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JOINT SPACING CRITERION FOR EQUIVALENT CONTINUUM MODEL

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SUMMARY

Currently, the Yucca Mountain Site Characterization Project is investigating the feasibility of the disposal of high-level radioactive waste in the unsaturated Topopah Spring formation.[1] The Topopah Spring formation is a heavily fractured, predominantly vertically jointed, welded tuff, and the potential disposal area is cut by the Ghost Dance fault and bounded by several other fault structures. The joints in the tuff and the faults may have an impact on the emplacement drift or borehole stability, as well as on the movement of fluids through the rock mass. The design of the repository drifts and layout, the waste emplacement scheme, and the thermomechanical performance of the rock mass will be analyzed using various numerical models. These models may be based on different assumptions regarding the representation of the fracture behavior under given applied stresses, and will range from discrete models where individual mechanically active fractures are treated distinctly, to continuum models where the joint behavior is smeared over a representative volume. There is always the question of applicability of a model with respect to a given material domain to be analyzed.

For the mechanical analysis of the rock mass response around a repository drift, the applicability of a equivalent continuum model is dependent on the joint spacing in the rock mass. Considering the joint spacings that may be encountered at the potential repository site, a ratio of joint spacing to the planned drift diameter may be adopted as a criterion for evaluating the applicability of the Compliant Joint Model (CJM) in the Yucca Mountain Site Characterization Project. In this paper, this criterion is established by reviewing basic continuum concepts and numerical approximation implications used to build the CJM and by examining rock mass conditions that may be encountered at the potential Yucca Mountain repository site.

The CJM is a two-dimensional continuum material constitutive description for a jointed rock mass with two orthogonal sets of joints. It was developed by Chen[2] based on previous studies by Chen,[3] Thomas,[4] and Morland.[5] The model captures the gross response of a rock mass by smearing the individual response of the joints into the entire body of the rock mass. As described by Chen,[2] this model includes two main features: a continuum approximation based on average discontinuous displacements across jointing planes within a representative elementary volume (REV), and a material constitutive description based on linear elastic behavior of intact rock and nonlinear normal and shear joint behavior between jointing planes. In this paper, we review the mathematical and physical meaning embedded in these two features.

While the finite element analysis is considered as a higher level of treatment for analyzing the mechanical phenomena of a material domain, the development of the constitutive material law is considered as a lower level treatment. At the high level of treatment, the global phenomena of the entire material domain is considered as macroscopic behavior and the local phenomena of a discretized element is considered as microscopic behavior. At the low level of treatment, the global phenomena of a REV used to develop the constitutive law is considered as macroscopic behavior and the local phenomena of a distinct joint is considered as microscopic behavior.

In the high level of treatment, the finite element method using iso-parametric elements is an approximation of the stress/strain analysis of a continuum in which the deformation over a large problem domain described by a

continuous function is approximated by a piecewise linear function using the element discretization. The element size in a finite element analysis is only used to reflect the mathematical accuracy of the piecewise linear approximation (as a collection of function values at each point within a segment) to the continuous function over the problem domain. The smaller the element size used, the better the approximation. The mechanically disturbed zone, i.e., the stress concentration zone, around a drift excavated in a rock mass is about a half diameter beyond the drift wall. Hence, to capture the accurate space variations of the stress/strain distribution, the size of elements in the area immediately around an excavation should be, in general, chosen such that twice the drift diameter is at least an order of magnitude larger than the element size.

In the low level of treatment, the continuum approach is an approximation in which discontinuous deformation at various zones (physical points) is described by coordinate (mathematical points) dependent continuous functions using the concept of the REV. A REV is an ensemble of many intact rock blocks which are separated by joints and are contained in the volume. The size of this volume should be much larger than the individual intact rock block. It should, however, be sufficiently small when compared to the mechanically disturbed around an underground opening so that averaging properties over the intact rock blocks and joints provide meaningful values. As described by Chen,[2] the model is applicable to situations in which the least dimension of the REV is at least an order of magnitude larger than the joint spacing to allow for a valid averaging process.

The CJM is an analytical constitutive model which was developed through mathematical derivations under the simplifying assumption of parallel and regularly spaced joints in a REV. Hence, the uniformly distributed stress field exists in the entire elementary jointed rock mass. The model input parameters are derived from the material properties of joints and intact rocks. Since the simplified assumption is used to develop the analytical constitutive model, the model should be treated as an empirical constitutive model. In other words, the model input parameters should be derived from the global deformation of the laboratory tests on specimens at the scale of REV. The validity of using model parameters derived from the testing of specimens with a distinct joint and specimens of intact rock should be confirmed using the laboratory testing results of specimens at the scale of REV.

Combining approximation concepts of the REV and the finite element discretization, the criterion of the applicability of the CJM in the mechanical analysis of an underground opening can be stated that the ratio of joint spacing to the planned drift diameter must be less than 0.02. According to the Yucca Mountain Site Characterization Project Reference Information Base (RIB)[6] the average number of natural fractures per 3m interval is about 13.3 (0.22 m joint spacing) in the densely welded part of the Topopah Spring formation. The diameter of the potential emplacement drift is about 4.3 m. The ratio of joint spacing to the planned drift diameter may be 0.05. In addition, not all joints that have been characterized in RIB are the mechanically active joint. The ratio of the joint spacing of mechanically active joints to the planned drift diameter is even greater than 0.05. Therefore, a concern is raised about the applicability of the CJM in the near field mechanical analysis for the Yucca Mountain Site Characterization Project. Since the joint spacings described in RIB are uncertain, this concern may not be readily be resolved at this point.

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