Study on Rock Mechanics Parameters of Benxi Formation in Yanchang gas field, Ordos Basin

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Abstract. Rock mechanics parameters can reflect the brittleness of the formation and determine the effect of reservoir fracturing, and they are very important for improving unconventional oil and gas production. Triaxial compression test and acoustic pulse test are carried out in the sandstone samples of Benxi formation in Yanchang gas field of Ordos basin in order to obtain the accurate mechanical properties of the formation. The static elastic modulus ranges from 23.74 GPa to 32.46 GPa and the static Poisson’s ratio ranges from 0.181 to 0.239 in triaxial compression test. The dynamic elastic modulus ranges from 33.18 GPa to 52.56 GPa and the dynamic Poisson’s ratio ranges from 0.26 to 0.30 in acoustic wave test. It can be seen that the dynamic parameters are generally larger than the static parameters, and the relation between them is $E_s = 0.3624E_d + 11.865$, $R^2 = 0.8119$; $\mu_s = 1.243\mu_d - 0.0911$, $R^2 = 0.7267$. The relation between dynamic and static rock mechanics parameters provides a reliable parameter basis for the study of mechanical properties, brittleness and fracturing.

1. Introduction

Rock mechanics parameters include static parameters and dynamic parameters [1]. Static parameters are obtained by static loading and deformation of rock samples, which could provide accurate data but cost very much. Dynamic parameters are obtained by measuring the propagation speed of ultrasonic wave in rock, which can dynamically and continuously reflect the mechanical characteristics of rock, but can’t accurately reflect the stress of stratum, so they need to be converted into static parameters. Combining the static parameters measured in the laboratory with the dynamic parameters obtained from geophysical well logging, a suitable mechanical parameter model is established, which can accurately reflect the mechanical properties of the formation and solve the problems in petroleum engineering [2].

Yanchang gas field is located in the east of Yishan slope in Ordos Basin (Fig. 1). In Paleozoic, the study area mainly experienced the stages of continental margin sea basin and craton formation. During the late Carboniferous sedimentary period, controlled by the central paleouplift, the study area is dominated by tidal flat lagoon facies and fan delta facies are developed in some parts [3]. The burial depth of Benxi formation ranges from 2300m to 3600m.
The static and dynamic rock mechanics parameters from typical wells in the study area are obtained and the relation between dynamic and static rock mechanics parameters is established, which would provide parameter basis for the subsequent study of reservoir brittleness and fracturing.

2. Lithologic characteristics

Benxi Formation in the study area is generally covered by the Ordovician strata in the form of angular unconformity or parallel unconformity. The thickness of the strata is from 0m to 70m. The sand-body is distributed in the form of beads in northeast direction, with poor continuity, showing typical characteristics of barrier coast in plane. The lithology is mainly grayish black siltstone and grayish white gravelly coarse sandstone (Fig. 2). The resistivity of the reservoir ranges from 20μm to 200μm, natural gamma 30-60api, and the acoustic time difference is about 190-230 μ s / M; the natural gamma of mudstone has a very high peak, the rest is about 100-140api, and the acoustic time difference is about 220-275 μ s / M; the resistivity of limestone formation is high, ranges 200 μ m to1000μ m, and natural gamma 30api. The acoustic time difference is less than 165 μ s / M (Fig. 3).

Fig. 1 The study area in Ordos Basin

Fig. 2 Photos of Benxi formation in study area
3. Rock mechanics parameters of Benxi Formation

3.1. Static mechanics parameters
The parameters obtained by static loading deformation of rock samples are called static parameters[4]. Triaxial compression test is carried out in rock samples from well Y-1 and Y-2 of Benxi formation in Yanchang gas field of Ordos basin (the rock sample specification is Ø38.1mm × h76.2mm), and the test results are shown in Table 1.

According to the test results, the static elastic modulus of well Y-1 of Benxi formation ranges from 23.74 to 27.9GPa, with an average of 25.7GPa; the static Poisson’s ratio ranges from 0.232 to 0.297, with an average of 0.265; the static elastic modulus of well Y-2 of Benxi formation ranges from 28.6 to 32.46GPa, with an average of 30.09 GPa; the static Poisson’s ratio ranges from 0.206 to 0.261, with an average of 0.244.

Table 1. Results of triaxial compression test

| Well | Depth(m) | Lithology   | σc(MPa) | σt(MPa) | μ   | Es(GPa) |
|------|----------|-------------|---------|---------|-----|---------|
| Y-1  | 2763.12-2763.25 | Fine sandstone | 194.258 | 17.908 | 0.286 | 29.000 |
|      | 2763.58-2763.75 |             | 195.880 | 15.387 | 0.277 | 27.200 |
|      | 2763.91-2764.04 |             | 147.042 | 13.888 | 0.260 | 24.300 |
|      | 2764.34-2764.50 |             | 144.419 | 13.353 | 0.249 | 27.900 |
|      | 2764.64-2764.80 |             | 152.437 | 13.306 | 0.275 | 25.350 |
|      | 2765.23-2765.41 |             | 195.880 | 15.387 | 0.277 | 27.200 |
|      | 2765.67-2765.81 |             | 150.591 | 13.021 | 0.297 | 23.744 |
|      | 2765.81-2765.97 |             | 161.822 | 13.546 | 0.249 | 24.848 |
|      | 2766.45-2767.75 |             | 170.335 | 14.868 | 0.279 | 23.860 |
|      | 2767.90-2768.01 |             | 155.092 | 14.252 | 0.273 | 25.700 |
|      | 2769.65-2769.81 |             | 146.982 | 14.550 | 0.275 | 25.725 |
|      | 2769.97-2770.13 |             | 165.910 | 13.979 | 0.232 | 25.623 |
|      | 2770.47-2770.65 |             | 174.781 | 14.828 | 0.255 | 26.560 |
|      | 2770.76-2770.93 |             | 150.737 | 15.766 | 0.264 | 26.100 |
|      | 2681.60-2681.76 |             | 180.051 | 15.114 | 0.206 | 29.800 |
|      | 2682.61-2682.78 |             | 170.501 | 15.554 | 0.244 | 29.300 |
|      | 2683.07-2683.30 |             | 162.582 | 15.923 | 0.261 | 29.677 |
|      | 2683.94-2684.16 |             | 147.387 | 15.229 | 0.258 | 28.601 |
|      | 2684.49-2684.70 |             | 173.077 | 15.664 | 0.252 | 30.062 |
|      | 2684.92-2685.10 |             | 178.215 | 15.726 | 0.250 | 30.700 |
|      | 2685.70-2685.87 |             | 207.665 | 16.501 | 0.246 | 32.463 |

Fig. 3 Lithologic profile of Benxi formation in the study area
3.2. Static mechanics parameters

Under the assumption that the rock is homogeneous and isotropic, according to Newton’s law of motion and the theory of linear elasticity, the relation between the velocity of P-wave and S-wave and the rock elastic parameters can be obtained\[5\], they are as following(1) and (2).

\[
E_d = \frac{\rho V_p^2 (V_p^2 - 4V_s^2)}{V_p^2 - V_s^2}
\]

(1)

\[
\mu_d = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)}
\]

(2)

In the equations, \(E_d\) is dynamic elastic modulus, GPa, \(\mu_d\) is dynamic Poisson’s ratio, dimensionless, \(\rho\) is volume density, g/cm\(^3\), \(V_p\) is P-wave velocity, m/s, \(V_s\) is S-wave velocity, m/s. It can be seen that the dynamic mechanics parameters of rock can be calculated when the density of rock and the propagation velocity of P-S wave are known.

Acoustic wave test is carried out in rock samples from Y-1 and Y-2 well of Benxi formation in the study area (the rock sample specification is 38.1 mm ×h76.2 mm). The velocity of P-wave and S-wave can be obtained by measuring the propagation time of waves along the length direction, and then the dynamic elastic modulus and Poisson’s ratio can be calculated (Table2).

| Well | Depth (m) | Lithology | Vp(m/s) | Vs(m/s) | \(\mu_d\) | \(E_d\)(GPa) |
|------|-----------|-----------|---------|---------|----------|-------------|
| Y-1  | 2763.12-2763.25 | Fine sandstone | 4714.435 | 2538.234 | 0.30 | 42.98 |
|      | 2763.58-2763.75  |            | 4721.446 | 2546.951 | 0.29 | 43.27 |
|      | 2763.91-2764.04  |            | 4569.886 | 2546.579 | 0.27 | 42.13 |
|      | 2764.34-2764.50  |            | 4528.571 | 2504.252 | 0.28 | 39.45 |
|      | 2764.64-2764.80  |            | 4451.942 | 2448.330 | 0.28 | 37.48 |
|      | 2765.23-2765.41  |            | 4340.057 | 2310.614 | 0.30 | 33.71 |
|      | 2765.67-2765.81  |            | 4326.995 | 2296.651 | 0.30 | 33.18 |
|      | 2765.81-2765.97  |            | 4403.702 | 2430.118 | 0.28 | 37.61 |
|      | 2766.45-2767.75  |            | 4473.841 | 2401.997 | 0.30 | 37.71 |
|      | 2767.90-2768.01  |            | 4453.241 | 2417.598 | 0.29 | 38.02 |
|      | 2769.65-2769.81  |            | 4380.553 | 2374.433 | 0.29 | 36.87 |
|      | 2769.97-2770.13  |            | 4451.942 | 2448.330 | 0.28 | 38.81 |
|      | 2770.47-2770.65  |            | 4569.886 | 2546.579 | 0.27 | 41.68 |
|      | 2770.76-2770.93  |            | 4584.907 | 2550.500 | 0.28 | 42.10 |
|      | 2861.60-2681.76  |            | 4852.934 | 2778.584 | 0.26 | 49.89 |
|      | 2862.61-2682.78  |            | 4985.771 | 2775.114 | 0.28 | 51.49 |
|      | 2683.07-2683.30  |            | 4862.973 | 2686.838 | 0.28 | 48.36 |
| Y-2  | 2683.94-2684.16  | Sandstone | 4842.015 | 2685.690 | 0.28 | 46.75 |
|      | 2684.49-2684.70  |            | 4937.472 | 2771.690 | 0.27 | 49.54 |
|      | 2684.92-2685.10  |            | 5024.190 | 2820.720 | 0.27 | 51.99 |
|      | 2685.70-2685.87  |            | 5001.641 | 2804.977 | 0.27 | 52.56 |

According to the rock acoustic test results, the dynamic elastic modulus of rock samples in well Y-1 of Benxi formation in the study area ranges from 33.18 to 43.27GPa, with an average of 38.93GPa; the
dynamic Poisson’s ratio ranges from 0.27 to 0.30, with an average of 0.286. The dynamic elastic modulus of Benxi formation of well Y-2 ranges from 46.75 to 52.56GPa, with an average of 50.08GPa; the dynamic Poisson’s ratio ranges from 0.26 to 0.28, with an average of 0.273.

4. Relation between dynamic and static rock mechanics parameters

Due to the heterogeneity of the formation, there is a certain difference between the dynamic mechanics parameters and the static mechanics parameters[6,7]. Generally speaking, the dynamic elastic modulus is greater than the static elastic modulus. The elastic parameters of rock measured by sonic pulse test are dynamic elastic parameters, while the deformation and failure of borehole are relatively slow. Based on the static elastic modulus and Poisson’s ratio measured by triaxial mechanics, the conversion relation between dynamic and static elastic parameters is established, and the static elastic modulus and Poisson’s ratio can be obtained.

The dynamic and static elastic modulus and Poisson’s ratio of rock samples from well Y-1 and well Y-2 of Benxi formation in the study area are regressed linearly (Fig. 4 and 5), and the relations are as (3)and(4).

\[
E_s = 0.3624E_d + 11.865 \quad \text{R}^2 = 0.8119 \quad (3)
\]

\[
\mu_s = 1.243\mu_d - 0.0911 \quad \text{R}^2 = 0.7267 \quad (4)
\]

In conclusion, the static elastic modulus of Benxi formation in the study area is smaller than the dynamic elastic modulus, and the relation between them is \(E_s = 0.3624E_d + 11.865\), \(R^2 = 0.8119\).The static Poisson’s ratio is slightly smaller than the dynamic Poisson’s ratio, and the relation is \(\mu_s = 1.243\mu_d-0.0911\), \(R^2 = 0.7267\).
5. Conclusion

In Benxi formation of Yanchang gas field, the static elastic modulus ranges from 23.74 to 32.46 GPa, with an average of 27.24 GPa, and the static Poisson’s ratio ranges from 0.206 to 0.297, with an average of 0.258. The dynamic elastic modulus ranges from 33.18 to 52.56 GPa, with an average of 42.65 GPa. The dynamic Poisson’s ratio ranges from 0.26 to 0.30, with an average of 0.282. The correlation between dynamic and static mechanics parameters of Benxi formation in Yanchang gas field is good, and the dynamic parameters are generally larger than the static parameters, the relation is $E_s = 0.3624 E_d + 11.865$, $R^2 = 0.8119$; $\mu_s = 1.243 \mu_d - 0.0911$, $R^2 = 0.7267$.

Acknowledgments

This work was financially supported by Department of industry and information technology Funds of Gansu Province, project number GGLD-2019-066, and by Xifeng Technology Bureau Fund Project, project number XK2019-10.

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