Design on Large-Scale Shaft Lining Mechanical Simulation Test System

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***Abstract*—Based on the background of studying shear stress bearing of shaft linings in the depth and thickness stratum, we carried out research and study in design of the large-scale shaft lining mechanical simulation test system. The simulation tests, namely the shear model tests on the interface of single layer shaft lining, the model tests on the coupling effect of double layer shaft linings and the mechanic characteristics of piles can be carry out. This system can simulate shear properties of the shaft lining loading up to 13MPa level pressure of the soil. A novel self-designed loading hydraulic cylinder with large diameter and hollow piston solved the problems of multi-cylinder synchronization and spatial arrangement. The flexible design of connector of test model is applicable condition in various test scheme of the thickness requirement for shaft lining. Loading method, load bearing bodies and the design of the connector of test model for simulation test provides a new way for large-scale model tests.**

Keywords- Test System; Simulation tests; Pressure Bearing on the Shaft Lining; loading method

I. INTRODUCTION

With the exhausting of shallow coal recoverable resources, the pit mining depth of our country is increasing at an annual rate of 8~15m presently. During the exploitation of coal resources under the deep alluvium in the east (central) region, many major theoretical issues on how to determine shaft lining mechanics model have been met. The surroundings in which the generally geotechnical engineering structure is placed are very complex. At great depth and under high geostress field, the stability analysis, failure mode and failure mechanism is now an urgent issue to be settled, and specialists in geotechnical engineering made a lot of researches on [1,3].Due to the influences of the complicated factors of geological environment, stratigraphic subsidence, confined water penetration, water-bearing layer consolidation, long time effect and so on, the shaft lining in the soft ground (water drainage settlement stratum) of the deep stratum is in the state of a dynamic strained condition. A lot of researches prove that[4,6], many accidents of the shaft lining broken occurred in east (central) China are controlled by the interfacial shear coupling effects of the surrounding soils and shaft lining (and the interior and exterior of the double layer shaft lining)[7].

In the deep and unstable stratum, shear coupling effects of the shaft lining and the soil around is characteristic of long displacement (the relative displacement is 0.5~0.8m) [8,9], unstable shear plane and so on. Currently, the conventional direct shear tests and simple shear tests cannot simulate the actual mechanical characteristics of the shaft lining interface. Regarding this, with the support of Henan province program for distinguished young scholars “large experiment studies of the shaft lining interface hear constitutive relations under high press”, large-scale shaft lining mechanical simulation test system is especially designed based on the existing similar test systems. It can simulate the interface coupling mechanism of the single layer shaft lining, double layer shaft lining and pile body. This paper mainly expounds the design consideration of the system.

II. STRUCTURAL DESIGN OF THE LARGE-SCALE SHAFT LINING MECHANICAL SIMULATION TEST SYSTEM

In 1986, a large-scale and deep vertical shaft simulation test has been developed by the state key laboratory of the deep geotechnical mechanics and underground engineering in China University of Mining and Technology for the study of the shaft lining mechanical problems under the water drainage of the aquifer in the depth and thickness stratum. The shaft lining confined pressure of 11.0MPa simulates by this test is realized by the pressurizing of the hydraulic sac or decentralized cylinder. There exist problems about hydraulic-sac bursting or sync coordinate control of the decentralized cylinders and so on. Besides, this system can only simulate the interaction between the single layer shaft lining and the surrounding soils.

Based on the advantages of the large-scale and deep vertical shaft simulation test in China University of Mining and Technology, its applications are developed, the following can be carried out:

- Interface shearing tests of various soils and single layer shaft lining.
- Complication interface shearing tests of various soils and double layer shaft lining.
- Interface shearing tests of different isolation materials between double layer shaft linings.
- Water drainage and settlement tests of the aquifer under high press.

- Test research for the bearing characteristics of various piles. Through the subsequent improvements, it can carry out tests about deformation law of force in soil mechanics, deformation law of excavation in tunnels and workings.

The large-scale shaft lining mechanical simulation test system mainly consists of geostatic analogue device, vertical additional force analogue device, water drainage controlling system, testing system, loading device of piles and so on. The geostatic analogue device is realized by the novel self-designed loading hydraulic cylinder. The vertical additional force analogue device is simulated by the pushing cylinder at the bottom of the system. The study on the forces of piles is simulated by the upside pushing cylinder.

Through the similarity design and studies of other simulation test device in geotechnical engineering[10,11], the testing system simulates the geo-pressure of the shaft lining by loading the large hydraulic cylinders vertically and the load-bearing tube constraints arising horizontal forces. Since the self-weight of soils in the load-bearing tube is less (maximum is 0.05MPa) compared to loading the hydraulic cylinders vertically (as much as 13MPa), forces of the soils in the load-bearing tube along the horizontal and vertical directions can be considered to be the same. From basic theories of elastic mechanics [12], variations of the radial stress outside the shaft lining can be determined by Eq. (1) approximately:

$$\sigma_r = \left(1 - \frac{a^2}{r^2}\right) q \tag{1}$$

Where is outside diameter of the shaft lining, r is the radius of the surrounding soils, q is the homogeneous geo-pressure.

Based on the similarity design of the entire test system, the outer radius of the simulation shaft lining is determined for 200mm. By Holy dimension south principle, the boundary effect can be ignored when the radius $r = (3:4)a$. Therefore, the interior radius of test device of the load-bearing tube r=4a=800mm. By Eq.(1), $\sigma_r = 93.75\% q$ can satisfy the requirements of the test and engineering design.

The similarity theory can be used to deduce mechanics similarity criteria [4]:

$$\pi = \frac{p}{E} \tag{2}$$

Where p is horizontal ground pressure, E is elastic modulus of shaft lining. Then we get the following relationship:

$$C_E = C_p = \frac{p}{p'} = 1 \tag{3}$$

Where p is the actual horizontal ground pressure, p' is the test system simulation horizontal ground pressure.

When the simulation test system imitated the vertical ground pressure, it used segmented simulation. According to the coverage of China's profound topsoil, the system determine the maximum simulated depth for 650m, the vertical pressure is considered to be 13MPa, that is, test system must meet the maximum vertical pressure of 13MPa. The total pressure area of the system is 1.884m^2, the needed loading force is 24500KN.

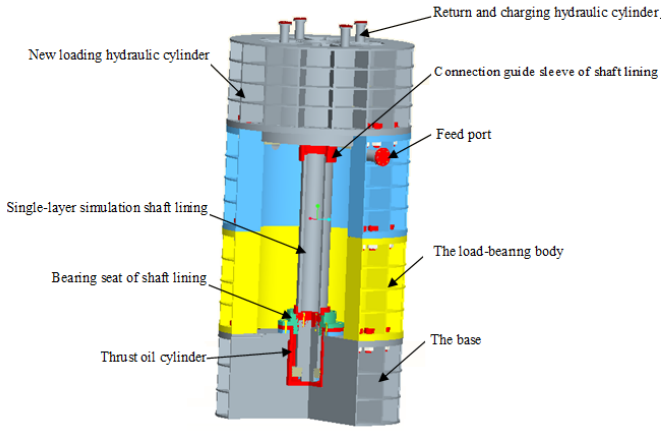
At present model test system loading methods are mainly heavy lever load, hydraulic cylinder concentrated load, hydraulic cylinder scattered load, hydraulic sac or air sac load and so on [13]. Heavy lever load, the loading range is limited, the uniformity is poor, the stability of the model is poor, the load is constant and the adjustment is difficulty. The demand of hydraulic cylinder load for hydraulic system is higher, especially for underground engineering simulation experiment body, request loading process long and stable and output of high precision. For distributed load, it needs more than one hydraulic cylinder to output at the same time, so the synchronization requirement of the hydraulic cylinders is higher and it occupies a larger space. When loading by hydraulic sac or air sac, it is difficult to observe the deformation of the model, furthermore, the pressure of air sac loading is little, hydraulic capsule, air sac can be easily burst, which will result in a higher test cost.

The pressure of 24500KN was needed when the large-scale shaft lining mechanical simulation test system simulated the shaft lining at the maximum surface soil depth of 650m. If we use the method of conventional hydraulic cylinder scattered load, the experimental device in effective space position is difficult to decorate and the synchronization requirements is higher. In view of this, we designed a novel self-designed loading hydraulic cylinder with a cylinder diameter of 1600mm and a ring piston (it is specially narrated in another article), which have the specialty of loading bigger pressure and taking up less space, simultaneously it solved the problems of multi-cylinder synchronization and spatial arrangement. A corresponding return oil cylinder is specially designed on loading oil cylinder. A thrust oil cylinder setting on the base is used to simulate vertical additional force produced by drainage settlement on single layer shaft lining or compound shaft lining (The vertical friction on the surface of shaft lining).

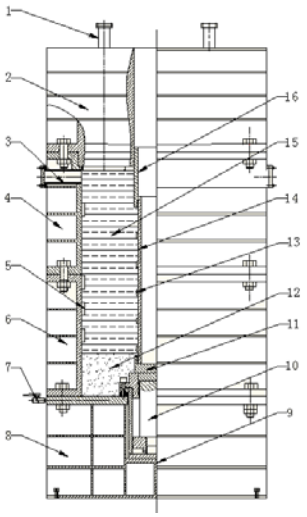
For different forms of shaft linings, the bearing seats of different structure forms and upper connection guide sleeve specially designed can simulate the different diameter shaft linings, which expands the test range. The load-bearing tube of the test device is divided into 2~3 quarter, alone or combined used to simulate different shaft lining height. 4 feeding ports are specially designed on load-bearing tube on the top layer, coordinating with return oil cylinder on the loading oil cylinder, can achieve the rapid filling of soil, avoid the trouble that every time you add the soil are required to open the main loading cylinder, in order to reduce the labor intensity of lab staff.

A. Scheme of Shear Test System for the Single Layer Shaft Linings

Fig.1 shows the shear model tests system on the single layer shaft lining. It can simulate the vertical additional force on the surface of shaft lining under a constant horizontally soil pressure and produced by drainage settlement. A dual action thrust oil cylinder setting on the centre of base move upward at low speed according to the ratio of similitude of the soil settlement, making shaft lining produce a displacement. By the load sensor and the foil gauge we can test the shear stress and deformation of the shaft lining and surrounding soils. In order to reduce the detection influence of the friction between shaft lining and loading oil cylinder to the vertical additional force, we design a high-precision connection guide sleeve between shaft lining and loading oil cylinder, 16, so as to fix the external diameter of shaft lining and play a role of guidance for the movement of shaft lining. The upper and lower connection guide sleeve of the single layer shaft lining take the external diameter as the locating datum, the inside diameter can vary according to the test program, so as to realize the shear tests of different thickness of shaft lining.



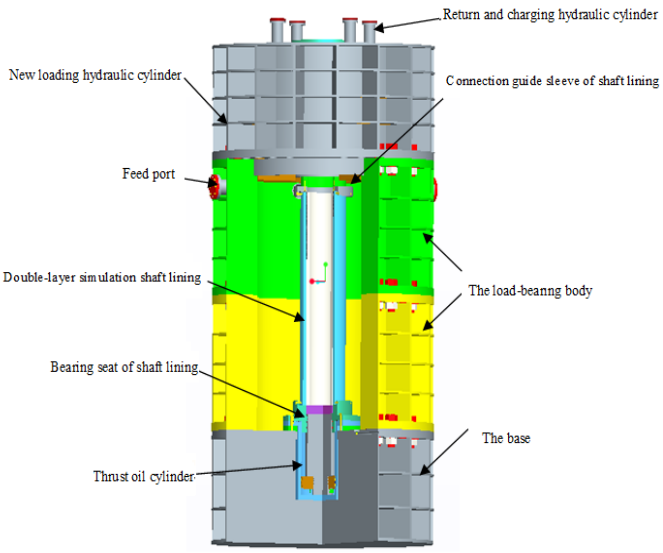
a) 3D simulation of the test scheme



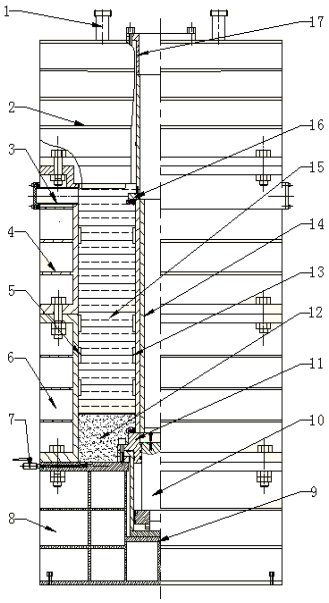
b) Structure diagram of the test scheme

Fig1. Shear model tests system on the interface of Single Layer shaft lining

1- Return and charging hydraulic cylinder ; 2- New loading hydraulic cylinder ; 3- Feed port ; 4-The upper load-bearing body ; 5-Pressure gauge ; 6-The lower load-bearing body ; 7- Drain valve ; 8- The base ; 9- Load sensor ; 10- Thrust oil cylinder ; 11- Bearing seat of shaft lining ; 12- Drainage layer ; 13-Strain chip ; 14- Single-layer simulation shaft lining ; 15- Overlying soil body ; 16- Connection guide sleeve of shaft lining



a) 3D simulation of the test scheme



b) Structure diagram of the test scheme

Fig2. Coupling tests system on the interface of the double layer shaft lining

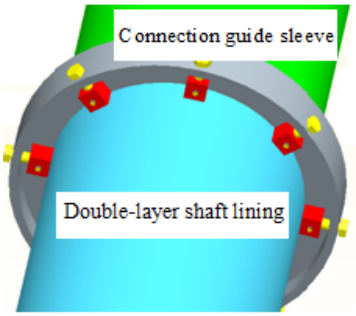
1-Return and charging hydraulic cylinder; 2-New loading hydraulic cylinder; 3-Feed port; 4-The upper load-bearing body; 5-Pressure gauge; 6-The lower load-bearing body; 7-Drain valve; 8-The base; 9-Load sensor; 10-Thrust oil cylinder; 11-Bearing seat of shaft lining; 12-Drainage layer; 13-Strain chip; 14-Double-layer simulation shaft lining; 15-Overlying soil body; 16-Connection guide sleeve of shaft lining; 17-End cover

B. Scheme of Coupling Tests System for the Double Layer Shaft Linings

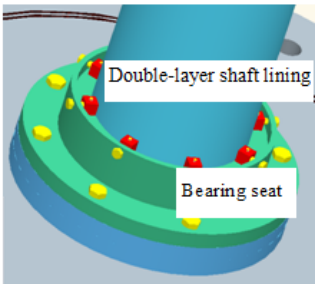
Coupling tests system of the double layer shaft lining is shown in figure 2.

It can simulate interfacial shear tests of the double layer shaft lining and the double layer complex shaft lining with shielded material, which the ground pressure simulator, vertical additional force simulator and hydraulic control system are the same with single shaft lining. In order to achieve the interface shear tests between various soil and double layer shaft lining and the interface shear tests of different shielded material between double layer shaft lining, in the test system design, the outer shaft lining is fixed with bearing seat, 11, the connection guide sleeve at the top of the shaft lining, 16, and the cover installed in the main loading oil cylinder, 17. The inner sidewall moves upward at low-speed under the action of oil cylinder to simulate the coupling vertical additional force caused by hydrophobic drainage settlement between the double layer shaft lining and shielded material and the inner and outer shaft lining.

In the system, the inner diameter and outer diameter of the outer shaft lining are fixed and adjustable respectively, which is opposite to the inner shaft lining, we can achieve shaft lining thickness of the test program on the request for conciliation. Therefore, the units of upper and lower linked are designed as adjustable structure (as figure 3).



a) The connection guide sleeve at the top of the shaft lining

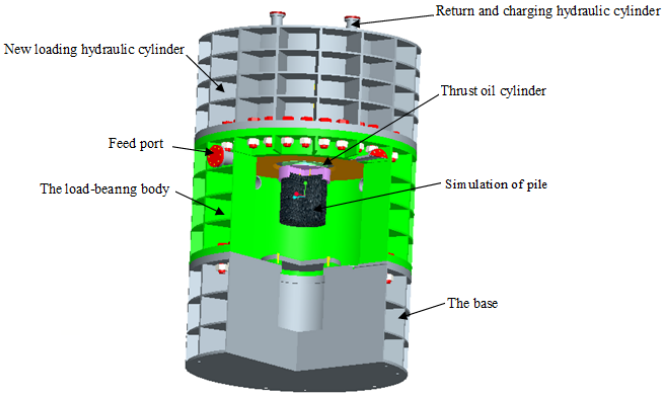


b) The connection bearing seat at the bottom of the shaft lining

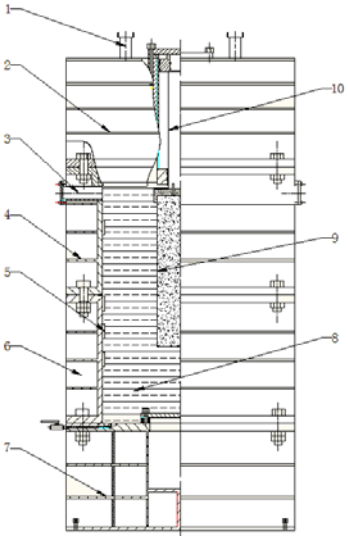
Fig3. Connectors of the double layer shaft lining

C. The Scheme of Stress Text for Piles

In order to expand the application range of the testing system, simulate the stress state of different pile body under upper loads, and the interface interaction between the pile body and surrounding soil, we demount the thrust oil cylinder in the mid-lower in the former testing scheme and installed it in the upper central of the main loading oil cylinder to simulate the loading state of the upper pile, the stress state of the surrounding soil is still simulated by the main loading oil cylinder, the diameter and fixing of the pile is achieved by the upper connection guide sleeve (as figure 4).



a) 3D simulation of the test scheme



b) Structure diagram of the test scheme

Fig4. Coupling tests system on the interface of the double layer shaft lining

1- Return and charging hydraulic cylinder; 2- New loading hydraulic cylinder; 3- Feed port; 4- The upper load-bearing body; 5- Pressure gage; 6- The lower load-bearing tube; 7- The base; 8 -Soil body; 9- Simulation of pile; 10- Thrust oil cylinder

III. CONCLUSION

In order to study interfacial shear stress of complex shaft lining and the single layer shaft lining, and the establishment of the shaft lining model in the deep stratum under high stress, large-scale shaft lining mechanical simulation test system is designed as a model testing carrier. Through this device, it can determine the shear strength criterion, yield criterion, and shear constitutive relations of the shaft lining interface under high stress. Simultaneously, it offers a test bed for the studies

of the forces of various piles, design of pile types, load cases of composite foundation, force and deformation law of deep soil mechanics, and deformation laws of excavation in subway tunnel.

The simulation test is composed of ground pressure simulator, vertical additional force simulator, water drainage control system, testing system and so on. So it can carry out tests on the shear of the single layer shaft lining, the coupling effects of double layer shaft linings, the mechanic characteristics of piles and so on. On the basis of designed experiences of similar devices, a novel self-designed loading hydraulic cylinder solved the problems about multi-cylinder synchronization, spatial arrangement and others. The connecting element is well designed in order to adapt to the thickness requirements of shaft linings of different experiments plans. Its loading method, load-bearing tube body and the connector of test model will provide a novel thinking for the large-scale simulation tests.

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