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What is to be learned from damage and failure of reinforced concrete structures during recent earthquakes in Turkey?

M.H. Arslan *, H.H. Korkmaz [1]

Selcuk University, Engineering and Architecture Faculty, Department of Civil Engineering, Konya, Turkey

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Abstract

In Turkey, generally, building stock is formed from reinforced concrete structures and during last earthquakes, a large number of these buildings in the epicenter regions were collapsed leading to widespread destruction and loss of life. In this paper, the performance of reinforced concrete buildings during recent earthquakes in Turkey is discussed. The objective of this paper is to provide a brief overview of damage as observed following the earthquakes. The failure modes consist of foundation failures, soft stories, strong beams and weak columns, lack of column confinement, poor detailing practice and non-structural damages. Observations from the earthquake damages are discussed and compared with TEC-98 (Turkish Earthquake Code) and TBC-500-2000 (Turkish Building Code) requirements. Measurements of some damaged reinforced concrete member examples are given and important general lessons learned from these earthquakes are formulated. Finally, a short overview of the emergency management measures taken is also presented.

Keywords: Damages; Reinforced concrete structures; Failure types; Earthquake; Seismic code

1. Introduction

Turkey is situated on an active earthquake zone with shortest return periods and earthquakes caused loss of lives in the history. In the last century, over than twelve major earthquakes with minimum magnitudes 7 (M_s) caused significant casualties and extensive structural damage in Turkey. Earthquakes in Turkey are generally of in land types that are more destructive than off shore types, even their magnitude could be smaller [1–3]. The earthquakes are concentrated along the North Anatolian Fault (NAF), East Anatolian Fault (EAF), North East Anatolian Fault (NEAF) and West Anatolian Fault (WAF) as a result of north-ward motion of the Arabian Plate and African Continent [4]. Most of the population and industry are under the threat of a possible major earthquake. The most obvious example of this is the Kocaeli Earthquake occurred in

* Corresponding author. Tel.: +90 332 223 1971; fax: +90 332 241 0635.
E-mail addresses: mharslan@selcuk.edu.tr, musahakanarslan@hotmail.com (M.H. Arslan), hhk73@selcuk.edu.tr (H.H. Korkmaz).
[1] Tel.: +90 332 223 1965.

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Nomenclature

C_0 seismic code coefficient
K coefficient related to the type of framing system
I importance factor
S, $S(T)$ spectral coefficient
A_0 effective ground acceleration coefficient
R structural behavior factor
R_a ductility factor
T_A spectrum characteristic period
T fundamental period of building
A_c gross section area of column
$N_{d\,max}$ greater of the factored axial forces calculated under vertical loads only and under simultaneous action of vertical and seismic loads
f_{ck} characteristic compressive cylinder strength of concrete
ρ_l the longitudinal rebar ratio
ℓ_b development length
f_{yd} design yield strength of longitudinal reinforcement
f_{ctd} design tensile strength of concrete
ϕ rebar diameter
W minimum column dimension
D longer column dimension
b_w beam width
s_k spacing of transverse reinforcement
s_1, s_2, s_3 tie spacing
M_{ra}, $M_{rü}$ ultimate moment resistances calculated at the bottom and the top of column
M_{ri}, M_{rj} ultimate moment at the ends of beam
V_e shear force
A_w effective web area of column cross-section
V_r shear strength of a cross-section column
Δ_i storey drift
V_n column shear strength
V_p max. probable shear force required for the plastic hinge form. at column ends
M_p max. plastic moment capacity of the column
L clear height of the column
l_n clear height of column between beams, clear span of beam between column
h_i story height
v_c shear strength carried by concrete
A_{sw} transverse reinforcement area within a spacing
f_{ywd} yield strength of transverse reinforcement

Marmara Region with the magnitude of 7.4 on 17 August 1999. This earthquake caused economic power decrease around 20 billion US dollars and over than 20,000 people is dead. During the last century, about 500.000 building collapsed and were heavily damaged.

The structural damage in all the recent disasters, considering the magnitude of the event, was much heavier than one would normally expected in a country better prepared for disasters [5,6]. Leave the non-engineered buildings aside, engineered structures in Turkey are far from possessing qualities that would ensure satisfactory seismic performance. Although Turkey has a developed seismic code called "The 1998 Turkish Earthquake Code" [7], [TEC-98] which was prepared to ensure that all structures have