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BRITTLE TECTONICS: A FACTOR IN THE INTENSITY DISTRIBUTION OF THE HANSHIN EARTHQUAKE

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ABSTRACT

A number of data concerning the Hanshin earthquake (January 17, 1995, Kobe, Japan) is first given, together with a general image if the composite regional geologic - neotectonic setting. Next, and based on the European Macroseismic Scale 1992 an attempt is made to analytically calculate the intensities in the urban complex of Kobe -with the utilization of specialized methodology. From this it is concluded that the maximum observed intensity was XI at certain few localities, the main intensity was X, while in the most part of the city the intensity was VIII to IX. The elongated arrangement of the isoseismal curves coincides with the trace of the reactivated fault zone, a fact showing the crucial impact of brittle tectonics on the distribution of intensity.

KEYWORDS

E.M.S.-1992, Intensity distribution, Kobe, Hanshin earthquake, Nojima fault

INTRODUCTION

The Hanshin earthquake (January 17, 1995) at Kobe, Japan, caused extensive damage and a multitude of victims. According to the official data (Feb. 23, 1995) 5,426 people were killed, 26,804 were injured, and more that 300,000 remained homeless. In addition, approximately 81,000 buildings collapsed or were damaged seriously, while a larger number suffered minor damage.

The shock took place at 05:46 local time and was of 7.2 Richter magnitude. Its focal depth was 20 km and the epicentre lay at 36.4°N, 135.0°E, at the Akashi straits, between Kobe and Awaji island. (FIG 1). The earthquake fault was estimated to be 50 km long, with an impressive, N40°-50° trending, 9 km-long surficial expression at Awaji island. The prolongation of the fault to the NE practically dissects the city of Kobe.
Damage to virtually every type of building was observed mainly inside the urban complex of Kobe. The bulk of destruction was along a well-defined elongated zone of NE-SW direction, twenty-five km long by 2 km wide. In addition, at certain localities the damage coincided with the manifestation of certain concomitant geodynamic phenomena. (Lekkas *et al.*, 1995a), as liquefaction and landslides and/or the occurrence of fires.

In the following paragraphs the methodology of the recording of damage and the calculation of intensities according to the new European Intensity Scale (E.M.S.-1992, Grünthal 1993) will be presented. An attempt for interpretation of the distribution of damage will follow and the data will be correlated with the prevailing neotectonic structures and deformation.

THE NEOTECTONIC SETTING

It is well known that the Japanese territory is characterised by a complex neotectonic deformation setting, a result of its position, at the boundaries of three lithospheric plates, namely the Eurasian that overthrusts the Pacific and the Philippine Sea ones (Fig. 1). This composite geodynamic setting determines the ongoing geologic procedures both at large scale and regionally. Thus, in Central-western Japan the structures are characterised by a general E-W compression that locally leads to transpressional fields and structures (Okada, 1980).

The region of Osaka, Kobe and Awaji island, together with Akashi straits feature a large, 1st order fault zone that strikes E-W (the Median Tectonic Line, MTL) with a pure dextral character and runs off the southern tip of Awaji island and at the South of the urban complex of Osaka. The occurrence of this zone leads to the creation of smaller order (en-echelon arranged tectonic structures) at its northern block. These structures are of general NNE-SSW and then NE-SW direction.

A representative example of such structures is the horst of Mt. Rokko and the graben of Kobe that lies at the south - south-eastern foot of the mountain. This is, of course a highly simplified picture of the existing conditions, as there is in fact a multitude of alternating minor horsts and grabens featuring tectonic block rotation, and being juxtaposed by a complex fault fabric that comprises either well-distinguished fault zones or isolated faults. One of these zones is the one that strikes NE-SW and forms the boundary between the horst of Mt. Rokko and the graben of Kobe. During the earthquake of 17 January 1995 and the ensuing seismic activity, certain segments of this fault zone were reactivated (Fig. 3).

GEOLOGIC- NEOTECTONIC SETTING

The greater area of Kobe corresponds to an uplifting horst and a graben. The former coincides with Mt. Rokko and the latter is occupied by the city of Kobe, together with the neighbouring ones, of Nishinomiya, Itami, Amagasaki and Takarazuka.

The horst of Mt. Rokko is formed by geologic formations of pre-Pliocene age. These are mainly igneous ones and are represented by Late Cretaceous granites that cover the most part of it. On the other hand, the graben (that is the urban complex of Kobe and the gulf of Osaka) is filled with sedimentary formations, mainly sandstones, clays, marls volcanic ash and various others, of Pliocene - Holocene age (Figs 1, 3).

A complex fault fabric occurs juxtaposes the two neotectonic units, arranged in an overall NE-SW trending fault zone. Some of the faults are visible at the flanks of the graben, at the foot of the mountain, while the rest occur inside the urban area and are covered either by recent formations, artificial landfill or the buildings themselves. The prolongation of the faults is visible outside the urban area mainly at the South-west, at the direction of Awaji island, where the surficial expression of he reactivated fault occurred.

The earthquake of 17 January 1995, as well as the whole of the seismic sequence was the result of the reactivation of certain of the faults that belong to the fault zone. The main shock resulted from the rupture in the fault that lies in the Akashi straits, that led to the reactivation of the Nojima fault. Its trend was N40°-50° E, its dip was 75-80° SE and presented a maximum horizontal (dextral) slip of 1.7 m. and a vertical offset of 1.3 m. It cuts through Plio-Pleistocene and Holocene formations and occurred at straight parts of a maximum

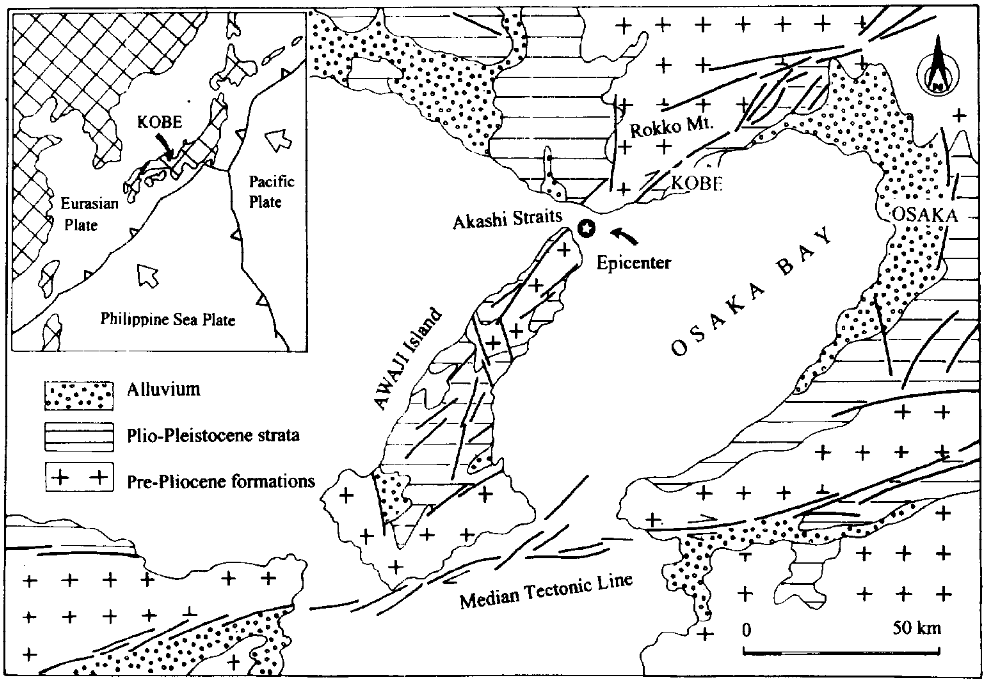

Fig. 1. Simplified geologic map of Kobe and environs.

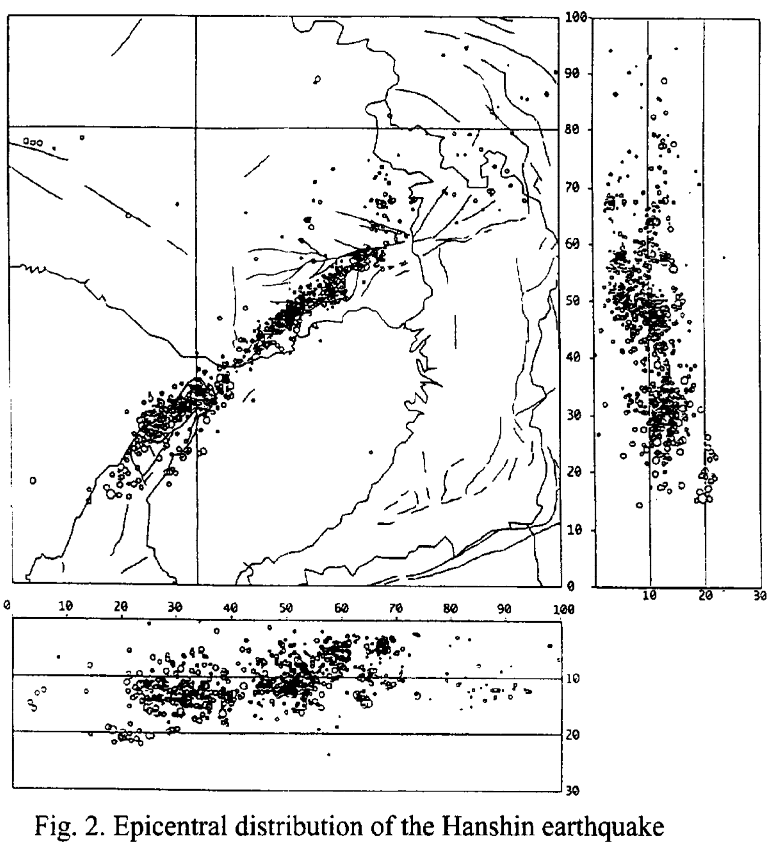

Fig. 2. Epicentral distribution of the Hanshin earthquake sequence (after RCEP-DPRI, 1995).

length of 200 m. These parts were arranged in a step-like (en echelon) arrangement, a fact in full concordance with the dextral character of the rupture. The prolongation to the NE of the fault dissects the urban complex of Kobe; besides, the epicentres of both the foreshocks and the aftershocks were distributed in a linear fashion, across the city. (Fig. 2).

The geologic formations that outcrop in the major area of Mt. Rokko, after Itihara *et al.* (1991), are the following:

(i) Sandstones, conglomerates, tuffs and pelites of Miocene age.
(ii) Cretaceous - Eocene granites, which occupy the most part of Mt. Rokko.
(iii) Cretaceous - Eocene diorites
(iv) Carboniferous - Permian clayslates, shales and cherts, of limited development.

The formations that occur at the graben and its flanks are the following:

(i) Alluvium, consisting of gravel, sand and clay; they outcrop at the central plane region.
(ii) Late Pleistocene gravel and sand.
(iii) Middle Pleistocene marine clay, sand, gravel and volcanic ash.
(iv) Early Pleistocene alternating beds of non-marine clay sand and gravel and volcanic ash.
(v) Pliocene non-marine clay, sand and volcanic ash.

The geologic formations that crop out in the study area are depicted in the map of Fig. 3.

RECORDING METHODOLOGY - PROBLEMS IN INTENSITY EVALUATION

The European Macroseismic Scale - 1992 (Grünthal, 1993) was utilized for the recording of the intensities of the 17 January 1995 earthquake. The use of this scale presents certain advantages over the previous ones, given the:

(i) Easier recognition of the grade of damage
(ii) Easier recognition of the type of structure. New types of buildings not existing in the previous scales are included.
(iii) Easier and objective recognition of the vulnerability of the structure.

The recording of damage was carried out per major urban block, throughout the urban complex of Kobe, initially based on *in situ* observations. Following, data from the local engineer parties that recorded the damage, as well as the official earthquake report forms. Besides, data that were later published on 1:0000 scale maps (KOKUSAI KOGYO Co. Ltd., 1995) were used.

An important question that arose during the evaluation of intensities was whether the damage caused by the concomitant geodynamic phenomena (Lekkas *et al.,* 1995a) and fires, should be included or not. That is, liquefaction contributed indirectly to the aggravation of damage mainly along the coastal zone, while the landslides destroyed some urban blocks at the foot of Mt. Rokko. It should be mentioned that, in the nearby locations, the damage directly attributed to the shock was limited. Also, the fires that broke out razed whole blocks, making any attempt for recording and evaluation impossible. Thus, the inclusion of this type of damage in the intensity evaluation actually distorts the existing image of intensities that are directly attributable to the seismic movement itself, not allowing for a solid correlation between the distribution of destruction and the existing geologic-tectonic conditions. Therefore, in the final evaluation, the damage caused either by liquefaction and landslides or fires has not been taken into account.

The synthesis of data that resulted from the recordings per urban block was made on A G.I.S./ARC INFO system, which gave that final intensity map of Fig. 4.

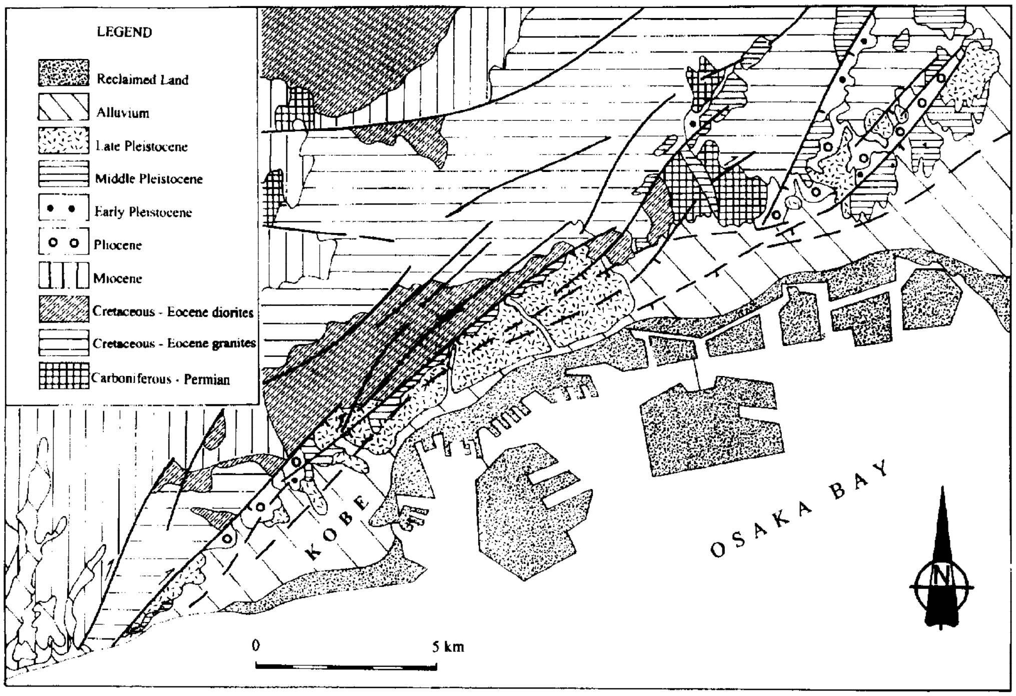

Fig. 3. Geologic map of Kobe (modified after Itihara *et al.*, 1991).

DESCRIPTION OF THE DISTRIBUTION OF INTENSITIES

Based on the specifications and the guidelines for the evaluations of E.M.S.-1992 intensities (Grünthal, 1993) the maximum intensity was found to have been XI. These intensities were observed only at certain parts of the city, and more specifically at groups of few urban blocks.
At those parts, buildings of vulnerability class C suffered damage of grade 7 at a percentage of 75%, buildings of class D suffered damage of grade 4 at more than 40% and grade 5 at 20%. Buildings of class E suffered damage of grade 3 at 30% and grade 4 at 10-20%. Buildings of class F suffered damage of grade 2 at 20-30% and grade 3 at 10-20% (Figs 5,6).

X grade intensities were observed at extended areas of the urban complex. That is, class C buildings suffered grade 4 damage at 50% and grade 5 at 15-25%. Class D buildings suffered grade 3 damage at 60% and grade 4 at 10-20%. Finally, E class buildings suffered grade 2 damage at 40% and grade 3 at 10-20%. The intensity contours are clearly elongated, along a general SW-NE trend. The area included in the X contour was approximately 20-25 km long by 1 km wide.

IX intensities were observed over extended area, too, together with VIII ones. The same observation, recording and evaluation procedure was followed, so as to determine the building class and the grade of damage. The IX and VIII contours also present an elongated form, while at right angles to the long axis of the X contour the intensity gradient is very steep.

Among all the contours plotted in the map of Fig. 4, of particular importance and usefulness are the X ones, as they represent in our opinion the crucial contours for the correlation of damage with factors as the geologic structure and the geotectonic - fault deformation. It also has to be noted that the X contours present locally a slight step-like arrangement.

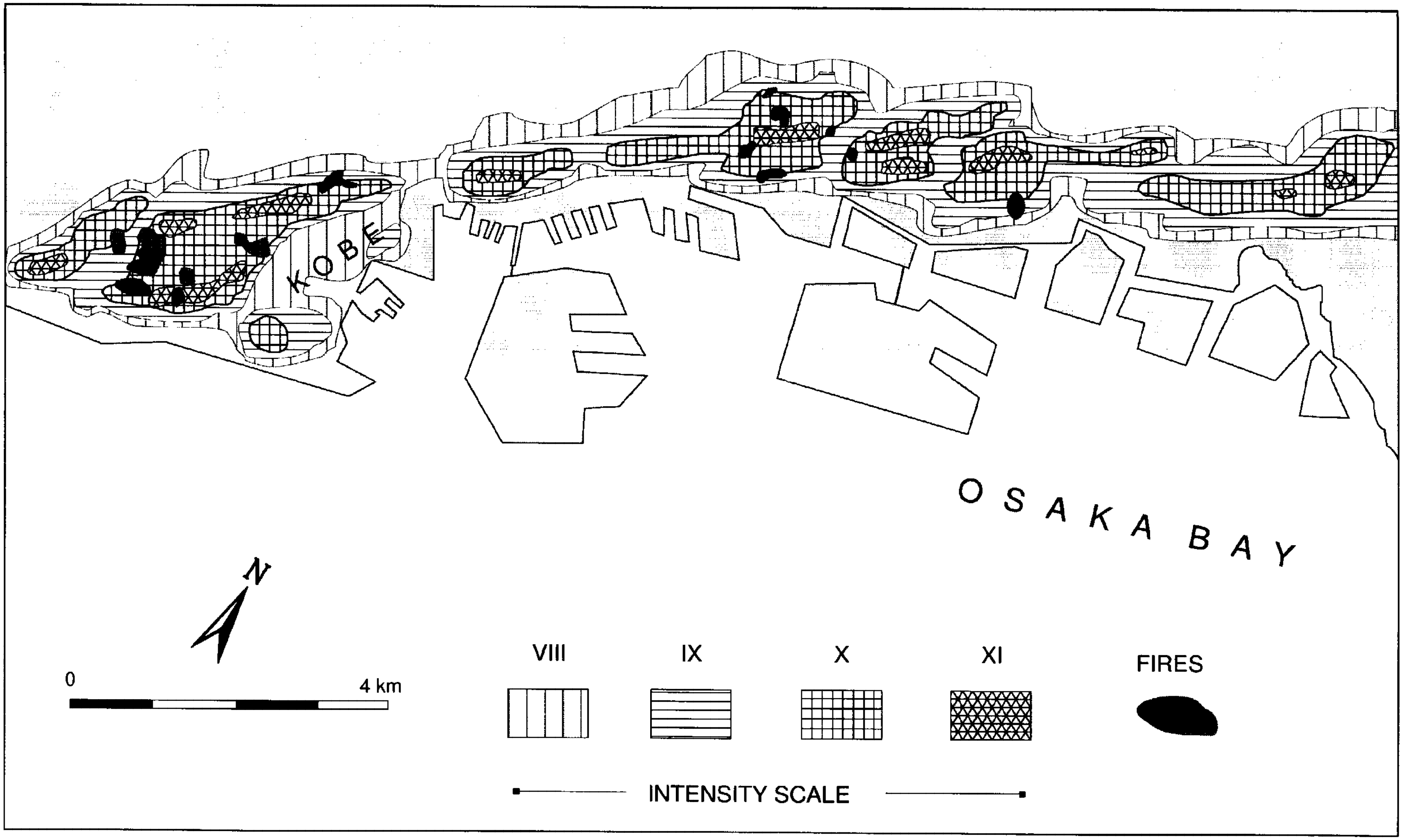

Fig. 4. E.M.S.-1992 Intensity distribution.

Fig. 5. Class D building with grade 5 damage.

Fig.6. Class D building with grade 5 damage.

CORRELATION - CONCLUSIONS

Considering all the data presented and on the geologic - neotectonic structure of the area, together with the data concerning the intensity distribution in the urban complex of Kobe (Figs 3,4), the following correlation and conclusions can be derived:

(i) The arrangement of the macroseismic intensities follows the general trend of the reactivated fault zone. In fact, the maximum intensity zones coincide with extension of the reactivated fault and its surficial occurrence. This reveals the crucial impact of the reactivated fault on the distribution of damage.
(ii) The steep intensity gradient normal to the development of the fault zone reinforces the notion that the reactivated fault has had significant impact of the occurrence of damage.
(iii) The occurrence and distribution of intensities does not seem to be affected by, or correlate with the existing geological conditions and the lithologic differentiation, which take place rapidly both inside and at the outskirts of the city. It is also noted that this differentiation occurs both along and normal to the development of intensities.
(iv) X grade contours present locally an unclear step-like arrangement; this could be the reflection of underlying fault zones that have been created by the transpressional stress field.

All the above-mentioned seem to confirm and to conform with recent analytical research (Lekkas *et al.*, 1995b) at certain parts of the city, where similar correlation between the fault fabric and the damage was verified. Besides, research on other seismic events (Pyrgos earthquake, March 26, 1993, Western Peloponnese, Greece) has shown similar correlation (Lekkas, 1995).

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