**Construction of Visual Rock Force Field Model based on Hermite Interpolation**

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**Abstract:** Based on the multi-port log data interpretation and indoor mechanical parameter test, the dynamic and static conversion model is established, and then the dynamic master data is constructed by Piecewise Cubic Hermite Interpolation optimization method, and the continuous static parameter data body (Young's modulus, Poisson's ratio, etc.) is established horizontally and vertically. Based on the data body, a spatial mechanical field visualization model of tight reservoir is constructed through MATLAB to form a method to predict the distribution of three-dimensional continuous rock mechanical field. The results provide guidance for the analysis of mechanical deformation characteristics of tight oil reservoir rocks.

**Key words:** Mechanical Field; Hermite Interpolation; Visualization Models

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## **1 Introdyction**

As oil extraction becomes more and more difficult, the world's oil and gas replacement resources are gradually replaced by unconventional oil and gas resources such as tight oil and gas, and the scale development of unconventional oil and gas resources has been achieved in many countries[1-6]. Since tight oil plays an important role in the global energy structure[7], China has made continuous research on Geological Evaluation Methods for Tight Oil[6,9], and made important breakthroughs in the exploration[8].

Conventional tight reservoir judgment is to roughly determine the location of stress concentration in the formation by experience or simple surveying instruments，but this method is not accurate and has spatial limitations. The study shows that the formation of effective fracturing fracture network has a good correlation with the development of natural rock fractures[10-12]，The distribution characteristics of rock mechanical field are mainly controlled by the heterogeneous distribution of rock mechanical parameters (Young's modulus, Poisson's ratio, etc.). Generally, the areas with weak Young's modulus or compressive strength are prone to stress concentration under the action of structural stress, which is the area of crack development. Therefore, Regions where natural fractures may develop can be predicted by the heterogeneous spatial distribution of rock mechanical parameters.

Based on the interpretation of multi-port logging data of the tight reservoir in the Ordos Basin and indoor mechanical parameter test, the dynamic and static conversion model is established, and the segmented cubic Hermite interpolation optimization method is adopted to establish the continuous static mechanical parameter data body in the transverse and longitudinal directions in this paper. Then, a visual model of Young's modulus and Poisson's ratio was established by MATLAB software, and the distribution characteristics of rock mechanical field at any position in the research area were analyzed, finally forming a set of methods for predicting the distribution of three-dimensional continuous rock mechanical field.

## **2 [Piecewise Cubic Hermite Interpolation](https://www.baidu.com/s?sa=re_dqa_generate&wd=Piecewise Cubic Hermite Interpolation&rsv_pq=bacb62fc004ffae6&oq=%E5%88%86%E6%AE%B5%E4%B8%89%E6%AC%A1Hermite%E6%8F%92%E5%80%BC%E5%A6%82%E4%BD%95%E7%BF%BB%E8%AF%91&rsv_t=56acbnljRztWlIKduC1xS5HzcqOGFI/QKvxjESM9utfhj+Mk2z3xf5kNp9vk2Czrxlzkdg&tn=15007414_2_pg&ie=utf-8" \t "https://www.baidu.com/_blank)**

When constructing the rock mechanical field, when the logging data is limited and cannot support the complete analysis, some mathematical methods need to be used to "simulate" some new but relatively stable and relatively accurate values to meet the requirements, which is the role of interpolation.

At present, the most common and basic interpolation methods are Lagrangian interpolation, Newton interpolation, and piecewise linear interpolation. Although these interpolation methods keep the same function value to the interpolated function, the similar interpolated polynomials cannot accurately show the character of the interpolated function. When dealing with practical problems, not only the interpolated function has the same function value as all nodes of the interpolated function, but also the interpolated polynomial value is the same as the low or higher order derivative value of the interpolated function on all nodes. From an algorithmic perspective, the Lagrangian and Newton interpolation clearly do not meet the requirements[13]。

The [Piecewise Cubic Hermite Interpolation](https://www.baidu.com/s?sa=re_dqa_generate&wd=Piecewise Cubic Hermite Interpolation&rsv_pq=bacb62fc004ffae6&oq=%E5%88%86%E6%AE%B5%E4%B8%89%E6%AC%A1Hermite%E6%8F%92%E5%80%BC%E5%A6%82%E4%BD%95%E7%BF%BB%E8%AF%91&rsv_t=56acbnljRztWlIKduC1xS5HzcqOGFI/QKvxjESM9utfhj+Mk2z3xf5kNp9vk2Czrxlzkdg&tn=15007414_2_pg&ie=utf-8" \t "https://www.baidu.com/_blank) used in this paper meets the accuracy requirements of the interpolation algorithm, which also ensures the accuracy of the prediction data, thus making the final visualization model more close to the actual situation.

The principle used in this interpolation method is to divide the function into n+1 mutual different nodes on the interval ，where dot .

Defined on , the function meet on the nodes：, ( conditions), but the only Polynomial of with no more than conditions satisfies：

，， (1)

The remaining items：

(2)

And [Piecewise Cubic Hermite Interpolation](https://www.baidu.com/s?sa=re_dqa_generate&wd=Piecewise Cubic Hermite Interpolation&rsv_pq=bacb62fc004ffae6&oq=%E5%88%86%E6%AE%B5%E4%B8%89%E6%AC%A1Hermite%E6%8F%92%E5%80%BC%E5%A6%82%E4%BD%95%E7%BF%BB%E8%AF%91&rsv_t=56acbnljRztWlIKduC1xS5HzcqOGFI/QKvxjESM9utfhj+Mk2z3xf5kNp9vk2Czrxlzkdg&tn=15007414_2_pg&ie=utf-8" \t "https://www.baidu.com/_blank) has a built-in function in MATLAB, which can simplify the programming process.

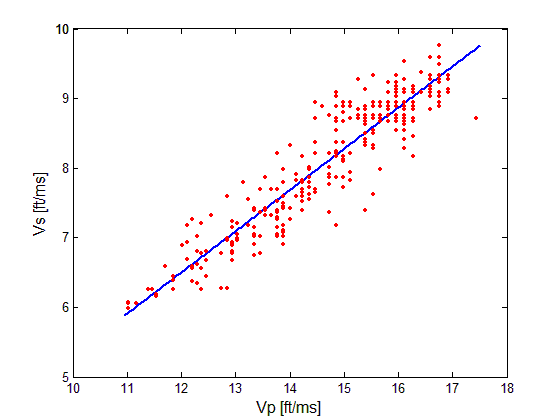
## **3 Method for constructing a rock mechanical field model**

Based on the acoustic wave logging data in the Ordos Basin, the transverse wave and longitudinal wave data are obtained, and the dynamic Young's modulus and Poisson ratio parameters are calculated[14]。At the same time, the indoor mechanics testing experiment was carried out to obtain the static mechanical parameters of Young's modulus and Poisson's ratio. After correcting the core buried depth, the dynamic and static parameter transformation model was established, so as to establish the static mechanical parameter database based on the logging data.

## **3.1 Calculation of the horizontal and vertical wave speed**

Most of the logging data have longitudinal wave data, but the transverse wave data is lacking. For the logging data of transverse wave and longitudinal wave in the study area, the fitting relationship between transverse wave velocity and longitudinal wave velocity is established：

*Vs*=0.592*Vp*-0.6016 (3)



**Figure 1. Horizontal and vertical wave logging curves**

The value above can be used to calculate the dynamic Young's modulus and dynamic Poisson ratio of rocks in the study area. For most Wells without shear wave data, the longitudinal wave velocity is calculated first by calculating the acoustic time difference：

(4)

Then the transverse wave velocity is calculated by the following equation：

(5)

Thus, a linear relation equation based on the horizontal and vertical wave velocity in the study area is established.

## **3.2 Dynamic Young's modulus and dynamic Poisson ratio**

Ultimately, the dynamic Young's modulus and the dynamic Poisson ratio can be calculated:

 (6)

 (7)

is the volume density of the rock sample；， for the vertical and transverse wave velocity, respectively，E for Dynamic Young's modulus， for Dynamic Poisson ratio。

## **3.3 Transformation model of both dynamic and static parameters**

The static parameters obtained by the indoor test mechanical test can directly reflect the mechanical properties of the rock[15]. In this paper, the dense reservoir rocks of Ordos basin are corred with different lithology along the buried interdepth end. This experimental rock sample is for the straight well core, and the core location is drilled along the horizontal direction of the formation, so the core is mainly considering the hydraulic fracturing engineering of the straight well. The experimental equipment adopts TAW-2000 microcomputer control electro-hydraulic servo rock triaxial testing machine produced by Changchun Chaoyang Testing Machine Co., LTD., with a stiffness of 40 MN, a loading capacity of 2000 kN and an upper circumference pressure limit of 100MPa. In the triaxis experiment, the surrounding pressure is loaded at a rate of 0.05MPa / s. First, the surrounding pressure is added to the predetermined value of 0.05MPa / s, and then the axial displacement is loaded at a rate of 0.005 m/s until failure. The study shows that when the diameter of cylindrical samples is 20 to 60 mm, and the high diameter ratio is 2 to 3, the experimental test results will not cause too much size effect. In this experiment, 17 standard cylindrical samples with a size of 25mm50mm were prepared by natural core drilling, cutting and grinding. The irness error of both ends of the specimen is less than 0.05mm, the height and diameter error along the specimen is less than 0.3mm, and the maximum deviation of the end surface perpendicular to the axis of the specimen is less than 0.25°. The axial and radial deformation of the sample is measured by extension gauge, the force sensor dynamically measures the axial load, and the extension gauge is calibrated through the deformation calibrator before the measurement to ensure that the processing value of the software system matches the actual deformation value. The 46 # hydraulic oil servo rock sample is used to simulate the actual formation surrounding pressure. In order to prevent the hydraulic oil from infiltrating into the sample, the hard heat shrink pipe is used to wrap the rock sample to ensure that the sample is completely isolated from the hydraulic oil. The experimental equipment and measuring instrument are as shown in Figure 2[17]。



**Figure 2. Experimental equipment and measuring instrument**

Based on the actual overlying pressure, the triaxial compression stress experiment was conducted to obtain the mechanical parameters of Young's modulus and Poisson ratio. Based on the mechanical parameters of indoor test and the dynamic parameters of logging, the conversion correlation between dynamic elastic modulus and static elastic modulus was established, and the dynamic mechanical parameters and static mechanical parameters were fitted based on the least squares method（Figure 3）：

（8）



**Figure 3. Dynamic and static Young's elastic modulus parameter correlation diagram**

Based on the logging data and experimental data, it is found that the dynamic Poisson ratio and static Poisson ratio are correlation, but the ratio of dynamic and static Poisson ratio and porosity *Φ* exist great rules. To this end, a quadratic fitting based on the least squares method is used to obtain transformation model of dynamic and static Poisson crossing.（Figure4）：

(9)



**Figure 4. Porosity and Poisson's ratio relationship**

Based on the logging data, as long as you know the formation depth, formation density, acoustic time difference, porosity, according to the dynamic and static transformation model, the static mechanics parameters (Young's modulus, Poisson's ratio) can be obtained for multiple wells in the study area.

## **3.4 Construction of rock mechanical field visualization**

In order to produce a full-space visual model after the dynamic and static transformation, we can simulate the [Piecewise Cubic Hermite Interpolation](https://www.baidu.com/s?sa=re_dqa_generate&wd=Piecewise Cubic Hermite Interpolation&rsv_pq=bacb62fc004ffae6&oq=%E5%88%86%E6%AE%B5%E4%B8%89%E6%AC%A1Hermite%E6%8F%92%E5%80%BC%E5%A6%82%E4%BD%95%E7%BF%BB%E8%AF%91&rsv_t=56acbnljRztWlIKduC1xS5HzcqOGFI/QKvxjESM9utfhj+Mk2z3xf5kNp9vk2Czrxlzkdg&tn=15007414_2_pg&ie=utf-8" \t "https://www.baidu.com/_blank) method combined with MATLAB statement, and obtain the 2 D and 3 D spatial distribution map of two mechanical parameters of Young's modulus and Poisson's ratio[15].

Firstly, the static Young's modulus and static Poisson's ratio are obtained based on the dynamic and static transformation model, then the continuous data volume is established based on interpolation, and then the MATLAB statement is simulated to obtain the plane two-dimensional spatial distribution map of Young's modulus and Poisson's ratio. Figure 5 is a two-dimensional diagram of rock mechanical field superimposed from the bottom to the top at the well depth of 2100m and 4300m, and finally forms a three-dimensional data ( three-dimensional space and mechanical parameter size ( indicated by color scale ) ). The figure shows that the different regions differ considerably in the same plane mechanical parameters.



**Figure 5. 3D plots of Young's modulus**

When observing the Young's modulus map in the 3000m layer, it was found that the image had very good continuity after interpolation. Since the [Piecewise Cubic Hermite Interpolation](https://www.baidu.com/s?sa=re_dqa_generate&wd=Piecewise Cubic Hermite Interpolation&rsv_pq=bacb62fc004ffae6&oq=%E5%88%86%E6%AE%B5%E4%B8%89%E6%AC%A1Hermite%E6%8F%92%E5%80%BC%E5%A6%82%E4%BD%95%E7%BF%BB%E8%AF%91&rsv_t=56acbnljRztWlIKduC1xS5HzcqOGFI/QKvxjESM9utfhj+Mk2z3xf5kNp9vk2Czrxlzkdg&tn=15007414_2_pg&ie=utf-8" \t "https://www.baidu.com/_blank) has relatively good interpolation characteristics, even no measured points were predicted（Figure 6）.



**Figure 6. Two-dimensional plot of Young's modulus at 3000m layer**

In the analysis of static Poisson ratio mapping, only part of the 2100m to 4300m deep intact data was drawn（Figure 7）.



**Figure 7. 3D diagram of the static Poisson's ratio**

Then observing the static Poisson ratio map of the 3000m layer can also observe the Poisson ratio of the unmeasured area（Figure 8）.



**Figure 8. Two-dimensional diagram of the static Poisson ratio at 3000m layer**

To construct the spatial stereo map formed by three-dimensional coordinates through the process of interpolation and fitting of the data programming, the two-dimensional plane map of static Young's modulus and static Poisson's ratio under a certain well depth condition can be output according to the requirements. The figure shows that the different regions differ greatly in the mechanical parameters of the same plane. This is more concise and directly shows the mechanical characteristics of the dense reservoir rock, which lays a certain theoretical reference foundation for the further study of the mechanical characteristics of the dense reservoir sandstone. In petroleum geological engineering, the paper also provides reference information for the further guidance of drilling and exploitation.

## **4 Conclusion**

1. This paper analyzes the characteristics of the rock mechanical parameters of a dense sandstone reservoir and the corresponding rock mechanical parameters. Based on the dynamic and static transformation relationship, the mechanical parameters such as static Young's modulus and static Poisson's ratio are calculated.

(2) Optimization is accomplished by using Piecewise Cubic Hermite Interpolation and the distribution of the 3 D space of Young's modulus and Poisson ratio was simulated by MATLAB software. The figure shows that the different regions differ considerably in the same plane mechanical parameters. The four-dimensional images drawn allow for the continuous visualization of the spatial mechanical field of the dense reservoir. The strength distribution of the mechanical parameters of different formation depths can be seen through the longitudinal direction of the model. And even in the same plane, the Young's modulus and Poisson ratio differ greatly from the distribution.

(3) In this paper, a method to construct a visualization of the reservoir continuous mechanical field model was discovered by study. This method provides guidance for the analysis of rock mechanical deformation characteristics of dense oil reservoir.

**References**

1. Zhao Zhengzhang, Du Jinhu. Dense oil and gas [M]. Beijing: Petroleum Industry Press, 2012.
2. Li Guoxin, Zhu Rukai. Current status, challenges and concerns of unconventional oil and gas development of CNPC [J]. China Petroleum Exploration, 2020 (02): 1-10.
3. Yao Jingli, Deng Xiuqin, Zhao Yande, et al. The tight oil characteristics of the Yanchang Formation in the Ordos Basin [J]. Petroleum Exploration and Development, 2013,40 (02): 150-158.
4. Lin Senhu, Zou Can, Yuan Xuanjun, et al. Status and enlightenment of tight oil development in the United States [J]. Lithologic reservoir, 2011,23 (04): 25-30.
5. Song Yan, Jiang Lin, Ma Xingzhi. Formation and distribution characteristics of

unconventional reservoirs [J]. Journal of Palaeogeography, 2013,15 (05): 605-614.

1. Zou CAI, Tao Shizhen, Hou Lianhua, etc. Unconventional oil and gas geology [M]. Beijing; Geological Press, 2011.
2. Yang Hua, Li Shixiang, Liu Xianyang. Characteristics of tight oil and shale oil and resource potential in Ordos Basin [J]. Journal of Petroleum, 2013,34 (01): 1-11.
3. Du Jinhu, Liu He, Ma Desheng, et al. On the effective development technology of

continental dense oil in China [J]. Petroleum Exploration and Development, 2014,41 (02):

198-205.

1. Jia Chengzao, Zou Cant, Li Jianzhong, et al. Evaluation criteria, main types, basic characteristics and resource prospects of tight oil in China [J]. Journal of Petroleum, 2012,33 (03):

343-350.

1. Bai Bin, Zou Cant, Zhu Rukai, et al. Characteristics of structural cracks and formation

period of the second section of dense sandstone reservoir in southwest Sichuan [J]. Journal of Geology, 2012,86 (11): 1841-1846.

1. Gong Lei, Zeng Lianbo, Zhang Benjian, et al. Control factors for fracture development of

Jiulongshan structural tight conglomerate reservoir [J]. Journal of China University of

Petroleum (Natural Science edition), 2012,36 (06): 6-12.

1. Xing Zhenhui, Cheng Linsong, Zhou Xingui, et al. Analysis of the formation mechanism of natural cracks in the upper Paleozoic dense sandstone gas reservoir in Tabamiao area of

northern Ordos Basin [J]. Journal of geomechanics, 2005 (01): 33-42.

1. Zhou Jianjie, Yu Rengui. Newton Interpolation Theory based on MATLAB software [J].

Henan Science and Technology, 2018,, 32 (02): 1-5.

1. Yu Tao, Wang Nianming, Tian Wentao, Xu Xueliang, Liao Chun, Yin Shuai. Elasticity

parameter prediction of dense reservoirs based on conventional logging [J]. Broken Block oil and gas field, 2019 (01): 1-8.

1. Zhang Haotian, Zhou Wen, Cao Qian, Xu Hao, Shan Yuming. Evaluation of brittle plasticity

logging based on stress-strain model [J]. Logging technique, 2018 (03): 2-10.

1. Songtao Wu, Zhi Yang, Songqi Pan, Jingwei Cui, Senhu Lin, Ling Su, Hrishikesh Bale, Youli Hong, Wen Shi. Three-dimensional imaging of fracture propagation in tight sandstones of

the Upper Triassic Chang 7 member, Ordos Basin, Northern China[J]. Marine and Petroleum Geology,2020,104501.

1. Hetenyi M.Handbook of experimental stress analysis[M].New York:John Wiley,1966.