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SEISMIC RETROFIT OF IRANIAN MASONRY SCHOOL BUILDINGS BY SHOTCRETE

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Abstract

One of the most important undertakings of Iran in reducing the seismic vulnerability of the country against earthquakes is dedication of more than 4 billion dollars to reconstruct the seismically dangerous school buildings and retrofit the vulnerable ones. "Organization for Development, Renovation and Equipping Schools of Iran (DRES)" is the sole organization in the country which is responsible for execution of seismic risk reduction plan in the school buildings. This paper is a brief review of the national project and achievements for retrofitting school buildings in I.R.Iran; mainly performed by shotcreting of peripheral walls.

Keywords: Shotcrete; Masonry school buildings; Seismic retrofit; Iran

1. Introduction

A glimpse into school buildings seismic vulnerability shows that nearly 90% of school buildings in Iran, constituting close to 400 thousand classrooms, are constructed of unreinforced clay-unit masonry (Figure 1). As an example shown in Figure 2, the majority of these masonry schools are single-story buildings [1]. Approximately 84% of school buildings in Iran are located in regions with high seismicity. Moreover, two-thirds of these buildings were constructed before seismic design requirements existed. As a result, Unreinforced Masonry (URM) schools buildings are the most life-threatening structural type in Iran. In response to this need, Iranian Parliament granted 4 billion dollars in 2007 according to the 4th Development Plan in order to demolish and reconstruct the seismically dangerous schools and retrofitting the vulnerable ones. According to this law, 132 thousands classrooms should have been demolished and reconstructed and 126 thousands ones should have been retrofitted. In the following, the plan was extended for another 4 years in 2012 to improve life safety of school buildings throughout Iran. In this paper, Iran's achievements in reconstruction and retrofit of masonry school buildings is elaborated with the emphasis on the details including shotcreting of peripheral walls as the major retrofitting method in recent years.

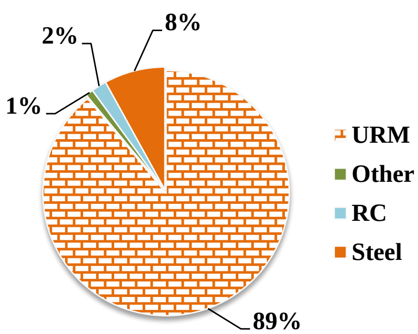


Fig. 1- Structural distribution of school buildings in Iran

Fig. 2- Example of an Iranian masonry school building

2. Failure modes of Iranian masonry school buildings

Although an earthquake will reveal case-dependent damage patterns for a particular building, some commonalities in damage continue to be recognized as a result of moderate or strong earthquakes. Photos of representative damage patterns are shown in Figure 3. These damage categories include failure of: (a) out-of-plane walls, particularly those walls that do not support gravity loads, (b) in-plane cracking of shear walls, (c) collapse of parapets, and (d) overturning of fence walls surrounding a school. Recognizing these patterns, obvious retrofit measures can be employed such as tying walls to roof diaphragms, strengthening shear walls, bracing parapets and providing lateral support of fence walls. More information on specific retrofit methods are given later in this paper, but identification of these common damage patterns helps one to understand how mitigation efforts might be strategically made on a country-wide basis.

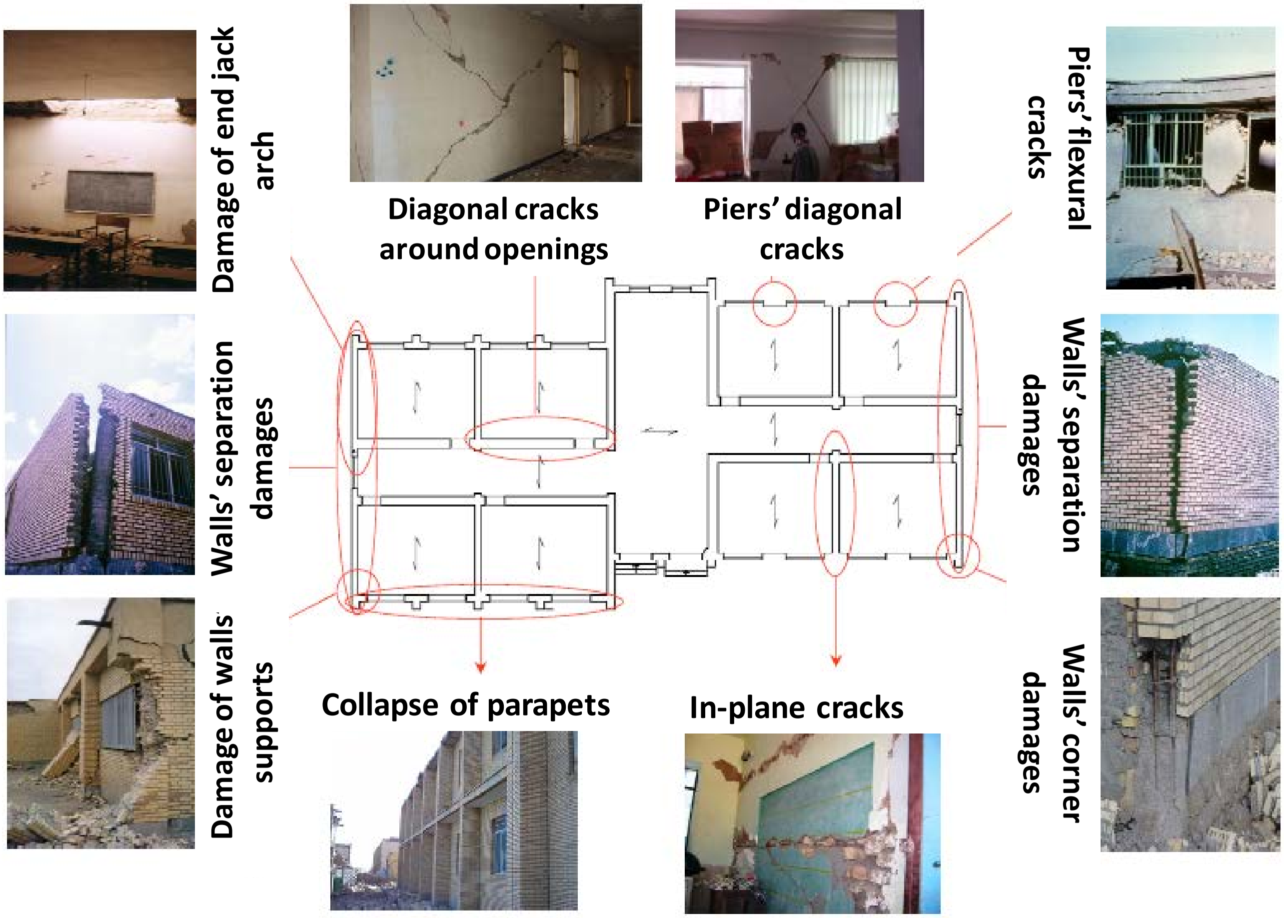


Fig.3- Failure modes in Iranian masonry school buildings [2]

3. Actions cycling in retrofitting projects

Procedure of complete retrofitting is a comprehensive method of evaluation that starts from project selection and covers all steps of study and finally enters to part of construction. Management of a large amount of these projects adds to the importance of accurate monitoring method which is shown in Figure 4. In this circulation, selection of retrofitting and geotechnical and material consultants is the next step after the project selection stage. Totally, qualitative report, geotechnical and materials testing, analysis report, preliminary retrofitting plan, final retrofitting plan are presented. All of this process is controlled by peer reviewer.

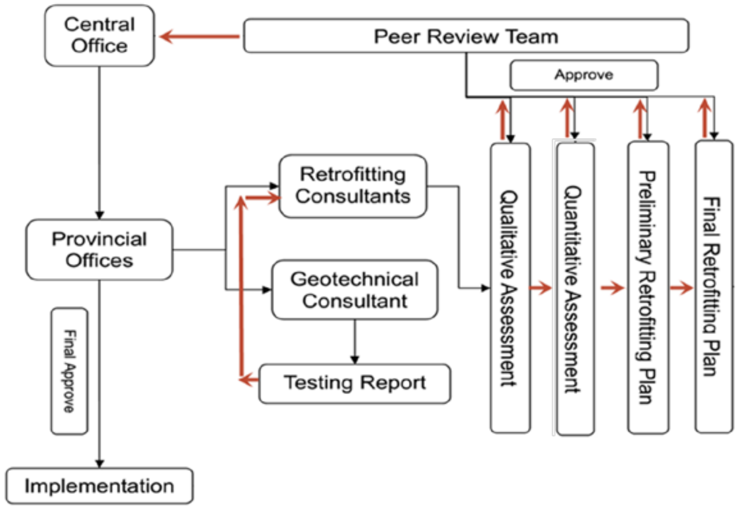


Fig.4- Schematic representation of the study process of retrofitting projects [3]

Results of the retrofitted school buildings and statistical analysis of this project show that strategy of retrofitting for a large number of buildings are completely different from limited number of buildings. Main reasons for this different are as follow:

- Seismic evaluation for retrofitting with prevailing methods consumes lots of time; so, this could not be practical for low rise buildings with small area.
- Large parts of each building need rehabilitation in final retrofitting plan that was prepared by consultants. So, high area of cladding and flooring should be diminished and reconstructed. Consequently, total cost and time of retrofitting increase in these projects for interior changes in buildings.
- Construction of these projects consumes lots of time, and cannot be finalize during restrained time (3 months for school retrofitting).

For these reasons finding a new strategy for retrofitting of a large amount of buildings is essential.

4. Common masonry school buildings in Iran

4.1 Seismic retrofit of walls

Confined and unconfined masonry walls are frequent type of the Iranian masonry school buildings; in contrast, reinforced masonry buildings are rare in Iran. Strength of concrete in tie columns and tie beams is much low due to lack of supervision in this type of the building. Table 1 shows average results of experimental tests in the Iranian masonry school buildings.

Table 1- Results of strength of materials tests

Type of test	Min (Kg/cm^2)	Max (Kg/cm^2)
compressive strength of concrete	80	160
compressive strength of brick	60	120
Shear strength of mortar	1	3

4.2 Improvement of diaphragm rigidity and integrity

Jack arch slab as the dominating roof system in the Iranian masonry school buildings consists steel beams that are covered by brick arches. They were used extensively in previous decades in Iran. The results of past earthquakes in Iran e.g. Boin Zahra,1962, Dashte bayaz,1968, Rudbar, 1990, and Bam, 2003 show that lack of integrity and rigidity are the main deficiencies of this slab that should be considered in retrofitting (Figure 5). Moreover, this slab should be assigned to the flexible diaphragms based on Iranian National Seismic Code [4].

Fig. 5- Collapse of jack arch slabs (partial and complete) for lack of integrity

Prevailing methods for seismic retrofitting of this slab type are: lying reinforce concrete layer on top of the slab, Diagonal steel bracing, two-way jack arch. The explanation of each method is described below.

4.2.1. Lying reinforce concrete layer on top of the slab

The first step for execution of this method is to diminish floor covering, then shear studs are connected on the beams and in final step concrete is placing on the slab. The available bricks could act as a mold in this method. The main points of these methods are: increase in total weight of a building and high cost of construction; however, integrity and rigidity are advantages of this method that have direct result on total cost reduction of retrofitting (0a).

4.2.2. Diagonal steel bracing

In this method, the retrofitting actions are done from bottom of slab. In this regard, one band of slab cladding is scratched away and ties steel bracing are connected to the beams. Finally, ends of these ties are welded to the corner angles of walls. The main advantages of this method are cost effective and light weight of added elements. However, experimental tests show that this method could not provide rigidity in jack arch slab (Figure 6b).

4.2.3. Two way jack arch

In this method the brick panel of jack arch slab is divided to the smaller parts by installation of secondary beams that are perpendicular to the main beams. This method is costly and cannot provide the rigidity in the slab (Figure 6c).

A) Lying reinforce concrete layer on top of the slab   B) Diagonal steel bracing   C) Two way jack arch

Fig.6- Samples of jack arch retrofitting methods

5. Shotcreting of masonry walls for seismic retrofitting; typical retrofitting pattern

The results of studies reveal that the retrofitting process in Iran is a very time-consuming and costly one. Covering all the stages in this process for structures with close details and specifications has been rarely experienced before in any countries. It was because this organization has been considered new methods and criteria for its retrofitting projects. In more than two years the different methods were studied and discussed. Various reports in this realm have been published and the results finally came in the form of new instructions about the new method for retrofitting of school buildings – Typical Retrofitting Pattern (TRP). The utilization of these new instructions was started in 2009 on limited number of school buildings and led to satisfactory results.

Typical retrofitting patterns increase performance level of buildings to assumed target level with specific methods; however, minor deficiencies exist after retrofitting by this strategy. Required time for seismic evaluation based on this strategy considerably decreases because the long-time preparing and verification are eliminated. This organization follows three following goals in development of these methods:

- **Reducing the studying time of retrofitting projects:** since a lot of school buildings should have been retrofitted according to unique methods and because of the close structural details, passing all the steps in retrofitting procedure for each of them is not logical. Moreover, this will require much longer period of time to achieve our goals in retrofitting of all school buildings in 5 years.

- **Increasing the speed and quality of execution of projects:** since implementation of these instructions leads to a unique retrofitting specifications and details, this will result in fast adaptation of the contractors with the executive methods and providing them with the equipment for a repetitive process.

- **Reducing the cost of retrofitting process:** the total cost of the project greatly depends on the required time of the project, the speed of execution and the amount of necessary equipment of the contractors. So repetition of the projects details and equipment will result in considerable cost saving in the retrofitting projects.

There are four retrofitting methods for masonry school buildigns developed by Organization for Development, Renovation and Equipping Schools of Iran (DRES); these include shotcreting the walls, center core, providing saferoom and adding reinforced concrete shear walls to the building. Among these method, shotcreting the walls is the mostly applied retrofit method by DRES in recent years. This method has been chosen based on the successful experiences from other countries and numerous experiments on masonry walls. In this method, the surrounding area of the single-story URM building is shotcreted. The size of rebar and the thickness of concrete are chosen in such a way that can fulfill the seismic demand of each building. In calculation of the base shear of buildings, the total weight of the structure plus the brick walls are considered and load-bearing capacity of the walls is neglected. The roof of the buildings in this class is usually jack-arch which should be converted to composite concrete. Figure 7 shows some samples of this project which have been executed in summer 2010 [5].

Fig. 7- Samples of retrofitted school buildings with peripheral shotcrete (*www.dres.ir*)

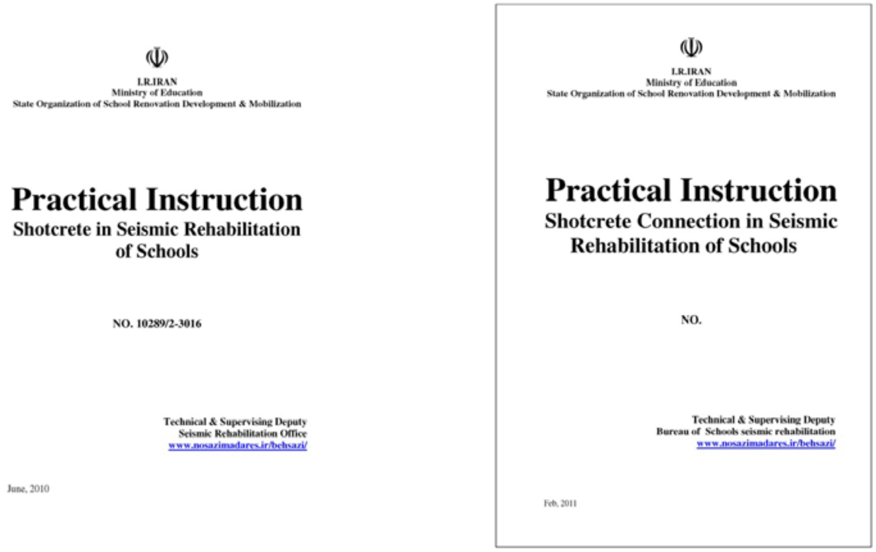


Fig. 8- Two guidelines for shotcreting masonry buildings [6,7]

In order to facilitate using shotcrete method, DRES developed two ptractical guidelines each containing various prescriptive details of shotcrete (Figure 8). These include the details of connection to the perpendicular walls (considering both confined and unconfined masonry walls), connection from the wall to the roof (considering various roof systems), connection from the walls to the foundation, shocrete details for areas around the openings and may other details. Examples of these detals are presetend in Figure 9 and Figure 10.

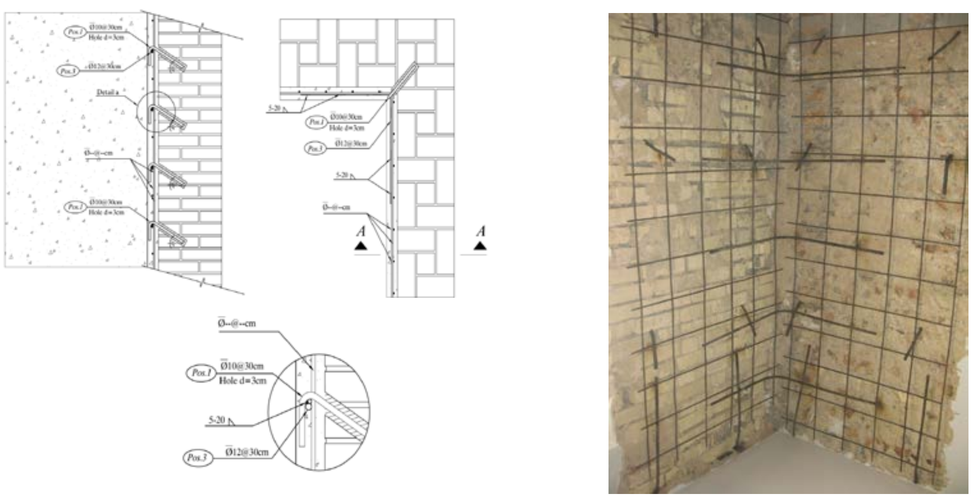


Fig.9- Examples of connection of shotcrete at walls' intersections

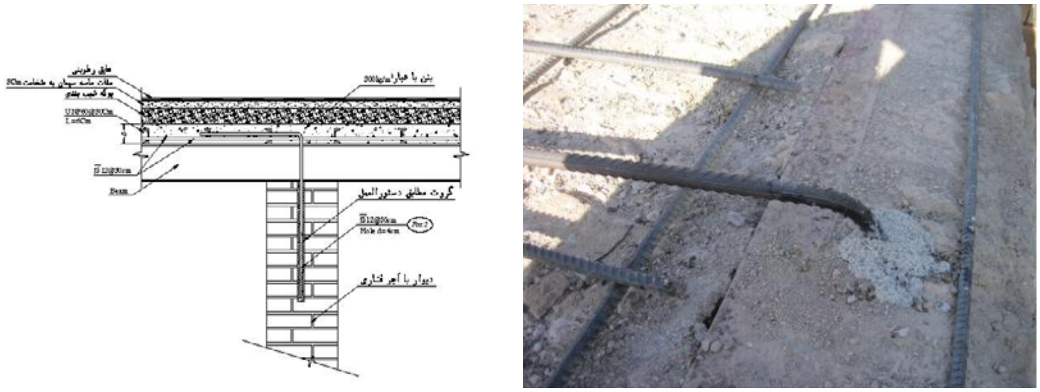
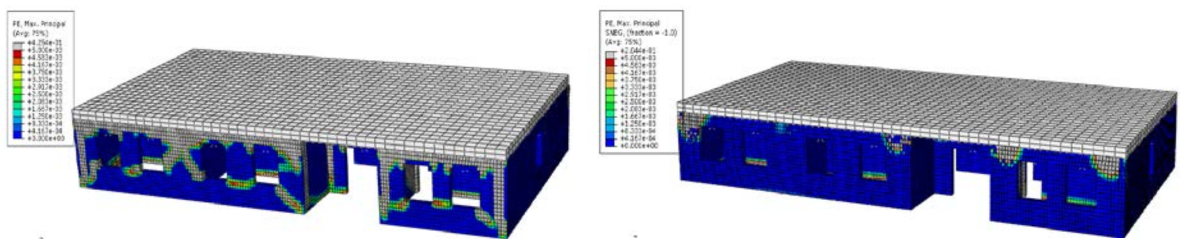


Fig. 10- Examples of connection of shotcrete to the roof

Apart from the recommended prescriptive details, several studies have been performed in order to evaluate the effciency of shotcrete method in reducing the seismic risk of Iranian masonry school buildings. DRES has been supporting three research projects in which various details of shotcreting masonry walls are to be studied making use of static cyclic loading and shaking table tests. Also, there are several numerical studies, among which the stuidies performed by Raissi et al. [8] can be mentioned (Figure 11).



a) Unretrofitted model b) Shotcreted model

Fig. 11- Numerical simulation of the effect of shotcreting on reducing walls' damages [8]

6. General strategy for retrofitting

The main concept to improve seismic performance of masonry buildings is to provide integrity of the buildings. In most of cases, lack of attention to the integrity of masonry buildings in earthquakes led to severe damages in this type of building. So, the general strategy of retrofitting should provide integrity of masonry building in earthquake. Providing slabs integrity and rigidity causes the general integrity of the masonry buildings. For instance, the jack arch slab is common slab type in Iran. This type has two main disadvantages: lack of integrity and rigidity; furthermore, compositing of this slab could provide general integrity of the building. Completing of tie beams and tie columns with steel members could provide general integrity in other cases that slab rigidity is not required or in light weight slabs. This method is schematically described in Figure 12. The more general strategies for retrofitting of masonry school buildings based on the selected retrofit method are also shown in Table 2 with shotcreting method highlighted as a part of this table.

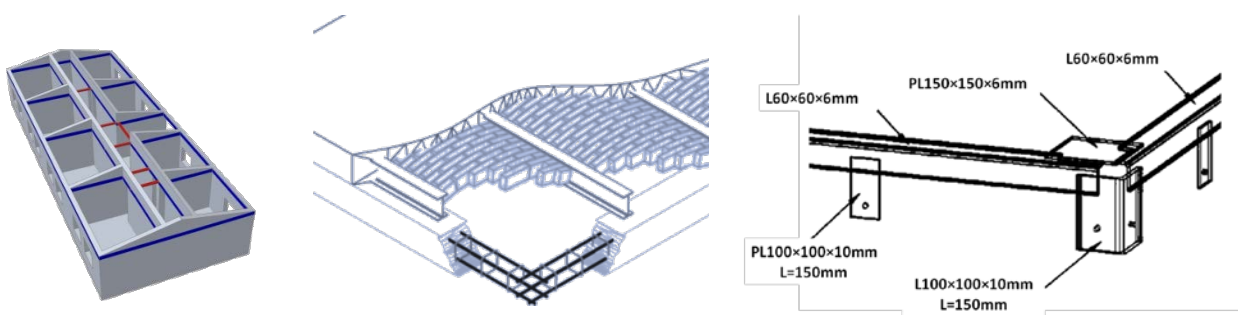


Fig. 12- Providing integrity by using of steel members

7. Effect of unification of retrofit methods on cost of retrofitting projects

There are three approaches have been implemented in school retrofitting projects: Typical Retrofitting patterns (2010 up to now), modifying retrofitting patterns based on cost distribution and performance level of structural elements, correction of details. Figure 13 shows the variation of school retrofitting cost according to time in recent years. These data is presented based on analyses of 90 schools in different provinces of Iran. As can be seen, the average retrofitting cost was about 175US$ (per m2) in 2008 and following from the new strategies resulted in reduction of 100US$ (per m2). Furthermore, the variation of total costs in different projects has decreased by pursuing of these strategies. Accurate estimation of time and cost is the direct result of this reduction. Also the cost of each major part of retrofit and renovation projects in complete retrofitting-renovation projects and TRP's are compared in Figure 14 which shows considerable reduction in each part and also more allocation to structural part.

Table 2- Current strategy of masonry buildings in Iran for Building in region with 0.25<PGA≤0.35

	One story masonry building						
	No Action	*Peripheral Shotcrete*		*Shear wall and shear box*		*Shear Supply*	
	Light Weight	*Jack Arch Slab*	*Concrete Slab*	*Jack Arch Slab*	*Concrete Slab*	*Type of slab*	
Building in region with 0.25<PGA≤0.35	✓ *Strengthening of connections* ✓ *Slab replacement*	✓ *Composite Slab*	✓ *No Action*	✓ *Composite Slab*	✓ *No Action*	*Slab retrofitting method*	*Building without tie column*
	✓ *No Action*	✓ *Center Coring* ✓ *No Action*	✓ *Bar implant in ties*	✓ *Center Coring*	✓ *Demolish and rebuild* ✓ *Bar implant*	*Connection of slab &lateral loading system*	
	✓ *Control of corner* ✓ *Piers* ✓ *Free edge of wall* ✓ *Strengthening of walls connections* ✓ *Out of plane control*	✓ *Control of corner* ✓ *Center Coring* ✓ *No Action* ✓ *Out of plane control*	✓ *Control of corner* ✓ *No Action* ✓ *Out of plane control*	✓ *Control of corner* ✓ *Center Coring* ✓ *Out of plane control*	✓ *Control of corner* ✓ *Out of plane control*	*Providing stability of members*	
	✓ *Installation of steel member* ✓ *Strengthening of ties connections* ✓ *Completing of ties*	✓ *No Action*	✓ *No Action*	✓ *No Action*	✓ *No Action*	*Providing integrity of building*	
	✓ *Strengthening of connections* ✓ *Slab replacement*	✓ *Composite Slab*	✓ *No Action*	✓ *Composite Slab*	✓ *No Action*	*Slab retrofitting method*	*Building with tie beam and tie column*
	✓ *No Action*	✓ *No Action*	✓ *Bar implant in ties*	✓ *Center Coring*	✓ *Demolish and rebuild* ✓ *Bar implant*	*Connection of slab &lateral loading system*	
	✓ *Piers* ✓ *Out of plane control*	✓ *Out of plane control*	✓ *Out of plane control*	✓ *Control of corner* ✓ *Out of plane*	✓ *Control of corner* ✓ *Out of plane*	*Providing stability of members*	
	✓ *Strengthening of ties connections* ✓ *Completing of ties*	✓ *No Action*	✓ *No Action*	✓ *No Action*	✓ *No Action*	*Providing integrity of building*	

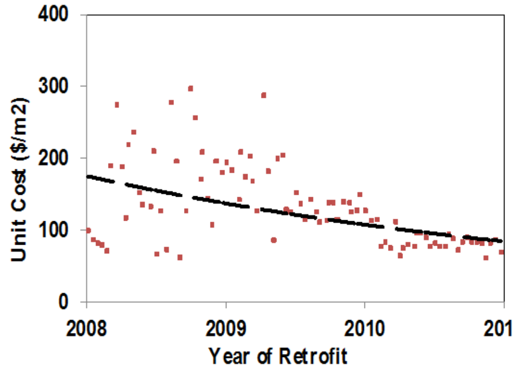


Fig. 13- Variation of retrofitting cost of schools in recent years

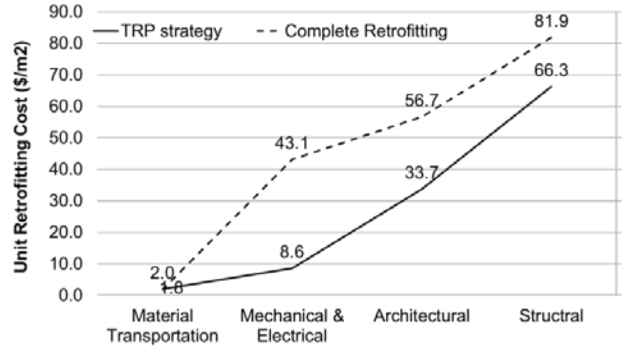


Fig. 14- Cost of each major part of retrofit and renovation projects

8. Achievements of the demolition, reconstruction and retrofitting schools law

An overview on achievement of last nine years is presented in this section. In Figure 15, numbers and area of retrofitted and reconstructed classrooms from 2006 to 2014 are shown. According to the statistics, The Islamic Republic of Iran has upgraded seismic safety of more than 28000 classrooms (equal to 1 million m2) in the form of retrofitting and more than 55000 classrooms (equal to 6.5 million m2) in the form demolition and reconstructing from 2005 to 2014. It is noteworthy than although the number of reconstructed classrooms is considerably higher than the retrofitted ones, the rate of retrofitting projects is increasing compared to the decreasing rate of the reconstruction projects.

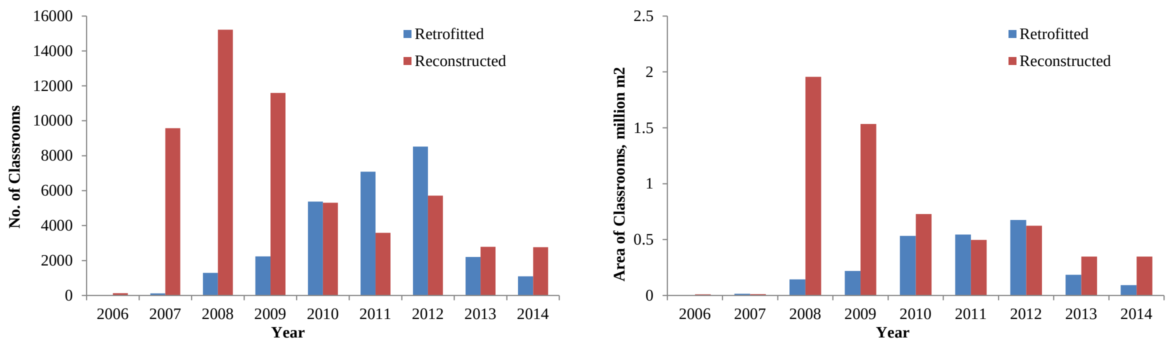


Fig. 15- Number and area of reconstructed and retrofitted classrooms from 2006 to 2014

DRES has made a major contribution towards structural development in implementation and retrofitting of school buildings and also promoting safety culture of students and school staff awareness that lead to disaster risk reduction in Iranian schools in the last 10 years. As a result of these efforts, there are great consequences in upgrading safety level of schools. For example a 6.4 Richter scales earthquake occurred in the city of Ahar (East Azerbaijan) in Aug. 2012 that caused damages on many buildings. Survey was conducted to evaluate the post-earthquake condition of East Azerbaijan province. Based on the survey, no damage was observed on newly constructed schools. From the post-earthquake condition, it can be concluded that the retrofitting and construction approaches adopted for the schools of this province have successfully prevented the school buildings from major damages. As a comparison, there were some houses located near school buildings that were seriously affected by the earthquake shaking. Figure 16 shows the post-earthquake condition of reconstructed schools.

Fig.16- Example of a survived shotcreted masonry school building after Ahar earthquake of 2012

9. Concluding remarks

Unreinforced masonry buildings constitute nearly 90% of the inventory of school buildings in Iran. Significant percentages of unreinforced masonry school buildings can also be found in other countries. Changing occupancy or lowering of the seismic demand forces are not options to enhance seismic integrity. The extensive seismic retrofit program underway in Iran serves as a good example in terms of depth, focus and technical direction for upgrading seismic safety in other countries. Programs must be put into place for comprehensive assessment of vulnerabilities, and retrofit measures to ensure the safety of the next generations. The Iranian experience is important in terms of accepting such a wide-range seismic retrofit challenge, not only from a structural engineering perspective, but also in terms of forming and executing a national assertive plan for protecting our young populace from disaster.

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