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Re-evaluation of building damage during recent earthquakes in Turkey

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Abstract

Over the past two decades Turkey has been hit by several moderate to large earthquakes that resulted in significant loss of life and property. A remarkable number of casualties and heavily damaged or collapsed buildings has emphasized inadequate seismic performance of multistory reinforced concrete buildings, typically three to seven stories in height. This study aims to evaluate seismic performance of the most common reinforced concrete building stock in Turkey considering nonlinear behavior of the components. A sample building set is selected to reflect existing construction practice; regular buildings and buildings with irregularities such as soft story, heavy overhangs, short columns, and soft story with heavy overhangs. Ductile and non-ductile details are taken into account by transverse reinforcement amount. Capacity curves of the investigated building set are determined by pushover analyses conducted in two principal directions. The inelastic dynamic characteristics are represented by equivalent single-degree-of-freedom (SDOF) systems. Their seismic displacement demands are determined using nonlinear response history analysis under selected ground motions. Seismic performance evaluation is carried out in accordance with the recently published Turkish Earthquake Code (2006) that has similarities with FEMA-356 guidelines. Analytical damage evaluation in this study has shown that the seismic effects of earthquakes experienced in Turkey are significant and some of the earthquakes impose excessive displacement demands. Therefore, a considerable portion of existing building stock may not be safe enough in Turkey or similar countries. Also, it is observed that structural irregularities affect seismic performance of buildings. Short columns and soft story with heavy overhangs have the most negative effect.

Keywords: Building damage; Earthquake; Nonlinear response history analysis; Nonlinear static procedure; Pushover analysis; Reinforced concrete structure

1. Introduction

Over the past two decades Turkey has been hit by several moderate to large earthquakes that resulted in significant loss of life and property. These are: 1992 Erzincan, 1995 Dinar, 1998 Adana–Ceyhan, 1999 Kocaeli, 1999 Duzce, 2002 Afyon–Sultandagi, and 2003 Bingol earthquakes. 1999 Kocaeli and Duzce earthquakes are the largest natural disasters of the 20th century in Turkey after 1939 Erzincan earthquake. For the Kocaeli earthquake, the official death toll was more than 15 000, with approximately 44 000 people injured and thousands left homeless. A total of 330 000 residences were damaged; the shares of light, moderate, and severely damaged or collapsed units are 118 000, 112 000, and 100 000, respectively [1,2].

A summary of major earthquakes over the last two decades is given in Table 1. A remarkable number of casualties and heavily damaged or collapsed buildings in Turkey has highlighted inadequate seismic performance of reinforced concrete building stock in Turkey and in countries with similar construction practice. Devastating life and property losses were mainly caused by heavily damaged or collapsed multistory reinforced concrete buildings, typically three to seven stories in height.

In the literature, there are many studies related to the aforementioned earthquakes in Turkey, especially about 1999 earthquakes [2–8]. Observed structural damages and their sources, performance of structures, structural deficiencies etc. were covered in these studies. Many structural deficiencies and mistakes such as non-ductile details, soft and weak stories, short columns, strong beams–weak columns, large and heavy overhangs, and poor concrete quality were observed. Studies

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Table 1
Destructive earthquakes in Turkey over past two decades [1]

Date (dd/mm/yy)	Magnitude	Location	# of deaths	# of injured	# of heavily damaged buildings	Latitude (N)	Longitude (E)	Depth (km)
13.03.1992	$M_s = 6.8$	Erzincan	653	3850	6702	39.68	39.56	27
01.10.1995	$M_s = 5.9$	Dinar	94	240	4909	38.18	30.02	24
27.06.1998	$M_s = 5.9$	Adana–Ceyhan	146	940	4000	36.85	35.55	23
17.08.1999	$M_s = 7.4$	Kocaeli	15 000	32 000	50 000 or 100 000 residences	40.70	29.91	20
12.11.1999	$M_w = 7.2$	Duzce	845	4948	15 389	40.79	31.21	11
03.02.2002	$M_w = 6.5$	Afyon–Sultandagi	42	325	4401	38.46	31.30	6
01.05.2003	$M_w = 6.4$	Bingol	176	521	1351	38.94	40.51	6

concluded that there are thousands of buildings vulnerable to severe damage in moderate or larger earthquakes.

General observations and conclusions of the studies are briefly summarized as: (1) there is a consensus about that mid-rise reinforced concrete buildings with low technology engineered residential construction have been responsible for considerable life and property losses during seismic events, (2) structural damages were mostly due to repetition of well known mistakes of the past in the design and construction of reinforced concrete buildings, (3) damaged buildings generally had irregular structural framing, poor detailing, and no shear walls, (4) Turkey has a modern seismic code that is compatible with the codes in other seismic countries of the world and periodically updated to reflect progress of knowledge in the field of earthquake resistant design. However, major weaknesses are in the enforcement of seismic codes and regulations and lack of an effective design and construction supervision system, (5) altering the member sizes from what is foreseen in the design drawings, poor detailing which do not comply with the design drawings, inferior material quality and improper mix-design, changes in structural system by adding/removing components, reducing quantity of steel from what is required and shown in the design, and poor construction practice were listed among common problems.

This study aims to evaluate seismic performance of the major portion of building stock in Turkey considering nonlinear behavior of reinforced concrete components as well as masonry infill walls. Two reference RC buildings are selected to represent low- and mid-rise buildings. The reference buildings are modified to have structural deficiencies observed in damaged buildings during devastating earthquakes in Turkey. Structural deficiencies include soft story, short columns, large and heavy overhangs, and transverse steel amount. Capacity curves of investigated buildings are determined by pushover analyses conducted in two principal directions. The inelastic dynamic characteristics are represented by equivalent single-degree-of-freedom (SDOF) systems and their seismic displacement demands are calculated under selected ground motions. Seismic performance evaluation is carried out in accordance with the recently published Turkish Earthquake Code (2006) [9] (TEC-2006) that has similarities with FEMA-356 [10] guidelines. Reasons for building damage in past earthquakes are examined using the results of performance assessment of investigated buildings.

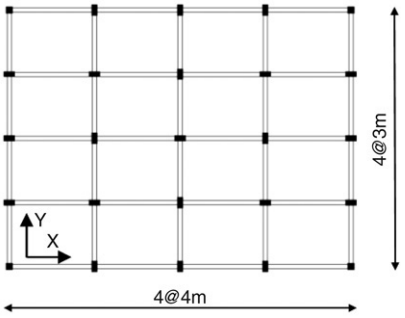

Fig. 1. Plan view of reference 4- and 7- story buildings.

2. Description of structures

Two RC buildings, 4- and 7-story, are selected to represent reference low- and mid-rise buildings located in the high seismicity region of Turkey. The selected buildings are typical beam–column RC frame buildings with no shear walls. Both buildings have the same plan view as shown in Fig. 1. Since the majority of buildings were constructed according to 1975 Turkish Earthquake Code [11] (TEC-1975), the selected reference buildings are designed according to this code considering both gravity and seismic loads (a design ground acceleration of $0.4g$ and soil class Z3 that is similar to class C soil of FEMA-356 is assumed [10]).

In design and detailing of model buildings, proper representation of building stock is the primary concern. Besides their academic studies, the authors are also working in seismic evaluation and strengthening projects of many public and private buildings which are in the range of building stock that is trying to be reflected by this study. In the creation of model buildings the authors' observations during these studies are taken into account, as well.

The 4- and 7-story regular frame buildings are 16 m by 12 m in plan. They have 4@4 m bays along X direction and 4@3m bays along Y direction (Fig. 1). Typical floor height is 2.8 m. The column and beam dimensions used in this study are typical frame element proportions in the existing building stock in Turkey. No effort has been made to obtain strong column–weak