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An analytic model for the historical Four-Legged Minaret resting on elastic medium

Murat A. Uğurlu[a1] and Abdulhalim Karaşin[*1]

[1]*Department of Civil Engineering, Dicle University, Diyarbakır, Turkey*

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Abstract. Minarets are towers near the mosques, generally with a physical connection. Four-legged minaret belongs to Sheikh Mutahhar mosque and located at Sur neighborhood, is one of the symbols of Diyarbakır. Without question four basaltic cylindrical slender pillar on the lower section of the structure is the main reason of uniqueness of the four-legged minaret. The four-legged minaret is composed of three parts; the first part is pillars, second is body section and the last one is balcony level. This slender masonry structure had no significant structural damages until the cracks developed in recent years. The purpose of this study is to discuss the effect of unexpected vehicle traffic-induced vibration on the structural damages of the unique minaret. For this reason macro models developed including soil structure interaction between ground and pillars by means of various finite element softwares.

Keywords: four-legged minaret; historical heritage, analytical model, elastic medium foundation

1. Introduction

There are countless types of masonry towers vary periodically, regionally and intentionally. However, a common point of this masonry towers is a more rigid body on the lower section of the structure except for Four-Legged Minaret as seen in Fig 1. Minarets are towers near the mosques and generally, they have a physical connection with the associated structure. The Sheikh Mutahhar Mosque which places the four-legged minaret was built by an unknown architecture during the Akkoyunlu period in 1500. The main function of minarets is to provide a platform for the muezzin to call out adhan, in Islam. Also in the case of physical connection, they have ventilation effect for mosques. In our day due to the technological progress of the vocal equipment and air-condition systems minaret is redundant elements, nonetheless, people still like minaret as a traditional symbol of the mosques. Nevertheless, without question four independent basaltic cylindrical slender pillar on the lower section of the structure is the main reason of uniqueness of the four-legged minaret. Local people believe that pillars symbolize four main denominations of Sunni-Islam. The minaret is a separate, different structure and is not connected to the body of the mosque. Nowadays because of the necessity of broad roads due to urbanization, mosque courtyard was shrunk and minaret stayed outside of the courtyard. There is significant traffic load on the road which passes next to minaret.

(a) Haigh windmill, 1845, Manchester, England

(b) Concord Point Light, 1827, Maryland, USA

(c) Santa Maria del Carmine, 13th century, Naples, Italy

(d) Four-Legged Minaret, 1500, Diyarbakır, Turkey

Fig 1. Types of masonry towers

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[*] Associate Prof., E-mail: karasin@dicle.edu.tr

[a] Ph. D. Student

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Except the cracks developed in recent years due to vehicle traffic-induced vibration, this slender masonry structure had no significant structural damages. It is stated that historic buildings which survived earthquakes are crude seismographs and the four-legged minaret is a vital example Gülkan and Wasti (2009). Furthermore, Kazaz *et al.* (2009), considered the minaret as a possible large-scale seismograph to examine possible limits of ground motion. The two different types of dynamic movements for the

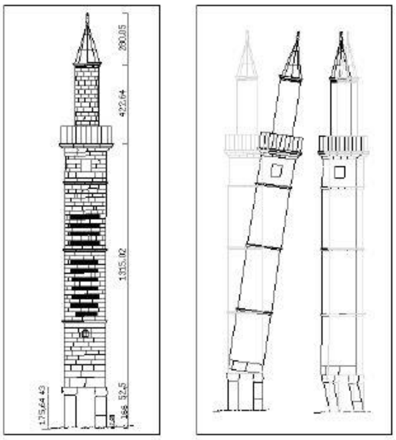


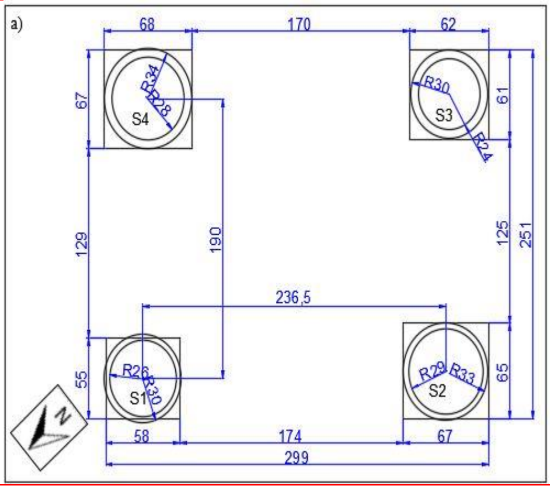
Fig. 2. The dynamic motion possibilities of the Four-Legged Minaret (Gülkan and Wasti, 2009)

Minaret can be determined by whether the anchoring behavior under the column works properly as shown in Fig. 2. It is also stated that long-period vibrations are more dangerous for such historic structures. On the other hand, Bedirhanoğlu and İrfanoğlu (2009) investigated the rocking behavior of the four-legged minaret under dynamic loading.

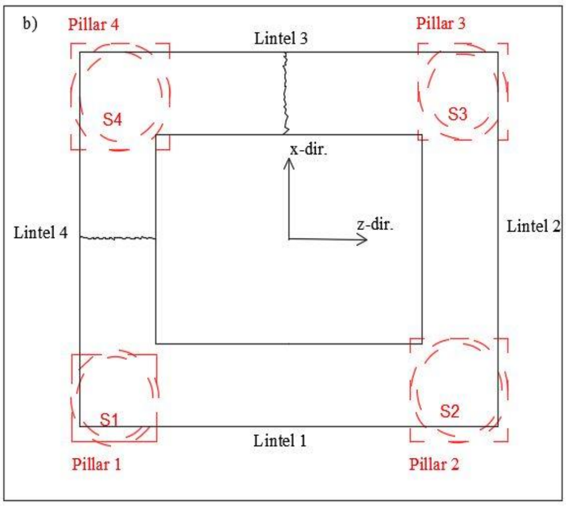
There are many studies in the literature to define the mechanical behavior of such tower type masonry historical structures such as D'Ambrisi *et al.* (2012), Peña et al. (2012), Mangia et al. (2016), Isık et al. (2016), Okuyucu and Aydın (2010). As an example of modeling of wide range Fanning and Boothby (2001), shown that with a reasonable set of material properties and visual observations of the construction of the structure, it can possible to make good predictions of a masonry arch bridge using three-dimensional finite element package. Lourenço (2002), addressed the possibilities of analysis of historical constructions and proposed a set of guidelines. Zuchhini and Lourenço (2002), proposed a micromechanical model for the homogenization of masonry. Giordano *et al.* (2002), investigated the applicability of different numerical techniques for the analysis of masonry structures. Mele (2003), Ivorra and Pallarés (2006) and Betti and Vignoli (2008) proposed analytical models for historic masonry structures.

2. Geometrical Descriptions

The minaret presents a squarish plan with 3 m one side and 2.5 m on the other (Fig. 3(a)); it is composed of three sections: pillars, body, and balcony. The minaret footing is unknown and location of the minaret is not available to determine footing type with ground examinations. It is possible to nondestructive methods of tests will be executed for determining the minaret footing in the further studies. The lower part of the minaret is constituted by four slender basaltic pillars and pillar caps with different radiuses from 0.48 m to 0.58 m. The height of the pillars is about 2.0 m. The body section of the minaret settled to pillars with a height of 13 m to the balcony level, is made of basalt stone in general. This section houses the entrance door of the minaret, staircase and staircase windows. The thickness of the walls is 0.53 m at the body section. The first two row of lintels is larger in size than the upper body. There is no connection between first and second row of lintels 3 and 4 on the clear distance between the pillars (illustrated in Fig. 4). This gap designed for transfer axially the dead load of the structure to the pillars. There are vertical cracks located along the first row of lintels on the southeast and northeast façade. These cracks are about 2~3 mm (seen in Fig. 3(b)). Then there is a cylindrical part with a length of 5 m including balcony level, is smaller than the main body in cross section and 4 m long cone with the lead coating.



(a) Pillars plan of the minaret



(b) Structural cracks of the minaret

Fig. 3 Plan view of the Four-Legged Minaret