TEMPORARY IMMEDIATE STEEL BUTTRESSING THE DAMAGED HISTORICAL STRUCTURES AFTER EARTHQUAKES

Beeson Saadet Toker¹, Ozmen Cengiz², Unay Ali Ihsan³

ABSTRACT

Historical monuments and buildings constitute significant part of the architectural heritage of a country by acting as a link between the past and the present. Turkey, being the homeland of many ancient civilizations, has a rich collection of historical sites and monuments. The country is also located in the intersection of Eurasian and African seismic plates and has witnessed many destructive earthquakes. Earthquakes are one of the most devastating forces of nature and one of the major causes of structural hazard risk for historical buildings and monuments. Historical monuments, which are structurally damaged during earthquakes, must be strengthened immediately due to strong possibility that these buildings already possessed some form of structural vulnerability prior to the seismic event. The combined effects of these vulnerabilities can be fatal to the overall structure. Detailed specialized studies should be conducted for proper long-term strengthening and restoration of historical monuments via the use of original materials and construction techniques however in cases where there is urgent need for structural strengthening; steel buttressing is a suitable solution for the fortification of historical monuments. Temporary steel frame scaffolding can be easily constructed with minimum or no damage to the historical structure. In this paper, the temporary structural strengthening of a 12th century masonry gate in Hasankeyf via the use of a simple yet multi-functional steel frame is described. The effect of the steel frame on the overall static and dynamic structural behavior of the building is analyzed with finite element analysis.

Keywords: Historical monuments, Steel buttressing, Temporary scaffolding, Strengthening historical structures

1. INTRODUCTION

Historical monuments, which constitute an indispensable part of our cultural heritage, are subjected to unrecoverable damages due to earthquakes and similar seismic activities. The structural strengthening works conducted on these buildings require a time consuming process involving planning, expert professional care and money. In times of crisis such as the immediate aftermath of large earthquakes, it may take some time to gather all the necessary resources and organize them effectively for all affected historical monuments. In such cases, temporary strengthening structures are urgently required to preserve the integrity of these buildings until the beginning of permanent restoration works. However, hastily conducted temporary strengthening works possess the risk of causing further damage to the historical monument by deviating the structure from its original structural behavior. The cardinal rule of temporary strengthening works for historical monuments is to conduct the necessary construction without leaving any significant permanent marks on the structure. Steel is the most widely preferred structural material due to its ease of construction and short erection time. However, the excessive elongation and shortening of steel due to temperature changes carry the risk of causing unpredictable changes in the overall structural behavior of the structure. If steel strengthening

¹ Assistant Professor, UTSA-College of Architecture, Saadet.Beeson@utsa.edu
² Assistant Professor, Cankaya University, Department of Interior Architecture, cengizozmen@cankaya.ed.tr
³ Professor, Gazi University, Department of Architecture, unayacademic@yahoo.com
is installed without special connection details, rusting may occur and leave permanent visual damage and cause material deterioration [1].

There are other factors, which may negatively affect the structural behavior of the building during temporary strengthening efforts. Among these are the vibrations caused by construction equipment during the installation process and possible changes in support conditions during the transportation and mounting of these equipments in the construction site.

Structural systems of historical buildings and monuments usually have a complex geometric form. Especially, partially damaged buildings have established a new structural balance over the course of time. Temporary strengthening structures designed according to the original structural configuration of the building may even disturb the structural stability instead of improving it. These temporary structures modify the structural behavior of the building in terms of rigidity. This change in rigidity may have a positive effect on the structural behavior as well as a negative one. Therefore, it is critical for these temporary strengthening structures to be designed by skilled professionals [2].

In this paper, the analysis and construction process of the temporary steel buttressing for the main gate of the City of Hasankeyf located in the south east of Turkey is described including the special constraints dictated by the geographic and topographic conditions [3].

2. STRUCTURAL PROBLEMS OF MAIN GATE OF HASANKEYF

Medieval City of Hasankeyf, which possesses cultural and architectural works from several civilizations, is not only an important part of Turkey’s cultural heritage but also a significant archeological site on an international scale. As shown in Figure 1, Hasankeyf includes over one hundred historical buildings some of which date back to 7th century AD as well as an impressive geological landscape, which rises almost 150 meters above the southern bank of River Tigris.

![Fig. 1 Medieval city of Hasankeyf.](image)

The gate of Hasankeyf was constructed in the 12th century. The height to thickness ratio of the structure is convenient for a proper observation of in-plane and out-of-plane behaviors. The dimensions of the structure are 6.85 m × 14.5 m × 1.6 m (Figure 2). The structural system of the gate suffered serious damages due to both man-made and environmental factors over the centuries. Some of the stone masonry units are displaced enough to threaten the overall stability of the gate. There are deep penetrating cracks in the two parallel walls around the entrance. These cracks begin at the two top corners of the entrance opening and descend to the ground level with a 60° angle. Additionally,
load-bearing stone masonry units located at the region where the gate comes into contact with the rocks slope are badly damaged due to material deterioration.

Fig. 2 The Main Gate of Hasankeyf Citadel

A detailed set of analyses was conducted for the temporary strengthening of the main gate. The gate was modeled for Finite Element Analysis (FEM) taking into account all the cracks and material deteriorations. As shown in Figure 3, linear analyses were carried-out with SAP2000 and non-linear analyses were conducted carried-out with ANSYS software [4, 5].

Fig. 3 ANSYS Finite Element Model of The Main Gate

Temporary steel buttressing is already applied and works for long-term strengthening is under way. While the temporary steel structure is not in conformity with the authentic architectural characteristics of the main gate, it was urgent and necessary due to the level of damage, risk of seismic activity and topographic conditions of the archeological site.

3. EXTERNAL STEEL BUTTRESSING OF HISTORICAL MASONRY GATE

In this section, the characteristics of the temporary steel buttressing applied to the main gate of Hasankeyf are described along with the analyses carried-out during the design stage. The main role of this steel structure is to prevent the progressing deep cracks on either side of the entrance from threatening the overall structural stability and integrity of the building.
Initial analyses on the present condition of the masonry gate are conducted with ANSYS software to understand the effects of the cracks and possible collapse mechanisms. As shown in Figure 4, lower right corner supports are critically damaged. According to the results of this analysis, highest priority is given to the strengthening of this section against the risk of further damage by possible seismic activity. A temporary steel shell buttressing is designed due to the constraints of topography and to keep the level of damaging architectural intervention to a minimum level.

During the design stage stone masonry gate and 3D steel buttressing frames are first analyzed with SAP2000 as an integrated system (Figure 5). Then, steel frame is detailed according to the results of the analysis carried-out under probable seismic load cases. The really noteworthy achievement is not the analysis stage but the designing of the temporary buttressing within the constraints of the topographic conditions.

![Fig. 4 Structural damages at lower right support of the Gate](image)

As seen in Figure 6, the Main Gate is sits on a steep rocky slope which makes it impossible to place a supporting structure on the flat ground located 50 m below. Topographic conditions also make the access of heavy equipment, such as cranes, into the construction site impossible. As a result, it becomes a necessity for the temporary structure to be compact enough to be located on the available space near the gate and to be modular enough to be transported and erected by the manual labor of the workers (Figure 7). The system is designed to be erected and dismantled with ease in a short period of time.
This 3D steel frame consists of 1200 steel profiles. Deep foundations were not built to avoid destroying the surrounding architectonic tissue. Instead, precast reinforced concrete panels were used for additional weight and stability (Figure 8). The number of the precast concrete panels is determined according to the support reactions determined by the numerical analyses. The main weight of the supporting structure is located on the left of the entrance. From this location, steel cantilever arms are protruded surrounding the critically damaged right portion of the entrance. In this configuration the weight of the concrete panels act as a counter balance preventing the gate tower to collapse towards the steep slope (Figure 9). At the same time, I beams passing through the entrance opening support the key stones on top thus helping them to carry the vertical load transferred by the upper portion of the gate tower.

4. CONCLUSIONS

Damaged historical masonry structures located in seismic regions must be strengthened immediately with simple temporary buttressing structures. However, this temporary strengthening structure must be designed in a way that will not cause permanent damage or leave visual marks on the historical monuments. In this paper, temporary steel buttressing of the Main Gate of the Hasankeyf Citadel is described due to its noteworthy status provided by the constraints of topography. Following principles were taken into account during the design and construction of this temporary strengthening structure:

- The designers opted for the most economic solution possible.
- Used materials and construction techniques are determined according to the specific conditions of the site.
- Because the topography prevents the use of heavy equipment, the dimensioning and detailing of the structure is made according to the requirements of manual labor.
- The system is designed to be easily dismantled after the preparation of permanent strengthening measures.
The design and dimensioning of the steel frame is made according to the worst possible load case and environmental deterioration scenarios.

The numbers and types of used structural elements are standardized as much as possible for ease of construction, economy and re-use in similar situations.

Measurements conducted after the installation of the steel buttressing demonstrated that the progression of the cracks has ceased. It can be concluded that this temporary strengthening structure has provided the required time and structural safety for the permanent strengthening and restoration efforts.

REFERENCES


