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SOLUTIONS FOR INCREASING THE STABILITY OF STRUCTURAL SYSTEMS OF IRAN TRADITIONAL BUILDINGS (ROOF LIGHTWEIGHT)

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ABSTRACT
One of the most important and crucial method for improvement, strengthening and increasing the stability of traditional buildings against side forces like earthquake is lightweight. Materials used for in Iran traditional architecture have high weight and density which impose a lot of force on the structure. One of the most important and remarkable solutions for improving the general stability of the structure is roof lightweight. Because of bearing the weight of heavy materials and rainfall is one of the most important parts in stability of the building. Accordingly, this paper aimed to, using research and field methods and examining the existing facts, reviews the important methods and techniques of roof lightweight in Iran traditional buildings. Structural form of the roof in most Iran traditional buildings is mostly seen convex (arch and dome). For flattening the roof two methods are used. The first one is to fill the space between level with heavy materials and the second one is making empty and resistant caisson between them.

KEY WORDS: structure, traditional architecture, roof lightweight, caisson-making

INTRODUCTION

Numerous valuable historical buildings in Iran and long history of civilization, especially at fields of remaining urbanization and architecture, is a Precious Heritage whose Preservation gives identity not only to historical values and Human civilization but also to National pride, culture and Honors which are regarded as a great scientific backing for every country. Historical buildings are of most important evidence of past life whose preservation is equal to preserving and reconstructing the Architectural heritage of the past and, in short, the culture (Ipekoglu, 2006). The fact is that the ancient and historic areas should be conserved for future generations (Sarvarzadeh and Abidin, 2012; Vatan, 2013). In terms of earthquake risk, Iran is placed among the first ten countries in the world, and it is located on the earthquake belt of Alpine–Himalaya (Bitarafan *et al.*, 2013). A lot of earthquakes take place in Iran annually (Mousavi *et al.*, 2011). Whose most important were Bam (Jafari, 2012) and Manjil (Fatemi Aghda *et al.*, 1995). Earthquakes that caused many Financial and human losses.

Information obtained from earth movement in seismic areas indicates that traditional buildings have no sufficient safety against earthquake (Mazloom and Mehrabian, 2006). According to related studies, these old buildings in which there is no attention to lightweight or the heavy and weak Traditional materials have been used are of most vulnerable and dangerous ones at the time of earthquake. Now, most of these buildings in Iran need Retrofitting and lightweight, and prediction of required contrivances before any loss and damage is of great importance. There are various ways for light-weighting the buildings; for example roof light-weighting using light materials instead of heavy traditional ones (Jagadish et al., 2003). Most of these traditional buildings are made of heavy Adobe blocks. Sufficient information about these adobe buildings in order to examine the earthquake impact on the building can reduce the effect of this catastrophic damage (Blondet *et al.*, 2011). Extending the affordable solutions for improving the Seismic Resistance of traditional constructions is an important and challenging issue for Earthquake Engineers to decrease the risk of earthquake (Shariful Islam and Iwashita, 2010). But it is clear that the Earthquake force has a direct relationship with the structure weight. The more the weight of a structure, the more the effects resulted from

the earthquake on it and, vice versa. In continuation, this paper will examine some the commonest styles of "roof lightweight" in Iranian traditional architecture.

ROOF LIGHTWEIGHT

Because of low Stretching resistance, high weight and lack of good Integration and Connectivity, The structures made by traditional materials (Mahdi, 2004), like brick adobe, are weak against Seismic loads (Samali *et al.*, 2011). The structural form of these buildings is seen often convex (vault and dome). The Interface of convex forms together creates concave volumes that are different from the level used for driving the rains and snows away and makes using its top level difficult for users (Figure 1).The architect changes these structural forms (convex) into a required form in external level (flat level) by contrivances which are:

1- Filling all concave levels made by some convex forms with construction soil and debris (as the easiest and commonest way) which increase the dead pressure. In castles and buildings which needed security, these empty spaces were filled with stones and bricks in order to be well- fortified and impervious. In this method the structure bore a heavy pressure.

2- Hollowing the spaces between two internal and external levels using Koonalbandi (caisson-making). The Ores transfer the pressures on themselves resulted from the alive or dead pressures of the higher roof or floor to the lower ceiling (Figure 2). The ores were made by construction materials like adobe, brick, plaster, mud and earthenware. In using this method, the most important purpose was to lightweight the structure and avoid from more pressure on the building. For example, deformation and destruction of a vault (Huerta, 2001) can be as a result of too much weight on it. It can be decreased using caisson making.

Figure 1: the convex structural form using traditional materials in Yazd Traditional houses (Keshtkaran, 2011).

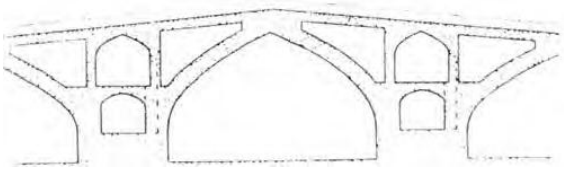

Figure 2: the two-story Caisson in Mir Bahaeddin Bridge, Zanjan (Mokhlesi, 2000).

CHARACTERISTICS OF CAISSONS

1- They transfer the pressure on themselves resulted from the alive or dead pressure of the higher roof or floor into the lower ceiling.
2- Their inner space is unusable and access to its inside is difficult.
3- They are made of construction materials like plaster, mud, adobe, brick and clay.
4- Because, after the structure is completed, they are attached to the building and eliminated in the building architecture, they are not considered as structural parts of a building.
5- Duty of Flooring, which is made on caissons, is to drive the surface waters away and to build the floor of higher Story and a special landscape for building.

KINDS OF CAISSONS

They are divided into five main kinds:

1. Caisson on the ceiling and between two vaults and arches having equal mouth.

1.1. This kind of caisson, following its sector cylindrical lower vault, takes the flat shape (it eliminates the concave levels and, some of its part is changed into a convex level which is lower than the ridge of porter vault). Its main function is to flatten the roof for more using (Figure 3).

Figure 3: Two vaults close together and the caisson-making between them.

1.2. The caisson on pillar of bridge; sometimes is parallel with the barrel vault and is seen clearly and covertly, in one-story or two-story shapes (Figure 4&5).

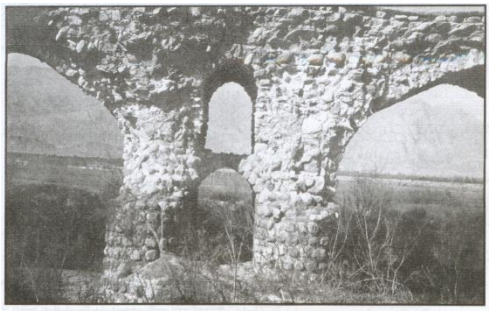

Figure 4: The two-story Caisson of Kool bridge, Bandar Abbas city (Mokhlesi, 2000).

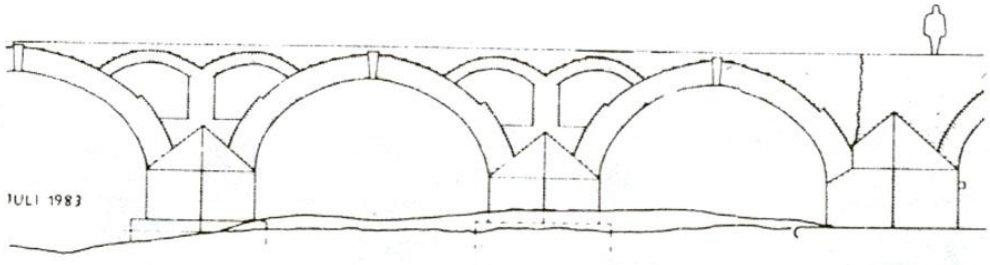

Figure 5: The hidden Caisson in Hasanabad Bridge in Kenargard (Mokhlesi, 2000).

2. Caisson on Colombo ceilings (external view with curved cover) having two curvatures.

2.1. The situation in which the caissons are clear (Figure 6).

Figure 6: The stable of Bam citadel and a view of its caissons.

2.2. The caissons which are used for flattening the external surfaces above Colombo vaults. Following the lower shape, they attach some part of the bottom line resulted from four bales of "vault rib" to vault using a curved skullcap. Ridge of this caisson is lower than that of vault and is used for flattening the roof completely like the underground bedchamber of Qazvin Jame' mosque whose part is located under the apron of the mosque yard (Figure 7). It is, whose another name is Kabir Jame' mosque, one of the oldest historical buildings in Qazvin (Moradi and Nassabi, 2011).

Figure 7: making caisson in Qazvin Kabir Jame' mosque.

3. Caisson-making with various parallel and vertical walls

This kind of making caissons doesn't follow its lower geometrical shape (since it has independent pillar) and can be used in cylindrical cover (vault), curved (dome) and conical and also for changing the height and includes two parts, a wall and cover between the walls. The building materials of wall and cover of caisson have been made by adobe and/or brick with mortar in some rows in the shape of partition wall, semi wall and complete wall using adobe or brick which is named Lariz in Iranian architecture (Figure 8).

Figure 8: caisson-making using blade walls.

4. Caisson-making on the vault of cellar

Generally, in buildings where big vault and arch are used, in different mouths, the ridge of vaults will be different and when leveling the roof is needed for building the higher floor, caisson-making is of great importance (Figure 9).

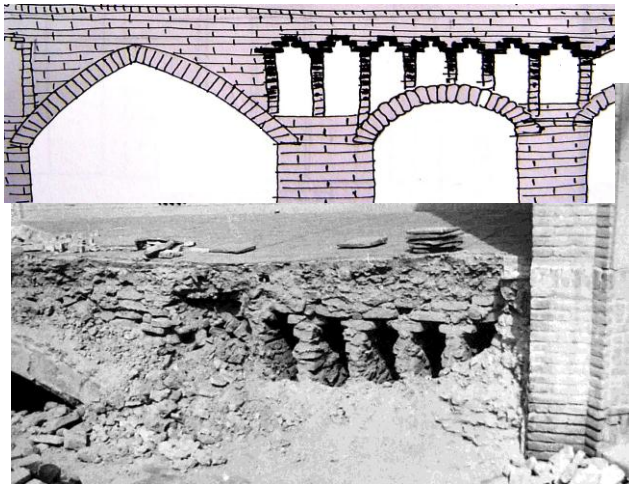

Figure 9: picture and chart of caisson-making on vault of cellar in Borujerdis' House, Kashan.

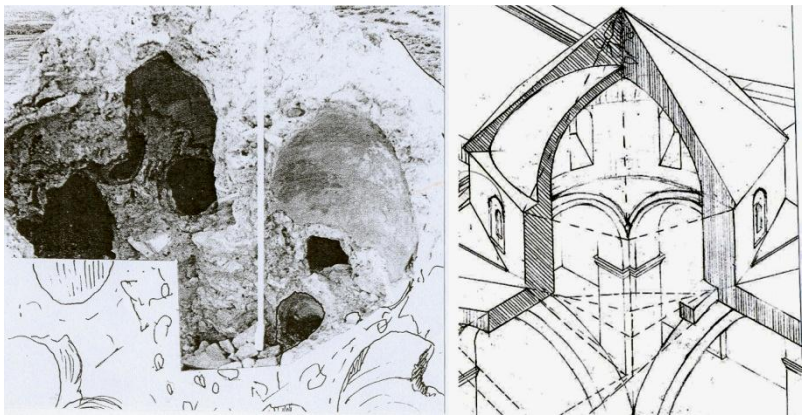

Figure 1: Special caisson-making in Ghara Church, West Azerbaijan Province.

5. Special caisson-making

Sometimes, in some cases and areas, special kinds of caisson making are seen. For example, in Ghara church in West Azerbaijan province we can see a kind different from other kinds of them we have seen before. In this kind, for

decreasing the dome weight, jug-form constructions are used which are put empty on the lower level in order to transform this level into the target higher level without increasing the load resulted from extra materials (Figure 10).

CONCLUSION

Based on existing evidence, in traditional buildings, roof is one of the most vulnerable parts because of Climatic factors, passing of time and earthquake which makes more damages than other parts due to its architecture and functional properties. In Iran traditional architecture, roof, as a "structural" phenomenon, was made by dense and native made materials like adobe, brick etc which did not have good resistance against side forces because of the high dead load. The main factor of vulnerability of these buildings against Natural Disasters is: weight of roof and, consequently, erosion and reduction of materials resistance over passing the time. Accordingly, the keeping strategies of these buildings against earthquake should eliminate this important defect. One of the important benefits of roof lightweight using hollowing or Koonalbandi is reduction of structure weight. Weight reduction is one of strategies for decreasing the Earthquake force. Other benefit of Koonalbandi is doing the retrofitting operation without or least destruction after years.

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