Seismic Performance of Vertically Prestressed Semicircular Anti-Slide Piles Based on Deep Machine-learning Algorithms

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Abstract: Deep machine learning algorithm is a method involving technology, data analysis, statistics, monitoring and so on. Its main goal is to extract, transfer, process and manage information from the data, so as to realize the acquisition and application of knowledge. Deep machine learning algorithms are those machine learning algorithms based on multi-layer neural network structure, with strong learning ability and expression ability. The semicircular vertical prestressed anchor cable anti-slide pile is a new technology for the treatment of large-scale landslides on the bank slopes of Jianghe Reservoir and mountain highways. In this structure, the prestressed steel strand is vertically placed in the anti-slide pile, which can reduce the failure of the prestressed anchor cable in water and the loss of the free length. Its semicircular section fully utilizes the eccentric stress characteristics. It not only enhances the compressive performance of the compression zone of the anti-slide pile, but also improves the weakness of the tensile zone of the anti-slide pile. At the same time, compared to traditional circular piles, the cross-sectional area of semicircular piles is reduced, significantly reducing the amount of materials used, and reducing disasters caused by landslide instability and damage caused by large-scale excavation of slopes. The engineering economy and safety are significant. Through theoretical analysis, this paper constructs key technologies such as structural calculation theory and design methods, and uses model tests to verify their correctness and practicality, thereby revealing the mechanical impact mechanism of semi circular vertical prestressed structures. The experimental data show that the seismic performance of horizontal and vertical prestressed anti-slide piles is different, and the seismic performance of vertical prestressed piles has advantages in the early stage of earthquake, with a change rate of 38.5% in axial force and 20.2% in shear strength. The application of deep machine learning algorithms in the seismic performance of anti-skid piles has potential advantages, which can provide more accurate and efficient prediction and optimization methods to support the seismic design and performance evaluation of sliding piles.

Keywords: Water Destroyed Landslide, Semicircular Anti-Slide Pile, Key Technology, Model Test

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1. Introduction

In recent years, large-scale landslides have occurred continuously along the bank of the Three Gorges Reservoir, mainly due to the instability of the reservoir bank caused by regular immersion of reservoir water. However, the current traditional method of constructing anti slip piles is not suitable for dealing with newly formed water damage landslides. Traditional anti-slide piles have technical problems such as landslides induced by large cross-section excavation, loss of prestress caused by the excessively long free section of the anchor cable, and prestress failure caused by the anchor cable encountering water. The vibration displacement of pile foundations, load effects, and the effects of earthquakes on vertical sites have a significant impact on engineering structures.

Semicircular vertical prestressed anchor cable anti-slide pile is a new type of structural anti-slide pile. Currently, no relevant research results have been reported in the world, and the relevant scientific research process of this structural type is significantly behind the production and practical application, which is worthy of further research. Some scientists have used the full power finite element method to compare the dynamic response of slopes supported by prestressed anchor cables and unsupported slopes during earthquakes [1-2]. Some experts believe that trapezoidal anchored prestressed vertical anti-skid rods are a new method for treating water damage and landslides [3-4]. In addition, some scholars have stated that the bearing capacity of pile foundations and the shear strength index of anti-slide piles have significant changes under earthquake action [5-6]. The vertical prestressed circular pile has shown a significant degree of relaxation under seismic loads.

Compared to traditional prestressed anchor cable anti-slide piles, there are still many difficult issues in the research progress of semicircular vertical prestressed anchor cable anti-slide piles. First, there is no systematic research on the calculation aspect. The second is a design method that has not yet formed a whole in terms of design. The third is that the structural characteristics and performance have not yet been demonstrated through experiments. Therefore, in order to reliably apply semicircular vertical prestressed anchor cable anti-slide piles to engineering projects, it is of important scientific significance to deeply explore many unresolved issues mentioned above.

2. Seismic Performance of Vertically Prestressed Semicircular Anti-Slide Piles

2.1 Deep Machine-learning Algorithms

In the engineering field, deep machine learning algorithms have been widely used in various fields, including image recognition, speech recognition, natural language processing and signal processing. Deep machine learning algorithms can play an important role in the seismic performance of anti-skid piles. Anti-skid pile is an engineering measure taken to improve the stability and seismic performance of pile foundation under earthquake action. Deep machine learning algorithms can establish the mapping relationship between seismic load and pile foundation response by learning large amounts of seismic data and pile foundation structure parameters, and then predict and optimize them. Specifically, the deep machine learning algorithm can learn a model that maps the input seismic load and the pile foundation parameters by training the seismic response data of the sliding pile. In this way, we can use a deep machine learning algorithm to predict the displacement, stress and strain response of sliding piles under a given seismic load to evaluate their seismic performance.

In addition, deep machine learning algorithms can also extract some effective feature representations by learning a large number of slide pile and seismic related data. These features can help us to better understand the seismic behavior of sliding piles, and thus provide guidance for seismic design and optimization. When applying deep machine learning algorithm to study the seismic performance of anti-skid piles, we need to reasonably select and process the data, select appropriate models and algorithms, and verify and adjust the actual engineering experience. In addition, deep machine learning algorithms, despite their potential advantages in prediction and optimization, still need to be combined with traditional engineering methods to ensure the safety and reliability of seismic design.

2.2 Anti Landslide and Vertical Prestress

China is a region with a high incidence of landslide disasters, especially in mountainous and hilly areas and reservoir slope areas. According to the China Statistical Yearbook released by the National Bureau of Statistics, landslides occur frequently in China, accounting for more than half of the total number of geological disasters. Among them, disasters caused by floods and landslides are even more common [7].

Over the years of water storage and navigation operation in the Three Gorges Reservoir Area, due to the annual fluctuation of reservoir water level, the frequency of landslides is increasing, and the scale of damage caused by landslides is gradually increasing [8]. A large-scale landslide occurred in Daxi Township, Wushan County, Chongqing City. In recent years, the impact of water level fluctuations in the reservoir area on the stability of bank slopes has become increasingly evident. The number of cases of traditional landslide anti-slide retaining structures damaged by water has gradually increased, with different degrees of damage occurring every year. Among them, structural failures caused by unreasonable design of retaining structures under the thrust of landslides account for a higher proportion.

Anti slide piles are the main means of landslide treatment, and cantilever anti slide piles are widely used in anti slide pile treatment. Its mechanism includes using the piles above the sliding bed to transfer the landslide thrust to the sliding surface, and transferring it to stable rock and soil through the piles below the sliding bed, forming a stable and balanced slope to achieve the goal of controlling the landslide [9]. However, in terms of engineering practice, there are two aspects of problems. Large cross-section excavation in landslide areas is prone to the emergence of new landslides, leading to instability and damage. The amount of materials used such as concrete and steel is large, and the project cost is high.

The pre-stressed anchor cable anti-slide pile is fixed in the bedrock through the anchor cable, changing the stress state of the cantilever pile structure, changing the passive stress to the active stress state, increasing the mechanical performance of the anti-slide pile, and improving its stability. Although the prestressed anchor cable anti-slide pile fully utilizes the anchor cable as an external force to reduce the structural dead weight of the anti-slide pile, there are still two problems. When the geological conditions correspond to a relatively large thickness of the sliding mass or a relatively flat sliding surface, the designed free section of the prestressed anchor cable is relatively long, which not only has a high engineering cost but also has a large prestress loss. When the prestressed anchor cables embedded in the soil are periodically soaked in water, it is easy to cause the prestressed tensile force to fail, which has been an unsolved problem in the Three Gorges Reservoir area for a long time.

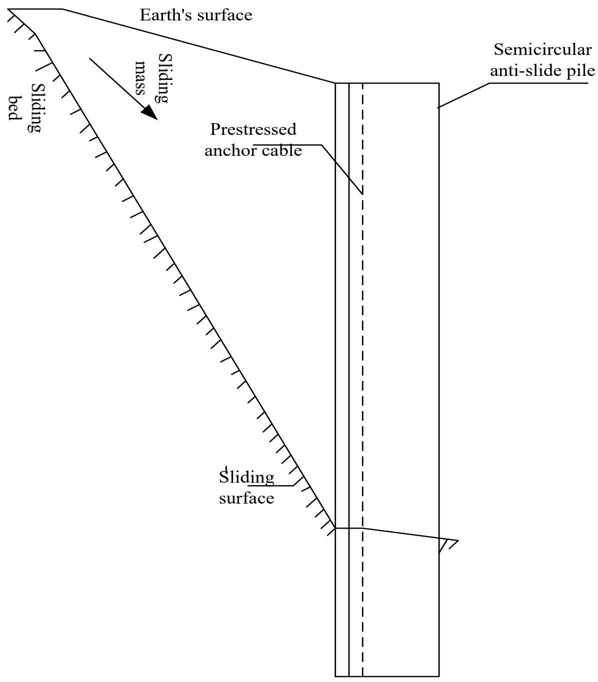

Fig.1 Arrangement of Vertical Prestressed Anchor Cables for Semicircular Anti-Slide Piles

As shown in Figure 1, it can be seen that both cantilever anti-slide piles and prestressed anchor cable anti-slide piles have significant structural design defects. In view of this, a semi circular vertical prestressed anchor cable anti-slide pile is proposed to provide a new choice of treatment technology for bank slopes of Jianghe Reservoir and mountain highway landslides.

2.3 Vertical Prestressed Semicircular Anti-Slide Pile

Vertical prestressed semicircular anti-slide pile is a commonly used bridge foundation structure, its seismic performance is affected by various factors, such as prestress level, soil properties, bearing capacity, and so on. Under earthquake action, due to the frictional resistance between the pile and soil and the adhesive force between the pile and concrete, vertically prestressed semicircular anti-slide piles can effectively reduce the impact of seismic forces on the piers and improve the seismic performance of the bridge [10]. In addition, the use of beam column pier integrated design can enhance the overall stiffness and seismic performance of the bridge structure, while the use of lateral resistance support systems can further improve the seismic performance of the bridge [11]. Vertical prestressed anti-slide pile is a foundation structure used in bridge and tunnel engineering. Its main feature is that before the concrete pouring of the pile body, the reinforcement is prestressed and reinforced, and the pressure is transmitted to the surrounding soil layer through the tensile action of the reinforcement to improve the bearing capacity of the pile body underground, as well as the ability to resist overturning and sliding [12].

The advantages of vertically prestressed anti-slide piles include improving the stability of bridge piers. For bridge projects that need to resist overturning and sliding, the use of vertically prestressed anti-slide piles can effectively improve the stability and bearing capacity of bridge piers, thereby ensuring the safe operation of bridges.

To save construction costs, prestressed anti-slide piles are a technical means to improve the rigidity and bearing capacity of the pile body by controlling the internal stress state of the pile body in advance. Compared to other foundation structures, they have higher economic benefits and save construction costs. Adapting to different geological conditions, vertical prestressed anti-slide piles can choose different parameters such as prestress grade, diameter, and length based on the geological conditions and design requirements of different sites, which can flexibly respond to various geological conditions and improve the adaptability and flexibility of construction. In short, vertical prestressed anti-slide pile is a reliable, economical, and adaptable foundation structure, which has been widely used in bridge and tunnel engineering construction. The section form of the semi circular vertical prestressed anchor cable anti-slide pile is half of the full circular section. The prestressed steel strand is vertically arranged in the anti-slide pile body and located near the edge of the normal section of the landslide thrust. The bottom end of the steel strand is fixed in the pouring concrete using an anchor plate, and the top end is fixed by the anchor after the prestress tensioning.

Semicircular vertical prestressed anchor rope anti-skid pile fills the gap of traditional anti-skid pile. It not only utilizes the protective effect of concrete, but also utilizes the vertical bending moment formed by preload, further compensating for the bending moment generated by landslide impact, and reducing the direction of the anti-skid pile tip. At the same time, the semicircular shape optimizes the stress pattern of the structural section, greatly increases the compression range of the structural section, improves the compression performance, effectively saves engineering costs, and has good economic significance. The structure of semi circular vertical prestressed anchor cable anti-slide pile is shown in Figure 2:

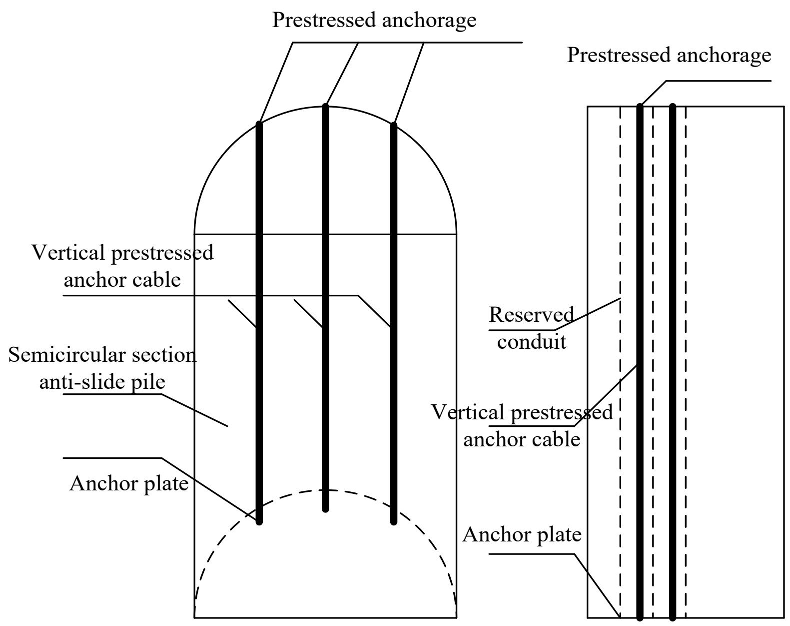

Fig.2 Semicircular Vertical Prestressed Anchor Cable Anti-Slide Pile Structure

Overall, the structural form of semicircular vertical prestressed anchor cable anti-slide piles has the following advantages after induction, avoiding the large cross-section excavation of anti-slide piles causing new landslides, and reducing the probability of instability and failure. It prevents failure of the anchor cable due to periodic immersion in groundwater. Compared to traditional circular anti-slide piles, the amount of materials such as concrete and steel is reduced, and the engineering cost is saved. The loading performance of the structure itself is enhanced to inhibit the development of cracks in the pile body. Compared with rectangular anti-slide piles, semicircular sections are more conducive to counteracting landslide thrust in different directions. The anchor cable is installed in the anti-slide pile, effectively reducing the disturbance and damage of the steel strand caused by the earthquake, thereby reducing the loss of prestress. It can be applied to landforms where the soil covering of the sliding body is thick or the sliding surface is relatively gentle, which is beneficial to reducing the loss of the prestressed free section. The compression performance of the anti-slide pile is improved, and the bending resistance and stiffness are further enhanced. The semicircular section avoids the "protruding" shape in front of the traditional circular pile, with a smooth and beautiful structure and increased traffic width. It can be seen that the application prospect of semi circular vertical prestressed anchor cable anti-slide pile is very broad.

3. Semicircular Anti-Slide Pile Experiment Using Finite Element Method

3.1 Numerical Analysis of Seismic Performance of Semicircular Anti-Slide Piles Using Finite Element Method

The finite element numerical analysis method is often used to evaluate the performance of semicircular anti-slide piles in seismic design [13]. The main steps are as follows: establish a mathematical model, use three-dimensional finite element software to establish a mathematical model of a semicircular anti-slide pile, including structures such as piers and surrounding soil, taking into account different material parameters and seismic dynamic loads. It can analyze particle motion laws, conduct dynamic analysis, generate seismic response spectra and seismic wave time history, and simulate the movement of specific models to obtain data such as the stress situation and deformation of bridge piers. Because semicircular anti-slide piles are complex nonlinear systems, it is necessary to comprehensively consider their elastic, plastic, destructive, and other characteristics, and analyze their seismic performance and optimize design schemes by evaluating the displacement, deformation, and stress conditions of bridge piers during earthquakes. Based on the measured data and theoretical analysis results, the finite element model is verified, and targeted parameter adjustment and optimization design are conducted to ensure the feasibility and rationality of actual construction [14].

In order to derive the equations for each finite element, strain displacement and stress strain relationships are required. The relationship between the strain λ_a and the displacement v in the direction a is as follows:

$$\lambda_a = \frac{cv}{ca} \tag{1}$$

The simplest constitutive relation of materials is Hooke's law:

$$\ell_a = F\lambda_a \tag{2}$$

ℓ_a is the stress in the direction a and F is the elastic modulus. Assemble the element equation to obtain the global equation and introduce boundary conditions.

$$|G| = [L]|C| \tag{3}$$

$|G|$ is the global nodal force matrix, [L] is the global stiffness matrix, and $|C|$ is the global unknown nodal moment of freedom.

The finite element numerical analysis of semicircular anti-slide piles is one of the core methods in current seismic design of bridges, which can accurately evaluate the seismic safety of bridge structures and guide the design, construction, and maintenance of practical projects. The finite element method is used for the calculation and analysis of pile foundations under vertical loads. After considering the seismic effect, the overall anti-sliding moment distribution of the structure is carried out. When conducting anti-slide tests of vertically loaded semicircular piles under earthquake action, simulation experiments can be implemented based on the finite element method [15].

3.2 Experimental Monitoring of Seismic Performance

Experimental monitoring of seismic performance of semicircular anti-slide piles mainly includes the following aspects: establishing seismic models, using computer simulation technology to establish a three-dimensional finite element model of semicircular anti-slide piles, and conducting dynamic analysis and seismic response time history analysis on this basis. Seismic performance evaluation: Real-time monitoring and evaluation of shear deformation, seismic displacement angle, seismic capacity, and other parameters of semicircular anti-slide piles are conducted through seismic dynamic testing and vibration testing. On-site monitoring: At the construction site of semicircular anti-slide piles, sensors such as accelerometers and displacement meters are installed to conduct real-time monitoring and data collection of bridge vibration responses caused by ground motions. At the same time, combined with geological exploration data and geotechnical mechanical tests, the characteristics of the soil layer are analyzed and evaluated. Statistical analysis: Through the collection, collation, and processing of monitoring data, statistical and data analysis methods are used to obtain the reliability indicators of semicircular anti-slide piles under various earthquake actions, and suggestions for optimal design and strengthening measures are proposed.

Experimental monitoring of seismic performance of semicircular anti-slide piles is an important means to ensure the safety and stability of bridge structures, and can provide scientific basis and technical support for bridge design and construction [16]. The time-history response analysis of vertically prestressed semicircular anti-slide piles under earthquake action mainly refers to describing the effect by calculating the strain rate and acceleration curves after applying a load in a certain direction [17]. The change of vertical load moment under earthquake action is a function of the bearing capacity and displacement of the pile foundation within a certain period of time. When the structural stiffness of the anti-slide pile is large, it would generate additional force on the vertical axis [18]. Under earthquake action, the magnitude of vertical load is an important indicator that affects the distribution of pile bending moments and the strength of anti-sliding capacity [19]. According to the calculation results, the pile would generate time-history responses under different circumstances. Under earthquake action, the magnitude of vertical load would affect the safety of the pile structure, and it is also related to the corresponding adjustment of vertical prestressed horizontal load on parameters such as pile bottom settlement, shear force, and bending moment changes. Therefore, anti-slide piles have great requirements for the bearing capacity of the foundation [20]. The design of vertically prestressed semicircular anti-slide piles is determined based on the sag force under vertical loads, taking into account the impact of seismic effects, structural deformation, and other factors on their stability and bearing capacity. The anti sliding performance of vertically prestressed semicircular piles is mainly related to the stiffness changes generated under different loads, and the impact of pile length on it.

3.3 Experimental Design

The seismic experimental design of semicircular anti-slide piles can be divided into the following steps:

The test plan can be determined, including selecting appropriate soil models, ground motion wave sources, and materials and dimensions of components such as piers and bearings, while taking into account uncertainties that may occur during the test process, to develop a detailed test plan. A numerical simulation model can be established, using the finite element method to establish a full size numerical simulation model of a semicircular anti-slide pile, analyze its static and seismic loads, and obtain key parameters such as vertical vibration displacement, base shear, and other data. Simulate seismic loads. By simulating different seismic loads such as seismic waves, observe the deformation and stress conditions of bridge piers under dynamic action, and obtain their seismic performance parameters. During the loading test, sensors are used to record the vertical vibration displacement, acceleration, and base shear force at different time points, and the seismic performance indicators of the bridge pier are analyzed based on the data obtained from the test. Result analysis and evaluation: Based on the test results, statistical methods are used to process and analyze the data, evaluate the seismic performance of semicircular anti-slide piles under different earthquake loads, and determine their reliability and safety. The seismic experimental design of semicircular anti-slide piles requires comprehensive consideration of various factors, such as the selection of test sites, test methods, evaluation indicators, etc. Through scientific, systematic, and reasonable design schemes, their seismic design level can be effectively improved.

4. Mechanical Performance of Vertically Prestressed Semicircular Anti-Slide Pile

4.1. Comparison of Results of Different Seismic Design Parameters

The shear deformation of vertically prestressed semicircular piles is caused by changes in their anti slip modulus. Under earthquake action, the pile produces different displacements and displaces as the load increases. The stress analysis of vertically prestressed semicircular anti-slide piles under earthquake action is mainly achieved by changing the loading method. Set the material model number to M1-10, M2-10, M1-30, M2-30, M1-50, and M2-50. The design of vertically prestressed semicircular piles mainly involves the analysis of the concrete strength and shear stiffness parameters of the pile body. The basic information of materials is shown in Table 1:

Table 1. Basic Information of the Material

	Stirrup spacing (mm)	Concrete compression strength(MPa)
M1-10	120	32.4
M2-10	120	35.6
M1-30	240	29.2
M2-30	240	29.3
M1-50	360	26.5
M2-50	360	29.4

The ability and variation of shear strength and axial force in the horizontal and vertical directions are different at different time periods. The specific shear strength and axial force of the section are shown in Figure 3. It can be seen that the shear strength under the vertical seismic capacity is stronger in the early stage compared to the horizontal direction. There is a positive correlation between axial force and shear strength.

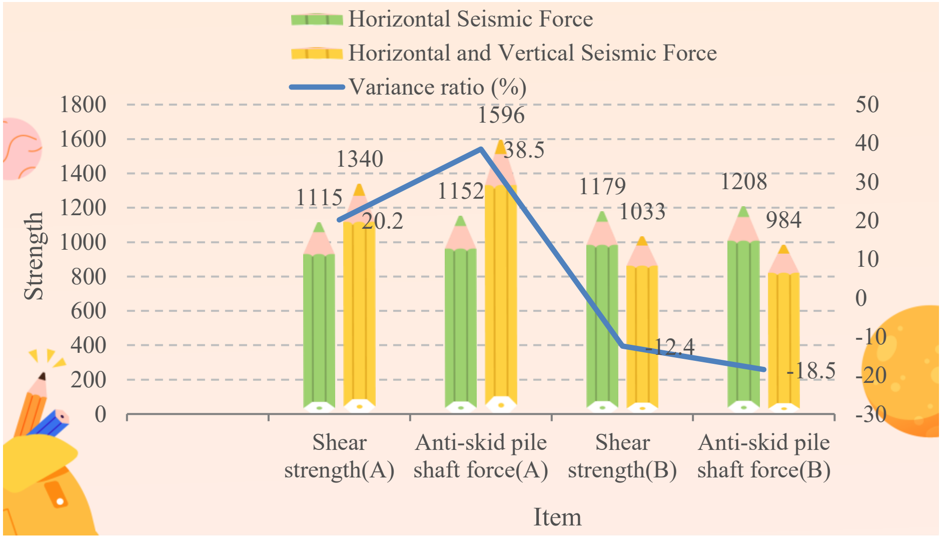

Fig.3 Section Shear Strength and Axial Force

The pile length is a key parameter of vertical prestress, while the pile end bending moment and axial force vary within a certain range. Large deformation occurs when loading time is long. The bending moment has a significant impact on the shear deformation coefficient. The shear strength decreases first and then increases with the increase of sliding resistance times. When the loading amount is greater than the maximum resistance point, the slope of the relationship curve between the vertical prestress and the pile end bending moment changes within a certain range. The greater the capacity of the anti-slide pile, the higher its stiffness.

4.2. Shear Strength of the Model

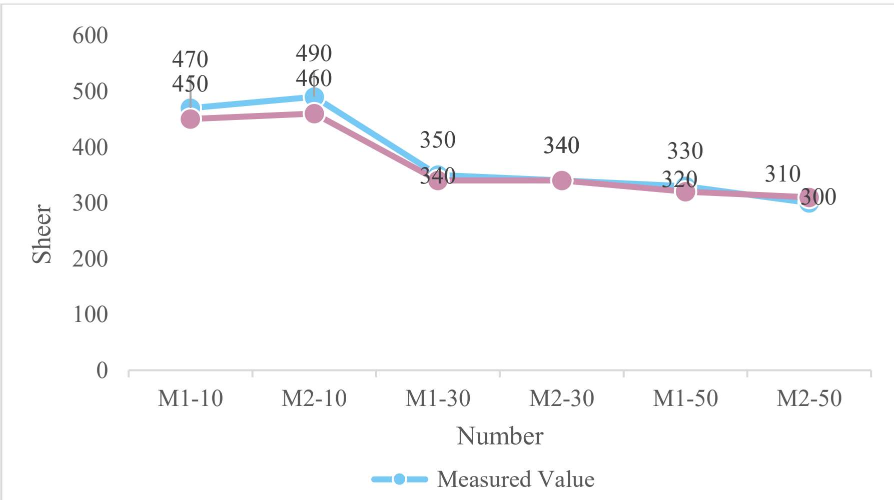

Fig.4 Shear Strength of the Model

As shown in Figure 4, it can be found that under finite element calculation, the shear strength of the model does not differ significantly from the actual test value. The shear failure of vertically prestressed semicircular piles under seismic action is mainly caused by superstructure loads in the soil, and its anti-sliding effect is also related to the pile stiffness. Therefore, it is necessary to reinforce it.

5. Conclusion

The stability of piles under vertical loads is affected by various factors, including pile length, inclination, and soil depth. As the friction coefficient of pile foundation increases, its anti-sliding and shear resistance capacity decreases. It is very important to effectively control the displacement of pile foundation. Under the action of earthquake, the seismic performance of semi circular vertical prestressed anchor cable anti-slide piles is also worthy of attention. Under earthquake action, the lateral shear and bending forces on the pile body would increase, which puts forward higher requirements for the seismic performance of semi circular vertical prestressed anchor cable anti-slide piles. Research has found that by installing longitudinal reinforcement inside the pile body, the seismic resistance of the pile body can be improved, and the deformation and damage of the pile body can be reduced. In addition, the construction technology of semi circular vertical prestressed anchor cable anti-slide piles can also affect their seismic performance. During construction, construction shall be carried out in strict accordance with the design requirements to ensure that the tensioning force and tensioning method of the prestressed anchor cable meet the requirements, and to avoid quality problems of the pile body caused by improper construction. This paper only studies the shear strength and moment coefficient of semicircular piles under vertical loads, and does not analyze the effects of different axialities and inclinations. Therefore, it is necessary to further analyze the seismic performance of vertically prestressed semicircular anti-slide piles from these aspects.

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