LESSONS LEARNT FROM REPAIR PROJECT OF 300 BUILDINGS DAMAGED IN DARB-E-ASTANEH, IRAN EARTHQUAKE OF MARCH 2006

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ABSTRACT :

In 31st March of 2006 an earthquake of 6.1 magnitude hit the Silakhor plain in Lorestan Province, Iran, which affected cities of Boroojerd and Dorood, and created damage in hundreds of building, including houses in these two cites and their neighboring villages. 'Behsazeh-Andishan Aria Consulting Engineers' has been chosen as one the consulting firms for seismic evaluation and retrofit or repair design of damaged buildings, and has been responsible for around 300 buildings in Boroojerd. Most of these buildings were of non-reinforced masonry and semi-skeleton type. At first, seismic evaluation of buildings was performed and then, an estimation of repair costs was done for each case so that the owner of the building can make decision on doing the full repair, doing just minor repair, or demolishing the building. Because of time pressure, and very high number of buildings, doing test on the existing materials was not possible, and this led in some decrease in the precision of seismic evaluation, and therefore the repair design was decided to be conservative to some extent. The repair design in case of brick masonry building was mainly using steel mesh and shotcrete on walls in east-west direction. In some cases the wall section area was not sufficient based on the code requirements, and therefore adding some walls sections was necessary, and in some cases using steel profiles as ties was necessary to give enough integrity to the building. The detailed explanation of the repair design and its challenges are presented in the paper.

KEYWORDS: Boroojerd City, Non-reinforced Masonry, Steel Mesh, Shotcrete

1. INTRODUCTION

In 31st March of 2006 an earthquake of 6.1 magnitude hit the Silakhor plain, in Lorestan Province, Iran. The epicenter of the earthquake was close to Dar-e Astaneh town, and it affected cities of Boroojerd and Dorood, and caused damages in hundreds of building, including houses in these two major cites and their neighboring villages. 'Behsazeh-Andishan Aria Consulting Engineers' was chosen as one of the consulting firms for seismic evaluation and retrofit or repair design of damaged buildings, and was responsible for a project containing around 300 buildings in Boroojerd. Most of these buildings were of non-reinforced masonry, and semi-skeleton type. It is worth mentioning that almost 70% of residential buildings in Iran are of masonry type, mostly non-reinforced and many others are semi-skeleton type, and therefore any study and investigation with regard to these types of buildings is useful for all cities of the country and even countries with similar situation. Table 1 gives some basic information about the retrofit project buildings.

Table 1. The general information about the evaluated buildings

Building Type	No. of Stories			Sub-total
	1	2	3	
Masonry	118	142	38	298
Steel	0	2	3	5
Total				303

The project consisted of two main phases: 1) seismic evaluation, and 2) retrofit or repair design. The fist phase has been presented briefly in another paper by the authors (Aghabeigi et al., 2008), and the next phase is presented here in brief.

2. RETROFIT DESIGN OF A SAMPLE BUILDING

To show how the retrofit project has been preformed, the whole process of retrofit design is explained for one of the project buildings whose view and plan are shown in Figure 1.

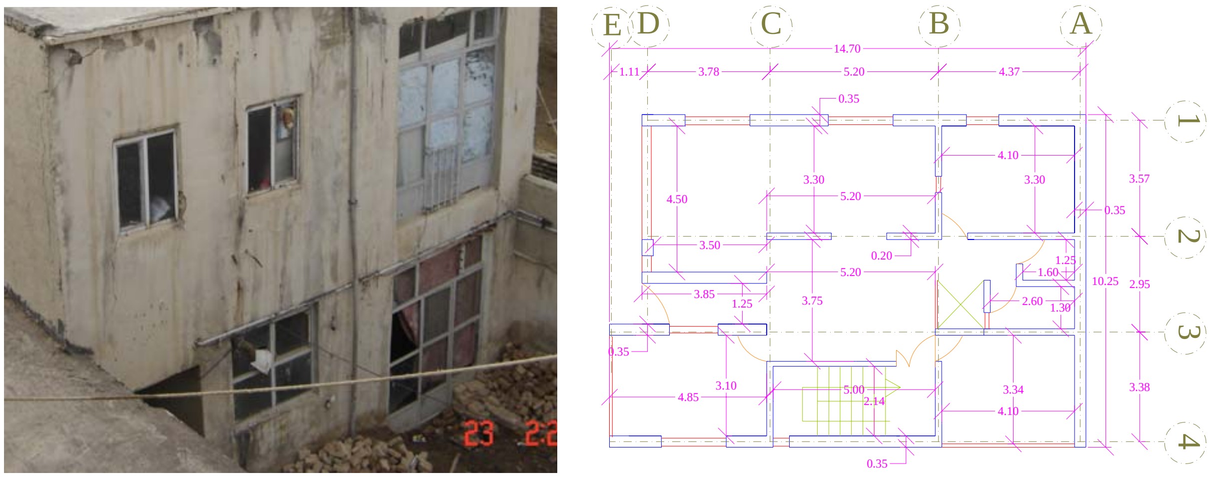


Figure 1. A view of the sample building and its architectural plan

This selected sample building is a 2-story masonry building for residential use of around 10 people. The load bearing system is consisted of just walls without any horizontal or vertical ties. To show briefly the vulnerability of this building Figures 2 and 3 show the plans of ground and first floor of the building along with the observed damage at each wall. On this basis the strength of the building has been estimated.

D.C = DIAGONAL CRACK

H.C =HORIZANTAL CRACK

V.C = VERTICAL CRACK

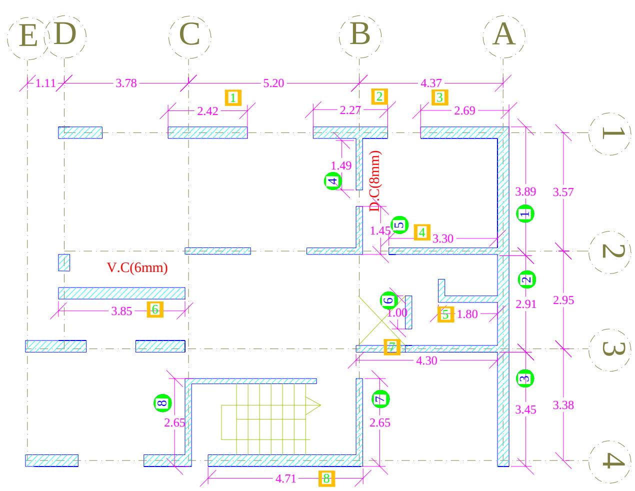


Figure 2. Plan of the ground floor of the sample building, and the observed wall damages

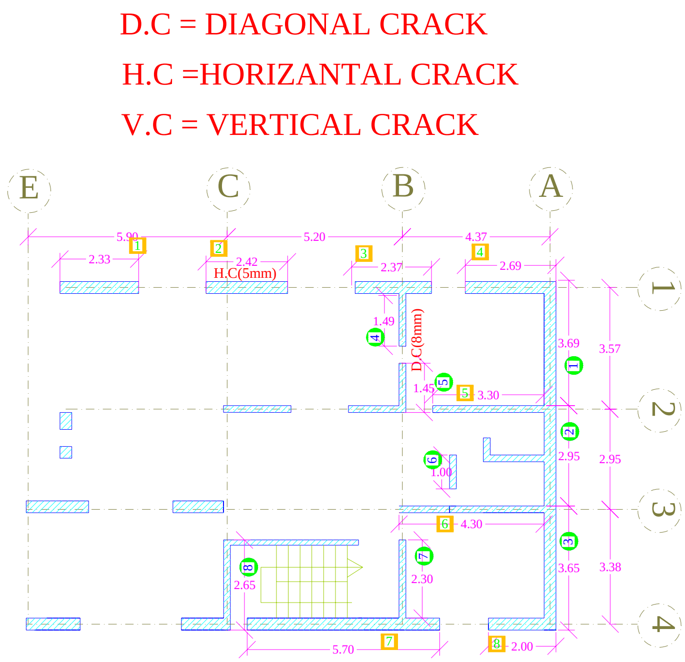


Figure 3. Plan of the 1st floor of the sample building, and the observed wall damages

2.1. Selection of the Appropriate Retrofit Technique

Considering the level of vulnerability of this building, it has been realized to be repairable. For such a system there are five main retrofit techniques as follow:

1. Adding some walls to increase the shear resistance of the building
2. Using shotcrete to increase the walls shear strength
3. Adding external shear walls
4. Adding external bracings
5. Decreasing the building weight

In the following section these five techniques are compared to select the most appropriate one for the building at hand.

To choose the most appropriate retrofit techniques for any existing building all the possible techniques should be compared from various aspects, including cost, construction easiness, architectural effects, reliability, and so on. For the sample building at hand this comparison is done here between the five possible techniques mentioned above.

- First technique, which is adding walls, needs some major modifications in the architectural plan of the building at both floors which is not desirable. Furthermore, this technique leads to increase in the building weight, and making reliable connections between the existing walls and floors with the new ones is not easy.
- Second technique, which is using steel mesh with shotcrete at the surface of existing wall to increase their shear strength, has less effect than the first technique in increasing the shear strength of walls, however, it is less costly and does not have adverse architectural consequences. Its construction work is also less that the first technique.
- The third technique, which is adding external shear walls, does not have adverse architectural effects, can give very good strength to the building, and the connection of the added walls to the existing system can be provided by adding ties. But, because of need to frameworks for casting the concrete is needs relatively long time and is also more costly than the two previous techniques.
- The forth technique, which is adding external bracings (trusses), has less adverse architectural effects, is less costly and has less construction work than the other techniques. But, since there is some uncertainty in the proper connection of steel truss to the existing masonry is still under question.

- The last technique, which is decreasing the building weight by removing some materials from the floors, can result in the sufficient strength of the building without any need to add some resistant elements, and is architecturally acceptable, but, since it needs the building to be out of function for relatively long time, and may cause some damages to the building's facilities, particularly water pipes and similar components, and therefore can be costly.

Based on the above comparison, finally steel mesh with shotcrete has been realized to be the best alternative for strengthening the building at hand. Table 2 shows deficiencies of the building and its components along with the effect of each retrofit technique in removing deficiencies.

Table 2. Seismic evaluation items, the condition sample building, and the effect of various retrofit techniques

Items to be checked in seismic evaluation	**Observation result**	**The positive effect of upgrading technique in removing the deficiency or providing the required condition**			
		External shear wall or bracing	**Strengthening the ties**	**Strengthening the wall**	**Decreasing the weight**
Lateral resistance	Insufficient	√	√	√	√
Structural integrity	Insufficient	×	√	√	×
Connections	Improper	×	×	√	×
Wall materials quality	N A	×	×	√	×
Vertical joint	N A	×	√	√	×
Wall h/t ratio	Improper	×	√	√	×
Wall length	Improper	×	√	√	×
Wall density	Improper	×	√	√	×
Distance of opening to wall edge	Improper	×	√	√	×
Wall crossing connection	N A	×	×	√	×
Tie materials quality	Improper	×	√	×	×
The existence of horizontal tie of foundation	No	×	√	×	×
Discontinuity in ties	Lack of proper ties	×	√	×	×
Floor integrity	N A	×	√	×	√
Seat length	N A	×	√	×	×
Wall to tie connection	Improper	×	√	√	×
Connections of ties together	Improper	×	√	×	×
Wall connections	N A	×	√	√	×

It can be seen in Table 2 that adding the walls' strength (by steel mesh and shotcrete) has the most advantages in removing the deficiencies and providing the required conditions for the sample building. The locations of shotcrete construction are shown in Figure 4.

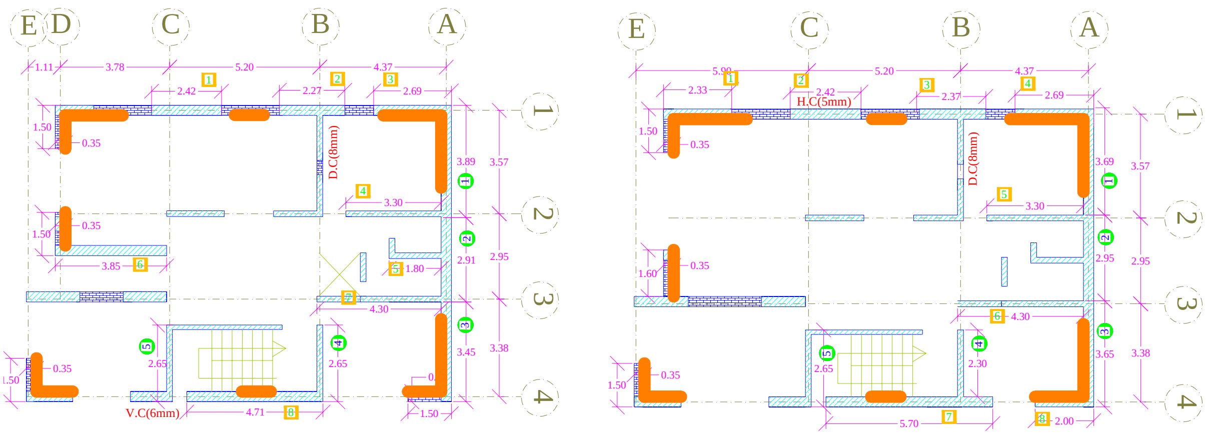


Figure 4. The locations of shotcrete construction at the building's walls

It should be noted that there were some cases that the wall area was not enough based on the shear resistance calculations. In such cases, at first the wall area has been added by brick masonry, and then the shotcrete has been constructed. Figure 5 shows the sample of shotcrete construction.

Figure 5. Sample of shotcrete construction, steel mesh (left) and the finished surface (right)

The diameter of steel bars of the mesh has been 6 mm in this case, and the thickness of concrete cover has been 50 mm. If the require shear strength can not be provided by shotcrete on one side of the wall the other side is used as well. The calculation of shear strength of the retrofitted walls is done by using the following simple formulas.

$$V = V_M + V_{SH} \tag{1}$$

$$V_{SH} = V_C + V_S \tag{2}$$

In these equations V is the shear strength of the retrofitted wall, as the summation of the strength of the masonry wall, V_M, and V_{SH}, which is itself the summation of concrete shear strength, V_C, and steel mesh shear strength, V_S. It should be noted that because of adding the shotcrete the wall weight is increased, and therefore, the sufficiency of the strength should be checked by considering the effect of this added weight in the seismic forces. Another check should be also done for walls, and that is the walls strengths for out-of-plane forces. This is done based on the bending and axial resistances of walls as explained in the other paper of the authors with regard to this retrofit project (Aghabeigi et al., 2008).

2.2. Complementary Retrofit Items

The other retrofit or modification cases which have been applied to this building include:

1. Adding the strength and the integrity of the jack arc floors, to act as diaphragms, by adding a reinforced concrete top layer, or using steel diagonals at their beneath
2. Modification of openings by adding brick masonry,
3. Strengthening the foundation by adding ties, and
4. Replacing the weak part of mortars in wall masonry and filling the vertical joints between bricks.

Figure 6 shows the details of connection of added reinforced concrete slab at the top of the building roof with the walls, and also the top slab under construction.

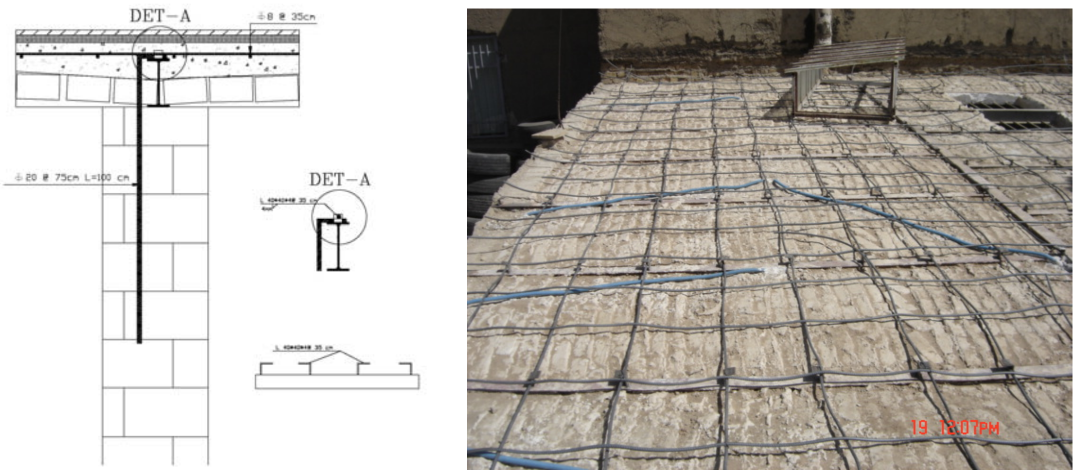


Figure 6. Connection details of added roof slab to the walls (left), and the slab construction (right)

Figure 7 shows the locations of added diagonal steel profiles for increasing the floor diaphragms integrity in the plan of the building and a sample of constructed steel diagonals.

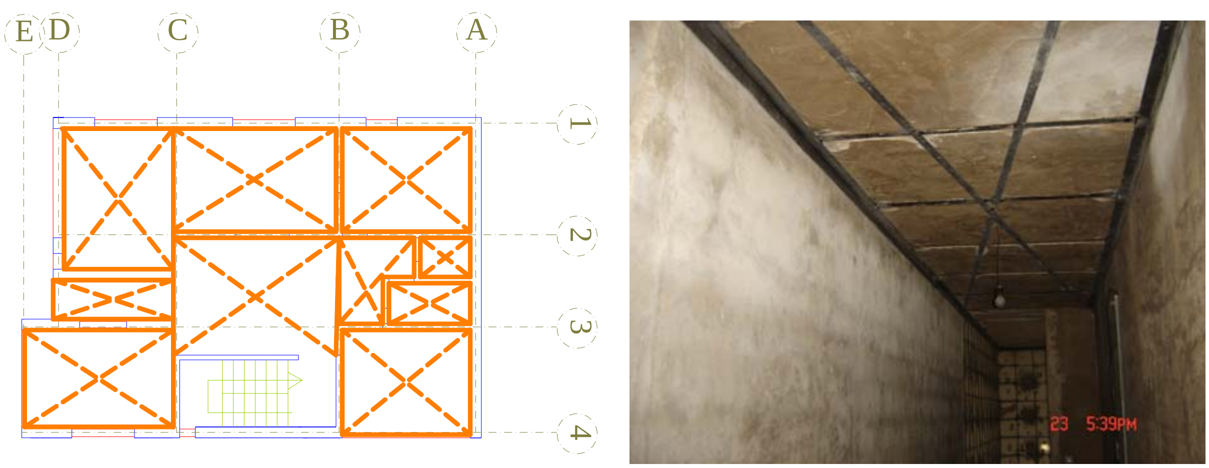


Figure 7. Locations of steel diagonals and frames at floors (left), and their construction (right)

It should be noted that to add steel diagonals it is necessary to add some steel frames as well, as shown in Figure 7, and these steel frames should be also connected together by passing them through the walls' corners. With regard to modification of openings Figure 8 shows how the brick masonry has been added to the existing walls at edges of openings, and also at those places where the wall thickness has not been enough.

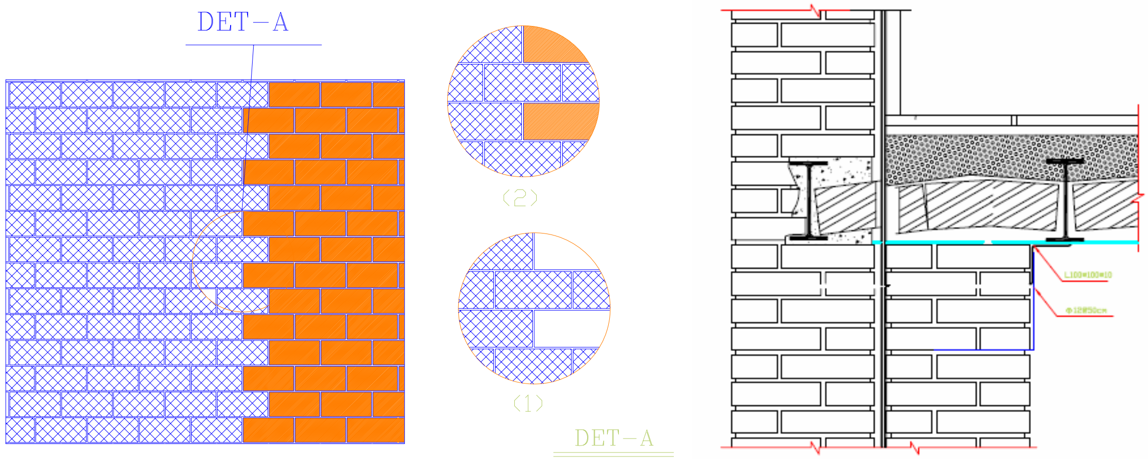


Figure 8. Wall addition for modification of opening edges with completer connection to the existing wall (left)and also the places where the wall thickness has not been enough (right)

Figure 9 shows the modification of the wall foundations by adding reinforced concrete ties beneath the walls and connecting the wall masonry to it.

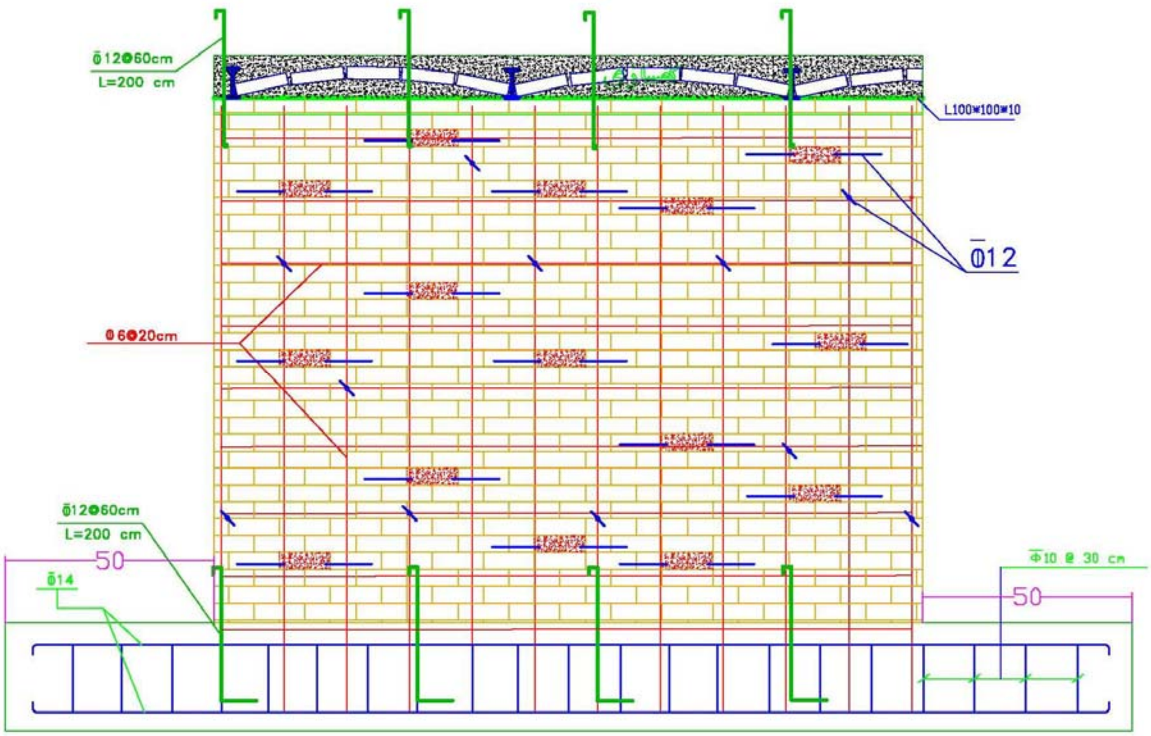
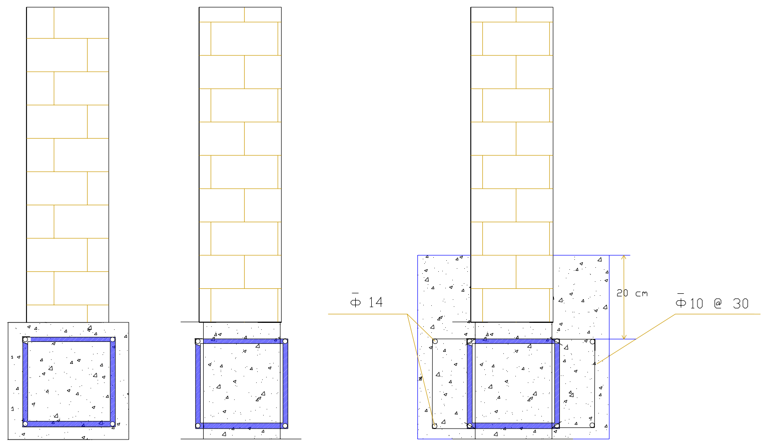


Figure 9. Adding reinforced concrete ties beneath the wall and connecting the wall masonry to it and to the floor

Also Figure 10 shows how the ties have been added beneath the walls by passing the steel bars trough the wall and adding some more concrete around it. This part of retrofit constriction is one the most deliberate parts, since it needs to remove the materials under the walls and if it is not done with enough care it can cause serious damages to the wall and the whole building, as the walls are under the vertical loads and there is not way to transfer the vertical loads to somewhere else.



(1) **(2)** **(3)**

Figure 10. Addition of ties beneath the walls by passing the steel bars trough the wall and adding some more concrete around it

3. CONCLUSIONS

Based on the retrofit project presented in this paper the following lessons can be learnt:

- Because of time pressure, and very high number of buildings, doing test on the existing materials was not possible, and this led in some decrease in the precision of seismic evaluation, and therefore the repair design was decided to be conservative to some extent.
- In some cases the wall section area was not sufficient based on the code requirements, and therefore adding some walls sections was necessary. However, such cases were usually resisted by the owners, and this made the repair design more difficult.
- In some cases using steel profiles as ties was necessary to give enough integrity to the building.
- Since the Jack arc system can not act as a rigid diaphragm, to give enough rigidity to floors, in addition to the reinforced concrete top slab it was required to use some diagonal steel profiles beneath the floors, and to connect them to the top slab by some vertical ties passing through the floors.
- The wall foundations were mostly not adequate, and it was necessary to make them stronger. Since developing foundations beneath the existing wall could be harmful for the building the construction of these foundations needed special procedure which was very challenging.

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