Guest Editorial

It is well known that the real behavior of rock structures such as tunnels, caverns, slopes, etc. often differs from that predicted by numerical analyses, even though sophisticated computer programs are used. This discrepancy between the real and the predicted behaviors depends not only on the mechanical parameters of the rock, but also on what numerical model is used to express the mechanical characteristics of the rock. Thus, the numerical modeling must be carefully investigated. However, it is hard to make an accurate modeling of a rock mass because there are various uncertainties involved in its geological and geomechanical characteristics. Particularly for jointed rock, the evaluation of its joint characteristics is extremely complex and it is difficult to model.

In the modeling of jointed rock, there are two approaches available. One is a discontinuum approach and the other is a continuum approach. If a rock mass contains few joints, then all the joints can be identified by a geological survey and the rock mass can be modeled explicitly as a discontinuous body. The distinct element method (DEM) can then be used for analyzing the behavior of the discontinuous body. For highly jointed rock, on the other hand, it is obvious that the discontinuum approach is not suitable, because it is almost impossible to identify the entire joint system. Thus, if a rock mass is highly jointed, the continuum approach may be well applicable, since the rock mass can be modeled as a continuous body mechanically equivalent to a highly jointed rock mass.

In engineering practice, Young's modulus and shear strength are the most fundamental mechanical parameters of a rock mass. They can be determined by in situ tests, such as plate bearing tests and direct shear tests, respectively. It should be noted that both Young's modulus and shear strength are defined as the mechanical parameters of a continuous material. This means that the Young's modulus and the shear strength of a jointed rock mass determined by the in situ tests cannot be determined unless the jointed rock mass has been implicitly assumed to be a hypothetical continuous material from which all joints disappear.

Regarding the failure criteria of a rock mass, the Hoek-Brown criterion is commonly used. It contains material parameters m_b, s, and a, which are functions of the geological strength index (GSI), depending on the type of rock, the joint pattern, the joint density, and the joint surface conditions. However, it should be noted that the Hoek-Brown criterion is also defined for a continuous material which is mechanically equivalent to the concerned jointed rock mass. Therefore, the Hoek-Brown failure criterion can be used only for a hypothetical continuous rock mass which has no joints existing in it any more, although the material parameters and GSI are evaluated by considering the joints.

The continuum approach is of great advantage to numerical analyses because it is easily applicable to engineering practice. However, if rock bolts are installed into the hypothetical continuous material, the effect of the rock bolts on restricting the movement of the joints may be misleading. This is because all the joints have already disappeared; thus, the effect of the rock bolts tends to be underestimated.

In engineering practice, it is well known that rock bolts are extremely effective for reinforcing jointed rock masses, particularly in hard rock rather than in soft rock. This is due to the fact that the deformational behavior of hard rock is mainly brought about by the joints. Therefore, the installation of rock bolts is a good way to restrict joint movement. On the other hand, the deformational behavior of soft rock is mainly due to the matrix of the rock, not to the joints; thus, rock bolts are not very effective. Physical model tests also demonstrated that both Young's modulus and the uniaxial compressive strength of jointed rock increased greatly by the installation of rock bolts more particularly in hard rock than in soft rock.

Contrary to the engineer's experiences, as well as to the above-mentioned physical model test results, a finite element analysis carried out on a hypothetical continuous rock mass indicated that the reinforcement effect of rock bolts is more dominant in soft rock than in hard rock. This is due to the fact that in the continuum approach, the rock bolts are modeled as if they were installed in a continuous body. Thus, the effect of rock bolts is only for reinforcing the matrix of the materials and not for restricting joint movement.

This must surely be a shortcoming of the continuum approach for modeling jointed rock reinforced by rock bolts. Thus, in the continuum approach, the effect of rock bolts on restricting joint movement tends to be misleading and underestimated. In order to overcome this shortcoming, needless to say, the discontinuum approach can be used. However, it is almost impossible to detect explicitly all the joints existing in highly jointed rock and to investigate all its geomechanical characteristics properly. In engineering practice, therefore, the continuum approach is preferable.

In the continuum approach for modeling a jointed rock mass reinforced by rock bolts, it should be emphasized that the reinforcement effect must be taken into account in a proper manner, particularly for hard rock. In this respect, the author has proposed a method for which the jointed rock mass should not be modeled independently of the rock bolts, but should be modeled simultaneously together with the rock bolts by considering the reinforcement effect of the rock bolts. The most important point of the proposed method is that a jointed rock mass should be modeled after the installation of the rock bolts, so that the interaction between the rock bolts and the rock mass can be taken into account in an appropriate manner in the equivalent continuum. This implies that the mechanical parameters of the equivalent continuum should be evaluated in such a way that they are determined locally in each region reinforced by rock bolts considering the relation between the joint orientation and the rock bolt direction. As a result, the mechanical parameters differ from place to place due to the different direction of the rock bolts installed, although the joint systems are homogeneous. The mechanical parameters evaluated in this way are called "equivalent mechanical parameters", and the restricting effect of the rock bolts has been taken into account.

For determining the equivalent mechanical parameters, the homogenization theory can be used. It considers the interaction effect between the joints and the rock bolts. Furthermore, once the excavation has been initiated, these mechanical parameters can be verified by a back analysis of the field measurements carried out during the excavation and, if necessary, they can be modified.

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