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The Significance of Multistage Shear-Permeate Feature of the Hard Clay and Experimental Methods

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Abstract The impermeability of the hard clay imbedded in the Quaternary or Neogene systems has an important impact on the stability of underground engineering. It has a great significance that the hard clay in the middle of Neogene systems cut off the relationship between the upper aquifer and the lower aquifer when mining in the concealed coalfields close to outcrop. The paper mainly clarified the meaning of the multi-stage shear-penetration tests and the significance of research. Another major task is to discuss the method of multi-stage shear-penetration tests and phenomenon under multi-stage shear stress conditions.
Keywords hard clay, multi-stage shear, shear-penetration

Introduction

There are a large number of coal resources near outcrop buried under aquifers of Quaternary or Neogene systems in provinces of Henan, Shandong and Anhui in China. The thick layer of cohesive soil in the middle of Quaternary or Neogene systems often has a higher content of minute granule and clay mineral. It was found to be hard and dry when coring form the drill hole. This cohesive soil was named as hard soil or hard clay according to its uniaxial compressive strength from 0.3 to 1.5 MPa (Zhang 2000). In the stress-strain process, this hard clay always performs the strain softening characteristics. The model tests see the destruction of the hard clay layer is the fractures opened and closed during time with mining. This process is somewhat like a multistage shear and failure condition. It was found that the permeability of hard clay would reduce with pressure increasing (Zhang 2008), while this kind of deformation-leakage process is controlled by structure changing of the clay. This structure-permeability process has great significance to mining safety and underground water protection. And it is necessary to find effective methods for structure-permeability tests.

The interaction of stress, strain and penetration is one of the key problems in geotechnical engineering. Basing on the full stress, strain and infiltration curves, it was suggested that permeability of soft rock relates to its stress-strain process and changing of internal structure closely (Peng 2003; Wang 2001; Sun 2012; Zhang 2006). More complicated is there does not exist the uniqueness relations between permeability and strain, and the porosity and fracture, plastic and creep all have different roles to permeability (Yang 2007). But it is the fractures occurred before and after the peak point changed the permeability of soil and rock largely. However, the works about multistage shear - permeability is relatively rare. The study on relations between stress and structure, structure and seepage is necessary.

Stability and impermeability of hard clay in mining

Because of the huge energy consumption and energy extraction, many coal mines in Shandong, Hebei, Henan, Jiangsu and Anhui province in China have to develop the deep buried coal resources under high stress and the concealed coalfield under surface water and alluvium aquifer. These mining activities have gained a lot of experiences about leaving waterproof coal pillars. For example, the fig. 1 reveals a typical structure of the Quaternary and Neogene systems above coal seam in southwest of Shandong. The overall thickness of these alluvium layers is 150-170 m, while it is more than 700 m in some local area. Among these strata, several clay layers imbedded in Quaternary or Neogene systems are continuous and stable in thickness and impermeability. The most remarkable difference with shallow buried soil is the high degree of consolidation and high strength. What is more, there is a layer of clay is often covered on the ancient erosion surface at the bottom of the alluvium layer, which is another important advantage for safety decision-making. These impermeable barriers have cut off the relations of the upper aquifers and lower aquifers. When the lower aquifer has a poor water-rich, the basic conditions for sand proof pillar or collapse proof pillar are formed. But the long-term and dynamics water resistance function of this clay is still needs further study and testing. The underground water level drop is an indisputable fact around coal mines although there has no direct data about the changes of shallow groundwater level. Except for the natural hydraulic connection between the shallow groundwater and the bottom aquifer, the mining induced leakage is an outstanding reason to underground water hazards and deterioration of the environment.

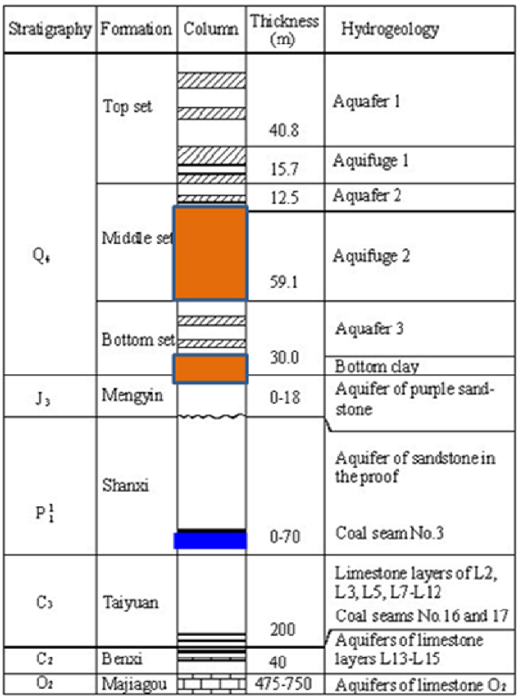
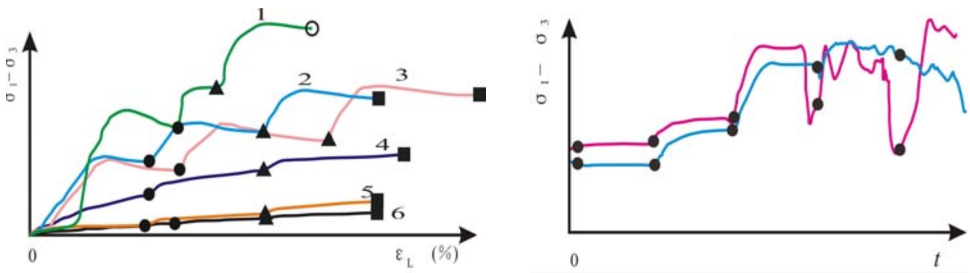


Fig. 1 *The structure of alluvium layers in typical area*

Because of the thin bedrocks covered above the coal seam is only 0-60 m thick in the outcrop area, the adjacent alluvium layer will be driven to bending, tension, shear and compression by mining subsidence and damage directly. The closer the distance is, the more obvious the deformation and failure are. Being influenced by the upper aquifer, water content of this clay layer is not uniform from top to bottom. As a result, the deformation and failure will cause complex seepage process and water-soil interaction. Would the water resistance keep stable? How does the strength and structure of this clay change? These questions are important engineering problems and need further study and discussion.

The stress path of the penetration process

The multilevel shear stress–strain curves of over consolidated soil were proved to change like footsteps. It can be seen in fig. 2a that the curves of remolded samples 1, 2, 3 vibrate greatly and the others of undisturbed samples 4, 5, 6 change like footsteps more stably (Che 2003). According to the numerical calculation, the deep buried hard clay under the repeated deformation caused by mining located in a dynamic stress environment as shown in fig.2b. This mining induced a stress path for the hard clay is quite similar to the multilevel shear stress - strain curves in fig.2a. Therefore, the process of deformation and failure of hard soil in mining can be abstracted as a multilevel shear - deformation process in fact. In this process, each roof caving will result in a step growth of load to the hard soil. In other words, it is the growth of partial stress periodically.



(a) test *(b) calculation*

Fig. 2 *Multilevel shear stress – strain curves*

Since Raymond and Philip found the permeability of clayey soil in the 1960's (J Miller,1963), influences of the water content, initial water head and micro structure to permeability are all have been studied(Moutier 2000; Swartzendruber 1991; Dudoignon 2004). During the infiltration process, the clay fractures are undergoing complex changes (Chert 1998), and sometimes are also affected by the water content (Bronswijk 1991). It was pointed out in literature (Di 1992) if the clay content has reached 10%-15% the cohesive soil will statically have good water resistance. But the leakage caused by excavation all happened during the stress or strain evolution processes. It was verified that partial stress has greater influence on permeability (Li 2012). In addition to the water content, the initial water head, the microstructure and the content of clay mineral, the stress path is another very impotent factor that can determine the permeability of hard clay.

Test methods for multistage shear- penetration

The control condition of multilevel shear test is the stress path loaded. This stress path comes from the mining caused stress redistribution. According to the results in Fig. 2b, the loading plan was conceptualized as Fig. 3. The test was beginning with consolidation for the undisturbed soil at first. Except for the infiltration process, the drainage pipeline was keeping open all the time. Suppose each mining caving as a loading process, shear stress was applied gradually until the new cracks emerged in clay, and then turned into the infiltration process under stability stress state and so forth. The experiment will continue until the soil sample is completely destroyed.

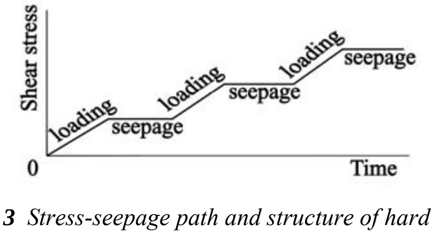


Fig. 3 *Stress-seepage path and structure of hard clay*

Upon the data observed, the shear-permeability curves were gathered in figure 4. The initial permeability coefficient is about 10^{-9} cm/s under the water head 0.3 MPa. During the multilevel shear procedure, the saturated clay reveals a basically constant permeability and changes in 10^{-9}-10^{-8} cm/s. But for the unsaturated clay, one kind of the changing is the permeability increased monotonically with shear and failure, and the other kind of changing is the permeability increased first and then decreased in the same stress path. These test results are the direct evidences to analysis the water resistance of hard clay during mining.

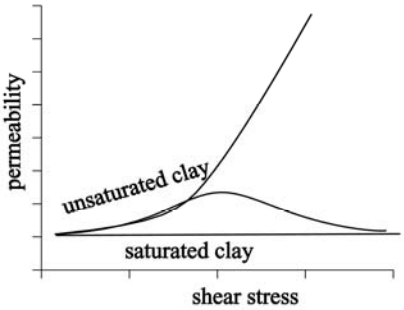


Fig. 4*Results of multilevel shear-penetration tests*

Conclusions

1) As a part of the aquifuge, the deformation and permeability of hard clay is important for water disaster prevention and water resources protection when mining under thin bedrock.

2) Put the deformation and permeability process under the multilevel shear stress path is an objective conceptualization for the water-clay interaction research during mining.

3) The tests of multilevel shear-structure and structure-permeability are important methods to study the water resistance of deep buried hard clay.

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