# CONSERVATION OF TRADITIONAL HOUSES AND A CASE STUDY ON SAFETY EVALUATION BY USING LIMIT ANALYSIS

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**Keywords**

*Traditional Houses*
*Failure Mechanism*
*Hımış Structures*
*Orhaneli Houses*

**Abstract**

*Most of the traditional houses in western Anatolia are a type of hımış (traditional timber frame) structure. Deterioration of these traditional houses is mostly due to their abandonment. Abandonment causes the structure's load-bearing system vulnerable to environmental effects and ultimately weakens the structure against seismic loads. A case study is performed on the Orhaneli houses. Building-scale suggestions are proposed towards the conservation of these houses based on the performed analysis and documentation. The results of simplified limit analysis of 20 houses utilized in this study are presented and the need for finite element modeling of these structures with sophisticated connection detailing is underlined. It is observed that the majority of examined houses are resilient for the seismic events of 50% probability of exceedance in 50 years, however, they need to be retrofitted for the seismic events of 10% probability of exceedance in 50 years.*

## GELENEKSEL KONUTLARDA KORUMA VE LİMİT ANALİZİ KULLANILARAK GÜVENLİK DEĞERLENDİRMESİ ÜZERİNE BİR VAKA ÇALIŞMASI

**Anahtar Kelimeler**

*Geleneksel konut*
*Hasar mekanizması*
*Hımış strüktürler*
*Orhaneli evleri*

**Öz**

*Batı Anadolu'daki geleneksel konutların çoğu hımış (geleneksel ahşap karkas) yapı tekniğiyle inşa edilmiştir. Bu geleneksel konutların bozulmaları daha çok terk edilmelerinden kaynaklanmaktadır. Terk, yapının taşıyıcı sisteminin çevresel etkilere karşı savunmasız kalmasına neden olmakta ve zamanla yapıyı sismik yüklere karşı zayıflatmaktadır. Bu kapsamda, Orhaneli evleri üzerinde bir vaka çalışması yapılmıştır. Yapılan analiz ve belgelere dayalı olarak bu evlerin korunmasına yönelik yapı ölçeğinde öneriler sunulmuştur. Bu çalışmada kullanılan 20 evin basitleştirilmiş limit analizinin sonuçları sunulmuş ve bu yapıların karmaşık bağlantı detaylandırması ile sonlu elemanlar modellemesine olan ihtiyacın altı çizilmiştir. İncelenen evlerin çoğunluğunun 50 yılda aşılma olasılığı %50 olan sismik olaylara dayanıklı olduğu, ancak 50 yılda aşılma olasılığı %10 olan sismik olaylar için evlerde güçlendirme yapılması gerektiği görülmüştür.*

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## 1. Introduction

Historic settlements must be protected from the effects of natural disasters (International Council on Monuments and Sites, 2011). Natural disasters and abandonment severely affect the structural strength of traditional houses. A field study was conducted in the vicinity of Orhaneli to document traditional housing culture as well as to determine the behavior of traditional houses against seismic loads. Since the area is located in an earthquake-prone zone, determination of their seismic behavior is significant for their proper conservation methods.

Orhaneli is one of the rural-dominant towns of Bursa city, which was the first capital of the Ottoman Empire. Orhaneli is a mountainous region with its surrounding villages located in the southern part of the city and settled around the mountainside of Uludağ (Figure 1). According to sources, Orhaneli was founded by the Roman Emperor Hadrian in the 2nd century BC (Schwertheim, 2014).

Figure 1. The location of Orhaneli in Marmara Region (Google Earth, 20.04.2022).

This study is based on traditional houses which have been documented for the center of Orhaneli and the surrounding villages. Existing traditional houses are built with natural materials of the surrounding area: stone, soil, wood, various types of limestone, and high-quality marble. Although the traditional texture is preserved, increasing deterioration rates due to abandonment threaten the environment. The rapid decline in the population increases the abandonment and this situation leads to adversarial effects on the condition of the load-bearing system of these houses. A careful study of the previous collapse mechanism of similar structures in the past earthquakes showed major mechanism formation in the stone wall section of these types of houses. Therefore, as a case study, a simplified mechanism analysis for 20 houses was performed to determine the performance levels.

## 2. Literature Review

Documentation of many traditional structures has revealed that the original textures of Orhaneli villages and houses in the town center are at high risk of structural deterioration caused by abandonment. For this reason, studies have been taken one step further. Kinematic limit analysis has been carried out to determine the robustness of the structures and their behavior against seismic loads.

The possible failure mechanisms for masonry structures and formulations for their analysis are given in various studies (D'ayala & Speranza, 2003). Observations outlined specific damage patterns and failure mechanisms (Casolo, Neumair, Parisi & Petrini, 2000; D'ayala & Benzoni, 2012). Systematic observations and inspections of earlier earthquakes helped to determine different collapse mechanisms of structures and based on this, a damage and vulnerability assessment approach was developed (Lagomarsino & Podesta, 2004). Lagomarsino and Podesta (2004) described collapse mechanisms related to different macroelements. A method for vulnerability analysis with a damage probability matrix based on structural collapse mechanisms of various elements of the structure was also established (Lagomarsino & Podesta, 2004a). Identification of damage states in a proper way, the damage mechanism activation, and the ultimate capacity of the masonry structure are crucial (Lagomarsino & Resemini, 2009). In general, the limit analysis is performed on a structure through an assumed failure mechanism, both by evaluation of the horizontal static multiplier of vertical loads and mass proportional inertial forces (Lagomarsino & Resemini 2009).

Many researchers recently focused on the seismic performances of traditional buildings in Turkey. For example, Doğangün, Tuluk, Livaoğlu & Acar (2006) focus on traditional buildings and their damage during earthquakes in Turkey, while Ural, Doğangün, Sezen & Angın (2007) investigate the seismic performance of masonry buildings during the 2007 Ankara earthquake. Recent and frequent earthquakes of Elazığ (2010 and 2020) have been the source of new studies as well. Studies on masonry and concrete building failures during the 2010 Elazığ earthquake (Celep, Erken, Taşkın & Ilki, 2011) were also carried out. Assessments of masonry buildings in Elazığ and Malatya following the 2020 Elazığ earthquake (Günaydın et al., 2021) was also among the recent studies.

## 3. Characteristics and Structural Problems of Traditional Buildings

The foundation of the houses and the ground floors are masonry structures built of local stone. There are also examples where ground floors are built with adobe over a stone foundation. For some of the structures built for residential use, a wooden-frame skeleton system with adobe infill instead of stone masonry is utilized above the foundation level. The wooden-frame skeleton system with adobe infill is often preferred for the upper floors. However, the entire upper floor is not a wooden-frame system, the exterior walls with stoves and cabinets are of stone masonry. There are a small number of examples where the upper floor is completely stone masonry or wooden-frame skeleton system. The facades are partially and interior walls are completely plastered and the Baghdadi technique is not utilized. A hip roof is formed by wooden beams and it is covered with tiles.

Dual-function (residence and barn) structures have ground floors with two entrance doors for each function and small ventilation windows. In residential buildings, there exist large windows as well as doors. The floors are built with floorboards with an average thickness of 2-3 cm installed over wooden beams. Ground floor ceilings are covered with wood if the venue is room. The ceilings of other areas are uncoated and making the floor beams visible. The same applies to the upper floors. While the ceilings of the rooms are covered by wooden planks – some even with embellishments on them-, "sofa" usually does not have a ceiling cladding. Within the scope of this study, Orhaneli district center and the nearby villages of Deliballılar, Kusumlar, Sadağı, and Serçeler were examined. Some sample images of Orhaneli houses are given in Figure 2 and Figure 3.

Figure 2. Raimler House in Serçeler village, 2018.

Figure 3. Deliballılar village door no: 100, 2014.

One of the 20 buildings that are subject of this study, has a commercial function and 19 are residential. The floor plans of all these studied houses are shown in Figure 4. The ground floor exterior walls of the commercially functioning Altıncılar Coffeehouse are stone masonry. The upper floor of the coffeehouse with wooden skeleton walls with adobe infill has a residential plan with an internal "sofa".

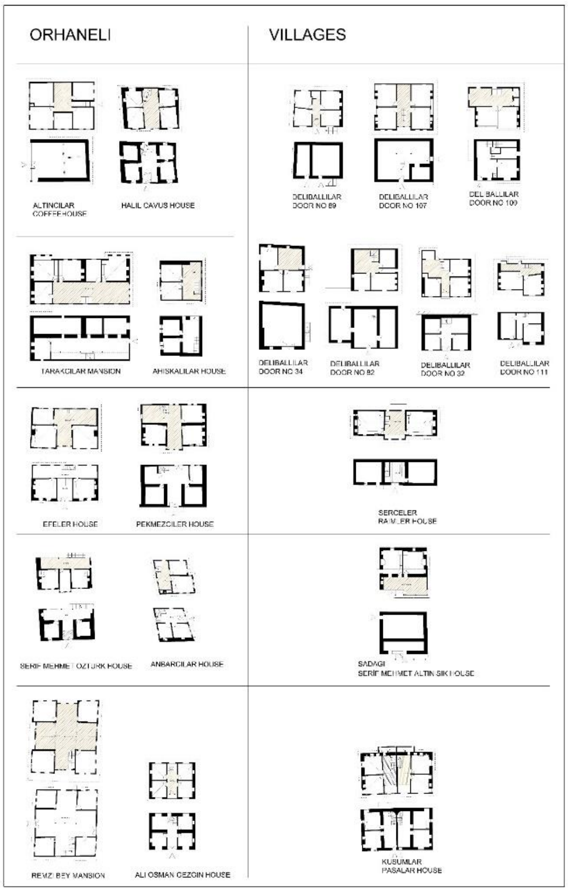


Figure 4. Floor plans of the studied Orhaneli houses

The ground floors of the residential houses are predominantly built with stone masonry with wooden beams placed horizontally at an average of 1.25m intervals as shown in Figure 5. For some of the houses, there are both stone masonry walls and wooden skeleton walls with adobe infill, on the ground floor (Ali Osman Gezgin House, Anbarcılar House, Efeler House, no: 32, no: 100, no: 111). It is observed that some of the houses were completely built by a wooden frame system with adobe infill (Remzi Bey Mansion).

Figure 5. A typical example of a continuous stone masonry wall on the ground floor and upper floor with embedded wooden beams.

The walls on the upper floors where the stone hearth and other complementary elements like cabinets exist, walls are continued as stone masonry. However, while some of the masonry walls are rising as masonry on the upper floor (Efeler House, no: 100, no: 107), in some, masonry walls are built with adobe blocks (Pekmezciler House, Paşalar House). The adobe blocks as the filling were preferred into the wooden frame system, where the partition walls and the facades without the stone hearths are located. For this reason, the minimum center of gravity asymmetry encountered on the ground floors increases on the upper floors.

The floors of the buildings are formed with wooden planks on wooden beams. The entrance sofa is named "taşlık" and its ceiling is not covered, however, the ceilings of the rooms are mostly covered. Like floors, the roof is also a wooden structure. Hipped roofs with tiles are very common in Orhaneli. There are wooden planks on top of the roof structure for the tile placement.

Only 20% of these mentioned structures are in constant use today. Bursa is one of the largest cities in Turkey and its population is constantly increasing. Despite this, the population growth rate of Orhaneli town has always been negative in recent years for various reasons. The following chart in Figure 6 shows the population growth rate and the dramatic population exchange. Bursa's population has exceeded 3 million recently, while Orhaneli's population has not reached even 20000 in the last 30 years.

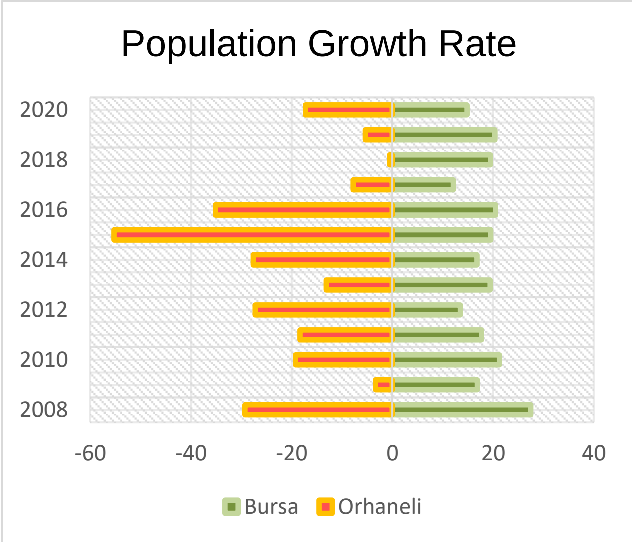


Figure 6. Comparison of population growth rate for Bursa and Orhaneli (TÜİK, accessed : 17.05.2021).

Traditional houses, as opposed to the new buildings with reinforced concrete framing, are abandoned first due to the decreasing population in Orhaneli and its surrounding villages. Abandonment causes acceleration of the strength loss in various parts of the structure. Earth materials cover wood materials and preserve wood from external factors like water and humidity. When a house loses its preservative layers of earth materials, both the earth and wood materials are compromised and begin to deteriorate and disappear. The most common deteriorations are loss of earth material like adobe filling and adobe mortar or decay of wood materials of roof framing or floors. For the abandoned houses, first, the roof gets deteriorated, and this leads to water intrusion into the walls and inside the house to the wooden floor. Water intrusion into the wall causes mortar degradation, degradation of the wooden beams in the wall, and finally section loss. Severe material deterioration weakens connections and finally jeopardizes the structural integrity of the house. In case of a seismic event, the deteriorated walls with improper floor diaphragms will be more susceptible to out-of-plane movement of the walls. All of these lead to a reduction in the robustness of the traditional houses and ultimately, these traditional houses become non-livable as per basic standards.

## 4. Kinematic Limit Analysis of The Traditional Orhaneli Houses Based on The Failure Mechanisms

Socio-cultural effects, environmental factors, and material availability are the main variables to form the historical and traditional environment (Özdemir, Tavşan, Özgen, Sağsöz & Kars, 2008). The old Turkish-style house is identified with its stone masonry ground floor and the wooden-frame upper floor and this type of construction in Turkey has been used for well over 400 years. The structural system of the civil structures in different settlements around Orhaneli that are subject to the current study is usually composed of stone and wood, and the insulation on the walls is provided by soil plaster.

There are many different types of hımış houses in terms of infill material in different parts of Turkey (Cerasi 1998; Kuban 2018; Sözen 2001). Hımış structures of Orhaneli houses are mostly wooden frames with adobe infill. Orhaneli houses are composite structures, ground floors are stone masonry and upper floors are composed of a wooden frame with adobe infill. Some of the exterior walls on the upper floor are stone masonry. Floors are composed of one-way floor beams covered by wooden planks and the assumption on the diaphragm stiffness has a paramount effect on the response of masonry wood composite structures. Floor diaphragms are neither infinitely flexible nor rigid. The rigid diaphragm assumption of these types of floors yields unrealistic results (Lagomarsino, Penna, Galasco & Cattari, 2013).

There have been many types of research for masonry structures with numerous modeling techniques. The common methods utilized are micro-modeling, simplified micro-modeling, and macro-modeling in the Finite Element (FE) Models (Chácara, Mendes &, Lourenço, 2017; Kamal, Hamdy & El-Salakawy, 2014; Lourenco, 1996; Özen, 2006). Equivalent frame modeling is utilized in the non-linear analysis of masonry structures (Lagomarsino et al., 2013; Yousefi and Soltani, 2019). Tremuri software with an equivalent frame modeling approach is very powerful for non-linear analysis of masonry structures, it can be utilized for stone masonry parts of the Orhaneli houses, and it is even possible to model the flexible wooden floor system. However, the wooden frame wall with adobe infills is still an important issue in the modeling of these houses.

Hımış structures are traditional timber housing in many parts of Anatolia and studies on their seismic structural performance is very limited. Aktaş et al. have performed a robust experimental study to develop the seismic performance of hımış frames with different infill material and cladding (Aktaş, Akyuz & Turer, 2014). However, finite element modeling and analysis of the combined stone masonry and hımış structure is still not pursued. Appropriate modeling requires depicting first the connection on the horizontal plane between the ground level masonry walls and upper hımış walls, Second the connection on the vertical plane between the hımış walls and stone masonry on the upper floor, and the last proper modeling of the wooden frame floor (Aktaş, 2017). Besides, the inclusion of the effect of material degradation, modifications, and workmanship to the modeling is also a very challenging issue (Aktaş, 2017). The individual response of walls is often observed during an earthquake for these types of structures (Erdik et al., 2003).

In recent studies for traditional houses in Turkey as referenced in the literature survey section, the performances of these houses and sustained damages during earthquakes suggested that the mechanism failure of the walls is very common. Therefore, kinematic limit analysis is performed towards the understanding of the behavior of Orhaneli houses, before relatively complex non-linear finite element analysis.

### 4.1. Methodology

Technical guides and the standards in seismic codes developed for the new buildings are not appropriate for the architectural heritage. Therefore a guide was developed by the Directorate General of Foundations of Turkey for the management of earthquake risks for architectural heritage buildings (The Directorate General of Foundations of Turkey, 2017). The analysis method is based on the assumed failure mechanisms. For a specific mechanism, the expected vertical and horizontal loads are placed in the system and virtual displacement compatible with the mechanism is taken into consideration. The opposing horizontal force is calculated using the virtual work principle. The inertia force of all possible mechanisms and the effects that occur in the junctions are calculated and checked, the possible state of collapse is determined.

The connection between ground floor stone masonry and the upper wooden frame with adobe infill, connection of the exterior masonry wall, and the wooden framing in the upper floor, and flexible one-way wooden floor system makes the structure very sensitive to the generation of collapse mechanism of the individual walls. Post reconnaissance reports show heavy damage to masonry structures and the common damage type is x-type shear cracks, failure of infill materials in out-of-plane direction (Erdik et al., 2003; Şahin Güçhan, 2007).

The possible mechanisms are projected by assessment of past damages for these types of structures and these mechanisms are shown in Figure 7. The subject Orhaneli houses are all solved for the cases given based on Eqs. (1) through (6).

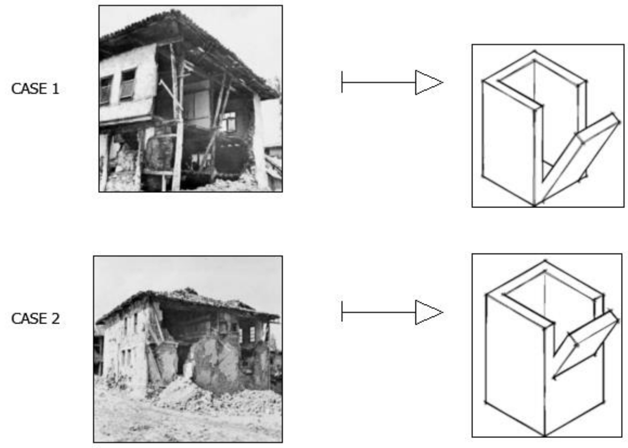


Figure 7. Failure mechanisms of the typical masonry and wooden frame combined houses.

$$\alpha_0 \sum_i P_i\delta_{xi} + \alpha_0 \sum_i W_i\delta_{xi} - \sum_i P_i\delta_{yi} - \sum_i W_i\delta_{yi} = 0 \quad (1)$$

$$M^* = [\sum_i(W_i\delta_{xi}) + \sum_i(P_i\delta_{xi})]^2 / [g \sum_i(W_i{\delta_{xi}}^2) + g \sum_i(P_i{\delta_{xi}}^2)] \quad (2)$$

$$a_{capacity} = [\alpha_0(\sum_i W_i + \sum_i P_i)]/M^* = \alpha_0 g e^* \quad (3)$$

$$e^* = gM^*/(\sum_i W_i + \sum_i P_i) \quad (4)$$

$\alpha_0$ is the coefficient for the load in the horizontal direction, $e^*$ is the mass participation factor, $M^*$ is the effective modal mass, $W_i$ is the self-weight of the wall at level i, $P_i$ is the load from the level i on the wall, $\delta_{xi}$ and $\delta_{yi}$ are the horizontal and vertical displacement of the corresponding forces (The Directorate General of Foundations of Turkey, 2017). For immediate use performance level, Eq. (5) is used for the capacity. If the capacity is required above the base level for the same performance, then Eq. (6) is employed.

$$a_{capacity} \geq 0.4gS_{DS} \quad (5)$$

$$a_{capacity} \geq S_{ae}(T_1)\phi(z/h)\Gamma \quad (6)$$

$S_{ae}(T_1)$ is the elastic spectral design acceleration for the respective mode, $\phi(z/h)$ is the normalized first mode shape to top, $\Gamma$ is the modal contribution factor.

The elastic response spectrum for the work area is presented in Figure 8 for the seismic level of DD-3 (exceedance probability of 50% in 50 years with a return period of 72 years) and seismic level of DD-2 (exceedance probability of 50% in 10 years with a return period of 475 years). The analysis is pursued both for DD-2 and DD-3 seismic levels based on the guidelines on seismic risk management of historical structures (The Directorate General of Foundations of Turkey, 2017). The seismic hazard map of Turkey and the close-up map for the current site is shown in Figure 9.

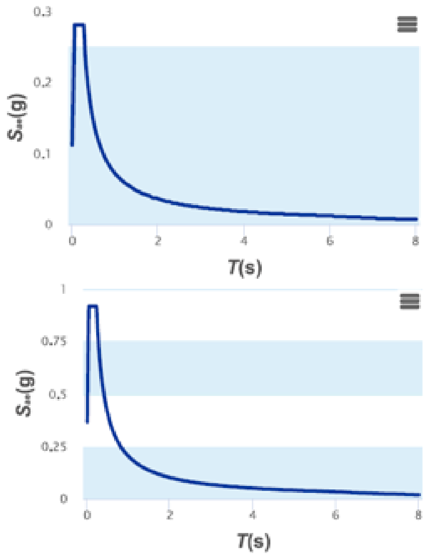


Figure 8. The response spectrum for the work area, DD-3 and DD-2 seismic levels.

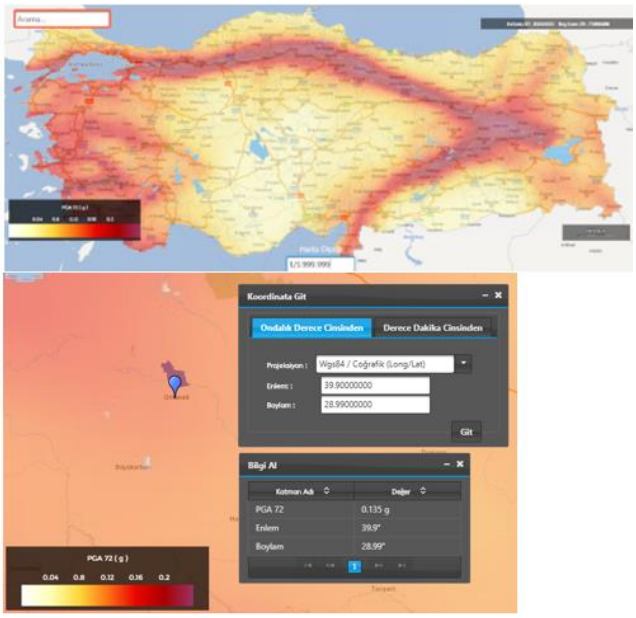


Figure 9. Seismic map of Turkey with a 50% probability of exceedance in 50 years and a close-up map of PGA for the site under investigation (AFAD Turkey Seismic Risk Map Interactive Web Application, 2020).

### 4.1. Analysis and Results

For all the houses considered in this study, failure mechanism analysis is performed for seismic load levels of DD-2 and DD-3. Short period design spectral acceleration coefficient for the desired level is taken from AFAD that are specific to the site. For simplicity soil class is assumed as ZB for all the cases. Two performance level is considered as life safety and immediate use. For the life safety performance level, the response modification factor is taken as 2 and for the immediate use safety level, the response modification factor is taken as 1 as per recommendations given in the management of earthquake risks for architectural heritage buildings (The Directorate General of Foundations of Turkey, 2017). Material properties used in the analysis are presented in Table 1. In the calculations, 30% of the live load is taken into account. The resisting moment is calculated over the base or the first-floor level depending on the chosen collapse mechanism. The overturning moment is also calculated over the base or the first-floor level. Relative floor displacement for both mechanisms is found in both cases. Modal mass participation and effective modal mass are calculated. By use of effective modal mass, the capacity is calculated. Obtained capacity value is then compared to the demand values for seismic levels of DD-2 and DD-3 and each seismic performance level.

Table 1.

The material properties used in the analysis

| Type of material | Unit weight ($kN/m^3$) |
|---|---|
| Masonry | 20 |
| Adobe | 16 |
| Wood | 8 |

Capacity demand ratio (C/D) results for the failure mechanism of case 1 and case 2 are given in Figure 10 and Figure 11, respectively. In these figures, ratios are given for seismic performance level of immediate occupancy (IO) and life safety (LS) for DD-2 and DD-3. As it can be noticed, the C/D of many houses is above 1.0 for seismic level DD-3 for both LS and IO seismic performance levels for case I and case II. However, the C/D of most of the houses is less than 1.0 for seismic level DD-2 for both LS and IO seismic performance levels for the case I and case II. For the total of 20 case studies, the C/D is below 1 in one of the case studies for seismic level DD-3 and LS seismic performance level for the mechanism I. However, for mechanism 2 for the same seismic level (DD-3) and performance (LS), the number of case studies with C/D below 1 is 3. It is observed that the lower C/D is obtained for mechanism 2 and mechanism 2 is more critical. For the total of 20 case studies, seismic level DD2 and IO performance level, both for the mechanism I and mechanism 2, C/D is below 1.

A sample capacity demand ratio calculation for one of the 20 buildings used in the study for a given performance level and a collapse mechanism is given in Table 2. In the table, the calculation for one of the case studies, Tarakçılar house, is presented. The analysis in the given example is based on collapse mechanism II and life safety performance level. For this mechanism, the expected vertical and horizontal loads are placed in the system and virtual displacement compatible with the mechanism is taken into consideration by use of the formulas 1 through 6 given in the methodology section. The opposing horizontal force is calculated using the virtual work principle and inertia force of the considered mechanism. For the given example, the capacity is calculated as 0.286g. The demand is 0.291g and 0.086g for seismic levels DD-2 and DD-3, respectively. Therefore the C/D is calculated as 0.286g/0.291g for DD2 and 0.286g/0.086g for DD-3. As it is seen in Figure 11, the C/D is above 1 for DD-3 and LS case, however, it is slightly below 1 for the DD-2 and LS case for the presented example of Tarakçılar house.

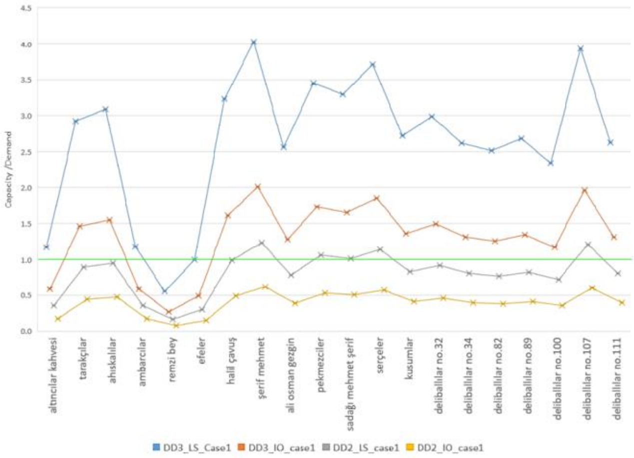


Figure 10. Capacity demand ratio results for collapse mechanism case 1.

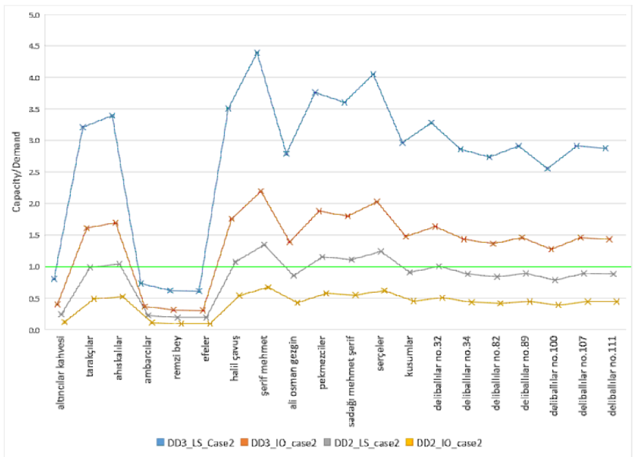


Figure 11. Capacity demand ratio results for collapse mechanism case 2.

Table 2.

A sample capacity demand ratio calculation for life safety performance level and collapse mechanism II: Tarakçılar house

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| collapse mechanism II | | | | | | | |
| *performance lev life safety* | | | | | | | |
| DD2 | | | | | | | |
| $S_{DS}$ | 0.916 | | | | | | |
| DD3 | | | | | | | |
| $S_{DS}$ | 0.281 | | | | | | |
| R | 2 | | | | | | |
| g | 0.25 | kN/m2 | dead load | | | | |
| q | 2.453 | kN/m2 | live load | | | | |
| g - çatı | 1 | kN/m2 | roof dead load | | | | |
| q - çatı | 1 | kN/m2 | roof live load | | | | |
| $\Upsilon_z$ | 20 | kN/m3 | | | | | |
| A | 7.841 | m2 | 0.5 | 3.22 | 4.87 | | |
| $W_Z$ | 121.7 | kN | | | | | |
| $P_z$ | 7.729 | kN | dead load+30% of live load over a tributary area | | | | |
| $B_z$ | 3.22 | m | | | | | |
| $h_z$ | 2.7 | m | | | | | |
| $t_z$ | 0.7 | m | | | | | |
| $\Upsilon_1$ | 20 | kN/m3 | | | | | |
| A | 7.841 | m2 | 0.5 | 3.22 | 4.87 | | |
| $W_1$ | 108.2 | kN | | | | | |
| $P_1$ | 10.19 | kN | | | | | |
| $B_1$ | 3.22 | m | | | | | |
| $h_1$ | 2.4 | m | | | | | |
| $t_1$ | 0.7 | m | | | | | |
| $M_{resisting}$ | 41.43 | kN-m | resisting moment about level 1 | | | | |
| $M_{overturning}$ | | | | | | | |
| $\alpha_0$ | 0.269 | | | | | | |
| $\delta_{Wz}$ | 0 | | | | | | |
| $\delta_{Pz}$ | 0 | | | | | | |
| $\delta_{W1}$ | 0.5 | | | | | | |
| $\delta_{P1}$ | 1 | | | | | | |
| | | | | | | | |
| M* | 11.31 | N-s2/m | | | | | |
| e* | 0.937 | | | | | | |
| $a_{capacity}$ | 2.810 | m/s2 | or | 0.286 | g | | |
| φ(z/h) | 0.529 | | | | | | |
| N | 2 | | | | | | |
| Γ | 1.2 | | | | | | |
| $a_{demand}$ | 2.854 | m/s2 | or | 0.291 | g | for DD2 level | |
| $a_{demand}$ | 0.876 | m/s2 | or | 0.089 | g | for DD3 level | |

The minimum thickness requirement and maximum aspect ratio (the ratio of wall height to its thickness) for unreinforced masonry structures are given in Turkey Building Seismic Code as shown in Table 3 (T.C. İç İşleri Bakanlığı Afet ve Acil Durum Yönetimi Başkanlığı, 2018). In this table $(t_{eff})_{min}$ is the minimum thickness of the masonry wall, and $(h_{eff}/t_{eff})_{max}$ is the ratio of maximum wall height to its thickness. Masonry walls of Orhaneli houses comply with the code requirement.

Table 3.

Thickness and aspect ratio requirement of unreinforced masonry wall for base shear in Turkey Seismic Building Code 2018

| Masonry type | $(t_{eff})_{min}$ (mm) | $(h_{eff}/t_{eff})_{max}$ |
|---|---|---|
| Masonry (unreinforced) with natural or unnatural cut-stone | 350 | 9 |
| Masonry (unreinforced), with other masonry units | 240 | 12 |

## 5. Suggestions for Structural Consolidation

Increasing structural deteriorations in buildings due to abandonment render buildings vulnerable to earthquakes. The increases in deterioration levels not only weaken the structure but also causes the loss of a whole traditional house and traditional texture. It is possible to reconstruct the lost traditional structure with reconstruction. Although reconstruction is one of the most major conservation techniques, it is debatable how much the reconstructed building reflects the original spirit of a traditional house. Therefore, reconstruction is chosen as the last option of conservation techniques and it is preferred to avoid reconstruction if possible.

Consolidation, renovation, and adaptation are suitable restoration applications for traditional Orhaneli houses. Survival of these structures heavily depends on their periodic inspection and minor repairs to the structural system as necessary. Consolidation should be applied for structures whose structural conditions are weakened. Consolidation not only prevents the destruction of the traditional house but also protects against earthquake effects, which are natural risk factors in Turkey.

## 6. Conclusions

The main purpose of this study is to determine the structural deteriorations and seismic behavior of traditional Orhaneli houses. The article indicates the importance of the structural strength of traditional Orhaneli houses and the main deterioration problems in the load-bearing system and building materials.

The construction system of Orhaneli houses is similar to typical hımış construction. Natural building materials such as wood, stone, and adobe used in buildings need constant maintenance. However, population loss and abandonment cause rapid deterioration. Discrete materials within the construction system of Orhaneli houses make them vulnerable to the individual rigid body motion of the walls. The connection of masonry walls to the upper wooden-frame adobe infill walls in a horizontal plane and the connection of masonry walls to the wooden frame adobe infill walls at vertical planes require utmost attention. Based on the limit analysis results, Orhaneli houses need to be retrofitted for design seismic level (DD-2) both for seismic performance levels of IO and LS. It is also observed that the performance of the houses for the seismic level DD-3 is acceptable. It is also observed that among the case studies, DD-3 and LS performance level is more critical for mechanism 2 compared to mechanism 1. C/D ranges between 0.08 and 0.61 for seismic level DD-2 and IO performance level for collapse mechanism 1. C/D ranges between 0.09 and 0.67 for seismic level DD-2 and IO performance level for collapse mechanism 2. Both for mechanism 1 and mechanism 2, the seismic level DD-2 and IO performance levels are not satisfactory. C/D ranges between 0.17 and 1.23 for seismic level DD-2 and LS performance level for collapse mechanism 1. C/D ranges between 0.19 and 1.35 for seismic level DD-2 and LS performance level for collapse mechanism 2. For mechanism 1 with seismic level DD-2 and LS, 5 out of 20 study cases, are satisfactory. For mechanism 2 with seismic level DD-2 and LS, 7 out of 20 study cases, are satisfactory.

The seismic performance of the traditional Orhaneli houses needs to be elaborated further, for the development of proper seismic retrofit techniques and to conserve and pass these historic heritage values to the next generations. As a future recommendation, the material tests and vibrations tests on these houses need to be performed and the results need to be used in a refined finite element model with nonlinear analysis.

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**Authors Contributions**

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In this study; Author 1 contributed on execution of the field work, documentation of the traditional houses, literature survey, writing the manuscript, and preparing the drawings; Author 2 contributed on literature survey, execution of the limit analysis, analysis of the results, and writing the manuscript; Author 3 contributed on setting guides for the execution of the field work and the analysis.

**Conflict of Interest**

No conflict of interest has been declared by the authors.

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