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Fracture Analysis of Rocks for Slope Stability Assessment in SiriKot Area, District Haripur, Khyber Pakhtunkhwa, Pakistan

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Abstract: The landslides are common and hazardous the Northern Gandghar Ranges, Pakistan. The slope failures have affected road sections between Ghazi to Sari area (~65 Km) along the Sirikot road in district Haripur, Pakistan. The objectives consist of failure mechanisms, slope sensitivity and remedial measures in potentially unstable. To analyze slope stability and understand failure mechanisms, Inventory Circle Method (ICM) has been employed at six locations. Most of the landslides have been found in the Precambrian metamorphic Manki Formation, consisting of slate, phyllite and schists. The data acquired through ICM technique have been used to measure the density of fractures and hydraulic properties (porosity and permeability). The fracture analysis revealed two episodes of deformation. Rose and pole diagrams were plotted for stress analysis and fracture orientation to determine the direction of principal stress σ^1. Geological Strength Index (GSI) also provided details about the interlocking pattern of the rocks. Topple and rock fall were found in the limestone and quartzite. Moreover, the fractures also provided channels for the water to flow through and penetrate the foliation planes, decreasing the friction and causing a landslide.

Keywords: Slope stability, inventory circle method, fracture analysis, geological strength index.

Introduction

The fractures have been studied in detail by various workers for their different properties and classified accordingly (Laubach et al., 2014). Fractures are developed in response to various stresses exerted on a rock body (Davis et al., 1996). The sets of fracture are classified according to their orientation associated with the fold axis of a folded areas (Billings, 1972). Several methods here applied to carry out slope stability analysis, that limit equilibrium method, physical, kinematic, and numerical models (Vishal et al., 2010; Nazir-ur- Rehman et al., 2017; Dasti et al., 2018; Wang et al., 2020). One of the most commonly used methods is fracture analysis, based on the Inventory Circle Method (ICM) proposed by Daviset al. (1996).

The study area is in district Haripur, Hazara, Pakistan, with latitude N 34° 02' 47.5" to N 34º 01'45.2" and longitude E 072° 44' 20.9" to E 72° 49' 21.2" covered by the Geological Survey of Pakistan topographic sheets 43 C/19 and 43 C/13 (Fig. 1). The landslide is one of the major geological hazards in Northern Gandghar Ranges, Pakistan, especially along the roads and highways. Many factors control the slope stability, such as rainfall, groundwater table and variation in stress conditions, changes in geometry, exterior forces, and loss of shear strength (Abramson et al. 2002).

To analyze slope stability and understanding failure mechanisms ICM has been employed at 30 locations along the road section from Haripur to Sirikot area. The fracture analysis has been used to analyze the landslide problems along the road. The broad concepts of structural geological relationships have been established to demarcate endangered areas, determine potential failure mechanism and suggest remedial measures.

Materials and Methods

Annual average temperature is 21.32°C which increases gradually and (Hylland et al., 1990). The soil shows silty and clayey texture (Nawaz et al., 2015). The Sirikot area is part of the Northern Gandghar range and lies between the Plio-Pleistocene Haripur and Peshawar basins (Riaz et al., 1991). Northward lies the Hazara Ranges, where the Tanawal Formation comprises the Cambrian Mansehra granite (Yeats and Hussain, 1987). Khanpur hills on the east side, and on the southeast, it is bounded by Margala hills comprising mostly metamorphosed to sedimentary rocks. The entire succession is intruded by basic igneous dikes and sills. Furthermore, the Range is divided into eastern and western structural blocks separated by Baghdarra fault (Fig. 2).The former demonstrates an almost complete succession, whereas the latter has two limestone lithologies missing, that marks an unconformity (Riaz et al, 1991). Northern Gandghar Range, is comprised of formations ranging in age from Precambrian to Cambrian (Fig. 2). The study area contains three north dipping thrust faults, a normal fault and two dominant folds (Fig. 1). Three faults are running through this area i.e., the Baghdarra, Gudwalian and Sirikot faults named after the localities of their occurrences. The Baghdarra and the Sirikot faults are thrust faults, whereas the Gudwalian fault is a normal fault.

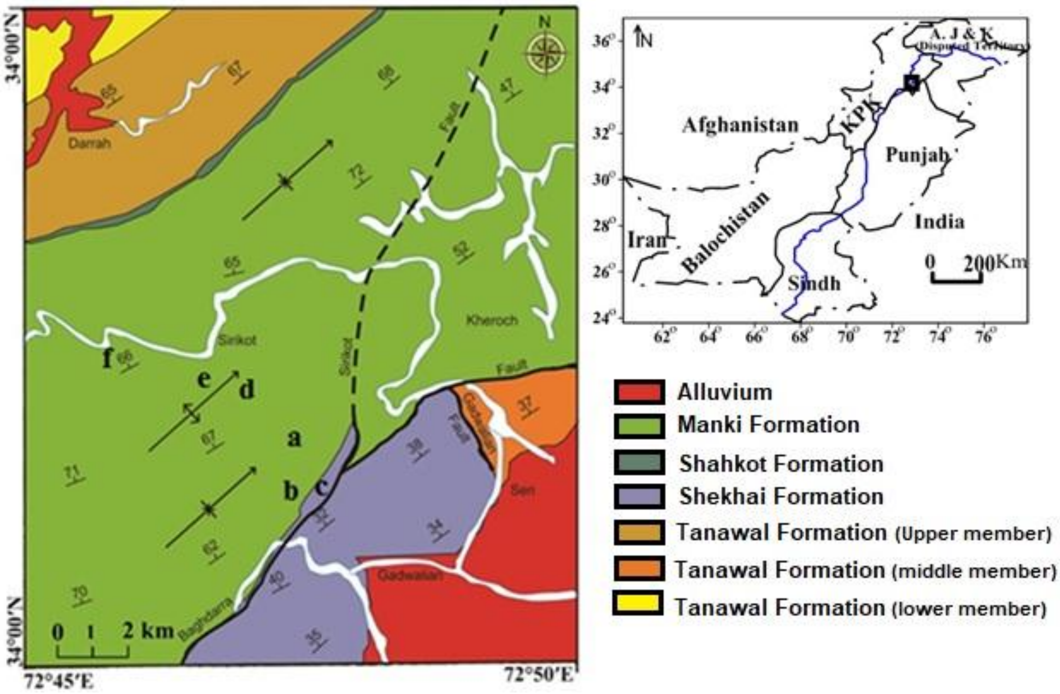

Fig. 1 Geological map of study area (adapted from Riaz et al, 1991) with (a-f) showing the selective locations of representative samples. Inset shows the general location of Haripur marked with black rectangle. Blue line shows the Indus River.

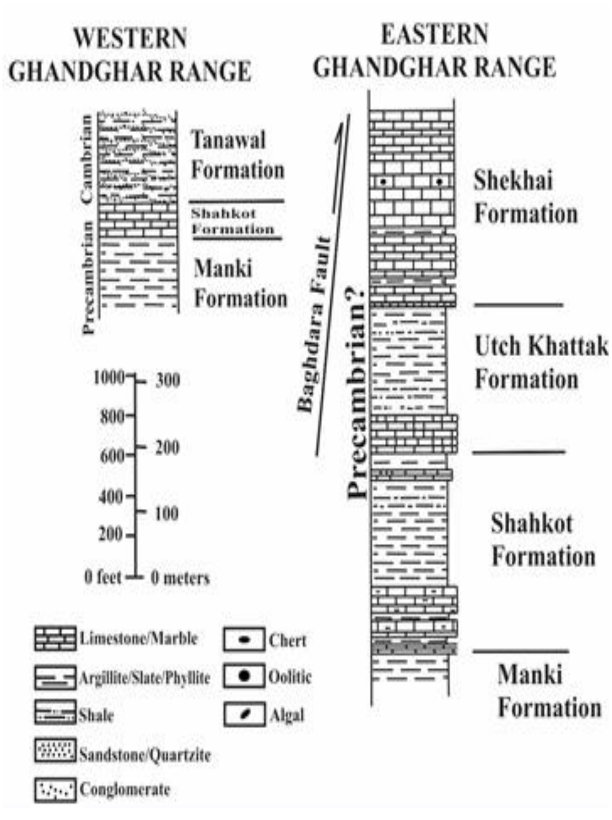

Fig. 2 Stratigraphy and nomenclature of the Gandghar Range (Hylland et al., 1990).

Thirty localities were selected from different parts of the Sirikot area for the present. However, only six representative locations were used to classify areas of potential hazards (Fig. 1). The method is to draw a circle of already known and the determined radius (Davis et al., 1996). A predetermined circle of 50-70 cm radius was drawn, and then all the fractures lying in that circle are marked and characterized by lengths, widths, strike, and dip (Baitu et al., 2008). Following three formulae have been used for calculations of the analysis,

$F.D = \Sigma L / \pi r^2$ (Davis et al., 1996)

Porosity = $(1/A) \sum_{i=1}^{N} (Li \times Wi)$ (Baitu et al., 2008)

$K = (3.5 \times 10^8)(1/A) \sum_{i=1}^{N} (Li \times Wi^3)$ (Muskat, 1949)

Where
F.D = Density of fractures (m^{-1})
ΣL= Sum of lengths of fractures in an inventory circle (m)
r = Inventory circle's radius (m)
i = individual fracture index in inventory circle
Li = i^{th} fracture's length (m)
Wi = i^{th} fracture's width (m)
N = Total fractures in circle
A = Inventory circle area (m^2)
K = Permeability (cm^2)

Results and Discussion

The Manki and Shekhai formations are cut by several sets of fractures (Table 1, Fig. 3). Two anticlines can be seen in the figure with a syncline passing along the length of the Gandghar Range, while another adjacent anticline runsparallel to this syncline. In Inventory circle 5, thenumbers of fractures are fewer, but the total length and density are more than all other inventories. Whereasin 6, there are 22 fractures, with little less than 5 total length. All the inventory circles show the same lithology, i.e., the Manki Formation except the location 3, where Shekhai Formation occurs. The geological strength index of all the locations lies between 80 to 90 that is described as the rock intact or massive with very less widely spaced discontinuities except at location 6, where it varies between 60 and 70, showing that the rock is well connected, consisting of cubical blocks, formed by three intersecting discontinuity sets (Hoek et al., 1995). The generalized direction of principal compressive stress σ^1 is perpendicular to the extension fracture, while minimum principal stress σ^3 is parallel to the conjugate fracture set 1, mostly planar and correspond to Mode-I fractures. Set 2 belong to the Mode II origin (Davis et al. 1996). The fracture density varies between 0.02 to 0.085 (Table 1). Fracture density shows a direct relationship with porosity and permeability enhancement.

Table 1. Fracture characteristics measured along the road section of Sirikot area, Haripur.

S. No.	Density cm^{-1}	Porosity %	Permeability 10^8Darcy	Rock type	Geological Strength Index (GSI)
1	0.051	9.104	1.032	Slate	80-90
2	0.02	2.007	0.07	Slate	80-90
3	0.026	1.309	0.01	Quartzite	90
4	0.058	12.192	1.88	Slate	80-90
5	0.085	13.649	1.22	Slate	80-90
6	0.082	12.836	1.26	Slate	60-70

The results of strike and dip data plotted on a rose diagram show that the circle 1 with two sets and dominant is set 1 located the northwestern and southeastern quadrant of Figure (3a). The inventory circle 2 contains two sets, and dominant is set 1 oriented in the northwestern to southeastern direction and is lying near the fault line (Fig. 3b). The inventory circle 3 contains three sets and dominant set 1 is in the NE-SW direction, on the Baghdarra fault (Fig. 3c). The inventory circle 4 contains three sets, and dominant is set 1 in the NE-SW direction and is lying on the limb of the anticline (Fig. 3d). The inventory circle 5 contains three sets, and dominant is set 1 located northwestern to southeastern quadrant and lying on the limb of the anticline (Fig. 3e). The inventory circle 6 contains three sets and dominant is set 1 in the NE-SW direction which lies in thewestern part of the Sirikot region (Fig. 3f). Factures are discontinuities in the rocks, enhancing the porosity and permeability (Table 1). The longitudinal fractures (Baitu et al, 2008) dipping at high angles from 0.1-0.3 cm in width are very uncommon. Their length within stock circles (50-70 cm radius) ranges from 0.14-0.96 cm. These are 7.9% of total fractures (76) measured at all sampling stations. Extension fractures resulted from minor elongation parallel to the fold axis (Billings, 1972), with high dip angle and varies between 0.1-0.3cm in width. Within the inventory circles of 50 to 70 cm radius, their length varies from 0.15-0.8cm. Extension fractures are 25% of all fractures measured at six sampling stations. Conjugate shear fractures width ranges from 0.1-0.4cm(Jadoon, 2003). Within the inventory circles (50 to 70cm radius), their length increases from 0.1 to 0.92 cm. These constitute 67.1% of total fractures measured in any sampling location.

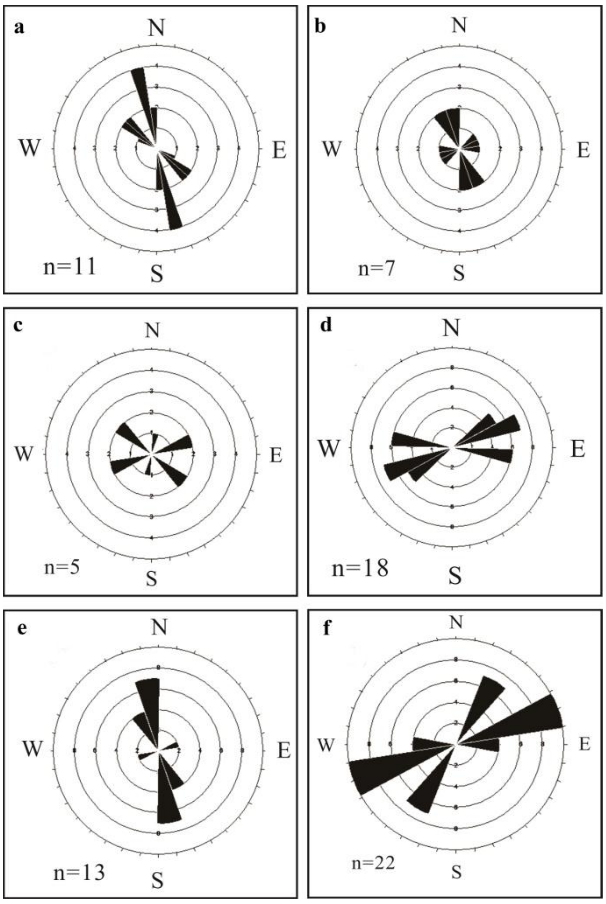

Fig.3 (a-f) Rose diagrams of fractures orientations measured at six representative localities.

The controlling factors determined for these landslides include the types of rocks, fracture type and orientation, movement and preventive measures. Most of the landslides are in the metamorphosed Manki Formation (Fig. 1a). The fracture sets based on their orientations may be classified on the basis of their occurrence on various limbs. The inventory circles 2, 3, and 5 show similar fractures orientation pattern, whereas the inventory circles 4 and 6 show another pattern. The reason being the intensity of deformation and the first category lies on the western limbs, while the other lie on the eastern limb. The third category is the stereo plot of circle one that lies between Baghdarra and Sirikot faults, which show two distinct deformation phases, where the fractures are generated. The Manki Formation consists of slate, phyllite and schists. These rocks have an inherent capability to fail along with their foliation planes. If the foliation planes arrangement is obliquely cutting the roads, then the fractures pave the way for the sliding of the material. Moreover, the fractures also provide channels for the water to flow through and penetrate the foliation planes decreasing the friction and causing a landslide.

Two types of landslides were observed in the study area, (a) translational and (b) rockfall. The prevention of these land slides in the metamorphic region is possible by improving the surface and subsurface drainage, excavating the head, strengthening the toe and constructing piles and retaining walls. While, preserving the vegetation, ditches at the base of the rock exposure, and rock bolts also control landslides in the area. Topple and rockfall are possible in the limestone and quartzite. This is linked to the process of biological weathering by trees and leads to breakage of rocks into pieces, which fall sometimes on the road. Nevertheless, the occurrence of this type of landslide is very rare, as there is usually a fair sloping ground between roads and rocks prone to fall.

Conclusion

The rockfall was found in the limestone and quartzite. This is due to the process of biological weathering by trees, which lead to the instability of the slope. These slopes required proper treatment to make this crucial road safe and stable for public transport. The failure in the stability of the landslide body is associated with decreased strength of clayey rocks along the shear surface due to moisturizing and groundwater flow pressure. Drainage work is recommended to increase the stability, besides many other engineering solutions for increasing the stability of the slopes to prevent the seepage.

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