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SYNOPSIS The macrozonation and classification studies are carried out for the induced landslides in the imprinted area of the Manjil, Iran earthquake of 20 June 1990, in view point of engineering geology. The earthquake induced landslides are classified in 7 classes and all of them are mapped on the seismotectonic map of the region. Landslides of the historic time are considered as well. These studies showed that the most of large earthquake induced landslides are occurred within the earthquake origin zone of this earthquake and in the area which is specified with the earthquake intensity of more than VII (7) MSK. The earthquake faulting was associated with landslides. The occurrence of landslides was one of the geological-geotechnical diagnostics of the Manjil earthquake, such that they were of the main devastating factors.

INTRODUCTION

The Manjil earthquake of 20 June 1990 (Mw7.3) strongly shocked the northwestern Iranian territory. It left a life loss of about 35000, where about 100000 were injured and about 500000 became homeless. The quake affected a densely populated area in Gilan and Zanjan provinces. The most parts of the imprinted great area was located in the mountains of western high Alborz and Tarom district. The topography, weathering and neotectonic conditions, and the high kinetic energy of the mainshock provided such conditions that over 80 landslides are reported.

Six en-echelon earthquake fault segments are introduced in the vicinity of Manjil, Ab-Bar, Baklor, Kabateh, Borebon and Pakdeh (Figure 1) (Moinfar and Naderzadeh 1990, Zaré 1991a, 1991b and 1992, Ramazi 1991, Berberian and Qorashi 1991, Tsukuda et al 1991, Qorashi and Berberian 1991, Berberian et al 1992).

Some ground ruptures were dubious for the investigators from this point of view that if they are landslides or earthquake faults. The coincidence of the sites of earthquake faults with some slides and the complexity of event were the main causes of this difficulty. A macrozonation study is represented in this paper as a result of about 2 years of investigations . All of the introduced landslides, earthquake fault segments and other geologic features are checked carefully during the field surveys. The aerial photos which have been taken from the understudied region (1956-1958) are considered and compared with the aerial photos that were taken during the months after the earthquake.

GEOLOGIC IMPLICATION AND MOUNTAINS STRUCTURE

The area understudy is located in the Alborz system within the western part of the tertiary central zone. Several NW-SE to east-west trended faults imprinted the southern Caspian ranges. These faults create some imbricated structures overthrusting each other. The Sefid-Rud valley is formed in the strike of a lineament (Zaré, 1991b) which crosses the alignment of NW-SE faults. The earthquake faults are settled in an uplifted structure. Some traces of earthquake faulting and "Earthquake Fault Induced Slides" are formed in the vicinity of the "Harzevil fault zone" of about 130Km length, in the northern flank of the Ghezel-Uzan - Shahrud valley. Along this fault zone the Eocene Karaj formation (tuff-andesite) overthrusts the Mio-Pliocene Upper-Red formation (sandstone-conglomerate). A phyllite complex is thrusted steeply upon the Paleozoic-Mesozoic rocks of Kuh-e Kabateh (Kapateh) range and these are thrusted upon Eocene Karaj formation in the south (Eftekharnezhad et al. 1965).

According to Tsukuda et al. (1991), the aftershocks are distributed within a zone, which contains the earthquake fault segments and the large landslides. It is recorded a peak horizontal ground acceleration of a=0.56g, where it is determined a maximum vertical ground acceleration of a=0.52g at Ab-Bar station (BHRC 1992)(Figure 1).

CLASSIFICATION OF THE EARTHQUAKE INDUCED LANDSLIDES

The occurrence of the large landslides were one of the diagnosis of Manjil earthquake. The existence of different geological outcrops , an imbricated fault zone and the strong ground motion caused a lot of earth movements of any types which are classified. The author has investigated all over the region and found the described landslides. In this paper, it is tried to consider the landslides and carry out a preliminary macrozonation.

The classifications introduced by Selby (1982) and, Fookes and Vaughan (1986) are used to

determine and classify the earth movements.

Class 1: Rockfalls and Debris Slides;
These type of landslides which are observed in a vast area of the imprinted region (Figure 1) , caused several road blocks and made a lot of difficulties for the search and rescue teams in the first hours after the quake.

Several rockfalls and debris slides are observed in northern Rudbar along the Ghazvin-Rasht road. They impressed a traffic tunnel near the Sefid-Rud (Manjil) dam (the most important engineered structure in this region). Several rock falls were occurred (Figures 2 & 3) and caused the fall down of a transmission tower in the left bank of dam. These slides which were located on or near the earthquake fault of the sefid-Rud dam, have blocked the accessory roads to the dam site at the quake time.

The historical city of Masuleh (Figure 4) which is one of the best looking sites of the Iranian traditional architecture, and is one of the UNESCO registered cities of the world, has sustained some damages (about 20 percent) through the rock fallings.

Class 2: Soilfalls;
After the evacuation of the Sefid-Rud dam, it is observed several soilfalls in the reservoir

Fig.2 Rockfalls nearby the Sefid-Rud dam.

of the dam. The soilfalls have occurred in the form of progressive failures in the sediments of the dam reservoir. This type of slides was more developed toward the Ghezel-Uzan river (which is one of the sources for this reservoir; where the other one is Shahrud river ;Figure 1). The soilfalls have continued in the further months after the quake.

Class 3: Earthflows and Debris Flows;
The Galdian earthflow in eastern Rudbar is the most dominant feature of flow slides in the earthquake imprinted region. The debris materials in this flow were clay, silt and gravel; therefore it is named as the "earth"

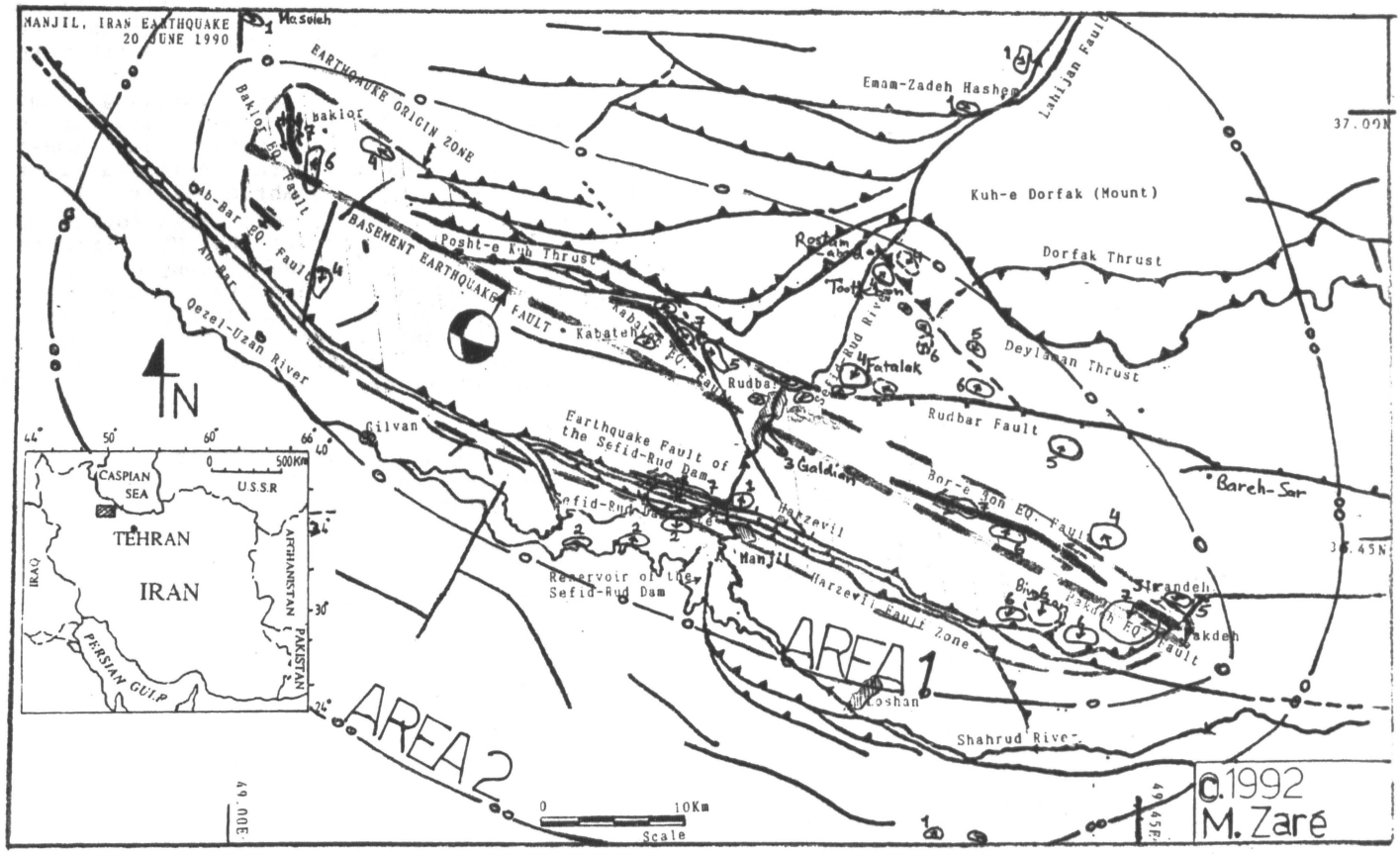

Fig.1 Seismotectonic and Landslides Macrozonation map of the Earthquake Origin Zone of the Manjil Earthquake of 20 June 1990 (after Zaré 1991b and 1992). The earthquake origin zone is shaded and bordered by the dashed lines. The dashed-pointed lines show the landslides zonation boundaries.

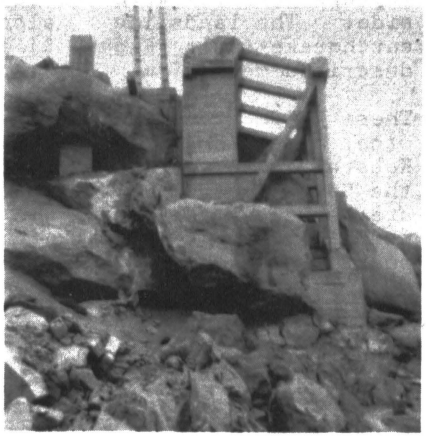

Fig.3 Rockfalls and the earthquake fault induced slides near the Sefid-Rud dam. The foundation of the tower crane of dam and its retaining wall is obvious.

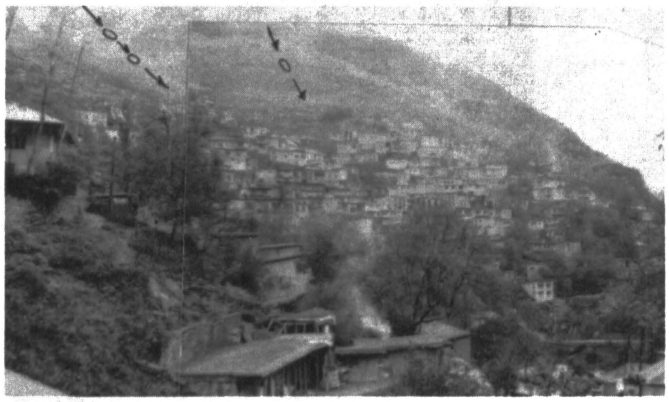

Fig.4 A close-up view from the historical city of Masuleh. The direction of the rockfalls are specified on the figure.

flow. The flow has begun after the mainshock and continued until 15 days later. It has about 3Km length and from 20 to 500m width. Its probable depth is about 50m or more. Haeri (1991) believes that its probable causing phenomena are (1) Liquefaction in one of the subsurface aquifers; (2) Sliding in a weak saturated clay layer. Some local pools are formed after the occurrence of this flow. In the present study, it is understood that the failure of the petroleum pipeline was one of the important causing factors for lubrication of the slop surface and saturation of deposits in Galdian earthflow.

Class 4: Rotational Slumps;
Some rotational slumps near Rudbar were the typical forms of the large slides in this earthquake. The slump of Fatalak in some 5Km north of Rudbar has displaced and demolished the site of the Fatalak village and has buried the Fishom village. It has about 1000m length, 500m width and 50m estimated depth. The site of this landslide is located on the conglomeratic quaternary terraces of the Sefid-Rud river. There are killed about 70 persons, such that most of their bodies are buried by the thousands of tons of waste materials for always. It is created here a large headscarp form.

Another rotational slump is created in the vicinity of the Tootekabon village (Figure 5). This slide occurred in the loess terraces between the valleys of the Sefid-Rud and Siah-Rud rivers. The author believes that; the great thickness of the Loess terraces (about 100m) in this area may originates from a

Fig.5 The rotational slump of Tootekabon.

probable natural lake, reserved beyond a large landslide in the quaternary time which has blocked the opening of the Siah-Rud valley. Therefore the high loess terraces could be formed after the deposition of the reservoir sediments.

The Tootekabon slump has about 100m length, 150m width and 20m depth. A typical form of step scarps is observed in this landslide (Figure 5).

The rotational slump of Lakeh is observed in south of this village. This slump is occurred within few hundred meters distance from the earthquake fault of Kabateh. It has about 100m length and about 50m width.

Class 5: Rotational and Planar Slides and Block Guides;
The quake in this area was associated with different types of slides. A system of the rotational and planar slides is investigated in the Lakeh area (western Rudbar and near the Kabateh earthquake fault).

In the other hand, there are observed a plenty of planar and rotational slides along the roads. In the road from Rostam-Abad to Bareh-Sar (Figure 1), a lot of planar slides have blocked this road at the quake time. According to the suitable geologic conditions, the phenomenon of landsliding is always a common event in this area. A planar slide (shown in Figure 6) is occurred in May 1992 (about 2 years after the quake) in the Bareh-Sar road. The growth of the roots of trees in the plane of a rock joint system was one of the facilitating factors for this slide.

The Block Guides were the other important type of slides during this quake. A block guide (nearby Jirandeh, Figure 7) is created at the quake time and is located near Pakdeh and Borebon earthquake fault segments.

Class 6: Debris Avalanches;
Several debris avalanches are observed. The debris avalanches of Baklor (Figure 1) are occurred in a high angle north-south striked valley, and therefore; are hardly accessible.

Fig.6 A planar slide in the Bareh-Sar road.

Fig.7 The block guide of Jirandeh.

These slides are in the vicinity of the Baklor earthquake fault segment.

A debris (rock) avalanche of historic time in the vicinity of the village of Bivarzan, (northern Loshan) showed another motivation during the Manjil earthquake. This rock avalanche is located in the Harzevil fault zone (Figure 1).

Class 7: Earthquake Fault Induced Slides;
The mechanism of the Manjil earthquake is described by the author as Left-Hand Transpression (Zaré 1991a, 1991b and 1992). According to this mechanism, a Flower structure is suggested and a basement earthquake fault of about 75Km length and 19Km depth is introduced (Figure 1). The focal depth is determined by Eslami (1991). This basement fault has acted both compressional and left-lateral strike slip. Therefore; several fault segments have appeared in an area, which is named by the author as the "Earthquake Origin Zone". This zone is an ellipsoid shape area at the surface of a quake induced flower structure, which is bordered by the northern fault segments of Baklor, Kabateh , Borebon and Pakdeh, where the reactivated Harzevil fault zone and the earthquake fault segments of the Sefid-Rud dam and Ab-Bar are situated in its southern margin (Zaré 1991a, 1991b and 1992, Figure 1). These features of earthquake faulting were associated with several Earthquake Fault Induced Slides (EFIS) that are occurred just in the rupture zones. These landslides are flower shape in their section and show the local long settlements which are bordered with the earthquake fault rupture in their one side and another induced rupture parallel with the fault in the another side. The landslide along the Baklor earthquake fault (Figure 8) is formed with the described mechanism.

These EFIS are observed in almost all of the other introduced earthquake faults; such as Kabateh, Borebon, and the earthquake fault of the Sefid-Rud dam. The fault segment which is created after the quake in the left bank of the Sefid-Rud dam site caused a lot of rockfalls in the road toward Gilvan (Figures 2 & 3) and made some damages to the foundation of tower crane of the dam. This fault has displaced some rock blocks and induced some rupture zones in the left bank of the dam (Figure 9), consequently; the block fallings and debris slidings were induced.

Fig.8 The earthquake fault induced slide of Baklor.

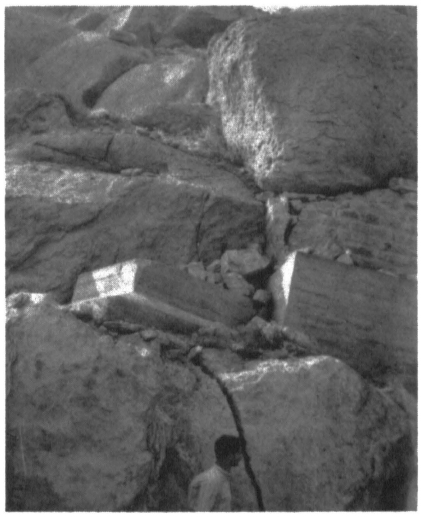

Fig.9 The earthquake fault of the Sefid-Rud dam and its induced rockfalls.

ANCIENT LANDSLIDES

The imprinted area of the Manjil earthquake is specified with the high potential for Landslide occurrence. Several historical landslides are determined in the impressed region; included by Sendes rotational slump, rock avalanche in Bivarzan and the Rudbar landslide. In the northern flank of the Siah-Rud valley (north of the Tootkabon earthquake

induced slump), it is observed a Larger rotational slump which has happened about 90 years ago (based on a research and asking from local habitants and old persons ; H. Pedram; Personal communication, 1992). This slump has made a rotational headscarp form and a displaced debris mass in the vicinity of Sendes village (Figure 10). It has about 500m length and about 1000m width. A road, which passes from the toe of this slide, is exposed to the blocking damages which induce from continuous debris slides. The impressions of remolding are observed in the headscarp of this slide (Figure 11) on the deformed and compacted soil fragments.

The Rudbar landslide is situated in the vicinity of the Galdian earthquake induced earthflow, in northern Rudbar. This slide which shows a slump form, has about 100m length and about 200m width. The first class road of Rudbar-Rasht passes from the toe of this slide and in rainy seasons the debris slides (Figure 12) are the main problem for this road. The olive oil-manufacturing factory of Rudbar in constructed in the front area of the toe of this slide, and is always in the slide hazard zone.

The rock avalanche of Bivarzan (northern Loshan) which is probably related to an earthquake in some several years ago, is located in the Harzevil fault zone. This rock avalanche is the largest one in this area which has about 1000m length and about 500m width.

PRELIMINARY MACROZONATION OF LANDSLIDES

As shown in Figure 1; the described landslides are mapped on the seismotectonic map of the region and are marked by the numbers of each determined classes. It is observed that the large landslides are dispersed in and around the "earthquake origin zone" (AREA 1) which is more or less coincided with the earthquake intensity zone of over VII (7) (MSK scale) where the rock falls are distributed in this area and its surrounding region (AREA 2) that is almost fitted with the earthquake intensity zone of over VI (6) (MSK scale)(Figure 1).

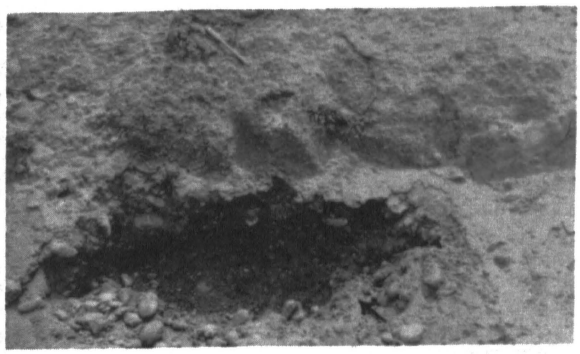

Fig.11 Remolding of the compacted and deformed soils, in the headscarp of the Sendes slump

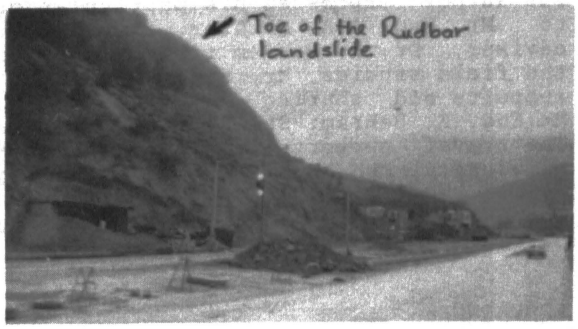

Fig.12 The toe part of the Rudbar landslide in the north of Rudbar. The Rudbar-Rasht road is obvious in the figure.

CONCLUSIONS

1. The earthquake induced landslides were one of the devastating factors of the Manjil earthquake, such that they caused directly a lift loss of about 200 persons and made a lot of damages to the human environment. Some pastures and soil resources sustained severe irreparable damages.

2. The regional geology and tectonic situation of the area were facilitating factors of landsliding.

3. The earthquake origin zone contained most of the large landslides.

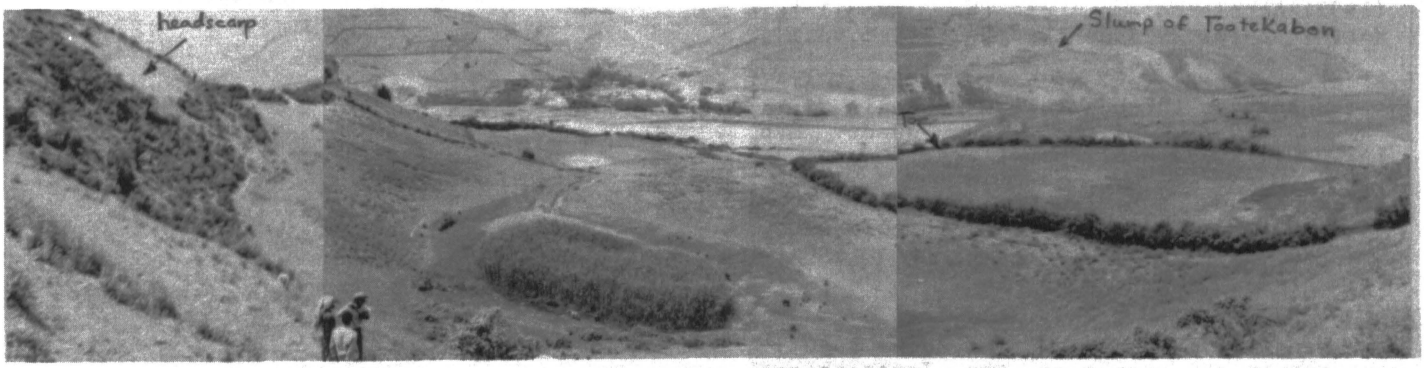

Fig.10 The rotational slump of Sendes; the headscarp form is obvious in the left side of the figure.

4. The large landslides have occurred in the earthquake intensity zone of over VII (7) (MSK scale) where the rockfalls are observed in the area which sustained an earthquake intensity of about over VI (6) (MSK scale).

5. The features of earthquake fault induced slides were from the dominant features of landslides in this event.

6. The Manjil earthquake revealed that the landslide investigations must be one of the main parts of urban plannings, and should be considered carefully within the hazardous regions.

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