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March 13, 1992 Erzincan (Turkey) earthquake

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ABSTRACT: Erzincan City has been stricken by numerous earthquakes. That of 1939 (Ms=7.8) destroyed the entire city and killed thousands of people. The city was then relocated. The main shock of March 13, 1992 and its aftershocks killed about 500 people, injured 2800, damaged 11 000 houses and caused the collapse of 180 buildings. There were pronounced site effects and many instances of liquefaction and landslides. Damage to various types of construction, the good behavior of others and post-earthquakes experience underline lessons taught by earthquakes in other parts of the world, and teach us new lessons. Although plans existed for disaster response and mitigation, their implementation was hampered by lack of rehearsal.

1 OVERVIEW

Throughout its history the city of Erzincan has been subjected to damaging earthquakes. The one of 1939 (Ms =7.8, MKS-64 intensity IX) destroyed the entire city and killed 33 000 people. Erzincan was then rebuilt at a new location and with new town planning. The new plan involved wider streets, houses limited to a single story and other buildings to two stories. Over the years, however, the limitation was raised to four stories, with some six-story buildings along the main streets.

Erzincan, on the North Anatolian Fault, exhibits the highest hazard in Turkey, comparable to localities on the San Andreas Fault in the USA. The peak ground acceleration with a 10% probability of exceedance in 50 yr (475-yr return period) is 0.60g (Erdik et al, 1985).

Erzincan Province is located in Northeastern Anatolia. Its population is about 300 000. That of its capital, the city of Erzincan, is about 80 000.

The main shock of March 13, 1992 and its aftershocks affected the Erzincan Province and northern portions of Tunceli Province. About 500 persons lost their lives and 2800 were injured; 11 000 houses were damaged affecting a population of 70 000. In the city of Erzincan, of a total of 28 000 houses, 28% were damaged: 5% collapsed or suffered major structural damage, 10% experienced moderate damage and 14% light damage. About 180 buildings collapsed. Direct economic loss is estimated at 0.4 billion US dollars.

For a more complete description of this earthquake's effects, antecedents, disaster response and mitigation the reader is referred to the report of Boğaziçi University (1992) and the paper by Erdik et al (1992), of which the present paper is a brief summary.

2 TECTONICS

With reference to fig 1, the Anatolian and the Northeast Anatolian Blocks are wedged out respectively to the west and the east due to convergence of the Arabian and Eurasian Plates. The dextral strike-slip North Anatolian Fault forms the northern boundary of the western Anatolian Block, which is bounded in the south by the East Anatolian Fault. The two faults intersect at the Karlìova Triple Junction. The rectangle indicated by double lines is enlarged in fig 2. Here the thick dashed lines show the ruptured segments. The sinistral Ovacìk Fault has been involved in the opening of the Erzincan Basin. The Northeaster Anatolian Fault has a small thrust component and is associated with the Tercan earthquake of 1939, a foreshock of the Erzincan earthquake of December 1939, which marks the beginning of a sequence of ruptures of this fault, ending in 1967. There is though, a 75-km unruptured segment just east of Erzincan (Barka and Toksöz, 1992).

3 SEISMOLOGICAL ASPECTS

The North Anatolian Fault has originated numerous damaging earthquake during several

rupture episodes in the last two millennia. During the 1939-1967 episode its activity has migrated toward the west, causing seven earthquakes with magnitude 7.0 or greater (Ambraseys, 1988). Major earthquakes along this fault, usually associated with hundreds of kilometers of rupture, do not tend to occur in the same fault segment within several decades and do not produce aftershocks with magnitude greater than 5.0. Aftershocks tend to be concentrated near the ends of the rupture, and these regions may continue to experience small quakes for some years (Dewey, 1976).

The Erzincan earthquake of March 13, 1992 occurred at 17:18:40.1 UTC time, had an Ms magnitude of 6.8 and a 28-km depth. The best double-couple solution coincides with the strike of the North Anatolian Fault. Contrary to previous experience with earthquakes of comparable size, no surface rupture has been found associated with this event. Microseismic networks were deployed right after the main shock aftershocks. The largest had Ms =5.8 while four others had MB exceeding 4.0.

Main-shock intensities are depicted in fig 3.

4 STRONG GROUND MOTION

Main-shock accelerograms were obtained at three stations — Erzincan, Refahiye and Tercan —, at epicentral distances of 5, 70 and 70 km, respectively (fig 2). The Erzincan station lies 3.5 km from the trace of the North Anatolian Fault. All these records are practically free field. Peak ground accelerations, velocities and displacements are displayed in table 1.

The Erzincan station displacement traces are shown in fig 4. The corresponding accelerograms are very similar to those from Station 2 of the Cholame-Shandon array during the Parkfield, California earthquake of June 27, 1966. The latter station lay 80 m from the San Andreas Fault, which in many respects closely resembles the North Anatolian Fault. In both cases there was the same impulsive motion, in which the ground moves about 30 cm and returns to the original position. The motion manifested itself in 35-cm shifts of transformers in the Erzincan switch yard. Such a simple displacement pulse may be characteristic of near-field ground motion associated with strike -slip mechanisms. Similar shapes were observed during some of the aftershocks in Erzincan.

Fourier amplitude spectra of the main shock at Erzincan are consistent with Brune's (1970) model with an effective stress of 46 bars, a corner frequency of 2 Hz and minimum radius of the dislocation surface of 1.4 km. The apparent stress as defined by Wyss and Brune (1968) and based on the expression by Uhrhammer and Bolt (1991) for the radiated energy, is about 10 bars.

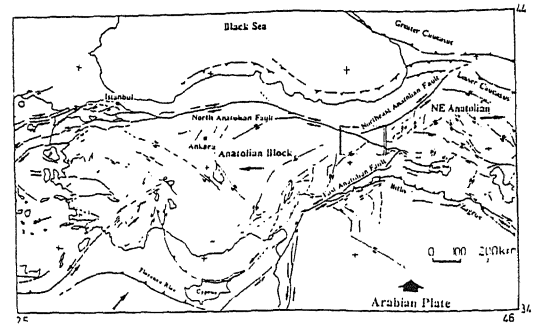

Fig 1. Neotectonic map of Turkey and vicinity (after Barka and Toksöz, 1992). Shown are surface ruptures associated with this century's earthquakes.

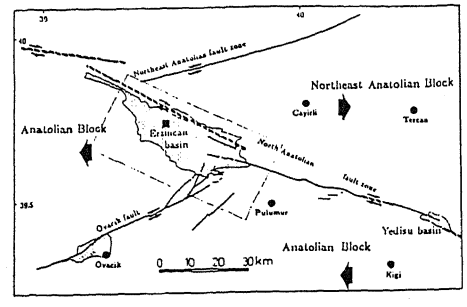

Fig 2. Simplified geometry of major blocks around Erzincan Basin (after Barka and Toksöz, 1992).

5 SITE EFFECTS IN ERZINCAN BASIN

The prominent geologic feature in the area is the pull-apart Erzincan Basin. It contains the city of Erzincan as well as a number of townships and villages. Its long axis is parallel to the North Anatolian Fault and measures 50 km. Its width reaches 15 km. A simplified geologic map of the basin is provided in fig 5. The exposed sediments belong to the Plio-Quaternary, characterized by fluvial facies, coarse clastics and basin margin conglomerates, the latter reaching 200 m in thickness. The alluvial fans consist of recent debris flows and coarse-grain braided stream deposits. The total thickness of the sediments is estimated to range between 0.5 and 3.5 km. Borehole data (DSI, 1981) indicate lenses or discontinuous layers of sand and gravel series with small amounts of clay, at least down to 250 m. The depth of the water table to the north of the basin (including Erzincan) is 30 m and decreases a few meters toward the center. Fig 6 shows a topographic map and a geologic section of a basin strip (identified in fig 7). With basis on

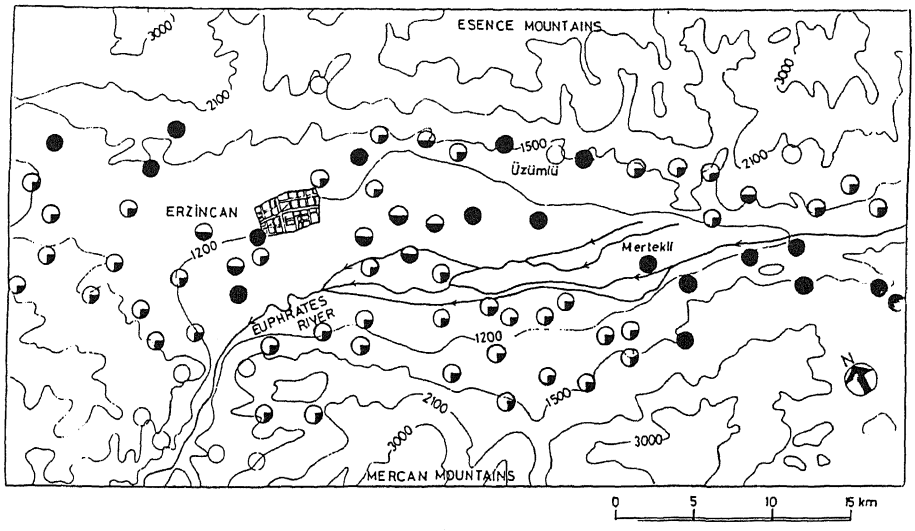

Fig 3. Damage distribution in and around Erzincan Basin. Shading indicates the percentage of medium plus heavy damage. 0.25% of total dwelling stock: one-fourth circle shaded (≃ MSK VI); 25-50%: half circle shaded (≃MKS VI-VIII); more than 50%: whole circle shaded (≃ MSK VII-VIII).

two-dimensional analyses of other idealized basins by Bard and Bouchon (1985) experiments by King and Tucker (1984) and empirical shear wave velocities proposed by Ohta and Goto (1984) one finds the fundamental frequency of vibration of the basin in the vicinity of 0.27-0.29 Hz, which is in accord with the prevailing frequency of 0.3 Hz determined from Fourier amplitude spectra on the basin as compared with surrounding sites.

6 GEOTECHNICAL PROBLEMS

The main event and some large aftershocks triggered numerous small landslides, rockfalls and avalanches throughout the region. Most slides occurred along the steeper slopes of the road cuts, blocking transportation routes and damaging road surfaces of localities with high water table and granular soils. Fig 7 shows the distribution of surface cracks and instances of liquefaction. Fissuring and settling of sediments damaged irrigation facilities. Compaction of saturated materials was often associated with ejection of water-silt mixtures and formation of sand mounds.

Criteria by Tokida (1990) for liquefaction include the requirement that 0.02 mm ≤ D50 ≤ 0.2 mm in the grain-size accumulation curve. This criterion is not easily met at most sites in the basin and is believed to explain the spotty nature of liquefaction during the Erzincan earthquake.

At the eastern entrance to the basin, response of the railroad embankment and underlying soil resulted in plastic deformation manifested as rail undulations. Following the earthquake a grid of cracks was observed in snow covering the flat marshy terrain on which lies this embankment. After snow melting there was no evidence of these cracks in the ground.

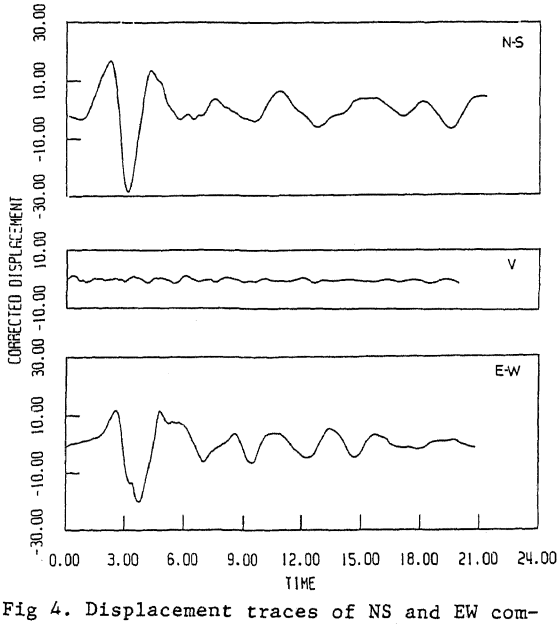

Fig 4. Displacement traces of NS and EW components, main earthquake recorded at Erzincan station (displacement in cm, times in s).

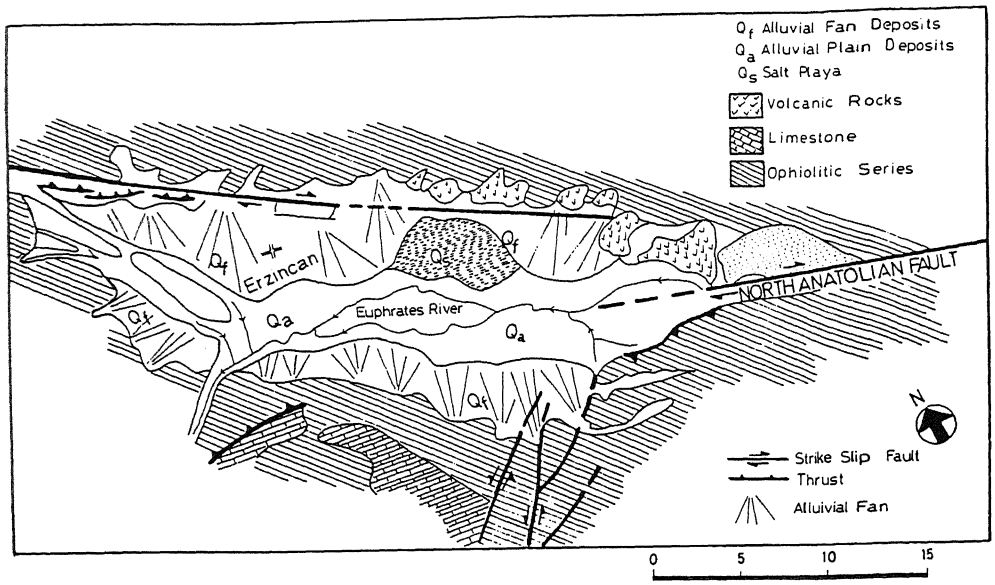

Fig 5. Simplified geologic map of the basin (after Barka and Gülen, 1989),

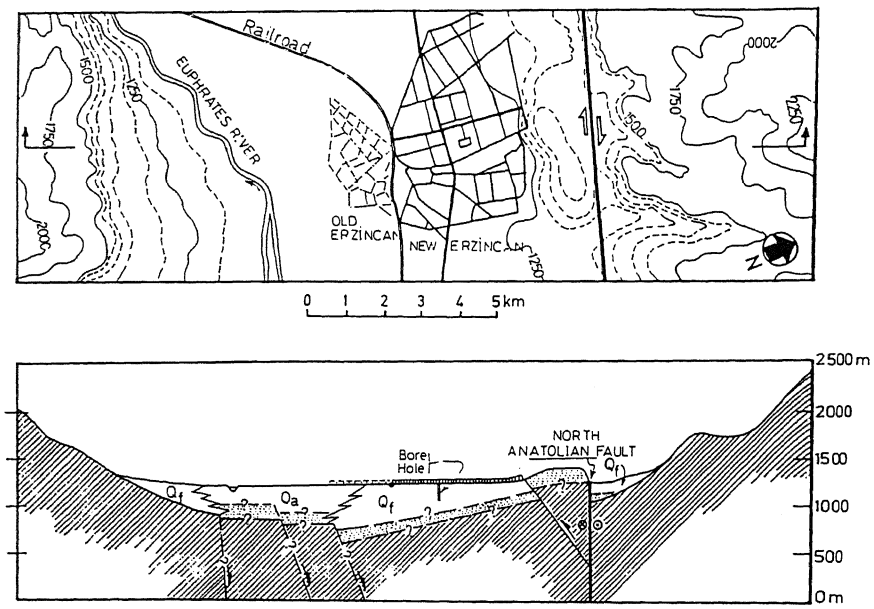

Fig 6. Topograpic map of a NS strip of the basin around Erzincan and approximate section. The area covered is identified in fig 2.

7 STRUCTURAL DAMAGE

Distribution of the building stock according to structural type is shown in fig 8. Almost all multistory buildings have reinforced concrete moment resisting frames with unreinforced masonry infill walls. These nonresidential buildings are located along the main streets which cross the city at right angles. The remaining buildings consist of 3-4 story reinforced concrete residential apartments, 1-2 story unreinforced brick masonry or single story adobe houses and single story prefabricated lightweight houses. The latter can be classified in two groups. Group I encompasses those built after the

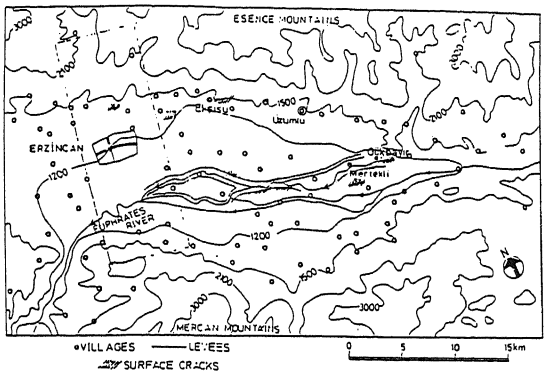

Fig 7. Regional distribution of surface cracks and liquefaction.

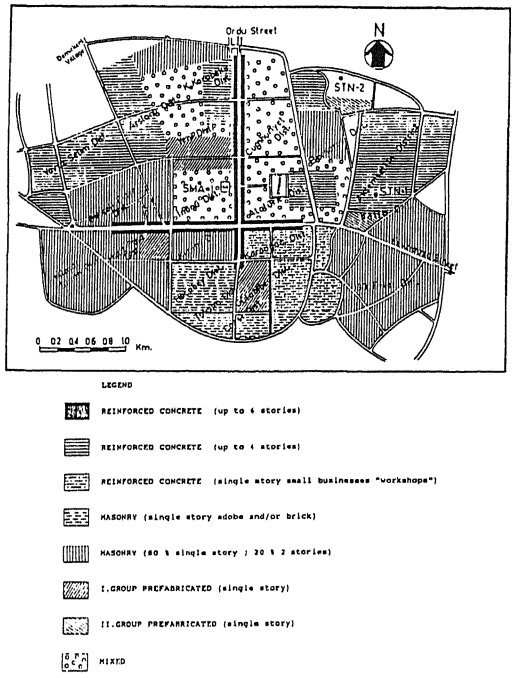

Fig 8. Erzincan City layout and building type distribution. Names correspond to districts.

1939 earthquake with imported material. These have wooden frames plastered on both sides with wire mesh. Group II prefabricated buildings were erected recently with light-weight panels. The small businesses in the south-east of the city occupy single story reinforced concrete constructions.

A map showing damage concentration and percentage of collapsed buildings by district is given in fig 9. Maps are also available with percentages of various degrees of damage. Causes of damage are analyzed below.

1. Reinforced concrete buildings. The main causes of failure or damage were: soft story (chiefly the first story), lack of redundancy (all columns in one story failing simultaneously; very few structures with shearwalls), concrete quality (mean concrete strengths 100 kg/cm^2 in damaged structures), poor connections (insufficient confinement and poor detailing), short columns (hence brittle failure), structural alterations (stories added), inadequate repair (plastering rather than retrofitting), torsion (mostly in structures at ends of groups of buildings), pounding (with slabs at different elevations in adjoining buildings) and strong-beam-weak -column (causing damage concentration in columns).

2. Masonry buildings. Causes of failure were much fewer than in reinforced concrete structures. The most significant were: insufficient wall strength (excessive openings), wrong construction practices, structural alterations (suppression of bearing walls) and poor maintenance.

Prefabricated buildings. Only superficial damage was observed in prefabricated buildings.

3. Other structures. Causes of damage in individual industrial buildings were: insufficient dimensioning of columns; collapse of a chimney causing secondary damage; poor joint strength; inadequate floor connections of machinery, and inadequate beam-column connections in a prefabricated concrete structure.

No failure was observed in two reinforced concrete arch highway bridges and one steel trussed railroad bridge about 50 km east of Erzincan. One reinforced concrete slab type highway overpass 10 km away from the city had damage at its abutments and piers due to the instability of loose and heavy material at the abutments.

The majority of rural structures consisted of masonry buildings (adobe, stone, concrete block and brick) and some timber framed buildings (with adobe and stone fillers or closely spaced laths nailed to vertical members and plastered). The adobe and stone buildings were usually covered with a flat heavy earthen roof or a galvanized corrugated metal. Among typical failure patterns are: partial or complete collapse, separation of peripheral walls, vertical cracks at the joints or intersecting walls, out of plane collapse of peripheral walls, and vertical cracks at the junctions of walls. Timber framed houses had only plaster damage.

8 EARTHQUAKE RESISTANT CODE ISSUES

The previous editions of the Turkish Earthquake Code were published in 1942, 1953 (IAEE, 1963) and 1961 (IAEE, 1966). The last edition published in 1975 (IAEE, 1988) is still applicable. Not until the last edition

were the concept of ductility and detailing for confinement in the critical regions specified and enforced. For reinforced concrete framed structure up to 40 m high the maximum lateral force coefficient was 0.10 according to the 1961 edition of the code; this coefficient is 0.15 (to 0.225 for important buildings such as hospitals) in the 1975 edition. For a number of old buildings designed and built following the existing codes of their times collapse or heavy damage was inevitable due the inferiority of the codes in terms of both strength and ductility.

Since the duration of the main portion of the strong ground motion was limited to only several seconds representing a single displacement pulse, behavior of the structures was governed by strength rather than ductility. The structures that survived (including brick masonry buildings) had apparently enough strength to resist the initial impact.

Although in general not included in the design, infill walls contributed substantially both to stiffness and strength. For those structures, if prevailing amplitude had continued through several cycles heavy damage or collapse would have been inevitable. In most of the heavily damaged or collapsed reinforced concrete structures, plastic hinges developed within the first high-amplitude excursion of the ground motion. The joints had neither the adequate amount of strength to take care of the first shock, nor the ductility. According to the applicable earthquake code (Ambraseys, 1988), reinforced concrete buildings with unreinforced infill walls are to be designed for a maximum base shear coefficient of 0.15 or 0.225. Both NS and EW response spectra give an average value of acceleration a=0.75/0.15=5 and 0.75/0.225=3.3. Since the prevailing construction practice in the city is far from supplying these ductilities, the main reason behind the good earthquake performance of some structures is the overstrength supplied by the infill walls.

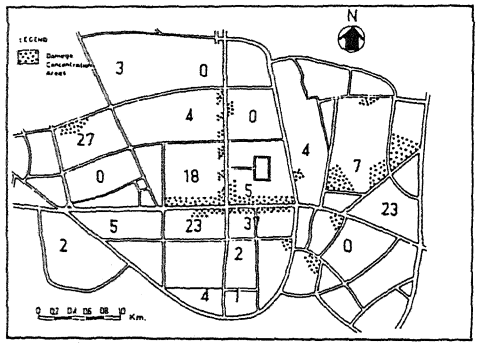

Fig 9. Percentage of collapsed buildings in each district. Dots indicate damage concentration.

9 LIFELINES

Following is a point-by-point summary of the performance of lifelines in the affected area.

Tercan dam, located 70 km to the east of Erzincan, is built on the Euphrates River. The dam and hydroelectric facilities did not experience damage.

The railroad connecting Sivas, Erzincan and Erzurum transverses the Erzincan basin and the affected area from west to east. With the exception of embankment problems causing undulations in the railways at the eastern end of the basin, the railroad did not experience damage and provided continuous service.

At certain locations of the main and secondary highways the earthquake triggered embankment instabilities with extensive cracking and in few cases with collapses. These sections were quickly repaired and the traffic moved without difficulty. With the exception of one overpass on Erzurum-Kemah road there was no damage to the bridges.

No damage was reported in the water mains supplying the city of Erzincan. However, a large part of the city did not receive water for about a week because pipe connections to damaged buildings were not repaired and the city water system had no redundancy. No problems were reported with the sewage system.

The main switch yard of the electricity system feeding the city of Erzincan was intact after the earthquake save for shifts at the base of the main transformers. Some failures in the secondary transformers were quickly repaired and, other than the first day when the power was cut off, the power was restored in a few days.

Telephone communication was interrupted right after the earthquake due to the fact that the equipment inside the communication building toppled although the building itself was only slightly damaged. Through a portable relay truck and a satellite dish the emergency telecommunication was restored in 10 hr. Telephones in the city were mostly operational within a few days.

The airport, which is located 6 km to the southeast of the city of Erzincan, did not experience damage in the earthquake and was fully operational for emergency transportation right after the earthquake.

10 DISASTER RESPONSE AND MITIGATION

Emergency plans and scenarios were ready at the government level but had not been rehearsed. This resulted in ineffective response during the first days following the earthquake.

Damage assessment forms refer to rural dwellings and are oversimplified. They are

ambiguous for multistory buildings.

During the first 24 hours after the earthquake, most of the survivors from collapsed buildings were rescued by military personnel stationed in Erzincan and by unorganized volunteers. Lack of necessary equipment hindered these activities. With the arrival of the national and international rescue teams the rescue efforts became more professional. There were great differences in the nature of international rescue teams. Need for coordination between the national and international teams was apparent for their full utilization.

Apart from casualties and destruction, the earthquake caused significant economic damage. Short-term losses encountered by small businesses can make individual recoveries a difficult task. The government will be providing houses of interest-free loans to qualified families to reconstruct or repair the damaged houses. The loan is to be paid back in 20 years. Public expenditures to this end is estimated at 0.5 billion US dollars. No radical changes in urban planning are being envisaged.

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REFERENCES

Ambraseys, N N. 1988. Engineering seismology, Earthq Eng and Struct Dyn. 17. 1-105.

Bard, P-Y, and M Bouchon. 1985. The two dimensional resonance of sediment-filled valleys. Bull Seism Soc Am. 75. 2. 519-451.

Barka, A A and M N Toksöz. 1992. Seismotectonics and seismic gaps of the eastern part of the North Anatolian Fault Zone. Journal of Gephys Rev. (To be published.)

Barka, A A and L Gülen. 1989. Complex evolution of the Erzincan Basin (Eastern Turkey). Journal of Structural Geology. 11. 3. 275-283.

Boğaziçi University. May 1992. March 13, 1992 (Ms=6.8) Erzincan Earthquake, a preliminary reconnaissance report.

Brune, N J. 1970. Tectonic stress and the spectra of seismic shear waves from earthquakes. L Geophs Res. 75. 4997-5009.

Dewey, J M. 1976. Seismicity of Northern Anatolia. Bull Seism Soc Am. 64.

DSI. 1981. Erzincan Ovasi Hidrojeolokik Etüd Raporu, T C Enerji ve Tabii Kaynaklar Bakanliöi Devlet Su ÿfleri Genel Müdürlüöü, Jeoteknik Hizmetler ve Yeraltì Suralì Dairesi Bafkanlìöi, Ankara.

Erdik, M, V Doyuran, N Akkas, P Gülka. 1985. A probabilistic assessment of the seismic hazard in Turkey, Tectonophysics. 117. 295-344.

Erdik, M, O Yuzugullu, C Karakoc, C Yilmaz and N Akkas. 1992. March 13, 1992 (Ms=6.8) Erzincan Earthquake: a preliminary reconnaissance report. This conference.

IAEE. 1963. Earthquake Resistant Regulations - A world list Compiled by International Association for Earthquake Engineering, Tokyo.

IAEE. 1966. Earthquake resistant regulations - A world list compiled by International Associationf for Earthquake Engineering. Tokyo.

IAEE. 1988. Earthquake resistant regulations - A world list compiled by International Association for Earthquake Engineering, Tokyo.

King, J L and B E Tucker. 1984. Observerd variations of earthquake motion over a sediment filled valley. Bull Seism Soc Am. 74. 655-670.

Ohta, Y and K Goto. 1978. Empirical shear wave velocity equations in terms of characteristic soil indexes. Earthq Eng and Struct Dyn. 6. 167-187.

Tokida, K. 1990. Earthquake disasterand approach to damage reduction. Proc ESCAP/-UNDRO Regional Symposium on the International Decade for Natural Disaster Reduction, Bangkok.

Uhrhammer, R A and B A Bolt. 1991. Loma Prieta magnitude from strong motion records. Bull Seism Soc Am. 81. 1511-1517.

Wyss, M and J N Brune. 1968. Seismicmoment, stress and source dimensions for earthquakes in the California-Nevada region. J Geophs Res. 73. 4681-4697.