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Deformation tests and failure process analysis of an anchorage structure

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ABSTRACT

In order to study the failure process of an anchorage structure and the evolution law of the body's deformation field, anchor push-out tests were carried out based on digital speckle correlation methods (DSCM). The stress distribution of the anchorage interface was investigated using the particle flow numerical simulation method. The results indicate that there are three stages in the deformation and failure process of an anchorage structure: elastic bonding stage, a de-bonding stage and a failure stage. The stress distribution in the interface controls the stability of the structure. In the elastic bonding stage, the shear stress peak point of the interface is close to the loading end, and the displacement field gradually develops into a "V" shape. In the de-bonding stage, there is a shear stress plateau in the center of the anchorage section, and shear strain localization begins to form in the deformation field. In the failure stage, the bonding of the interface fails rapidly and the shear stress peak point moves to the anchorage free end. The anchorage structure moves integrally along the macro-crack. The de-bonding stage is a research focus in the deformation and failure process of an anchorage structure, and plays an important guiding role in roadway support design and prediction of the stability of the surrounding rock.

1. Introduction

An anchorage system is a complicated structure, which is composed of an anchor, surrounding rock, anchoring agent and two interfaces. The surrounding rock is compressed into a structure by the anchor, and the anchorage structure can then bear high load to support the roadway [1–3]. Research into the anchorage mechanism has some engineering significance in improving roadway support design and predicting stability of the surrounding rock [4,5].

Until now, there is no unified theory relating to the anchorage mechanism because of the complicated surrounding rock properties and engineering conditions [6–9]. Professors have conducted many studies on the anchorage mechanism. Based on pull tests on an anchored system, Zhao revealed three failure types: thread failure, body failure and interface failure, the third being the main failure type [10]. In anchor support, resin medicine-one is widely used for its high bonding strength. But because of the differences in anchorage conditions and styles, interface failure is still common [11]. Research on the interface is therefore important in the study of the anchorage mechanism. The main theories on interface stress distribution include: power function distribution form, neutral point theory, distribution form based on Mindlin's solution of displacement [12–14], and so on. Besides the interfaces, there is still a part of the surrounding rock forming the anchorage system, and the deformation and failure laws of the rock are therefore also important features of the anchorage mechanism. But because of the limitations on test conditions and deformation measuring methods, there is little related research. The digital speckle correlation method (DSCM) can measure the interface deformation field, and is widely used in rock and soil mechanics research [15–17]. Ma studied the uniaxial compressing process of the rock, and researched the damage accumulation and deformation localization by using DSCM [18]. Song studied the evolution of the deformation field and the energy in failure process in red sandstone based on DSCM, and revealed the relation of the deformation localization and energy release and accumulation [19]. Because of its accuracy and convenience, DSCM can be an effective test method in researching the evolution of the deformation field in an anchorage structure.

In order to study the evolution law of the deformation field in an anchorage structure, DSCM was introduced into anchorage mechanism research. The stress distribution of the anchorage interface was studied using the particle flow method. The relation between the deformation field and stress distribution was studied,

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which was helpful in revealing the anchorage mechanism more comprehensively. Because of the limitations on test conditions, the anchor push-out tests were carried out instead of pull-out tests.

2. DSCM test of the anchorage structure

2.1. Preparation of the anchorage structure

In order to research the evolution law of the deformation field, an anchorage structure was prepared, as shown in Fig. 1. The structure was comprised of two rectangular red sandstone blocks with dimensions 100 mm × 40 mm × 25 mm. A steel plate with dimensions 120 mm × 4 mm × 25 mm served as the anchor. The plate was bonded between the two sandstone blocks with an anchorage agent. The sandstone blocks and the interfaces must be smooth. The speckle field with black back and white spots was sprayed onto the model to measure the deformation.

2.2. Test scheme

Anchor push-out tests with an RLJW-2000 testing machine as the loading equipment were carried out, after considering the system performance of the testing machine and the equivalence of the anchor's push-out and pull-out characteristics. The test system is shown in Fig. 2. A constant vertical stress of 5 MPa was loaded on the model by a vertical device. The push-out force was loaded on the anchor by the horizontal device until the structure failed. The push-out loading velocity was 0.25 mm/min. The horizontal force and displacement in the loading process were recorded at 0.2 s intervals. The speckle images were obtained by CCD camera, five photos per second.

3. Deformation and failure process of the anchorage structure

The relation curve of the push-out force and the displacement is shown in Fig. 3. The deformation and failure process of the anchorage structure were divided into three stages: I-elastic bonding stage, II-de-bonding stage and III-failure stage. Seven points on the curve were chosen for analysis of the evolution law of the deformation.

The horizontal displacement curves along the measured line at different analysis points are shown in Fig. 4. At point 1, the displacement along the measured line was small and approximately linear. From point 2 to 5, the curvature of the graph increased with a high value close to the anchorage section and decreasing as far from the push-out end. At point 6, the push-out force reached a peak value. As the loading stress exceeded the strength of the sandstone, the sandstone began to fail, and the displacement below the anchor decreased sharply. At point 7, there were sharp displacement changes at the upper interface and the lower sandstone block, where failure occurred. Because of the interface failure, the upper sandstone block rebounded, and the displacement at point 7 was smaller than at point 6.

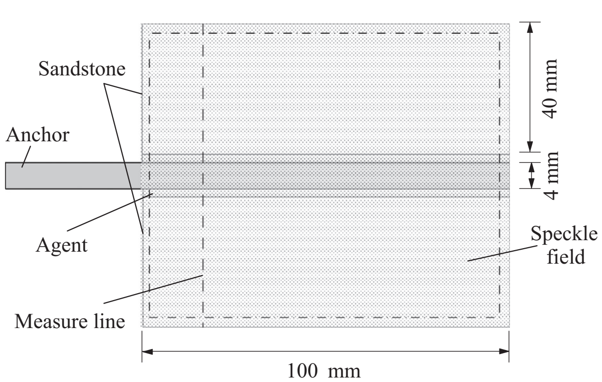

Fig. 1. Anchorage structure.

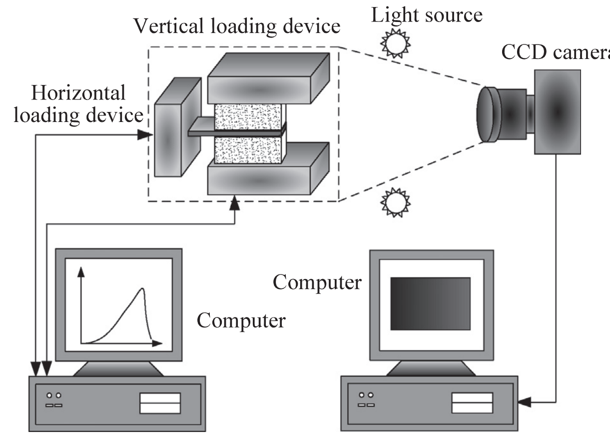

Fig. 2. Test system of DSCM.

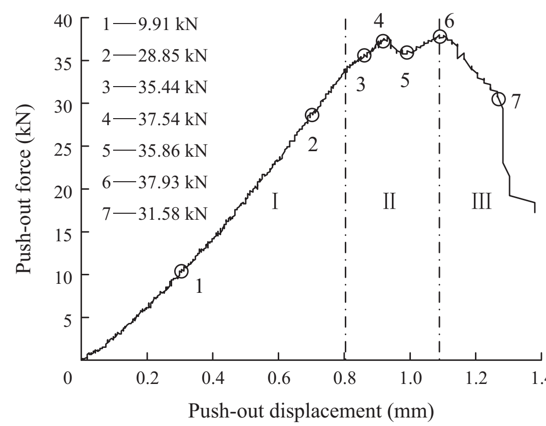

Fig. 3. Relation between push-out force and displacement.

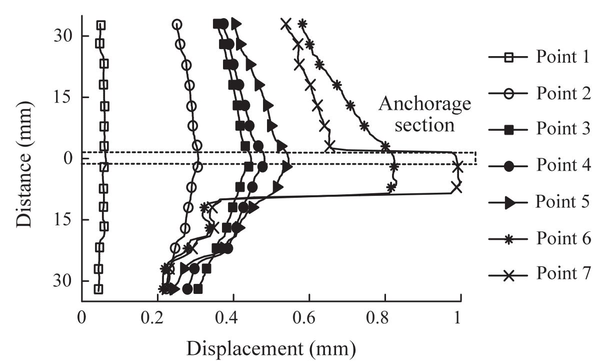

Fig. 4. Horizontal displacement curves along the measured line.

3.1. Elastic bonding stage

During the initial loading phase, the slope of the curve was essentially constant, which showed a linear relationship between the push-out force and displacement. In this stage, the loading