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Experimental Study on the Mechanical Properties of Coal Seam as a Main Aquifer of Xiaojihan Coal Mine

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Abstract: *Usually the aquifer is above or below the coal seam, for the first time, the mining coal seam is found as the main aquifer in Xiaojihan Coal Mine of China's western Yuheng Mining Area. In this paper, we studied the mechanical properties of the water bearing coal seam in Xiaojihan Coal Mine. Based on the study of strength characteristics of water bearing coal seam, its special mechanical characteristics which are different from the other seams are obtained. Through uniaxial compression test, triaxial compression test and split test, the parameters such as the compressive strength, elastic modulus, Poisson rate, tensile strength and internal friction angle of each rock stratum are obtained. The research shows that the tensile strength and internal friction angle of the coal specimens from the water bearing coal seam are lower than that from the other rock strata. These mechanical properties indicate that the structure of coal seam is loose and it contains a large number of pores and has good permeability. Therefore the coal seams of Xiaojihan Mine Coal posses the aquifer condition. The obtained mechanical properties provided a reliable theoretical basis for forecasting mining face and mine water inflow, for establishing the early pre-warning system of mine water disaster, for designing and optimizing the technology of driving and coal mining related with water disaster prevention.*

Keywords: *Xiaojihan Coal Mine, main aquifer, mechanical properties, experimental study*

1. Introduction

Yuheng Mining Area [1] in China is located in the bordering area of Maowusu Desert and Loess Plateau, which is a typical desert beach area, and has been defined as a region of drought and semi drought water shortage [2] for a long time. However, water disasters in the western mining are a have occurred frequently in recent years, and have caused people to pay attention to the water-bearing stratum of this area. The existing survey and exploration data and detailed studies about Xiaojihan Coal Mine of Huadian Coal Group Company have not found or pointed out that the coal seam is the main aquifer. However, with the development of Xiaojihan Coal Mine, they found a special geological phenomenon that the mining coal seam is the main aquifer [3-5] for the first time, especially in the western shaft area. Field observation and research showed that Xiaojihan coal seam of Yuheng Mining Area was aquifer. In the process of tunnel excavation, the main source of water seepage [6] is No.2 coal seam fissure water and sandstone fissure water in coal roof, which contains more than 80% mine water inflow. The No.2 coal seam was stable, and its structure was simple. However, the fracture of this seam development well and its direct roof has a certain thickness of water resisting layer and had a good water storage space. Due to the No.2 coal seam was a high pressure aquifer, the original geologic exploration report and research report on the mine water inflow was expected to be far from the actual situation, which caused that the mining work was always in a passive state, and has a severe influence on the mine construction schedule. Based on the local geological structure and hydrological structure, the existing literature [7-9] analyzed the characteristics of the water bearing coal seam. Wuqiang [10] etcanalyzed the basic classification status and characteristics of the hydro-geological types in China's coal mines, the main water disaster problem and water prevention and control organization and safeguard measures of four main coal mining areas in China; By using transient electromagnetic method and integrated hydrological exploration of seismic exploration, Liu Shu-cai[11] etc improved the accuracy of coal mine water exploration; Based on the analysis of the combination of theory and experimental measurement, Ding Huan-de[12-13]studied the geological evolution law of coal measure strata, and revealed the characteristics of the geological environment of the special geological environment.

The aquifer is usually located above or below the coal seams, which rarely exists in the coal seams. Based on the special structure of "confined water storage in the No.2 main coal seam" in the Xiaojihan Coal Mine, this paper puts forward a new problem for the mine project [14].The mechanical properties of water bearing coal seams have great influence on the fracture production of coal seam[15], in relation to the production efficiency and safety of super large mine. However, the physical and mechanical properties of water bearing coal seams are different from that of conventional coal, which has special characteristics. In the paper, mechanical properties such as tensile strength and internal friction angle of water bearing coal are studied by the experiment[16-19], which provided some necessary basic data for the similar simulation and numerical simulation of the safety mining of the super large mine.

To summarize, prevention and control of water disasters and water conservation measures have a great significance in western coal mine. Yuheng Mining Area was a typical structure with shallow and thin loose sand strata-thick bedrock-coal seam bearing water. Based on the special geological conditions of Yuheng Mining Area, in this paper we analyzed geological conditions of coal seam as aquifer, and studied the mechanical characteristics of water bearing coal seam and explored the mechanism of mine water inrush.

2. MECHANICAL PERFORMANCE TEST OF XIAOJIHAN COAL SEAM

2.1. Sample and Test Plan

Collecting coal (rock) from Xiaojihan coal seam, according to the test procedure requirement for physical and mechanical properties of DY-94 rock, we processed sample as the core. The sample numbers are shown in Table 1.

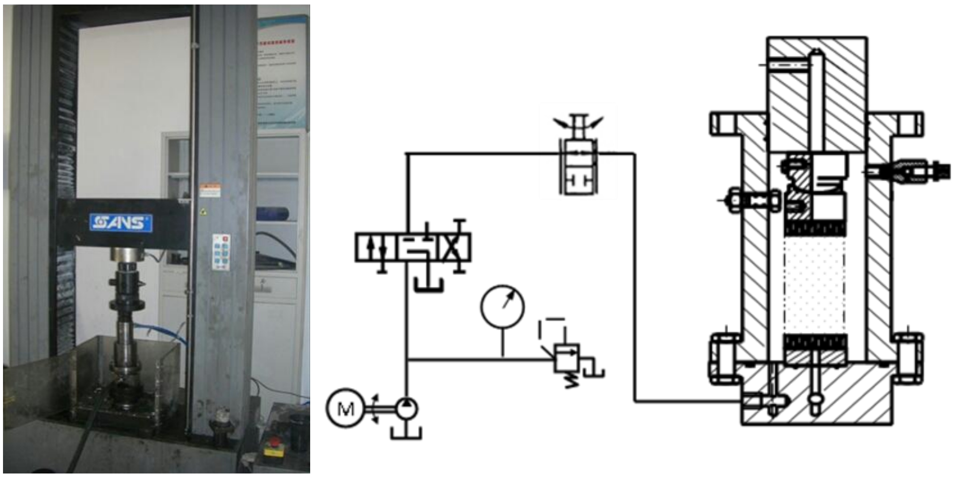
Table1. *Sample size*

Strata No.	Rock name	Sample number	Numbers (piece)	Diameter (mm)	Height (mm)	Thickness (mm)
1	Grain arkose in luohe group	C1	15	50	100	25
2	Stable set of sandstone and mudstone interbed	C2	15	50	100	25
3	Straight set of mudstone and sandstone interbed	C3	15	50	100	25
4	Yanan group leader stone sandstone	C4	15	50	100	25
5	Sandy mudstone yanan group	C5	15	50	100	25
6	Yanan leader Shi Shayan	C6	15	50	100	25
7	Sandy mudstone yanan group	C7	15	50	100	25
8	No.2 coal	C8	15	50	100	25
9	Rich county sandy mudstone	C9	15	50	100	25

The mechanical properties of typical strata of BS5 hole-drilling was tested, which includes uniaxial compression, triaxial compression and split test. Though uniaxial compression tests, we can get the rock uniaxial compressive strength, elastic modulus and ratio of Poisson. Through splitting test, we can get the tensile strength of rock. Through the three axis test; we can obtain the compressive strength and the internal friction angle of the four stage confining pressure.

2.2. Test Equipment and Principles

Uniaxial compression test, triaxial compression test and split test were carried out by the CMT5305 electronic universal machine, as shown in **Fig1.**



(a) CMT5305 Test Machine (b) Confining pressure loop

Fig1. *Test system diagram*

2.3. Uniaxial Compression Test

The uniaxial compression tests are shown as Fig 2. Measure the diameter for d_s and height for h_s of rock (coal) before the experiments. During the loading the system can collect the axial displacement u_a, axial load for $p$and radial displacement u_r.We can get the axial failure load $p_b$in the test data fileand according to the following formula, we can calculate the uniaxial compressive strength of rock (coal) sample forσ_c.

$$\sigma_c = \frac{P_b}{\frac{\pi}{4}d_s^2} \qquad (1)$$

(a) Before the test

(b) After the test

Fig2. *Uniaxial compression test*

For every moment, axial strain, circumferential strain and axial stress can be calculated by the formula$\varepsilon_\alpha = \frac{u_\alpha}{h}$, $\varepsilon_\theta = \frac{2u_r}{d_s}$, $\sigma_\alpha = \frac{P_b}{\frac{\pi}{4}d_s^2}$respectively, sowe can draw out the axial stress-strain curves and circumferential strain-axial strain curves. The elastic modulus for E can be calculated by the straight line slope of the axial stress-strain curve, while Poisson's ratio can be calculated by the slope of the linear segment of the circumferential strain-axial strain curve.

2.4. Split Test

During the testing, the concentrated load is applied along the diameter direction of the cylindrical specimen; at last the specimen is cracked along the force direction. According to the elastic mechanics formula, the rock produced approximately horizontal uniform tensile stress along the direction perpendicular to force; the average value is as follows.

$$\sigma = \frac{2P}{\pi d_s h_s} \qquad (2)$$

Where $d_s$is thecore diameter, $h_s$is therock height, $P$is theload.The tensile strength of rock is

$$\sigma_t = \frac{2P^*}{\pi d_s h_s} \qquad (3)$$

Split test device is as shown in Fig 3.

(a) Before split (b) After split

Fig3. *Split test*

2.5. Triaxial Compression Test

Triaxial compression test device is as shown in Fig 4.

(a) Before the test (b) During the test (c) After the destruction

Fig4. *Triaxial compression test*

The diameter d_s and the height$h_s$were measured before the test. In test, we controlledthe displacement velocity and load time and collected the axial displacement u_a and the axial load for P.Thus read axial loadP_b at failure in the test data file and based on equation (1), we can calculate the compressive strength of rock.

The broken rock obeys the Mohr-Coulomb criterion, when the failure occurs, the axial stress and confining pressure satisfied

$$\sigma_1 = \frac{2C\cos\Phi}{1-\sin\Phi} + \sigma_3 \tan^2\frac{\pi+\Phi}{2} \tag{4}$$

Let$k_1 = \frac{2C\cos\Phi}{1-\sin\Phi}$,$k_1 = \tan^2\frac{\pi+\Phi}{2}$, we can obtain $\sigma_1 = k + k_1\sigma_3$by the test results and linear regression, and then can calculate the internal friction angle for$\Phi = 2\arctan\sqrt{k_1} - \pi$by $k$andk_1.

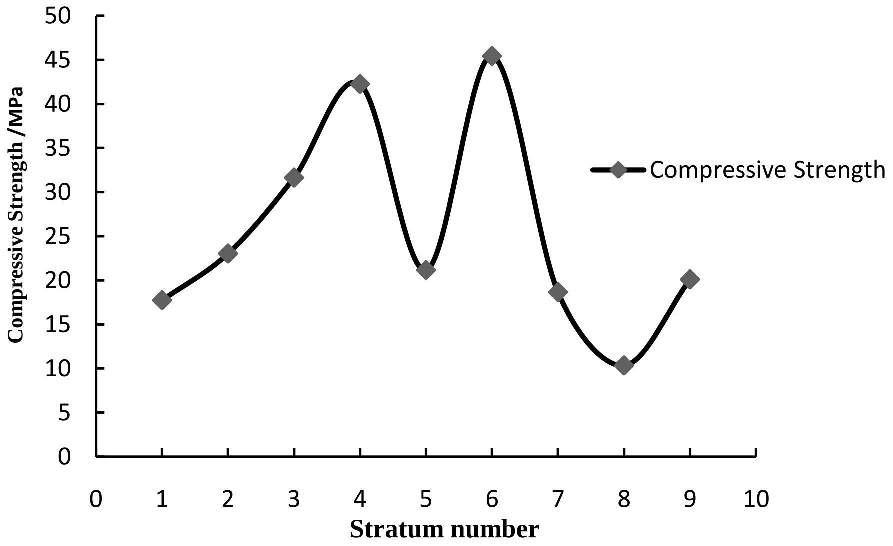
3. TEST RESULT

3.1. Compressive Strength

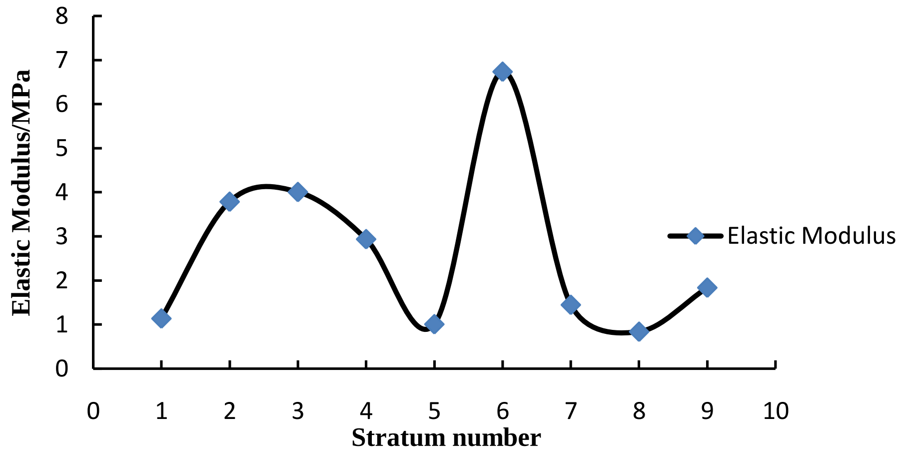
The uniaxial compression tests were carried out on the cylindri calrock sample with 100-mm-height and 50-mm-diameterfrom each stratum as shown in Table 1.Thesamples number from each stratum is 5. The compressive strength, elastic modulus and Poisson ratio of the specimens were obtained by tests. Results from an average of 5 groups are shown in Table 2.Comparison curves from uniaxial compression test results of different rock stratum are shown inFig5.

Table2. *Results of uniaxial compression test*

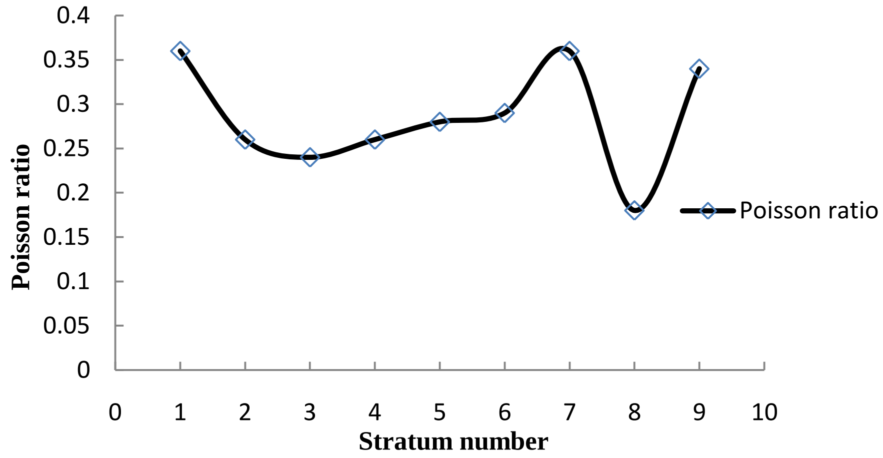
Strata No.	Rock name	Diameter (mm)	Height (mm)	Elastic modulus (Gpa)	Poisson ratio	Compressive strength (MPa)
1	Grain arkose in luohe group	50	100	1.14	0.36	17.73
2	Stable set of sandstone and mudstone interbed	50	100	3.79	0.26	23.02
3	Straight set of mudstone and sandstone interbed	50	100	4.01	0.24	31.62
4	Yanan group leader stone sandstone	50	100	2.94	0.26	42.23
5	Sandy mudstone yanan group	50	100	1.01	0.28	21.15
6	Yanan leader Shi Shayan	50	100	6.74	0.29	45.4
7	Sandy mudstone yanan group	50	100	1.45	0.36	18.65
8	No.2 coal	50	100	0.84	0.18	10.34
9	Rich county sandy mudstone	50	100	1.84	0.34	20.09



(a) Compressive strength



(b) Elastic modulus



(c) Poisson ratio

Fig5. *Comparison of uniaxial compression test results for different rock strata*

3.2. Tensile Strength

The split tests were carried out on the circular-plate type rock sample with 25-mm-thick and 50-mm-diameter from each stratum as shown in Table 1.The samples number from each stratum is 5. The tensile strength of specimens was obtained by the average of 5 groups, as shown in Table 3.Comparison curves of tensile strength of different rock stratum are shown inFig6.

Table3. *Split test results*

Strata No.	Rock name	Diameter (mm)	Height (mm)	Tensile strength (MPa)
1	Grain arkose in luohe group	50	25	1.62
2	Stable set of sandstone and mudstone interbed	50	25	2.11
3	Straight set of mudstone and sandstone interbed	50	25	3.03
4	Yanan group leader stone sandstone	50	25	4.18
5	Sandy mudstone yanan group	50	25	2.26
6	Yanan leader Shi Shayan	50	25	4.31
7	Sandy mudstone yanan group	50	25	1.83
8	No.2 coal	50	25	1.27
9	Rich county sandy mudstone	50	25	1.92

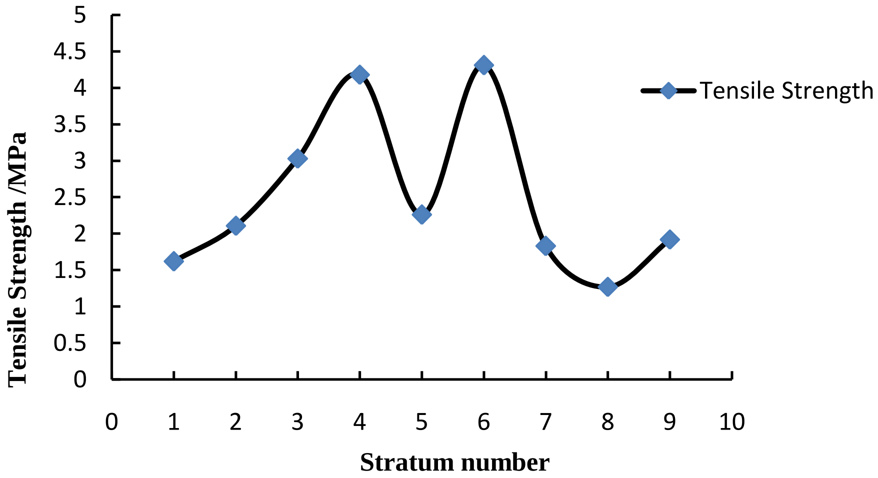


Fig6. *Tensile strength curves of each stratum*

Based on the research on the strength characteristics of water bearing coal seam(No.2),the compressive strength, elastic modulus, Poisson ratio (as shown in Fig. 5) and tensile strength (as shown in Fig. 6) are lower than that of the other strata, and its tension resistance ability is rather lower. This is the special physical and mechanical property which differs from the other rock stratum.

3.3. Internal Friction Angle

The confining pressure in triaxial compression test is set with five levels, which is divided into0MPa, 2MPa, 4MPa, 6MPa and 8MPa respectively. The test results of the internal friction angle are shown in Table 4.Comparison curves of internal friction angle for different rock stratum are shown in Fig7.

Table4.*Triaxial compression test results*

Strata No.	Rock name	Sample number	Diameter (mm)	Height (mm)	Confining pressure (MPa)	Compressive strength (MPa)	Internal friction angle (°)
1	Grain arkose in luohe group	C1-01	49.37	100.85	0	18	32.9
		C1-02	50.24	101.56	2	28.5	
		C1-03	50.82	99.97	4	34.5	
		C1-04	51.08	100.82	6	40.2	
		C1-05	49.8	101.31	8	46	
2	Stable set of sandstone and mudstone interbed	C2-01	51.16	101.35	0	23.03	32.9
		C2-02	50.28	101.56	2	34.8	
		C2-03	50.72	100.87	4	40.2	
		C2-04	49.98	99.92	6	45.7	
		C2-05	49.29	101.41	8	51.3	
3	Straight set of mudstone and sandstone interbed	C3-01	49.37	99.65	0	31.95	30.2
		C3-02	49.24	101.56	2	34.3	
		C3-03	50.52	99.87	4	41.5	
		C3-04	51.78	100.42	6	47.9	
		C3-05	51.89	101.41	8	55.4	
4	Yanan group leader stone sandstone	C4-01	51.37	100.98	0	41.5	30
		C4-02	50.24	100.43	2	52.9	
		C4-03	49.52	99.87	4	57.6	
		C4-04	51.08	101.42	6	61.4	
		C4-05	49.89	99.81	8	67.3	
5	Sandy mudstone yanan group	C5-01	51.49	99.68	0	18.02	30.1
		C5-02	49.38	101.76	2	26.4	
		C5-03	50.83	100.39	4	31.5	
		C5-04	51.82	101.76	6	37.4	
		C5-05	50.76	99.28	8	42.6	

6	Yanan leader Shi Shayan	C6-01	51.24	99.12	0	46.2	30.2
		C6-02	49.78	101.38	2	53.4	
		C6-03	50.69	101.59	4	59.8	
		C6-04	51.01	99.46	6	65.2	
		C6-05	50.48	100.28	8	70.6	
7	Sandy mudstone yanan group	C7-01	50.35	101.78	0	17.82	34.3
		C7-02	51.24	100.49	2	26.3	
		C7-03	49.92	99.79	4	35.9	
		C7-04	50.08	100.02	6	38.6	
		C7-05	49.81	99.87	8	47.5	
8	No.2 coal	C8-01	51.23	100.68	0	8.89	24
		C8-02	49.88	101.43	2	9.2	
		C8-03	50.13	100.48	4	14.6	
		C8-04	50.81	100.74	6	19.8	
		C8-05	51.76	101.28	8	27.3	
9	Rich county sandy mudstone	C9-01	51.04	99.66	0	19.6	35.1
		C9-02	49.78	100.31	2	28.6	
		C9-03	50.69	101.45	4	38.5	
		C9-04	49.91	100.46	6	42.6	
		C9-05	50.48	100.28	8	49.7	

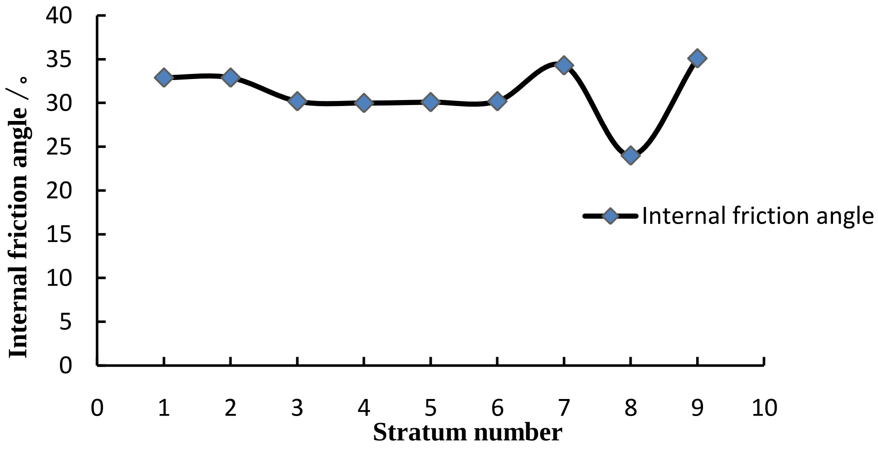


Fig7. *Comparison of the internal friction angle for different rock layers*

It can be seen from Fig7 that the internal friction angle of other strata is normal, while this angle of theNo.2 coal seam is small, which explained that the fracture of the No.2 coal seam is not easy to close. The internal friction angle of the other adjacent rock stratum located at the up or down coal seam is large, so the fracture is easy to close; therefore, water in the No.2 coal seam streams (or flows)hard up and down. This is also an important reason for the No.2 coal seam is the main aquifer.

4. CONCLUSIONS

By CMT5305 Testing Machine, the experiments including uniaxial compression, split, triaxial compression were carried out to the rock (coal) sample from the Xiaojihan coal mine.Asa result, we obtained some mechanical properties of the test rock from the coal seam being the main aquifer of Xiaojihan Coal Mine. Research shows:

1) Differing from the common rock seam, the special physical and mechanical characteristics of the water bearing coal seam(No.2) is that its compressive strength, modulus of elasticity, Poisson, tensile strength and internal friction angle were lower than that of the other rock strata. Compared with the geological and hydrological structure of coal seam, the mechanical properties are more suitable to describe the characteristics ofNo.2 coal seam as main aquifer.

2) An important reason for coal seam containing water is that the internal friction angle of coal seam, by contrast, is too small for its fracture to close easily.

3) By studying the mechanical properties such as tensile and internal friction angle of water bearing coal seam (No.2), a reliable theoretical basis can be provided for predicting the working face in coal mine and the mine discharge, for establishing an early warning system about water disaster in mine, for designing and optimizing the technology in tunneling and coal mining about the flood preventing and controlling.

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