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Mechanical properties of steel pipe pile in foundation engineering

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Mechanical properties of steel pipe pile in foundation engineering

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Abstract. With the construction of large bridges in the deep sea, people are paying more and more attention to stability of bridge piles. The deep sea-bridge could be affected by many factors, and the force mechanism is very complicated. In this paper, the Hong Kong Zhuhai Macao Bridge navigation hole steel composite pile is used as the prototype pier. We establish 1:7.33 scale model and the same proportion of RC pile by analysis software, and make a comparison under compression, bending and shear load. Analysis results shows that pipe can improve the mechanical properties of core concrete and reduce the displacement of structure. The seismic response time history analysis of two kinds of structure shows that steel composite pile has larger lateral stiffness, smaller lateral displacement and better seismic performance.

1.Introduction

Rapid economic development makes serious demand of the traffic near coastal and marine engineering, driving a growing number of cross sea bridge construction planning.Depth of cross sea-bridge is about 10m-40m, such as the East China Sea Bridge, Hangzhou Bay Bridge, Hongkong Zhuhai Macao Bridge.

Marine environment of deep bridge shows more severe and complicated comparing to inland bridge including sea erosion, wave force, wind load. People often demand higher structural safety of bridge, so it is necessary to study the pier foundation of deep-water bridge.

Conventional open caisson foundation in marine environment has little construction experience, long timescale and large amount of slag which is not conducive to environmental protection. Large diameter precast reinforced concrete pipe pile has low vertical bearing capacity but large deadweight, which leads to poor seismic performance. Bored pile, several advantages like adaptable and mature in construction technology is the most widely used. However, the steel casing is not involved in the structural stress, which causes the material can not be fully utilized. If some measures are taken to make the steel cylinder tightly integrate with the concrete, the steel canister can be involved in the structural force and the structural performance can be improved.

2.Research status of steel composite pile

Steel composite pile is composite pile interaction of thin-walled steel tube wrapped concrete core, which plays a high compressive strength and a good ductility of steel reinforcement. Therefore, the steel pipe composite pile has good mechanical characteristics and economy.

Many scholars of the United States and the Soviet Union, Britain, Japan, New Zealand, Australia and other places give experimental research and theoretical analysis since 1920s, which mainly include:(1) the study on complex stress of bending shear includes the mechanical properties of the members under axial load, eccentric compression, pure bending and bending, shear and torsion, mechanical performance and complex stress state of the member; Mechanical properties of concrete filled steel tubular joints and concrete filled steel tubular frames; Bond friction between steel pipe and concrete; The concrete filled steel tubular members combined with the new structural members, or the concrete filled steel tube members can be applied to other structural forms (such as trusses) to form a new composite structure system.(2) nonlinear analysis of the whole process of seismic response.

Hong Kong Zhuhai Macao bridge,connecting the Hong Kong, Zhuhai City and Macao, is of vital importance to the economic zone of the Zhuhai Delta and to strengthening the link between the mainland and Hong Kong and Macao. After the comparison of selected, the deep sea foundation of the above sea bridge is made of large diameter steel pipe composite pile, and the steel pipe and reinforced concrete together form the main body of the pile structure.

Southwest Jiao Tong University professor Ma Jianlin and his team researches diameter steel pipe composite pile test pilot project, comparison of steel tube reinforced concrete composite and steel pipe pile's performance, the experimental results show that: The steel tube can share load, improving the deformation capacity, effectively reducing the maximum lateral displacement, the maximum longitudinal strain and the maximum longitudinal compressive strain of core concrete.

Table1. Results of compression bending shear test

Number	Final loading value press / bend / shear (kN/kN·m/kN)	Maximum lateral displacement /mm	Max longitudinal direction of core concrete strain / με
No steel tube specimen	402/67/53	8.52	-700
Steel composite pile	402/67/53	5.06	-441

3.Finite element model analysis

Topic takes the large-diameter steel pipe composite pile of the Hong Kong Zhuhai Macao Bridge as the prototype, and uses the finite element software to study the scale model: (1) The work performance, bearing capacity and deformation characteristics under the combined action of compression, bending and shear loads investigating to investigate the synergistic performance and reliability of the composite pipe piles. (2) The seismic response analysis of steel pipe composite pile, and the dynamic performance and seismic response of the model are tested. The effect of steel pipe on the behavior and seismic behavior of RC pile piers is studied.

3.1Element model

The steel tube is made of Q345C steel with elastic modulus Es=2.06e5MPa, and the isotropic elastoplastic model is used. The four node reduced integral shell element (S4R) and 9 integral points in the thickness direction are used to improve the computational accuracy. The length of steel bar is 2500mm, and the modulus of elasticity is 2.0e5MPa with two grade steel bar (HRB335), and the Truss unit simulation (T3D2) is adopted.

The concrete solid element (C3D8R), the elastic modulus Es=3.35e4MPa, Poisson's ratio is 0.2.The concrete plastic damage model is used to simulate, because the core concrete changes one-way force into three to force due to pipe package. Behave as: softening of initial hardening under compression; the material softens under tension; initial compressive strength is greater than (or equal to) ten times the initial tensile strength; under the compression and tension conditions, the elastic stiffness degradation is different. The embedded contact between the core concrete and the reinforcing steel is adopted, and the tie contact between the steel pipe and the core concrete is adopted.

3.2Pier model

Test pier high 2500mm, round section, section radius d =300mm, steel pipe wall thickness t =3mm.The longitudinal tension ring is arranged and the bottom of the model is consolidated.

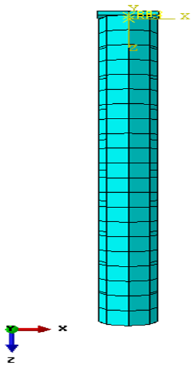


Figure 1. Model after mesh generation

3.3Static analysis

The load type combines action of compression, bending and shear loads. Design axial compression is 402kN, shear is 52kN, bending moment is 67kN·m.

Table 2. Design load of steel pipe composite pile in construction site

Condition	Field design axial force (kN)	Bending moment (kN·m)	Shear force (kN)
N_{max}	40231	9452	1149
N_{min}	602	9452	1149
M_{max}	37888	12570	1462
V_{max}	3628	12570	1462

The shear direction is X, the bending moment direction is Y and the axial direction is Z. Bending moment and transverse shear force produce the opposite direction of the bending moment, so moment of the pile body is variable, maximum stress distribution is found at the top either end of the pile, and the reverse bending point is in the pile and the force is smaller. The load size is the same as that applied model test, and is increased to 1.7 times of working load.

3.4Seismic response analysis

Modal analysis of specimen. The thirteen order frequencies of composite specimens without steel tube and composite pipe are listed. Among them, the first order frequency of the steel tube is 19.563Hz, and the first order frequency of the composite pipe pile is 24.502Hz, which is about 25.25% higher than the first-order frequency of the steel tube without the steel member.

Time history analysis of specimens. EL-Centro Wave (LH-E12140) is adopted, the acceleration is input by rare earthquake, and the maximum peak acceleration is amax=0.21g.

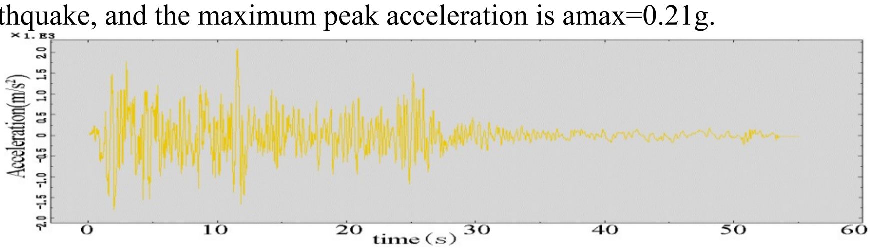
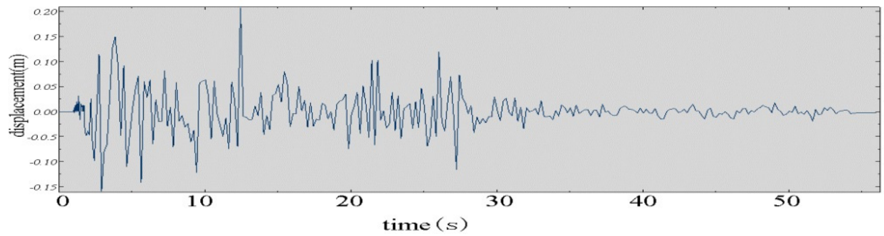
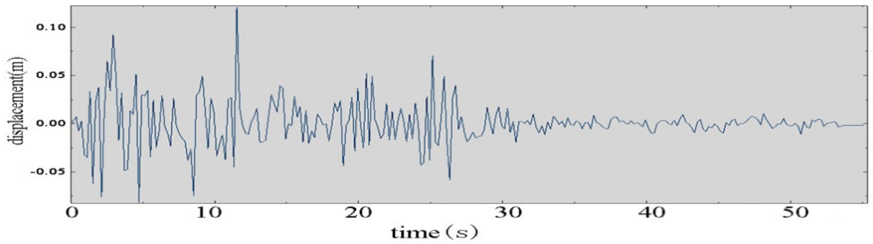


Figure 2. *EL-Centro* wave acceleration time history



（a）No steel tube specimen



（b）Steel pipe composite pile

Figure 3. Displacement time curve

It is found that the maximum displacement occurs at the maximum acceleration of seismic wave. Maximum lateral displacement of reinforced concrete is 0.2077mm, steel pipe composite pile is 0.1216mm. The maximum stress of the specimens is respectively, and the maximum stress of the reinforced concrete is 2.756MPa; The maximum stress of steel pipe composite pile is 1.748MPa.It is found that the lateral displacement decreases by about 41.45% and the stress within the structure decreases by 36.57% when the steel pipe composite pile is under the action of earthquake. Therefore, the steel pipe composite pile is more conducive to the stability of the foundation under earthquake

4.Conclusions

(1) The numerical calculation model is established by ABAQUS. The conclusion in the deformation and stress characteristics are consistent with the experimental results, can be calculated and evaluated by the finite element method of composite steel pipe pile work performance.

(2) Under the complex stress state, the steel tube can improve the deformation characteristics and the compressive performance of reinforced concrete piles obviously. Through the structural stress, the steel tube reduces the stress of concrete and steel bars, and obviously reduces the displacement of the reinforced concrete structure.

(3) The seismic performance of the pier model is good when the input of the bridge is subjected to earthquake; The steel pipe improves the cross sectional stiffness of the pier, improves the natural frequency of the reinforced concrete pile, and reduces the stress and displacement of the foundation under the action of earthquake.

Acknowledgments

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