Πρακτικά	6ου Συνεδρίου		Μάϊος 1992
Δελτ. Ελλ. Γεωλ. Εταιρ. Bull. Geol. Soc. Greece	Τομ. XXVIII/3 Vol.	σελ. 397-408 pag.	Αθήνα 1993 Athens

THE ERZINCAN, NE TURKEY, EARTHQUAKE OF 13 MARCH 1992: FIELD OBSERVATIONS

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ABSTRACT

Observations contacted in the macroseismic field of the 13 March 1992 Erzincan earthquake revealed a maximum intensity rating of IX - X (MM) with a death toll up to 600. The meizoseismal area , trending SE - NW and defined by the isoseismal of VIII degree, seems to be a reliable estimate of the rupture zone which is as long as 47 km. Through-going , co-seismic, surface faulting has not appeared. Only cracks in alluvium , of length no more than 200 m each, were observed. The peak ground acceleration (= 0.5g) measured in alluvium in Erzincan indicates an intensity excess with respect the intensity expected from such an acceleration value. This is interpreted by that most of the multi-storey buildings in Erzincan are not earthquake - resistant structures.

INTRODUCTION

The Erzincan earthquake of $M_s = 6.8$ (USGS) occurred at 17:18:40 UTC on 13 March 1992 in the eastern branch of the North Anatolian Fault Zone (NAFZ) causing extensive destruction in the city of Erzincan which is of a population of 100,000. Forty six hours after the mainshock origin time a Greek mission, Organized by the Earthquake Planning and Protection Organization arrived in Erzincan. The mission consisted of three scientists, a 25-member medical team, a 20-member rescue team and two radioamateurs. This article is devoted to the presentation of field observations conducted by the scientific team of EPPO.

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THE ERZINCAN BASIN: STRATIGRAPHY, TECTONICS AND SEISMIC HISTORY

The Erzincan basin is situated at an altitutde of about 1300 m on the eastern branch of the right-lateral NAFZ (Fig.1). Its main axis strikes NW - SE parallel to the trend of the fault zone. The basin is about 50 km long and widens to the SE, where its width reaches up to 15 km. The left-lateral Northeast Anatolian Fault and the Ovacik Fault obliquely intersect the NAFZ to the NW and SE of the basin, respectively (Fig. 1).

The Erzincan basin has been described as a typical rhombic pull-apart basin, bounded by two parallel master faults which are presumed to be the segments of the NAFZ (Şengör,1979; Aydin and Nur,1982; Hempton and Dunne,1984; Şengör et al.,1985). According to Barka and Gülen (1989), however, it is not a typical rhombic pull-apart basin, instead it has a rather complex pull-apart mechanism and basin evolution due to the critical role of the Ovacik Fault.

Barka and Gülen (1989) reviewed the strtigraphic and structural details of the Erzincan basin. From this review and references given there we learn the following. As a result of the continued collision along the Bitlis Suture Zone in mid-late Miocene, the main fault zones of the region were formed in early Pliocene. The escape of continental blocks away from the maximum compression zone tectonically overprinted some of the existing suture zones and basins, and also created new basins such as the Erzincan one. In this basin, all the exposed sediments are Plio-Quaternary mostly fluvial deposits. A rapid deposition in a tectonically active environment is suggested. Thickness estimates of the basin fill range from 500-1000 m to 2.5-3.5 km. The basin's NW-SE trend is parallel to the trend of the NAFZ which forms the entire northern boundary of the basin and serves as a master fault. The NAFZ consists of three major segments in this region; the eastern (S1), central (S2) and western (S3) ones. The segment S2 forms the northern boundary of the Erzincan basin. It is dominated by right-lateral strike slip. There is no evidence that the southern margin is controlled by an active strike-slip master fault. Small dacitic and rhyolitic volcanic cones of Plio-Quaternary age are aligned mainly along the northern margin of the basin.

The great (M_s = 7.8) event of 26 December 1939 has been the largest and more destructive earthquake in Turkey since 1668 producing seismic intensity as high as XI (MSK) in Erzincan and causing the loss of more than 30,000 lives (Ambraseys,1988). This earthquake created 350 km of surface ruptures on the S2 and S3 segments of the NAFZ in the Erzincan area, producing 4m right-lateral slip and 1m uplift of the southern block. The 20° difference in strike between these two segments forms a restraining bend to the NW of the Erzincan basin. The epicenter of the 1939 earthquake was located near this bend (Dewey,1976). It seems that there is a general connection between the strike-slip fault geometry and the location of large earthquake rupture segments in Turkey (Barka and Kandinsky-Cade,1988) as well as the size and frequency distribution of earthquakes in California and Turkey (Wesnousky,1988).

An earthquake of M_s = 6.0 took place on 26 July 1967 near Pülümür in the segment S1. This destructive shock was strongly felt in Erzincan (Ambraseys,1988). The fault plane solutions of the 1939 and 1967 earthquakes are consistent with right-lateral motion in NAFZ (McKenzie,1972). However, the solution (ISC Bulletin,1983) of the 18 Novenber 1983, M_s = 5.4, earthquake, which occurred within the Erzincan basin, implies ENE-WSW extension, which is consistent with the active opening of the basin.

THE MAIN ZONE OF DAMAGE

The earthquake of 13 March 1992 caused extensive damage mainly within the Erzincan basin. In the city of Erzincan about sixty modern reinforced concrete buildings were totally collapsed creating a death toll up to about 500. Most of these buildings were three- to five-storey structures. Many others have been damaged beyond repair. Out of about 25,000 buildings, the total number of buildings in Erzincan, 2,169 were either collapsed or heavily damaged which means a percentage of about 9%, while the numbers of moderately and slightly damaged buildings are 3,290 (13% of the total number) and 4,061 (16% of the total number), respectively (Gencoglu,1992). Building damage occurred in the towns of Üzümlü and Pülümür and in a large number of villages

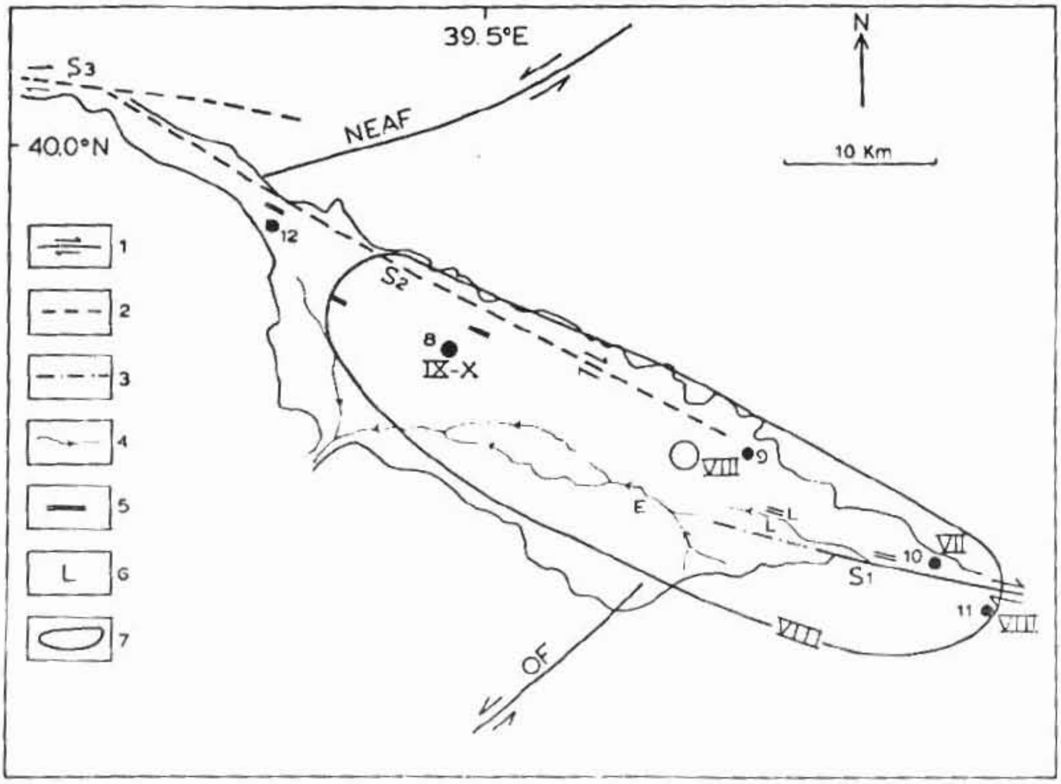

Figure 1. Simplified tectonic map of the Erzincan area (after Barka Gülen, 1989) and features of the 13 March 1992 macroseismic field as described in this paper. Key: strike-slip fault, 2; surface rupture of the 1939 earthquake, 3; tectonic lineament, 4; river flow, 5; earthquake surface cracks, 6; liquefaction in soil, 7; isoseismal, 8; Erzincan, 9; Uzümlü, 10; Tanyeri, 11; Pülümür, 12; Davarlı, S; segment of the North Anatolian Fault, NEAF; Northeast Anatolian Fault, OF; Ovacik Fault, E; Euphrates river. Seismic intensity assigned to several places is shown by roman figures. Open circle shows the epicentral location of the 13 March 1992 mainshock.

so that the total numbers of collapsed or heavily damaged, moderately damaged,and slightly damaged building units are 4,318 , 5,253 , and 7,292 , respectively. The total death toll in these areas has been about 100.

The Erzincan earthquake injured some hundreds of people and rendered about 50,000 people homeless. Damages to the transportation and life lines have been reported. The seismic intensities assigned to localities affected strongly by the earthquake in the Erzincan basin are shown in Figure 1. All intensities reported here are according the 12-point modified Mercalli-Sieberg (MM) scale . The intensity assigned to the city of Erzincan is IX. However, the fact that most of the collapsed and heavily damaged multi-storey buildings occurred on the two main streets running along the E-W and N-S directions, crossing each other in the city center, implies that the intensity may have reached up to X there. Another interesting feature of the lateral damage distribution in the city of Erzincan is the significantly low degree of damage which occurred to the north of the city center. As a rule the earthquake caused no damage to one- or two-storey brick masonry buildings as well as to the mosques of the city. Almost half of the totally collapsed units were corner structures of block buildings.

The meizoseismal area, that is the area of maximum seismic effect, is defined by the isoseismal of VIII degree (Fig. 1). Its main axis, as long as about 47 km, strikes SE-NW , that is parallel to the long axis of the Erzincan basin and the strike of the NAFZ. The meizoseismal area may roughly represent the lateral extent of the earthquake rupture zone, which is the zone where the stress after the earthquake is substantially reduced with respect the stress prevailing before the earthquake (Kelleher, 1972). In the absence of other more appropriate means for defining the lateral extent of rupture zones of large earthquakes , such as surface fault breaks and accurately located aftershocks , the places from which substantial destruction is reported have been used (Kelleher, 1972; Wyss and Baer, 1981; Papadopoulos, 1988; Dorbath et al., 1990). In this sense the isoseismal of degree VIII seems to be a reliable estimate of the lateral extent of rupture zones of large earthquakes. The length ($\sim$47 km) of the largest axis of the Erzincan earthquake meizoseismal area is compatible with the rupture length , L, predicted for M= 6.8 by the relation log L = -3.932+ 0.812 M (L in km), which has been found (Erdik and Öner, 1982) for NAFZ earthquakes.

Knowledge of the geometry and distribution of rupture zones of large earthquakes is of special importance in understanding better the seismic cycle and promoting the solution of the seismic hazard assessment and earthquake prediction problems. There is evidence that rupture zones of large subduction earthquakes abut and do not overlap (e.g. Sykes,1971; Kelleher, 1972). In environments of strike-slip faulting, however, it seems that rupture zones of large earthquakes tend to overlap significantly. For example, in the San Andreas fault the rupture zones of the 1989 Loma Prieta large (M= 7.0) shock overlapped significantly the rupture zone of the great (M=7.7) 1906 San Francisco event. The 1992 Erzincan rupture zone is completely overlapped by the rupture zone of the 1939 great event as it is expressed by its main zone of destruction elaborated by Ambraseys(1988).

Directional aspects associated with the damage observed in the city of Erzincan have been among the most interesting features of the macroseismic field. The directivity effect is not well expressed in composite structural units such as multi-storey reinforced concrete buildings. Simple structural units, however, have been characteristically affected so that to show very clearly two main components of the strong ground motion, one N-S and another E-W. Both components are evident in many places of the city where decades of bricklaying enclosures have been overthrown either from south to north or from east to west. In addition, the S-N component is also evident in at least two distant localities of the city, in Fatimmahalesi and Erzincan Bulvari at the eastern and western parts of the city, respectively, where we observed electric power pylons obviously deformed because of the strong ground earth shaking. These observations supply macroseismic evidence about the epicentral location towards about SE with respect the position of Erzincan city, as well as about the approximate direction of the main component of strong ground motion from SE to NW. According to preliminary determinations the earthquake epicentre is located at 39.90°E and 39.75°N (Kandilli Observatory, Istanbul), which is consisted with the macroseismic location.

Recordings of SMA-1 type instruments have shown that the maximum ground acceleration in the Erzincan alluvium has been equal to 0.5g, 0.4g and 0.25g in the E-W, N-S and vertical components, respectively (Gencoglu, 1992). This verifies the macroseismic observation that two strong ground motion components, the N-S and E-W ones, have affected with roughly the same strength the structures in Erzincan. The measured maximum acceleration, a, however, is significantly lower than that expected for intensity I = X from the relation log a= 0.01+ 0.30 I, which has been found by Trifunac and Brady (1975) for Western U.S. earthquake data set, that is for a seismotectonic environment similar to that of northern Turkey. This means that for the observed level of maximum acceleration a considerable seismic intensity excess has been observed in Erzincan. This conclusion and its possible interpretation are discussed later.

GROUND FAILURES AND LOCAL EFFECTS

According to our field observations there is no evidence for through-going , co-seismic, surface faulting. Cracks in alluvium have been observed in several places mainly along the fault segment S2 which bounds the basin to the north. In the Davarli village area (Fig. 1), at the western portion of segment S2, cracks as long as about 200m were observed parallel to the strike of the main fault, that is SE-NW. Similar cracks have been reported in the vicinity of the Yalnisbag village some 7 km SE off Davarli (Demirtaş and Yilmaz, 1992) (Fig. 1). In the central part of S2, tension cracks in filling ground have been observed in the northern edge of the Erzincan basin around the Eksisu mineral water spring. They are settlement cracks having a 200-250m length and a 50 cm vetrical offset.

More important are two tension cracks opened in the westernmost part of segment S1 at the eastern side of the Erzincan basin at the west of Tanyeri town (Fig. 1). Right-lateral displacements varying between 5cm and 20cm, with a normal component up to 10cm, have been measured. Some minor cracks were observed along the Euphrates river bank as well. The system of discontinuous ground cracks exhibits a total length of about 45km. In many places it is of en echelon structure trending NNW-SSE.

Liquefaction in soil is one of the most important ground failures associated usually with strong earthquakes. The maximum epicentral distance, R, at which liquefaction may occur is a function of the earthquake magnitude, M (e.g. Kuribayashi and Tatsuoka, 1975). Empirical relations between M and R found for world data (Ambraseys,1988; Papadopoulos and Lefkopoulos,1992) show that for M= 6.8, the magnitude of the Erzincan earthquake, R is about 110 km. In the inspected area, which covers the largest part of the Erzincan basin, surface manifestation of liquefaction in soil, having the form of mud and sand volcanoes, was observed along the Euphrates valley in the epicentral area. However, the R-value of 110 km does not preclude the occurrence of liquefaction in more remote places.

Local ground effects play an important role in the configuration of basic features of the strong ground motion, such as the duration and amplitude of mainly the larger period components of the seismic motion,and consequently of the seismic intensity levels in particular places. There are well-documented cases of local ground effects associated with earthquakes which occurred in the 1980s, e.g. the large magnitude events of 19 September 1985 in Mexico (M= 8.1)(e.g. Bech and Hall,1986) and of 18 October 1989 in Loma Prieta, California (M= 7.1)(e.g. Darragh and Shakal, 1991), as well as the smaller event of 16 October 1988 in western Greece (M= 5.9)(Papadopoulos and Profis,1990). The foundation ground of the Erzincan residential zone is a plain consisting of mainly Late Quaternary, thick alluvial fan deposits. This means that large-scale , lateral ground effects are, as a general rule, not favoured. This picture changes slightly to the north of the city center where the elevation increases and the deposits thickness decreases. On the contrary, small-scale ground effects may have been very frequent as indicated by the abundant cases of completely different behavior of adjoining building units of similar type in many places of the city. The stratigraphic heterogeneity, because of the high sedimentation rate, and the asymmetry of the sediment thickness, features which result from the pull-apart tectonic evolution of the basin, could be considered as the primary causes of small-scale, lateral ground effects.

DISCUSSION

From earthquake engineering point of view the most important feature in Erzincan is that the modern reinforced concrete multi-storey buildings are non-earthquake resistant structures with only few exceptions. This is mainly due to that many of the collapsed or damaged reinforced concrete buildings had been designed and built without taking into account basic requirements of the building code. As a matter of fact, many of the collapsed buildings had been initially designed as two-storey structures. However, one or more stories were added later without proper reinforcement of the older parts of the buildings.

Such a systematic ignorance of the building code explains well-enough the seismic intensity excess reported from mainly the city center. This excess may be also related with the long duration of the strong seismic motion recorded in Erzincan. It is of special interest to examine whether or not the long shaking is associated with certain features of the rupture process itself.

Preliminary instrumental determination and our field observations show that the earthquake epicenter is located somewhere in the eastern side of the Erzincan basin. According to Barka and Kadinsky-Cade (1988), a releasing bend of about 15°, with a stepover width of 4-5 km, separates the fault segments S1 and S2 there. These authors have concluded that the geometry of Turkish strike-slip faults, that is the distribution of discontinuities such as bends and stepovers along the main fault trace, plays an important role in controlling the location of large earthquake rupture segments along the fault zones. Therefore, the suggestion that the earthquake consisted of two separate events, rupturing the westernmost portion of S1 and the easternmost portion of S2, seems to be reasonable , explaining the long duration of shaking in Erzincan.

The large-scale anomaly of low seismic intensity to the north of the city center seems to be rather associated with the good quality of the structures, many of them being military buildings From macroseismic inspection there is no evidence for particular local ground conditions which have substantially contributed to the collapse of many multi-storey modern buildings in the city center. The fact that as a rule the earthquake caused no serious damage to one- or two-storey brick masonry structures and mosques in the center and other places of the city, implies that the frequency content of the seismic waves may have been a factor of importance for the collapse of multi-storey buildings.

The lack of co-seismic surface break is an interesting feature of the Erzincan earthquake. The system of cracks observed in alluvium at a length of about 45 km nearly along the main fault zone may mark the position where the pre-Neogene bedrock has been ruptured during this earthquake. The relatively large focal depth ($\sim$ 20 km) of the mainshock and the very thick layer of recent deposits may have been the principal causes for the non-appearance of co-seismic surface faulting. This reminds the 18 October 1989 Loma Prieta, M= 7.0, earthquake, of a focal depth of about 15 km, and the 29 April 1991, Racha, Georgia, M= 7.0, earthquake, of a focal depth of 6-14 km, which similarly have not been accompanied by co-seismic surface faulting (USGS Staff, 1990; Borissoff and Rogozhin, 1992). According to Scholz's (1990) terminology, these three earthquakes are of "small" size so that their rupture dimensions are smaller than the width of the "schizosphere", which is the brittle part of the lithosphere.

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