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Earthquake faulting and human life loss

E.L. Lekkas & H.D. Kranis
Department of Geology, University of Athens, Greece

ABSTRACT: The aim of this paper is the investigation on the distribution of the loss of human lives in relation to the occurrence of earthquake faults during recent earthquakes that took place in urban centres. The study cases were the three shallow, near-field earthquakes in Kobe (Japan, 17 Jan. 1995), Dinar (Turkey, 1 Oct. 1995) and Egio (Greece, 15 June 1995). The intensities exceeded locally the X grade of E.M.S.-1992 and there was surficial occurrence of earthquake fractures. The distribution of victims was plotted against the fault trace and the processing of data involved the elimination of the consequences of the related surficial earthquake effects, as liquefaction and landslides. Important part in the mortality distribution is played by the fires that broke out, a factor that was also taken into consideration. The resulting charts (mortality plotted against the distance from the fault trace) present a bell-shaped distribution around the fault trace. The distribution width has a maximum of 4 km (Dinar earthquake) and becomes almost zero, virtually coinciding with the fault trace at the case of Egio earthquake. On the other hand, the deaths that are due to the earthquake-related effects and fires are randomly distributed, in relation to the distance from the fault trace. Therefore, as the occurrence of active faults near or through urban centres constitutes a major risk for human life loss in case of earthquakes, the localisation and the systematic study of active faults is capable of significantly reducing the number of victims in a potential earthquake event.

1 INTRODUCTION

Earthquake (seismic) faulting is one of the most serious geologic effects of an earthquake. It is usually expressed in the form of well-delineated surficial cracks displaying measurable offset, not decreasing with depth. Depending on the nature of the exposed geological formations, the parameters of the shock and the pre-existing tectonic features, earthquake faulting can be expressed in smaller or longer segments, along a pre-existing fracture or not, and with the appropriate geometry to accommodate stress release on the ground surface. A discrimination has to be made here: severe ground shaking, induced by a tremor, may produce ground fissures, too; these are markedly distinct from pure earthquake faulting. They bear little, if any, genetic relationship to the local stress field, they gradually disappear with depth, are found randomly distributed and display the localized response of the surficial geological formations, that is mainly differential settlement and response to ground liquefaction. In this paper, only the effects of surficial earthquake faulting are to be dealt with.

On the other hand, constant population increase and urbanization has resulted in more and more people inhabiting tectonically active areas. In

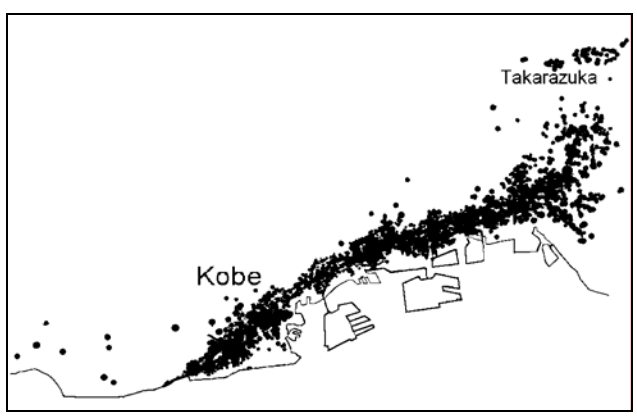

Figure 1. Spatial distribution of mortality during the Kobe earthquake.

countries like Greece, Japan, the USA and others, towns and cities are being built and expand over the traces of active tectonic lineaments –seismic faults. Thus, the danger of human life loss in an earthquake becomes more substantial, as earthquakes by nature are largely unpredictable and so far human know-how has not been able to deal with their effects with absolute success.

In this paper, we shall deal with three cases where earthquake faulting affected urban areas and many people were killed, that is the Kobe (Japan), Dinar (Turkey) and Egio (Greece) earthquakes. The three cases had several things in common: the epicentral distance of the towns/cities was small ('near field' earthquakes), the earthquakes were shallow and the maximum intensity was I_{EMS92}=XI. All three earthquakes caused surficial earthquake faulting. We shall try to trace the relationship between earthquake faulting and the spatial distribution of casualties.

2 KOBE EARTHQUAKE

Hyogo-ken Nanbu prefecture was hit by on of the most devastating earthquakes of the century on 17 January 1995. The shock was assigned a magnitude M=7.2. The focus of the earthquake lay at 34.6°N, 135.0°E, depth = 10 km, about 20 km southwest of Kobe city, inside the Akashi straits, between mainland and Awaji island. In all, about 5,000 people were killed, buried under the debris or burnt.

The urban complex of Kobe and environs is built in the alluvial plain of Kobe - Osaka and the southern foot of Mt. Rokko. Rokko Mt. fault zone divides the horst of the mountain form the graben of Kobe - Osaka. Certain segments of this fault zone were reactivated during the earthquake of 17 January. The fault zone is clearly visible in its southwestern prolongation on Awaji island – the Nojima fault that displayed a maximum 1.5 m horizontal and 1.2 m vertical offset, for a length of 9 km (Lekkas et al., 1996a; Lekkas and Kranis, 1996). Two step-over segments were also found to have been reactivated inside the Akashi straits (segment length 7 km); furthermore, a segment displaying right-lateral faulting was found in Suma ward, western Kobe (EERI, 1995). Tracing the reactivated fault portions in Kobe turned to be more arduous and ambiguous, because of building coverage.

The distribution of victims, as shown in Fig. 1, followed a linear trend, over a SW-NE, 2.5 km wide zone (Fig. 2), in which 96% of the casualties occurred. People were killed outside the zone, too, but at most cases (e.g. Takarazuka-shi) victims were caused by earthquake related surficial effects (in this case a large landslide). The distribution of victims inside the zone was controlled by two factors, separately, or a combination of them: building collapse and fires. After extensive on-site investigation and consultation with the official damage-victim reports (Kokusai Kogyo Co., 1995; Lekkas et al., 1996b), we could tell, with significant certainty, whether the deaths were the result of fire, building collapse, a combination of both, or neither of them.

After the elimination of fire victims, as well as the casualties of landslides, a 'mortality - distance form fault zone' diagram was constructed (Fig. 3) The distribution of victims across the fault zone follows a bell-shaped form, with the highest values about 1 km to the south from the projected trace of the fault and decreasing mortality percentage moving away from it.

3 EGIO EARTHQUAKE

The seaside town of Egio (pop. 23,000) and its environs have been repeatedly hit by earthquakes. The shock of 15 June 1995 (Ms=6.1) was the latest to this destructive series. Its focus lay at 38.26° N, 22.15°E and at a depth of 15 km, in the Gulf of Korinthos, 10 km NNE of the town. According to the research carried out by the National Centre for Marine Research, the causative fault must have been an offshore one, with E-W trend (Lykoussis et al., 1995).The earthquake reactivated portions of the E-W trending Egio fault, an active tectonic feature. It is clearly visible at the west of the town, but also inside it, where it has produced a 15 m high topographic scarp. Egio is built on Quaternary alluvial fan and coastal deposits, (sand and conglomerates).

In this case, all the victims were caused by the collapse of two multi-story buildings, an apartment block in the town and a seaside hotel 4 km east of the city (Carydis et al., 1995). The apartment block was built on cohesive conglomerates , just by the eastern tip of the reactivated portion of Egio fault. The reactivation is a fact confirmed by recent research; it is more obvious at the west of the town, where it destroyed the earthquake resistant building of Hellenic Weapon Industry, and becomes less accentuated heading eastwards, towards the town. No signs of reactivation, however, could be traced

Figure 2. Collapse of a reinforced concrete building in downtown Kobe.

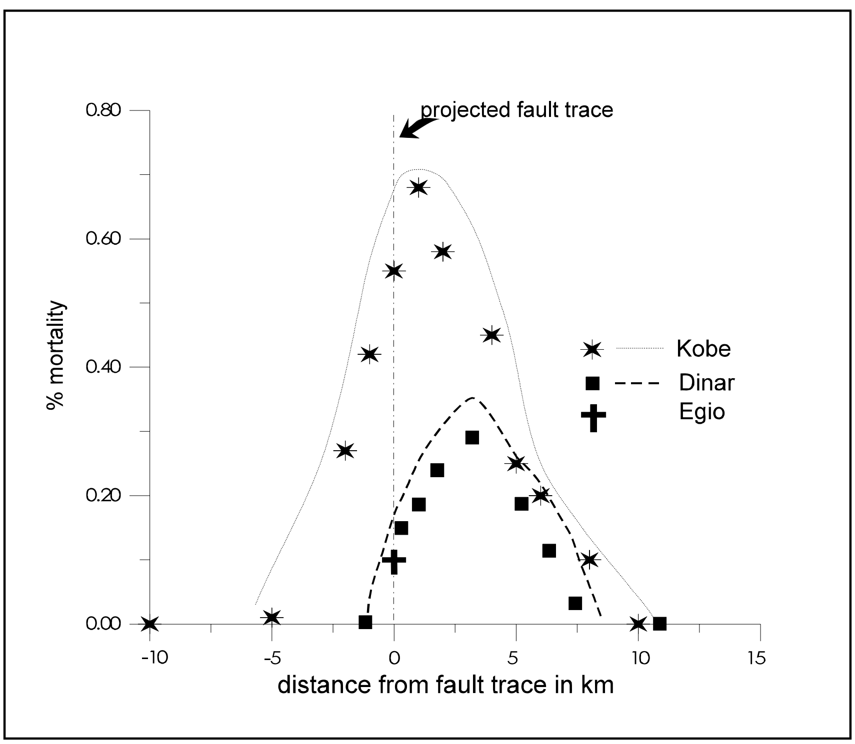

Figure 3. Mortality distribution in the earthquakes of Kobe, Egio and Dinar.

Figure 4. The collapsed apartment block in Egio, where 18 people were buried and died under it debris.

Figure 5. Collapsed multi-story residential building in Dinar.

further to the east and at the premises of the collapsed hotel (Lekkas et al., 1996).

As for the victim distribution and regardless whether one takes into account the victims of the collapsed hotel or not, is clearly seen that the totality of the casualties occurred exactly on the trace of the reactivated fault (Fig. 3).

4 DINAR EARTHQUAKE

Dinar is located in South-western Turkey, on the premises of ancient Meandros. Since its establishment, the town (population 40,000) has experienced strong earthquakes (more that 20 of I≥VIII (Carydis et al., 1995; Carydis and Lekkas, 1996) The earthquake occurred on October 10, 1995 and was assigned a 6.1 magnitude on the Richter scale. Its hypocenter lay at 38.00°, 30.10° E, a few km SW of the town. 90-100 people were killed, 2,043 buildings collapsed and 4,500 were damaged.

Dinar is built on an alluvial plain drained by Meandros river. A large part of the town is built on alluvial formations (mostly sand and gravel) and the eastern extremities of the town expand towards the nearby hilly area, where Eocene and Cretaceous limestones, marls and schists crop out. At the outskirts of the town a seismic fracture occurred; its trend was NNW-SSE had a maximum throw of about 0.4 m.

The casualties of this earthquake were caused inside the town and around its centre. The highest mortality rates were recorded at a distance of 2-4 km from the observed earthquake fracture (Fig. 3).

5 DISCUSSION - CONCLUSIONS

Surficial earthquake faulting is the most serious geologic effect of an earthquake. In the three examined cases, earthquake faulting occurred, to a greater or lesser degree, from the viewpoint of segment length and measurable offset. Besides, earthquake faulting is known to strongly affect ground acceleration and velocity during a tremor. From the instrumental recordings during the earthquakes, together with the experience from other shocks, we know from other earthquakes that along the strike of the fault ground acceleration and velocity is substantially higher than away, across it. Increased ground velocity and acceleration along seismic faults, coupled with surface offset (if existing), lead to major building collapse and consequent human life loss. All three cases had certain things in common: they were hit by shallow, near field earthquakes and surficial faulting was produced. As the number of victims in the three cases had an overall difference of two orders of magnitude, the calculations were made not on absolute figures, but on mortality percentage.

In the three examined cases, it was confirmed that the vast majority of victims was caused at a distance of not more than 4-5 km across fault strike. In two of the three cases the peak of mortality percentage did not coincide with the mapped trace of the surficial earthquake fracture. Indeed, this peak was offset by about 500 and 2.5 km in Kobe and Dinar, respectively. In Egio the peak lay just at the trace of the reactivated fault. What accounts for the peak mortality offset is the geological structure of the areas; both Kobe and Dinar are built on alluvial plains, adjacent to hilly or mountainous land. In Dinar, alluvium is transgressively deposited on Tertiary bedrock, while in Kobe the Plio-Quaternary formations are faulted against the bedrock. In both cases though, alluvium thickness increases heading towards the alluvial plain. As proved by Takemiya and Adam (1996) there is a critical alluvium thickness where interference of horizontal and vertical components of earthquake waves result in significant amplification of velocity, while acceleration and displacement become maximum (‘bump effect’). In Egio, no such hard bedrock - soft alluvium fill interaction occurs and the projected trace of the fracture coincides with the peak mortality percentage.

Mortality distribution may be modified by other factors, as fires or surficial earthquake effects; however, the determination of earthquake faulting remains crucial. Modern urban complexes built on tectonically active areas run the risk of potential human life loss in an earthquake. Thus, for the citizens to be better armed against earthquakes, a very accurate recognition and evaluation of the active tectonic features that cross urban areas is necessary.

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