

## Introduction

Cement soil mixing piles are widely used in soft ground reinforcement, but the traditional cylindrical mixing piles have the problems of poor pile formation quality, insufficient bearing capacity, large amount of waste slurry and pollution. In order to realize the integration of material and structure of soil-cement pile, improve the quality of pile formation and reduce the amount of waste slurry, we have researched a new type of variable-section pipe pile. The upper part of the variable-section pile is a large-diameter pile with closed exterior and hollow interior, and the lower part is a traditional cylindrical pile. The upper part of the large-diameter pile gives full play to the pile load-bearing capacity, while the internal hollow structure saves a large amount of cement without affecting the pile load-bearing capacity.

## Research Method

In this study, numerical simulations were carried out by ABAQUS3D software to analyze the bearing characteristics of variable-section pipe piles, T-piles and conventional cylindrical piles by establishing their 3D monopile static load models. And the economic factors are integrated to calculate their unit volume bearing capacity. The superiority of variable-section pipe pile structure is proved by the lateral comparison of the three piles, and its geometric parameters, such as pipe length and casing thickness, are optimized.

## Model Parameter

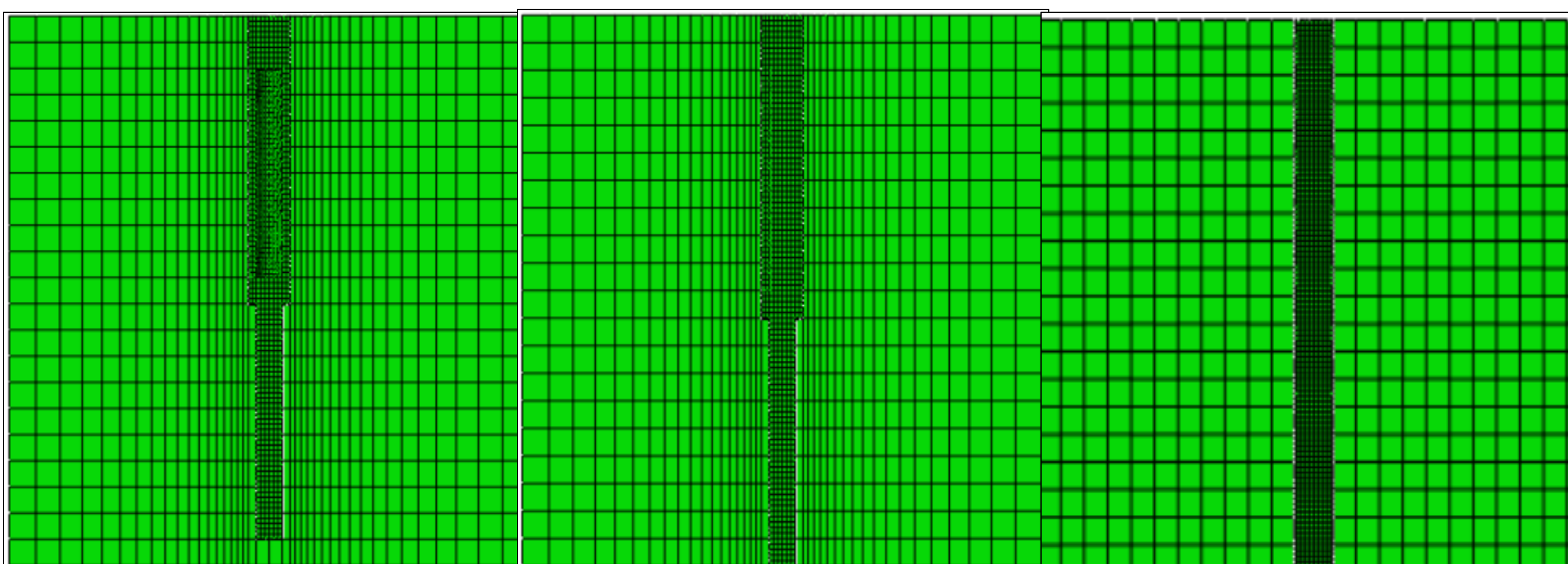
The soil parameters of the model for this study were selected from a highway in the yellow panhandle of Shandong Province, China, and the geometric parameters of the model were set based on the dimensions that could be achieved with the available construction tools. The Young's modulus  $E$  of the pile is taken as 100 times the strength of the column according to the Chinese code. The thickness of the sealing shell is the thickness of the top sealing layer and the bottom sealing layer. The vertical load is 100kN per level.

### Summary of parameters

Parameter	Value or range
Outer diameter of the upper pile (m)	0.8
Inner diameter of the upper pile (m)	0.5
Thickness of sealing shell (m)	From 0.5 to 3
Thickness of the hollow part (m)	From 1 to 5
Diameter of the lower pile (m)	0.5
Total length of pile (m)	10
Column strength, $q_u$ (MPa)	2 and 6
Undrained shear strength of soft soil, $c_u$ (kPa)	22.8

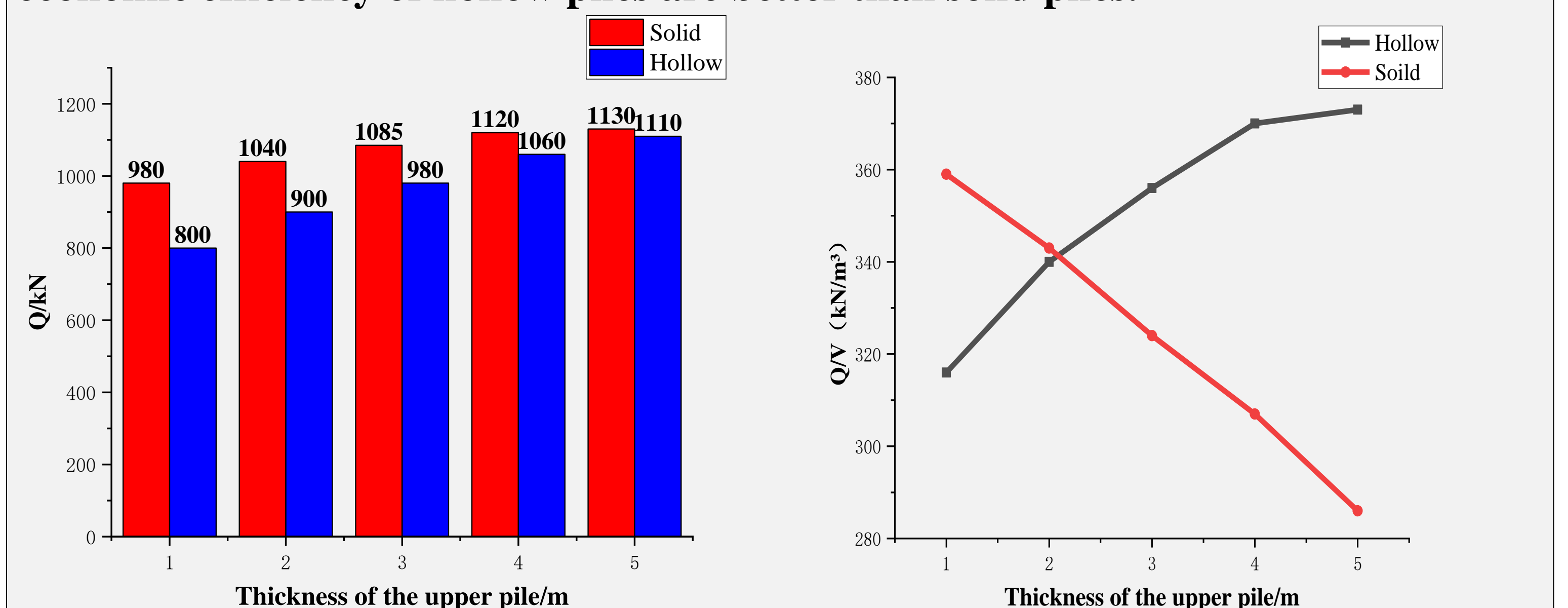
## Model building

Since variable-section pipe piles and T-shaped piles are the focus of this study for comparison, the grid is encrypted for the pile perimeter of these two models when dividing the grid



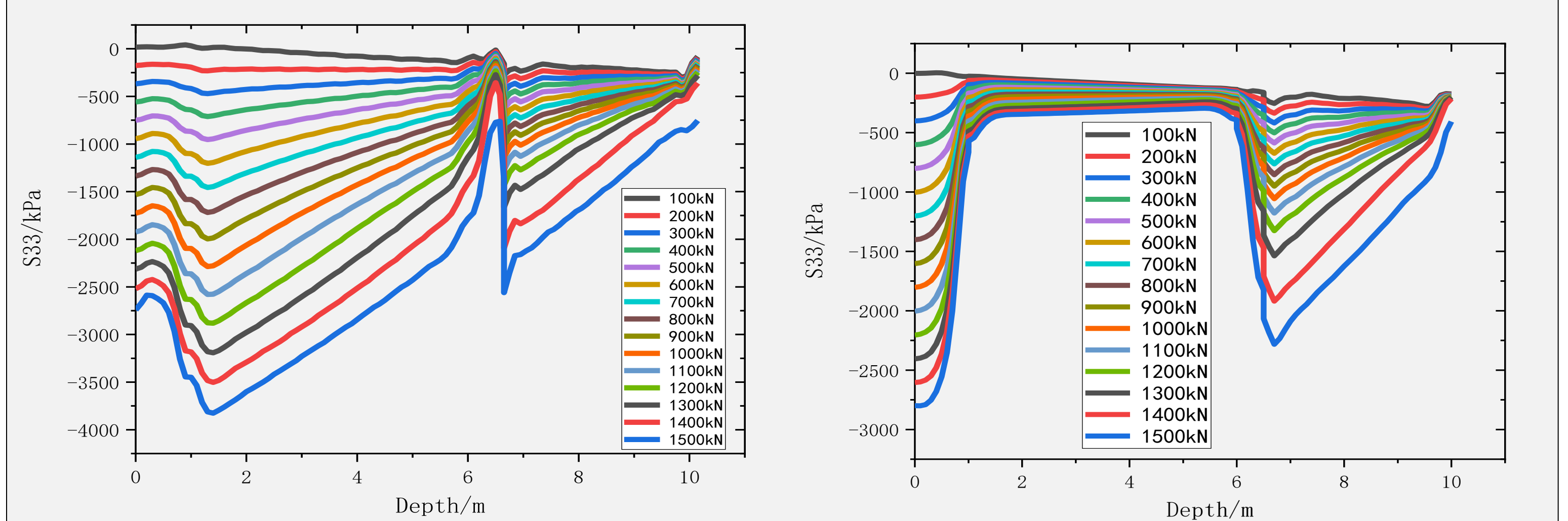
## Pile Comparison

For the comparison of the ultimate bearing capacity of single pile and unit volume bearing capacity of hollow pile and solid pile, it is found that the solid pile is more advantageous when the upper pile length is small; when the upper pile length is larger, the hollow pile is more advantageous. Overall, the bearing capacity and economic efficiency of hollow piles are better than solid piles.



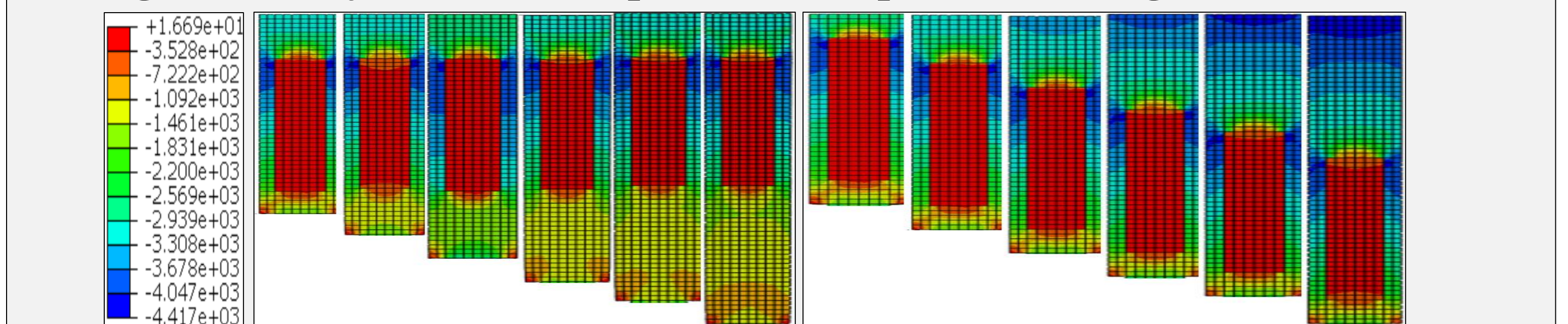
## Bearing Characteristics

For the variable-section pipe pile, the vertical stress distribution along the inner and outer sides of the vertical direction was extracted separately. It can be found that, unlike the conventional cylindrical pile, the maximum stress value of the variable-section pipe pile appears at the external junction of the upper casing and the cylinder wall, where the large stress value is due to the stress concentration phenomenon caused by the change of the cross-sectional area.



## Study of Seal Thickness

It can be found that the increase of the thickness of the upper casing and the thickness of the lower casing can make the pile's load-bearing characteristics more similar to those of conventional piles, i.e., the damage occurs at the upper part of the pile rather than at the stress concentration. The increase of the thickness of the lower casing can effectively reduce the stress concentration at the lower junction, making the lower junction of the pile less susceptible to damage.



## Conclusion

Compared with conventional piles and nail piles, variable section pipe piles have excellent load carrying capacity and economy. The bearing characteristics of variable section pipe pile are different from those of conventional pile, the maximum stress occurs at the junction of the upper casing, with the increase of the thickness of the upper casing, the bearing characteristics of variable section pipe pile tend to be similar to those of conventional pile.