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YİVLİ MİNARE'NİN YAPISAL ANALİZİ VE SİSMİK DAVRANIŞI

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Özet

Minare İslam mimarisinin sembolü olarak kabul edilen bir yapı formudur. Etrafındaki bütün yapılardan daha yüksekte tek başına ayakta duran yapısıyla minareler doğal olarak kent içinde belirgindirler. Ancak minarelerin yüksekliği bir yandan onları kentsel olarak simgeleştirken diğer yandan yapısal olarak kritik hale getirir. Özellikle sismik risk altındaki bölgelerde tarihi minarelerin stabilitesi önemli bir konudur. Bu çalışmanın amacı Antalya'daki Selçuklu eserlerinden olan Yivli Minare'nin sismik risk altındaki strüktürel stabilitesini anlamaktır.

Anahtar Kelimeler: Selçuk Mimarisi, Yığma Kule, Minarelerin Sismik Davranışı

STRUCTURAL ANALYSIS AND SEISMIC BEHAVIOR OF YIVLI MINARET

Abstract

Minaret is symbolic structural form of Islamic architecture. It is significant with its free- standing structure which is higher than any neighboring structure. While the height of a minaret makes it a landmark, it also makes the structure delicate. Especially in regions under seismic risk, the stability of historic minarets becomes issue of a vital importance. The aim of this paper is to evaluate the structural performance of Yivli Minaret, a Seljuk structure in Antalya-Turkey, under expected earthquake loads.

Keywords: Seljuk Architecture, Turkish Minarets, Masonry Tower, Seismic Behavior of Yivli Minaret

1. INTRODUCTION

The Seljuks moved from Asia to Persia, Azerbaijan and Mesopotamia where they founded the Iran Seljuk Sultanate or the Great Seljuk Empire in the 10th century. In the following century, they expanded to west and established Anatolian Seljuk Dynasty. In their long run from Asia to Anatolia, they contacted with local cultures, learned and harmonized all of them under their own civilization, which later on was inherited to the Ottoman Empire. The diversity found its reflections in new building types and construction techniques as well.

The main innovation of Seljuk architecture is the simultaneous use of both stone and brick. Stone had been a very common structural material in Anatolia while brick was the main structural material of Persian architecture. This dual use of material was due to the employment of both Persian and Anatolian architects and masons together and showed the influence of local environments and building culture (Mitchell, et al. 1978). The interaction is not only limited with building technologies. They improved forms derived from the local cultures. Instead of the usual square plan type, Seljuk minaret was cylindrical in plan with

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tapered shaft often broken by balconies. This form was first adopted from Persia (Saoud, 2003) and spread out to the majority of the Muslim in the following decades.

The earliest minarets in Anatolia were built by the Seljuks. The structure of Seljuk minarets consist of three main parts as the base, shaft and the cap. The base is generally square shaped and constructed of stone. The shaft is cylindrical and constructed of brick, stone or both. The diameter gets smaller as it rises. The fluted type with semi-cylindrical grooves supporting the shaft such as Qutb Minar Minaret (Delhi 1199) and Yivli Minaret (Antalya-circa 1220) is specific to India and Anatolia. The last part is the cap of minaret, which is conical unlike the usual domed caps of other minaret types. This kind of pure geometries also preferred in Seljuk architecture in the architecture of *türbe* (tomb).

As the oldest Seljuk strudture in Antalya, Yivli Minaret was built in the 13th century for a mosque, which was probably originally built as a Byzantine church. With its fluted shaft, the minaret is not only one of the most characteristic examples of Seljuk architecture but also a symbol of Antalya. Threatened by several effects over the centuries and the seismicity of the region as the rest of the historical structures in the vicinity, Yivli Minaret already went under repair and stabilization processes twice in the 20th century. The aim of this paper is to analyze the structural capacity of Yivli Minaret under gravity forces and to examine its seismic performance in an earthquake that is likely to occur in Antalya. Having served as one of the most important cultural treasures of the region over the centuries, the structure should be examined carefully and provided with the necessary strengthening process if necessary. The analyses performed in this paper would be a guide to underline the facts about the seismic performance of the structure.

2. ARCHITECTURAL AND STRUCTURAL CHARACTERISTICS OF YIVLI (Fluted) MINARET

The Yivli Minaret was constructed on the orders of Sultan Alaaddin Keykubat I, between 1219 and 1238 (Kırmızı, 1986). The main building may have been built as a Byzantine church originally and may have been converted into a mosque by Seljuk Sultan Alaaddin Keykubat I (URL 1). The minaret is a part of a religious complex (külliye- Figure 1-2) which consists of a mosque, madrasa (called either as Ulucami Madrasa or Imaret Madrasa), Mevlevi Lodge, Turkish bath and two domed tombs (Armağan, 2006). Yivli Minaret is the minaret of Alaaddin Mosque that is one of the oldest examples of multi-dome construction in Anatolia. The brick minaret is located to the east of this mosque, about four and a half meters away from its southeast corner. The original mosque was first built in between 1219-1236 and was destroyed 14th century. It was repaired in 1373 by Architect Balaban et-Tavaşi (Sönmez, 1995). In 1953, it was restored again by the General Directorate of Museums and was stabilized further in 1973.

Figure 1 Yivli Minaret

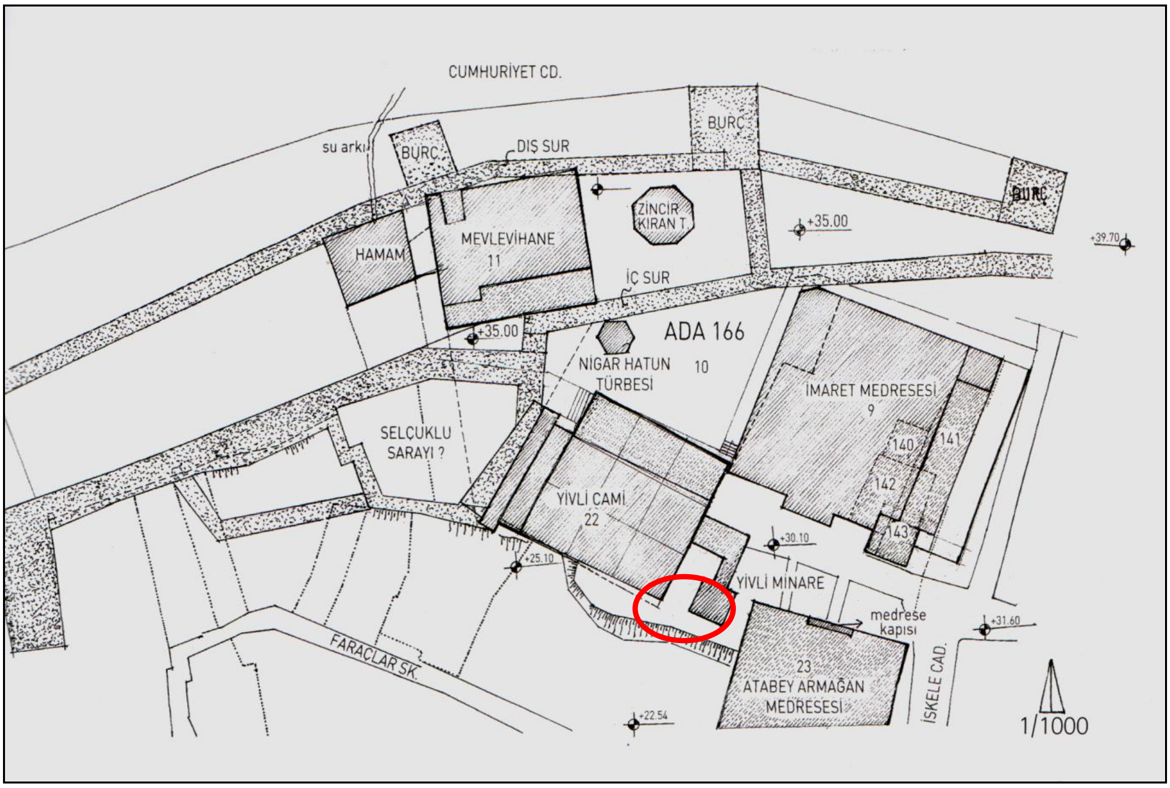


Figure 2 Location of Yivli Minaret in the Religious Complex (Külliye), (Sönmez, 2009)

Yivli Minaret, built on a stone base with tranches and flutes from brick, gets its name from these flutes (Başgelen, 2006). Which makes it more famous than the mosque it was built for. The aesthetic structure which is cut up into slices by bricks and constructed with 8 pieces of semi-cylindrical flutes (Vakıf Abideler ve Eski Eserler I, 1983). Seyit Mahmut Tomb in Akşehir and Konya Mevlana Tomb (its fluted trunk was constructed in Karamanoğulları period) are the other similar Seljuk works with fluted structural shafts (Figure 3).

1 2 3

Figure 3 1-Seyit Mahmut Tomb in Akşehir (URL 2), 2- Konya Mevlana Tomb (URL 3), 3-Yivli Minaret

Stone, brick and grog were used for the construction of the 38 meter high Yivli Minaret (Figure 4). It is built on a square stone base which is approximately 5.5m x 5.5m x 6.5m with eight fluted sections (Projects obtained from Environmental Protection Agency for Special Areas-EPASA). The top of the minaret is accessible by means of 90 steps staircase through a 0.64 m x 1.11 m door on the north side of the trunk (Uyar, 2003).

Figure 4 Yivli Minaret

The upper corners of the base are cut a sloping edge to meet an octagonal transition zone carved with a blind niche on each side. These niches are decorated with the mosaic of turquoise and cobalt-blue tiles (Figure 5). The minaret ends with a simple cylindrical turret above the balcony (minaret's balcony named as "şerefe") and is capped with a lead-covered conical cap (URL 4).

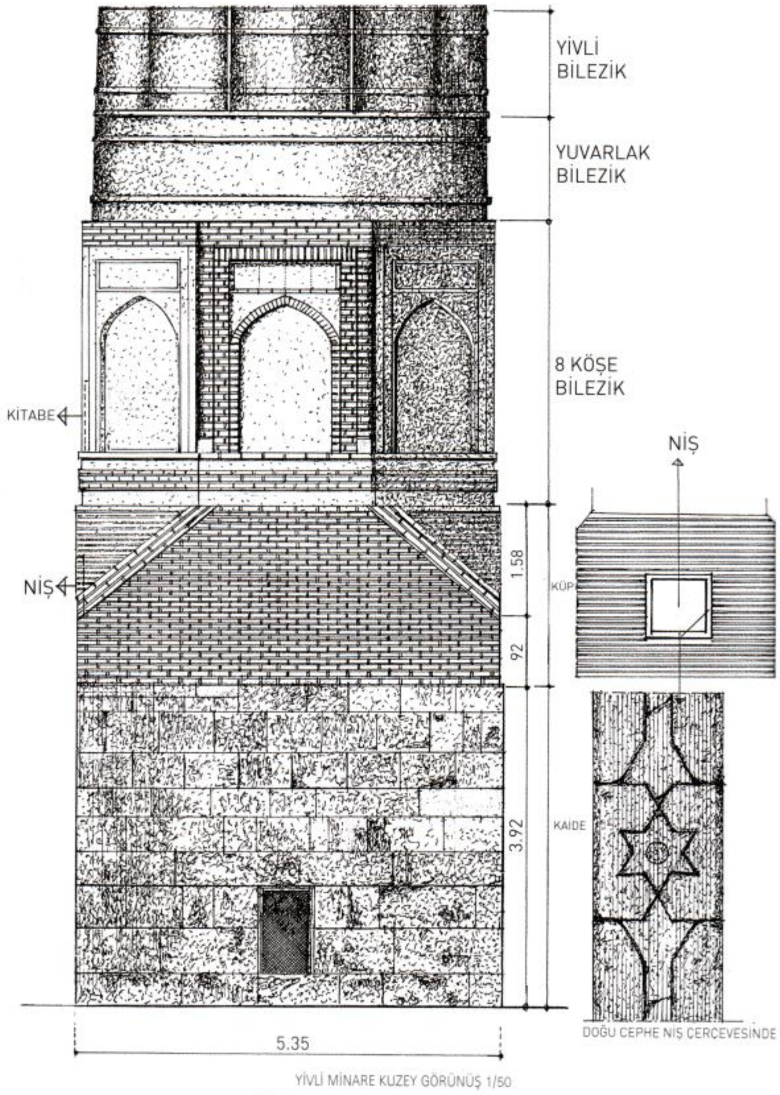


Figure 5 Yivli Minaret (Sönmez, 2009 pp:122)

3. FINITE ELEMENT MODEL OF YIVLI MINARET

The developments in computer hardware and software technologies have dramatically augmented the capacity, speed and graphical quality of structural analysis programs in the recent years. These programs increased and satisfied the demand for the structural analysis of historical buildings with complex geometrical forms. However, structural analyses conducted without paying attention to appropriate analytical modeling procedures may result in serious mistakes in the assessment of the actual structural conditions of these buildings. This is why analytical modeling phase is very critical in the finite element analysis of historical structures (Örmecioğlu et al, 2011).

A detailed finite element model of Yivli Minaret as shown in Figure 6 is prepared according to the modeling properties and rules of SAP2000 software (SAP 2000, 2002).

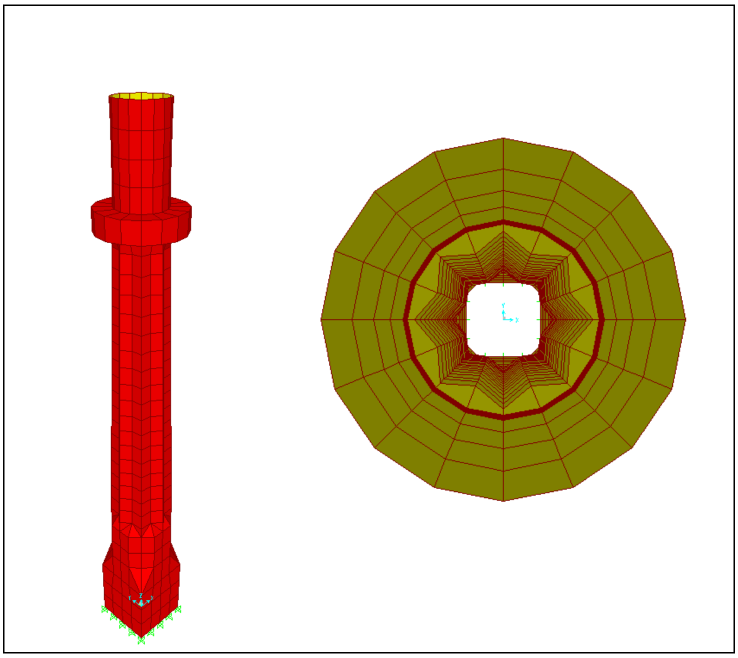


Figure 6 Analytical model of Yivli Minaret

The geometric properties and dimensions of the building were obtained from existing survey drawings. The parameters for calculations and the model are given below:

- The model consists of 530 joints, 764 shell and 16 solid elements.
- Material properties of the structure have been obtained from the literature on the similar type of structures and suggested values of the masonry material properties of the current earthquake code.
- For the determination of the modulus of elasticity and unit weight of the material, masonry units and the mortar have been assumed as one single material.
- On the model, spectrum has been applied in two major directions as EQx and EQy.
- For convenience in the evaluation of the results, two different load combinations have been made as, "gravity loads + earthquake loads" in both directions (G+EQx and G+EQy).
- Antalya is located on second degree earthquake zone according to earthquake map of Turkey and the soil type is Z4 according to earthquake code of Turkey.
- Spectrum used for the dynamic analysis is given in Fig. 7.
- Material properties accepted for the finite element model of Yivli Minaret are given in Table 1.

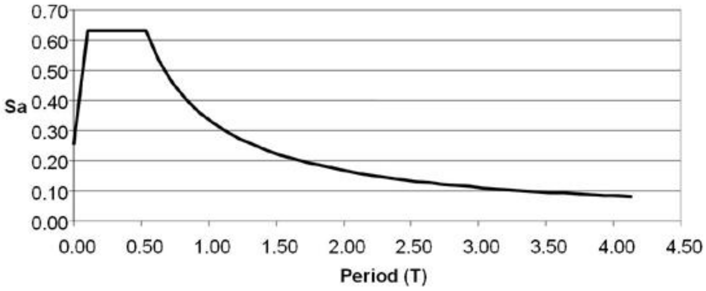


Figure 7 Spectrum used for the dynamic calculations

Table 1 Material properties of the masonry

Structural elements	Modulus of Elasticity (kN/m^2)	Specific weight (kN/m^3)	Mass (t/m^3)
Stone	450000 (450 MPa)	24	2.44

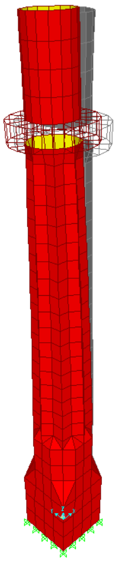
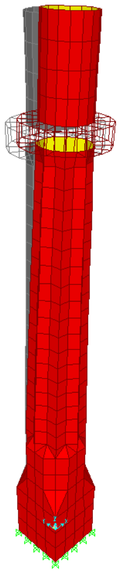
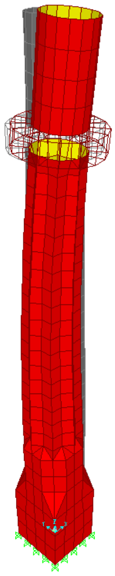
4. RESULTS OF FINITE ELEMENT ANALYSIS

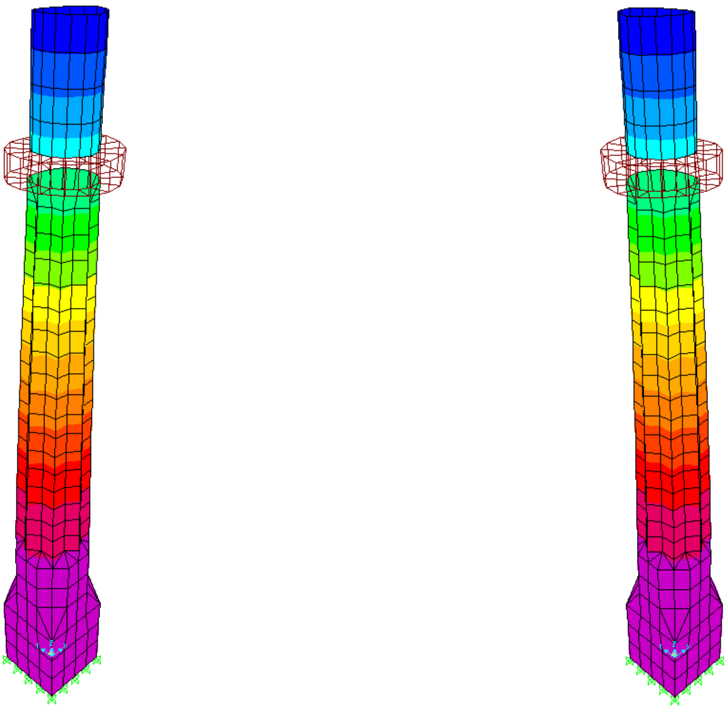
Shear forces, modes and periods are provided for load combinations in Table 2 and Table 3. S22 tensile stresses and S12 shear stresses appeared due to G+EQx and G+EQy loadings can be seen in Table 4. Total weight of the structure is seen to be 9286.38 kN while total base shear is 3695.25 kN and 3695.27 kN in x direction and in y direction, respectively. According to these results, base shear force that the structure is subjected is 39% of the total weight in x-direction and 39% of the total weight in y-direction. Maximum displacements are Δx=95.8 mm Δy=95.5 mm in x and y direction, respectively as shown in Fig. 7.

Table 2 Base shear and axial forces

Loading type	**Analysis type**	**Step**	**Base shear in x-direction (kN)**	**Base shear in y-direction (kN)**	**Vertical reactions (kN)**
G	Linear Static		0	0	9286.38
EQx	Linear Behavior spectrum	Max	3695.25	0	0
EQy	Linear Behavior spectrum	Max	0	3695.26	0
G+Ex	Combination	Max	3695.25	0	9286.38
G+Ex	Combination	Min	-3695.25	0	9286.38
G+Ey	Combination	Max	0	3695.27	9286.38
G+Ey	Combination	Min	0	-3695.27	9286.38

Table 3 First Three Mode Shapes with Periods

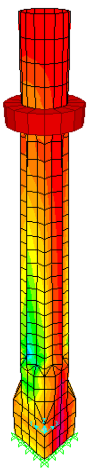
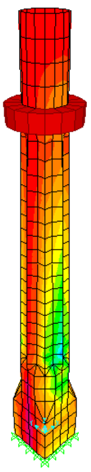
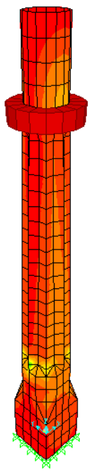
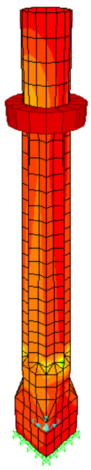
Mode 1 T_1= 2.03 sec.	Mode 2 T_2=2.03	Mode 3 T_3=0.49 sec
		



Under EQX   Under EQY

Figure 7 Deformed shapes under EQx and EQy

Table 4 S22 Tensile Stresses and S12 Shear Stresses Appeared due to G+EQx and G+EQy Loadings

S22 G+EQx (MPa)	S22 G+EQy (MPa)	S12 G+EQx (MPa)	S12 G+EQy (MPa)
Min -0. 497 Max 3.770	Min -0.497 Max 3.777	Min -0.178 Max 1.816	Min -0.178 Max 1.819
			

7. CONCLUSIONS

This paper aims to interpret the current seismic performance of the Yivli Minaret. Thus, the results of finite element analysis of the minaret under a probable earthquake are discussed. The observations regarding the results are provided below:

- The maximum deformations obtained show that the structure is rigid, and the maximum stress values show that the structure is safe. The verification of the rigidity of the structure can be observed from the mode periods of the structure. Compression and shear stress limits provided in Turkish Earthquake Code are not exceeded in any of the structural elements.

- It should be underlined that for the analysis material properties are taken from the literature and current guidelines for masonry. Within this context, it can be said that the behavior of the structure can be affected from the material deterioration and loss of quality of the materials in some structural elements. However, considering the fact that the values for stresses and displacements are in an acceptable range, even with the inclusion of all probable factors the structure seemed not to face with any serious structural problem.

- According to the assumed analysis principles, the strength of the structure is sufficient without causing serious damage for the probable earthquake forces.

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URL 4: http://archnet.org/library/sites/one-site.jsp?site_id=12121