Comparative Cost Analysis of Possible Seismic Retrofitting Schemes for Multi-Story Unreinforced Masonry Building

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Abstract

The core objective of this study is to identify the cost effective seismic retrofitting option for multi-story unreinforced masonry (URM) buildings. A seismically deficient 3 story URM structure assumed to be located in the moderate seismic zone of Bangladesh is taken as a reference for this work. Depending on the expected seismic performance level, 5 possible retrofitting schemes are designed for the building and then compared in terms of cost of construction. It is evident from the study that, the ‘Splint and Bandage’ and the ‘Internal Concrete Box’ are the cheapest solutions considering ‘Life Safety’ and ‘Immediate Occupancy’ performance level respectively. Expensive retrofitting options like ‘Seismic Isolation’ and ‘Internal Concrete Box’ have added advantage to withstand multiple earthquake events over the cheaper methods such as ‘Splint and Bandage’ and ‘jacketing’.

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1. Introduction

Earthquakes are sudden and uncontrolled natural disasters. Though it is feared all over the world, interestingly, earthquakes are not the major cause of injury or loss of life when they strike. It is often the buildings and the environment around them that put people at risk. There are numerous unreinforced masonry (URM) buildings throughout the world which have not been designed for seismic loads. It is estimated (Matthys and Noland 1989) that more than 70\% of the buildings throughout the world are masonry
buildings. Moderate to strong earthquakes can devastate these buildings, which may result in massive death toll and extensive losses.

In the event of an earthquake, URM buildings show poor performances due to the inherent brittleness, lack of tensile strength, and lack of ductility which means the lack of properties provided by the steel reinforcements in reinforced masonry.

Due to the earthquake forces, when a crack occurs in masonry walls, subsequent earthquake pulses can trigger uncontrolled displacement resulting in partial or full collapse of masonry units or walls. In most of the cases, demolition and replacement of the masonry structures are not feasible due to several factors like preservation orders for historic importance, dwelling places of poor communities etc. Recognizing all these shortcomings of URM buildings, there has been a surge of interest in recent years to develop techniques for improving seismic behavior of these structures. A number of techniques have been proposed, and a complete overview of these approaches has been documented (Lizundia et al. 1997).

The core objective of this study is to identify the cost effective seismic retrofitting options for multi-story URM buildings in both ‘Life Safety’ and ‘Immediate Occupancy’ level of performance.

2. Scope of Research

2.1. Problem Statement

A seismically deficient 3 story URM structure assumed to be located in the moderate seismic zone of Bangladesh is taken as a reference for this work. Depending on the expected seismic performance level, 5 possible retrofitting schemes are designed for the building and then compared in terms of cost of construction. The prime objective of this research is to identify the cost effective retrofitting options based on the level of performances.

2.2. Description of Building

The Building is located in Dhaka, the moderate earthquake prone zone having seismic zone coefficient, \( z = 0.15 \) as per Bangladesh National Building Code (BNBC-2006). The building is located in a mainly residential area and has an open ground surrounding it on all sides. The structure may have been built around 50 years ago. The original building is constructed from thick masonry walls with reinforced concrete slabs at first floor and roof level and is rectangular on plan as shown in Figure-1.

The building area excluding the void spaces is 172 sqm. per floor, which gives a total area of 516 sqm. for the 3 storey URM building. The building has got a well defined load path.

There are numerous windows and doors in each elevation. Internally, the building has a centrally located concrete stair from ground to the second floor/roof. Partition walls are of masonry up to 600mm thick and run similarly from ground to roof level.
Mud mortar is used in the masonry joints of the structure. Floor to floor height of the building is measured as 3600mm.

The first and second floor/roof slabs are 100mm in depth. The foundation is found to be around 800mm wide at a depth of 1500 mm below the existing ground level. It has been observed that, the soil consists of dense sand mixed with some silts and there is a very little chance of liquefaction in an event of an earthquake.

2.3. Building’s Strength & Weakness

The building is generally in good condition. However, there are seismic weaknesses in the structure. Since, the reinforced concrete slabs are just sitting on top of the walls and there are no connections in between them it may be concluded that, the structure is well designed for gravity loadings, whereas, for lateral loadings, the structure exhibits serious deficiencies due to the lack of diaphragm actions in between the walls and slabs. Furthermore, the height of the masonry walls is more and there are lots of openings in the walls which may result in the collapse of the partial or full structure during a medium to high seismic tremor.

![Figure 1. Building Layout Plan](image)

3. Analytical Research

3.1. Level of Performances

As per FEMA 356 (American Society of Civil Engineers 2000), there are six (S-1 to S-6) levels of structural performances. This research is more concerned with ‘S-1:
Immediate Occupancy’ and ‘S-3: Life Safety’ performance levels only. As per FEMA 356 structural performance level: S-1, ‘Immediate Occupancy’ means the post-earthquake damage state in which only very limited structural damage has occurred. The basic vertical and lateral-force-resisting systems of the building retain nearly all of their pre-earthquake strength and stiffness. The risk of life threatening injury as a result of structural damage is very low, and although some minor structural repairs may be appropriate, these would generally not be required prior to re-occupancy.

Whereas, structural performance level ‘S-3: Life Safety’ means the post-earthquake damage state in which significant damage to the structure has occurred, but some margin against either partial or total structural collapse remains. Some structural elements and components are severely damaged, but this has not resulted in large falling debris hazards, either within or outside the building. Injuries may occur during the earthquake; however, the overall risk of life-threatening injury as a result of structural damage is expected to be low. It would be possible to repair the structure; however, for economic reasons this may not be practical. While the damaged structure is not an imminent collapse risk, it would be prudent to implement structural repairs or install temporary bracing prior to re-occupancy.

3.2. Retrofitting Options

Based on the level of performances, the following 5 retrofitting options are designed.

(a) Jacketing: This option alone would afford the medium level of structural building performance raising it nearest to Immediate Occupancy level. This method includes the works consist of stripping off the internal and external plaster from all the walls and installing a “jacket” of concrete and steel mesh on both sides of the walls to improve the shear resistance and out of plane bending of the wall. Though the method is well tried and tested, it may not work efficiently where the building geometry is complex in nature and if there are existence of lot of door and window openings in the structure. This system provides no additional benefit to the building in terms of sustainability, maintenance, time of construction and cost reduction.

(b) Base Isolation: The method of seismic isolation would entail the highest level of structural building performance raising it to Immediate Occupancy level. The construction work includes the excavation of the foundations internally and externally and insertion of elastomeric rubber and lead bearing below the existing wall foundation. The system seems quite sound in retrofitting having few limitations like installation difficulty, time and cost of construction etc.

(c) Internal Concrete Box: This option is more suitable for the structures of historical importance. In this method all the internal walls and floors are removed and a new earthquake resistant R.C.C structure is constructed inside the existing outer brick wall. The outer wall is connected to the internal R.C.C structure by shear connectors. The method is very straight forward and would serve the purpose during a seismic event to Immediate Occupancy structural performance level.
(d) **Steel Strong Point:** This option includes the incorporation of a new steel stiff frame within the walls, floors and roofs of the existing structure. The basic intent is to stiffen and connect the building elements (foundation, wall, floor and roof) so that they move as a single entity under seismic loading. This method of retrofitting is cost effective, relatively less destructive to existing structure and would provide the structure with lowest level of structural performance.

(e) **Splint and Bandage:** This option provides a midway option between options (a) and (d) giving the building at least Life Safety Performance Level and even up to Damage Control Level. This option requires the addition of vertical and horizontal steel strips placed around the building, inside and outside, to restrain and support the existing structure during an earthquake. As this system requires only discreet areas of additional reinforcement, the architectural appearance of the building is likely to be quite different. This method of retrofitting is cost effective and quick.

4. **Results & Interpretations**

Applying all the retrofitting options described in section 3.2 to the current building, a bill of quantity for each of the options is formed. Latest PWD (Public Works Department Bangladesh, 2008) standard rates are then applied to the estimated quantity and an engineer’s estimate for each of the retrofitting options is computed. Figure 2 represents a bar chart showing comparative cost estimate of applying each of the 5 retrofitting schemes.

![Figure 2. Comparative cost of retrofitting](image)

It is evident from figure 2 that ‘Splint and Bandage’ and ‘Internal Concrete Box’ are the cheapest retrofitting options considering ‘Life Safety’ and ‘Immediate Occupancy’ performance level respectively. Though ‘Jacketing’ is cheaper in comparison to ‘Base Isolation’ and ‘Internal Concrete box’, its performance during a seismic event may not
help reaching the structural performance to ‘Immediate Occupancy’ level. Expensive retrofitting options like ‘Seismic Isolation’ and ‘Internal Concrete Box’ have added advantage to withstand multiple earthquake events over the cheaper methods such as ‘Splint and Bandage’ and ‘Jacketing’.

From the recent construction trend in Bangladesh, it can be estimated that the cost of seismically sound 3 storey new R.C.C building of same area as the current URM building is approximately 19.43 million BDT. Table 1 represents the cost of different retrofitting options in comparison with a new construction.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Retrofitting Options</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jacketing</td>
<td>33%</td>
</tr>
<tr>
<td>2</td>
<td>Base Isolation</td>
<td>92%</td>
</tr>
<tr>
<td>3</td>
<td>Internal Concrete Box</td>
<td>84%</td>
</tr>
<tr>
<td>4</td>
<td>Steel Strong Point</td>
<td>83%</td>
</tr>
<tr>
<td>5</td>
<td>Splint &amp; Bandage</td>
<td>22%</td>
</tr>
</tbody>
</table>

It is clear from table 1 that, the cost of ‘Splint and Bandage’ is only 22% of a new build whereas; cost of ‘Base Isolation’ is as high as 92% of a new build. Therefore, retrofitting by ‘Jacketing’ and ‘Splint and Bandage’ can be tried frequently where the major concern is ‘Life Safety’ rather than ‘Immediate Occupancy’. Expensive retrofitting methods like ‘Base Isolation’, ‘Internal Concrete Box’ and ‘Steel Strong Point’ can be applied to the buildings which are under preservation orders because of their historical importance.

5. Conclusion

‘Splint and Bandage’ is the most cost effective method of retrofitting in so far as ‘Life Safety’ level of structural performance is concerned. Retrofitting by this technique would afford occupant’s egress following a seismic event. The building may require substantial structural or cosmetic repairs and it is uncertain whether the retrofitted structure will perform in subsequent events. Expensive retrofitting options are more suitable for structures requiring the external facade to be intact during a seismic tremor. Though these options are costly and require more time in construction, retrofitting by these methods will enable the structure to withstand multiple earthquake events.

Acknowledgement

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References


Public Works Department Bangladesh (2008). Schedule of Rates for civil works