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Earthquake-induced landslides during the great Hanshin Earthquake of January 17th, 1995 (Kobe, Japan)

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ABSTRACT: The landslides that occurred as a result of the Hanshin Earthquake are described. First the geological and neotectonic setting of the greater area where slides occurred is outlined. Then, the location of approximately 125 landslides, both in and outside the urban area in a composite map. The dominant trend of the disrupted slopes was NE-SW, while the geological formations that were affected were mainly the weathered soil mantle and formations of special characteristics. Finally, the direct impact of the active tectonics, the incision of streams and human interventions on the manifestation of landslides is confirmed.

INTRODUCTION

The earthquake of January 17, 1995, M=7.2 R in Kobe-Nishinomiya megalopolis (also known as Hanshin earthquake) caused extended damage and a multitude of human life losses. According to the official data, 5.426 people were killed, 26,804 injured, more than 300.000 remained homeless and 107.388 buildings were damaged. The first estimations on the immediate cost of the tragedy amount to 7 trillion ¥, while the long term impact is certain to be considerably higher. The earthquake of January 17 induced a number of concomitant geological phenomena, the most prominent of which were the landslides and liquefactions, which drastically increased the damage that was due to the tremor itself.

In the following sections and after a brief outline of the neotectonic setting of the area has been given, the results of the survey that was carried out soon after the earthquake, will be given. Then, the factors that played a key role will be analysed and certain interpretations on the manifestation of those phenomena will be proposed.

THE GEOLOGICAL SETTING OF THE LANDSLIDE OCCURRENCE AREA

The area where earthquake-triggered landslides occurred lies at the north-northwestern part of the urban complex of Kobe-Nishinomiya (Fig. 1). It is characterised by a relatively intense relief with heights of as much as 930 m (Mt. Rokko), while the drainage network is significantly developed.

A certain number of geological formations participate in the geological structure of the area; those can be distinguished in the following groups according to Itihara (1966) and Itihara et al (1991).

Alluvial formations, which lie mainly at the area covered by the urban complex of Kobe-Nishinomiya. They overlie the other formations and are juxtaposed against them to the north with faults striking NE-SW.

Plio-Pleistocene formations, which comprise a complex sequence of sedimentary as well as of volcanic origin (formations). The Plio-Pleistocene formations occur at the SE foot of Mt. Rokko and are juxtaposed with the oldest ones that are at the NNW by faults striking NE-SW.

Pre-Pliocene formations which comprise mainly granitic rocks. These formations form the mountanous mass that lay to the NNW of the urban complex of Kobe (Mt. Rokko).

The alluvials and Pliocene - Pleistocene formations occupy a large surficial portion of the graben which lies at the Southeast of Mt. Rokko and coincides with the urban area. On the other hand, the Pliocene - Pleistocene formations form the horst that lies to the NW and presents an elongated development. The horst is an uplifting block a fact also clearly revealed by the incision of streams.

The juxtaposition between the horst and the graben is performed through a number of faults (RGAFJ, 1991). Some of them are directly visible some others are buried under recent deposits and some are covered by the urban constructions. All these constitute a large fault zone which strikes

NE-SW. This fault zone is an active tectonic structure, segments of which were reactivated during the main tremor or during the aftershock sequence.

The landslide occurrences are located north of the fault zone on Mt. Rokko. Additionally slides were observed along the fault zone at the boundary of the graben as well as to the south, inside it.

THE LANDSLIDE PHENOMENA

The landslide phenomena that occurred during the main tremor of January 17 were mapped in the course of field work or with the use of aerial photographs. Accordingly, all the phenomena were surveyed, so as to provide with the necessary data for the study.

In total, 125 landslides were located and studied in the greater area (Fig 2). Particular attention and study was given to the ones that occurred inside the urban area (Fig. 3) and had significant impact, as well as human victims. Two of those landslides in Nishinomiya and Takarazuka killed 34 and 3 people, respectively. It has to be noted in this paper only the landslides that occurred during the main tremor are referred to, and not in subsequent periods, given that in the period immediately after the earthquake other factors, such as rainfalls, led to the manifestation of slides in numerous locations.

THE GEOGRAPHICAL DISTRIBUTION

The field mapping that was carried out showed that a large number of landslides occurred at the hilly-mountainous area north of the urban complex of Kobe, at the foot of Mt. Rokko. Most of the slides that took place were at a distance of up to 4 km from the fault zone (fig. 2). In greater distances, although the existing morphological, geological and geotechnical conditions were identical, the number of landslides was significantly smaller. In addition, and for distances more than 6 km, as well as in the greater area, no landslide occurred despite the fact that the conditions were more favourable, mainly as far as the slope inclination and the occurrence of geological formations are concerned. This relationship of the distance between earthquake epicentre and landslide manifestation has been presented and verified for numerous great historic and recent earthquakes (Keefer, 1984).

This fact denotes the determining impact-correlation of the earthquake faults -and the reactivated fault zone- on the geographical distribution of geodynamic phenomena, such as the influence of the fault zone on the distribution of landslides.

THE MORPHOLOGICAL CONFIGURATION OF THE LANDSLIDE AFFECTED AREAS

In order to classify the impact of the slope morphology the average gradient and trend of each affected slope was recorded. All the data were input in computer and projected in the diagram of fig. 4.

Figure 4 shows that the dominant trend of the landslides affected slopes was NE-SW, while in other trends there is significant decrease in the observed landslides. In addition, one can observe in the same diagram that along this trend (i.e. NE-SW) the mean morphological gradient of the disrupted slopes was significantly lower, in contrast to the other trends, along which the gradients are considerably higher.

Bearing in mind that the focus of the tremor of January 17, 1995 lay in the Akashi straits, between Hanshin and Awaji islands, (that is to say Southwest of the landslide sites) the direct correlation of the position of the earthquake epicentre, the morphological gradient and landslide sites is confirmed. This fact denotes the crucial impact-correlation of the direction of ground acceleration - motion on the manifestation of the phenomena.

THE INCISION OF STREAMS

During the field mapping of the landslides we observed the direct neighbouring of them with streams that drain the area (fig. 2). As mentioned above, the drainage network is well developed and presents its marked development at the horst that lies Northeast of the city while it has less pronounced linear development in the graben which coincides with the urban area. Most of the streams are deeply incised a fact that owes its presence to the uplifting tectonic block.

The map of fig. 2 shows that most landslide phenomena occurred close to or along the incised streams. These phenomena are due to the removal of support caused by intense erosion.

GEOTECHNICAL FACTORS

Besides the observations on each landslide that were mentioned above, certain data concerning the geotechnical parameters to the disrupted formations were recorded. In order to acquire a clean overall picture of the geotechnical conditions at the landslide types, the disrupted formations were distinguished into three categories according to their geotechnical parameters.

In the first category fall all the disrupted formations that bore the characters of rock mass. In

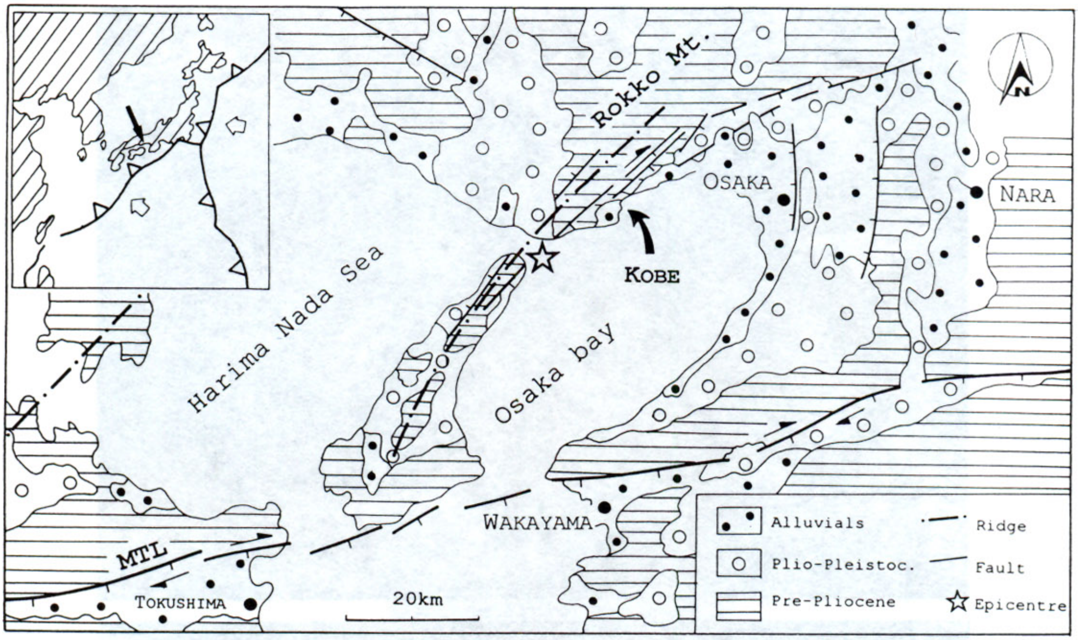

Fig. 1 Geological - tectonic map of the greater area of Kobe (Japan), with the epicentre of the earthquake of January 17, 1995. (After Itihara et al (1991) with modifications and alterations).

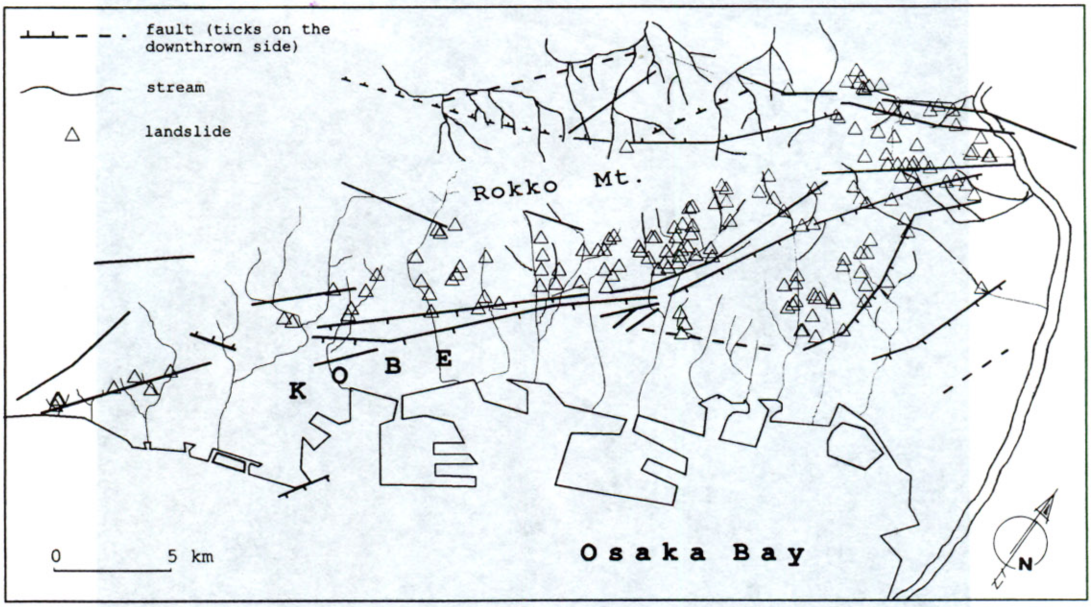

Fig. 2 Map of the area of Kobe with the landslide occurences (triangles) induced by the earthquake of January 17, 1995. Also shown the drainage network (light lines) and the fault traces (heavy lines).

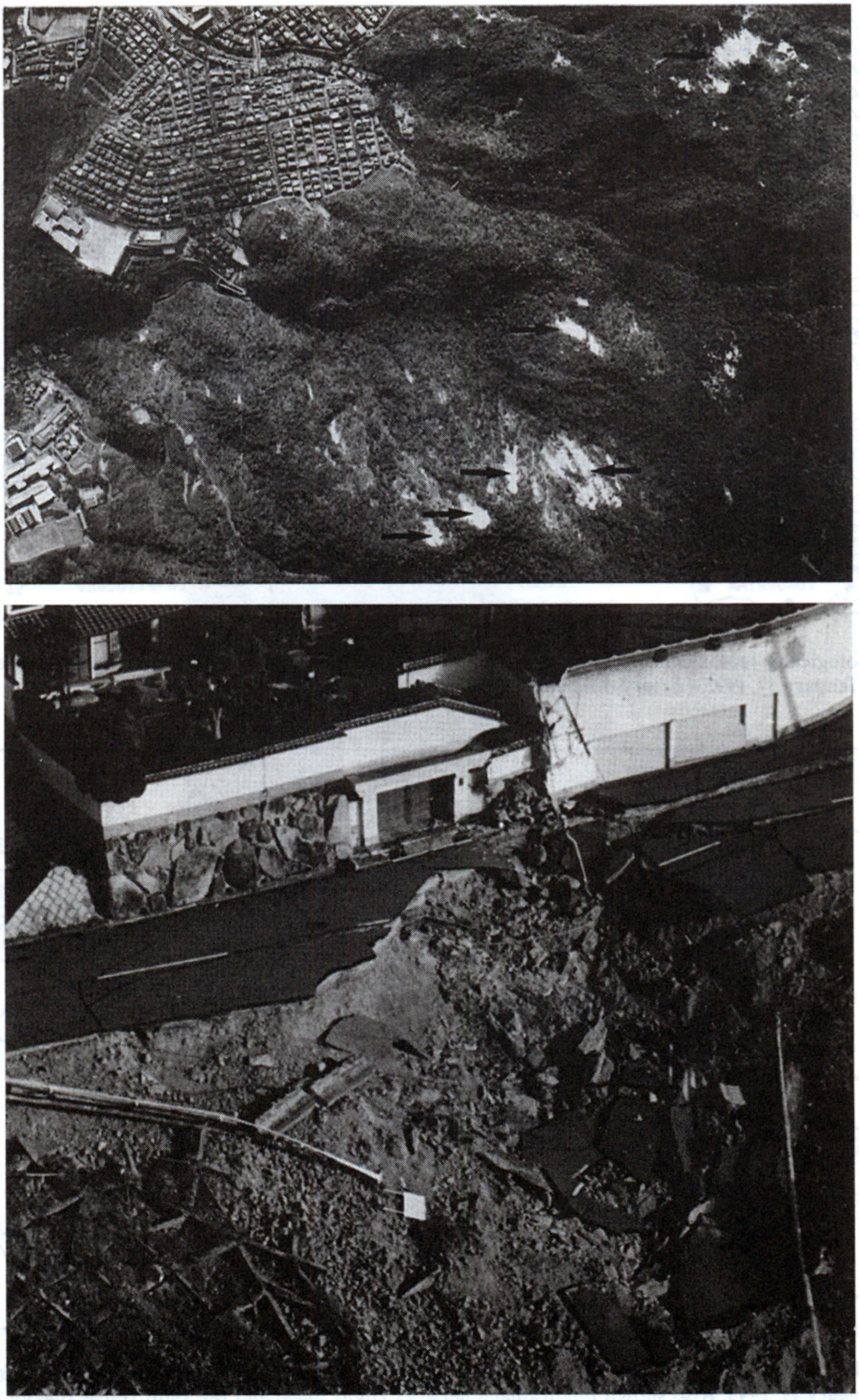

Fig. 3 Landslides that occured outside (up) and inside (down) the urban area. The latter caused considerable damage.

the second, the formations which had the characteristics of "soil" masses, while in the third we have classified the ones with special features. Such formations are the talus scree and the weathered soil-mantle (regolith). Our recording showed that landslides occurred in rocky formations in very few cases, and only where the rocks were highly fractured. On the other hand, the vast majority of landslides occurred in soil formations or "special character" ones, and were of larger dimensions, too.

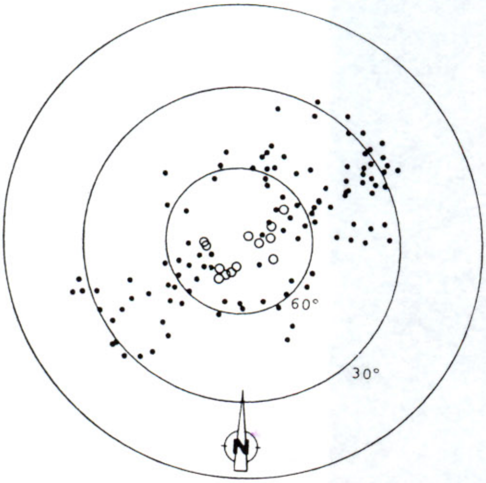

Fig. 4 Diagram showing the trends and gradients of the disrupted slopes by the earthquake of January 17, 1995. (Filled circles: regolith slopes. Open circles: rocky slopes).

THE IMPACT OF THE LANDSLIDES - HUMAN INTERVENTION

A large number of the landslides of January 17, 1995 took place outside the urban area (fig. 3). Fewer slides occurred in inhabited areas, causing victims. It has to be noted that the landslides that occurred outside the urban area were smaller in dimensions; their breadth was not more than 15-20 m. while the thickness of the disrupted material was approximately 5-10 m (Ishikawa, 1995).

On the other hand, the landslides that occurred inside the inhabited area were much greater in dimensions. In Nishinimoya, the slide was about 80 m in breadth by 150 in length while in Takarazuka it was 40 m by 80 m (Ishikawa, 1995). These very two cases of landslides in the inhabited areas denote the fact that their size was affected, apart from the other factors, by human intervention that is to say additional burden due to construction, roadworks, and so forth.

CONCLUSIONS

The earthquake of January 17, 1995 in the megalopolis of Kobe - Nisihinomiya (M=7.2 R) led to the manifestation of extended damage and a large number of victims. The tremor, among others, caused the occurrence of concomitant geodynamic phenomena which one of the most prominent were the landslides.

The landslide phenomena took place in the semi-mountainous area which is an uplifting tectonic block north of the city of Kobe. The survey that was carried out showed that most of the landslides occurred at slopes with NE-SW trends, while quite fewer were the ones in slopes of other dimensions. In addition, in the former case (NE-SW) landslides occurred at slopes with lower gradient; that was not the case with slopes of other orientations, where the gradients were significantly higher. This fact is attributed to the direction of the main seismic motion, which was NE-SW for the landslide stricken area.

The landslide sites are in close proximity with the fault zone, segments of which were reactivated during the main tremor, a fact denoting the influence of active tectonics, which has also been confirmed for various cases in other regions (e.g. Lekkas, 1992, Lekkas et al, 1995). On top of that, the field survey showed that a basic factor in the manifestation of landslides was the incision of currents in the uplifting horst of Mt. Rokko; this fact contributed to the loss of support at the slopes.

Finally, it is confirmed that the manifestation of landslides in most cases was favoured either by the geotechnical parameters of the formations or the human intervention, which consists of constructions, roadworks, slope modification and so on.

Hence, it has been verified that there is direct correlation and interdependence of the landslide phenomena with the factors that participate in the intense ongoing geodynamic process of the region.

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