DDA Simulation of the Deformation Process for the Slopes with Thin Metamorphic Schist

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Keywords: Discontinuous Deformation Analysis (DDA), rock slope, simulation, deformation, schist; joint

The thin layered metamorphic schist is widely distributed in the orogenic area of Protozoic era. The rocks were originally sandstones and mudstones and were metamorphosed to be harder and thinner in structure. As outcropping in sides of rivers or cutting slopes, they tend to slip or deform under gravity whether dipping inward or outward the slope surface. As they dip outward, sliding along the schistose planes occurs frequently; while inward, the deformation may begin to topple and develop into rock falls or large slides, which often cuts the roads, damages houses in the mountain areas and causes serious loss of lives and properties.

However, the popular methods based on the continuum theories, like FEM or FLAC, are not suitable for the blocky rock system. The Discontinuous Deformation Analysis (DDA) proposed by G.H. Shi (1985) gives a unique solution for the rock system. The Discontinuous Deformation Analysis theories, like FEM or FLAC, are not suitable for the blocky properties.

The DDA is introduced in this paper. The slope is the right side of the outlet of a deep gully opening to the Heihe reservoir which is the water resource of Xi’an City. The national road No.108 crosses through the lower position of the slope. Further deformation may lead the road and the downward dam in a high risk situation. The deformed rock are distributed in 1500m wide, 300m high slope area and has the thickness of 18-30m, so it is a shallow and broad deformation slope. The slope extends with strike of 130° and the dip direction of 40° and the dip angle of 35°-50°. The rocks outcrop with chlorite schist, mica schist and carboniferous schist oddly intervened by quartz veins. The schistose plane of the undeformed rocks has thin layer thickness of 2cm to 5cm, dip direction of 196°-214° and dip angle of 70°-88°, which dips inward of the slope and commonly is preferable for slope stability. There are two sets of joints developed in the rock. One is gentle, with dip direction of 40°–55° and dip angle of 28°–35°, which approximately dips outward of the slope. Another one is vertical, with dip direction of 307°–325° and dip angle of 54°–75°. The schistose planes and the joints cut the rock into thin tabular blocks as shown in figure 1. For 2D simulation, the strike of the vertical joints is approximately perpendicular to that of the slope, so it can be neglected in the model. The schistose plane and the gentle joint are the key control discontinuities to the slope stability. A slope profile combining with the attitudes, spaces, length and roughness of the discontinuities were measured in site. The normal stiffness of them was also tested by rebound equipment in situ. The modulus $E$ and ratio $n$ of the rocks as well as the shearing stiffness and strength of the discontinuities were measured in laboratory with the...
collected samples. The 2D model was built based on the measured profile and the parameters inputted on the measured and statistic results. The DDA program was applied to simulate the deformation process with deepening of the gully by erosion in geological time. The simulated result is shown in figure 2. It suggests that the shallow rocks of the slope were toppling with down cutting of the gully. In the process, the gentle joints were extended to open and the schistose were sheared to slip. The key rock controlling the slope deformation is the slope toe. Continuous cutting of the toe by water erosion may cause further deformation to evolve a rock avalanche or a slide, so it is proposed that a barred dam may be built at the outlet of the gully to deposit the block material in the base of the gully, which could not only protect the slope toe from erosion, but also keep the solid material from impinging the reservoir.

Fig1. The deformed rock slope in the Heighe reservoir and the national road No.108

Fig2. The simulated result of the deformed rock slope