IJournals: International Journal of Software & Hardware Research in Engineering
ISSN-2347-4890
Volume 4 Issue 10 October, 2016

Joints in rocks: its multi-applications in rock engineering and mining

Ahmed H. Ahmed

Abstract

Most rocks are broken relatively small fractures known as joints. The length of such fractures could be in metres, tens or even hundreds. Because of weathering, joints may be enlarged into an open tissue that is especially common in limestone regions. A knowledge of joints is important in many kinds of geological and geotechnical studies. Quarry operations, especially for obtaining blocks of certain dimension and sizes are obviously greatly influenced by the joints. The orientation and concentrations of joints is very significant in engineering projects such as in tunnelling, highway landslide and water supply in granites. Relatively few data are available on the age of the pointing which are of vital in any analysis of the genesis. The paper discusses origin of the joints, types and most significantly the practical significance of joints particularly in mining.

1-Introduction

What is joints? Joints are defined as fracture surface along or across which the movement is negligibly small. A joint may not show a displacement in the macroscopic scale, but may show evidence of displacement in microscopic scale. An array of parallel joints constitutes a joint set. Planar, parallel joints are also described as systematic joints. Joints may range from the shortest few mm (micro joints) to many tens of meters (master joints) in length. As shown in Figure 1 Joints are brittle fractures which develop either by tensile failure or by shear failure. When this happens, the rock fractures in a plane parallel to the maximum principal stress and perpendicular to the minimum principal stress (the direction in which the rock is being stretched). A large number of joints form after the close of the tectonic cycle and during a slow uplift of the rocks.

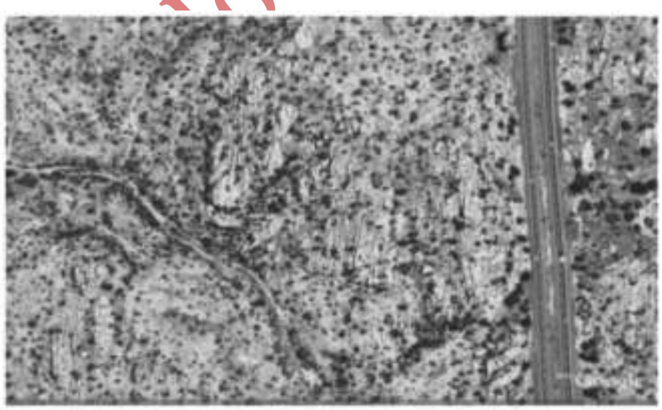

Figure1: Aerial photo showing joints in granite

Dr. Ahmed H. Ahmed is a faculty member in the university of Zambia, School of Mines , Department of Geology, Lusaka, Zambia.aahmed@unza.zm

ISSN-2347-4890
Volume 4 Issue 10 October, 2016

A key point to remember when using your compass to measure strike and dip, is that the long axis of the compass is the line you are measuring the orientation.

2-The Origin of Joints

All rock bodies at some stage of their history have been subjected to some kind of structural movement in one way or another. Examples of such movements are compaction, contraction, expansion, uplifting, subsidence, thrusting and folding. These movements take place in response to stresses of various origin, such as gravity, thermal stresses and tectonic stresses. In turn, however, these movements will build up new stresses within rock bodies and the rocks will try to adjust themselves in order to accommodate (‘get rid of’) these stresses. Joints, then are in many cases the planes along which the internal adjustments within the rock bodies take place. The variety of structural processes involved already indicates that joints can be formed in many ways. The main mechanisms are as follows:

a. By contraction that takes place in cooling igneous bodies, in particular in tabular igneous bodies like dykes and sills. These bodies frequently exhibit typical polygonal or columnar jointing, as a result of tensional stresses. The 6 – sided columns are formed perpendicular to the cooling surface so that they are often vertical This process is similar to the formation of polygonal cracks in a drying mud. Figure 2

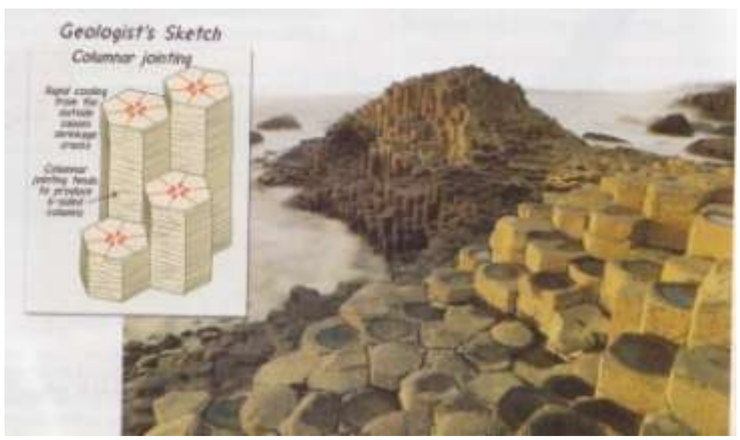

Figure2: Columnar joints in basalts

b. By unloading. Due to the weight of overlying rock masses, deeply buried rocks are compressed under great stress. While the overlying rocks are being eroded away, the load pressure reduces and in response the rocks expands. Hereby the stored stresses are released by the development of tensional joints. These joints tend to be parallel to the bedding or, in the case of massive rocks, to the Earth’s surface. The latter type can often be seen in larger exposures.
c. By volumetric_changes, connected with weathering processes. This mechanism may be closely related to the previous one. Alternate cooling and heating with large temperature differences between day and night may result in exfoliation_joints_Figure 3, or sheet joints which are parallel to the exposure surface, and is often seen in massive granites.

ISSN-2347-4890
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Figure3: Pressure release could have caused the exfoliated granite sheets shown

d. In response to regional deformation, connected with stresses of tectonic origin. Joints formed this way are associated with other structures, such as folds or faults which were formed by the same stresses. These joints tend to form systematic geometrical patterns over larger areas which can be related to the orientation of the folds or faults

The difficulty in the study of joints is, that it is often impossible to tell why and how exactly they were formed. Because no displacements can be observed along them, it is impossible to establish the age relations between different joints or joint sets. For the same reason it is not possible to link the formation of joints in a given area to a deformation event. Furthermore, because joints are surfaces of no cohesion, already existing joints will be picked out to serve as the sites of renewed movement during later deformation, whereby the original joints may develop into faults. For these reasons the study of joints tends to ignore the history of their formation but instead concentrates on their geometrical aspects.

3-Classification of joints by geometry

The geometry of joints refers to the orientation of joints as either plotted on stereo nets and rose-diagrams or observed in rock exposures. In terms of geometry, three major types of joints, nonsystematic joints, systematic joints, and columnar jointing are recognize

Nonsystematic joints are joints that are so irregular in form, spacing, and orientation that they cannot be readily grouped into distinctive, through-going joint sets.[

Systematic joints are planar, parallel, joints that can be traced for some distance, and occur at regularly, evenly spaced distances on the order centimeters, meters, tens of meters, or even hundreds of meters. As a result, they occur as families of joints that form recognizable joint sets. Typically, exposures or outcrops within a given area or region of study contains two or more sets of systematic joints, each with its own distinctive properties such as orientation and spacing, that intersect to form well-defined joint systems.

Based upon the angle at which joint sets of systematic joints intersect to form a joint system, systematic joints can be subdivided into conjugate and orthogonal joint sets. The angles at which joint sets within a joint system commonly intersect is called by structural geologists as the *dihedral angles.* When the dihedral angles are nearly 90° within a joint system, the joint sets are known as *orthogonal joint sets*. When the dihedral angles are from 30 to 60° within a joint system, the joint sets are known as *conjugate joint sets*

Within regions that have experienced tectonic deformation, systematic joints are typically associated with either layered or bedded strata that has been folded into anticlines and synclines. Such joints can be classified according to their orientation in respect to the axial planes of the folds as they often commonly form in a predictable pattern with respect to the hinge trends of folded strata. Based upon their orientation to the axial planes and axes of folds, the types of systematic joints are:

- *Longitudinal joints* – Joints which are roughly parallel to fold axes and often fan around the fold.
- *Cross-joints* – Joints which are approximately perpendicular to fold axes.
- *Diagonal joints* – Joints which typically occur as conjugate joint sets that trend oblique to the fold axes.
- *Strike joints* – Joints which trend parallel to the strike of the axial plane of a fold.

Cross-strike joints – Joints which cut across the axial plane of a fold

Some joints are irregular in form and orientation and cannot be combined into a distinctive set. These joints are said to be non-systematic and are of little value in the analysis of joints.

The magnitude of joint planes varies enormously, from microscopic cracks in minerals to through – going surfaces hundreds of meters in extent. Within a joint set all sizes may occur and according to their size it can subdivide themin the following way Figure 4:

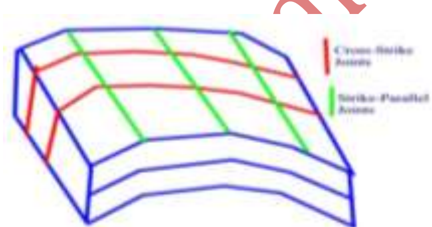

Figure 4 Joint sets

Figure 5 show block diagrams illustrating the three modes of crack surface displacement (a) Mode I, (b)Mode II, (c) Mode III. Mode I is a tensile crack and Mode II and Mode III are shear-mode cracks.

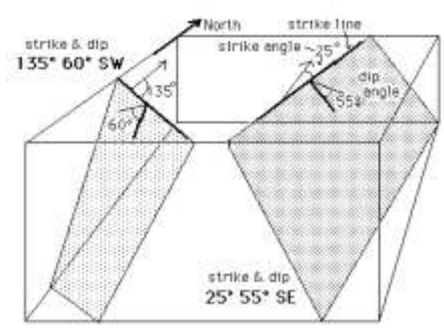

Figure5: Fracture patterns developed in joints and measurement of the angles of joint

Master joints: joints cutting through a number of beds or rock units, which can be traced over tens of metres or more.

Major joints: joints which are a magnitude smaller than the master joints, but still very well defined in an outcrop.

Minor joints: joints represented by relatively unimportant breaks.

Micro joints: minute fractures measuring up to some centimeters.

It should be noted that this classification is not very strict. The divisions between the different categories can freely be chosen to suit the user and will depend on the actual size range present in the study area.

Joint frequency indicates the number of joint planes of one particular set encountered within a unit distance, for instance per meter. A high joint frequency implies a small spacing between adjacent joints in a set. This spacing may vary from some millimeters to tens of metres and this variation is related to the lithology. In incompetent rocks such as shale or mudstone the joint frequency is usually much higher than in competent rocks such as sandstone or limestone. Furthermore, thin layers tend to be more jointed than thick, massive layers. A sudden increase in the joint spacing may also indicate the presence of a fault.

In many outcrops one set of joints is seen to be dominant, having a higher frequency and larger size than other sets in the outcrop. The joints of this dominant set are refered to as primary joints. The subsidiary set(s) is termed secondary joints.

When taking genetic aspects into account, we can classify joints by looking at the sense and nature of movement that produced them.

(i) Dilatational, tensional or extensional joints are joints formed by (minute) displacement **perpendicular** to a fracture surface (Figure .6). After discussion of principal stresses in chapter 8, you will understand that the joint plane must be a principal plane normal to the minimum principal stress σ_3, because there is no shear component.
(ii) Shear joints form when the movement is **parallel** to the fracture surface: a **shear** movement . Often they form conjugate sets under an angle of c. 60^o.
(iii) Hybrid joints show components of both extension and shear displacement

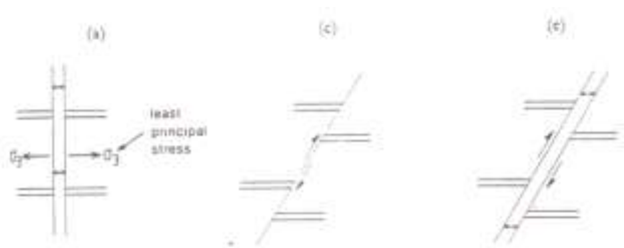

Figure 6: The basic types of joints (after MacClay 1987)

Pure tension joints will have a rough, irregular surface with a tendency to emphasize small variations in lithology . Plumose structures are also thought to be indicative of extensional joints. Shear joints, on the other hand, will tend to cut across in homogeneities and may be characterized by a smooth, even, slicken sided surface, maybe coated with quartz or calcite fibres parallel to the joint surface

Very often, however, it is impossible to tell from one joint only if it is of the extensional, shear or hybrid type. Joints and joint sets have to be studied in relation to each other and in relation to fold systems (see below). Another complicating factor is that later deformation may cause movement along joint planes that is quite different from the initial movements. It is only the **last** movement which leaves its traces.

Tension and shear joints are often well developed in flat lying sediments Figure 7, where they form well defined sets of systematic joints at right angles to the bedding . Commonly, only two joint sets are found at right angles to each other, which are probably extension joints. Another two sets, forming together a **conjugate** set, may be developed at an acute angle of c. 60^{o} to one another. These are most likely to represent shear joints.

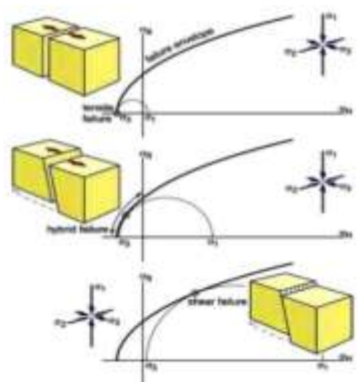

Figure 7 **Tension shear joints**

4-The practical significance of Joints

Knowledge of joints is important in many branches of geology, because they may control the transport and circulation of various types of geological fluids through rocks.

In hydrogeology, for instance, the study of joints is essential to determine the movement and storage of ground water and penetration of surface water into the rocks. Well-jointed rocks, which are otherwise impermeable to water, may form important water reservoirs.

Hydrothermal fluids are hot_fluids charged with all sorts of chemical components formed from cooling magmas which have intruded the Earth crust. They represent the late-stage residue of the magma after most of it has crystallized. These fluids are injected into the surrounding rocks, through fractures formed by the intruding magma and along already existing joints and faults. From these fluids metallic and non-metallic economic minerals may be precipitated to form veins. Many of the worlds' mineral deposits are formed this way.

Joints also may play a role in the migration and concentration of hydrocarbon fluids, such as oil and gas and are therefore important in oil exploration.

Furthermore, joints are extremely important in mining and quarry operations from a geotechnical point of view. They not only determine the design and safety of mine shafts and tunnels but also the actual technique to be applied to exploit the ore in mines. The quarrying of slabs of ornamental stones, such as marble, granite or slate etc., is fully determined by the presence and disposition of joints.

It is not always possible to make a definitive test on support of engineering decision involving rock, and sometimes it is not even possible.

Numerous schemes have been developed to guide judgement through standardized procedures and descriptions. Thereespecially well – received rock classification systems, originally advanced for tunnelling, are those developed by Barton, Lien, and Lundu (1974), Bieniawaski (1974,1984), and Wickham, Tiedeman and Skinner (1974).

Bieniawski Geomechanics classification system is based upon five universal parameters; strength of rock, drill core quality (RQD), ground water conditions, joints and fracture spacing, and rock joint characteristics. A sixth parameter, orientation of joints is used entirely for different application in tunnelling, mining and foundation. Rock mass rating corresponding to each parameter are summed up to determine rock mass rating (RMR). The overall RMR rating of the rock mass, the rock in one of the five categories defined in Table 1*Table 1. Geomechanics classification of rock mas*

class	Description of rock mass	**RMR**
I	Very good rock	81 - 100
II	Good rock	61 - 80
III	Fair rock	41 - 60
IV	Poor rock	21 - 40
V	Very poor rock	0 - 20

The other method of rock mass classification suggested by Barton, Lien, and Lunda (1974) (also called NG I system) consider six parameters in multiplicative functions as given below:

$$Q = \left(\frac{\mathrm{RQD}}{\mathrm{Jn}}\right)\left(\frac{\mathrm{Jr}}{\mathrm{Ja}}\right)\left(\frac{\mathrm{Jw}}{\mathrm{SRF}}\right) \quad \text{eq.} \quad \text{(i)}$$

Where RQD is the Rock Quality Designation, Jn relates to the number of joint sets, Jr relates to the roughness of the most important joints, Ja releases to the wall rock condition and/or filling material , Jw relates to the water flow characteristics of the rock. and SRF relates to looseness of rock and stress condition

The Q system and RMR system approximate connecting relationship, based on large number of case histories with standard deviation (9.4) is given below:

RMR = 9 log Q +44 eq. (ii)

It is worth noting that both RMR and the Q – system uses joints in rock to class rock as very good rock, good rock, fair rock, poor rock and very poor rock. This type of classification of rock help in determining hardness of rock which has application in choosing metals for drilling and cutting for mining, deep exploration, construction of pressure tunnels for storage of fluid (petrol and hydrocarbon gases) construction of dams. Also the overriding influence on rock behaviour in many instances stems from the characteristics of the discontinuities including joints, fractures, foliation and bedding. Joints have very special significance in excavation of dimension stones such as, limestone, marble, mica sheets where dimension and size matters in their applications.

5-Conclusions

A knowledge of joints is important in many kind of geological studies, rock engineering (which have thousands of applications in dealing with sensitive engineering projects, building rocks including some precious stones where certain dimension and sizes of utter importance. These are greatly influenced by joints. Many studies of joints have been made in order to deduce the orientation of the stresses to which the rocks have been subjected. However, the research is still in progress to have precise knowledge to have better use of joints in every aspect of engineering and mining projects. The need of precise study of joints cannot be over emphasized.

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