Proposals for Strengthening the Earthquake Resistance of Traditional Residential Architecture in Antakya (Ideal model)

(1) Enhance the strength of mortar used in rubble-stone masonry construction.
(2) Use a raft foundation (mat foundation) made of reinforced concrete mat slab for the foundation.
(3) Ensure horizontal rigidity by making the second floor of reinforced concrete.
(4) Put reinforcement in the rubble-stone masonry wall and rigidly connect it to the foundation slab and floor slab.
(5) Enhance the strength of the wooden joints on the second story.

(1) Enhance the strength of mortar used in rubble-stone masonry construction.

If the goal is to rebuild the old city of Antakya, which was devastated by the earthquake in February 2023, and to strengthen its earthquake resistance, or to strengthen earthquake resistance while recreating the historical landscape, various construction methods can be considered. These proposals are aimed not only at reconstructing the historical landscape but, also, to strengthen the earthquake resistance of the area while taking into consideration the preservation of the traditional building construction methods that create the townscape. On the other hand, there is a view that traditional construction methods have historically been able to provide a certain degree of earthquake resistance, and that if the building had been constructed using traditional methods in an orthodox manner, the collapse would have been avoided; however, it is not easy to objectively verify this or to specify orthodox construction methods. Therefore, these proposals aim to strengthen earthquake resistance by improving on traditional construction methods with modern techniques. In the old city of Antakya, there are a variety of historical buildings from different eras, with different sizes and construction methods; thus, these proposals focus on the residential buildings, which are the most numerous.

The majority of residential buildings registered, or proposed for registration, as historic structures in Antakya are two-story court-house-style homes. The first story is made using rubble-stone masonry; the second story is made of Turkish-style wooden frame construction with a tiled roof; the first-story exterior wall facing the courtyard utilizes ashlar cladding; and the second-story exterior wall is generally made of a wooden lath base, called "Bağdadi," with a plaster coating.

If we look only at the amount of walls, which determines the earthquake resistance of a building, it is far greater than that of traditional Japanese houses, and the buildings' external shape gives them a highly earthquake-resistant character. Nevertheless, the cause of the collapse must be attributed to the walls' weakness in terms of strength and ductility.

Antakya's traditional rubble-stone masonry walls (with a wall thickness of about 40-50 cm) are constructed by stacking limestone or marble rubble-stone (with a grain size about 15-20 cm) with pebbles and mortar packed between them. Earth mortar (or mud mortar or lime mortar) is used, which is a mortar made by mixing soil with lime, gypsum, etc., and then mixing it with water. Judging from the composition of the finished product, which is mineral aggregate and mortar, the rubble-stone masonry walls are no different from ancient Roman concrete or modern dam concrete (with a maximum coarse aggregate particle size 150 mm). Therefore, although the construction method is different, in terms of material mechanics it can be considered a type of concrete. In regular masonry construction, dry stacking is also possible with ashlar and burnt brick masonry, but with rubble-stone masonry, if the mortar does not have enough compressive strength and adhesive strength, it cannot be considered masonry; rather, it is a structure that should be considered a concrete wall.

The rupture strength of concrete is determined by the minimum of the aggregate strength, mortar strength and bond strength between the aggregate and mortar, but, looking at the failure properties of the rubble-stone masonry walls in the old city of Antakya, it is the failure of the mortar that causes the failure of the masonry walls. The compressive strength of earth mortar is only about one-tenth that of modern cement mortar. Therefore, if modern cement mortar is used in rubble-stone masonry, its strength will be increased to the same level as cement concrete, and its earthquake resistance will be dramatically improved.

Poor earth mortar

Damaged state of a rubble-stone masonry wall

On the other hand, it is possible to improve earthquake resistance without strengthening the walls by increasing wall ductility through steel bar or fiber reinforcement; however, with even slight deformation, masonry walls are fragile and will crack and become damaged before the reinforcing materials can exert their reinforcing effect. Even if the walls crack, the reinforcement materials maintain their strength and prevent the building from collapsing, but the damage caused to the masonry walls remains and accumulates with repeated earthquakes. In other words, the earthquake resistance of buildings damaged by earthquakes deteriorates, their remaining earthquake resistance cannot be guaranteed, and their continued use is questionable.

Therefore, in order to achieve improved, sustainable earthquake resistance, it is desirable to minimize the damage caused by earthquakes. The first suggestion, therefore, is to use modern cement mortar in the rubble-stone masonry to enhance wall strength. Earth mortar contains fine voids, and like Japanese clay walls, it has excellent moisture absorption and release properties, contributing to its prominent improvement of the indoor environment, but the fine voids also reduce its strength. In other words, although the strength of mortar and its moisture absorption and release properties are inversely related in this case, we believe that improving earthquake resistance should take priority.

(2) Use a raft foundation (mat foundation) made of reinforced concrete mat slab for the foundation.

The old city of Antakya is located at the southeastern end of Antakya Graben on a plateau formed by the accumulation of sediment from the Asi River at the foot of the Habib-i Nejjar Mountain and on terraces. Given Antakya's long history, it can be assumed that there are ruins, remains and artifacts buried near the surface, and a boring survey conducted near the Greek Orthodox Church in Antakya after the earthquake revealed that about 3 m beneath the surface was a layer of rubble, about 4 m below that was a layer of consolidated alluvial clayey soil, and more than 7 m below the surface was a layer of strongly weathered rock.

Exposed Roman culvert

Therefore, apart from the surface layer of rubble, the ground is strong enough to support low-rise housing and is unlikely to sink. Pile foundations penetrating the rubble deposits could be considered, but if consideration is given to preserving the ruins, a non-invasive foundation construction method is required.

On the other hand, though, the upper rubble-stone masonry wall is fragile and may crack even with slight deformation or uneven settlement, so a highly rigid foundation is required. Therefore, we propose a raft foundation made of reinforced concrete mat slab (a single thick foundation slab) be used.

By using a mat slab, the upper rubble-stone masonry wall can be integrated, preventing uneven settlement and localized horizontal movement. At the same time, by using a raft foundation (mat foundation), the ground reaction forces can be averaged out, minimizing the impact on ruins and artifacts buried underground.

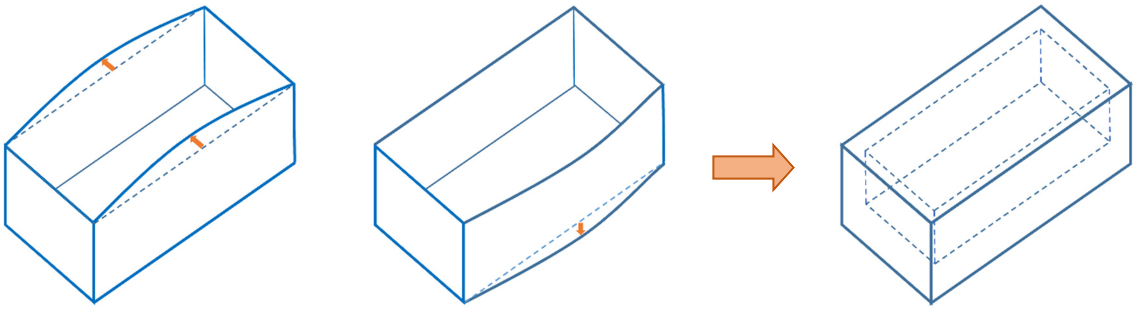
Since the mechanical properties of the rubble layer buried underground are unpredictable, there is a possibility that the building may tilt due to an earthquake; however, even if the building does tilt, by using a mat-slab structure, the building will not deform but tilt as a whole. Even if the building does tilt, the tilt can be easily corrected by drilling holes in the mat slab and injecting mortar between the foundation slab and the ground.

(3) Ensure horizontal rigidity by making the second floor of reinforced concrete.

In the traditional residential architecture of Antakya, wooden beams are placed on top of the rubble-stone masonry walls of the first story, and a wooden floor structure is laid on top of that. Masonry walls have strength and rigidity against in-plane horizontal forces, but they are weak against out-of-plane horizontal forces. Therefore, for masonry construction to be earthquake-resistant, the out-of-plane horizontal forces occurring in the wall must be transmitted to the orthogonal wall (as in-plane horizontal forces) by the floor, and therefore the floor is an essential structural element.

Rubble-stone masonry walls and wooden floors

However, in traditional construction methods, the joints between the floor and the masonry walls are not necessarily designed with this in mind. Even if a wooden floor has strength against in-plane horizontal forces, wood has lower rigidity than other building materials and cannot ensure sufficient horizontal rigidity.



Out-of-plane deformation of the upper part of the wall

Uneven settlement at bottom of wall

A rigid, box-shaped structure that does not cause local deformation

Therefore, we propose installation of a reinforced concrete floor slab on top of the rubble-stone masonry wall to integrate each wall body. By using a reinforced concrete floor slab, the in-plane horizontal rigidity of the floor can be ensured at more than 10 times that of a wooden floor. In addition, when it comes to a traditional house, the span of the floor slab is 4 m or less, and a single floor slab can be used across the entire floor without the need for floor beams.

(4) Put reinforcement in the rubble-stone masonry wall and rigidly connect it to the foundation slab and floor slab.

By placing a reinforced concrete foundation slab at the bottom of the masonry walls and a reinforced concrete floor slab at the top, the masonry walls can be integrated to form a sturdy, box-shaped structure which has extremely high earthquake resistance. Its structure is equivalent to Japan's reinforced concrete bearing-wall structure, and its earthquake resistance has been proven in past earthquakes.

To form a box-shaped structure, it is necessary to ensure the foundation slab and the masonry wall, as well as the masonry wall and the floor slab, are reliably joined. For this, we propose using a minimum amount of reinforcing bars in masonry walls to ensure joint strength.

Although the steel bars placed in masonry walls do not increase the walls' resistance to damage, they can prevent the expansion of drying shrinkage cracks and unexpected collapse due to earthquakes.

(5) Enhance the strength of the wooden joints on the second story.

By making the rubble-stone masonry on the first story a closed box-shaped structure, high horizontal rigidity can be ensured, which helps to keep the amplification of earthquake forces on the wooden structure on the second story low.


Rubble-stone masonry and Bağdadi exterior walls

Antakya's traditional wooden construction is Turkish frame construction, which is not fundamentally different from the wooden frame construction commonly used in Turkey today, although the current frame construction makes more use of plywood than braced panels, as stipulated in the Turkish Building Earthquake Code (TBEC-2018).

Unlike Japanese post-and-beam construction, the joints in frame construction are not rigid, so braces are needed to keep the frame stable during construction, but the amount and placement of braces vary depending on the building. A bracing system that meets the requirements of TBEC-2018, or a plywood alternative to bracing, is required. In addition, since the in-plane horizontal strength and rigidity of the roof can be ensured by laying sheathing boards, TBEC-2018 does not specify regulations for the in-plane horizontal strength of the roof, but it does require joints that can ensure the in-plane horizontal strength.

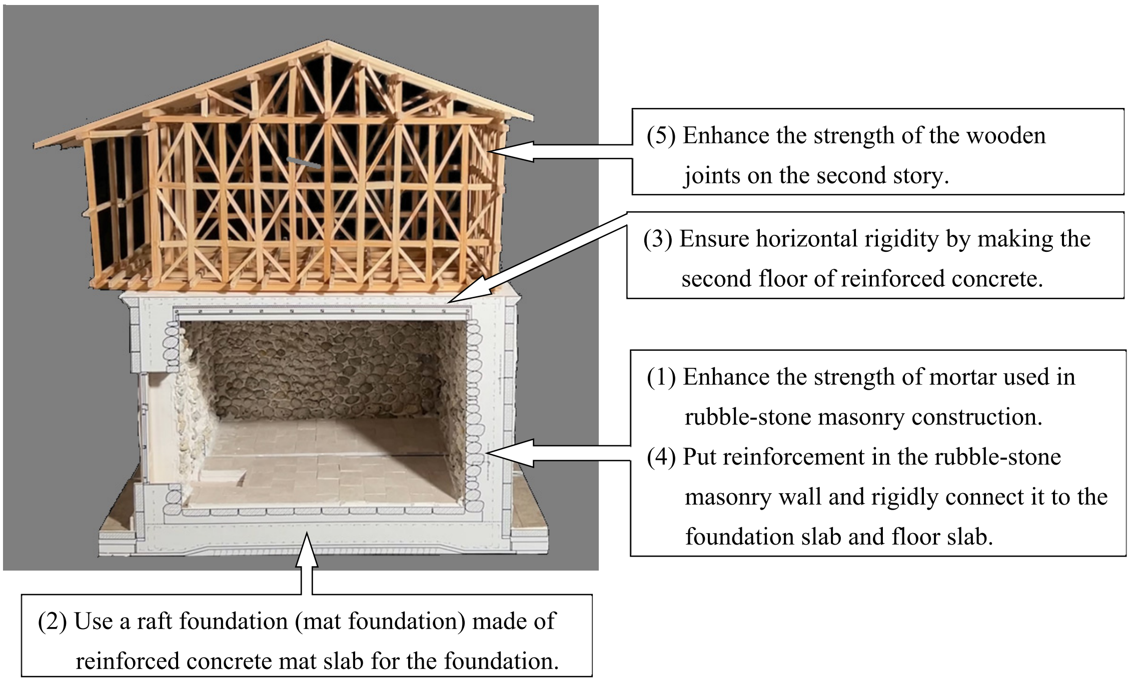
Modern Turkish timber frame construction using plywood, insulation material and metal joints is similar to Japanese timber frame construction and is considered to have a high earthquake resistance, which can be ensured if the provisions of TBEC-2018 are observed.

On the other hand, Antakya's traditional wooden frame construction method uses cross braces and wooden laths (Bağdadi) instead of plywood, nails instead of metal fittings and screws, and pebbles and mud walls instead of insulation material, and it is not only weaker in strength and rigidity than current frame construction methods, but also heavier. Therefore, improvements that bring the methods used as close as possible to current frame construction methods are desirable.

However, at the same time, there is a need to preserve traditional construction methods. When a wooden building collapses due to an earthquake, it is said that the joints break before the wood is destroyed, causing the structure to fall apart, leading to the building's collapse. Therefore, in order to strengthen the earthquake resistance of traditional frame construction, it is recommended to not only arrange the braces in accordance with the provisions of TBEC-2018, but also to ensure the strength of the joints.

In the disaster-stricken areas of Antakya, there are many instances of ceilings made of plaster applied to a wooden lath base collapsing due to the earthquake, but traditional wooden frame construction methods do not provide enough rigidity for buildings, increasing the likelihood of damage to fragile ceilings. It is also advisable to review non-structural components whose collapse could pose a danger to human life.

<u>Model of a traditional Antakya house that has been made earthquake-proof based on these proposals</u>



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