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A proposed method for estimating in-situ stress direction using panoramic stereo-pair imaging and stressed borehole geometric shapes

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1. Introduction

In-situ stress is one of key parameters in rock and soil mechanics, which have a significant impact on the stability of rock engineering in tunnel, roadway, mining and hydropower station.[1–4] Research on the measurement of in-situ stress is one of important aspects in geo-mechanics and geotechnical engineering. Presently, the main measuring methods of in-situ stress include hydraulic fracturing, stress relief method, sound emission method and the elastic strain recovery technique.[5–7] These traditional measuring methods of in-situ stress all can work well under a specific rock condition or certain borehole situation[8–10] but these methods are complicated to operate under the hole. Especially, it is very difficult to carry out every step of these methods in case of deep hole, which hinders the advancement of in-situ stress testing technique. Therefore, research on how to rapidly, effectively and accurately measure in-situ stress in a deep hole, or break through the bottleneck problem of key technique and push forward the innovation and development of in-situ stress testing technique, is of great theoretical significance and practical application value.

As we know, the existed meas:urement theories of in-situ stresses almost are related to the quantitative relation between the deformation of borehole aperture (such as strain and deformation of borehole wall) and in-situ stress. It is realizable to obtain the stereo-pair images of borehole wall with the downhole panoramic stereo-pair imaging system based on double-conic mirror imaging, and then the digital elevation of borehole aperture based on the image pairs can be calculated. The geometrical morphologic characteristics of borehole wall and morphologic change of the hole can be also obtained according to this panoramic stereo-pair imaging technique.[11] Lastly, using the inner correlation between borehole shape and in-situ stress can estimate the in-situ stress direction.[12,13] Therefore, a rapidly and effectively estimating method of in-situ stress direction is proposed in this paper based on the geometric shapes of stressed borehole, which is obtained by using panoramic stereo-pair imaging technique.

2. Borehole panoramic stereo-pair imaging technique

Borehole panoramic camera technique is widely used in the drilling borehole of geotechnical engineering and geological disaster. Since the surface of field borehole wall is uneven, borehole wall will deform under the action of stress. Traditional borehole camera/imaging technique is based on the hypothesis of cylindrical surface of borehole wall. This technique is less effective in obtaining high precision images of field fine structure and morphological characteristics of borehole wall. There are the limitation of the fundamental assumption of borehole imaging technique and the unicity of quasi-three dimensional imaging technique.[14–17] To solve these problems, our proposed borehole panoramic stereo-pair imaging technique adopts double-conic mirror imaging technique and space positioning technique to obtain the borehole images, which are reflected from the rock mass structure, and also to obtain the digital elevation data, which can reflect the size variation of borehole aperture. Borehole panoramic stereo-pair imaging technique has solved the technical problem of downhole panoramic stereo imaging detection and the true three dimensional imaging of rock mass structure morphology. It has provided a scientific method of precisely detecting downhole rock mass structure.

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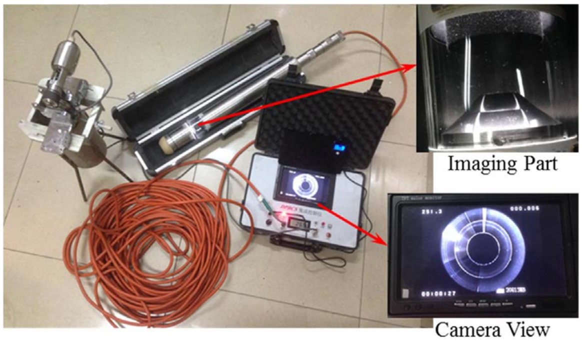

Fig. 1. Panoramic stereopair imaging system.

2.1. Panoramic stereo-pair imaging system

Panoramic stereo-pair imaging system is comprised of hardware part and software part. The hardware is consisted of a stereo-pair probe, a control cabinet, a depth pulser, a video recorder, a hoist and a special cable. It can be showed in Fig. 1. The panoramic stereo-pair probe shown in Fig. 1 is consisted of combined-type double conical mirrors, compass, light source, lens hood, camera device, transparent glass ware, lower connector and upper connector. The transparent glassware, lower connector and upper connector constitute the seal housing, in which the double-conic mirror, compass, light source, lens hood and camera device are installed. Another, the software system of this system is divided into two parts. One part is used for real-time monitor and field image data collection. Another part is used for indoor processing and statistical analysis.

Panoramic stereo-pair imaging system is realized on the basis of the double-conic mirror image-forming principle. When photographing the same area from two different directions, stereo imaging can be obtained if the included angle between the two directions is larger than a certain angle, and then stereo-pair images of the area in the hole-wall can be realized. The double-conic mirror is consisted of an upper conical mirror and a lower conical mirror. The upper conic mirror top-truncate is used to form the top surface, and the lower conic mirror bottom-truncate is used to form the bottom surface. The intersecting line between the undersurface of the upper conic mirror and the top surface of the lower conic mirror is the inscribed circle of the formed images from the double-conic mirror. The single imaging component (i.e., one camera) is installed above the double-conic mirror, of which the lens faces the double-conic mirror. The imaging principal optic axis coincides with the center line of the double-conic mirror. A panoramic image can be produced on the image plane after the 360° borehole wall image is reflected by the double-conic mirror. For example, imaging points P1 and P2 are produced on the image plane by reflecting the point P of borehole wall via the upper and lower conic mirrors respectively, which can be shown in Fig. 2. The 360° borehole wall image on the image plane appears to be in the shape of circular ring. With the inscribed circle in the image plane as the limit, the image of the inner circular ring is formed by reflecting via the upper conic mirror, and the image of the outer circular ring is formed by reflecting via the lower conic mirror. The image-forming principle of double-conic mirror is as shown in Fig. 2.

Since the images on the image plane formed by reflecting via the double-conic mirror are separable, it is viable to obtain the borehole panoramic stereo-pair image with a single imaging component (i.e., one camera). Therefore, the development of a panoramic stereo-pair imaging system consisting of a built-in light source, a combined-type double-conic mirror and a single camera has been realized via systematic structural design according to the image-forming principle of double-conic mirror and in combination with the technical features of downhole panoramic image pair imaging.

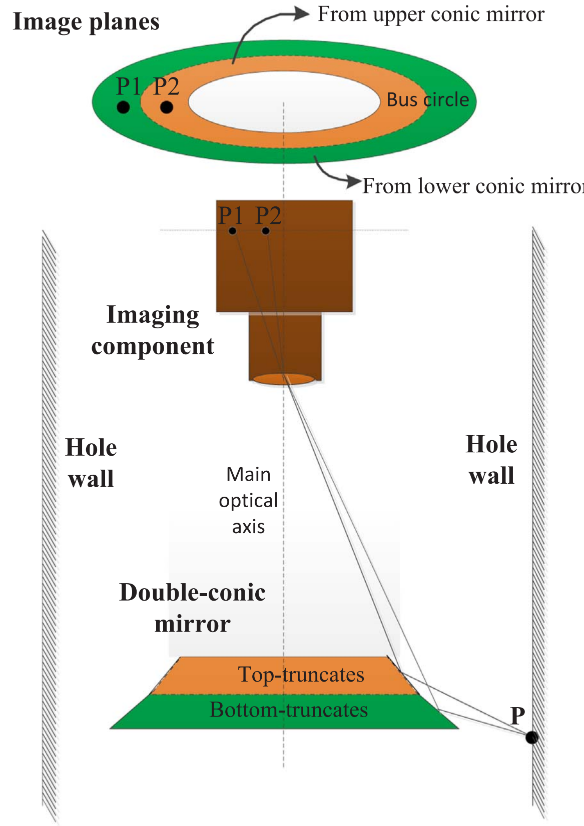

Fig. 2. Stereopair imaging principle of double-conic mirror.

2.2. Acquisition of shape of borehole wall

It can be realized to acquire two hole-wall images of the same position from different visual angles with the panoramic stereo-pair imaging system, and solve the distance from any point on the borehole wall to the imaging central axis according to the imaging principle of double-conic mirror. To solve the distance, the coordinates of different positions of the points in the image pair under the uniform coordinate system are required.

One image plane obtained with the single imaging component contains two separable images of the same position in different visual angles, of which one is called image-based image, and the other is called image-pair image. And a coordinate system is established on the image plane, which is the uniform coordinate system of the image-pair image. The coordinate system is established by taking the point of intersection between the image plane and the imaging center line as the original point, and the due north direction determined according to the position information is set as the positive direction of *Y*-axis, which *X*-axis is vertical to *Y*-axis and the *X-Y* axis form a right-handed coordinate system. On the image plane, the panoramic image-pair image appears to be in the shape of circular ring, as shown in Fig. 3, of which the excircle C_1, mid-circle C_0 and inner circle C_2 are the images of the excircle and inscribed circle of the bottom-truncating surface and the excircle of the top-truncating surface, respectively.

The steps of registering the image-pair image are: take a point P on the circular ring ranging from C_1 to C_0 or from C_0 to C_2 (the bearing line OP links this point and the center of the circle), search for a point P' same with point P in another circular ring along with OP line, and then calculate out the coordinates of point P', namely the registered point of point P.

The steps of establishing a computational formula of image-pair image are: define the basic parameters (including cone apex angle θ_1 of the lower conic mirror, cone apex angle θ_2 of the upper conic mirror,