2,200 and $3,000 per column depends on the size of the column and connections. Thus, for a total of 90 columns, the overall cost varies between $198,000 and $270,000.

In summary, the above techniques can be implemented separately or in combination. However, regardless to the type of technique used, the average retrofit cost of a typical school in Lebanon can be achieved reasonably with $160,000 and should not exceed $300,000 in case of using advance carbon fibrous composites.

Conclusion

The assessment of seismic structural vulnerability of Lebanese public school buildings by the application of standardized questionnaires is an effort to quickly identify existing structural deficiencies, to identify the most vulnerable buildings and to compare different school buildings with each other. Therefore, identifying the most vulnerable structures using this quick approach is the first phase that must be followed by deeper investigations using structural analysis methods to supplement the findings obtained by the survey process. The analysis of a sample of targeted school buildings has revealed the urgent need for seismic retrofitting for such facilities as a part of a national risk-reduction program that enhance the resilience of Lebanese communities to future disasters. Thus, these schools are highly vulnerable to existing earthquake hazards and are susceptible to potential future earthquakes, which can lead to severe infrastructural damage and to the death of students and teachers.

In addition to the pressing need for a structural retrofitting of school buildings in Lebanon, proper safety procedures must be taught to teachers and students to improve their safety during earthquakes. Children who become more aware of earthquake risks and proper preparedness through education may convey the message to their home and their communities, thus reinforcing the philosophy of disaster risk reduction. Lebanon has a confirmed seismic risk; thus, government officials should acknowledge their moral obligation to protect those children who are obliged to attend schools that are highly vulnerable to collapse during an earthquake.

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