New Approach to seismic Rehabilitation of Masonry School Buildings

A.Mahdizadeh, J.Borzouie, M. Raessi
State Organization of Schools Renovation and Mobilization

SUMMARY:
According to the retrofitting program of Iran, state Organization of schools renovation has to retrofit 126010 classrooms. The results of this retrofitting program have shown that the retrofitting strategy for low rise masonry buildings needed to be reviewed for the following problems. First, required time for evaluation was high in comparison with dimension of this type of buildings. Secondly, similarity between defects of these buildings led to minor differences between final retrofitting plans. So, the new strategy was designed on the basis of typical retrofitting plans for the rehabilitation of one story masonry buildings. The first part of this study touches on the issue of statistical analysis of school masonry buildings according to earthquake hazard zoning, year of construction, number of stories, type of slab, dimensions of buildings, etc. The result of the statistical analysis describes that most of Iranian school buildings have similar defects and small dimension. Finally, feedbacks of this new approach show that the new approach considerably reduces the evaluation and construction time.

Keywords: School retrofitting, typical retrofitting pattern, Masonry buildings, Jack arch slab

1. INTRODUCTION

Iranian Parliament granted 4 billion dollars in 2007 according to 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.

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:

1. Seismic evaluation for retrofitting with prevailing methods consumes lots of time; so, this could not be practical for low rise buildings with small area.
2. 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.
3. 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.

2. QUALITATIVE EVALUATION OF THE SCHOOL BUILDINGS WHICH SHOULD BE RETROFITTED

Results of statistical analysis in school buildings are in table1.

Table 1: Qualitative results of school buildings

<table>
<tr><td colspan="2">Type of Roof</td><td colspan="2">N.Story</td><td colspan="2">Type of Structure</td></tr>
<tr><td>4.99</td><td>Concrete</td><td rowspan="4">86.09</td><td rowspan="4">1 story</td><td rowspan="6">88.53</td><td rowspan="6">Masonry</td></tr>
<tr><td>9.70</td><td>Wood</td></tr>
<tr><td>5.35</td><td>Other</td></tr>
<tr><td>79.96</td><td>Jack arch masonry</td></tr>
<tr><td></td><td></td><td>12.40</td><td>2 story</td></tr>
<tr><td></td><td></td><td>1.51</td><td>3&More</td></tr>
<tr><td></td><td></td><td></td><td></td><td>7.98</td><td>Steel</td></tr>
<tr><td></td><td></td><td></td><td></td><td>2.00</td><td>Concrete</td></tr>
<tr><td></td><td></td><td></td><td></td><td>1.49</td><td>other</td></tr>
</table>

This table shows that more than 75% of the buildings in this project are one story and more than 80% have the jack arch masonry slab. As a result, most of the Iranian schools have similar seismic deficiencies. Recognition of these deficiencies is important step that could lead us to unique strategy. This new strategy is the best method for risk reduction in Iranian schools. Furthermore, the strategy could be effective in schools that were assigned to diminish and reconstructed group.

3. COMMON IRANIAN MASONRY WALLS

Confined masonry walls are frequent type of the Iranian masonry 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 2 shows average results of experimental tests in the Iranian masonry school buildings.

Table 2: 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

Furthermore, the distance of tie columns is limited to 5 meter based on Iranian code for seismic resistant design of buildings (Standard No.2800).

4. JACK ARCH SLAB AND CURRENT RETROFITTING METHODS OF THIS SLAB

Jack arch slab is steel beams that are covered by brick arches. They were used extensively in previous decades in Iran. The results of past earthquakes in Iran like Boin Zahra.1962, Dashte bayaz.1968, Rudbar.1990, Bam.2003 show that lack of integrity and rigidity are the main deficiencies of this slab that should be considered in retrofitting. Moreover, this slab should be assigned to the flexible diaphragms based on Iranian standard code No.2800.

Figure 1: 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.

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 dim point of this method 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.

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 m,ain 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.

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.

A. Lying reinforce concrete layer on top of the slab

B. Diagonal steel bracing

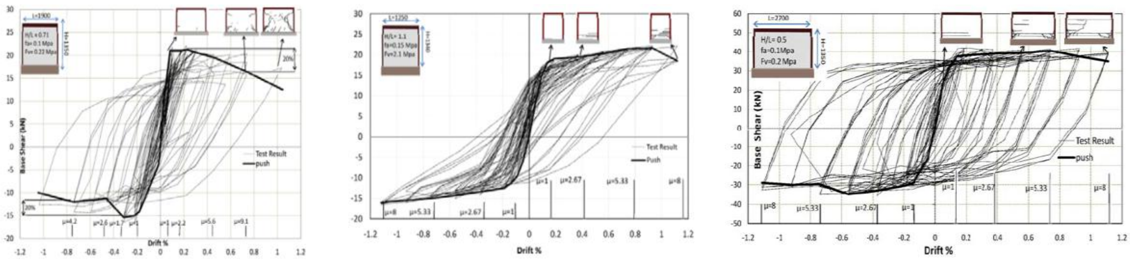
C. Two way jack arch

Figure 2: Samples of jack arch retrofitting methods

In the rest of this section, rigidity of jack arch slabs in each retrofitting methods are explained. In this regard, stiffness of jack arch slab and each masonry wall (as a lateral loading system) are compared together. All the results are based on experiments that were done in recent years in Iran. In 2009, typical Iranian retrofitted and un-retrofitted masonry walls with different aspect ratios on a scale of 1:2 were experimentally tested by Khan Mohammadi et al. Figure 3 and Table 3 show the results of these tests.

Table 3: Results of experimental tests on masonry retrofitted and Un-retrofitted walls

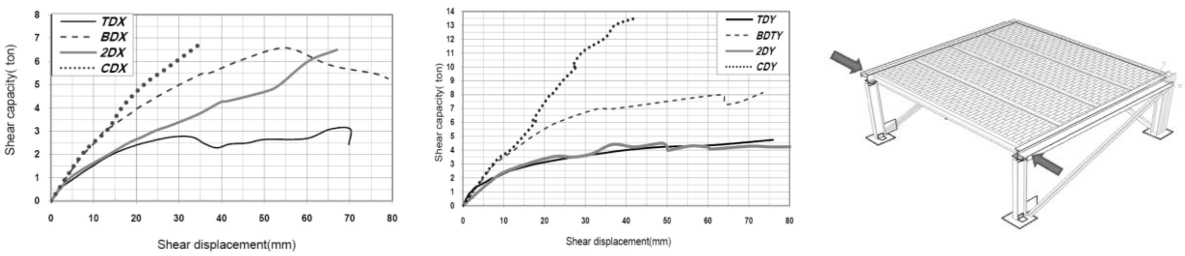
Sample	Length(m)	Thickness(cm)	Height (cm)	Ratio of height to length	Ratio of height to thickness	f`c of brick	mortar Shear strength(Kg/cm^2)	f`c of mortar (Kg/cm^2)	σ` (Kg/cm^2)	$K_{effective}$ (positive) (KN/mm)	$K_{effective}$ (negative) (KN/mm)	$K_{effective}$ (Average) (KN/mm)	Total strength (positive) KN	Total strength (negative) KN	Total strength KN
URMW-1	270	16	140	0.5	8.75	91	2	80	1	20.6	31.2	25.9	41.7	34.7	38.2
URMW-2	190	11	140	0.71	12.75	87	2.2	84	1	6.7	21.4	14	22.1	15.4	18.75
URMW-2	125	16	140	1.1	8.75	82	2.1	75	1.5	8.6	11.6	10.1	22.2	16.5	19.35



URMW-2 *URMW-2* *URMW-1*

Figure 3: Hysteretic behaviour of models (Khan Mohammadi et al,2009)

Mirjalili et al (2009) has done experimental researches on the jack arch slabs in order to evaluate rigidity, total strength and ductility of this type of slab that were retrofitted by constructing composite slab, Diagonal steel bracing, two way jack arch. Finally, performance of different retrofitting methods was compared with un-retrofitted jack arch slab. Figure4 and Table3 show the results of these tests.



C *B* *A*

Figure 4: A. Schematic test's setup, B. results of imposing lateral load in direction of jack arch beams, C. results of imposing lateral load perpendicular of jack arch beams (Mirjalili et al,2009)

Table 3: Results of experimental tests on Jack arch slab (Mirjalili et al, 2009)

Type of slab	Force parallel to jack arch beams		Force perpendicular to jack arch beams	
	Shear capacity(KN)	Slab rigidity (KN/mm)	Shear capacity(KN)	Slab rigidity (KN/mm)
Un-retrofitted	28	0.62	42.5	1.27
Retrofitted by tie bracing	65	2.2	96	2.65
Retrofitted with two way jack arch	60	1.46	59	1.74
Retrofitted by Composite slab	>80	2.84	14	3.31

Considering the above figures and tables show us good indices for rigidity evaluation of jack arch slab in masonry building. Table 4 shows ratios of strength and stiffness of wall to slab for different types of slab retrofitting and aspect ratios of wall.

Table 4: strength and stiffness ratios of wall to slab

Type of slab	Wall	Stiffness ratio of wall to diaphragm			Strength ratio of wall to diaphragm		
		URMW-1	URMW-2	URMW-2	URMW-1	URMW-2	URMW-2
Direction of beam and load are perpendicular	Unretrofitted slab	41.8	22.6	16.3	1.4	0.7	0.7
	Retrofitted by tie bracing	11.8	6.4	4.6	0.6	0.3	0.3
	Retrofitted with two way jack arch	17.7	9.6	6.9	0.6	0.3	0.3
	Retrofitted by Composite slab	9.1	4.9	3.6	0.5	0.2	0.2
Direction of beam and load are parallel	Unretrofitted slab	20.4	11	8	0.9	0.4	0.5
	Retrofitted by tie bracing	9.8	5.3	3.8	0.4	0.2	0.2
	Retrofitted with two way jack arch	14.9	8	5.8	0.6	0.3	0.3
	Retrofitted by Composite slab	7.8	4.2	3.1	0.3	0.1	0.1

It is obvious from Table4 that stiffness ratios of wall to diaphragm in all of the cases are more than 2; moreover, the length of the slab in these tests was 3.6m; so, in real buildings with larger bays the rigidity of diaphragm decreases. What's more, the scale factor of walls was 1:2, thus minimum real stiffness of walls are two times of these data. In addition, in real projects, each slab is supported by two resistance lines of masonry walls; however, in this test the stiffness of only one wall was considered.

As a result, for the current Iranian masonry buildings with jack arch slab the ratio of $\frac{\Delta_{Diaph}}{\Delta_{Story}}$ is more than two. So, this type of slabs should be assigned to the flexible diaphragms. Additionally, the large difference between strength of slab to masonry walls shows that the integrity of slabs could be provided if masonry walls are not faced with serious damage during earthquake, and the current slab retrofitting methods could provide sufficient strength in the jack arch slab.

5. CURRENT METHOD FOR SEISMIC EVALUATION OF MASONRY BUILDINGS

Current method for seismic evaluation of Iranian masonry buildings takes root in FEMA 356 (FEMA 356). In this method, base shear of building is evaluated based on weight of building, stories, and objective earthquake hazard level and this force is distributed between different stories with consideration of weight and height of each story from the ground. In the next step, slab and wall rigidity are determined force distribution between masonry walls. In the final step, acceptance criteria are compared force with strength of each wall.

This evaluation is not considered the effect of two horizontal components of earthquake. In contrast, high weight of these walls increases the importance of this effect. Furthermore, fewer experiments were dedicated to this topic, and in these experiments the force was imposed by deformation-control. So, the direct result of these tests resulted in large ductility of masonry walls. However, Force- control is the real mechanism of loading in masonry Walls.

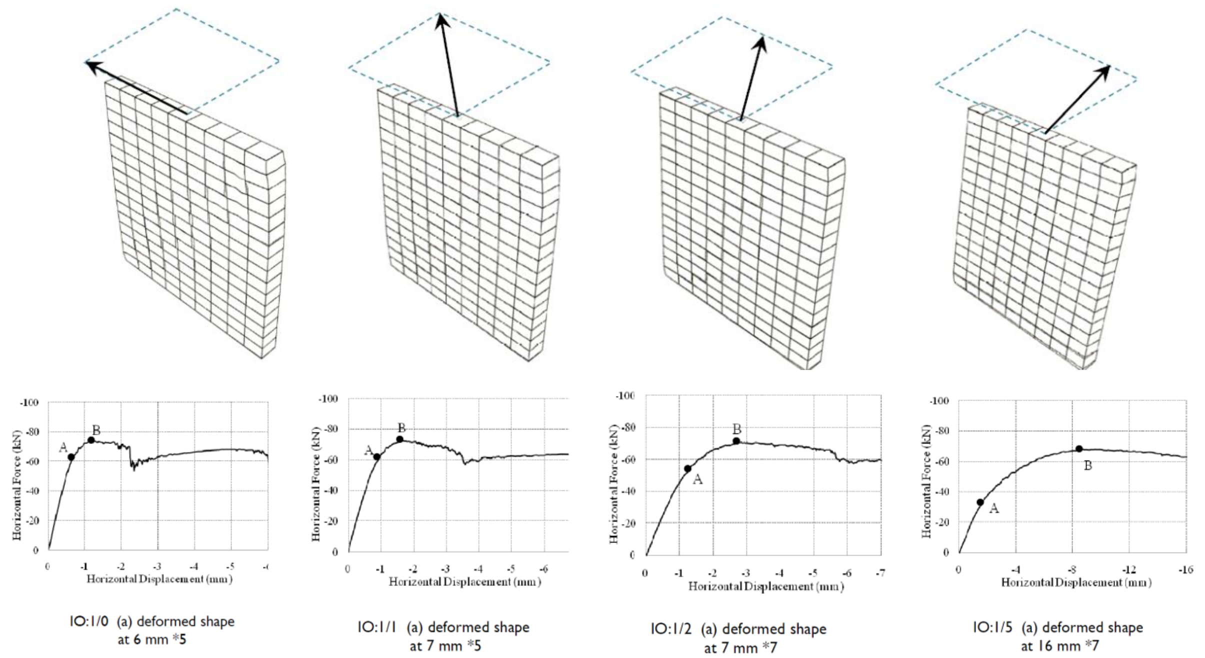


Figure 5: Increasing of ductility of masonry wall in earthquake with two horizontal components (Dolatshahi,2011)

Dolatshahi (2011) indicated that into two directional lateral loading the ductility of a masonry wall decreases considerably for force-control loading mechanism. Actually, the masonry wall can be unstable with minor out of plane loading when in-plane load imposes to the wall. This phenomenon can be observed in tilting of a masonry wall that is subjected to in- plane loading and its high ductility. In addition, the experience of last 5 years of school retrofitting in Iran show that following from this strategy leads to extend of retrofitting process in all parts of building. So, cost of retrofitting project increases due to renovation of architectural and mechanical and electrical facilities. The new strategy of school retrofitting for small masonry buildings is based on stability of elements in the building, and it is described in the next section.

6. GENERAL STRATEGY OF RETROFITTING

General performance of masonry buildings in previous earthquakes shows that although strength of walls was much higher than earthquake force, several cracks appeared on them. These cracks divide the masonry walls to major parts that oscillate independent from the masonry building. Most of damage in masonry buildings is rooted in lack of stability of these elements in masonry buildings. So, retrofitting process of masonry building can be divided into two main categories: The first step is to provide sufficient total strength of masonry building against earthquake shaking, and in the next step, stability of each element should be provided. The general methods for retrofitting of masonry buildings are combination of these two methods.

7. PROVIDING LATERAL STRENGTH OF BUILDINGS

If the rigidity of slab is sufficient then lateral strength of a building is provided by concentric methods. These methods are categorized in three types in Iran: shear wall, shear box and peripheral shotcrete.

Shear wall: In this method tables of shear walls and piles capacity are proposed with different bar sizes and arrangements, compressive strength of concrete, and soil types, and in the next step, standard detailing is presented. A structural engineer can rapidly calculate number of shear walls and their lengths, bars arrangement by calculation of base shear. The strength of masonry buildings are neglected in calculating of these shear walls.

Figure 6: typical retrofitting by shear wall

Peripheral shotcrete: This method was achieved by experience of other countries and different experimental tests in masonry buildings. In this method, the peripheral of one story masonry building is shotcreted completely. Bars dimension, arrangements and thickness of shotcrete are determined based on lateral earthquake force. Weight of slab and masonry walls are considered in calculation of base shear, and shear capacity of masonry walls are neglected in calculation of the shotcrete.

Figure 7: typical retrofitting by peripheral shotcrete

Shear Box: Peripheral shotcrete leads to extent change in veneer of building. This leads to considerable increase in total cost of retrofitting. The main advantage of shear wall method on the peripheral shotcrete is concentration of this method on minimum area. However, this concentration needs special foundation and piling. Experiences of this project in Iran show that more than 30% of total cost of project is dedicated to the foundation in this pattern. The shear box method tries to solve the above problems. In this method, masonry walls of four classrooms in four corners of school buildings are completely shotcreted. Bars dimension, arrangements and thickness of shotcrete are determined based on lateral earthquake force. So, total cost of foundation and changing in architecture are reduced considerably.

Light weight slabs: Strength is not serious problem in these slabs; however, providing stability is the main index for retrofitting of this type of building.

8. PROVIDING STABILITY OF ALL MASONRY WALLS

Providing stability of structural elements is based on two concepts: First of all, providing general integrity of the building. Secondly, prediction of damage location in earthquakes, and providing the stability of the cracked walls. Consideration of these two concepts is important to propose retrofitting patterns. In some cases providing of sufficient strength leads to providing of these two concepts. In contrast, in other cases it may not happen. As a result, beside of operations to provide strength in building, additional operations should be done to provide stability of elements.

8.1. Providing general integrity of buildings:

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 Figure8.

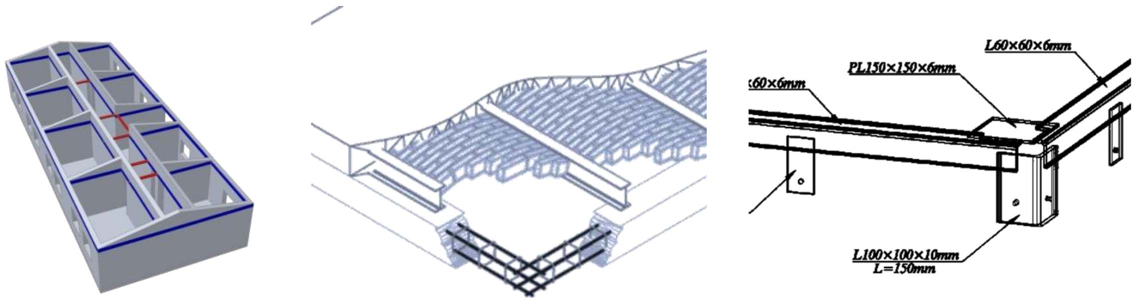


Figure 8: Providing integrity by using of steel members

8.2. Prediction of damage location of the building in earthquake, and providing the stability of the cracked walls:

This prediction is applicable in most of cases. However, high propagation of cracks in building causes that some of them are not considered. Pattern of cracks, importance of crack on whole stability of building and stability of cracked elements should be considered, in addition to the prediction of cracks. Results of past earthquakes show that piers, connection region of perpendicular walls, walls with height of upper than 5m, free edge of walls, and exterior corner of building have high possibility for the cracks. In this regard, damage to exterior corner of building and piers could cause to further instability in whole of the building. Moreover, out of plane control should be checked for all of masonry walls.

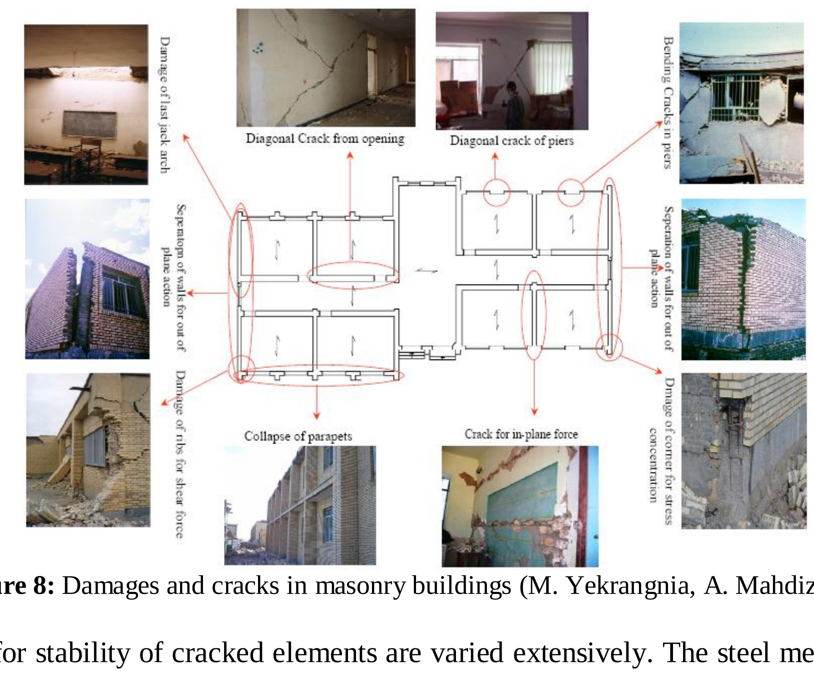


Figure 8: Damages and cracks in masonry buildings (M. Yekrangnia, A. Mahdizadeh)

Current details for stability of cracked elements are varied extensively. The steel members, shotcrete, center coring of full height of wall or only one meter of higher part (causes to considerable increase in out of plane strength of wall due to decrease in free height of wall) can provide stability of cracked walls. The following pictures show the current details to provide this stability of walls in Iran.

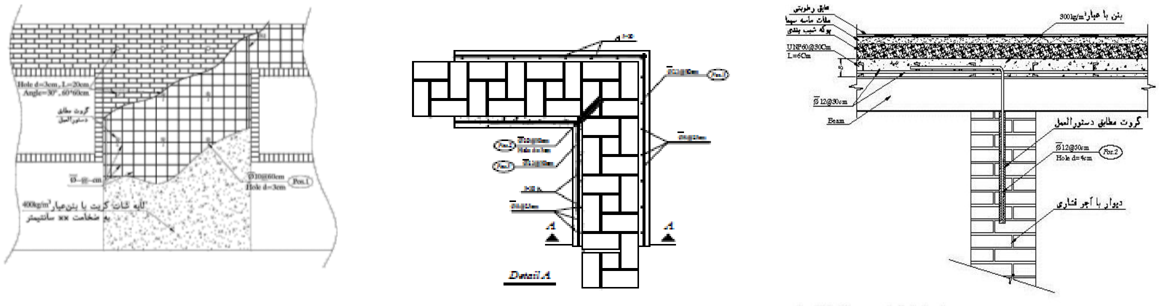


Figure 9: Current details for providing stability in masonry building

Final pattern of retrofitting is combination of related operations to provide stability and strength. The Iranian pattern to follow this strategy is shown in Tables 5,6.

Table 5: 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*	✓ *Diminish&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 ofcorner* ✓ *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*	✓ *Diminish&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 control*	*Providing stability of members*	
	✓ *Strengthening of ties connections* ✓ *Completing of ties*	*No Action*	*No Action*	*No Action*	*No Action*	*Providing integrity of building*	

Table 6: Current strategy of masonry buildings in Iran for Building in region with PGA≤0.25

	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 PGA≤0.25	*Light Weight*	*Jack Arch Slab*	*Concrete Slab*	*Jack Arch Slab*	*Concrete Slab*	*Type of slab*	*Building without tie column*
	✓ *Strengthening of connections* ✓ *Slab replacement*	*Composite Slab*	*No Action*	*Composite Slab*	*No Action*	*Slab retrofitting method*	
	✓ *Strengthening of connections* ✓ *No Action*	*No Action*	*Bar implant in ties*	*No Action*	*Diminish&rebuild*	*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 control*	*Providing stability of members*	
	✓ *Strengthening of ties connections* ✓ *Completing of*	*No Action*	*No Action*	*No Action*	*No Action*	*Providing integrity of building*	

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