Impact on the Seismic Performance of Steel Pipe Sheet Pile Foundation by the Joint Mechanical Properties

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Summary

With its strong stiffness, large bearing capacity and trustworthy construction, steel pipe sheet pile structures are widely used as bridge foundations, especially for large scale bridges in cases where the bridge spans a river or a bay where the surface ground is very weak and the water is very deep. A typical bridge pier steel pipe sheet pile foundation is being discussed. The vibration behaviour and seismic performance of the bridge pier and the SPSP foundation were investigated by nonlinear dynamic response analysis by taking into account the effects of the mechanical properties of the joints. As a result, the joint mechanical properties affect the seismic performance of the SPSP structure and the pier that it supports sensitively.

Keywords: steel pipe sheet pile foundation, joint mechanical property, bridge pier, nonlinear dynamic analysis.

1. Introduction

Steel pipe sheet pile (SPSP) is composed of a steel pipe and couplings welded on the side/sides of the steel pipe. The interlocking of the coupling of the steel pipe sheet pile links SPSP to construct SPSP foundation and the interlocked couplings form the joints of SPSP structure. Comparing with the steel pipes, the joints of SPSP structures are flexible in stiffness and weak in strength. The mechanical properties of the joints affect the vibration behaviour and seismic performance of the SPSP structure. When the joints are strong and stiff enough, the SPSP structure might perform as a caisson foundation. While the joints are too weak, the SPSP structure might perform as a pile foundation. P-P type joint is a typical example of SPSP joints, which are formed by steel pipes of 165,2 mm in diameter and 11 mm in thickness and, are often employed in SPSP foundation. The design stiffness and shear strength of P-P type joint are $1,2\times10^6$ kN/m^2 and 200 kN/m, respectively. In order to improve the stiffness and strength of the joints, several kinds of joints, such as P-T type, L-T type, H-H type etc. have been developed recently. It is clear that the bearing capacity of the SPSP structure is improved with the increase of the stiffness and the strength of the joint. Nevertheless, the effects of the joint mechanical properties on the seismic performance of the structure that is supported by the SPSP foundation has not yet be clarified.

2. Prototype bridge pier-SPSP foundation-soil condition

A typical steel pipe sheet pile supported highway bridge pier was considered in this work. The SPSP foundation consisted of 28 steel pipes forming the outside wall of a diameter of 11,145 m. The steel pipes with a diameter of 1000 mm were driven to a depth of 20,5 m below the pile cap that had a thickness of 4,0 m and a diameter of 12,145 m. The joint pipe had a diameter of 165,2 mm. The material of the pipes was SKY400. The pier was constructed of reinforced concrete with a typical T shape. The column was 11,0 m high with an oval section of 2,5×7,5 m. The strengths of the concrete and reinforcement were 21 MPa and 295 MPa (yielding point), respectively. The bridge pier foundation was located at a relatively soft ground. The surface ground comprised 4 layers. The first layer was a soft clay layer with an average Standard Penetration Test (SPT) value of 2. The second layer was also a clay layer with an average SPT value of 3, an adhesion of 30 kN/m^2 and a

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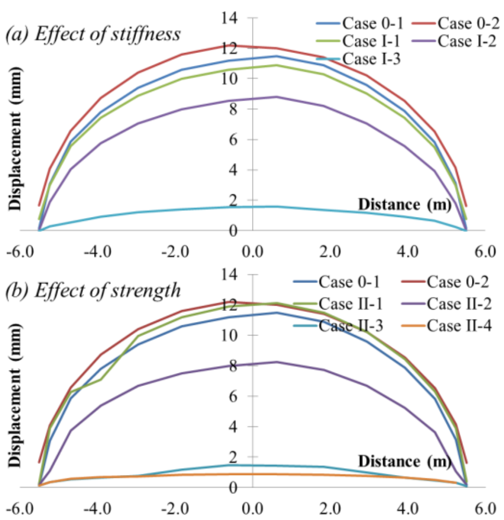


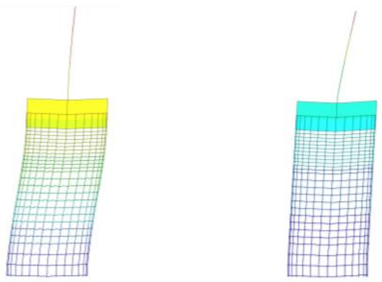
Fig. 1: Shear deformation of the joints

depth of 21.0 m. A sand layer with an average SPT of 20 and an angle of inner friction of 32 degrees was followed. It had a depth of 3,0 m. The base ground for seismic design was a gravel layer where the average SPT value was 50 and inner friction angle was 40 degrees. The characteristic value of the surface ground calculated was 0,77 s.

3. Analytical model, input ground motion and analytical method

The prototype bridge pier, SPSP structure and the surrounding soil were modelled as a 2D model. The pier column and steel pipes were modelled as beam element. The soil was modelled as plane strain element. The SPSP joints and the connector between the structure and soil were modelled as springs. The nonlinear properties of the RC column, soil, joints and connectors were represented by the Takada-model, the modified Ramberg-Osgood model and elasto-plastic model, respectively.

Acceleration time history, named JMA KOB wave obtained from 1995 Hyogokennabu Earthquake was used as the input ground motion. The time history direct integral calculus method was employed in the nonlinear dynamic analysis.



(a) Case 0-1 *(b) Case 0-3*
Fig. 2: Horizontal displacement of structure

4. Analysis cases and calculation results

The shear stiffness and the shear bearing capacity of the joint were adopted as the parameters to verify the influence by the joint mechanical properties on vibration behaviour and seismic performance of the bridge pier and SPSP foundation. Table 1 shows the analytical cases.

With the increase of the joint stiffness and bearing capacity, the shear deformation reduced (Figure 1) and the deformation mode changed as well (Figure 2). With the joint strengthening, the SPSP structure performed as a rigid body, little energy could be dissipated from the inner of the SPSP structure, so the response of the structure became bigger except the steel pipe normal stress.

5. Conclusion

The main findings in this work were as follows: 1) the increase of the joint stiffness shortened the natural period of the structure; 2) the increase of the joint stiffness and bearing capacity increased the horizontal displacement and the residual displacement of the superstructure, the rotational angle of the plastic hinge and the SPSP foundation, the shear force of the column and the uplift amount of the SPSP structure bottom; and 3) the increase of the joint stiffness and bearing capacity reduced the normal stress of the steel pipe. The SPSP joint functions as a damper, whose mechanical properties affect the vibration behaviour and the seismic performance of the SPSP foundation and the structure supported.

Table 1: Analysis cases unit: stiffness kN/m^2; resistance kN/m

Item	Case 0-1	Case 0-2	Case 0-3	Case I-1	Case I-2	Case I-3	CaseII-1	CaseII-2	CaseII-3	CaseII-4
Stiffness	$1{,}2\times10^6$	0	Rigid	$1{,}2\times10^5$	$1{,}2\times10^7$	Rigid	$1{,}2\times10^6$	$1{,}2\times10^6$	$1{,}2\times10^6$	$1{,}2\times10^6$
Resistance	200	0	∞	200	200	200	100	400	1000	∞