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Seismic Safety of a Historical Row House Complex Built during Ottoman Period

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ABSTRACT

In this study, seismic safety assessment is presented for one block of Akaretler Row Houses, which was constructed in the second half of the nineteenth century in Istanbul. The row houses include six blocks and 133 housing units with similar characteristics. The procedure for seismic safety assessment and results of this assessment are summarized briefly, as well as architectural and structural characteristics of this housing complex. The assessment procedure includes preparation of in-situ drawings of the structural system, damage inspection, determination of chemical and mechanical characteristics of building materials through laboratory tests, soil investigation study and structural analysis using finite element method and a simple approximate method. At the end of the study, in spite of presence of several non-complying aspects, it was concluded that the housing complex built more than hundred years ago, had sufficient seismic safety as required by the Turkish Seismic Design Code.

Introduction

In the late eighteenth century, row houses emerged first in England, and then they spread to other areas like Western France, Belgium, Northern German, Holland and Denmark, (Peters and Henn 1988, Sagdic 1999). The row houses were built to provide accommodation for the growing number of workers due to the Industrial Revolution. While these construction activities were going on in Europe, the first urban planning activities of the Ottoman Empire began at the end of nineteenth century to reduce losses those could occur due to fires, which had destroyed several big cities in the nineteenth century. For this purpose, basic measures were to construct wider roads, to widen and stabilize the existing roads and to arrange new dwellings for the increasing population.

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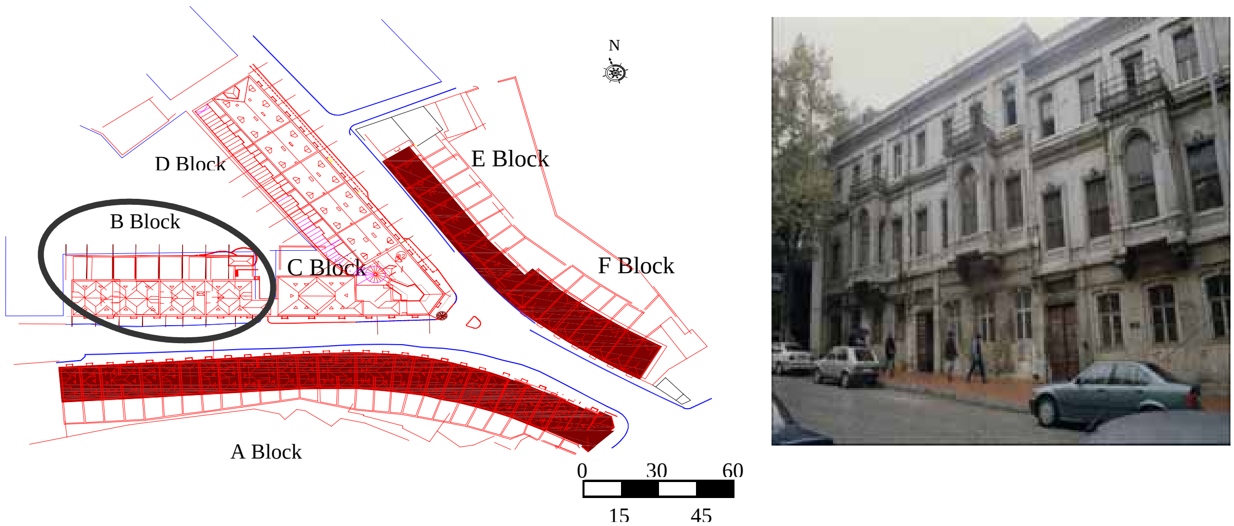
Although some dwellings were built for collective use in the fifteenth century, the construction period of row houses in the form of groups like western row houses was the nineteenth century, (Sagdic 1999). Row houses in Turkey constitute a part of cultural heritage of Ottoman period. In addition to the influence of the Industrial Revolution, social class and ethnic factors in the Ottoman Empire played an important role in the formation of these houses. The first example of this form of dwelling was Akaretler Row Houses. Akaretler Row Houses were constructed around 1875 as the first housing complex for the accommodation of the workers of Dolmabahce Palace, (Erenoglu 1998). The row houses, which are currently located in the heart of Istanbul, are composed of different blocks, namely A, B, C, D, E and F with similar characteristics. Block A is currently being used mostly by private companies as offices, while the other blocks, which are planned to be used for residential purposes, offices, shops, a hotel and a museum, are in restoration phase. This set of residences, which is one of the best examples of the civil architecture of this period with their neoclassical front design, were constructed by the order of Sultan Abdulaziz of the Ottoman Empire. Elmadag Surp Agop, Ortakoy Eighteen and Fener-Balat Row Houses are some other examples of the row houses of this period, (Sagdic 1999 and Cakmak 2001).

Since the Akaretler Row Houses are located in highly seismic area in south part of Istanbul close to Marmara Sea, the seismic safety of these buildings is a major concern for ensuring their existence in future. Therefore, during the restoration project, a seismic safety assessment is seen necessary. In this study, the seismic safety assessment procedure carried out for the Block B of this particular housing complex and the results of this assessment are presented together with information on the structural and architectural characteristics of Block B. The assessment procedure includes determination of in-situ structural characteristics such as dimensions of structural members and plan of the structural system, load paths from floors to foundations, damage inspection, determination of chemical and mechanical characteristics of materials through laboratory tests, soil investigation study and structural analysis using finite element method and a simple approximate method. At the end of the study, in spite of presence of several non-complying aspects, like excessive amount of window openings, it was concluded that the housing complex built more than hundred years ago, had sufficient seismic safety as required by the Turkish Seismic Design Code (1998). As mentioned by Lourenço (2005) and Mele (2003), there were many difficulties during the seismic safety evaluation such as the uncertain arrangement of the bricks and mortar joints, and the variability of the mechanical characteristics of the masonry material throughout the structure and the lack of codes.

General outline of Akaretler Row Houses

Akaretler Row Houses, constructed around 1875 under the western influence, are the first example of row houses in the Ottoman Empire. These group houses, built by the financial support of the Ottoman Court, have a significant place among the other historical row houses, with their neo-classical façade, ornaments and location. These row houses erected in Istanbul consist of six blocks with 133 housing units, which were stepped parallel to the slope of the terrain. The region on which the row houses are located had been exposed to numerous destructive earthquakes during the history, (Ilki et al 2006). According to Seismic Zoning Map of Turkey, these houses are located on the second degree seismic zone, representing quite high seismic risk. The general layout plan of these blocks, namely A, B, C, D, E, and F can be seen in Fig. 1. The façade of Block B is presented in Fig.1. The original structural system of Block B consisted of masonry walls and vaulted brick floors. However, the brick floors were demolished and reinforced concrete plate slabs were constructed during the past restoration activities. The main construction materials of Block B are stone for foundations, and brick for the walls of the basement and upper structure. While the doors and balustrades of balconies of these masonry houses were made of cast iron, stairs were originally built with masonry or wood, which were later reconstructed using reinforced concrete. Bricks were also used for relatively smaller span arches covering the entrance of corridors. The cut stones on façade are for a decorative finishing rather than being a part of the structural system. The Block B has eight houses attached to each other. Each of them is three stories high consisting of entrance story and two upper stories, Fig. 2. The levels of some stories are different from each other due to the slope of terrain as shown in Fig. 2. The floors have different heights, varying between about 3.15 and 5.0 m. The plan of the building is given in Fig. 3. The structure has a rectangular plan that is about 17 m wide and 77 m long. Several additions were made including new brick masonry walls (the blue color in the plan), and reinforced concrete columns (brown color in the plan), during past restoration works. The thicknesses of walls are varied between 50 and 120 cm for outer walls and between 20 and 70 cm for inner walls.



(a) (b)

Figure 1. a) The site general layout plan of Akaretler Row Houses, b) The façade of the Block B.

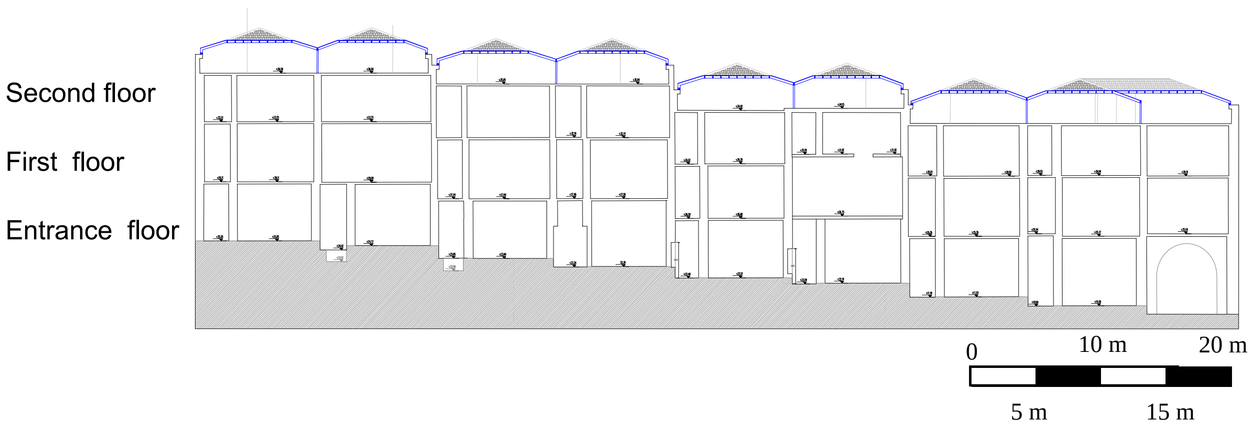


Figure 2. The longitudinal section of the B Block.

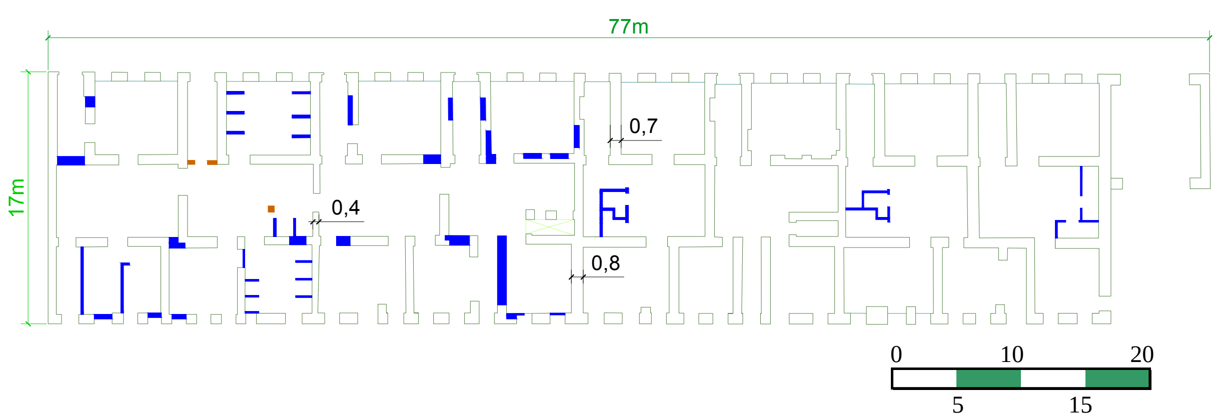


Figure 3. The plan of the B Block (entrance level).

Observed Structural Damage

The buildings have experienced a severe earthquake in 1894, which effected many different parts of Istanbul. According to available information and observations on-site, the Block B of Akaretler Row Houses did not experience a considerable seismic damage after 1894 Istanbul Earthquake. Although not formed because of seismic events, several minor cracks in structural walls are observed. According to the authors, these cracks were formed due to singular loads concentrated on walls, mostly because of inadequate lintel lengths and/or local minor alterations in structural plan. Since the damages are almost negligible, it is concluded that these damages are not needed to be taken into account while assessing the seismic safety of the buildings. It should be noted that, although not directly related with seismic safety, some of the newly constructed reinforced concrete flat slabs have some damages, mostly because of insufficient flexural capacity due to improper placement of reinforcing bars, careless formation of supports and low concrete strength. Although the reinforced concrete slabs are not perfectly connected with structural walls, according to the authors, the friction forces between the structural walls and the reinforced concrete plates would be sufficient for providing the diaphragm effect. No doubt, the replacement of vaulted brick floors with reinforced concrete flat slabs improves the diaphragm effect, since the original vaulted slabs, which are still present in Block E and F had been poorly constructed. The connection of existing walls and reinforced concrete slabs of Block B, and original vaulted slabs in Block E are shown in Fig. 4.

(a) (b)

Figure 4. a) The connection of existing walls and reinforced concrete slabs of Block B, b) original vaulted slabs in Block E.

Geotechnical Aspects

Soil conditions of the Akaretler row houses are determined by in-situ tests including six boreholes and laboratory tests conducted on disturbed/undisturbed samples and cores. One of six boreholes, 21 m deep, is on the area of the B Block. In addition to the borehole, two pits are trenched for defining the properties of the B block soil. The standard penetration tests indicate an artificial fill layer underlain by greywacke layer. The artificial fill comprises of coarse gravel and soft organic soil, from surface to 1.2 m depth. There is a layer of brown colored, weak greywacke with discontinuities below the fill layer. The greywacke consists of fine grained and greenish-grey colored claystone and siltstone. According to the results of the soil investigation, allowable bearing capacity and modulus of subgrade reaction (k) of the soil are estimated as 250 kN/m^2 and 35000-50000 kN/m^3, respectively. Ground water table is not observed at the pits.

Experimental Study on Chemical and Mineralogical Characteristics of Materials

In this paragraph, experiments carried out for determining the chemical and mineralogical characteristics of structural materials, namely bricks and mortars, results of these experiments and evaluation of these test results are summarized. All material specimens are taken from inner structural walls. Specimens include four samples from bricks, 17 samples from jointing mortars and one plaster mortar. During chemical analysis, wet chemistry and instrumental methods are utilized. Wet chemistry method is utilized for determination of high silica, while UV (ultra violet) visible spectrophotometer and atomic absorption methods are utilized for the determination of other oxide components. While determining the percentages of carbonate, organic contents and loss of ignition, calcimetry analysis is applied. XRD (X- ray diffraction) is applied for mineralogical analysis and the presence of feldspar, quartz and calcite, determined using chemical rational approach, is verified. Percentage of oxide components for mortars and bricks are presented in Table 1. In this table, arithmetic means ($\bar{x}$) and standard deviations (σ_n or σ_{n-1}), as well as number of samples (n) taken into consideration are given for mortars, while only maximum, minimum and mean values are given for bricks, since the number of brick samples is only four. While determining the means and standard deviations for mortars, the values with very high deviation are not included in the analysis. During the study on mineralogical compositions, only feldspar, quartz and calcite are considered. Results of the mineralogical study for mortars and bricks are presented in Table 2.

Table 1. Oxide components for mortars and bricks.

Mortars*					**Bricks**** (n=4)			
	n	$\bar{x}$	σ_n	σ_{n-1}		Max	Min	$\bar{x}$
SiO_2	13	0.505	0.092	-	SiO_2	0.357	0.198	0.279
CaO	10	0.183	-	0.05	CaO	0.053	0.020	0.035
Al_2O_3	14	0.051	0.016	-	Al_2O_3	0.244	0.158	0.221
Fe_2O_3	15	0.030	0.016	-	Fe_2O_3	0.251	0.201	0.226
MgO	12	0.033	-	0.016	MgO	0.101	0.061	0.079
Na_2O	16	0.040	0.017	-	Na_2O	0.046	0.019	0.030
K_2O	15	0.074	0.022	-	K_2O	0.041	0.028	0.036

* Arithmetic means for other minor oxide components: NiO=0.024; CdO=0.015, ZnO=0.008; CoO=0.006; CaO=0.001; n: 18
** Arithmetic means for other minor oxide components: NiO=0.002; CdO=0.002, ZnO=0.010; CoO=0.018; CaO=0.001; n: 4

Table 2. Values of arithmetic means and standard deviations of mineral components for mortars.

Mortars				**Bricks** (n=3)	
	n	$\bar{x}$	σ_n		$\bar{x}$
Feldspar	18	0.638	0.071	Feldspar	0.410
Quartz	12	0.207	0.082	Quartz	0.330
Calcite	14	0.246	0.082	Calcite	0.090

Considering the construction period of the building, one would think that as binder Khorassani type mortar, which is obtained by addition of brick powder to hydrated lime might have been used. In this case, hydrates of calcium silicates and calcium aluminates should have been formed due to pozzolanic effect. However, in XRD tests, these formations are not observed. Consequently, it is decided that the binder is made of hydrated lime mortar, without brick powder. However, in this case, the presence of adequate conditions and sufficient aging should be discussed for the carbonation of $Ca(OH)_2$. According to the results of XRD tests, it might also be possible that $Ca(OH)_2$ remained as hexagonal portlantide crystal without being carbonated. However, considering the absence of portlantide, it is assumed that all hydrated lime was transformed into calcite. The results of mechanical tests on mortar specimens support the validity of this assumption. The high content of feldspar indicates that the sand used in the mortars also contained eruptive rock particles. In addition, the sand contains quartz and calcite from sedimentary origin. It is a high probability that same type of sand was used during the production of bricks as non-plastic flushing material. The significantly higher ratios of calcite in mortars with respect to bricks prove that the increase in the ratio of calcite in mortars is due to carbonation of hydrated lime, as well as the sand content. The origin of clay minerals of the bricks is sodium feldspars. According to their appearance and color, it is clear that the bricks are simply produced (common type) in field kilns and they contain components with iron.

Mechanical Characteristics of Materials

In order to define material characteristics of the B Block, laboratory tests are carried out. According to the restoration project, since some walls of the block are demolished partly or fully, core samples could be taken from these walls. Core samples are used to determine the compressive and shear strength, and elastic modulus of the walls, Fig. 5. These samples consisted of two-brick parts and a mortar layer between them. These cylindrical specimens have a diameter of about 95 mm and a length of 100 mm.

a) Compressive strength test

b) shear strength test

Figure 5. Laboratory tests.

The compressive strength tests are conducted on core samples taken from different floors of the structure, Fig. 5a. While evaluating the results of these tests, specimens exhibiting large variations were taken out of evaluation according to Chauvenet Criteria (Akman 1978). The compressive strengths and elasticity moduli are presented in Table 3. As seen in this table, both compressive strength and elasticity moduli of the specimens taken from the second floor are significantly lower than the specimens taken from the entrance and first floors. The buildings have not been maintained for almost more than 10 years. Therefore, this difference in compressive strength and elasticity modulus may be attributed to reduction of their capacities due to wetting and drying cycles, and humidity conditions, caused by insufficient maintenance of the roofing system. The relationships of axial stress and average axial strain are given in Fig. 6. Average compressive strength is 2.96 MPa and minimum compressive strength is 1.99 MPa. It should be noted that the allowable compressive stress for ordinary structural bricks produced in the field kilns is given as 0.8 MPa by the Turkish Seismic Design Code (2006).

Table 3. Compressive strengths and elastic moduli of core samples.

Sample No.	**Location**	**Compressive strength** (MPa)	**Elastic modulus** (MPa)
BK-1	Entrance	4.28	324
BK-19	Entrance	3.59	257
BK-17	First floor	3.13	219
BK-5-5	Second floor	2.34	176
BK-7	Second floor	1.99	181
BK-16	Second floor	2.43	151

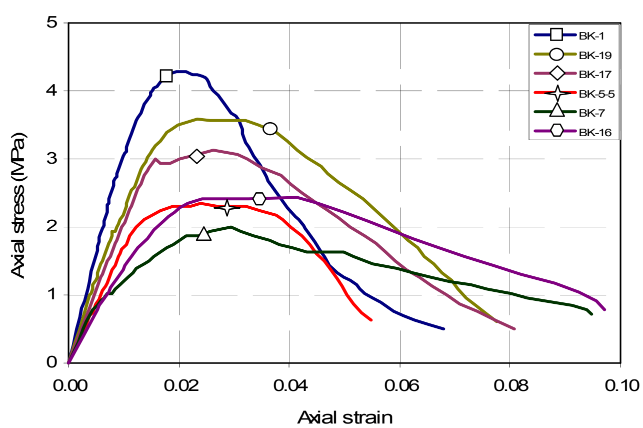


Figure 6: Axial stress-average axial strain relationships of the core samples.

Shear strength of core specimens is experimentally found for three different vertical stress levels, which are 0, 0.15 and 0.3 MPa, Fig. 5. These values are chosen to represent vertical stresses in different floors, namely no axial stress case represents the situation in the second floor, while the axial stress levels of 0.15 and 0.3 MPa is assumed to represent the first and entrance floors, respectively. The location of the specimens in the buildings, vertical stress, axial load and shear strength are shown in Table 4. The relationships of shear stress and average horizontal displacement are given in Fig. 7. Average shear strengths are calculated for each axial stress level and shown in Table 4. As seen in this table, shear strength of cores under varying axial stress conditions are around 0.35- 0.40 MPa. According to Turkish Seismic Code; the shear strength of walls constructed with ordinary solid bricks considered is given as 0.2 MPa, when experimental data is not available. Since the applied axial stresses on the bricks are not high, the shear strengths are found to be close to each other for different levels of axial stresses. It should be noted that many factors may also affect the shear strengths obtained, such as the quality of jointing mortar, environmental conditions, the processes during taking out the cores from walls and preparation process of cores for experiments. Therefore it is believed that the obtained shear strengths just give general information about material qualities.

Table 4. Shear strengths of core specimens.

Sample No.	**Location**	**Vertical Stress** (MPa)	**Axial Load** (kN)	**Shear Strength** (MPa)
BK-19-1	Entrance	0.30	2.20	0.46
BK-18	First floor	0.30	2.40	0.36
BK-10	First floor	0.15	1.21	0.30
BK-13	First floor	0.15	1.19	0.39
BK-16-1	Second floor	0	0	0.40
BK-6	Second floor	0	0	0.39
Average		0.30		0.41
Average		0.15		0.35
Average		0		0.40

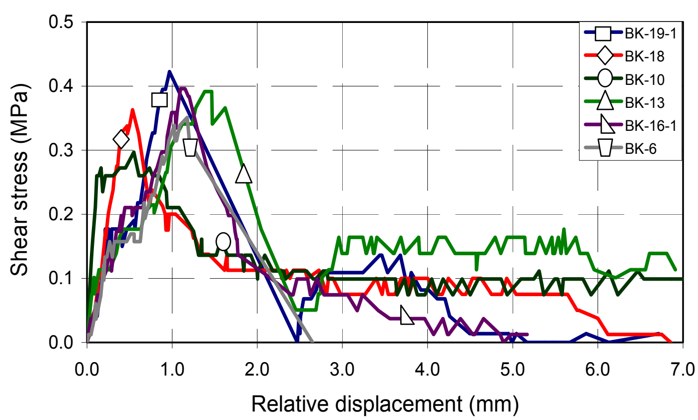
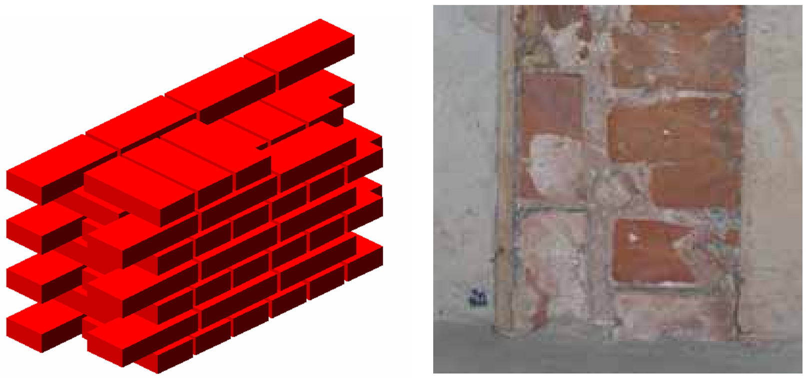


Figure 7. Shear strength-average horizontal relative displacement relationships of the core samples.

Details of Walls

Composite structure of the walls is composed of bricks, mortar and steel ties, Fig. 8. Deteriorated by the environmental conditions and damaged by several interventions during the last century, steel ties, which were originally aimed to compensate the lack of diaphragms constraining the main walls, are evaluated to be out of service. Five different types of brick, having average dimensions of 60x110x240 mm^3 have been used in the construction. Almost all masonry walls have cross bond (also known as English bond) brick arrangements with approximately 20 mm thick horizontal and 10 mm thick vertical mortar joints, Fig. 8.



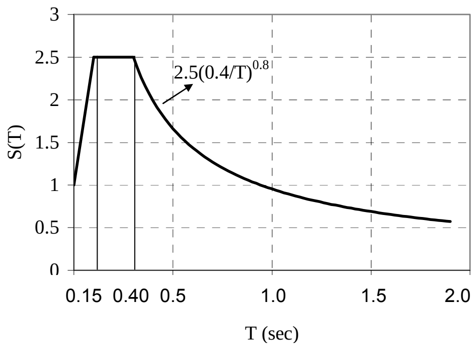
(a)

(b)

Figure 8. a) Brick arrangement of the masonry walls, b) the steel tie.

Seismic Analysis of the Building

In order to investigate the seismic safety of the building, a macro-level linear elastic finite element analysis has been carried out. Though having limitations, linear elastic analysis constitutes a useful tool for understanding the general seismic behavior of masonry structures. Walls and reinforced concrete slabs of the three dimensional analytical model has been constructed by using four node shell elements and SAP 2000 structural analysis program. Since the structure has a form of repeating blocks in plan, aiming to decrease the run time, only 4 of the repeating blocks out of 8 has been taken into consideration during the modeling phase. The analysis has been performed for vertical and horizontal loads. Vertical loads includes the dead weight of the structure (unit weights: 18 kN/m^3 for masonry and 25 kN/m^3 for reinforced concrete) and the live load acting on the slabs (2 kN/m^2 as defined in TS 498/T1 (Turkish Standards Institution, 1997)), while the horizontal loads are derived through Turkish Seismic Design Code (Ministry of Public Works and Settlement, 1998). The equivalent static earthquake forces are acted in both longitudinal and transverse directions of the building. The structure is located in European part of Istanbul on a highly seismic zone, which is defined as second degree seismic zone. However, considering the uniqueness of the structure and the demand of the owner, the design horizontal acceleration required for the calculation of the base shear force is taken as 0.4g as given for the first degree seismic zones in the Turkish Seismic Design Code (Ministry of Public Works and Settlement, 1998), Fig 9. As also stated in the same code; building importance factor and spectrum coefficient are taken as 1 and 2.5, respectively. For masonry buildings, the seismic load reduction factor based on the ductility of the structural system is given as 2.5 by the Turkish Seismic Design Code 1998, while it was reduced to 2.0 in Turkish Seismic Design Code 2006. Therefore, although 1998 code is still valid, to be on the safer side, the seismic load reduction factor is taken into account as 2.0. Consequently, base shear coefficients are determined as 0.5 for longitudinal and transverse directions. Utilizing the average compressive strength value obtained from laboratory tests on brick masonry cores, the elasticity modulus is obtained approximately as 600 MPa (200 times the wall compressive strength) as formulated in the Turkish Seismic Design Code (Ministry of Public Works and Settlement, 2006). Natural vibration periods of first two modes are 0.28 and 0.27 seconds for longitudinal and transverse directions, respectively. A general view of the three dimensional mechanical model and shear stress contours of typical axes for longitudinal and transverse directions are shown in Fig. 10. In order to verify the results obtained from the three dimensional linear elastic analysis, a hand calculation has also been done. Average shear stresses obtained by dividing the earthquake induced shear forces by the net wall areas of each story results as 0.37, 0.30, 0.17 MPa for the entrance, first and second stories of the longitudinal direction; 0.24, 0.33, 0.20 MPa for the entrance, first and second floors of the transverse direction, respectively. These average shear stress values are in good agreement with the results of finite element analysis. Comparing the experimental shear strength values with these results it can be concluded that the structure has sufficient capacity for a design earthquake foreseen in the Turkish Seismic Design Code (Ministry of Public Works and Settlement, 1998 and 2006). According to the results of the analysis, the average compressive stresses are around 0.5 MPa, which is below the 2.96 MPa compressive strength value obtained from laboratory tests.



$$V_t = \frac{W \times A_o \times I \times S(T)}{R_a(T)}$$

V_t: Base shear force
W: Total weigth of the structure
A_o: Effective ground acceleration coefficient (0.4g in this case)
I: Building importance factor (1 in this case)
S(T): Spectrum coefficient (2.5 in this case)
$R_a(T)$: Seismic load reduction factor (2 in this case)

Figure 9. Calculation of base shear force according to Turkish Seismic Design Code, 2006.

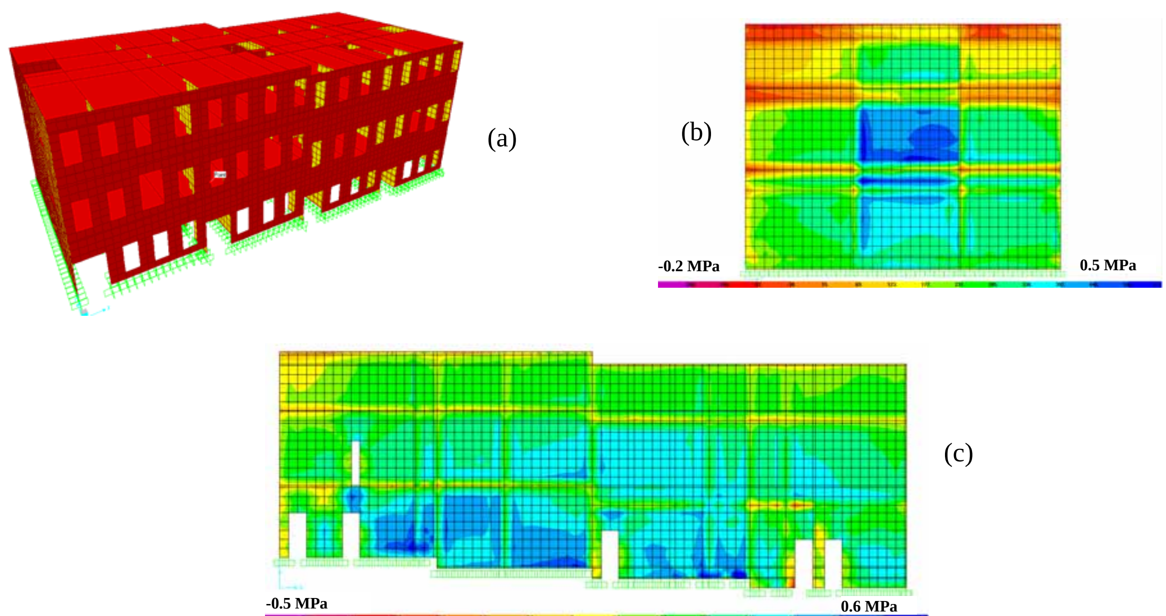


Figure 10. a) Three dimensional mechanical model b) Shear stress contours in transverse direction c) Shear stress contours in longitudinal direction.

Conclusions

In this study, seismic safety assessment is presented for one block of Akaretler Row Houses, which was constructed in the second half of the nineteenth century in Istanbul. After obtaining the in-situ geometry of the structural system and soil investigation results, the chemical and mechanical characteristics of building materials are obtained through laboratory tests. Finally, structural analysis is carried out using finite element method and a simple approximate method. At the end of the study, in spite of presence of several non-complying aspects, like large openings in walls, story heights, it is concluded that this block of Akaretler Row Houses Complex, built more than hundred years ago, have sufficient seismic safety as required by the current Turkish Seismic Design Code, as well as having a significant safety factor against gravity loads.

Acknowledgments

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