Soil Dynamics and Earthquake Engineering 88 (2016) 412–426

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

A generalized seismic source model for the Eastern Marmara Region along the segments of the North Anatolian Fault System

Selim Cambazoğlu [a], Mustafa Kerem Koçkar [b], Haluk Akgün [a,*]

[a] Geotechnology Unit, Department of Geological Engineering, Middle East Technical University, Dumlupınar Blv., 06800 Ankara, Turkey
[b] Earthquake Engineering Implementation and Research Center, Gazi University, Ankara, Turkey

ARTICLE INFO

Article history:
Received 21 July 2014
Received in revised form
29 June 2016
Accepted 7 July 2016

Keywords:
Seismic source modeling
ASTER
North Anatolian Fault System (NAFS)
Probabilistic seismic hazard assessment
Düzce city
Eastern Marmara
Turkey

ABSTRACT

The North Anatolian Fault System (NAFS) has a complex geometry and bifurcates into several branches in the eastern Marmara region. The scientific studies conducted in the area have led to numerous fault and fault segmentation interpretations. This study covers detailed lineament extraction from ASTER images and segmentation delineation by using an extensive literature review on a regional scale and focuses on the continental branches of the NAFS in the eastern Marmara region with their known off-shore extensions. A seismic source model with segmentation, fault length, width and slip rate information was prepared as a newly developed line source model for seismic hazard assessment. A probabilistic seismic hazard assessment for the Düzce city center was performed with segment-source-scenario relations and historical seismicity identification for each defined seismic line source in order to check the applicability of this model.

1. Introduction

A seismic hazard study essentially requires three components; a seismic source model representing earthquake generating mechanisms, an earthquake catalogue which allows estimation of seismicity and relation with the source model, and a ground motion prediction relationship which enables prediction of the ground motion to be generated for the established seismic source model. Among these, as a point of origin of any seismic hazard study, the reliability and spatial accuracy of a seismic source model are essential. This is important since both the spatial location of an earthquake generating mechanism (essentially faults) in terms of its proximity to any engineering structure, and also integration of an earthquake catalogue and forming a relationship between a seismic source model and the catalogue in terms of seismicity to define activities are the major initial steps of a seismic hazard study. Consequently, identifying segments and sources within a region is the starting point and an important basis for defining a source model. Therefore, generation of a generalized, concordant and spatially accurate seismic source model for the Eastern Marmara region along the North Anatolian Fault System (NAFS) to form a viable segmentation model is significant for future studies.

The NAFS is one of the most important transform fault systems in the world which generates destructive earthquakes. This was, unfortunately, most recently observed during the 1999 Kocaeli and Düzce Earthquakes. The general westward propagating seismic activity starting from the 1939 Erzincan Earthquake and most recently, the 1999 Kocaeli and Düzce Earthquakes have caused more than ten destructive earthquakes and more than 50,000 casualties during this time period [1–3]. There have been numerous studies performed, either in terms of tectonics or seismicity in the region in which each study had its own scale (either local or regional) [e.g., 2,4–18] (Fig. 1). In Fig. 1, it can be clearly observed that previous studies are not consistent with each other.

This study encompasses the segments of the NAFS in the Eastern Marmara region, their continuation towards the Marmara Sea due west and towards east to the Western Black Sea region in order to incorporate the segments of the 1944 Bolu Earthquake as a complementary seismic source. The purpose of this study is to compile a generalized segmentation model for the area of interest in order to combine the previous studies with the satellite imagery data. For this purpose, 10 ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) satellite images were analyzed, lineament extraction was performed and the resultant lineaments were compared and correlated with the literature. The correlation has been based on the major seismic events that occurred in the region or the significant fault zones defined within the study area in the literature. Based on this generalization, the study area was divided into 7 seismic sources, namely; the Bolu-

* Corresponding author.
E-mail addresses: selimcambaz@gmail.com (S. Cambazoğlu), mkockar@gazi.edu.tr (M.K. Koçkar), hakgun@metu.edu.tr (H. Akgün).

http://dx.doi.org/10.1016/j.soildyn.2016.07.002
0267-7261/

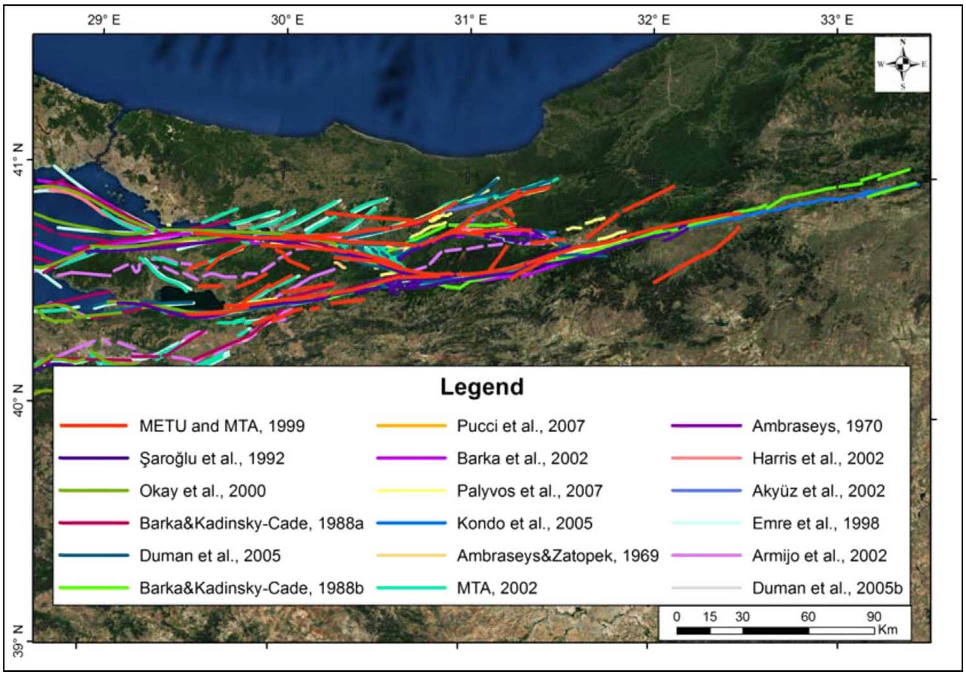

Fig. 1. The fault models reproduced from the literature (the references are presented in the legend).

Gerede seismic source (BGSS), the Çınarcık seismic source (ÇSS), the Düzce seismic source (DSS), the Geyve-İznik seismic source (GİSS), the Hendek seismic source (HSS), the Kocaeli seismic source (KSS) and the Mudurnu-Abant seismic source (MASS). The line segments have been derived from satellite imagery, therefore allowing spatial consistency, and have been delineated based on an extensive literature review. This segmentation model has been expanded in terms of width and slip rate from the literature within a Geographical Information Systems (GIS) environment.

The generated database allowed utilization of a weighted segmentation model for a probabilistic seismic hazard assessment of the Düzce city center. The weight of each seismic source has been assigned based on its individual seismicity, with the employment of segment, source and scenario relationship defined by the USGS Workgroup on California Earthquake Probabilities, San Francisco [19]. The earthquake data have been extracted from the instrumental period earthquake catalogue compiled by the Kandilli Observatory and Earthquake Research Institute [20] following employment of declustering and catalogue completeness analyses. The catalogue contains earthquake data with a homogeneous magnitude scale and covers the time span between 1900 and 2011. In order to determine these weights, recurrence models of the seismic sources were developed based on the seismicity of the sources and the Youngs and Coppersmith composite model [21]. Finally, a probabilistic seismic hazard assessment (PSHA) [22] was performed based on all this information for the Düzce city center in order to check the applicability of the model with two alternative Düzce seismic source models as 2 and 3 segments as well as two alternative seismic source models for the Bolu-Gerede seismic source as 3 and 5 segments, respectively. The Haz39 hazard code developed by Abrahamson [23] was used for the PSHA calculations the with equally weighted average of 2 different GMPEs (Ground Motion Prediction Equations) and the bedrock site condition (i.e. $Vs_{30}=760$ m/s).

2. Seismo-tectonic framework of the study area

The study area lies in the Eastern Marmara and Western Black Sea regions that are bounded by 28.55 latitude – 41.20 longitude coordinates from the northwest and by 33.75 latitude – 40.00 longitude coordinates from the southeast. It covers an area of approximately 37.000 km^2 and lies in the UTM Zones 35N and 36N. On the other hand, the location of the PSHA analysis, namely the Düzce city center, is at 31.16N 40.84E coordinates. The area includes the 17 August 1999 Kocaeli, the 12 November 1999 Düzce, the 22 July 1967 Mudurnu, the 26 May 1957 Abant, the 1 February 1944 Bolu-Gerede and the 20 June 1943 Hendek earthquakes which have caused significant economic losses and have led to severe casualties [1–5] (Fig. 2).

The North Anatolian Fault System is a right lateral strike slip continental transform fault [24,25]. Starting with the 1939 Erzincan earthquake, a westward propagating destructive earthquake generation trend has been observed along the fault zone [1,16,26,27]. The movement along the faults was also documented by geological studies as well as with GPS measurements [27–29]. The length of the NAFS is reported to be between 1200 and 1600 km [30–32] starting from Karlıova, following roughly an east-west trend through north Anatolia as a single strand until the Mudurnu Valley. From this point on, the fault splays into three strands in the Marmara and the Northern Aegean regions [32]. The NAFS forms an 80 km to 100 km wide zone at northwest Anatolia [1,6,32] where the study area lies (Fig. 2).

Following the two destructive earthquakes (i.e., the August 17, 1999 Kocaeli and the November 12, 1999 Düzce earthquakes); the fault system and especially its western half was studied intensely due to the severe destruction caused by these earthquakes and due to the anticipated future westward propagation of the fault system towards İstanbul having a population of about 15 million [2,31]. The major earthquake events in the area may be listed from the most recent to the past as: the 1999 Düzce ($M_w=7.2$), 1999 Kocaeli ($M_w=7.4$), 1967 Mudurnu ($M_s=7.1$), and 1957 Bolu-Abant ($M_s=7.0$) [4–6,12,13,16,33] (Fig. 2, focal mechanism solutions reproduced from [31]).

The most recent destructive earthquakes, namely the 1999 Kocaeli and the 1999 Düzce earthquakes have caused surface ruptures with lengths of 145 km and 40 km, respectively, leading to a total surface rupture of 185 km [12,13]. The exact location of the 1943 Hendek earthquake has not been accurately determined in the literature and it is discussed that it may be associated with