

## Experimental Study on Borehole Collapse

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### Abstract

In order to observe wellbore collapse process visually, by using the real triaxial simulation experiment system, the borehole enlargement rate and the borehole collapse changing laws were tested through exerting triaxial stress on the samples under different conditions including the stress state, deviation angle and azimuth of the wellbore. The results show that the borehole enlargement rate increases with the increase of vertical crustal stress and azimuth angle, while formation stability decreases with them; and the borehole enlargement rate decreases with the increase of deviation angle, while formation stability increases with them. The conclusion could provide references for the field drilling operation.

**Key words:** Borehole collapse; Deviation angle; Azimuth angle; Experimental study

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### INTRODUCTION

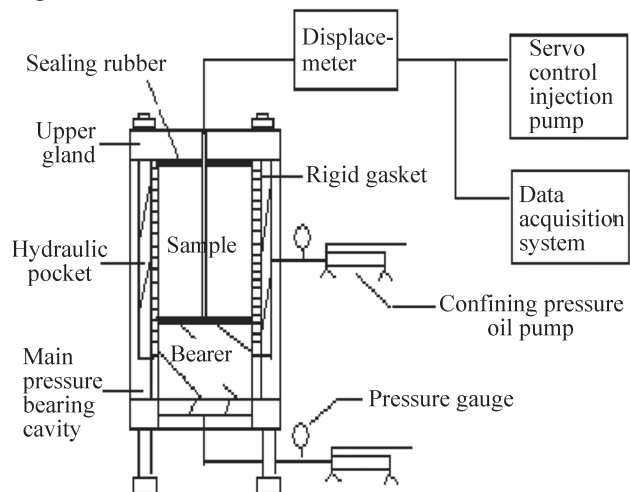
The petroleum industry has been puzzled by the problem of borehole collapse, which exists in drilling process universally. According to statistics, this problem has brought 0.5~0.6 billion dollars loss to the world petroleum industry every year<sup>[1-3]</sup>. Due to the hard observation and measurement on borehole collapse on the well site, the finite element software is usually used to study the collapse process through numerical simulation method<sup>[4-6]</sup>.

In order to observe the wellbore collapse process directly, the real triaxial simulation experiment system with large-scale size was adopted to study the influence of different parameters including stress state, deviation angle and azimuth on borehole collapse. The borehole enlargement rate and the process of borehole collapse were studied under the condition of different parameters. The borehole collapse changing laws were obtained.

## 1. LABORATORY EXPERIMENTS

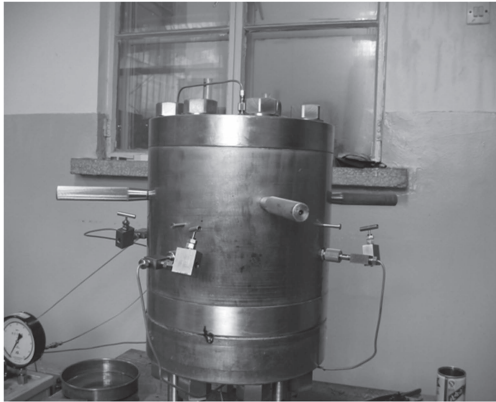
### 1.1 Experimental Apparatus

The real triaxial simulation experiment system was developed and built by rock mechanics laboratory of China University of Petroleum (East China) independently. This system is composed of main pressure-bearing cavity, confining pressure oil pump, servo control injection pump, hydraulic pocket, data acquisition system and other service units. The overall structure is shown in Figure 1.



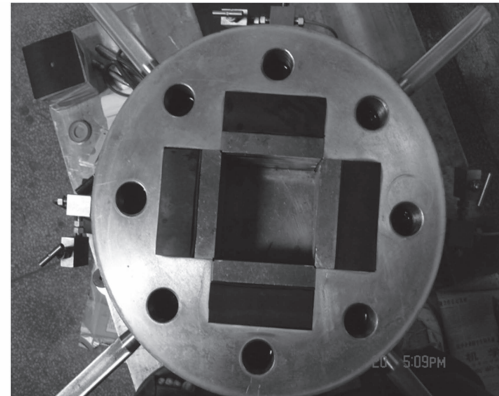
**Figure 1**  
**Schematic Drawing of Real Triaxial Simulation Experiment System**

During the simulating test, the simulation crustal stress was realized by hydraulic pocket, where, the two pairs of hydraulic pockets, which are symmetric in horizontal direction, will apply the maximum and minimum horizontal crustal stress respectively. The hydraulic pocket placed on the bottom is used to apply vertical crustal stress. The maximum crustal stress applied by this system can be up to 40 MPa. The outside drawing and inner structure drawing of main pressure-bearing cavity are shown in Figures 2 and 3 respectively.



**Figure 2**  
**External Structure Diagram of Main Pressure-Bearing Cavity**

The rigid gasket with 1.5 mm thickness is arranged densely in front of every hydraulic pocket. It contacts the surface of rock sample vertically. The function of this gasket is to make sure the crustal stress applied on the surface of sample is even as far as possible. The hydraulic power of each hydraulic pocket is produced by gas-liquid booster pump. Moreover, in pressure condition, the operation should be uniform and shall not be too fast. During experiment, the pressure and the borehole deformation displacement are gathered by all kinds of sensors, and stored by a computer.



**Figure 3**  
**Internal Structure Diagram of Main Pressure-Bearing Cavity**

### 1.2 Preparation of Rock Sample

The natural rock sample or man-made sample could be used in laboratory test on wellbore collapse, however, the natural rock sample is hardly obtained. Therefore, man-made sample is adopted in this experiment. The preparation process is as follows.

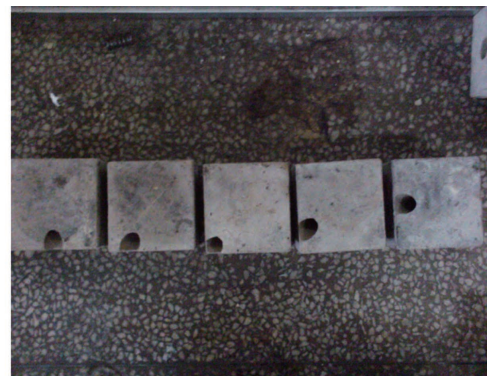
- (a) Weighting cement powder and sand according to cement-sand mass ratio 1:9.
- (b) Adding proper amount of water to cement-sand mixture and stirring them evenly by blender.
- (c) Putting the mixture into mold, then placing the mold into high temperature water tank until the concretion of mixture.
- (d) The sample should be processed into test specimens (Length: 105 mm; width: 105 mm; height: 93 mm;

parallelism error:  $\pm 0.05$  mm) by abrader due to the requirement of test accuracy.

The test samples punched a hole by a power drill are classified into 3 types, the first type is used to simulate straight hole (size:  $\Phi 10$  mm  $\times$  80 mm), the second type is to simulate holes with different deviation angle. The upper hole section has a hole size of  $\Phi 10$  mm  $\times$  30 mm, the lower hole section shown in Figure 4 has the same diameter with the upper section, but presents different deviation angle ( $0^\circ$ ,  $30^\circ$ ,  $45^\circ$ ,  $60^\circ$  and  $90^\circ$  respectively). The third type models wellbore with different azimuth. The size of upper hole is  $\Phi 10$  mm  $\times$  30 mm, the lower hole shown in Figure 5 remains diameter and deviation angle unchanged (Diameter: 10 mm and deviation angle:  $45^\circ$ ) and has different azimuth ( $0^\circ$ ,  $30^\circ$ ,  $45^\circ$ ,  $60^\circ$  and  $90^\circ$ ).



**Figure 4**  
**Picture of Specimens With Different Deviation Angle (Bottom Face)**



**Figure 5**  
**Picture of Specimens With Different Azimuth (Bottom Face)**

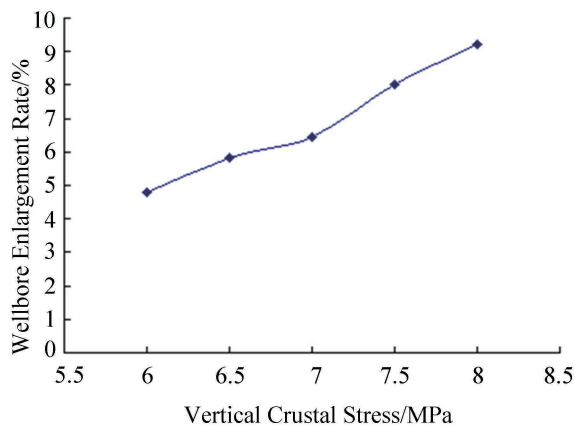
### 1.3 Experimental Process

The sample was put into main pressure-bearing cavity, then some assorted components including pressure board, sensors, etc. were installed. After that the gas-liquid booster pump shall force the hydraulic pockets, then the hydraulic pockets shall apply a slow and uniform triaxial stress on the sample. When the triaxial confining pressure reached a set value, stop applying pressure and keep this pressure unchanged for 20 minutes. Read the deformation of hole diameter from displacemeter, then reduce the confining pressure to zero slowly and dismount the sample from test equipment and take pictures for the deformed sample.

## 2. ANALYSIS ON TEST RESULTS

### 2.1 Influence of Stress State

In order to study the influence of different stress state on wellbore collapse, 5 unified samples were selected to test,



**Figure 6**  
Relation Curve of Vertical Crustal Stress and Wellbore Enlargement Rate

### 2.2 Influence of Deviation Angle

To research the influence of deviation angle on borehole collapse, 5 samples with different deviation angle were selected to test. The maximum and minimum horizontal crustal stress and vertical crustal stress were kept to 3 MPa, 2 MPa and 7 MPa respectively. Deviation angle would be changed (0°, 30°, 45°, 60° and 90°) to study the change rule of borehole enlargement rate and analyze the effect of deviation angle on borehole collapse. The relationship between deviation angle and borehole enlargement rate is shown in Figure 8. It can be seen from Figure 8 that the enlargement rate decreases approximately linearly with the increase of deviation angle, the enlargement rate is only 0.56% under the condition of 90° deviation angle, and it lowers 2.4% when the deviation angle changes from 45° to 90°. This shows that the borehole is not easy to collapse in big deviation angle condition. In actual drilling operation, it is easier to drill directional well than vertical well.

and the maximum and minimum horizontal crustal stress the borehole wall bears were fixed to 3 MPa and 2 MPa respectively. The vertical crustal stress will be changed (6 MPa, 6.5 MPa, 7 MPa, 7.5 MPa and 8 MPa) to study the influence of vertical crustal stress on well collapse when straight hole suffered smaller confining pressure. Figure 6 shows the change of borehole enlargement rate along with vertical crustal stress. The enlargement rate increases linearly with the increase of vertical crustal stress, which means the borehole stability decreases as the vertical crustal stress increases. When the vertical crustal stress is up to 8 MPa, the borehole enlargement rate could increase to 9.2%. The results was shown in Figure 7, a severe borehole collapse occurred, and the lower borehole section was plugged by sloughing cuttings. It means that the hole wall is easy to collapse when it is compressed by a bigger vertical crustal stress, thus a bigger borehole enlargement rate formed. This shows that drilling fluid density should be boosted to prevent borehole collapse when drilling in formations with bigger stress difference.

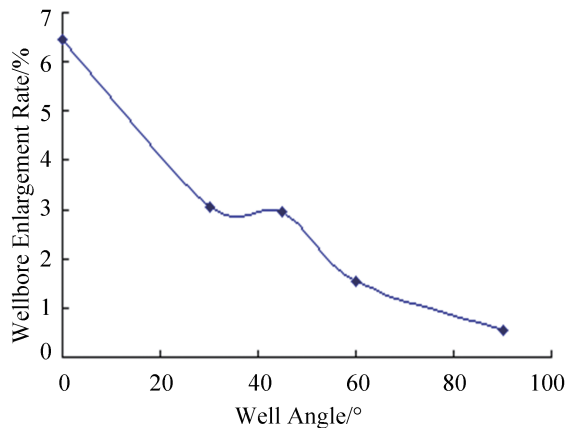


**Figure 7**  
Experimental Result Picture of Sample Collapse

### 2.3 Influence of Azimuth

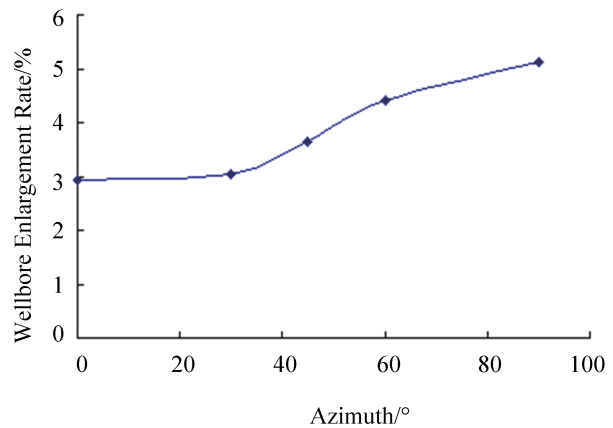
In order to study the influence of azimuth on wellbore collapse, 5 unified samples with different azimuth were selected to test. The confining pressure and deviation angle were set unchanged (The maximum and minimum horizontal crustal stress and vertical crustal stress were kept to 3 MPa, 2 MPa and 7 MPa respectively, and the deviation angle was 45°.) and the azimuth would be changed (0°, 30°, 45°, 60° and 90°) to study the change of wellbore enlargement rate and then analyze the influence of azimuth on wellbore collapse. Figure 9 shows that the enlargement rate increases almost linearly with the increase of azimuth. When the azimuth is less than 45°, the curve is relatively flat, and the borehole enlargement rate is small and has little change, it means that the borehole collapse is slight. When the azimuth is bigger than 45°, the slope of this curve is bigger, and the wellbore enlargement rate increases faster, and reaches

the maximum value (5.12%) at 90°, suggesting that the borehole collapse is more severe. This shows that the formation will not readily collapse when drilling along



**Figure 8**  
**Relation Curve of Well Angle and Wellbore Enlargement Rate**

the maximum principal stress. On the contrary, drilling along the minimum horizontal crustal stress will cause formation collapse. This coincides with the practical case.



**Figure 9**  
**Relation Curve of Azimuth and Wellbore Enlargement Rate**

## CONCLUSION

(a) During drilling operation, the wellbore is easy to collapse in formations with bigger stress difference. Therefore, to prevent borehole collapse, the drilling fluid density should be boosted, the well structure with bigger deviation angle should be designed as much as possible and drilling along the maximum principal stress is necessary.

(b) Due to the restriction on test condition and source of test specimens, the confining pressure applied on test samples is smaller than actual. It is suggested that the actual rock samples should be used, and tested under real formation confining stress state in future research to get more accurate changing laws of wellbore collapse.

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