CHAPTER VIII

MAJOR FINDINGS AND RECOMMENDATIONS

The major areas of current research in the field of mechanical behaviour of jointed rocks are :

(a) a generalized criterion of friction,

(b) a phenomenological parameter for dilation,

(c) a constitutive relationship incorporating volume change and

(d) a realistic joint element for engineering analysis.

In perspective of these principal objectives a few expositions have been established through theoretical and experimental investigations in the present study. The basic premise is centered around the phenomenon of dilation in jointed rocks.

Unequivocally, it has been recognized that the classical friction criterion in its present form is not adequate to describe the sliding on discontinuities in jointed rock. It has been clearly observed that surface characteristics during the sliding necessarily undergo alterations, the reflection of which is volumetric distortion during sliding. The question is how to account for these changing surface characteristics in the classical friction relations. While verifying the concept of friction, on the basis of experiments on plane and aspirated surfaces, it is seen that volume change is involved while sliding on asperities, underlying the need to include an appropriate parameter into the conventional friction equation.

This finding is corroborating with experimental observations on jointed rocks in laboratory as well as in in situ direct shear tests. To account for the continuous surface alterations during the process of sliding, a structural parameter independent of the basic friction is to be incorporated in the classical equation of friction. To describe adequately the mechanical behaviour of sliding in jointed rocks, it is not only imperative to incorporate the volumetric distortion in the constitutive relationship but also should bear out with a versatile mathematical technique for its meaningful utilization in the solution of problems of engineering interest.

The following are the major expositions from the present investigation :

(i) The classical laws are followed in case of sliding on plane surfaces, whether lubricated or unlubricated, while deviation from the classical laws of friction is observed in case of sliding over aspirated surfaces. The deviation is a consequence of volume change occurring during sliding. The classical friction equations, independent of volume change, therefore, need to be generalized by incorporating an appropriate parameter for volume change.

(ii) The generalized equation of sliding friction for all types of surfaces, shall be the integration of the classical sliding friction equation, rigorously true at every instant. The process of integration should include the consideration of distrotion of plane at every instant. The resultant distortion of plane at every instant of sliding can be accounted for in terms of a geometrical parameter, consisting of ratio of principal strains, well known as Poisson's ratio in classical mechanics. The classical equation,

$$\tau = f(\mu, \sigma)$$

must have a generalized form of

$$\tau = f(\mu, \nu, \sigma)$$

(iii) The phenomenon of sliding on discontinuities in jointed rock is analogous to the phenomenon of sliding on aspirated surfaces. The sliding in jointed rock therefore, is associated with continuous alterations of surface characteristics. In physical terms, the process of sliding is occurring at new plane of orientation continuously. The phenomenological parameter representative of the alteration of surface characteristics has been identified in terms of change of Poisson's ratio at every instant.

(iv) The operative equation to describe the sliding behaviour in jointed rock as deduced from the experimental observations in laboratory as well as in field is,

$$\tau = \sigma^{\cos i_0} \tan(\phi_\mu + i_0)$$

Alternatively,

$$\tau = \sigma \tan(\phi_\mu + i_{av})$$

where,

$$i_{av} = \frac{2}{3} i_0 \, \sigma^{-\tan^2(45 - \phi_\mu/2)}$$

(v) A new joint element has been developed from the basic phenomenon of sliding in jointed rock, by incorporating change in Poisson's ratio at every instant in the constitutive matrix. The constitutive matrix can be given in the following forms :

$$(D) = \frac{1}{E} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1-\nu^2 & 1-\nu \\ 0 & 0 & 1+\nu \end{bmatrix}$$

Alternatively,

$$(D) = \frac{1}{E} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 2D(1-\nu)(1+2\nu) & 0 \\ 0 & 0 & 1+\nu \end{bmatrix}$$

(vi) The developed joint element has a utility as a solid element in a finite element method. The utility has been demonstrated in predicting the behaviour of jointed rocks observed in laboratory as well as in field as also in engineering situations.

(vii) The efficiency and efficacy of the proposed new joint element has been established by realistic predictions of not only the generalized parameters of stresses and displacements but also the particular parameter associated with volume change, which is the distinguishing characteristics of the mechanical behaviour of jointed rock.

(viii) The superiority of the new element developed during this investigation is the incorporation of the phenomenological parameter of dilation in terms of change in Poisson's ratio, consequent upon which it is possible to delineate various deformation modes like compression, sliding and dilation.

It is recommended to utilize the developed joint element in nonlinear analysis of typical field situations in jointed rock like underground openings in rock, stability of rock slopes etc. It would be worthwhile to undertake the future work on dynamic behaviour of jointed rocks.