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# Brief Description of Bearing Characteristics of Soft Rock Socketed Piles

Yutong Fu, Jindong Zhou, Junfeng Zhang

Nanchong Vocational and Technical College, Nanchong 637000, Sichuan, China


## Abstract

**The rock-socketed piles are characterized by strong bearing capacity, small settlement and good seismic performance because of their embedded in the bedrock at a certain depth or all of them. They are the basic types of construction, bridges and ports. The rock-rock piles of soft rock are different from those of hard rock and rock-socketed piles because of the particularity of soft rock, and many of them have studied the bearing characteristics of soft rock-bearing rock from different angles. This article mainly describes the bearing performance of soft rock socketed piles from the current research status of pile side and pile end resistance.**



## Keywords

**Soft Rock; Rock - Socketed Pile; Side Friction Resistance; End Resistance.**


## 1. Introduction

Soft rocks are widely distributed in the southwestern region of China. In recent years, soft rock socketed piles have been widely used to meet the needs of high, heavy, and large buildings in storage areas. Due to the low bearing capacity, large deformation, poor water stability, and susceptibility to degradation of soft rock compared to hard rock in terms of mineral composition and bearing characteristics, the deformation theory of hard rock cannot fully explain the deformation and failure mechanism of soft rock. Existing construction and design specifications for hard rock cannot be applied to soft rock engineering. Therefore, Chinese scholars have conducted research on the bearing performance of soft rock socketed piles from multiple aspects.

## 2. Research on Side Resistance of Soft Rock Embedded Rock Pile

The lateral friction resistance of rock socketed piles is essentially provided by the shear force between the pile and rock. Therefore, studying the shear properties of the pile and rock can help analyze the load transfer law of the pile rock contact surface, and further study the bearing mechanism of the pile foundation.

Cai[1] made two concrete piles with a diameter of 1.0m and a length of 43m. Both piles are embedded in rock at a depth of 6m, with pile 6 embedded in strongly to moderately weathered siltstone and mudstone, and pile 3 embedded in slightly weathered rock section - original rock at a depth of 1.2m. By conducting static load tests and using the slow sustained load method, the lateral resistance performance of two piles was studied using multiple parallel synchronous jacks for loading. The research results show that there is a significant difference in the measured ultimate bearing capacity between the two test piles, and the lateral resistance of the soil around the two piles shows an asymmetric bimodal pattern along the pile body, and the larger the load, the more obvious this pattern is. The peak value indicates a larger lateral soil resistance of the pile, while the valley value indicates a smaller lateral resistance effect of the soil layer. The emergence of the first peak area is due to the plastic zone expansion of the soil around the embedded rock pile being limited to the upper part of the pile, especially near the top. The emergence of the second peak zone is due to the strong support

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effect at the bottom of the pile, which causes radial deformation of the pile (increasing diameter), resulting in an increase in the normal force of the pile on the soil or rock around the pile. In addition, the lateral resistance of the embedded rock section is easier to exert, because the relative displacement between the pile and soil required for the lateral friction of the embedded rock section is smaller than that of the embedded soil section. Under the action of various levels of loads, the position of the peak areas of the two piles relative to the pile body is generally consistent, but there are differences in the magnitude of the peak values. Finally, Cai concluded that under the action of ultimate load, it can be seen from comparing the lateral resistance of different pile sections of the two piles that although there is not much difference in soil properties around the piles and the burial depth of each layer of soil is generally the same, the difference in lateral resistance is extremely significant. It can be inferred that the pile end support plays a controlling role in the lateral resistance of the soil around the pile.

Li[2] studied the lateral friction characteristics of pile foundations with mudstone surrounding the rock mass through indoor experiments. From the experimental results, it can be concluded that the distribution curve of pile frictional resistance shows a unimodal distribution, and the distribution of pile side frictional resistance is related to the strength of the rock on the pile side and the depth of the pile embedded in the rock. The distribution of axial force on the pile decreases with the increase of rock embedding depth, and the lateral deformation of the pile will also decrease. The normal stress acting on the rock around the pile will also decrease. When the lateral friction of the pile reaches the limit value, the displacement generated by the pile top is very small. When the lateral friction of the pile reaches the limit, the displacement of the pile top mainly manifests as compression of the pile body, and there is no overall displacement of the pile body. Before the lateral friction of the pile reaches the limit, it is mainly borne by the bonding force between the pile and the rock mass.

Peng[3] studied the pile rock lateral resistance of red mudstone. Through research, it has been found that the red layer soft rock is a semi plastic and semi rigid body, and the τ-s curve of the embedded rock section is different from that of ordinary soil. It generally exhibits brittle failure, and the relative displacement required to exert the ultimate lateral resistance is very small, much smaller than the displacement when the limit is reached in the soil layer. The relationship curve between the lateral resistance of the embedded rock section and the relative displacement of the pile rock shows obvious processing softening characteristics, that is, the lateral resistance is more likely to reach its peak and cause brittle failure of the rock mass. Peng studied the influence of different tests and stress-strain tests on the measured values of red layer lateral resistance, and found that the red layer lateral resistance values determined by different test methods have the following relationship: shear index<calculated lateral pressure test result<short column test result.

He[4] measured the lateral friction load displacement curve and Q-s equivalent conversion curve of large-diameter rock socketed piles in soft rock areas through self balancing pile testing, and compared them with empirical statistical formulas. The results show that the lateral friction resistance of the lower section of the test pile is more fully exerted than that of the upper section of the test pile; The measured lateral resistance of large-diameter rock socketed piles accounts for 87.85% of the total bearing capacity, and large-diameter rock socketed piles in muddy soft rock belong to end bearing friction type piles; The predicted value of the empirical formula is greater than the measured value. When designing and optimizing large-diameter rock socketed piles, it is necessary to conduct self balancing pile tests to determine their ultimate bearing capacity.

Wang[5] found through his research on Wuhan ultra long soft rock socketed piles that the lower and upper side friction forces of the ultra long soft rock socketed pile can be simultaneously exerted, and there is no softening phenomenon of the shallow soil layer side friction force of the pile body. The maximum relative displacement of pile soil (rock) occurs in the upper soil layer of the pile body.

Mei [6] mentioned that on-site testing and indoor model testing are important methods for revealing the bearing mechanism of soft rock socketed piles. Due to the large diameter and high bearing capacity of soft rock socketed piles, the cost of on-site testing increases, and the repeatability needs to be discussed. He used materials such as cement, gypsum, sand, water, and early strength agents to

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simulate soft rocks, and based on this, conducted indoor experiments. In indoor experiments, he studied the bearing characteristics of soft rock socketed piles by setting different pile diameters, rock socketed depths, and overlying pressures. The research results show that as the depth of rock embedding increases, the diameter of the pile body increases, and the overlying pressure increases, the bearing capacity of rock embedded piles is significantly improved. However, the overlying pressure has a relatively small impact on the lateral friction resistance of soft rock embedded sections.

## 3. Research on the End Resistance of Soft Rock Embedded Pile

Liu[7] found through his research on cast-in-place rock socketed piles in muddy soft rock that: (1) whether it is drilled or manually excavated, the rock socketed piles in muddy soft rock areas mainly exhibit the characteristics of friction piles, and the pile end resistance is generally less than 20%. (2) The end resistance of soft rock socketed piles can still be exerted when the rock socketed ratio hr/D >5. When hr/D is>7, the end resistance is almost zero, which means that the depth of rock socketed piles in muddy soft rock areas can be appropriately deepened to 7D. (3) The performance of the end resistance of rock socketed piles generally requires the displacement of the pile top to be greater than 15mm, and it increases with the increase of the pile top displacement.

Cai[8] found through actual measurement of two large-diameter soft rock socketed piles that the end resistance of the socketed piles is closely related to the properties of the rock at the bottom of the pile. The speed of end resistance is controlled by the strength of the rock at the pile end, which is high in strength and slow in development; If the strength of the rock at the bottom of the pile is low, the end resistance will exert more quickly. When the test pile reaches its ultimate load, the end resistance of the pile supported on the soft rock weathering layer accounts for about one-third of the total external load. From this, it can be seen that for rock socketed piles supported by weathered rock in soft rock areas, when the depth of the embedded rock mass is greater than 5 times the diameter of the pile body, the effect of end resistance still exists. This issue should be noted during design.

Zhan[9] proposed a range of correction values for the ultimate end resistance of extremely soft rock socketed piles in moderately weathered extremely soft rock by studying the ultimate end resistance. It is recommended that the standard value range for the ultimate end resistance of moderately weathered extremely soft rock piles be between 1500 and 3800kPa. When the natural uniaxial compressive strength of extremely soft rock is 2.5 to 5MPa, the interpolation method is used to take values; When the natural uniaxial compressive strength of extremely soft rock is less than 2.5 MPa, the lower value is taken. Zhan also pointed out that for moderately weathered bedrock, when the embedded rock pile is calculated using the empirical parameter method, the influence of changes in the lateral and end resistance coefficients on the vertical bearing capacity of a single pile can be ignored when the embedded rock depth to diameter ratio is less than or equal to 3. However, when the embedded rock depth to diameter ratio is greater than 3, the influence of changes in the lateral and end resistance coefficients should be considered.

After studying moderately weathered soft rock piles, Luo[10] pointed out that the characteristic value of the end resistance of moderately weathered soft rock piles can be increased by 30% to 50% based on the comprehensive determination of the rock foundation bearing capacity characteristic value based on the rock compressive strength index, rock integrity, and bedding plane attitude.

Xie [11] obtained through finite element numerical simulation analysis that rock socketed piles have the best effect when the pile end and pile side resistance work together in soft rock layers. With the increase of rock socketed depth, when the depth ratio of the pile foundation embedded in the rock mass is greater than 5, the pile end resistance basically loses its effect.

## 4. Summary

In summary, Chinese scholars have conducted a lot of beneficial research on the bearing performance of soft rock socketed piles, including the following aspects:

(1) Through the analysis of a large amount of on-site test data on rock socketed piles, it is found that the bearing characteristics of soft rock socketed piles under test pile loads are mainly manifested as end bearing friction piles, which also have the characteristics of friction end bearing piles or end bearing piles.

(2) The lateral resistance and end resistance of rock socketed piles are not synchronous, but asynchronous, that is, the lateral resistance occurs before the end resistance, and the lateral friction of the soil layer occurs before the lateral friction of the rock layer. When the vertical bearing capacity of the pile foundation reaches the limit value, the ultimate lateral friction of each rock and soil layer does not reach the limit value at the same time.

(3) When the pile top load is small, the pile end resistance is extremely small or even almost zero, and at this time, the lateral friction resistance of the rock socketed section is also very small. The load is mainly borne by the lateral friction resistance of the upper soil layer pile. When reloading, the pile end resistance and the lateral friction resistance of the rock socketed section slowly increase, and when continuing to load, the two almost increase linearly.

(4) There is no maximum depth of rock embedding in soft rock foundation, but there is an optimal depth of rock embedding, which is not a certain value and requires specific engineering analysis. In practical engineering applications, a comprehensive analysis should be conducted from the perspectives of bearing capacity, economy, and construction to determine.

(5) As the load on the pile top gradually increases, the frictional resistance of the soil on the pile side decreases after reaching its peak, and then gradually stabilizes, showing a displacement softening characteristic, indicating that it has reached its limit value. The side friction and end resistance of the embedded rock section continue to increase with the increase of the pile top load, indicating that their side friction and end resistance have not reached their maximum values. If the pile top load continues to increase, the side friction and end resistance of the embedded rock section will continue to increase.

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