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Experimental Research on Rock Mechanics Parameters in the Lower Youshashan Formation, Wunan Oilfield

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Abstract: Qinghai oilfield has moved one of its currently developmental focuses onto the Lower Youshashan formation, Wunan oilfield. This paper presents acoustic features of 16 vertical and 40 horizontal core samples (56 samples in total) from Youshashan Formation, Wunan Oilfield, which tested by SCMS-E high-temperature & pressure core multi-parameters tester and the furtherly dynamic modulus of elasticity and Poisson's ratio of core samples were obtained. Most specimens present a strong plastic deformation characteristic by applying the RTR-1000 high-temperature & pressure triaxial rock mechanics testing device to evaluate the stress-strain curve of the corresponding specimens; Static modulus of elasticity and Poisson's ratio of the separate core samples were calculated as per GB/T50266-2013. Experimental results demonstrate: static modulus of elasticity of core samples shows much less than dynamic modulus of elasticity of that while static Poisson's ratio presents much greater than dynamic Poisson's ratio. This paper provides a comparative analysis on dynamic & static mechanics property parameters according to the classification of vertical and horizontal and complete samples, and the conversion relation between dynamic and static mechanics property parameters was established, which lays the foundation of rational and efficient reservoir exploitation in the Lower Youshashan Formation, Wunan Oilfield in terms of mechanics parameters.

1. Introduction

Rock mechanics parameters take great place in oil & gas well drilling and exploitation, especially in fracturing engineering^[1-3], which play a decisive role in crack propagating morphology and geometry to some extent, and furtherly impact hydrofracturing stimulation effect^[4-5]. The main methods of getting rock mechanics parameters include indoors uniaxial or triaxial stress experimental testing method^[6] and acoustic character calculation method^[7-8] or logging interpretation method^[9-11]. Generally, static modulus of elasticity and Poisson's ratio can be obtained by the experimental testing, which relatively and truly reflect the deformation characteristics and have been widely used in petroleum engineering^[12-14]. The logging interpretation method technically represents the acoustic character calculation method to calculate dynamic modulus of elasticity and Poisson's ratio based on P & S wave logging datas, which is able to be applied to engineering practice only when dynamic value adjustment to static one has been made^[15]. Practically, rock's acoustic features show relevance with lithology, porosity and clay content etc.^[16-17], consequently, the conversion relation between dynamic



and static mechanics property parameters of different area and lithology also shows variation.

Wunan oilfield is one of the main battlegrounds for ten-million ton's plateau oilfields which PetroChina intends to exploit and the reservoir of the Lower Youshashan formation is the most enriched oil-bearing series in this oilfield, which has the main burial depth of 1200~2500m ("whose burial depth varies from 1200 to 2500m"). The reservoir formation shows relatively developed cracks, furtherly complicating the reservoir structure. $\phi 25$ specimens (56 in total) from 16 groups (each group includes 1 vertical sample and 3 horizontal samples every 45°) of 9 wells with various burial depths in the reservoir of the Lower Youshashan formation, Wunan oilfield is also included in this research. Dynamic Young's mechanics parameters (mainly modulus of elasticity and Poisson's ratio) are calculated based on Wave Propagation theory with P & S wave speed measured by experimental testing, and then conduct experimental testing for static mechanics parameters under triaxial condition. This paper presents the conversion relation between dynamic and static mechanics parameters concluded by the comparative analysis, which lays the foundation of efficient reservoir exploitation in the Lower Youshashan Formation, Wunan Oilfield in terms of basic parameters.

2. P & S wave speed testing on rocks and dynamic mechanics parameters

2.1 P & S wave speed experiment on rocks

P&S wave speed testing on rocks was performed with SCMS-E high-temperature & pressure core multi-parameters tester based on the ultrasonic transmission method measuring principle. Namely: Put the test specimens in the core gripper and the two ends of specimens respectively connect to the acoustic pinger and oscilloscope. The acoustic pinger receives a pulse while the oscilloscope will collect one group of waveform. By measuring the arrival time of head wave, the propagation speed of P&S wave on rocks can be obtained. The calculation formulas show as following:

$$V_p = \frac{L}{\Delta t_p - \Delta t_{p0}} \times 10000 \quad (1)$$

$$V_s = \frac{L}{\Delta t_s - \Delta t_{s0}} \times 10000 \quad (2)$$

Where:

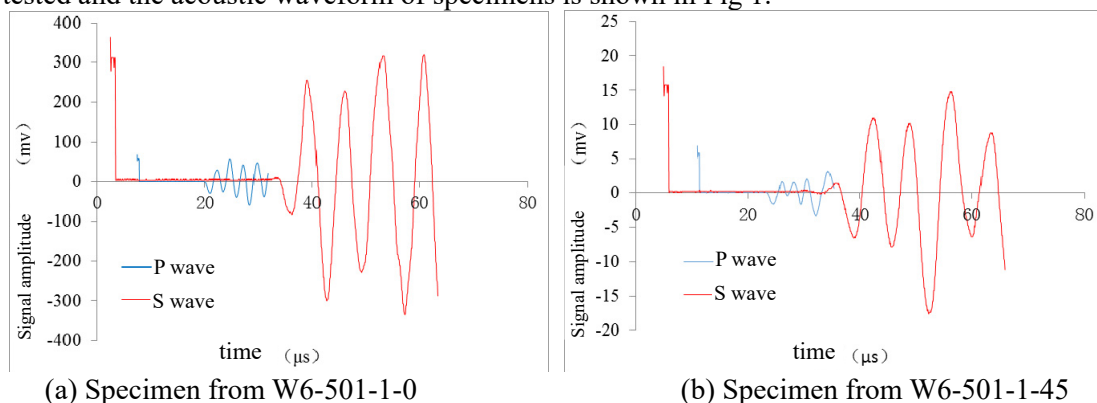
V_p 、 V_s —P & S wave speed, m/s;

L —Length of the rock sample, cm;

Δt_p 、 Δt_s —Propagation time of testing P & S wave, μs ;

Δt_{p0} 、 Δt_{s0} —Propagation time of P & S wave in the probe, μs .

The experiment performed the P & S wave speed testing of 56 specimens which came from the 9 wells tested and the acoustic waveform of specimens is shown in Fig 1.



(a) Specimen from W6-501-1-0
(b) Specimen from W6-501-1-45
Fig.1 P & S wave speed testing of 56 specimens from the 9 wells tested and the acoustic waveform of specimens

The calculation results of P & S wave speed based on the time difference and P & S wave are indicated in Fig 2. The wave speed of P & S wave is between 2856 and 4859m/s (3705m/s on average) and 2149~3014m/s (2477m/s on average). The speed ratio of P and S wave shows between 1.448 and 1.665 (1.537 m/s on average). A good correlation between P and S wave speed on rocks is presented as following:

$$V_s = 0.56V_p + 341.1 \quad (R^2 = 0.899) \quad (3)$$

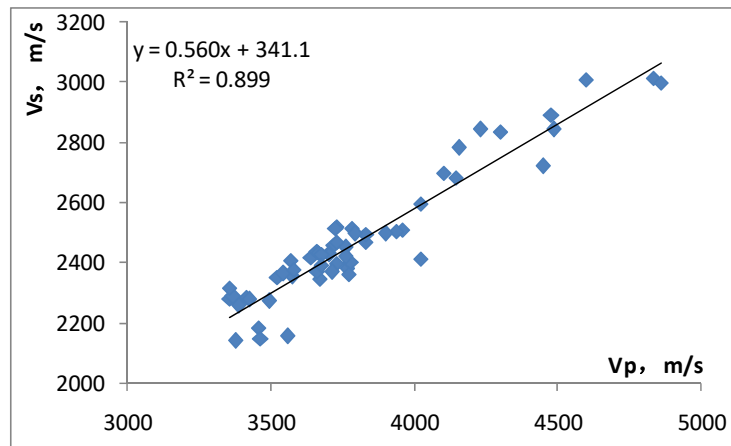


Fig 2 Testing results of P & S wave speed on rocks in Wunan region

2.2 Dynamic analysis on rock mechanics parameters

Assuming that the rock is homogeneous and isotropic linear-elastic structure, the relation between rock mechanics parameters and P & S wave speed on rocks can be expressed as below:

$$E = \frac{\rho V_s^2 (3V_p^2 - 4V_s^2)}{V_p^2 - V_s^2} \quad (4)$$

$$\mu = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)} \quad (5)$$

Where:

ρ —Bulk density of rock, kg/m³;

E —Dynamic Young's modulus of elasticity of rock, Pa;

μ —Dynamic Poisson's ratio of rock, dimensionless ;

Dynamic mechanics parameters of rocks in the Lower Youshashan formation, Wunan oilfield from the calculation based on P & S wave speed from acoustic features testing are presented in Fig 3. Dynamic Young's modulus of elasticity and Poisson's ratio respectively are 25.8~56.7GPa (34.65GP on average) and 0.082~0.2089(0.1301 on average). Poisson's ratio and Young's modulus of elasticity go up with the increase of depth. The mechanics parameters show difference in some way for various lithology of core with close depth.

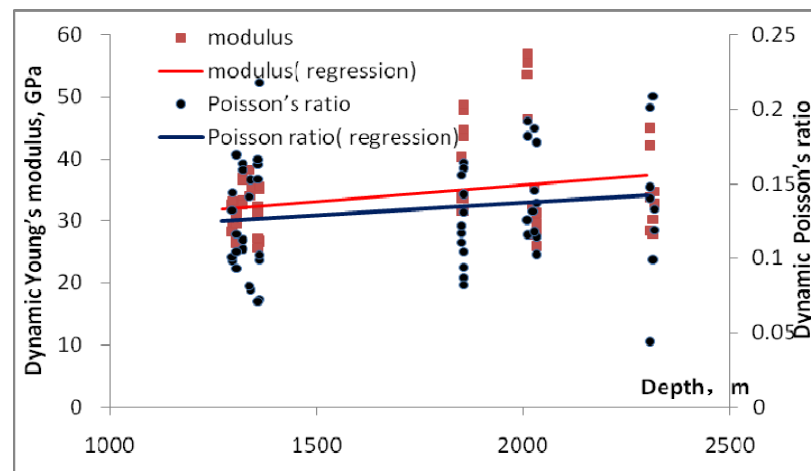


Fig 3 Testing results of dynamic mechanics parameters of rocks in the Lower Youshashan formation, Wunan oilfield

3. Experimental testing for rock static mechanics

The partially typical testing curve from triaxial mechanics experiment (testing on 56 specimens with RTR-1000 high-temperature & pressure triaxial rock mechanics testing device from State Key Laboratory of Oil and Gas Reservoir Geology and Exploration, Southwest Petroleum University) is presented in Fig 4 and Fig 5.

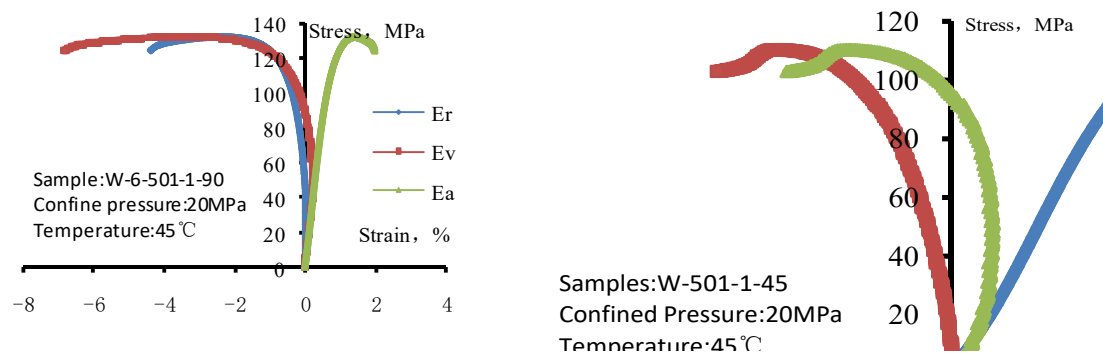


Fig 4 Stress difference-axial strain curve by triaxial experiment (specimens at 1323.5m from W6-501 well)

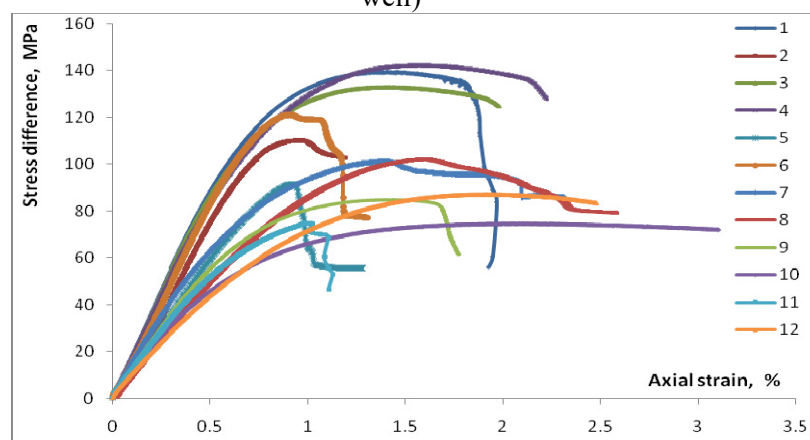


Fig 5 Stress difference-axial strain curve (specimens (partial) from the Lower Youshashan formation, Wunan oilfield)

Overall, most specimens present a strong plastic deformation characteristic and few of them show

evident brittleness (such as sample #5 and #11). Static Young's modulus of elasticity and Poisson's ratio calculated as per GB/T50266-2013 is indicated in Fig 6.

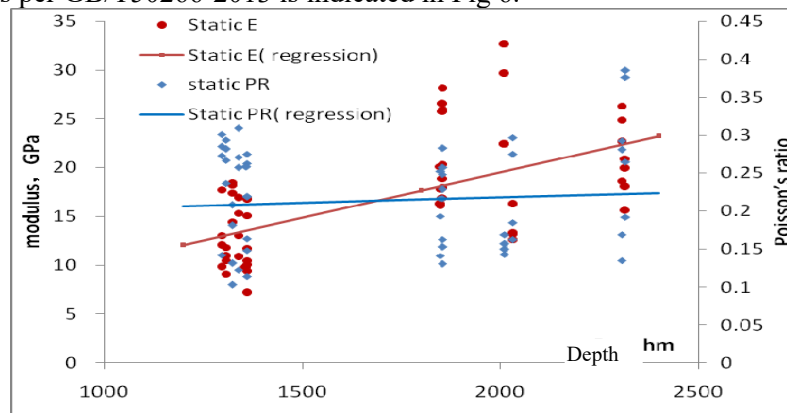


Fig 6 Variation trend of static Young's modulus of elasticity with depth (specimens from the Lower Youshashan formation, Wunan oilfield)

Dynamic Young's modulus of elasticity of specimens is 7.21~32.71MPa (17.14 MPa on average), which shows a positive correlation with depth. Poisson's ratio is 0.103~0.385(0.220 on average), There is almostly no correlation with depth.

4. Relation between dynamic and static rock mechanics parameters

Dynamic and static rock mechanics parameters are derived respectively from calculation on P & S wave speed testing on specimens and triaxial experiment on rocks. Fig 7 and Fig 8 present the comparative study on dynamic and static parameters in accordance with vertical, horizontal and complete rock samples. The conversion relation established between dynamic & static Young's modulus of elasticity and Poisson's ratio is shown in the following table:

| | The conversion relation between dynamic and static Young's modulus of elasticity | | The conversion relation between dynamic and static Poisson's ratio | |
|--------------------|--|---------------|---|---------------|
| Vertical samples | $E_s = 0.643 \times E_d - 5.326$ | $R^2 = 0.699$ | $\mu_s = 0.181 \times \mu_d + 0.196$ | $R^2 = 0.010$ |
| Horizontal samples | $E_s = 0.757 \times E_d - 9.645$ | $R^2 = 0.680$ | $\mu_s = 0.586 \times \mu_d + 0.156$ | $R^2 = 0.074$ |
| Complete samples | $E_s = 0.651 \times E_d - 5.396$ | $R^2 = 0.769$ | $\mu_s = -0.329 \times \mu_d + 0.261$ | $R^2 = 0.012$ |
| Remark | E_s —static modulus of elasticity, GPa; E_d —dynamic modulus of elasticity, GPa | | μ_s —static Poisson's ratio, dimensionless μ_d —dynamic Poisson's ratio, dimensionless | |

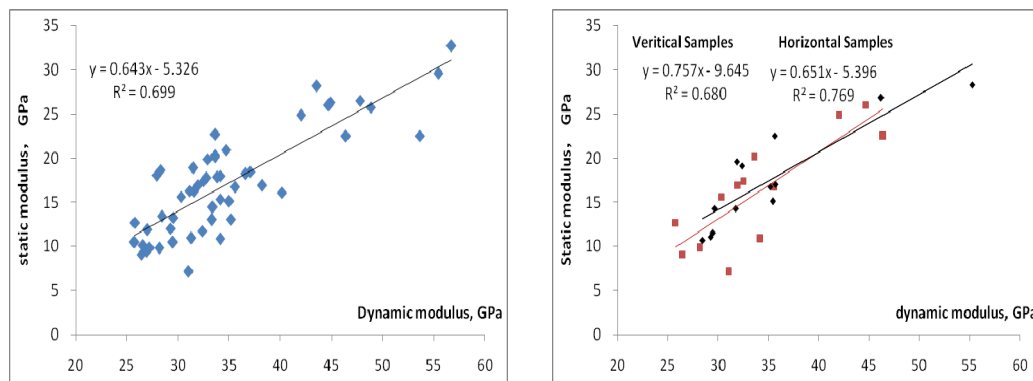


Fig 7 The conversion relation between dynamic and static Young's modulus of elasticity (specimens from the Lower Youshashan formation, Wunan oilfield)

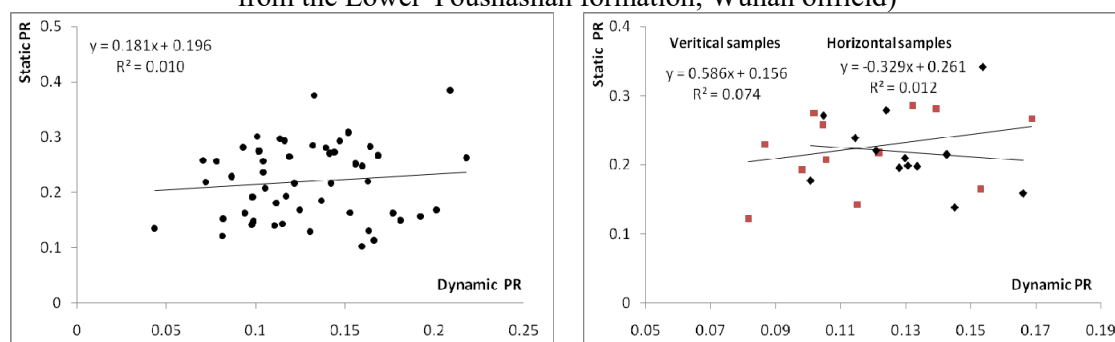


Fig 8 The conversion relation between dynamic and static Poisson's ratio (specimens from the Lower Youshashan formation, Wunan oilfield)

From the conversion relation between dynamic and static rock mechanics parameters it is able to tell that: the correlation of modulus of elasticity presents much higher than that of Poisson's ratio; Dynamic & static modulus of vertical, horizontal and complete rock samples show a close conversion relation, while dynamic & static Poisson's ratio presents relative dispersion relation.

5. Conclusion

The following conclusions can be obtained by the experimental testing analysis on specimens (56 in total) from 16 groups of 9 wells in the reservoir of the Lower Youshashan formation, Wunan oilfield:

- The wave speed of P wave on rocks varies from 2856 to 4859m/s and the wave speed of S varies from 2149 to 3014m/s. A good correlation between P and S wave is presented. Dynamic modulus of elasticity and Poisson's ratio respectively are 25.8~56.7GPa (34.65GP on average) and 0.082~0.2089(0.1301 on average), both of them present a positive correlation with depth.
- Most specimens present a strong plastic deformation characteristic and few of them show evident brittleness, indicated by the experiment testing under the triaxial condition. Modulus of elasticity of specimens is 7.21~32.71MPa (17.14 MPa on average), which shows a positive correlation with depth. Poisson's ratio is 0.103~0.385(0.220 on average), which almostly presents no correlation with depth.
- From the comparative analysis according to the classification of vertical and horizontal and complete samples it is able to tell that: the correlation of modulus of elasticity presents much higher than that of Poisson's ratio; Dynamic & static modulus of vertical, horizontal and complete rock samples show a close conversion relation, while dynamic & static Poisson's ratio presents relative dispersion relation.
- The established P & S wave correlation formula and conversion relation between dynamic and static mechanics parameters are provided with high reliability as a guidance for oilfield development.

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