A Structural Design Case Study on Reconstruction of a Historical Timber Mansion

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1. Introduction

Historical structures have essential importance in the ways of both they are cultural heritage to the next generations and they give idea about the building technology in their construction time. Hence, the protection of these structures should be taken with attention. Turkey has a lot of historical structures, which mostly were built during Ottoman Empire in almost 700 year period of time. Although these structures have architecturally significant, many of them were demolished mostly due to the lack of maintenance. One of these structures is the Mansion of Tunuslu Hayrettin Pasha, which was built in the second half of the 18th century in Istanbul. Timber framed mansion was suffered severe damages and finally disappeared in the middle of 20th century.

In this paper, reconstruction of a historical timber mansion was investigated. For that, a computer structural model of the structure was created. Spectral analysis was applied on the model using mode superposition analysis and spectral response diagram was modified from Turkish Seismic Code 2007 (TSC 2007) with %10 damping ratio by using a scale factor. After the analytical results, steel plates were chosen in design of structural timber elements connections.

2. History of the mansion

Istanbul’s old town area consisted of a multi layered structures. The great palace of Constantinople was located in the south-eastern end of the peninsula now known as Old Istanbul. It served as the main royal residence of the Eastern Roman or Byzantine emperors from 330 to 1081 and was the centre of imperial administration for over 800 years. After Ottoman emperor conquered Istanbul, the Ottoman palace and new mosques were built on the great palace ruins of Constantinople. Mansion of Tunuslu Hayrettin Pasha was located south-east direction of the Sultanahmet Mosque (Blue Mosque) and constructed over ruins of an old ottoman mansion and great palace of Constantinople in 18th century. In 1878 mansion was bought by Hayrettin Pasha. After his death, the mansion renovated as a veterinary school in 1903. In 1906 a new building was constructed near to old mansion and veterinary school was extended with new service buildings. The fire in 1919 destroyed some sections of the building and the veterinary school moved to a new place. The latest photograph of the mansion was dated in 1937 (Fig.1).

Restitution work of the mansion (Eldem, 1986) was studied by Sedad Hakki Eldem in “Turkish Houses Ottoman Period” book (Fig.2). Layout plans of mansion, veterinary school and other buildings were appeared in historical Istanbul maps which dated in 1913-1914. External dimensions of structures were indicated on the map. This map and restitution work of the
Fig. 1 - Photograph of the mansion

Fig. 2 - Floor plans

Fig. 3 - Superposed plan
mansion were superposed as well as compared with the dimensions (HASSA, 2012). The results showed that the dimensions represent the structure with ignorable mistakes (Fig.3). The old photographs were used for getting detailed information of floor’s plan as well as material information (Fig.4).

3. Structural system of the historical mansion
Two-storied Mansion of Tunuslu Hayrettin Pasha has dimensions of almost 14m x 26m in plan according to detailed restitution project, and has traditional Turkish timber structural system. The mansion is located on the ruins of ancient buildings found on the construction area of the mansion. Therefore, a few structural systems were compared in order to transfer minimum load to the ruins of ancient buildings, and one of them was adopted in structural design (Fig.5). Mansion of Tunuslu Hayrettin Pasha consists of main traditional structural members including timber studs, diagonal members, and beams as a traditional Turkish house. All of vertical continuous walls are load bearing members including timber studs standing side by side. Bottom and top plates are placed under and top of timber studs. Timber studs are connected to top and bottom plates using nailed connections acting as pin ended connections. Studs having dimensions of 7x15cm and 15x15cm carry only compression loads due to gravity and live loads. However, only the studs placed at each ends of braces having dimension of 15x20cm works for not only compression but also tension forces because of transferred loads from X braces. Timber braces were placed on determined vertical continuous load-bearing walls in order to resist lateral forces. Traditional nailed connection system of timber braces works only in compression therefore all braces are designed as compression-only braces which have larger cross-sections, however, connec-

Fig.4 - Photographs of the mansion
tions of timber braces were achieved using steel plates and bolts because of sharing lateral loads between tension and compression braces (Fig.6). Steel connection plates should not be affected by corrosion in reconstruction projects. Therefore, stainless or galvanized steels are used generally in projects. Galvanized steel members were used for all timber braces having dimension of 15x20cm. Timber beams resist and transfer all vertical loads to load bearing walls. Second important function of beams is to achieve rigid diaphragm behaviour at floor levels. In order to increase lateral rigidity of beams, beams are connected to each other at one-fourth of their span length with using bridging member having same cross-section with beams as seen in Fig.7. In addition to bridging, plywood covers having minimum thickness of 3cm are attached to top and bottom faces of beams. All beams are connected to top plates by nailed connections (Fig.8). Laminated timber was used for long beams, over 10m, although the main material of the mansion is oak. Because, procurement of long members made of natural oak is hardly possible
today. The material properties of timber most commonly used and considered in the present work are reported below (Table 1).

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Laminated Timber</th>
<th>Oak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of Elasticity</td>
<td>E</td>
<td>13500</td>
<td>12500</td>
</tr>
<tr>
<td>Bending</td>
<td>f_b</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Tension parallel to grain</td>
<td>f_t</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td>Compression perp. to grain</td>
<td>f_p</td>
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<td>3</td>
</tr>
<tr>
<td>Compression parallel to grain</td>
<td>f_c</td>
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<td>12</td>
</tr>
<tr>
<td>Shear in beam</td>
<td>f_s</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 1. Material properties

4. Structural and Seismic Analyses

Computer based structural and seismic analyses were carried out by using SAP 2000 V.14 software. Structural model was prepared by using frame elements for studs, braces and top-bottom plates, and membrane shell elements for floor load transfers (Fig.9). Response spectrum analysis was applied on the structural model using mode superposition analysis. TSC 2007 has defined specific equations for each range of the spectrum curve for four different soil types from the strongest one, Z1, to the weakest one, Z4. All of spectrum functions given in TSC 2007 are based on damping ratio of 5%. Although timber buildings have almost damping ratio of 15%, the damping ratio was assumed as 10% in this reconstruction project in order to limit the damage level of the structure under severe earthquake excitations. Soil class of the construction area is Z4. The spectrum function was scaled for the damping ratio of 10% while using in dynamic analysis (Fig.10).
Timber braced structures behave elastically in seismic load conditions. Therefore, response modification factor (R) is taken around 2~3. R was selected 3 for the mansion. Building importance factor (I) was taken 1, and design ground acceleration was taken 0.4g according to TSC 2007. Seismic parameters were used in detailed dynamic analysis. High damping ratio (10%) of timber provided significant decrease of the base shear more than 18% (Fig.11). Lateral drifts were limited and controlled, significantly.

5. Conclusions
Structural and seismic behaviors of the timber mansion were investigated. The following conclusions can be drawn from this study:
1. Assumed damping ratio of 10% of timber achieved significant decrease of base shear up to 20%.
2. Response modification factor was taken 3 although seismic design of timber structures was ignored in TSC 2007.
3. X braces in the structure not only resist the lateral loads but also decrease the drifts of the structure effectively.
4. Galvanised steel plates were preferred for connections when compared costs of galvanised and stainless steel plates.
5. Connections of timber braces are achieved using steel plates and bolts because of sharing lateral loads between tension and compression braces. Traditional nailed connections provide larger brace sections than bolted connections with using steel plates.
6. Dimensions of used members directly affect the usage of natural and fabricated timbers. Procurement of natural timber is obviously difficult for timber members having length of over 10m. Laminated timber is suggested for long spans and large sectional dimensions.

References