Application of H-joint steel pipe sheet piles in bridge foundations

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ABSTRACT: Parametric study is carried out to show that the diameter of a bridge pier foundation can be reduced when H-joint steel pipe sheet piles (SPSP) are used as opposed to using P-P joints. Mechanical and deformation behavior of a circular 8.85 m diameter H-joint SPSP is compared with a 10.352 m diameter P-P joint SPSP foundation under lateral loading. Their lateral capacities are equal; P-P joint foundation deforms more.

1. INTRODUCTION

H-joint is developed from a simple idea in which two steel pipe piles are connected by H-steel section welded on them as shown in Fig. 1, Kimura et al. (2003a, b). The H-steel section is what is referred to as the H-joint and will still have to alternate in series with the traditional joints pending development of another suitable joint referred to as H-H joint, Kimura et al. (2003a) and Inazumi et al. (2004). H-joint SPSP have high bending rigidity because H-steel section is welded rigidly and continuously against two steel pipes. Kimura et al. (2003a) have shown by centrifugal modeling on rectangular H-joint SPSP foundations that H-joint SPSP exhibit higher lateral capacity than the SPSP with traditional joints. In this paper, it will be shown that smaller foundation dimensions can be designed which results in saving of steel material used. Methods of estimating soil spring parameters are summarily given.

2. FOUNDATIONS AND PARAMETERS

P-P joint and H-joint foundations will be designated Case-1 and Case-2 respectively; their properties are shown in Table 1. Total area moment of inertia I^*_g and total second moment of inertia of piles in the foundations in the global X and Y axes, ΔI_g, are respectively given by equation (1) and (2):

$$I_g^* = A_p . r_o{}^2 . \frac{n_p}{2} \quad (1) \qquad \Delta I_g = \frac{n_p}{2}\left(I_{xp} + I_{yp}\right) \quad (2)$$

Where: A_p = sum of cross section area of 1 pile and it couplings; n_p = total number of SPSP piles in the foundation; I_{xp}, I_{yp} = 2nd moment of inertia of individual piles in their local x and y coordinates respectively, as shown in Fig. 2. Soil profile, N-values and elastic modulus of the respective soil layers is shown in Fig. 3. Triaxial tests and borehole pressure-meters were used to estimate elastic modulus (E_o) of soil; their results were averaged to obtain E values for the respective layers.

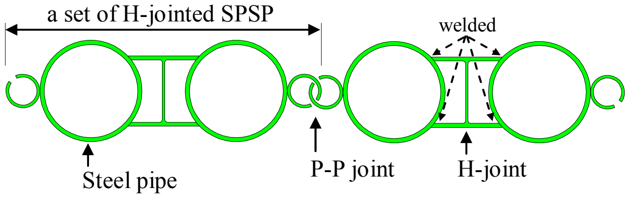
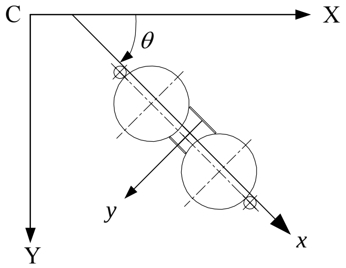


Figure 1. H-joint SPSP alternating with P-P joints



$$\Delta I_g = \sum \left(m_0^2 I_{xp} + l_o^2 I_{yp}\right) i$$

$$l_o = \frac{\partial X}{\partial x} = \cos\theta$$

$$m_o = \frac{\partial Y}{\partial x} = \sin\theta$$

Figure 2. Conversion of pile coordinates to global coordinates of foundation

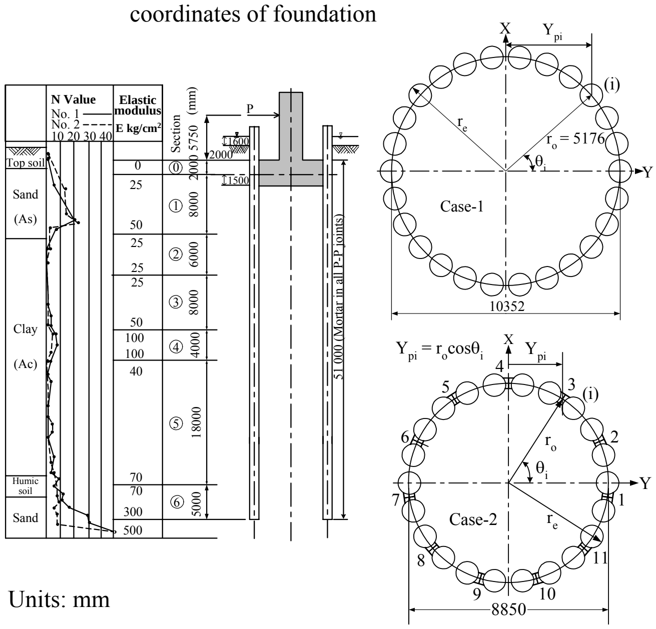


Figure 3. Soil profile, N-values and elastic modulus of the ground and circular H-joint bridge pier foundation

Young's modulus, E_o, of the bearing soil layer was $5\mathrm{x}10^4$ kN/m^2. It is assumed that coefficient of subgrade reaction in the front side and backsides of foundations are equal. Soil and P-P joints are treated as springs while piles are treated as beams. H-jointed SPSP is treated as a unit beam whose bending rigidity (EI) is the combined

Table 1. Properties of H-joint and P-P joint bridge pier SPSP foundations: Units: mm

	Foundation size	Piles	No. of pipe piles	P-P joint size	H-joint size	No. of P-P joints	Flexural rigidity	Sectinal area of steel
Case-1	ϕ10352	ϕ1000xt12	26	ϕ165.2xt11		26	$3.89\mathrm{x}10^9$ kN/m^2	1.2954 m^2
Case-2	ϕ8850	ϕ1000xt12	11	ϕ165.2xt11	H488x300x11x18	11	$2.47\mathrm{x}10^9$ kN/m^2	1.1583 m^2

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rigidity of the welded components of the H-joint piles. The shear modulus (G: kN/m^2) and bearing capacity (q: kN/m) of the P-P joint are those for a standard P-P joint pipe of ϕ165.2 mm, PWRI (1977). Soil springs on the sides of the foundation are estimated using E_o values for soil in Fig. 3 by the following relations:

$$k_{HO} = \frac{1}{30}\alpha E_o \quad (4) \qquad k_H = 12.8 k_{HO} B_H^{\frac{-3}{4}} \quad (5)$$

$$b_e = \pi r_e \quad (6) \qquad k_Z = 0.2 k_H \quad (7)$$

$$k_V = \int_0^{2\pi} k_Z r_e d\theta = 2\pi k_Z r_e \quad (8)$$

$$k_M = k_Z r_e^3 \int_0^{2\pi} \cos^2\theta d\theta = \pi k_Z r_e^3 \quad (9)$$

Where; k_{HO} = lateral subgrade reaction (kN/m^3) as obtained from a load test on a 0.3m diameter pile; k_H = coefficient of lateral subgrade reaction (kN/m^3); E_o = the elastic modulus for respective soil layers, (kN/m^2);. α = coefficient of earthquake resistance, assigned according to the method used to estimate E_o, α = 4 when it is from triaxial test; r_e = outer radius of foundation; k_z = horizontal pile-soil shear on the sides of the foundations; k_V = vertical foundation-soil shear spring (kN/m^2); k_M = rotation spring of foundation, (kN.m/m); θ = angle between Y-Y axes to the centre of pile i, Fig. 3. At the foundation bottom, coefficient of vertical subgrade reaction, $K_{V,}$ (kN/m^3) is estimated as follows:

$$K_{Vo} = \frac{1}{30}\alpha Eo \quad (10) \qquad K_V = 12.8 K_{Vo} B_V^{-\frac{3}{4}} \quad (11)$$

Total bottom vertical spring, K_Z, (kN/m), rotation springs, K_M (kNm) are given by:

$K_Z = n_p K_V A_v$ (12) $K_M = n_p K_V I$ (13) $K_S = 1/3 K_Z$ (14)

Where, K_{Vo} = vertical subgrade reaction obtained from plate bearing test using a rigid plate of diameter 0.3 m on a single pile in the foundation (kN/m^3). B_V = length of foundation reacting load, estimated in accordance with PWRI, (1977); K_S = total horizontal shear spring between foundation base and bearing layer (kN/m).

3. RESULTS AND DISCUSSION

Case-1 and Case-2 a lateral capacity of 4.8 MN and 4.4 MN respectively at foundation head displacement of 1 % D, where D is diameter of the piles making the foundation; their capacities were 30.3 MN and 33.7 MN respectively at 10 %D. In Fig. 4, it can be concluded that their capacities are equal despite difference in their sizes. Weak nature of Case-1 may be attributed to relative shear movements that occur at the P-P joints when the structure is loaded. Case-2 has high bearing capacity because it contains fewer P-P joints and more significantly is the fact that the H-joint is rigidly welded continuously along the pile length. Rotations and displacements along the lengths of the foundations are checked to ensure that reduction in foundation size does not compromise other SPSP design requirements. Rotations below the bottom of the footing after head displacements of 1 % D are shown in Fig. 5, the footing is 3.5 m; displacements along the foundation length are also shown in Fig 6. It is

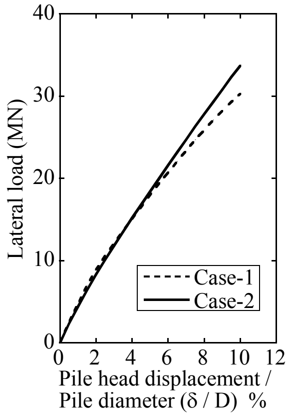

Figure 4. P-δ relations

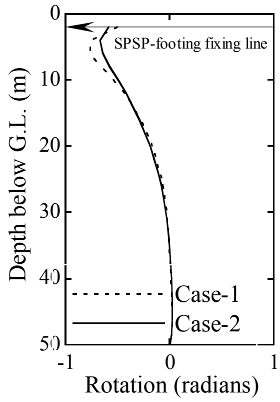

Figure 5. Foundation rotation

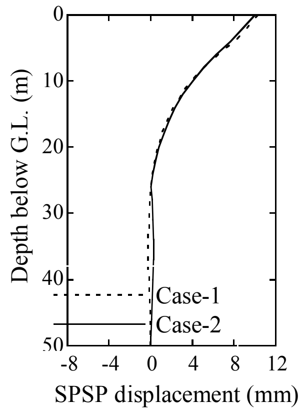

Figure 6. Displacements along foundations lengths

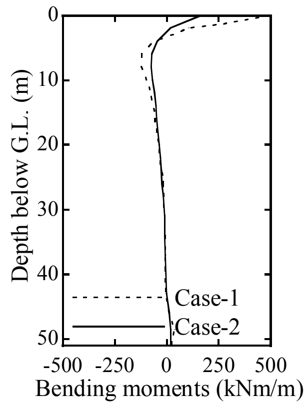

Figure 7. Moment distribution along most stressed piles

observed that rotations and displacements along the foundations lengths are nearly equal. Bending moments of the most stressed piles in the two foundations are compared at 1 % D in Fig. 7, Case-1 and Case-2 had maximum bending moments of 494 kNm/m and 166 kNm/m respectively; clearly Case-1 piles experience high bending moments compared to piles in Case-2 despite its large size. In summary, H-joints affords reduction in SPSP foundation sizes; if need for a strong structure, such as in offshore waste disposal landfills and retaining walls, overrides need for structures with small sizes, the high strength of H-joint SPSP enables smaller diameter pipe piles to be adopted.

4. CONCLUSIONS

High lateral bearing capacity of H-joint SPSPs enables designs of smaller foundations which not only saves steel material but also affords constructions where space is a limiting factor.

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