Experimental study on rock mechanics characteristics of clastic reservoir with different stress paths

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Abstract. At present, the development of clastic reservoir has become an important way to increase oil and gas productivity in China, and the exploitation of oil and gas will inevitably affect the mechanical properties of rocks. Therefore, it is of great significance to study the rock mechanical properties of clastic reservoir rock. In this paper, the path tests of axial pressure rising-confining pressure rising and axial pressure constant-confining pressure unloading are carried out on the clastic rock samples. The results show that the clastic rock exhibits obvious elastoplastic characteristics under the path of rising confining pressure, but has certain characteristics of elasticity and brittleness under the path of unloading confining pressure; The increase in confining pressure can effectively inhibit the expansion of the rock and increase its bearing capacity; At the same initial confining pressure, the loading failure is less severe than the unloading failure; In the unloading path, the damage of the rock sample during the deformation and failure process is higher; As the confining pressure increases, the degree of rock damage also increases.

1. Introduction
With the continuous improvement of oil and gas exploration and development, China's high-quality oil and gas fields are gradually in the stage of high water cut development, and their reserves and production are decreasing year by year. Oil and gas exploration is bound to move into a new field[1]. At present, the utilization of clastic reservoir to develop resources has gradually become an important way to improve oil and gas exploration in China[2-3]. Oil and gas production is a very complicated stress loading and unloading process. For this reason, it is necessary to study the mechanical properties of reservoir rocks under different stress paths. Many scholars have carried out related researches on the mechanical properties of reservoir rocks. Jiang Yongdong[4] conducted uniaxial and triaxial compression tests on sandstone, and studied the influence of different initial confining pressures and increments on rock mechanical properties; Wang Lehua[5] studied the mechanical properties of deep-buried soft rock under the influence of different confining pressure levels, different unloading stress levels, and different unloading rates; Li Xinping[6] carried out pre-peak and post-peak unloading tests on marble to explore the influence of different stress paths on rock strength; Li Diyuan[7] proposed...
that the main controlling factor of granite's resistance to failure in the constant axial pressure unloading confining pressure test is the friction force, and the cohesive force in the axial unloading confining pressure test; Li Xiang[8] conducted triaxial compression tests with various confining pressures in order to study the compression failure mechanism of breccia, and found that the peak strength and residual strength of the rock increased with the confining pressure. Although the above-mentioned scholars have studied the mechanical properties of various rocks under different stress paths, there are few reports on the mechanical properties of clastic rocks. Therefore, this paper has carried out different stresses on the rocks of the Hudson deep clastic reservoir Path test research to explore its mechanical properties.

2. Experimental research

2.1. Test rock sample

The test samples were taken from Hudson HD4-H100, HD4-22H and HD4-9-2H wells in the 5056-5078.5m interval, a total of 8 groups. According to the standard size recommended by the International Society of Rock Mechanics (ISRM), they were processed into cylindrical specimens of $\Phi 25\text{mm} \times 50\text{mm}$. The test rock sample is shown in figure 1.

![Figure 1. Core photographs required for testing; (a) Sample A1~A4; (b) Sample B1~B4.](image)

2.2. Test scheme

This paper adopts two test schemes:

- **Scheme I**: Axial pressure rising-confining pressure rising path test. Test procedure: (1) According to the hydrostatic pressure, gradually apply $\sigma_2=\sigma_3$ to the predetermined value at a rate of 0.1MPa/s; (2) Keep $\sigma_3$ unchanged, and slowly increase by $\sigma_1$ until failure.

- **Scheme II**: Axial pressure constant-confining pressure unloading path test. Test procedure: (1) Apply $\sigma_2=\sigma_3$ gradually to the predetermined value at a rate of 0.1MPa/s according to the hydrostatic pressure; (2) Keep $\sigma_3$ unchanged, and increase to the set value $\sigma_1=0.7\sigma_{A1}$ at a rate of 0.1MPa/s, $\sigma_{A1}$ is the peak stress of the rock sample under the path of axial pressure rising-confining pressure rising; (3) Keep $\sigma_1$ unchanged, and slowly decrease $\sigma_3$ until it fails.

| Test scheme   | Sample number | Initial axial pressure (MPa) | Initial confining pressure (MPa) | Loading rate (MPa·s$^{-1}$) |
|---------------|---------------|------------------------------|---------------------------------|-----------------------------|
| Scheme I      | A1            | 0                            | 0                               | 0.1                         |
|               | A2            | -                            | 25                              | 0.1                         |
|               | A3            | -                            | 40                              | 0.1                         |
|               | A4            | -                            | 55                              | 0.1                         |
| Scheme II     | B1            | 85                           | 10                              | 0.1                         |
|               | B2            | 140                          | 25                              | 0.1                         |
|               | B3            | 192                          | 40                              | 0.1                         |
|               | B4            | 245                          | 55                              | 0.1                         |
3. Analysis of test results

3.1. Deformation characteristics analysis

The axial and radial stress-strain curves of clastic rocks under two stress paths are shown in figure 2. It can be seen from figure 2 that the clastic rock exhibits obvious elastoplasticity in the axial pressure rising-confining pressure rising path test. The stress-strain curve can be divided into five stages: crack compaction stage, linear change stage, pre-peak plastic yield stage, post fracture stage and residual deformation stage. In the residual deformation stage, the load-bearing capacity of the specimen dropped rapidly, but did not drop to zero, indicating that the ruptured rock still has a certain load-bearing capacity, which is maintained by the friction between the fracture surfaces of the rock. The clastic rock exhibits a certain degree of elasticity and brittleness in the axial pressure constant-confining pressure unloading path test, and the pre-peak stress-strain curve shows a nearly linear relationship, when the peak strength is reached, the expansion of the rock is gradually significant. In the post-fracture stage, the accumulated energy inside the rock is released, the slope of the stress-strain curve becomes negative, the deformation of the rock increases drastically, and the bearing capacity is lost.

![Stress-strain curves of clastic rock](image_url)

Figure 2. Stress-strain curves of clastic rock; (a) Axial pressure rising-confining pressure rising path test; (b) Axial pressure constant-confining pressure unloading path test.

In order to analyse the influence of different stress paths on rock deformation characteristics, figure 3 shows the comparison of stress-strain curves of rock samples under the two stress paths when the confining pressure is 40 and 55 MPa. It can be seen that the stress-strain curves of the rock samples with different stress paths are significantly different. As the test progresses, the radial strain of the rock sample in the confining pressure unloading test is always smaller than the confining pressure rising test, indicating that the confining pressure has increased to a great extent suppresses the expansion of rocks. In addition, the axial stress and axial strain during rock failure in the rising confining pressure test are greater than those in the unloading confining pressure test, while the radial strain during rock failure in the unloading confining pressure test is larger, indicating that under the same initial stress level, the unloading confining pressure test results in more obvious brittleness characteristics and stronger volume expansion of the rock sample. This is because the rock has accumulated a large amount of energy before unloading. During the unloading process, the rock still absorbs energy from the outside, which leads to its failure. Violent volume expansion occurs at the time, and there is an obvious stress drop phenomenon.
3.2. Strength characteristic analysis

Table 2. The test results of clastic rocks under different stress paths.

| Sample number | Initial axial pressure (MPa) | Initial confining pressure (MPa) | Strength $\sigma_1-\sigma_3$(MPa) | Elastic Modulus (GPa) | Poisson's ratio |
|---------------|-----------------------------|---------------------------------|----------------------------------|-----------------------|----------------|
| A1            | -                           | 0                               | 48.02                            | 8.32                  | 0.283          |
| A2            | -                           | 25                              | 170.50                           | 20.40                 | 0.232          |
| A3            | -                           | 40                              | 219.65                           | 19.46                 | 0.205          |
| A4            | -                           | 55                              | 226.58                           | 20.19                 | 0.182          |
| B1            | 85                          | 10                              | 79.60                            | 9.73                  | 0.279          |
| B2            | 140                         | 25                              | 123.11                           | 19.52                 | 0.235          |
| B3            | 192                         | 40                              | 159.14                           | 19.78                 | 0.215          |
| B4            | 245                         | 55                              | 204.22                           | 20.87                 | 0.191          |

It can be seen from table 2 that the peak strength and elastic modulus of the clastic rock under the two stress paths will increase with the increase of the initial confining pressure, because the confining pressure has a certain restrictive effect on the hoop strain of the rock. It limits the crack development and hoop deformation of the rock, and at the same time improves the compressive strength of the rock, thereby increasing the axial ultimate strain of the rock.
stress path causes the difference of the strength of the specimen to be more significant.

4. Conclusion
In order to study the mechanical properties and complex stress loading and unloading changes of clastic rock during the exploitation of clastic rock reservoir, this paper has carried out the path tests of axial pressure rising-confining pressure rising and axial pressure constant-confining pressure unloading. The main conclusions are as follows:

1. Clastic rocks show obvious elastoplastic characteristics in the path of rising confining pressure, but have certain elastic and brittle characteristics in the path of unloading confining pressure. The radial deformation of the rock sample is not obvious under the path of rising confining pressure, while the deformation is significant under the path of unloading confining pressure, and the rock failure shows obvious volume expansion phenomenon.

2. Confining pressure has a certain restraining effect on the hoop strain of the rock, which greatly inhibits the expansion of the rock, improves the plasticity of the rock, and improves the bearing capacity of the rock.

3. The severity of unloading damage is obviously greater than loading damage. The rock absorbs more energy before failure under the path test of the unloading confining pressure. When it reaches failure, a dramatic expansion phenomenon will cause the rock sample to fail, and there will be a significant stress drop phenomenon.

4. In the path of unloading the confining pressure, the damage of the clastic rock is higher during the deformation and failure process. As the confining pressure increases, the damage degree also increases.

Based on the research content of this paper, the author thinks that temperature is an important factor affecting the mechanical properties of deep reservoir rocks, and the influence of temperature should be further considered in the follow-up research.

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