3

Defects in Rock Mass

3·1. Discontinuities and Defects in Rock Mass

When the foundation of an engineering structure will be put on a rock mass an information regarding the type of rock, such as igneous, sedimentary or metamorphic, is not sufficient. The rock may be an igneous one, but it may consist of a lot of discontinuities in the mass which may make the rock unable to withstand high stresses due to the superstructure.

Therefore, for proper design of engineering structures 'on' and "in" rock, it is necessary to have a good information about the existing and probable discontinuities or weaknesses inside the rock mass. These discontinuities and weaknesses may be in the following forms.

Fractures, Cracks and haircracks, Fissures, Bedding planes and laminations, Stratification, Joints, Faults, Folds and cavities.

In their 'in-situ' conditions rock masses consist of discontinuities in any of the above forms in varying degrees. Sometimes these fractures split the rock mass into blocks or units of rock materials. The size of blocks or units depends on discontinuities existing. Thus the rock mass has a predetermined structure prior to commencement of an engineering work. In engineering design it is necessary to specify the materials, such as brick, which will be used in forming the framework of the building. The engineer has to consider the strength and quality of the brick and accordingly he will design the framework such as foundations, and different bays with suitable columns. Similarly in case of rock masses we have to consider :

(*a*) the nature of the rock material present and

(*b*) the sub surface structural design depending upon the presence of structural faults present in the rock mass.

3·2. Cause of Defects in Rock Mass

Although the earth seems to be stable at its surface, but the earth's crust is in a state of continuous unrest which leads to gradual or sudden changes in its structure and configuration. The earthquakes generally confirms the existence of such forces. The forces within the crust which modify the structure of rocks bring out generally two types of crusted movement.

(*a*) Epeirogenic or continent-building movements.

(*b*) Orogenic or mountain building movements.

The epeirogenic or continental building movements are continuous but slow. In such cases, portions of continents or ocean floor are subjected to slow continuous movements. Due to such movements there may be upheaval or subsidence. Deformations in such cases may be uniform. The orogenic or mountain-building movements are associated with immense disturbing forces. Such movements are of more severe type, but affect the earth periodically. Due to sudden and severe disturbing forces the geological structures formed are of complicated nature.

Due to eperogenic or orogenic movements the resulting structures in sedimentary rocks are generally of simple nature due to their bedding planes. But in case of igneous or metamorphic rocks it is not so. In such cases complex structures are formed and their study is rather difficult.

3·3. Strike and Dip

Unequal forces acting on the crust cause unequal uplift or subsidence. Due to unequal uplift or subsidence, the original horizontal sedimentary beds get tilted. These tilted beds slope in some direction and subtend an angle with the horizontal plane.

The direction of the line along which an inclined bed meets a horizontal plane is known as the strike of the bed. It is described as $N(°)E$, $N(°)W$ or $S(°)E$, $S(°)W$ which means a particular angle of deviation in the direction of East or West from North or South direction. For example $N20°E$ means that strike makes an angle of 20° eastwards from the North direction. This has been shown in Fig. 3·1. Similarly $S30°E$ mean thats trike is 30° eastwards of south direction.

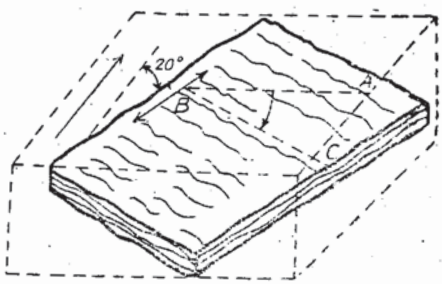


Fig. 3·1.

Dip indicates the maximum slope of a particular inclined plane. The significance of the term dip is evident with reference to the angle ABC, which the inclined plane BC makes with horizon BA, as shown in Fig. 3·2. Dip is described as $(°)N$, $(°)S$, $(°)SE$ etc. For example $20°S$ means a dip in southerly direction and $25°SE$ means a dip of 25° in South-east direction. While describing dip the true dip angle should be measured. A true dip means the angle made with horizontal by a line which lies in the inclined plane and is perpendicular to the strike. In Fig. 3·1 angle ABC is a true dip of the inclined bedding plane. Strikes and dips are used to describe joints.

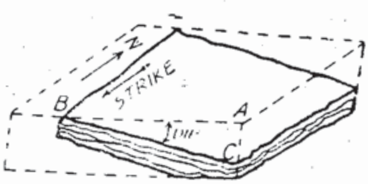


Fig. 3·2.

3·4. Bedding Planes, Stratification and other Defects

In addition to Fractures, Cracks, Fissures, Joints and Faults which indicate discontinuities of the rock mass, there are some weaknesses existing inside the rock mass which are named as Bedding planes, Laminations, Stratifications, Cleavage Planes and Partings.

Bedding planes are the planes which separate the sedimentary and stratified rocks in different layers.

Lamination of a rock strata also constitutes a discontinuity in the rock mass, and it is a mechanical weakness of rock en masse.

Stratification is layering of geological materials. There are different types of materials in the stratifications and these are the planes which helps the rock material to be separated along beding planes.

Cleavage is the property of rock mass to split into thin, parallel sheels. The cleavage planes are the planes in rocks along which cleavage takes place.

A parting is a thin layer of deposited and altered weak materials, such as carboneceous or organic, which exist as separating beds in sedimentary or metamorphic rocks.

Separation is a break between beds along bedding planes.

3·5. Joints

The tensile and compressive stresses which act within the rock are produced due to decrease in volume *i.e.*, shrinkage of the rock mass. These decrease in volume are caused due to :

(*a*) Drop in temperature

(*b*) Loss of moisture

(*c*) Drop in temperature as well as loss of moisture.

Due to tensile and compressive stresses in the rock mass regular and irregular cracks or discontinuities are developed in the rock mass.

Any break in a rock mass irrespective of its size is termed as *fracture*.

Minor fractures are designated as *cracks* and *fissures*.

Cracks along which the fractured rock masses appear to have suffered no relative displacement are known as *joints*.

Joints occur in all types of rocks, *i.e.*, igneous, sedimentary and metamorphic.

In sedimentary rocks generally there are two system of mutualy perpendicular joints both perpendicular to bedding planes.

In igneous rocks there are three regular sets of joints. They are :

(*i*) Flat laying joints

(*ii*) *Q* joints or cross joints

(*iii*) *S* joints or longitudinal joints.

Flat-lying joints are approximately horizontal and are parallel to the bedding planes.

Q joints or cross joints are almost perpendicular to the flow lines.

S joints or longitudinal joints, dip steeply and strikes parallel to the flow lines if projected to a plane surface.

The three joints are shown in Fig. 3·3.

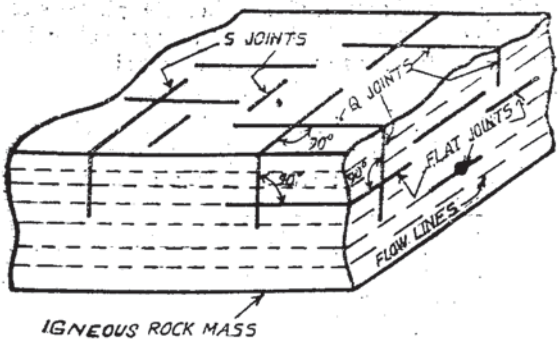


Fig. 3·3. Types of joints.

Joints seldom occur alone. Generally a number of more or less parallel joints occur together in the form of a joint set. Two or more joint-sets together constitute a joint system. A joint can be open or closed. A closed joint is one whose walls are in contact. Closed joints may be invisible. Along such surfaces there is no resistance against separation. Hence sometimes they pose serious problems if they are not detected by a proper investigation. When the structures are constructed and stresses act along such joints, sliding occurs and if not delt with properly it may endanger the structure. When a rock mass consists of many joints, the rock mass is divided into individual blocks to form a three-dimensional network. In such cases the rock mass may be considered as aggregate of uncemented,

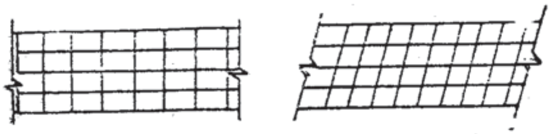


Fig. 3 4 (*a*)

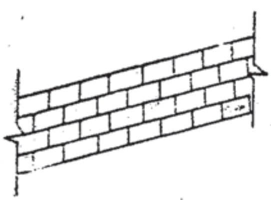


Fig. 3 4 (*b*)

cohesionless cuboid blocks. These may be compared with closely fitted blocks in a dry masonry wall. If the blocks are properly imbricated, shear strength will be more in the rock mass against the forces trying to dislocate the structure, Fig. 3·4 (*b*) whereas shear strength will be lessif imbrication will be poor as shown in the Fig. 3·4 (*a*).

3·6. Faults

When there is a displacement on each side of a fracture in the rock mass along the fracture plane, then the plane is classified as a fault. The displacement may be horizontal, vertical or both. In wide contrast with joints, faults are well defined cracks.

When several faults occur in close proximity and are parallel to each other, then the resulting zone of broken rock is called a shear or fault zone. As faults occur along well defined planes, their description in space is defined in terms of their dip and strike. In Fig. 3·5

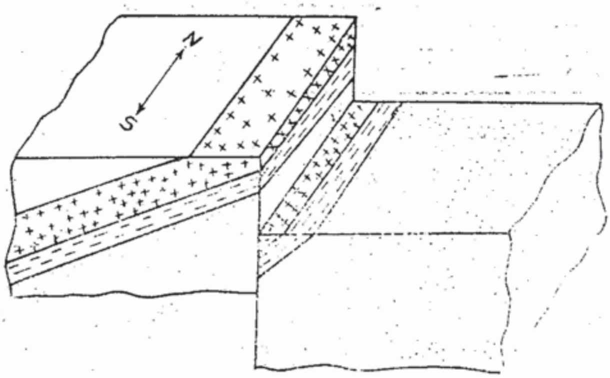
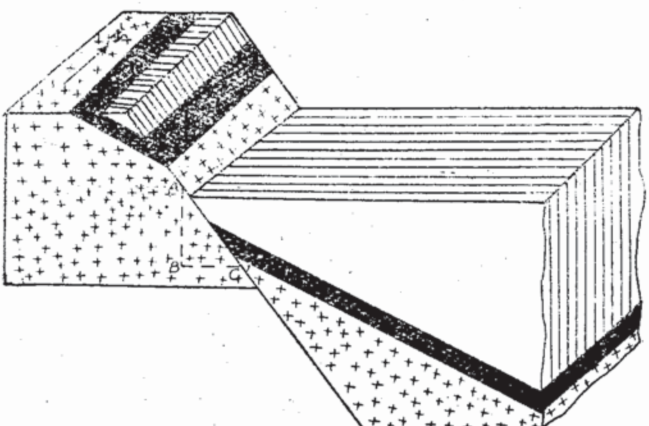


Fig. 3·5



Dip $\angle ACB=50°$
Hode $\angle CAB=40°$
Fig. 3·6

the strike of the fault is north-south and the fault is vertical. In Fig. 3·6 the fault is an inclined one and its dip is 50° towards east. The hade of a fault is the angle subtended by the fault plane to any vertical plane, striking in the same direction. Head and dip of a fault are thus complementary to each other.

The total displacement of the block due to a fault is known as its net slip. Movement of the block due to fault may be along the

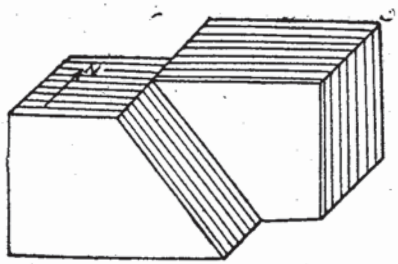


Fig. 3·7

strike or along the dip. In Fig. 3·7, it is a strike slip and in Fig. 3·8 it is a dip slip.

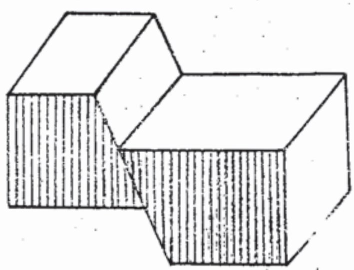
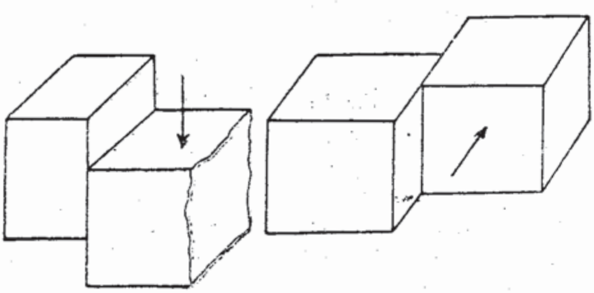


Fig. 3·8

Thus, slip along the true dip of the faulting plane is known as a dip slip whereas the slip parallel to the strike of the fault is known as a strike slip.

Depending upon the forces acting inside the crust the fault may be horizontal, or vertical as shown in Fig. 3·9 or it may be inclined



(*b*) Vertical Fault (*a*) Horizontal Fault

Fig. 3·9

as shown in Fig. 3·8. Since the fault is generally caused due to shear, failure inclined faults are more common. In otherwords it can be said that since the shear failure occurs along an inclined plane, faults occurring in nature are generally inclined. Thus the two blocks on each side of the inclined shear plane appear to rest on the other. The block which seem to support the other block is known as a foot wall side and to other one being supported on foot wall side is known as a hanging wall side as shown in Fig. 3·10.

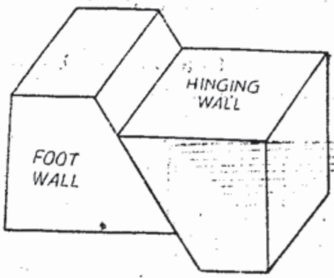


Fig. 3·10

Types of Faults

Considering the relative positions of footwall side and handing wall sides, the fault is classified in two types.

(*a*) Normal fault.

(*b*) Reverse fault.

When the hanging wall side appears to have moved relatively downwards in comparison with the adjoining footwall side, it will be called a normal fault. In a normal fault, the dip of the fault plane is usually more than 45°. In normal faults, the fault is caused mainly by vertical pressure as shown in Fig. 3·11.

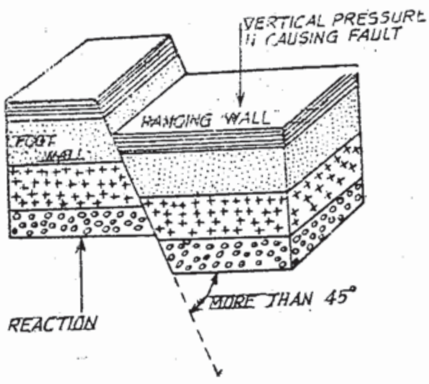


Fig. 3·11

When the footwall side appears to have shifted downwards in comparison with the adjoining hanging wall side, the fault is known as reverse fault. In such cases, the hanging wall side appears to have risen and dip of the fault plane is usually less than 45°. The reverse fault is usually caused by horizontal thrust as shown in Fig. 3·12.

When an engineering project has been taken up and a fault has been detected below the foundation, it is necessary to know whether the fault, which has occurred, may have movements in future. In fact it is very difficult to predict such phenomena. However, for

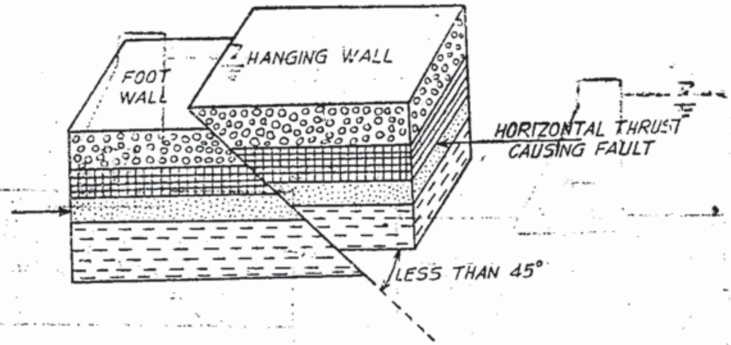


Fig. 3·12

precaution against such hazards, generally the faults are termed as Active and Inactive faults. Active faults are those in which the movements have occurred during the recorded history of mankind and in such cases further movements can be expected at any time. Inactive faults are also called as passive faults. When there is no recorded history of movement along the fault, it is known as an inactive fault. Such faults are generally assumed to be of static condition in future.

For important civil engineering works, such as the foundations of a bridge piers and masonary dam, thorough geophysical investigation is most important for an useful life of the project. For example, if a bridge foundation is put over a fault, as shown in Fig. 3·13,

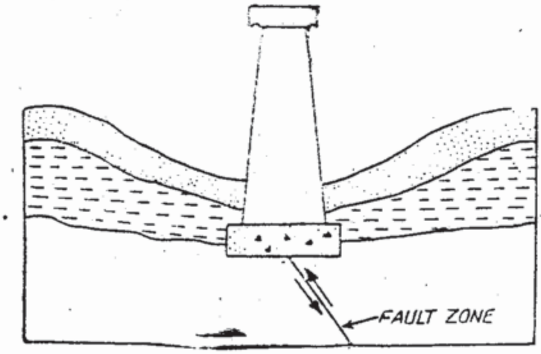


Fig. 3·13

there is a chance of sinking of the bridge pier due to the superstructure load because there might be sliding along the faulted zone.

Similarly, if a masonry dam is put on a faulted zone as shown in Fig. 3·14 (*a*), there is a chance of danger to the structure as sliding might take place due to a resultant force *R* as shown in the figure.

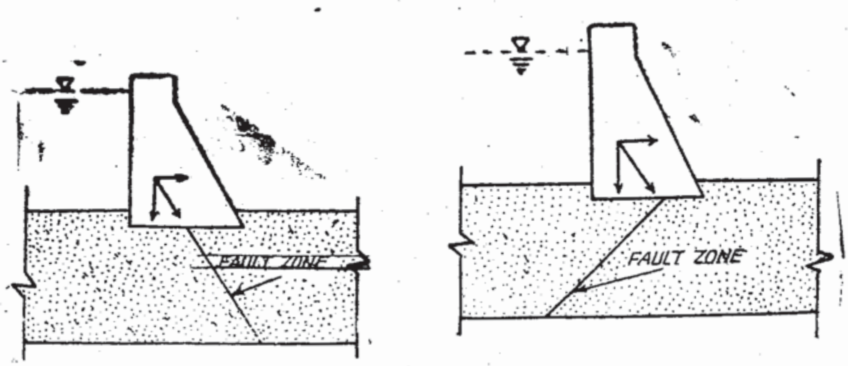


Fig. 3·14.

In such cases foundation bed is improved by grouting but if the location of the fault zone is as shown in Fig. 3·14 (*b*) danger to the structure may not be there.

Hence, with the above two examples, it is clear that location of faults or a fault zone is necessary before starting a project. But search for fault is not always effective. Sometimes, they are discovered during the construction. Faults might be burried deeply. If the foundation excavation has been started and faults containing gauge and bracciated rock is met with, then it is better to abondon the site from economic point of view. Because excessive excavation may be required to remove the fault or fault zone which may continue up to a great depth, or a ground improvement may be necessary. However, a proper decision depends upon other factors also.

3·7. Folds

Folds are wavy undulations which are developed in the country-rocks when the region is subjected to high stresses. The wave like form is made up of a series of alternate crests and troughs.

3·7·1. Modes of Folds

There are three fundamental modes of folding.

(1) Concentric folding

(2) Cleavage

(3) Flow.

Concentric Folding means that all internal movements are parallel to the bedding plane. It is fundamentally an elastic bending of an originally horizontal sheet, with development of parallel concentric shear planes in the flanks of the folds. The deformation may be called elastic-viscous, and is common in the upper part of the earth's crust, but it is not restricted to the upper part only. Concen-

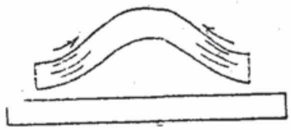


Fig. 3·15 (*a*) concentric Fold.

Fig. 3·15 (*b*) Elevage Fold.

tric folding is also known as parallel folding or distance-true folding, because the thickness of any concentrically folded bed remains unchanged.

Cleavage is a process by which all internal movement is along shear-planes which do not change their position during the process of folding. Normally they are perpendicular to the deformative stress. The process is a dilatation in a vertical direction and a compression in a lateral direction. Generally, the deformation is elastic-viscous where the elastic properties have not yet lost their influence, but it is almost near the plastic range. Cleavage is common in the lower region of *orogenic* belts [Fig. 3·15 (*b*)].

Flow is a kind of distortion in which fixed orientation between shear-planes and stress direction is lost. The internal movement is not oriented in any direction. It can take place in any direction with the result that it can no longer be represented adequately in a section. It is common in weak rocks like salt or in other rocks at very high confining pressures or high temperature The deformation of rock in such a case is plastic [Fig. 3·15 (*c*)].

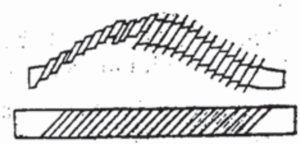
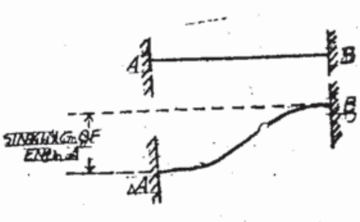


Fig. 3·15 (*c*) Oblique Shear Fold.

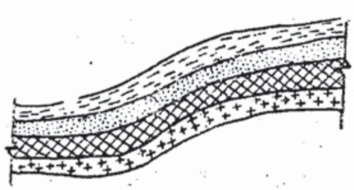
Combinations of cleavage and concentric folding are very common.

3 7·2. Types of Folds

The simplest kind of a fold is the monocline. It can be compared with a flexible beam firmly embedded at two ends. If the



(*a*)



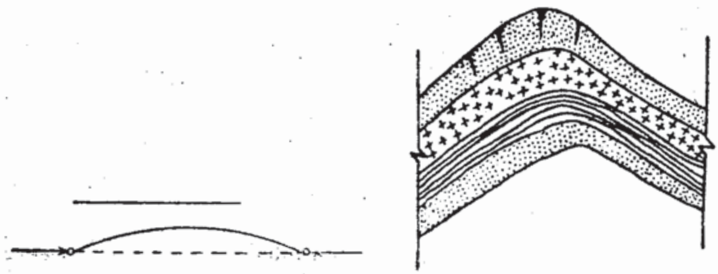
(*b*)

Fig. 3·16.

support sinks a point of inflection is formed as shown in Fig. 3·16.

Monoclinal fold may be compared with the deflected shape of the beam. Such folds are formed due to sinking of a part of the basin. Such types of folds are also termed as bedding folds.

When the fold appears in the wave form having crests and troughs, anticlines and synclines are formed. Anticlines are crests and synclines are trough of the wave form folds. In case of very large folds, consecutive crests or troughs may be hundreds of kilometres apart. The smallest folds may have several crests of troughs within a span of a few metres. The portion of rock beds laying between any crest and the adjacent trough is known as the limb of the fold. Such type of folds are known as buckling folds.



(*a*) (*b*)

Fig. 3·17

The mechanism of buckling fold can be compared with the buckling of a column as shown in Fig. 3·17 and 3·18.

An over loaded column may deflect as in Figs. 3·17 (*a*) or 3·18 (*a*). The vertical force acting on the column as shown in Figs. 3·17 (*a*) and 3·18 (*a*) can be compared with horizontal stresses acting on the rock mass inside the crust. When deflection is as shown in Fig. 3·17(*a*) Anticlines may

Fig. 3·18 (*a*)

be formed, and when deflection is an shown in Fig. 3·18 (*a*), a set of anticlines and synclines are formed. Some other theories also have been given to explain the phenomena of fold. According to this theory a change in the shape of mass is due to action of shearing stresses and not due to a compressive force. The horizontal shears may be compared with the horizontal couple, and this horizontal couple has to be counter balanced by a vertical couple. The vertical stresses are caused due to upward acting force of the vertical couple, and this causes wrapping in the upward direction which is called anticline and similarly the downward acting force of the couple will cause wrapping downward, and thus, synclines are formed. Due to folding, there will be stretching at the top of anticlines and bottom of synclines. At the top of anticlines there is no resistance to such stretching whereas at the bottom of synclines there is a resistance to stretching due to lower strata. Hence, more tension cracks develop

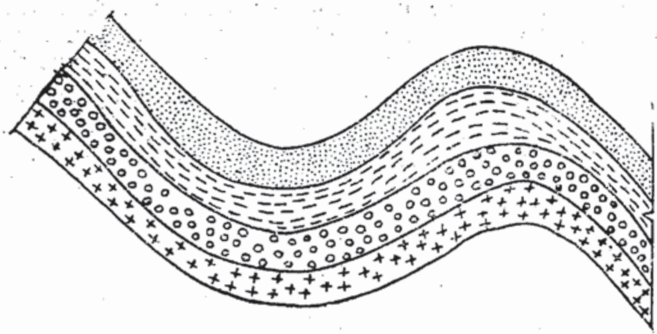


Fig. 3 18 (*b*)

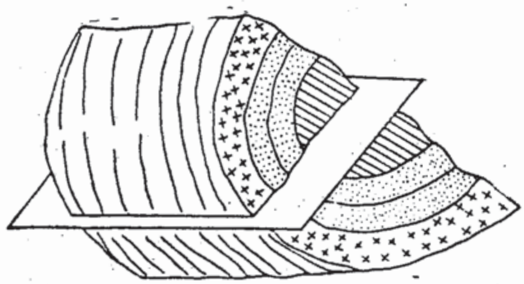


Fig. 3 19 (*a*)

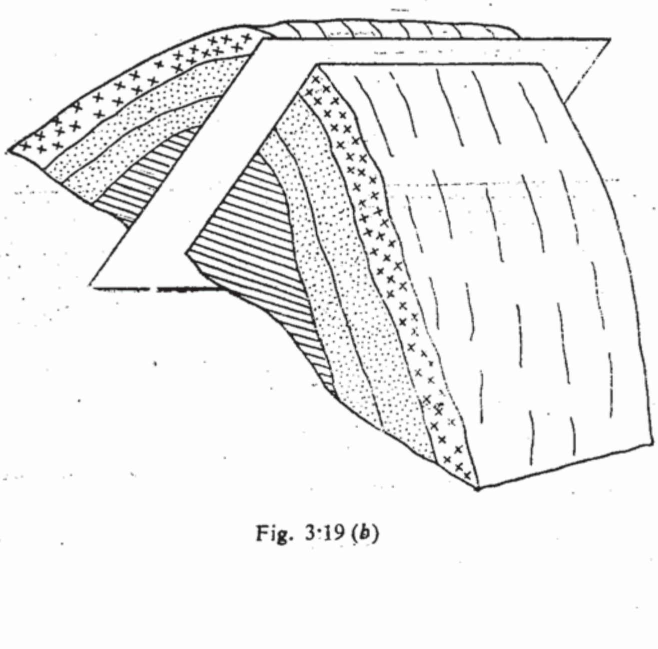


Fig. 3·19 (*b*)

at the top of anticlines. The extent of cracks depends upon nature of folding, type of rock and forces causing folding.

When the axial plane of the fold is vertical and both the limbs have the same amount of dip the fold is known as symmetrical. If the limbs have unequal dips the fold is described as asymmetrical.

3·7·3. Importance of Folds for Engineering Projects

Folds do not cause serious problems in case of foundations for buildings. But in case of dam foundations, reservoir locations and

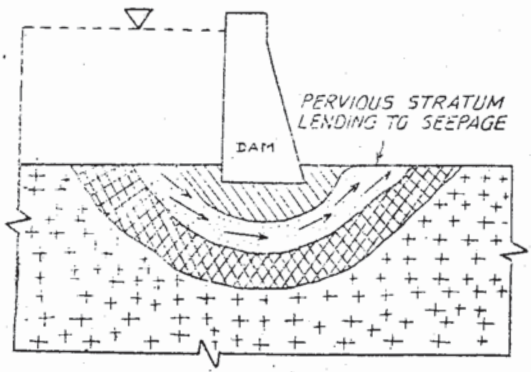


Fig. 3·20

tunnel locations, significances of folds are there. When a monocline containing pervious strata dips down stream, there will be excessive seepage below the dam from the upstream side to the down stream side as shown in Fig. 3·20. However, there is no such danger if the monocline dips upstream as shown in Fig. 3·21.

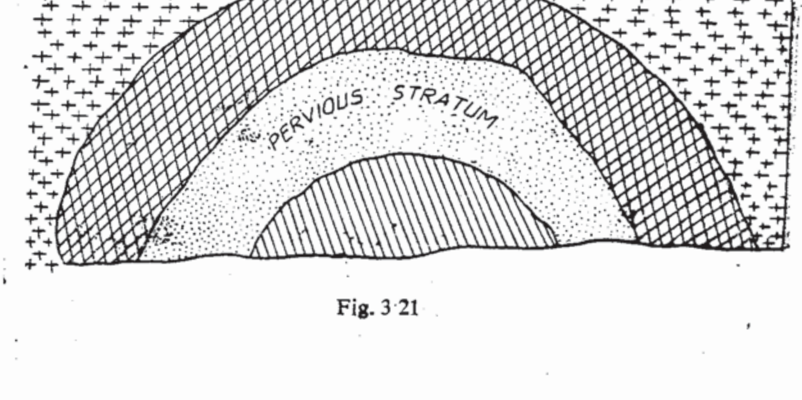


Fig. 3·21

If a tunnel passes through a cyncline, the maximum pressure is expected at the middle points of the tunnels and if pervious strata

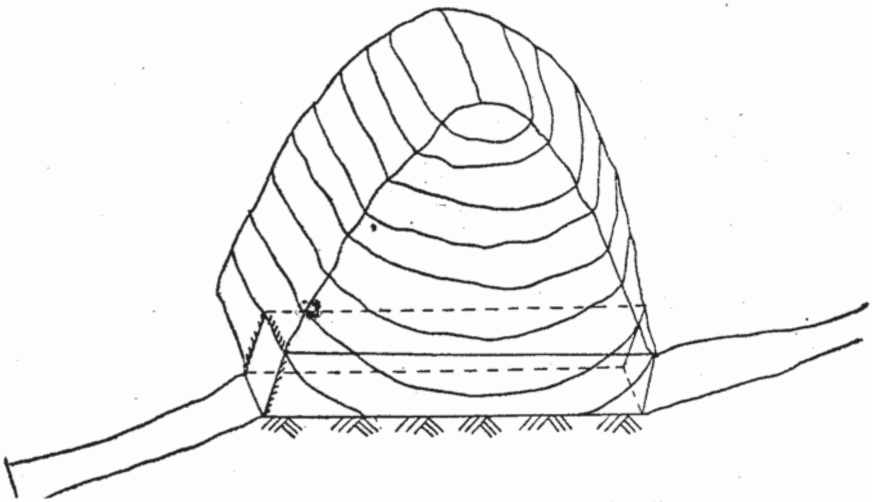
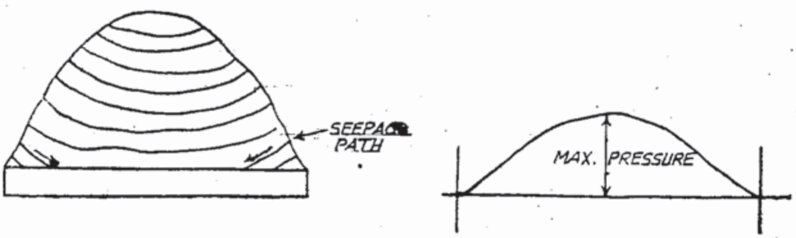


Fig. 3·22 (*a*) Tunnel Driven through a Cyncline.



(*b*) Cross-section. Fig. 3·22 (*c*) Pressure on Tunnel.

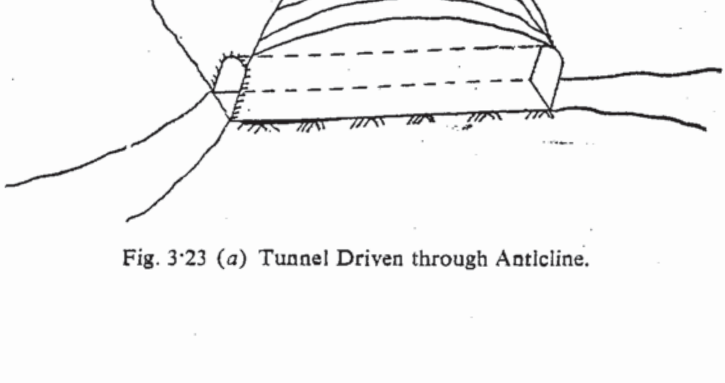


Fig. 3·23 (*a*) Tunnel Driven through Anticline.

exists in the layers, the seepage will be directed inside the tunnel which causes serious problems for the maintenance (Fig. 3·22) whereas, in case, an alignment passes through anticline, the pressure will be directed at the two ends due to an arching action, and maximum pressure will be at the two ends, and at mid-point the pressure will be minimum. Seepage due to pervious strata also will be directed at the two ends (Fig. 3·23).

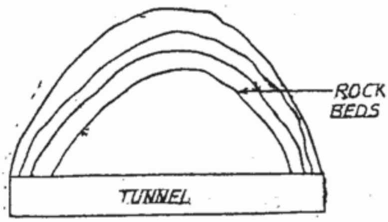


Fig. 3·23 (*b*) Cross-section.

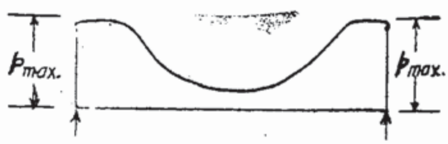


Fig. 3 23 (*c*) Pressure Distribution on Tunnel.

Thus, it is clear from the above examples that thorough information about folds is necessary for a successful performance of an engineering project.