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Landslides
Glissements de terrain

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Landslide in recent Roodbar earthquake in Iran

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ABSTRACT: The huge landslide in Roodbar, Iran, during the June 21, 1991 Manjil-Roodbar Earthquake with magnitude M7.3 has been analyzed. This slide started one day after the earthquake and continued for several weeks threatening the closure of road for emergency relief and the filling of downstream river of a major dam (Safid Rood gravity buttress dam). By using infinite slope approximation and finite element method, based on measured soil properties, it is shown that the original shock of 65% g could have induced initial slip which resulted in soil shear strength reduction to residual. However the continuous seepage of water and petroleum into the body of slide from broken pipelines and natural valley drainage induced the slide and the remedial measures of repairing the broken lines brought the slide to temporary equilibrium. Recent site visit indicates that one year after the slide, the valley drainage is still seeping into the slide and has formed small ponds. The heaves of soil along the slide length indicates that new movements of slide could be triggered.

1 INTRODUCTION

On June 21, 1990 at 00:30 AM local time, a sever earthquake of magnitude M7.3 (reported by Geophysical Institute of Tehran University) shook Northern Iran which resulted in more than 30000 loss of life and left hundred thousands homeless. Besides the structural damages inflicted upon more than 100000 homes and several major lifelines, the earthquake resulted in liquefaction in vast areas of northern Gilan Province and several major landslides. Among these, a huge landslide of about 32 million cubic meters occurred east of the city of Roodbar. It's prevailing movements lasted for several weeks after its outset, with diminutive slides toward stabilization going on for several months.

In this paper after introducing the characteristics of the earthquake, landslide geometry is presented. Based on measured soil properties analysis of slope stability is, then, carried out prior to, at the time of, and after the earthquake incidence. It is shown that a horizontal acceleration component of such magnitude as that experienced during this earthquake could have caused the initial slip and reduction in soil strength with subsequent continuous water and oil seepage in the body of the slide inducing the prolonged movement of the body for several weeks.

2 CHARACTERISTICS OF THE EARTHQUAKE

The M7.3 Manjil-Roodbar earthquake of June 21, 1990, hit the northern part of Iran on 00:30 AM local time, Fig.1. Its epicenter was located at 36 degrees 50 minutes N and 49 degrees 25 minutes E in the vicinity of Roodbar. The quake shook an area about 600000 square kilometers with the maximum intensity between X and XI on the MSK scale at epicenter, as was reported by Moinfar and Naderzadeh (1990). The extent of damage to structures is reported, by IIEES (1991), between 10 to 100% and is shown in Fig. 2. The peak horizontal acceleration recorded at Aabbar station, some 60 kilometers to the west of epicenter, was 65% g. Several aftershocks, some with magnitude larger than 5.0, hit the same area within a few weeks after the main shock. As a result, vast liquefaction occurred in the saturated

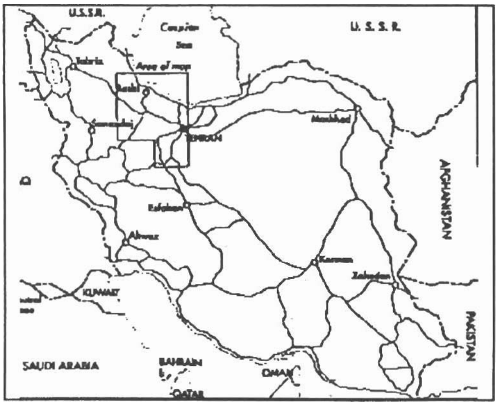

Fig.1 Location of earthquake area in Iran

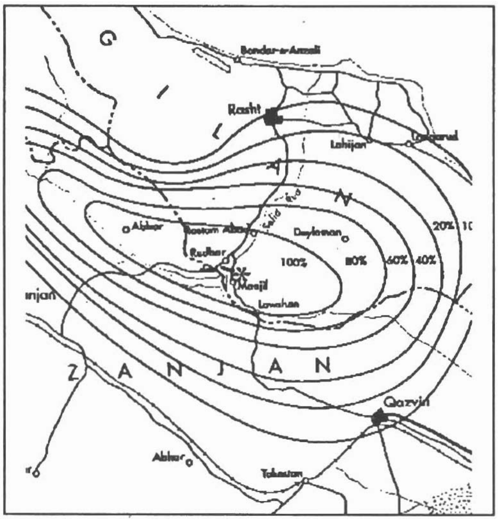

Fig. 2 Extent of structural damage

sand deposited area of the northern Gilan province, by the Caspian shores, and numerous landslides happened in the mountainous area of the southern Gilan province, the largest of which being Roodbar landslide studied in this article, Fig. 3.

3 SLIDE GEOMETRY

The landslide happened in the mountain to the east of Roodbar city overlooking the main road connecting Roodbar to Rasht. The surface of the

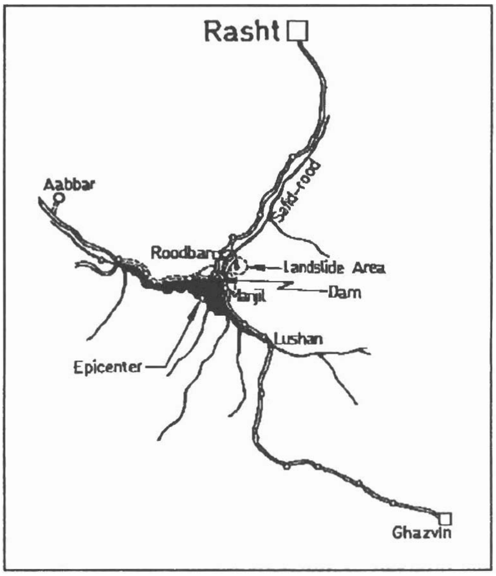

Fig. 3 Location of landslide

mountains in the area is covered with olive trees which need biweekly watering during most of the year. The local land owners use pools for surface irrigation thus bringing the water content of the soil to near saturation in some areas. Fig. 4 shows the slide area. The length of slide is about 4 km, its width varying between 300 to 800 meters and its thickness is between 5 to 50 meters averaging about 10 meters. The slide happened one day after the earthquake. The earthquake broke the water and petroleum lines and these broken lines constantly fed the slope area with water and oil. The natural small water way also introduced water to the slide area through the southern flank. The slide continued to move for more than two weeks and endangered rescue operations by threatening to block the Roodbar road. Furthermore it was feared that it may also block the Safid Rood river at downstream of Safid Rood gravity dam which was being drained as safety measures. After remedial measures were taken to repair the broken lines, the slide came to rest. The slide had an average slope of 20 degrees and came to rest at about a slope of 15 degrees and left three heaved areas as shown in Fig. 4. The recent visit to the site after one year showed that the height of the heaved areas has increased, indicating continuous small movement and possible future slide potential. Small water ponds are also formed

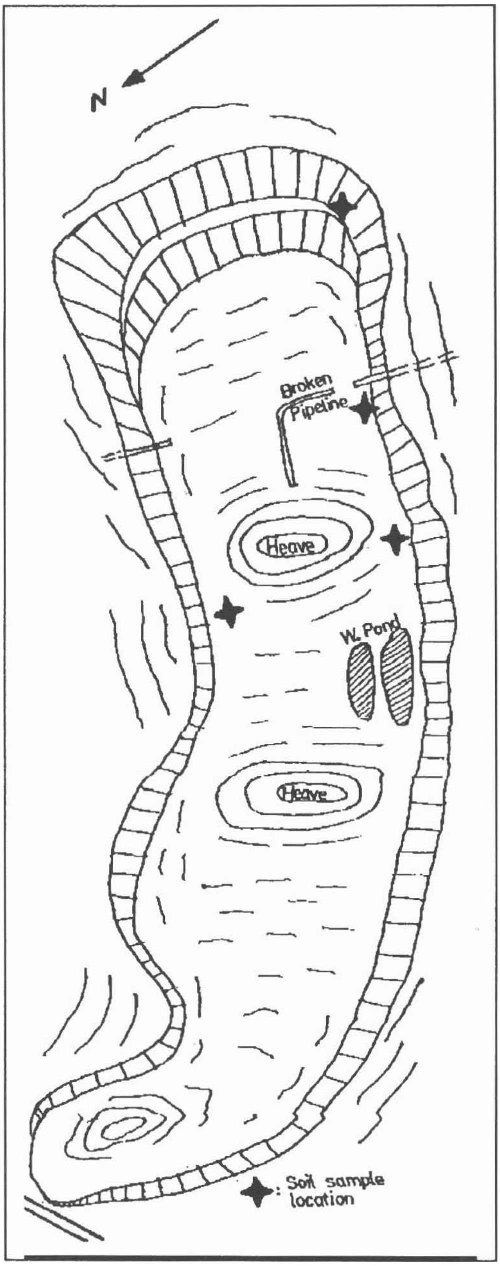

Fig. 4 Slide geometry

at the surface of the slide, halfway through the length fed by natural hill top drainage.

4 ANALYSIS OF SLOPE STABILITY

Due to the large extent of the slide, approximate formulas for infinite slope were used for the analysis. If the slope angle is α , the depth of soil during the slide is H, the angle of internal friction is ϕ, cohesion is c, and the unit weight is γ, then the static factor of safety is given by

$$F_s = \left(\frac{\tan\phi}{\tan\alpha}\right) + \frac{c}{\gamma\, H \cos\alpha\, \sin\alpha} \quad (1)$$

and the acceleration necessary to cause slide during earthquake, a_{max}, is given by

$$\frac{a_{max}}{g} = \left[\frac{c_d}{c}\left(F_s - \frac{\tan\phi}{\tan\alpha}\right) + \frac{\tan\phi}{\tan\alpha} - 1\right] /$$

$$\left(\frac{1}{\tan\alpha} + \tan\phi\right) \quad (2)$$

where c_d is the dynamic cohesion during earthquake. Substituting for static case c = 140 kpa, ϕ = 27.5°, α = 20°, H = 20 meters, γ = 20 KN/m3, and c_d = 160 kpa, then Fs = 2.52 and a_{max}/g =0.51 for triggering of slide during the earthquake. This indicates that the earthquake could have triggered the initial slip of the slope and has produced tension cracks especially at the top of the slide with the higher slope.

After the earthquake, considering the residual cohesion of 100 kpa and residual angle of internal friction of 19.5°, the slope has a factor of safety of Fs = 1.75. Thus although the earthquake had produced the initial slip, the residual strength was sufficient enough to prevent the movement of the slide, confirming the local farmer's report that the slide did not move during the first 24 hours after the earthquake.

The introduction of water to the surface of the slide could theoretically seep through the numerous tension cracks and produce seepage gradient parallel to the slide. This would make the factor of safety with a water gradient of i = sin α to be equal to

$$F_s = \frac{\gamma_b \tan\phi}{\gamma \tan\alpha} + \frac{c_r}{\gamma\, H \sin\alpha\, \cos\alpha} \quad (3)$$

where c_r is the reduced cohesion after saturation. Substituting c_r = 50 kpa and γ_b = 10 KN/m3 gives Fs = 0.88. This could theoretically induce slide in a part of the area and the movement could trigger slide further down. Field observations indicate that the slide behaved as waves during several weeks after the earthquake.

The analysis was also carried out by the finite element method using the Plaxis code developed by Delft university . The analysis showed that the slope had a factor of safety of

2.7 for pre earthquake condition
0.9 during earthquake with 65% g acceleration
1.9 after the earthquake with reduced strength
1.05 after earthquake with ground water effect.

The comparison with reported slides by Ishihara and Hsu (1986) shows that slides having a static factor of safety of 2.6, with slope angle between 0^o and 20^o, could yield during an earthquake with acceleration equal to 50% g.

5 CONCLUSIONS

The following conclusions can be presented

1. The initial shock of 65% g triggered the initial slip of the landslide and reduced the soil strength parameters to residual.
2. After the initial slip, the slope had sufficient factor of safety to remain stable although the surface was heavily cracked.
3. The seepage of water from broken water lines and natural valley drainage induced the slip that started one day after the earthquake and continued for several weeks.
4. Present valley drainage and heaving of the soil indicates that a new movement could be triggered.

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