Development of a lever type multi-functional plane strain model test device

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Abstract. The lever type multifunctional plane strain model test equipment is mainly composed of the basic frame, loading system, data acquisition and measurement system, and auxiliary device. Its biggest feature is the "multiple use of one machine", which means a variety of geomechanical tests can be carried out with one equipment. The load is carried out by the principle of double lever amplification. The load can be altered by changing the counterweight at the end of the rod. Since the counterweight is determined, the load is constant. Equipped with an automatic device integrating mining, chip removal, support and monitoring, it can realize quantitative mining, timely chip removal, temporary support, real-time monitoring, improve automation and intelligence of model test, which is closer to the simulated engineering practice. The equipment has excellent mechanical properties and can meet the needs of different geotechnical engineering research.

1. Introduction
A large number of engineering practices have proved that geomechanical model testing is an effective method to study large-scale geotechnical and mining engineering problems. The model test can not be only comprehensively and realistically simulate complex underground engineering structures, geological structures, underground rock formations, but also can be verified qualitatively or quantitatively with theoretical models and numerical simulation.[1-3]

To carry out the geomechanical model test, a corresponding set of model test equipment is required. In this research, domestic and foreign research units have achieved a lot of results. Internationally, such as the United States, Germany, Italy, Japan, and other countries have been done a series of experimental research work on geotechnical engineering models, and developed corresponding test equipment. Domestic Tsinghua University, China University of Mining and Technology, the General Staff Engineering Research Institute, and Shandong University have each developed experimental equipment for geotechnical engineering models [4-10]. On the whole, the types and styles of geophysical model test equipment at home and abroad are quite large. However, most large-scale model test equipment is loaded by jack group or hydraulic system. There are many actuators and large loading areas. There are defects in load unsynchronization and pressure fluctuation, which cannot strictly meet the constant stress boundary conditions of long-term creep test. Large-scale model equipment relies on a large number of supporting loading and measuring systems, which are limited by equipment, materials, time, space, etc., and are mostly suitable for specific engineering projects, and are not suitable for a large number of basic long-term tests. Therefore, a small model test equipment that is independent of large-scale loading
system, accurate, efficient, simple and easy to implement can be developed, which can overcome the above shortcomings and has high promotion value. On this basis, if automatic mining and support can be further realized, such functions will definitely play a positive role in the production safety, long-term operation and disaster prevention of interrelated projects.

2. Development thought of model test equipment
How to strictly meet the constant stress boundary conditions of long-term creep test is one of the fundamental problems in the success of plane strain model test. The equipment adopts the traditional lever principle and relies on heavy load loading to ensure long-term and constant simulation of the vertical ground stress caused by the overburden and overcome the hydraulic loading unsynchronization and pressure fluctuation. Decreasing the size of the model and increasing the geometric similarity ratio can increase the time similarity ratio, which is beneficial to consider the time effect of the long-term test. Figure 1 is the lever loading schematic. The counterweight can be calculated from the vertical ground stress of prototype through equations (1), (2) and (3):

\[ K = \frac{l_1}{l_2} \frac{l_3}{l_4} \]  

(1)

\[ F = A \sigma_p \]  

(2)

\[ \sigma_p = C_0 \sigma_m = C_\gamma C_L \sigma_m \]  

(3)

In the formula, \( A \) is the contact area of the head on the upper surface of the model. \( \sigma_p \) is the vertical ground stress of model.

\( \sigma_m \) is the perpendicular ground stress of prototype. \( C_\gamma \) is the bulk density similarity constant. \( C_L \) is geometric similarity constant.

Based on the traditional leverage principle, a lever type multi-functional plane strain model test equipment was developed. In the design, the "one machine multi-purpose" function is realized in one device, so the combination of the main structure and the supporting device is adopted. That is, all the tests share the same main structure, and different tests have their corresponding matching devices. The equipment mainly carries out geomechanical model tests, and can also switch the uniaxial and triaxial compression creep experiments of standard cylindrical test pieces. The model is adjustable in size and can be tested in a single model or simultaneously in a dual model. The independent tests on both sides do not interfere with each other. The following requirements are always observed during the
development of the equipment: the working principle is clear, the structure is compact and simple, and the strength and rigidity requirements are met, which is safe and reliable.

3. Structural design of model test equipment

3.1. Plane strain single model test
As show in Figure 2, the test equipment is mainly composed of a frame part, a loading system, a data acquisition and measurement system, and an auxiliary device. There are two sets of levers. Each set of levers consists of two levels of levers. Each stage of the lever has a power magnification of 10, and each set of levers can magnify the weight of the object in the counterweight by 100 times. A plurality of pressure sensors are located in the center of the base to detect the pressure at the bottom of the model. Transparent acrylic sheets are put on the front and back to observe the dynamic changes of the model in real-time. The equipment is equipped with a non-contact full-field measurement system, which is time-photographed and monitored in real-time. The specific operational steps of the equipment are as follows: Firstly, the model should be prepared, and the whole model should be laid in layers. Before laying each layer, the front and rear acrylic plates should be fixed on the main frame by screws. After weighing, batching, stirring, layering, compacting and other processes, the entire model is prepared. Secondly, the similar simulation theory is used to determine the weight of the heavy weight in the weight plate. Pressure changes were monitored in real-time by a pressure sensor at the step pressure plate and the base during the test. Then the contactless full-field measurement system is utilized to close-range measurement, real-time monitoring and timing photography. Finally, all monitoring data is uniformly imported into the computer for subsequent processing by professional software.

![Figure 2. Plane strain single model test equipment.](image-url)
3.2. Plane strain double model test

![Figure 3. Plane strain double model test equipment.](image)

Description: 15- joist steel, 16-pressure support plate, 17-intermediate partition, 18-screw

As show in Fig. 3, on the basis of the same main structure, the I-beam, the pressure support plate and the intermediate partition are added as compared with the plane strain single-model test device. It is consistent with the operation steps of the single model test equipment, and will not be described again.

3.3. Uniaxial compression creep test of standard cylindrical specimens

![Figure 4. Standard cylindrical test piece uniaxial compression creep test equipment.](image)

Description: 19-standard cylindrical test piece, 20-upper head, 21-displacement sensor, 22-pressure bar, 23-lower head

As show in Fig.4, on the basis of the same main structure, mechanisms such as an upper pressing head, a displacement sensor, a pressing rod, and a lower pressing head are added. The operation steps are as follows: the pre-treated standard cylindrical test piece is placed between the upper and lower indenters, and the weight of the heavy weight in the weight plate is calculated according to the similarity theory. The pressure and displacement during the loading process are real-time by the pressure sensor.
and the displacement sensor. All monitoring data is uniformly imported into the computer for subsequent processing by professional software.

3.4. Triaxial compression creep test of standard test piece

![Figure 5. Standard cylindrical test piece triaxial compression creep test equipment](image)

Description: 24-position support cylinder, 25-enclosed pressure chamber, 26-standard cylindrical testpiece, 27-pressure balance chamber, 28-upper head, 29-displacement sensor

Figure 5. Standard cylindrical test piece triaxial compression creep test equipment

As show in FIG.5, on the basis of the same core structure, a position support cylinder, a pressure plenum, a pressure balance chamber, an upper pressure head, a displacement sensor, and the like are added. In the experiment, the target confining pressure is driven into the confining pressure chamber by the external manual hydraulic pump and the confining pressure is kept stable, and the corresponding heavy pressure is placed in the weight plate to provide the target axial pressure. The data monitored by the pressure sensor and the displacement sensor are uniformly imported into the computer for subsequent processing by specialized software.

3.5. An automatic device integrating mining, chip removal, support and monitoring

![Figure 6. Device appearance.](image)

Description: 1-positioning rail mechanism, 2-multi-function integrated mechanism, 3-controller

Figure 6. Device appearance.
Figure 7. Positioning rail mechanism.

Description: 4-rail seat, 5-slide, 6-drilling module, 7-monitoring module, 8-chip module, 9-support module

Figure 8. Multi-functional integrated mechanism

Regarding the excavation of the model, domestic and foreign scholars generally use the method of “first loading, then excavating” to simulate the engineering excavation, and most of them utilize manual screwdrivers (or similar strip tools). Each mining quantity depends on the concentration of the test personnel. Force, it is difficult to ensure the accuracy of mining, and it will also cause secondary damage to the mining face when cleaning the accumulated debris, which in turn makes the accuracy of stability evaluation through model test insufficient. On the other hand, in addition to mining, chip removal, support and monitoring in the mining area is another important part of the model test. At present, manual methods are also used, which have defects in consistency, timeliness and accuracy. Aiming at the problems existing in reality, an automatic device integrating mining, chip removal, support and monitoring has been developed. As shown in Fig. 6-8, the device is composed of a positioning rail mechanism, a multi-functional integrated mechanism and a controller, and can be used together with the aforementioned model frame.

The operation steps of this device are as follows: First, the device is installed in combination and connected to a computer equipped with a control system. The working area coordinates are input in the control system, and the system controls the positioning rail mechanism to move the multifunctional
integrated mechanism to the designated position. The motor drive integrated slider then contacts the drilling module, energizing the drilling module and starting in the mining mode. After the excavation is completed, the drilling module and the integrated slider are simultaneously retracted to the specified position and then the power is turned off, and the rotating body is rotated by 90° to switch to the chip discharging mode. Similar to the mining mode, the quick female connector and the male connector are clamped together, the gasket compresses the spring by electromagnetic action, and the vacuum cleaner opens for chip removal work. After the chip removal is completed, the gasket separates the quick female connector and the male head under the elastic force, and integrates The slider retracts to the specified position and the rotating body rotates by 90° to switch to the support mode. The simulated cement mortar enters the support module through the inlet pipe and supports the hole through the spray hole. After the support is completed, switch to the monitoring mode to monitor the working effect of mining, chip removal and support in real time. Repeat the above work modes until the end of the test.

The advantages of this device are:

1) By controlling the motion guide mechanism, the multi-function integrated mechanism can be arbitrarily moved in the plane of the model and accurately positioned, and can realize any position, arbitrary shape, and arbitrary process operation, and expand the application range of the model test.

2) The drill bit in the mining mode can be fed in the three-dimensional direction under the program control, and the feed amount of each direction is slightly controllable, which avoids the accidental error of manual excavation and the stability evaluation distortion caused by insufficient precision.

3) It can realize quantitative mining, timely chip removal, temporary support, real-time monitoring, and improve the automation and intelligence of model test, which is closer to the actual engineering practice.

4. Conclusion

In view of the problems and shortcomings of some current geomechanical model test equipment, a lever-type multi-functional plane strain model test equipment was developed, and the research significance, development ideas, innovation and structural design was elaborated. The equipment adopts mechanical loading, does not depend on large supporting facilities, has less space occupation, unlimited time, simple operation, accurate and reliable. Its biggest advantage is the "multiple use of one machine". That is, a variety of geomechanical experiments can be carried out on a set of equipment. The equipment is equipped with an automatic device integrating mining, chip removal, support and monitoring, which can realize quantitative mining, timely chip removal, temporary support and real-time monitoring, avoiding the accidental error and precision of manual excavation. It can be anticipated that the equipment will have broad application prospects in model tests in the fields of national defense, geotechnical, mining, hydropower, and tunnels.

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