The role of weathering in the occurrence of landslides in centeral Alborz, Iran

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Abstract: The study of landslides in central Alborz mountainous range revealed that the frequency and type of failure mechanisms are strongly controlled by weathering processes. Slides on low angle occur most frequently near to faults, where the failures usually are rotational slides and mudflows. But in steep slopes avalanche and planar slides are dominant. Shallow slides are usually located near roads and rivers and in places in which vegetation coverage has been removed. Earthquakes and road construction are the main triggering factors in this area.

Résumé: Elude de glissement de terrain dans la zone montagneuse de l'Alborz central montre que la fréquence et les mechanism de repaître sont grièvement contrôlés par procès d'altération. Demonstrandum des glissement sur les versant des montagnes pres de la mer Caspian, autour tes failles, dans les vallées plus bas sont très abondent et mechanism de reîtres sont normalement de sorts de glissement rotatoire (rotational) et de covlee de boue (mud flow), mais, dans le cas de pente de grande grée, avavlanch et glissement en feuille (planar slide) sont dominant. La glissement profondes sont normalement s'installent près des routes ethniciser et les endroits que les ouvrages de végétations sont demoiselle.

Keywords: Landslide, Alborz, Weathering, Earthquake, Road instability.

INTRODUCTION

Landslides are common features in the Alborz Mountains of Iran. This mountainous terrain is characterized by steep slopes, high relative relief and weathered and folded rocks. Due to geological location, geomorphology, topography, climatic, active tectonics, vegetation and dense population, the area suffers a number of natural hazards of different types, including all kinds of mass movement.

There are many classifications of landslide, which to some extent is due to the complexity of slope movement (Varnes, 1978; Hansen, 1984). Varnes classified landslides according to the type of movement on the one hand, and the type of material involved, on the other. Reference is made below to different types of landslides using this classification. Landslides, debris slides, debris flows, and rock falls cause extensive damage to forests, roads and highways, residential areas, gas and oil pipelines, water supplies, irrigation channels and occasionally result in loss of life. Damage to property and people are particularly great during earthquakes and after intense rainfall. For example in the Manjil magnitude Ms=7.3 earthquake of 1990, a few hundred slides were triggered and more than 200 people were directly killed by landslides. Also in the recent earthquake of Baladeh in May 2004, of magnitude Ms=6.3, numerous landslides occurred in the epicentre area, especially along the Chalous-Karaj road. This road was rendered impassable for a long time and eighteen people were killed by rock falls and rockslides. In October 1996 after three days of intense rainfall many landslides occurred in the hilly slopes of Mazanderan and Gilan Provinces. Damage was caused to forestland, roads, gardens, farms and residential areas. In this paper the characteristics of landslides in four different areas in central Alborz folded belts are introduced (Fig. 1).

Figure 1. The location of study area in the north of Iran

GENERAL GEOLOGY AND CLIMATE OF THE ALBORZ MOUNTAIN RANGE

The Alborz range has been created by collision of Turan and Iranian plates. This area is one of the most active seismo-tectonic provinces in Iran. The mountain belt is part of Alps-Himalayas mountain chain with similar seismic activity, which is a direct consequence of its tectonic setting. The Alborz mountain belt consists of different sedimentary, metamorphic and igneous rocks aging from the Precambrian to the Quaternary. The geomorphologic features of the range are strictly related to the morpho-structural and selective erosion processes, which have led to rugged topography. The slopes are near vertical at the margin of strong rocks and main reverse faults. Inclined and undulating strata occur in outcrops of clay-rich weak rocks such as marl, shale and tuff. The mountains result in a the northern part, overlooking to Caspian Sea having a semi-Mediterranean climate with an average of precipitation from 700mm in mountains and up to 2000mm in the coastal plain. In this area the slopes usually consist of debris deposit and residual soils. The outer Alborz terrain in the north has thick vegetative cover due to the soft sedimentary rocks present there.

Common causes of landslides

The term landslide hazard is used as an umbrella term for wide range of complex landslide. Different threats are posed by different type of slope movement (Guzzetti et al., 1999). Landslide triggered casualties and economic losses are greater in many countries than is commonly recognized (Guzzetti et al., 1999; Schuster, 1996; Schuster and Highland, 2001).

Landslides are a frequent and devastating natural hazard in this mountainous region of Iran because of the topographic and geological conditions (Ghafoori & Lashkaripour 2002) in the area. Investigations reveal that in the Alborz fold belt lithology, geological structure, weathering and toe erosion are important pre-disposing parameters and that earthquakes, intense rainfall and road construction are the main factors triggering instability. Among these, weathering is an important factor affecting the development of slope instability in the area. The mechanism and location of slides are usually related to type and degree of weathering. The effects of weathering in slope instability in this area could be described as follows:

- Disintegration of rock mass
- Decrease of the shear strength of rock mass and discontinuities
- Increase the porosity and water absorption by decomposed material

In strong jointed rocks, weathering begins from discontinuities and increases the susceptibility of the rock mass to rock falls, and planar and block slides. In weak rock masses (such as marl, tuff and shale), the weathering proceeds homogenously in rock material rather along fractures and usually result in slumps, rotational failure, mudflows, and shallow and deep translation slides. The contact surface between fresh and highly weathered material that is usually parallel to slope surface has an important role in controlling instability of slopes in the weaker rocks. Also deep weathering in the toes of low angled slopes, decreases their stability and may result in deep rotational slides. In following sections the role of weathering in instability of slopes in four different areas of the central Alborz range is discussed.

LANDSLIDES IN THE MANJIL AREA

Manjil area is located in central-west part of the Alborz range. The various rocks such as tuff, shale, sandstone, schist, phylite, limestone, dolomite, andesite, loess and Quaternary deposits occur in the area. The Manjil earthquake of magnitude Ms=7.3 in 1990 triggered a few hundred slides around the hilly and woody epicenter area. Landslides affected large areas and blocked all the roads in this mountainous area, thus disaster relief efforts were impeded and this increased the death toll. During this earthquake a large landslide buried the village of Fatalak with about 180 inhabitants. All kind of slides such as rock falls, rockslides, planar slides, rotational slides, mudflows, and rock avalanches occurred during the earthquake (Komak Panah & Hafezi Moghaddas, 1993). The landslides were mainly located near the earthquake fault, ancient faults and the banks of rivers. Figure 2 shows the relationship between landslide occurrence and distance from main faults. As shown, more than 40 percent of landslides triggered by earthquakes are located less than 1km from main faults. The following characteristics are main reasons for this phenomenon:

- Closely spaced jointing and deep weathering near to faults
- High accumulation of debris deposits in foot area of faults
- High elevation difference

It was also noted that the type of lithology and geological conditions have great influence on the erodability potential and failure mechanism (Figure 3). In weak rocks such as tuff and loess which are more, susceptible to weathering, the rotational slides and mudflows are more common, but in strong rocks such as andesite and sandstone it is usually rockslides that are dominant. The failure surface of planar slides in both weak and strong rocks usually lie at the contact between fresh and weathered rock.

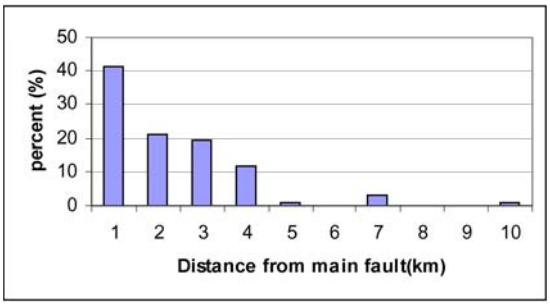

Figure 2. Relationship between percent of landslide and distance from main faults in the Manjil area

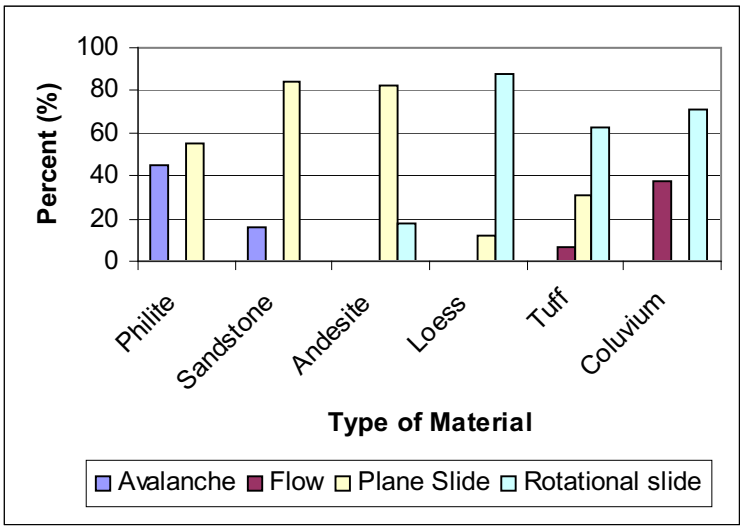

Figure 3. Relationship between type of material and failure mechanism of landslides in the Manjil area

LANDSLIDES TO SOUTH OF SARI

Sari, the capital city of Mazanderan province, is located at the foot of the Alborz range near to the middle. The area consists of grey shale, sandstone (Shemshak formation) and thinly-bedded limestone. The area is covered by dense forest. Weathering processes common in these formations change the soft sedimentary rocks, especially marls and shales, to unstable soils and result in frequent landsliding. The thickness of residual soil and highly weathered material in areas underlain by shale and marl are up to 40m, but in sandstone and limestone it is less than 5m. There are many ancient landslides in this area that become triggered by earthquakes and erosion of slope toes. The steeper slopes usually display evidence of creep failures. The construction of the Kiasar-Sari road in this area resulted in the reactivation of ancient landslides and the occurrence many new slides. Most are translational with a failure surface at the contact between fresh and weathered material. The great thickness of debris at the foot of slopes has an important role in the occurrence of landslides. Selective erosion leads to high relief where weak and strong rocks such as shale and limestone are present. The accumulation over time of debris material over decomposed shale results in landslides.

There are some large landslides downstream of the Tajan Dam. This structure is a 65m high concrete arch dam constructed in the Tajan river valley in Tangeh Soliman, North Sari. The bedrock downstream of the dam is marl and sandy marl. Landslides have occurred in both banks of the river with one about 200m from the dam axis. This 300 m long by 35m wide by 40m deep landslide is an ancient rotational slide that was reactivated during dam construction in 1996 and 1997.

It was not identified during the dam site study and the site selected for the power plant was in front of this slide. Reactivation was caused by building activities especially, the construction of the access road that entailed under cutting of slide toe. The storage of construction material was also responsible for the failure. Geophysical and geotechnical studies showed that the weathered marl is about 40m thick and that the failure surface is located at the contact of weathered with fresh marl. Figures 4 and 5 show the cross section and a view of the slide. The geotechnical properties of fresh and weathered marl are presented in Table 1.

LANDSLIDES TO NORTH OF RAMSAR

Ramsar is a beautiful city located at the foot of Alborz Mountains to the west of the Caspian coastal plain. The coastal plain in the Ramsar area is very narrow and the city extends on to the hilly terrain to the south. The bedrock in the latter area is alternations of shale and sandstone (Shemshak formation). The annual perception in this area is more than 1500 mm and the area covered by dense forests. The weak lithology, high rainfall, high degree of weathering and

also human-activities such as deforestation, road construction, housing and agriculture have increased the potential for slope instability in this area.

In October 1996 after a few days of heavy rainfall many landslides occurred in the hilly parts of Ramsar City (Hafezi Moghaddas & Montazerghaem, 1996). These were mainly mudflows, shallow and deep rotational slides, many of which were in the bank of rivers and road sides. One particular notable landslides occurred in 1966 in sandstone in a location where forest trees had been replaced by fruit gardens. The seepage of surface and irrigation water in sandstones resulted in solution of calcite cement in the rock mass. The slide damaged a few homes and 3 people were killed in the Sadat-Mahalleh area. Figure 6 shows a vertical cross-section of the slide.

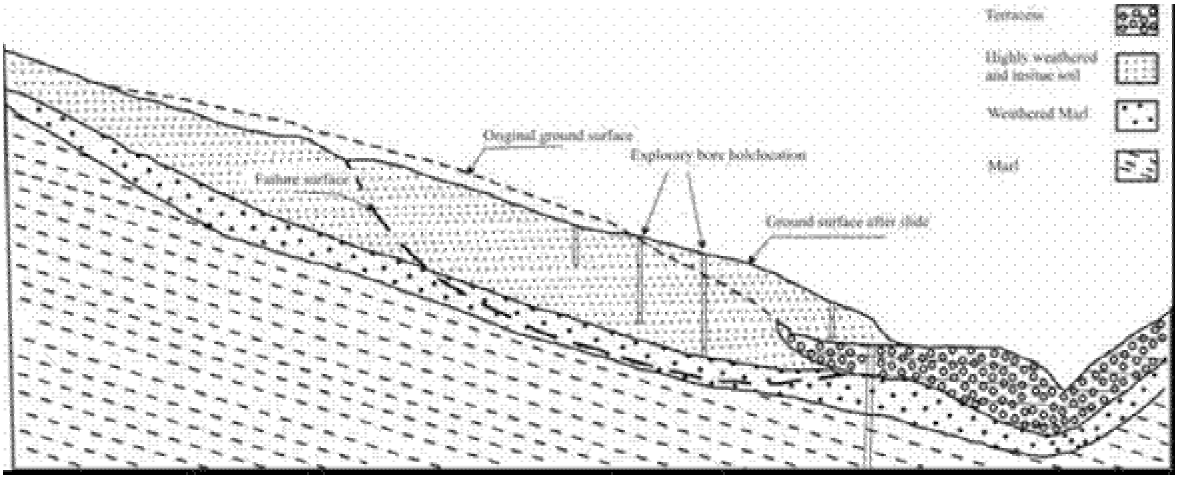

Figure 4. The cross section of landslide in downstream of Tajan dam

Figure 5. A view of landslide in downstream of Tajan dam

Table 1. Geotechnical properties of Marl and weathered marl in North of Sari (downstream of the Tajan dam)

Type of material	**Dry density** Mg/m^3	**Unconfined compressive strength MPa**	**Water content %**	**Liquid limit %**	**Plastic limit %**
Marl	2.1	0.8-0.9	5-6	-	-
Weathered Marl	1.7	-	20	45	25

LANDSLIDES IN THE KHOSH YELAGH AREA

This area is located to the south of Azadshahr city in the central-eastern part of the Alborz mountainous range. The lithologies of this area include shale and sandstone with interbedded coal horizons. The strike and dip of beds are respectively $N45^0$ E and $40\text{-}50^0$ towards the NW. Two groups of deep and shallow slides are present in this area (Hafezi Moghaddas & Mehdizadeh, 1997). The deep landslides are usually controlled by geological structures and water absorption by the coal horizons and decomposed shale layers that give rise to very weak surfaces resulting in large planar slides. Figure 7, a rose diagram for the direction of large slides and the strike of the beds, shows the slide

directions are usually normal to the bedding strike. Large planar failures result from increased intensity of weathering in zones of crushed rock. Secondary failures include mudflows and slumps. There are some active coal mines in this area and the construction of mining roads has triggered many new landslides and reactivated some ancient ones. The shallow slides are controlled by vegetation coverage. The averages of root extent and root penetration depth in this area are 4.5 and 1.5 m. respectively so the upper 1.5m of surface soils are reinforced. Shallow landslides mostly occur in areas of ancient slides, roads and man-made deforestation, especially where close proximity of villages has resulted in damaged root cover.

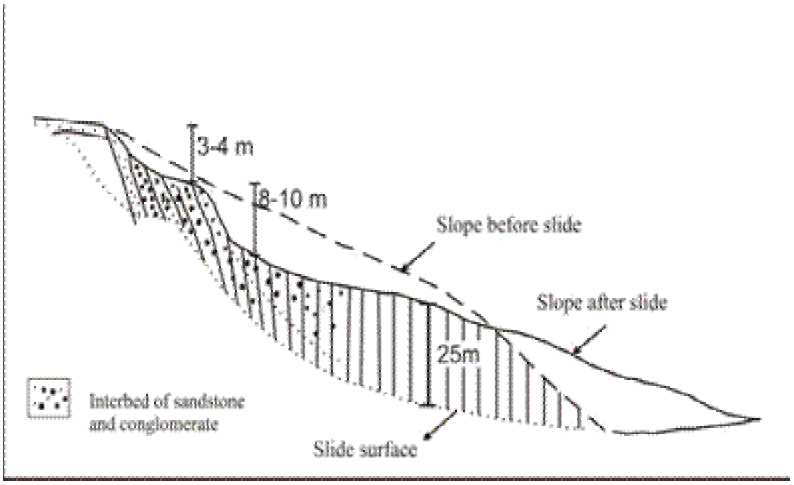

Figure 6. Cross section of Sadat-Mahalleh slide in south of Ramsar need to indicate horizontal scale

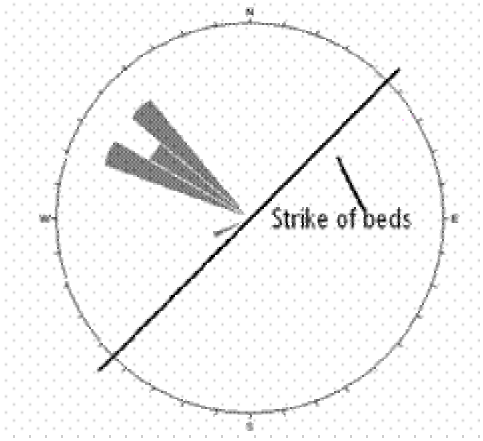

Figure 7. Rose diagram for the direction of large slides in relation to the strike of beds in Khosh-yelagh area

CONCLUSIONS

The landslides in Alborz Mountain range can be classified into two groups of deep and shallow slides. Investigations of these landslides have shown that lithology, geological structure, weathering and toe erosion of slopes are important factors that favor the occurrence of landslides whereas earthquakes, intense rainfall and road construction are the main triggers. Among these factors, weathering processes are very important. The locations and failure mechanisms of slides are strongly controlled by the degree and type of weathering. Shallow failures usually occur at the contact between fresh and weathered material and they are most prevalent where the forest cover has been degraded. On the other hand deep landslides are usually controlled by the geological structure, particularly the dip and dip direction of the bedding. . Such landslides also give rise to conditions that favor the development of shallow slides.

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