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Rockfalls in Sfeedan Village in the Northeast of Iran

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Abstract: Sfeedan village is located about 55 km in southeast of Bojnord city in the northeast of Iran. The village lies in Sfeedan valley about 1600 m.a.s.l. in Aladagh Mountains. During recent years instability has been reported in both sides of the valley in the eastern and western parts of the village. The last movement was a landslide in which a mass of soil slid down in the west of the village in July 1992. This slide damaged more than 3000 trees in a few gardens. Many of the landslides in this area are reactivated and have been triggered by human activity although are always related to periods of continued rainfall or other accelerating phenomena such as earthquakes. In December 2002 a rockfall was reported in the eastern side of the village. This instability has increased governmental and public awareness of rockfall hazard and the need to mitigate this hazard in this village with a population of more than 700 residents. A large outcrop of the Shurijeh formation that mainly consists of sandstone and shale of Lower Cretaceous age is overlooked in the eastern side of the village. The bedding of the Shurijeh formation is parallel to the Sfeedan valley and in general strikes northwest-southeast, dipping 10 to 25 degrees northeastwards. A sharp topographical slope and the difference between the direction of the bedding slope and the topographical slope are the main reasons for rockfall activities on this side of the village. Moreover, the occurrence of shale layers as high weathered zones between sandstone layers plays a positive role in the instability on the east side. The rockfalls in this side are natural rockfalls.

Key words: Geology . Iran . landslide . rockfall . instability

INTRODUCTION

Iran is heavily exposed to natural hazard such as earthquakes, landslide and floods. Landsliding is one of the most frequently occurring and devastating natural hazards in the mountainous regions of Iran. It causes enormous economic damage and the losses of life annually. From 1990 to 1999 about 280 people have been killed as the result of landslides in Iran [1].

Among many natural hazards, rockfalls are very frequent natural hazards in mountainous areas. Rockfalls are major hazards in mountain area, potentially threat in lives, settlement, equipment, facilities and transportation corridors [2]. In the recent earthquake with magnitude Ms = 6.3 in Richter scale on 29 May 2004 in the Central Alborz mountain range the loss of life due to tens of rockfalls was reported 33 people. The rockfalls occurred in an area about 1000 km2 and average elevation of about 2000 m above the mean sea level.

The word rockfall is a general term usually used to describe small phenomena, from block falls with a volume of a few m^3 to 10000 m^3 events [3]. Despite their often relatively small size, rockfalls are among the most destructive mass movements [4]. Rockfalls are always rapid phenomena and are difficult to predict without any extensive instrumentation [5] and travel at speeds ranging from few to tens of meters per second [4]. The number of people killed by rockfalls tends to be of the same order as people killed by other forms of rock slope instability [6].

Hazard assessment of rockfalls is necessary due to urbanization in the rockfall prone area. Evaluating rockfall hazard means estimating the location, magnitude and probability of occurrence in a given time period of potential events. The location and size of potential rockfalls are mainly dictated by geometrical patterns and geomechanical properties of the rock mass, especially concerning existing discontinuities. However, the role of geological factors (such as concentration of structural discontinuities, seismicity and vertical contrasts in permeability, particularly where permeable surface material overlie impermeable materials) in landslide generation has also been reported by many researchers [7, 8]. Ghayoumian *et al.* [9] reported that in recent years two significant factors which triggered landslides in mountainous areas in Iran are seismic shocks and heavy rainfall. For example, on

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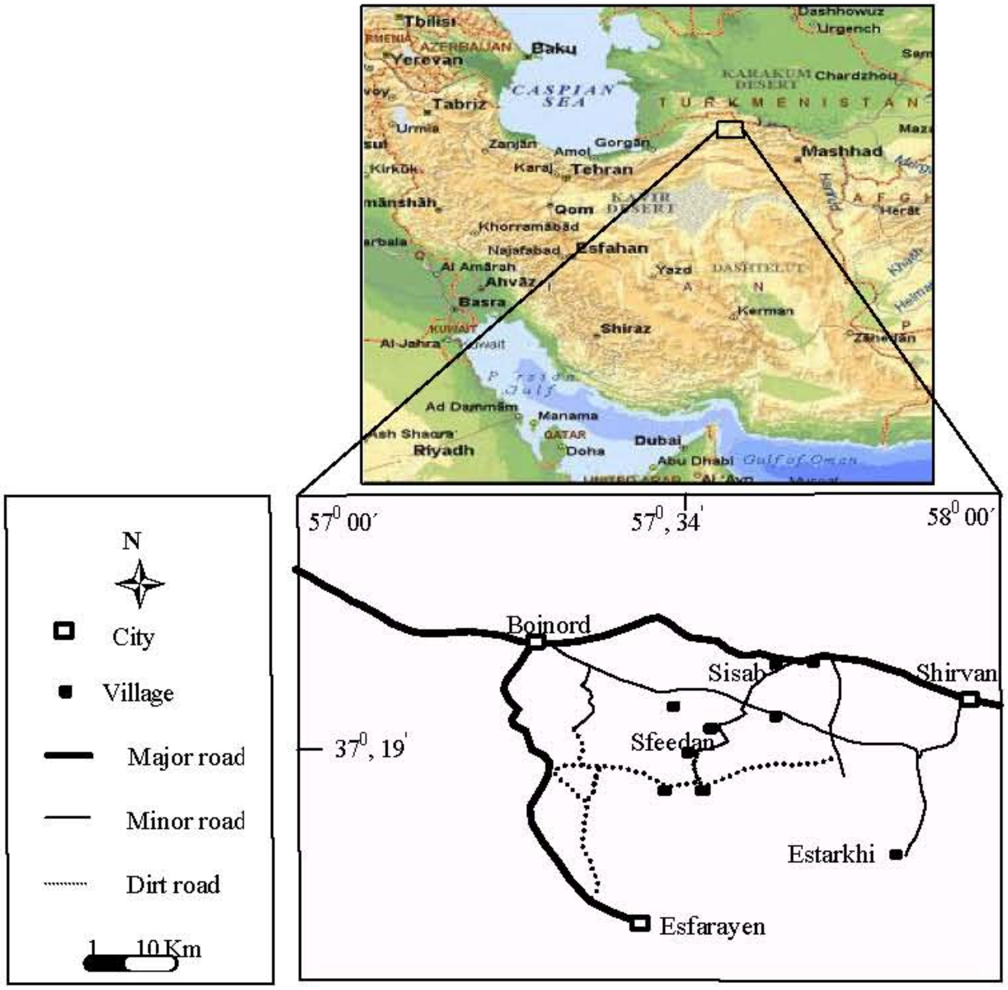

Fig. 1: Location of study area

1 April 1998 after heavy rainfall, a landslide occurred in Abikar village. This village is located on the foothill of Keno mountain in the Zagros range. This landslide buried Abikar village with all 55 residents [1].

This paper describes a practical rockfall problem in a public area. This area in Sfeedan valley (Fig. 1), where locally steep rock slopes with difficult and limited access extend to heights of 120 m, is located about 55 km southeast of Bojnord city in Aladagh Mountains in the northern part of North Khorasan province, northeast of Iran (longitude of 57° 34′E and latitude of 37° 19′N). This part of the country is a mountainous area that is tectonically active region usually forming hills with steep cliff faces. The danger of a rockfall occurring in the hill sides of this area is ever present, but the public are usually not aware of the danger until lives are lost. Average yearly rainfall and temperature in the study area during the last 25 years are recorded 408 mm/year and 8°C, respectively [10].

GEOLOGY AND GEOMORPHOLOGY

Geologic factors, such as bedrock lithology, joints and attitude of bedding influence the rockfall. Detailed field work based on geomechanical and expert analysis lead to the characterization of some specific instabilities [3].

Geological and geomorphological mapping along Sfeedan valley was carried out in Winter 2002. The location and size of potential rockfalls are mainly dictated by the geometrical patterns and geomechanical properties of the rock mass, with the strongest influence being existing discontinuities. The slope geometry is highly variable in Sfeedan valley and it is in the range of smooth slop in the alluvium of the western part of the valley to vertical cliff in the eastern part.

A large outcrop of Shurijeh formation (Ksh) that mainly consists of reddish brown shale, sandstone and quartzite sandstone of Lower Cretaceous age is overlooked in both sides of the village (Fig. 2).

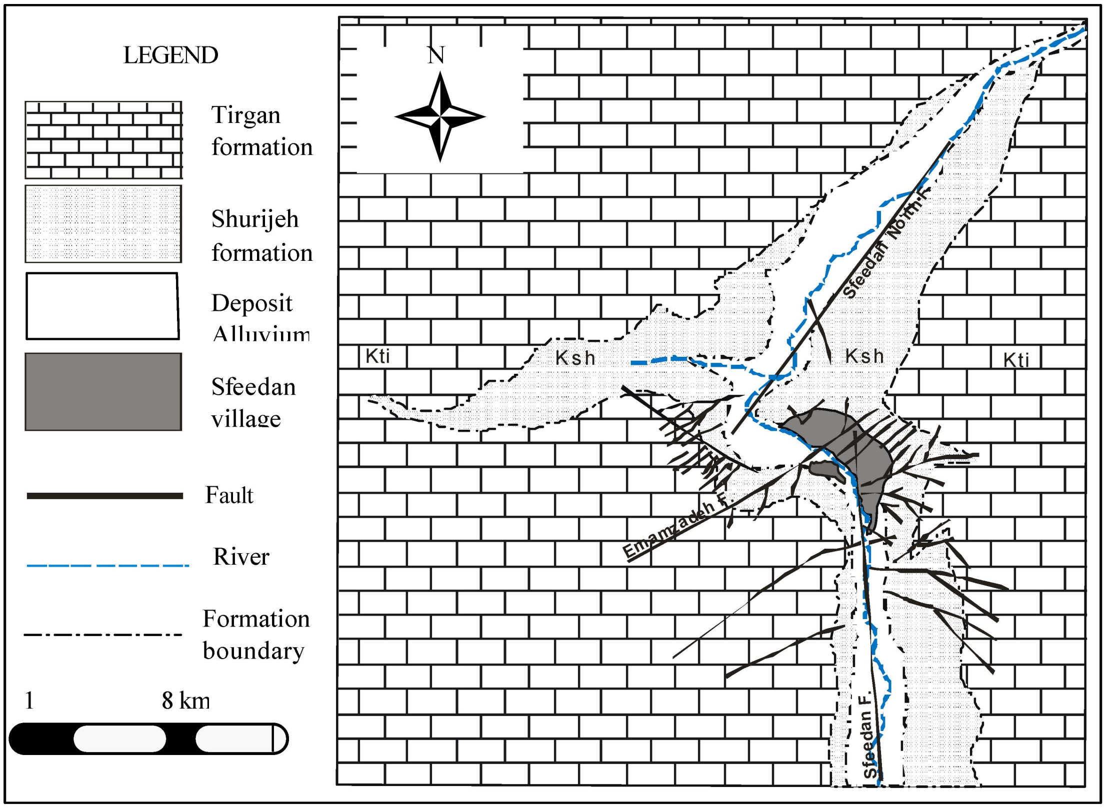

Fig. 2: Geology map of the study area

Fig. 3: Photograph of the studied slope in the eastern side of the Sfeedan village

Shurijech formation of the Upper Jurassic and Lower Cretaceous covers a large area in the northeast of Iran [11]. Limestone of Tirgan formation (Kti) of Lower Cretaceous age overlies the shale unit of the Shurijech formation. The bedding of the Shurijeh formation in general strikes northwest-southeast, dipping 10 to 25 degrees northeastwards. Major and minor geological discontinuities such as faults, shear zones, bedding planes and joints are present in the area. However, several joint sets affect the rock units of the Shurijeh formation.

The bedding planes and associated joints have played an important role in triggering rockfalls. This bedding direction is parallel to the Sfeedan valley or almost parallel to the slope surface. A sharp topographical slope and the difference between the direction of the bedding slope and the topographical slope are the main reasons for rockfall activities on the eastern side of the village. Moreover, the occurrence of shale layers as high weathered zones between sandstone layers plays a significant role in the unstability on this side. A view of the eastern side of the village is shown in Fig. 3.

CHARACTERISTICS OF SFEEDAN UNSTABILITIES

Two types of instabilities have been reported from both sides of the village, landslides in the western side and rockfalls in the eastern side of the village. Rainfall penetrates the ground surface and the increasing thickness of the weathered zone leads to failure in the western side. After a landslide, which involves the removal of a weathered zone, weathering commences again at the landslide scar, preparing for the next landslide. The last movement was a landslide in which a mass of soil slid down in the west side of the village on 15 July 1992 [12]. This landslide damaged more than 3000 trees in a few gardens. Many of the landslides in this area are reactivated and have been triggered by human activities although always related to periods of continued rainfall or other accelerating phenomena such as earthquake.

Sfeedan rockfalls in the eastern side of the village are natural rockfalls. Natural rockfalls can be defined as events occurring on natural cliffs, not mine or road cuts and triggered without any human intervention. The last rockfall on this side was reported in December 2002 and will be discussed later.

HAZARD ZONATION AND STABILIZATION

Rockfalls are among the most destructive mass movement and are a major cause of landslide fatalities, particularly along roads in many countries [4]. In mountain areas, roadways become a considerable challenge due to specific risks such frequent rockfalls and stone break up [13]. Landslide damages in recent years have increased government and public awareness of landslide hazard and the need for landslide stabilization and mitigation in this part of Iran. Rock properties and slope control the initiation behaviour of rockfalls vary widely and it is difficult to establish the actual hazard zone in which debris from a rockfall would travel. Regarding the temporal occurrence of such phenomena, the prevision in time can only be feasible over a short-term period (a few months to few days) if the unstable slope is well instrumented and the movement follows specific processes [14]. In most cases no instrumentation is available. Long term predictions (a few years, a few decades or a few centuries) are only quantitatively estimated on the basis of experience of an expert [6, 15]. The temporal evaluation appears to the weakest point of rock hazard studies [3].

Today several computer programs are available which may be used by the engineers to simulate the fall of a boulder down a slope and to compute rockfalls trajectories [2, 4, 16]. However, the accurate prediction of rockfalls is practically impossible. Variability in slope geometry, poorly defined initial conditions, uncertain material properties and an analysis method that is sensitive to minor changes in these parameters are contributing factors that made accurate prediction extremely difficult [17].

Rockfalls in Sfeedan village are sensitive to small changes in some geotechnical conditions and geological and geomorphological parameters. It can be concluded that sliding in the western part is controlled by both natural phenomena (such as geological conditions, rainfall and earthquake) and human activities but in the eastern part rockfalls are very complex process which almost reactivated by natural phenomena such as geological conditions, rainfall and accelerating phenomena.

Rockfalls are the most abundant type landslide triggered by earthquakes, as shown historical worldwide earthquake-induced landslide data compiled by Keefer [18]. The study area is located in highly seismic zone and has experienced, on occasion, several moderate to strong earthquakes. Earthquake magnitude of over 6 in Richter scale is usual for this part of the country. Therefore, earthquake is a main factor in triggering rockfall in this area. Vibration related to intense earthquakes affects this region periodically. Moreover, vibrations due to passing vehicles on the foot hill of the Sfeedan cliff may reactivate the rockfall in the eastern side. However, Rockfall hazards along Sfeedan village were identified. These instabilities have increased governmental and public awareness of rockfalls hazard. Due to high risk of rockfalls and landslides, especially the danger of rockfalls in the high slopes of the eastern side, stabilization works are necessary in order to protect the village. In December 2002 a rockfall was reported in this side of the village. A block of this fallen rockfall is shown in Fig. 4. It was estimated that the total volume and weight of the fallen rock was more than 10 cubic meters and about 30 tones respectively. It worth to mention that small to medium

Table 1: Classification of cliff faces and distances of safety zones

Type of cliff face	Highly dangerous zone	Danger zone	Safe zone
Very high risk	2.0 times the height of the cliff face	2.0 to 3.0 times the height of the cliff face	>3.0 times the height of the cliff face
High risk	1.5 times the height of the cliff face	1.5 to 2.5 times the height of the cliff face	>2.5 times the height of the cliff face
Low risk	1.0 times the height of the cliff face	1.0 to 2.0 times the height of the cliff face	>2.0 times the height of the cliff face

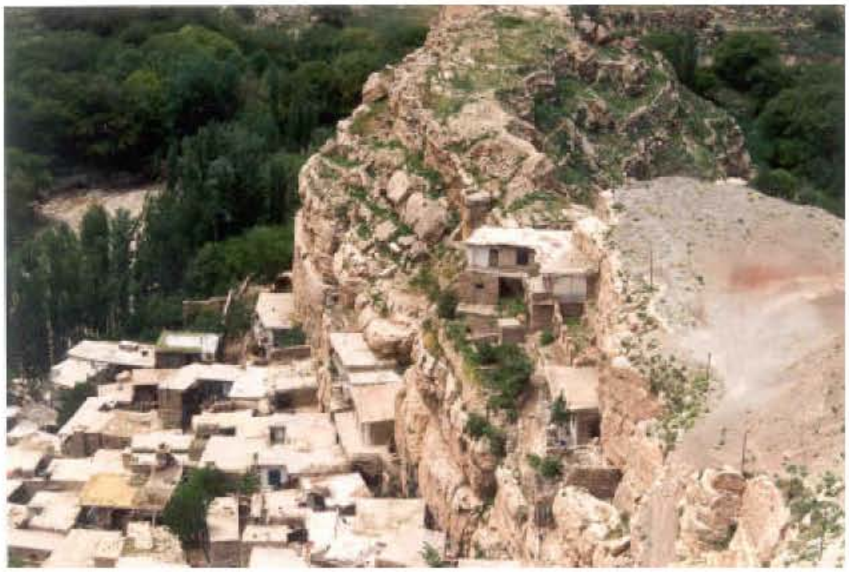

Fig. 4: A fallen block of the rockfall in December 2002

size of rockfalls have received much less attention in the scientific, literature, despite their greater frequency in many mountain area of the world. Thus, the related risk for connection routes and inhabited area located at mountain foothills has often been underestimated [19].

An accurate prediction of rockfalls is a major need for hazard assessment in the study area. Due to topography and existing features, it is recommended that landslide hazard zonation map be provided for the area. This map will be a relative ranking of the area according to the degree of actual or potential hazard from landslide or rockfall on slopes. Landslide hazard zonation maps are of great importance for planning various river valley developmental projects such as town planning, road construction and dam construction in the mountain and hilly terrain of this part of Iran.

Moreover, the distance traversed by falling debris from rockfall is very important for mitigation of rockfall hazards. Usually it is difficult to establish the actual distance in which debris from a rockfall would travel. There are many factors involved such as height of the cliff face, the type of failure and the condition of the ground on which the debris have fallen. Chow and Sahat [20] reported that to come up with an estimation of the safety zones around the cliff faces, geological mapping must be carried out to classify whether the cliff faces as very high risk, high risk and low risk. Based on this classification, the safety zones are proposed for the Sfeedan rockfall as shown in Table 1.

Rockfalls are always rapid phenomena and are difficult to predict and travel at speeds ranging from few to tens of meters per second. The rockfall velocity is reported by Mougin *et al.* [13] by the following equation.

$$v = (2gh)0.5$$

Where, v, g and h are velocity, gravity and height of the fall, respectively. According to this equation the block velocity in the study area is:

$$v = 2 * 9.81 * 120 = 15.34 \text{ m/s}$$

CONCLUSIONS

Rockfalls and landslides are important natural hazards in the study area and they are reactivated by continued rainfall or other accelerating phenomena such as earthquake. Human activities also play a role in sliding in the western part of the village. The area is highly seismic and has experienced, on occasion, several moderate to strong earthquakes. Due to high seimicity of the study area, particularly attention was given to the evaluation of seismic susceptibility to rockfalls.

This area is severely affected by rockfalls and landslides and the associated risk, is therefore, very high. Special lithology, geological structures and geomorphology have a great effect on the instability of the region. The presence of Sfeedan village and other infrastructures at the slope foothill make these phenomena extremely dangerous. Due to the high risk of rockfall and landslide, this is the first mention of stabilization works in order to protect Sfeedan village.

Rock mass classification and interpretation of field data, especially concerning joints along Sfeedan Valley is necessary due to the influence of existing discontinuities. On the other hand, identification of locations most susceptible to rockfall is necessary, based on geological and geomechanical considerations, in order to characterize potential instabilities. However, rockfall as a natural hazard is a very complex process in this region.

We recommend a landslide hazard zonation map is provided for the area. This map will be a relative ranking of the area according to the degree of actual or potential hazard from landslide or rockfall on slopes. An estimation of the safety zones around the cliff face in eastern side of the village is proposed.

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