



Dynamic response of traditional and buttressed reinforced concrete minarets



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ABSTRACT

The destructive 17 August 1999 M_w 7.4 Kocaeli and 12 November 1999 M_w 7.2 Düzce Earthquake caused significant damage on reinforced concrete (RC) minarets and many of them severely damaged or collapsed causing the loss of lives. Damages or collapses of these RC minarets after the miserable actions of nature compel us to revise our knowledge about the dynamic response. The experiences from the catastrophic strong ground motions also dictate to the practitioners that alternative structural load carrying systems should be used and/or the seismic resistance of widely used systems should be improved. In this study, the dynamic behaviors of traditional and proposed buttressed RC minarets were compared with each other. Findings of this study show that using buttressed structural load carrying systems in the earthquake prone regions is beneficial and these supporting system behaved well when compared to traditional RC systems.

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1. Introduction

Turkey is located in one of the most seismically active regions of the world. 57 destructive earthquakes have struck Turkey through the twentieth century resulting in destruction of structures and more than 90,000 deaths. During these earthquakes, many minarets were damaged or collapsed due to inefficient design. As it is well known that their tall and slender supporting systems make these structures easily vulnerable. Sezen et al. documented and discussed vulnerabilities and damages to 64 masonry and RC minarets after the 1999 Kocaeli (M_w 7.4) and Düzce (M_w 7.2) earthquakes. As a result of these two destructive earthquakes, the collapse of 115 minarets in the city of Düzce alone was reported. They also observed that approximately 70% of the RC and masonry minarets surveyed in Düzce sustained severe damage or collapsed [1].

Minarets are the tall and slender towers and may be built as adjacent to the main body of the mosques at the corner side or built individually. While most historical minarets were constructed using reinforced or unreinforced stone or brick masonry, the majority of minarets recently constructed in Turkey are RC structures. As shown in Fig. 1, a typical minaret structure comprises a base or boot on top of its foundation, a tapered transition segment, a circular body or shaft with one or more balconies, and a spire at the top. The base or boot is usually square or polygonal, and is sometimes called the pulpit by architects. The minaret can be free standing or the boot may be attached to the mosque structure [1].

Abbreviation: RC, Reinforced concrete.

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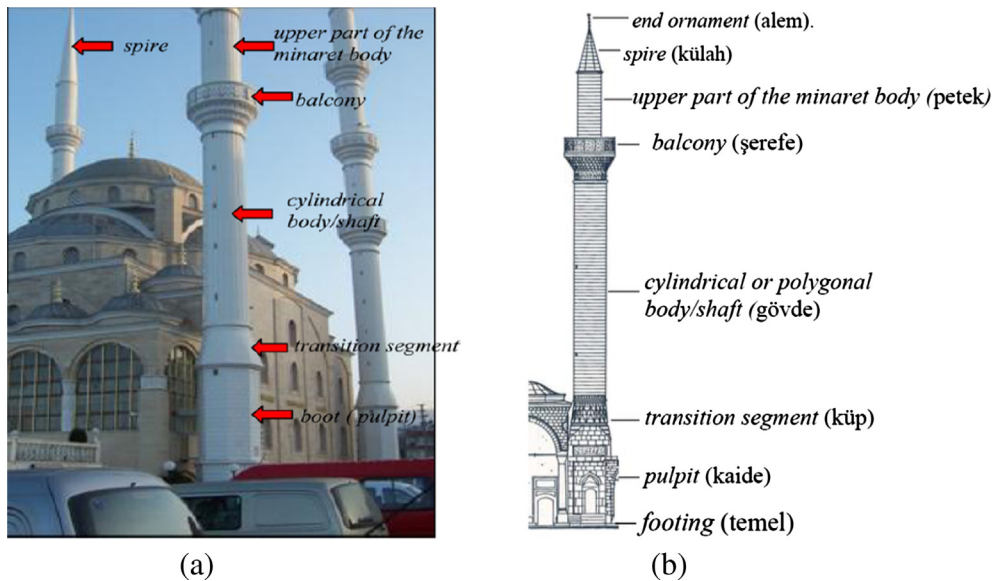


Fig. 1. A typical RC minaret with structural parts [1,3].

Minarets have been constructed generally by workmen without any project. Thus, most of them have been illegally constructed. Department of Religious Affairs explained report results for 1176 mosques under construction in Turkey after 1999 earthquakes that 80.9% of mosques did not have structural license. Furthermore, there is no official specification or code consisting of helpful details for workers directly related to earthquake resistant design of minarets. As a result, many minarets have suffered different level of damage depending on ability and technical experience of workmen [2].

Damages occurred on RC minarets are dependent on some factors such as detailing and properties of the structure and its components, soil properties, and the magnitude of the earthquake. Observations from recent earthquakes suggest that the damage in the minarets is usually concentrated in a few specific locations [4]. These damages occurred on RC minarets under seismic actions can be classified as follows; damages on spire, upper part of the minaret body, cylindrical body, transition segment and pulpit. Damage to spire, upper part of the minaret body, transition segment and balcony levels were encountered less frequently damage type. These rarely encountered damage types were shown in Fig. 2 [2].

The most common type of damage observed in RC minarets leading to the collapse of the structure occurs on the bottom of cylindrical body just a few meters above the transition segment. This is the place where lateral stiffness and strength are smaller compared with those of the transition segment or the pulpit [5]. There are two main reasons for this type of failure. First, the cross section size becomes smaller, which results in reduced lateral and flexural strength. Second, in most cases at

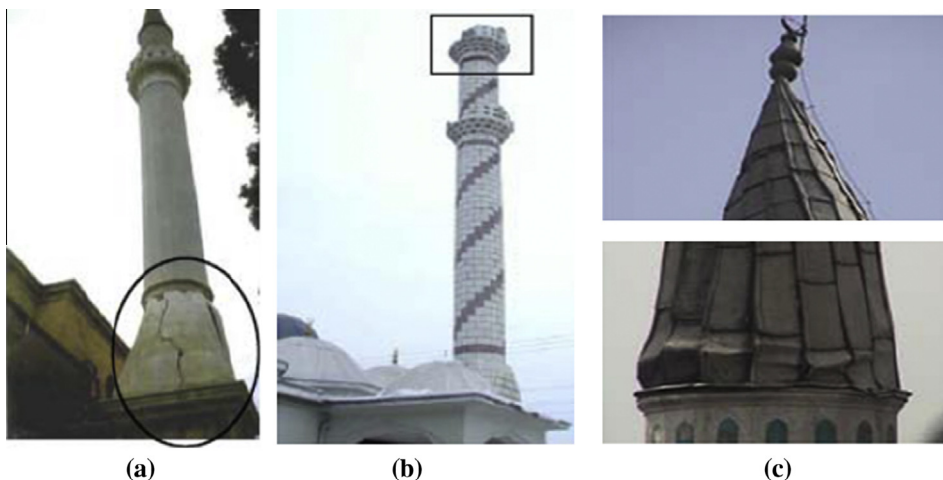


Fig. 2. Rarely encountered damages on RC minarets; (a) transition, (b) balcony and (c) spire [2].

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