Rock Cracks and its Effects on Concrete Structures

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Abstract— In this paper, rocks with existing cracks and the effects on concrete structures it supports is discussed. Based on this paper, rock cracks may occur naturally when the rock gets closer to the earth surface due to erosion, through weathering processes (particularly frost wedging in mountainous areas and the diurnal heating and cooling of a rock outer layer in hot arid environments) and through tree roots. Artificially, cracks in rock may be caused by shock waves during rock blasting. The effects of rock cracks on the concrete structure the rock supports could be any or all of the following: settlement of the structure, loss of strength by the concrete structure and the eventual collapse of the structure.

Keywords: Cracks, Concrete Structures, Discontinuities, Effects, Rocks

I. Introduction

Rock mechanics is defined as the study of the properties and behaviour of accessible rock masses due to changes in stresses or other conditions [1]. Rock (Fig. 1) is a commonly seen material in geotechnical engineering [2], [3], [4], [5]. Rock engineering is not a modern discipline because as reported in [6], even as early as 1773, Coulomb included results of tests on rocks from Bordeaux in a paper read before the French Academy in Paris. It has been in existence since ancient time without professional attention until the catastrophic failures of the foundation of the Malpasset concrete arch dam in France resulting into flooding and killing about 450 people in December 1959; as well as the death of about 2500 people in the Italian town of Longarone as a result of a landslide generated wave which overtopped the Vajont dam in October 1963 [6].

Fig. 1: Zuma rock in Nigeria [7]

Fig. 2: Cracks in rock [8]

A crack in rock is a kind of fracture that causes discontinuity in a rock mass (Fig. 2). According to [9], It is well known that rock mass is discontinuous and inhomogeneous due to numerous joints, cleavages, beddings, and faults present within it, and the increasing number of engineering practice, such as mining, tunnelling, and hydraulic power station, has fuelled growing research interests on fractured rock mass. Data about cracks and other fractures inside rocks are often times obtained through borehole core retrieved during the drilling process, scans using borehole television cameras or indirect methods using geophysical techniques [10]. Cracks in rock heavily influence its stability in geologic structural and engineering activities [11], [12], [13]. Cracks in rock have direct influence to its physical and mechanical property, which is directly linked to rock's deformation and failure [3], [4], [14], [15], [16].

Many researchers [17], [9], [18] have carried out a lot of investigations on cracks in rocks but none has sought to find the effect of rock cracks on concrete structures. For instance, "Ref. [17]" conducted a research on the mechanical properties and failure modes of rock specimens with specific joint geometries in triaxial unloading compressive test. Cracking and failure in rock specimen containing combined flaw and hole under uniaxial compression was conducted by [9]. "Ref. [18]" studied the evolution procedure of multiple rock cracks under seepage pressure. "Ref. [19]" studied the cracks generation, development, extension and connection; proposed eight crack connection patterns and found the influence of connection pattern to rock sample strength. This paper aims at explaining how cracks in a rock mass can affect the structural performance of concrete structures (Figs 3, 4 and 5) built on or around rocks.

Fig. 3: Houses built on rocks [20]

Fig. 4: Concrete bridge with its abutments on rocks 1 [21]

Fig. 5: Concrete bridge with its abutments on rocks 2 [22]

II. GEOMETRICAL PROPERTIES OF DISCONTINUITIES

Since crack like other rock fractures causes discontinuity within a rock mass, it is worthwhile to discuss the geometrical properties of discontinuities. In Fig. 6, a schematic representation of two planes within a rock mass is presented. According to [10], there are no assumptions about whether these planes are real or imaginary surfaces or sections. Also, the borehole or scan line could be real, or postulated solely for the purpose of analysis. This diagram shows the main features of rock mass geometry with, in particular, the following parameters being illustrated and explained by Hudson in 1989 and cited by [10]:

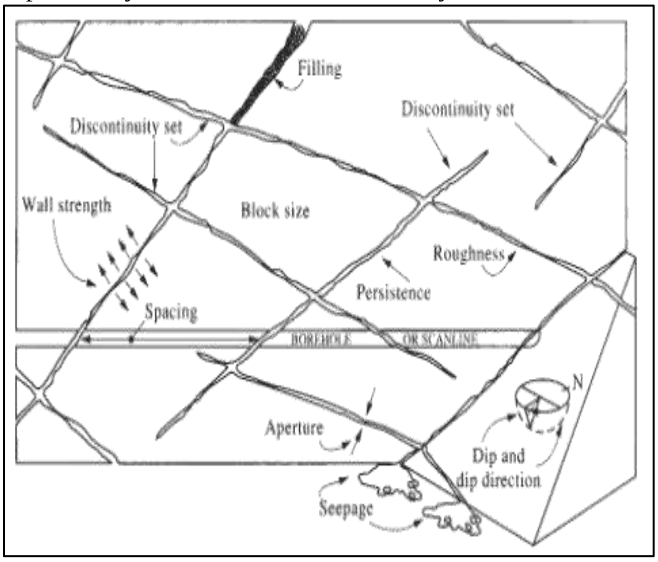

Fig. 5: Schematic of the primary geometrical properties of discontinuities in rock [10].

A. *Spacing and Frequency*

Spacing is the distance between adjacent discontinuity intersections with the measuring scan line. Frequency (i.e. the number per unit distance) is the reciprocal of spacing (i.e. the mean of these intersection distances).

B. *Orientation, dip direction/dip angle*

The discontinuity is assumed to be planar and so the dip direction (the compass bearing of the steepest line in the plane) and the dip angle (the angle that this steepest line makes to the horizontal plane) uniquely define the orientation of the discontinuity.

C. *Persistence, Size and Shape*

The extent of the discontinuity in its own plane, incorporating factors such as the shape of the bounded plane and the associated characteristic dimensions (e.g. the discontinuities could be assumed to be circular discs for the purpose of analysis and sampling).

D. *Roughness*

Although discontinuities are assumed to be planar for the purposes of orientation and persistence analysis, the surface of the discontinuity itself may be rough. Discontinuity roughness may be defined either by reference to standard charts or mathematically.

E. *Aperture*

The perpendicular distance between the adjacent rock surfaces of the discontinuity. This will be a constant value for parallel and planar adjacent surfaces, a linearly varying value for non-parallel but planar adjacent surfaces, and completely variable for rough adjacent surfaces.

F. *Discontinuity Sets*

Discontinuities do not occur at completely random orientations: they occur for good mechanical reasons with some degree of 'clustering' around preferred orientations associated with the formation mechanisms. Hence, it is sometimes convenient to consider the concept of a discontinuity set (which consists of parallel or sub-parallel discontinuities), and the number of such sets that characterize a particular rock mass geometry.

G. *Block Size*

As is illustrated in Figure 5 and depending on the previously described characteristics, rock blocks can be present. In terms of excavation and support, it is helpful to have an estimate both of the mean block size and the block size distribution, which is an insitu analogue of the particle size distribution used in soil mechanics.

III. Causes of Cracks in Rocks

“Ref. [23]” explained that the natural causes of cracks in rocks could happen in any of the following ways: A common process is that rocks crack occur as they get exhumed (that is, when they get closer to the earth surface as erosion occurs at the surface) because the release of pressure causes the rocks to expand slightly, causing them to crack. Weathering processes can also crack rocks; particularly frost wedging (common in mountainous areas) and the diurnal heating and cooling of a rock outer layer in hot arid environments. Tree roots can as well be responsible for the natural cause of cracks in rocks.

“Ref. [24]” opined that in rock blasting, the shock wave is mainly responsible for cracks lengths in the remaining rock walls; and that gases have no remarkable effect on cracks for an emulsion explosive but are responsible for moving the rock. Olsson’s findings are in line with the most common theory of breakage proposed by Langefors in 1973 as cited by [24] which states that, first the shock wave causes radial cracks to form around the hole, and then the gases penetrate into the cracks, widen them and make them longer.

IV. Effect of Rock Cracks on Concrete Structures

Rocks with existing cracks may have disastrous effects on concrete structures built on or around it. The following could occur to any concrete structure as a result of cracks in the rock on which it is built:

1) Settlement of structures like building and bridges having concrete foundation on rocks may occur as a result of cracks in the rock. This is because cracks in rocks tend to expand due to the reaction of the rock mass with chemical solutions that use the crack as a transportation medium. Frost action can also cause the expansion of cracks in rocks.
2) The presence of cracks in rocks could lead to the collapse of the concrete structure it supports. This is possible because when chemicals or water move through the cracks, they react with the rock mass, wear it away slowly, continuously reduce the strength of the rock mass, thereby making the rock mass unable to bear the load of the concrete structure it supports.
3) Cracks in rocks may also lead to loss of strength of the concrete structure due to acid attack, since acidic solution may flow through the cracks to the concrete structure. According to [25], acid attack is the dissolution and leaching of acid-susceptible constituents, mainly calcium hydroxide, from the cement paste of hardened concrete. This action results in an increase in capillary porosity, loss of cohesiveness and eventually loss of strength. In pronounced instances, acid attack may be accompanied by crack formation and eventually disintegration of the concrete, especially when the structure is subjected at one side to water pressure.

V. Conclusion

The following conclusion can be made from this article:
Cracks in rocks can be caused naturally by tree roots, weathering processes and as the rock gets closer to the earth surface. Artificially, rock cracks could be caused by shock waves during rock blasting. Cracks in rocks may cause the settlement of the concrete structure the rock supports. Cracks in rocks may also lead to the loss of strength by the concrete structure the rock supports and eventually leads to collapse of the structure.

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