Landslides : Investigation, Mitigation, Monitoring and Safety Measures of Al-Baha Descent

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Introduction

The government of the Kingdom of Saudi Arabia has linked all parts of the kingdom with modern roads and highways network. These roads cross many areas of various topography of high relief. The most difficult of which are those descents in the western part of the country which form an obstacle along the route of roads connecting the Red Sea coastal plain to the top of the high-rising mountains, and from there to the eastern part of the country. These descent roads play a vital role in connecting the various parts of the Kingdom in addition to ease goods transportation and security. A great deal of attention has been given by the government to solve such problems, by constructing the escarpment roads, where road cuts and bridges across the valleys have been made, in addition to driving of tunnels through the high mountains in these descents.

As one of many descent roads, Al-Baha escarpment road on Al-Baha descent was one of the important roads to be constructed across such difficult terrain, due to its importance, as it connects the Tihama coastal area with the southern parts of the most beautiful tourist areas in the country. The Al-Baha escarpment road is about 50 km to Al-Mukhwah city; along this distance there are a large number of critically man-made cut slopes in addition to the natural slope. Many of these slopes are dangerous and unsafe due to the rock fall, rockslides and different modes of slope failures, especially in rainy days. Therefore, the study and stability analysis of these slopes become of great importance to the safety of the roads which are of frequent use.

Rock slopes bearing structures, such as escarpment roads, foundations of mountain bridges, dams and open pit mines should be regularly investigated in terms of the stability of these slopes against sliding or other failures. All of these structures involve rock cuts in one way or another. Rocks occur in nature as separated masses by different types of fractures in different attitudes.

The rocks on the slopes are normally in a stable condition as long as they are not exposed to an aggravated state by disturbing the stability condition inside the rock mass, as a result of rock excavation during

building a road. Such aggravating conditions may cause graduall or sudden slope failure with a likelihood of destroying the infrastructure. In addition to loss of lives.

Literature Review

1. Rock slope stability analysis in similar descents

Stability analysis of rock slopes primarily involve a determination of the orientations of weakness surfaces (discontinuities) within the rock and the frictional characteristics of such surfaces (Hoek and Bray, 1981; Brand et al., 1983; Gianfranco, 1983; Woodard, 1999). In such study, orientation data were obtained for the dominant discontinuities in natural and man-made slope faces, then a kinematic stereonet analyses were performed for identification of combinations that could lead to rockslides (Hoek and Bray, 1981; Gianfranco, 1983; Portillo and Romana, 1983). Both fresh and altered discontinuity surfaces are tested using direct shear pull-testing techniques to ascertain shear strength parameters, cohesion (c) and friction angles (φ) (Jaeger, 1971; Chinsman, 1977; Sadagah, 1989; Watters, 1972).

A number of authors studied the stability of rock slopes along similar descent (mountains, open pits and quarries) roads in the world (Wylie, 1980; Baum, et al., 1998; and Woodard, 1999).

In the western mountainous region of Saudi Arabia, Abou-Seadah (1982, and 1989) and Ghouth-Ali (1989) studied Al-Hadah descent in the mid-western region, and Sadagah (1989), and Sadagah and de Freitas (1990a) studied both Al-Juwah and Al-Dilaa descents in the southwestern region. Sadagah and de Freitas (1990b) introduced the engineering geological maps as a technique to point the hazards along the mountain roads for 2 descents. Mathematical modeling of jointed rock masses was also discussed by Sadagah et al. (1990). Sadagah and de Freitas (1989) introduced a set of a design charts for rock-cut slopes along motorways in southern Saudi Arabia. Sadagah and Şen (1992) introduced the effect of the block size on the rock slope stability problems along the descent roads.

2. Types of rock slope failures

The structurally controlled failures in rock slopes are wedge, plane and toppling failures. Complex failure is a combination of two or more of these types. These failures are resulting from the intersection of the attitude of the present structural discontinuities (mainly joints) with the attitude of the natural or man-made slope face. Hoek and Bray (1981) used the lower hemispherical projection as a stereographic method to analyze the stability of rock slopes. The conventional stereographical method is widely and easily used. In the stereographical method, the

shear angle of the discontinuity is plotted on the Schmidt hemisphere net (lower projection) to decide the safety of the slope cut. Based upon the angle of intersection of the discontinuity with the attitude of the slope face in relation to the shear angle, the rock slope is decided wheather to be safe, critical, or failed. Direction of discontinuities dip with the slope face attitude decides the type of failure, wheather to be toppling (Choquet and Tanon, 1985; de Freitas and Watters, 1973; Goodman and Bray, 1976; Hoek and Bray, 1981; Teme and West, 1983; and Wylie, 1991, wedge or plane failure (Hoek and Bray, 1981), and others) or progressive failure (Barton, 1971). A comprehensive analysis of rock slope failure are described by a wide number of authors (Hoek and Bray, 1981).

As the scale of rock slope cut increases, simple structurally controlled failures are less dominant, and more complex failures such as step-path failures start to develop. From observations, it appears that for large scale slopes, two failure modes are especially important to consider. These are (1) rotational shear failure, and (2) large scale toppling failure. Rotational shear failure in a large scale slope involves failure both along pre-existing discontinuities and through intact rock bridges, but where the overall failure surface follows a curved path. Large scale (or deep seated) toppling failures have been observed in several large scale natural slopes and high open pit slopes.

Failure mechanisms are studied by means of numerical modeling. Analyses of different type of failure are conducted using the finite difference code *FLAC* and the distinct element code *UDEC*. Failure mechanisms of circular shear and large scale toppling failures are possible to simulate by using numerical modeling.

3. Engineering Geological Characteristics of the Rocks

The interaction between engineering geology and rock mechanics has attained today such a level as to ensure efficiency, specially in the problems associated mainly with rock materials and rock masses.

Completely watertight (impermeable) rock masses are unlikely to exist. Many types may be classified as practically watertight; however, rock masses are generally considered more or less water bearing because of their inherent porosity fractures and other discontinuities. Very watertight rock masses can be found in igneous rock massifs, and metamorphic rocks. On the other hand, properties of the rock fractures such as aperture and roughness distribution have an influence on the water transport in the fractures network systems.

Weathering conditions of the rock material in the site could lead to percolating any surface liquid to a distance from few centimeters to couple of meters; where it could later render through the fracture system

in the rock mass for an unlimited distance. Hence cause serious problems in the rock mass stability.

A detailed study of the engineering characteristics of the rock masses and rock materials in the critical sites will include the weathering characteristics, rock mass qualities identifications, rock mass and rock materials properties and strength properties.

In addition, application of a new technique of quantifying the regional fracture pattern in the mountainous areas (Sadagah and Qari, 1993) will be practiced.

Also, a study of shear strength characteristics of discontinuity surfaces, τ and c using insitu test methods such as direct Hoek's shear box test. In addition, too many other variables affecting rock mass/material parameters affecting the stability of the rock masses (Priest and Hudson, 1979; Palmstrom, 1982; Barton, et al 1974; Barton, 1976; Bieniawski, 1974; Bieniawski, 1976; and Deere, 1964).

4. Design of Rock Slope Stability & used methods

The graphical method using the stereographic projection technique by Hoek and Bray (1981) is widely used in the field of rock mechanics and structural geology for analyzing the planar discontinuity surfaces. This method of analysis is a useful tool for delineation between possible failure and non-failure conditions in slopes. The following parameters were studied:

1. Discontinuities characteristics such as attitudes, and number of sets.
2. Identification between modes of possible failures along the road.
3. Calculation of the safety factor for each studied rock slope.

Results

The findings of the research based on field, laboratory and analytical work, so far, are as follows:

1. Identifying the safe and unsafe areas along the descent road.
2. Classifying the degree of safety of rock slopes along the road using the GIS technique.
3. Calculating the probability of failure along the road.
4. Identifying the various types of failures along the descent road.
5. Recommending the remedial measures of the rock slopes along the descent road.

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فحص الانهيارات الأرضية في عقبة الباحة مع تخفيض ضررها ومراقبتها ووضع حلول لها

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المستخلص : تلعب الطرق دوراً مهماً فى تطوير إقتصاد أى دولة . وتعتبـــر الطـــرق الجبلية من أكثر المشاريع الهندسية صعوبة فى إنشائها خاصة فى المنـــاطق الـــوعرة . وتلعب الطرق الجبلية فى المملكة دوراً حيوياً فى إيصال المناطق المرتفعـــة بالمنـــاطق المنخفضة على طول ساحل البحر الأحمر.

لذلك تحتاج الطرق الجبلية عناية خاصة، وصيانة مستمرة، ومراقبة ودراسة فنية لضمان أمنها طول الوقت . وعندما تجتمع الأمطار مع التعقيد البنائى للجبال سينتج فـــى النهاية إنهيارات أرضية متعددة . هذه الإنهيارات الأرضية تحدث فجأة بدون إنذار يذهب ضحيتها أرواح بريئة كثيرة ، ولكن اعتماداً على الدراسات الفنية يمكن أن يُتوقع حدوثها ، ويُقلّل من مضارها ، ويُتجنّب حدوثها.

تعتبر عقبة الباحة من ضمن تلك العقبات التى تتعرض دائماً إلى انهيارات أرضية متعددة ، خاصة أثناء العواصف الممطرة فى فصلي الخريف والشتاء .

يهدف هذا البحث إلى دراسة المخاطر الأرضية ، ومشاكل ثبـــات المنحـــدرات الصخرية على طول طريق عقبة الباحة ، وذلك بغرض تحديد المناطق الخطرة ورسمها على خرائط جيوتقنية بإستخدام تقنية الإسقاط الرسمى المجسم ، وأحدث التقنيات ، مثل الاستشعار عن بعد ، ونظم المعلومات الجغرافية ، بالإضافة إلى الأجهزة الرقمية لتحديد المواقع . هذه التقنيات ، بالإضافة إلى الدراسات الأساسية لتحديد الخواص الجيوتقنيـــة للكتل الصخرية ، تهدف جميعها إلى التعرف على أسباب الإنهيارات الأرضية ، ووضع توصيات وحلول علمية لتجنب الأخطار على طول العقبة ، وذلك لوضع طريق العقبة فى حالة أكثر أمناً طوال السنة .