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Optimization of Pile Clamping Structure Under Utrong Waves

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Abstract: The clipped pile structure plays a significant role in enhancing the stability of the pile foundation. There is no specification for piled wharf pile structure design and construction of the guidance of systemic problems, based on an engineering example, through the relevant specification, structural mechanics, and finite element method of pile form, clip to pile layer, and the way of brace is studied under the condition of a strong wave of pile structure strength and stability, to provide a theoretical basis for the similar engineering design and construction.

Keywords: strong wave condition; Clip pile; Stability; Structure optimization

With the gradual development of coastal port engineering construction from the nearshore to the deep water without cover or semi-cover, traditional port planning, design, and construction technologies are facing new challenges [1]. In engineering, it is usually required to design pile clamped structure of pile foundation of high piled wharf according to the stress situation, and pile clamped structure should be time after the end of pile driving, to strengthen the stability of pile foundation after pile driving and improve the stress state during construction, so as to avoid overturn and deflection of pile foundation caused by single steel pipe pile due to the influence of water and wind waves. Usually, the design unit will require the construction unit to timely clamp the steel pipe piles vertically and horizontally, to connect the steel pipe piles as a whole and increase the ability of the sunk steel pipe piles to resist water and wind waves. The construction unit will also build a temporary construction platform to facilitate the construction of the superstructure [2].

At present, the high pile wharf pile structure is diversified and have different characteristics, different hydrogeological conditions, the role of the different, there is no clear design specification for clip pile design calculation of the reference [3], which is all a matter of experience in construction, in order to better guide the engineering construction, strengthen the stability of pile foundation, will now pile structure optimization comparison, A pile clamping scheme suitable for adverse wind and waves is proposed.

1. Project Overview

A petrochemical wharf in South China is in the offshore deep water without cover, which is characterized by frequent typhoons and heavy monsoon blowing. If the pile foundation under construction is not stabilized in time, or the pile stabilization measures are not firm, the typhoon will easily lead to pile tilt and collapse under the reciprocating action of wind, waves, and currents.

The elevation of the mud surface in the dockside area is -21.89m, and the soil quality from the first layer is silt, silt mixed sand, sand mixed silt, medium coarse sand, fine sand, and so on. The bearing layer is strongly weathered granite, represented by its geological conditions and material properties of pile foundation, and it’s supposed embedding point is calculated.

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2. Natural conditions and pile foundation load calculation

The pile head elevation above the water surface is small, and the wind load is much smaller than the wave load. Only wave action is considered here. The wave elements are calculated according to H4% of the wave elements occurring once in 5 years, and the wave elements are shown in Table 1.

Table 1 Wave elements of 5-year H4% design

Main wave directions,	Reappearance (year)	Wave height H4% (m)	Wave period T (s)	The wavelength L (m)	Extreme water depth D (m)
S	5	6.7	10.9	151.9	25

If the pile distance is greater than 4 times the pile diameter, the pile group coefficient is not considered, and the wave wavelength is greater than 100m, much larger than the pile distance, the force difference of the four pile foundations under wave force is little. As the ratio of wave height to water depth is relatively large, the wave load has strong nonlinearity, so the wave load on pile foundation [5] is calculated by Stokes' fifth-order wave theory and Morison equation, as shown in Table 2.

Table 2 Wave load of pile foundation

Diameter of steel pipe D (m)	Maximum total wave force Pmax (kN)	Maximum total bending moment Mmax (kN·m)）	Operating point above mud surface (M)	Depth of embedding point (m)
1.2	116.46	2170.97	18.64	7.22

3. Numerical model establishment and working condition classification

When the number of pile foundations is more than 4 during the construction period, the method of clamping piles to stabilize piles can well protect the constructed pile foundations from large deflection instability failure. Therefore, this paper studies the structure form of pile foundations based on four pile foundations at one pile foundation point, and the pile spacing is 7.0m, as shown in Figure 1. The pile foundation is made of φ120020mm steel pipe, the sandwich pile is made of φ32510mm or φ32520mm steel pipe, the pile foundation and the sandwich pile steel pipe are made of Q345 steel pipe material, and the yield strength is 345MPa.

In this paper, a large general finite element software ANSYS is used to analyze the stress situation of the pile group clamp pile. Considering that the phenomenon of stress concentration may occur on the welding surface of pile clamp and steel pipe pile or the contact surface of the hoop, Solid186 solid element with intermediate nodes is adopted as the element type, and the concentrated wave load is converted into unit width surface load applied to the pile. The position of the operation point is the same as the calculation result in Table 2.

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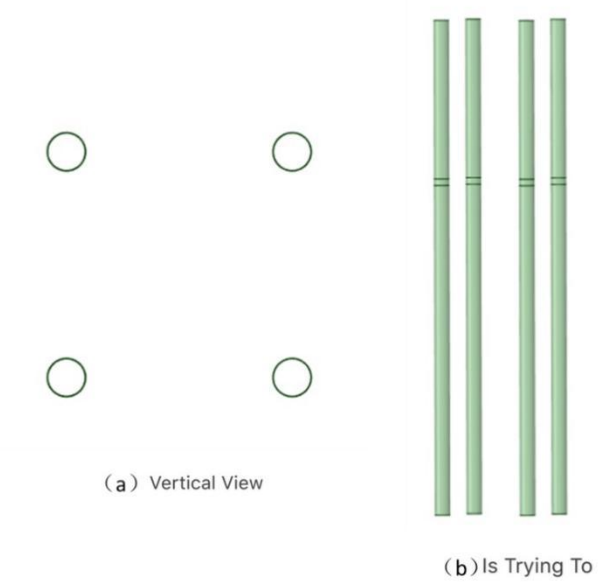

FIG. 1 Schematic diagram of pile foundation model

In this paper, according to the number of pile sandwich layers, the distance between pile sandwich layers and the form of pile sandwich, the optimal calculation conditions of pile sandwich stable structure are determined, as shown in Table 3, to further optimize the pile sandwich stable structure.

Table 3. Optimization list of pile clamping stability structure

Structure form	Clip pile layer	Spacing between piles (M)	Variable section hoops	Note
1	2	1.5	There is no	There is no
2	2	3	There is no	There is no
3	3	1.5	There is no	There is no
4	2	1.5	There is no	Using φ32520mm steel pipe
5	2	1.5	There are	There is no
6	2	1.5	There are	Add a horizontal diagonal support structure
7	2	1.5	There are	Add vertical diagonal brace structure

4. Numerical model results

The yield strength of the pile clamped structure is 345MPa, and the maximum horizontal displacement value stipulated in GB50017 steel structure design code [4] is H /150=254 (h is the distance from the embedded point to the pile top), which is used as the evaluation index of pile stability effect of the above different pile clamped structure forms. Through these two indexes, the structural forms are analyzed.

Structure form 1: the upper and lower layers of sandwiched piles are welded between the pile body, the pile spacing is 1.5m, and the sandwiched piles are made of φ32510mm steel pipe. FIG. 2 shows that the maximum horizontal displacement of pile top in structure form 1 is 308mm, larger

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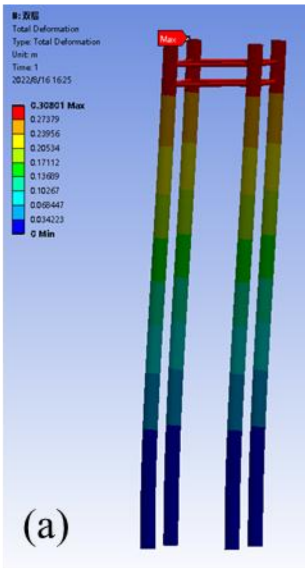
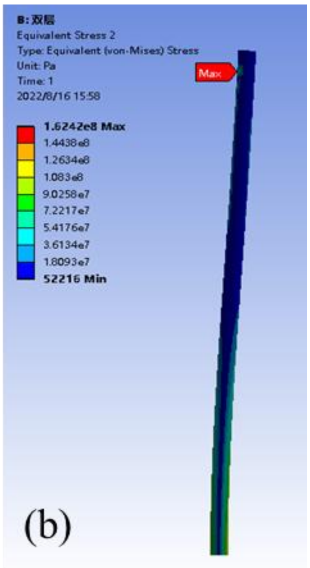
than 254mm, which does not meet the requirements. The maximum stress of the pile body is 162MPa, and the maximum stress is in the connection area between the pile body and pile-clip steel pipe on the wave surface. The maximum stress near the embedded point (the bottom constraint part) is 132MPa, and the maximum stress of pile-clip steel pipe is 439MPa. The maximum value is in the connection area between the pile body on the wave surface and the pile-clip steel pipe and is greater than the yield strength of the pile-clip steel pipe.





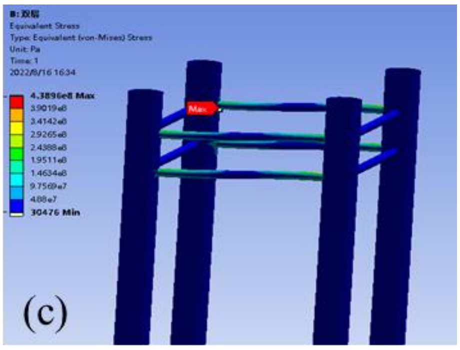
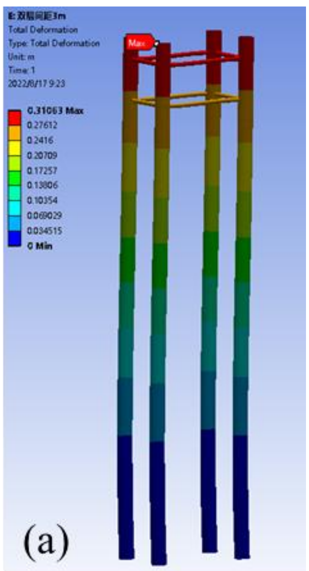
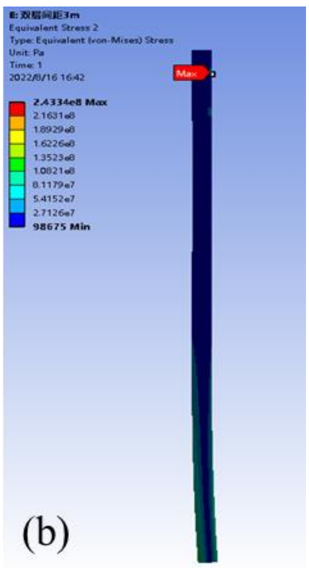


FIG. 2 Displacement and stress cloud diagram of structural form 1 (A: pile displacement; B: pile stress; C: pile clamping structure stress)

Structure form 2: the upper and lower layers of sandwiched piles are welded between the pile body, the pile spacing is 3m, and the sandwiched piles are made of φ32510mm steel pipe. FIG. 3 shows that the maximum horizontal displacement of pile top in structure type 2 is 311mm, larger than 254mm, which does not meet the requirements. The maximum stress of the pile body is 243MPa, and the maximum stress is in the connection area between the pile body and pile-clip steel pipe on the wave surface. The maximum stress near the embedded point (the bottom constraint part) is 136MPa, and the maximum stress of pile-clip steel pipe is 395MPa. Greater than the yield strength of pile sandwich steel pipe. By comparing the numerical simulation results of structure form 1, it is found that increasing the pile sandwich layer spacing will increase the pile stress and reduce the pile sandwich pipe stress, and the maximum horizontal displacement of the pile top will not change much.





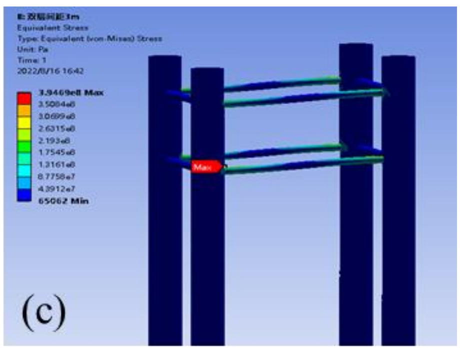


FIG. 3 Displacement and stress cloud diagram of structural form 2 (A: pile displacement; B: pile stress; C: pile clamping structure stress)

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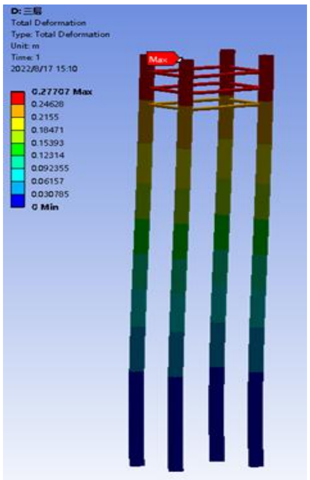
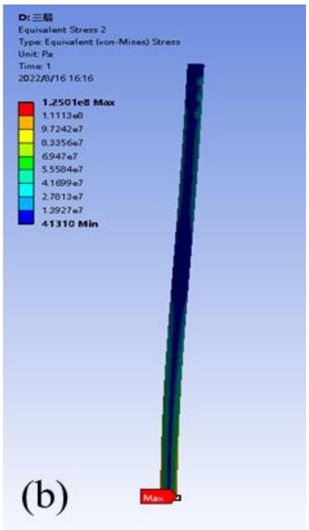
Structure form 3 is the upper, middle, and lower three layers of sandwiched piles welded between the pile body, pile spacing is 1.5m, sandwiched piles using Φ32510mm steel pipe. Figure 4 shows that the maximum horizontal displacement of pile top in structure form 3 is 277mm, larger than 254mm, which does not meet the requirements. The maximum stress of the pile body is 125MPa, and the maximum stress is located near the embedment point (the bottom constraint position). The maximum stress of pile sandwich steel tube is 331MPa, and the maximum stress is in the connection area between pile body on the wave surface and the lowest layer of pile sandwich steel tube. It is less than the yield strength of pile sandwich steel pipe, but the lowest pile sandwich is located near the water surface, which is not conducive to pile sandwich construction. By comparing the numerical simulation results of structure form 1, it is found that increasing the number of the pile sandwich layers will reduce the stress of the pile body, reduce the stress of pile sandwich steel pipe, and reduce the maximum horizontal displacement of pile top.





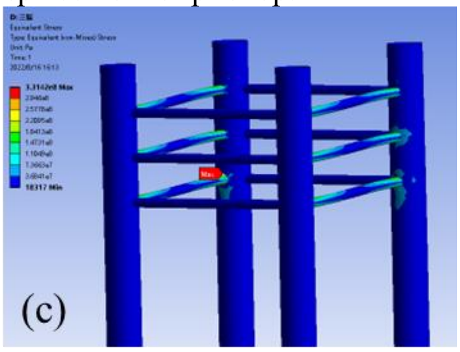


FIG. 4 Displacement and stress cloud diagram of structural form 3 (A: pile displacement; B: pile stress; C: pile clamping structure stress)

Structure form 4 is the upper and lower layers of pile sandwich welded between the pile body, pile spacing is 1.5m, pile sandwich steel pipe is thickened, and φ32520mm steel pipe is used. FIG. 5 shows that the maximum horizontal displacement of pile top in structure form 4 is 272mm, larger than 254mm, which does not meet the requirements. The maximum stress of the pile body is 217MPa, and the maximum stress is in the connection area between pile body and pile-clip steel pipe on the wave surface. The maximum stress near the embedded point (the bottom constraint part) is 113MPa, and the maximum stress of pile-clip steel pipe is 364MPa. The maximum value is in the connection area between the pile body on the wave surface and the pile-clip steel pipe and is greater than the yield strength of the pile-clip steel pipe. By comparing the numerical simulation results of structure form 1, it is found that increasing the thickness of pile-sandwiched steel pipe will increase the pile stress, reduce the stress of pile-sandwiched steel pipe, and reduce the maximum horizontal displacement of pile top.

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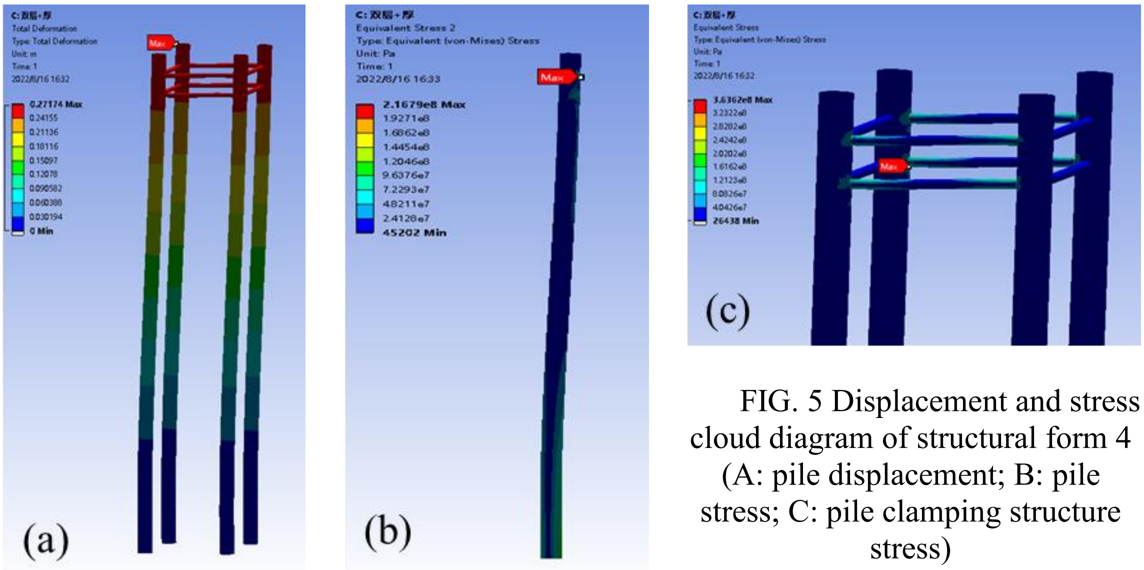

FIG. 5 Displacement and stress cloud diagram of structural form 4 (A: pile displacement; B: pile stress; C: pile clamping structure stress)

Structure form 5 is the upper and lower layers of pile clamping. The pile clamping steel pipe is connected between the pile body through the pile body holding hoop and the variable cross-section holding a hoop. The pile spacing is 1.5m, and the pile clamping adopts ф32510mm steel pipe. FIG. 6 shows that the maximum horizontal displacement of the pile top in structural form 5 is 302mm, larger than 254mm, which does not meet the requirements. The maximum stress of the pile body is 160MPa, and the maximum stress is in the connection area between the pile body hoop and pile clamp steel pipe hoop on the wave-facing surface. The maximum stress near the embedded point (the bottom constraint part) is 130MPa, and the maximum stress of the pile clamp steel pipe is 252MPa. The maximum value is in the connection area between the pile body hoop and the pile clamp steel pipe hoop on the wave surface and is smaller than the yield strength of the pile clamp steel pipe. By comparing the numerical simulation results of structure form 1, it is found that the stress of pile body can be reduced by adding a hoop in the connection area between pile body and pile-clip steel pipe, and the stress of pile-clip steel pipe can be significantly reduced, but the maximum horizontal displacement of pile top has little change.

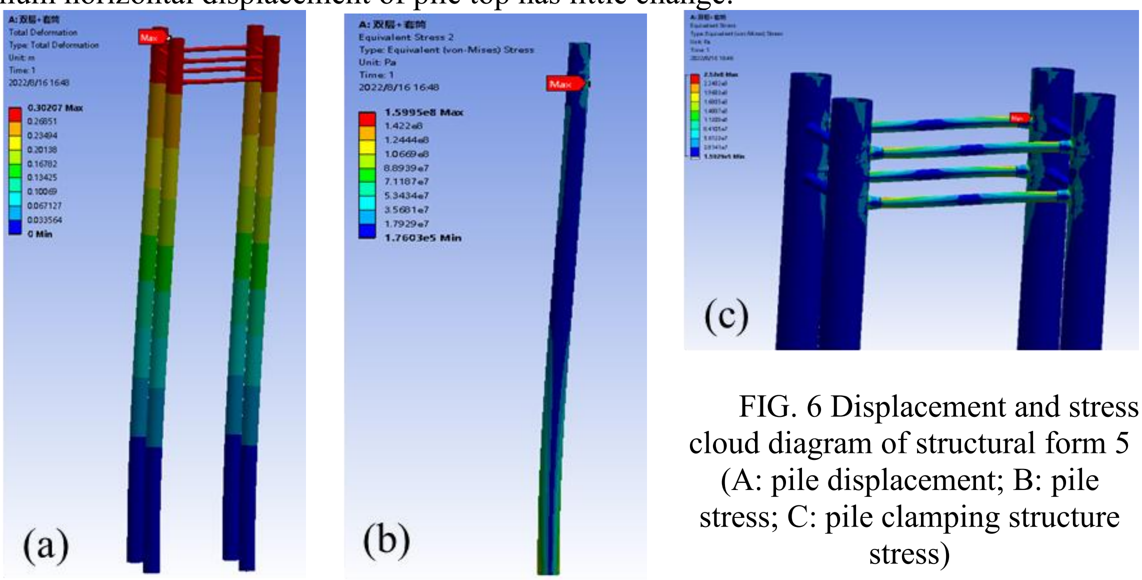

FIG. 6 Displacement and stress cloud diagram of structural form 5 (A: pile displacement; B: pile stress; C: pile clamping structure stress)

5. Structure form 6

Structure form 6 is the upper and lower layers of pile clamping. The pile clamping steel pipe is connected between the pile body through the pile body holding hoop and the variable cross-section holding hoop, and the horizontal diagonal support structure is added. The pile spacing is 1.5m, and

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the pile clamping adopts Φ 32510mm steel pipe. FIG. 7 shows that the maximum horizontal displacement of the pile top in structural form 6 is 267mm, larger than 254mm, which does not meet the requirements. The maximum stress of the pile body is 133MPa, and the maximum stress is in the connection area between the pile body hoop and the horizontal diagonal steel pipe hoop on the wave-facing surface. The maximum stress near the embedded point (the bottom constraint part) is 123MPa, and the maximum stress of pile sandwiched steel pipe is 308MPa. The maximum value is in the connection area between the pile body hoop on the wave-facing surface and the horizontal diagonal steel pipe hoop, which is smaller than the yield strength of the pile-clamped steel pipe. By comparing the numerical simulation results of structural form 5, it is found that adding horizontal inclined bracing to the connection area between pile body and pile-sandwiched steel pipe will reduce the stress of pile body, increase the stress of pile-sandwiched steel pipe, and reduce the maximum horizontal displacement of pile top.

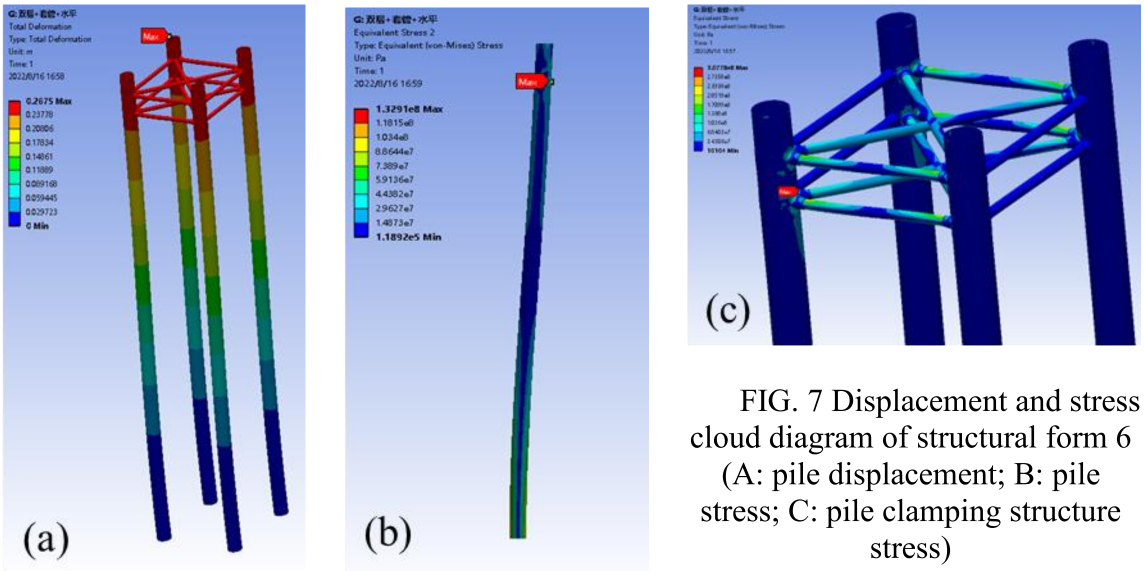

FIG. 7 Displacement and stress cloud diagram of structural form 6 (A: pile displacement; B: pile stress; C: pile clamping structure stress)

6. Structure form 7

Structure form 7 is the upper and lower layers of pile clamping. The pile clamping steel pipe is connected between the pile body through the pile body holding hoop and the variable cross-section holding hoop, and the vertical inclined support structure is added. The pile spacing is 1.5m, and the pile clamping adopts φ32510mm steel pipe. FIG. 8 shows that the maximum horizontal displacement of the pile top in structural form 7 is 192mm, less than 254mm, which meets the requirements. The maximum stress of the pile body is 111MPa, and the maximum stress is in the connection area between the pile body hoop and pile clamp steel pipe hoop on the wave-facing surface. The maximum stress near the embedded point (the bottom constraint part) is 99MPa, and the maximum stress of the pile clamp steel pipe is 254MPa. The maximum value is in the connection area between the pile sandwich steel pipe and the vertical inclined steel pipe on the wave surface, which is smaller than the yield strength of the pile sandwich steel pipe. By comparing the numerical simulation results of structural form 5, it is found that the pile stress can be reduced after the vertically inclined bracing is added to the connection area between the pile body and pile-sandwich steel pipe, and the stress of pile-sandwich steel pipe does not change much, which significantly reduces the maximum horizontal displacement of pile top.

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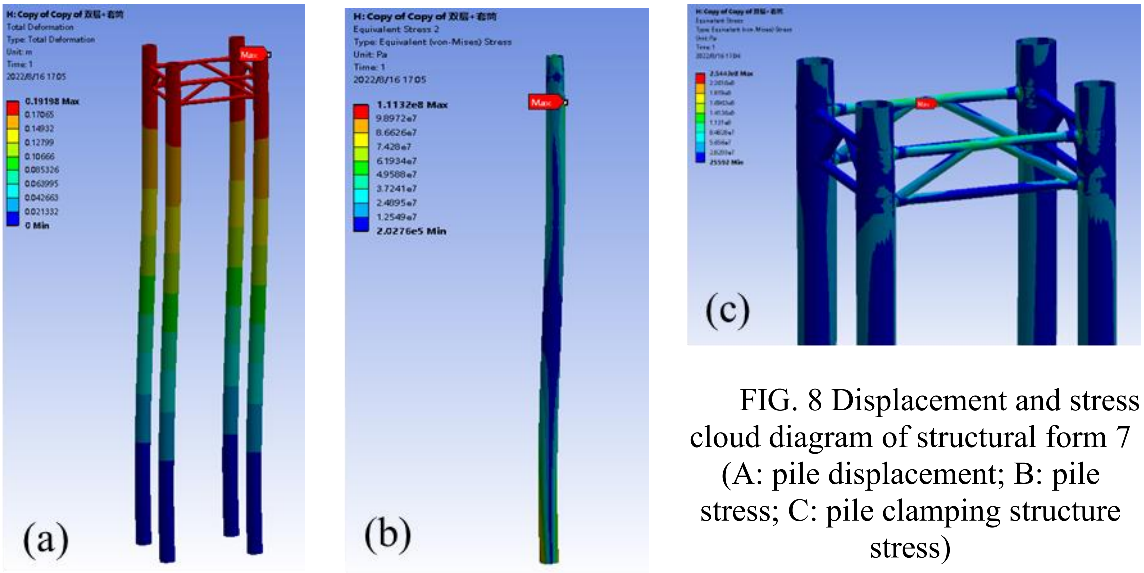

FIG. 8 Displacement and stress cloud diagram of structural form 7 (A: pile displacement; B: pile stress; C: pile clamping structure stress)

The pile displacement, maximum stress of pile body, maximum stress of steel pipe, and their distribution positions under various pile clamped structure forms are summarized as follows, as shown in Table 3. The maximum horizontal displacement of most pile tops is greater than 254mm, which does not meet the requirements. The maximum stress of pile-clamped steel tubes is generally greater than the yield strength without hoops.

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Table 3 Maximum stress value and location of pile clamping stable structure

Structure form	Maximum stress of pile (MPa)		Maximum stress of pile-sandwiched steel pipe (MPa)		Maximum stress at embedment point (MPa)	Maximum horizontal displacement of pile top (mm)
	The numerical	Location	The numerical	Location		
1	162	Connection area between pile body and pile clamp steel pipe on wave facing surface迎	439	Connection area between pile body and pile clamp steel pipe on wave facing surface	132	308
2	243	Connection area between pile body and pile clamp steel pipe on wave facing surface	395	Connection area between pile body and pile clamp steel pipe on wave facing surface	136	311
3	125	Region of embeddedness	331	Connection area between pile body and pile clamp steel pipe on wave facing surface	125	277
4	217	Connection area between pile body and pile clamp steel pipe on wave facing surface	364	Connection area between pile body and pile clamp steel pipe on wave facing surface	113	272
5	160	Connecting area between pile body hoop and pile clamp steel pipe hoop on wave facing surface	252	Connecting area between pile body hoop and pile clamp steel pipe hoop on wave facing surface	130	302
6	133	Connecting area between pile body hoop and pile clamp steel pipe hoop on wave facing surface	308	Connecting area between pile body hoop and pile clamp steel pipe hoop on wave facing surface	123	267
7	111	Connecting area between pile body hoop and pile clamp steel pipe hoop on wave facing surface	245	Connecting area between pile sandwich steel pipe and vertical diagonal steel pipe on wave facing surface	99	192

7. Conclusions

1) The pile sandwich structure adopts the direct welding method of the pile sandwich steel pipe, which is easy to causes the stress concentration at the welding point and is greater than the yield

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strength of the pile sandwich steel pipe; The increase of pile sandwich spacing, and pile sandwich steel tube thickness will increase the pile stress and reduce the pile sandwich steel tube stress, and the maximum horizontal displacement of pile top will not change much. Increasing the number of pile sandwich layers can reduce the stress on the pile body, the stress on the pile sandwich steel pipe, and the maximum horizontal displacement of the pile top. However, the lowest pile sandwich is located near the water surface, which is not conducive to pile sandwich construction.

2) In the structure of pile clamping, the pile clamping hoop and the combination of variable section clamping hoop are used instead of welding connection, which can reduce the stress on the pile body, significantly reduce the stress of pile clamping steel pipe, and solve the problem of stress concentration, but the maximum horizontal displacement of pile top has little change; When horizontal diagonal bracing is added to the connection area between the pile body and pile-clip steel pipe, the stress of pile body is reduced, the stress of pile-clip steel pipe is increased, and the maximum horizontal displacement of pile top is slightly reduced. When vertical diagonal bracing is added to the connection area between pile body and pile-clip steel pipe, the stress of the pile body will be reduced, and the stress of pile-clip steel pipe will not change much, the maximum horizontal displacement of the pile top will be significantly reduced.

3) The pile clamping structure adopts the combination connection of pile body hoop and variable section hoop, and the vertical diagonal brace is added to the connection area between pile body and pile clamping steel pipe, which can solve the stress concentration problem and improve the stability of pile foundation.

Ackonwledegment

The Estuary, Coast and Island Engineering Innovation Team Construction Project of Guangdong Laboratory of Southern Marine Science and Engineering (Zhuhai), No.311020009

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