

Proposal for Seismic Retrofit Design of a Traditional Residential Building in Antakya (Structural Design Proposal)

Earthquake-related factor

The target home is a single-story building made of rubble-stone masonry with a second floor wooden extension added to it. The gable wall of the second floor extension is made of masonry and was added on top of the masonry partition wall on the first floor, and it is believed that the large opening in the partition wall caused the second floor gable wall to collapse during the earthquake, resulting in extensive damage.

This property is not the only example of this. Many traditional buildings that have suffered earthquake damage appear to have undergone disorderly renovations and extensions that ignore earthquake resistance.



Target house:
The collapsed east gable wall of the second-floor extension

Reconstruction status

Reconstruction work by both public and private organizations is underway in some areas of the city. Many of these buildings have a reinforced concrete rigid frame structure on the first floor, but masonry curtain walls are used to maintain a traditional appearance. The second floor also uses traditional wooden frame construction. However, there are also a number of reconstructed buildings whose structural type cannot be clearly determined from their exterior.



Approach to earthquake-proofing

The buildings currently under reconstruction, like mentioned above, are expected to have a certain degree of earthquake resistance and to recreate the historic townscape in appearance. However, the building structures and construction methods are clearly different from the residential buildings registered as historic preservation buildings in Antakya. Therefore, these proposals aim to improve earthquake resistance while maintaining traditional construction methods, rather than simply improving earthquake resistance and recreating the exterior appearance. This will not only preserve the traditional landscape but, also, aim to preserve traditional construction methods. Specifically, the following five approaches are proposed.

- [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 using a reinforced concrete lateral beam to connect the top of the first floor masonry wall.
- [4] Put reinforcement in the rubble-stone masonry wall and connect it to the foundation slab and lateral beam.
- [5] Improve the earthquake resistance of the second floor wooden frame construction.

[1] Enhance the strength of mortar used in rubble-stone masonry construction.

The majority of residential buildings registered, or proposed for registration, as historic structures in Antakya are two-story courthouse-style homes. The first floor is made using rubble-stone masonry; the second floor is made of Turkish-style wooden frame construction with a tiled roof; the first-floor exterior wall facing the courtyard utilizes ashlar cladding; and the second-floor exterior wall is generally made of a wooden lath base, called “Bağdadi,” with a plaster coating. The residential building that is the target of this proposal is a typical example. However, only one main building on the north side of the site follows traditional construction methods. It is a single-story building with masonry walls and a tiled wooden roof, but it is believed that a wooden second-floor extension was added to the western end.

If we look only at the wall quantity, 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. In this particular case, the main cause of the collapse is presumed to be the collapse of the eastern gable wall of the second-floor wooden extension, which was built on top of the masonry gable wall and partition wall on the first floor. The masonry partition wall, which divided the gable into thirds, was partially removed to create an opening, which likely contributed to the collapse of the upper gable wall. If the second floor had not been added and the building remained a single-story structure, the house might have avoided collapse, but, even if it did not, some damage would have been sustained. However, the cause of collapse for many traditionally constructed homes must be attributed to the walls’ weakness in terms of strength and toughness.

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) and, from a material mechanics perspective, can be considered a type of concrete. In regular masonry construction, dry

stacking has a certain degree of stability, even with ashlar and burnt brick masonry, but, with rubble-stone masonry, if the mortar does not have the compressive strength and adhesive strength, it cannot be considered masonry; rather, it is a structure that should be considered a concrete wall.

The compressive strength of earth mortar is only about one-tenth that of modern cement mortar, and the fracture strength of such masonry is determined by the minimum of the mortar strength or the bond strength between the aggregate. In fact, 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. Therefore, if modern



Poor earth mortar

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.

On the other hand, it is possible to improve earthquake resistance without strengthening the walls by increasing wall toughness 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 in jeopardy.

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. While earth mortar, which has minute voids, is said to have excellent moisture absorption and release properties, similar to Japanese clay walls, which contribute to a good indoor environment, since the voids also reduce strength, this proposal prioritizes improving earthquake resistance.

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

A drilling 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. Given Antakya's long history, it can be assumed that there are ruins, remains, and artifacts buried near the surface, but, apart from the surface layer of rubble, the ground is strong enough to support low-rise housing and is unlikely to



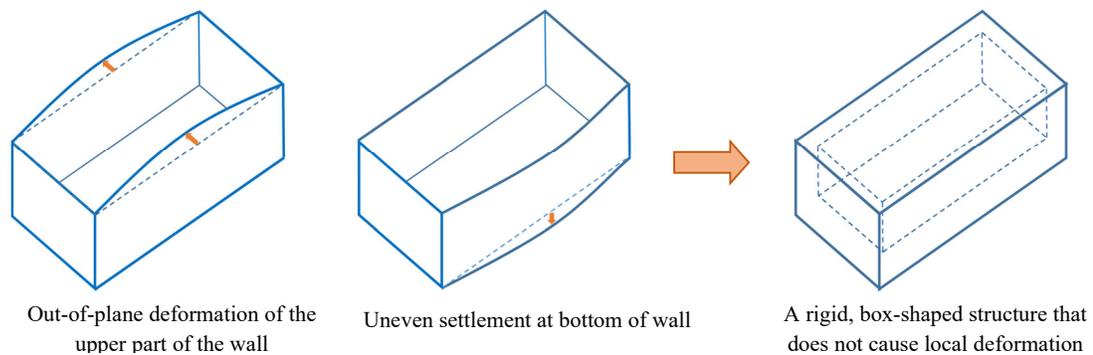
Exposed Roman culvert

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.



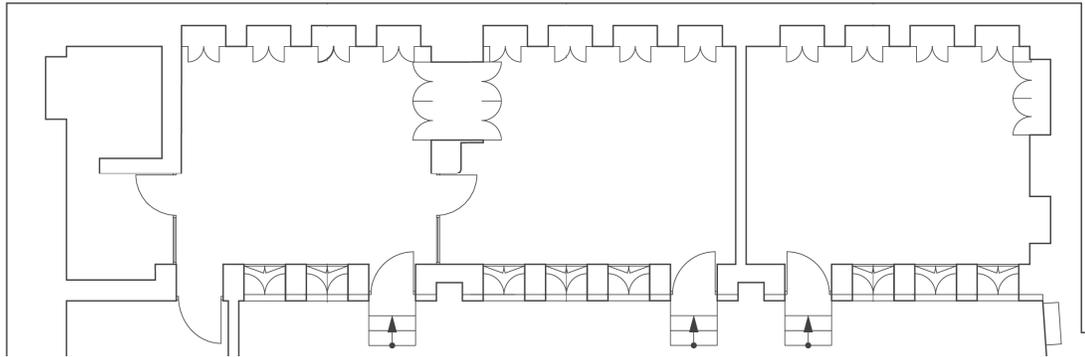
[3] Ensure horizontal rigidity by using a reinforced concrete lateral beam to connect the top of the first floor masonry wall.

In the traditional residential architecture of Antakya, wooden beams are placed on top of the rubble-stone masonry walls of the first floor, and a wooden floor or roof framing 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, the best solution is to install reinforced concrete slabs on the floor and roof surfaces so that each wall can resist earthquake forces as a whole.

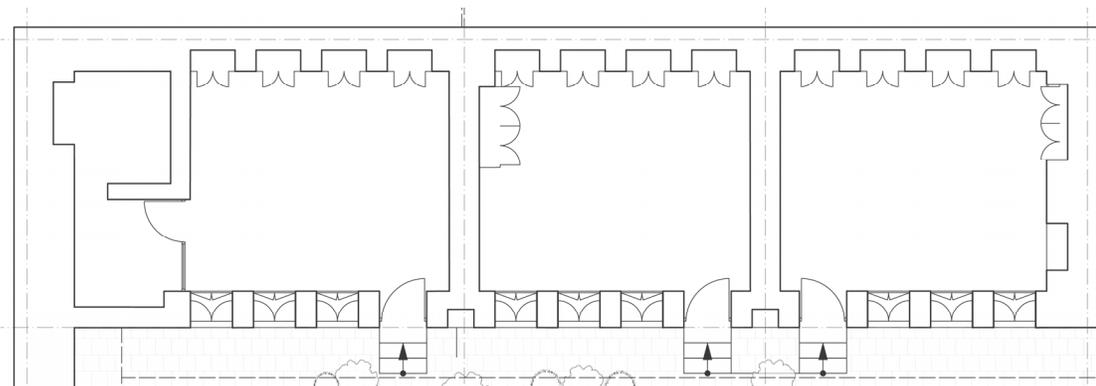
However, considering that the target building is mostly single-story, has partition walls at roughly three equal points along the beam, and the size of the rooms enclosed by the masonry walls is roughly 5.5 m x 5.5 m, which satisfies the Turkish Building Earthquake Code (TBEC-2018), it was decided to install reinforced concrete bond-beams on top of the masonry walls.

In addition, since it is assumed that some or all of the masonry partition walls had been

removed or reduced, this proposal, in order to improve earthquake resistance, calls for the restoration of structures that are presumed to have been there originally. In addition, traditional Antakya houses are basically separated into individual rooms, with access to a courtyard on the first floor and a terrace on the second floor. As a result, each room has its own entrance to the outside.



Target house: Original floor plan before the earthquake



Proposed floor plan

[4] Put reinforcement in the rubble-stone masonry wall and connect it to the foundation slab and lateral beam.

This proposal is to place masonry walls with partition walls at appropriate intervals on a single reinforced concrete foundation slab, and, then, to connect the tops of the walls with reinforced concrete bond beams, thereby integrating the masonry walls and forming a rigid box-shaped structure. This type of box-shaped structure has extremely high earthquake resistance. Its structure is equivalent to Japan's reinforced concrete 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 beam, are reliably joined. For this, we propose using a

minimum quantity of reinforcing bars in masonry walls to ensure junction 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. Furthermore, although this structure is not reinforced masonry, the Turkish Building Earthquake Code (TBEC-2018) stipulates that for reinforced masonry, rebars must be placed at intervals of 600 mm or less.

[5] Improve the earthquake resistance of the second floor wooden frame construction.

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

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 veneer than braced panels, as stipulated in the Turkish Building Earthquake Code (TBEC-2018).



Example of rubble-stone masonry and Bağdadi exterior walls

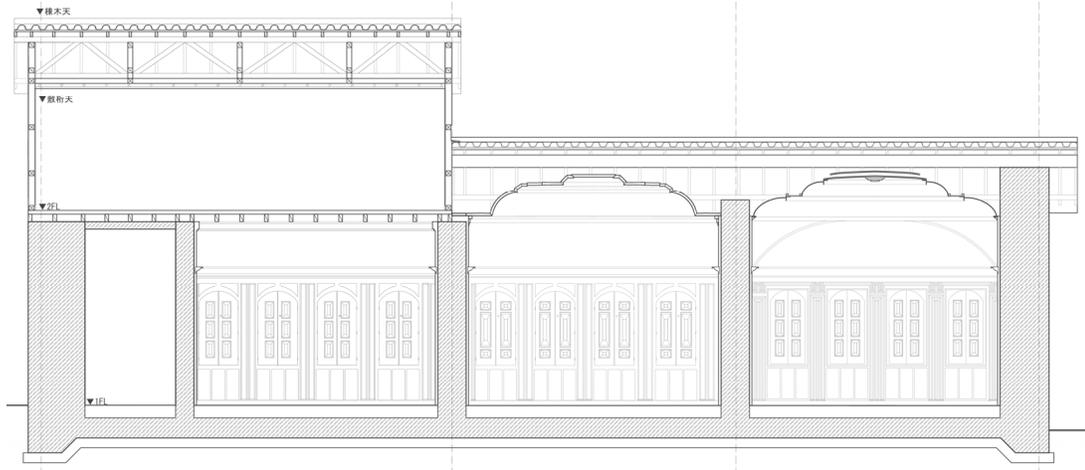
The joints in frame construction are not rigid, so braces are needed to keep the frame stable during construction, but the amount and placement of braces vary depending on the building. A bracing system that meets the requirements of TBEC-2018, or a plywood alternative to bracing, is required. In addition,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

Modern Turkish wooden frame construction using plywood, insulation and metal joints is similar to Japanese wooden 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. Compared to current frame construction methods, this method not only has lower strength and rigidity but, also, increases the weight; thus, it is desirable to improve it so that it becomes as close as possible to the current frame construction method.

However, in this particular case, the wooden portion of the second floor is small, and, as long as the bracing is adequate, earthquake resistance is believed to be sufficient even with traditional construction methods. Rather, the cause of the earthquake damage in this case is believed to be the masonry construction of the second floor gable wall. In the first place, the wooden structure,

or the connections to the wooden structure, cannot withstand the out-of-plane seismic forces that occur on the gable wall. For this reason, the proposal is to retain the wooden extension on the second floor but to use wooden construction on both gable walls, as well as limit the masonry construction to the first floor.



Proposed cross section

The partition wall on the first floor is reproduced, and the masonry gable wall on the second floor is removed, leaving the second floor entirely made of wood.