Study on Larsen Steel Sheet Pile as the Deep Base Pit Support

Yang Yang1*, Wanfeng Liu 1, Aiping Hu 1, Zhaqian Yang1, Dilun Shen1
1 School of Civil Engineering, Longdong University, Qingyang, Gansu, 745000, China
*Corresponding author’s e-mail: yy2513655687@163.com

Abstract. The steel sheet pile, a material featuring good quality, easy construction, high durability and strong interchangeability, has few restrictions for projects, and is therefore widely used as the deep base pit support. However, the complexity and specificity of base pit supporting demands an appropriate method to install it, which is the prerequisite of project safety. To ensure the safety, the paper studied the deformation by force and stability of Larsen steel sheet pile. It found that both indicators meet the requirements. Larsen steel sheet pile can provide effective protection for the base pit with decent performance. Therefore, Larsen steel sheet pile should be advocated in projects alike.

1. Introduction

As a material featuring strength, light weight and waterproof, the steel sheet pile allows easier construction and shorter project duration with greater durability. It is more environment-friendly, with fewer restrictions from the weather. It saves time for construction, and reduces the needs for soil and concrete, thus protecting land resources and lowering thresholds of construction. Therefore, it is widely used in deep base pit as a support[1,2]. Liu Yangping [3] analyzed the application of steel sheet pile in base pit supporting engineering adjacent to the existing line through calculation of steel sheet pile's stress, support and buried depth. Yang Wei et al. [4] took the deep base pit of Zhaojia Bridge on Shanghai-Kunming passenger railway line as an example and briefly introduced the design and construction method of the steel sheet pile support system during deep base pit excavation. Based on finite element software ABAQUS, Li Qionglin et al. [5] simulated and analyzed the process of deep trench excavation and steel sheet pile supporting engineering adjacent to soft soil subgrade. They also studied the influence of internal support spacing, steel sheet pile burial depth and deep trench excavation location on the deformation of subgrade and the stress of steel sheet pile. Zhao Xiushao et al. [6] took the steel sheet pile support of a deep base pit of an underwater island under a bridge as an example to analyze and study the stress deformation and safety features of the base pit. Liu Sinsheng[7]took the double-row steel sheet pile cofferdam located in a water gate of restricted coverage as an example to study the deformation and safety features of the base pit. Wang Aixi et al. [8] took a steel sheet pile cofferdam in Hotel Lisboa Macau as an example and introduced the construction technology and key construction processes of Larsen steel sheet pile in deep base pit. Based on seepage consolidation coupling, Cao Liqiao [9]used finite element software ABAQUS to analyze the uplift deformation at the bottom of deep base pit and its influencing factors. The paper studied the deformation and stability of Larsen steel sheet pile through theoretical analysis and numerical analysis of finite element software, providing references for projects of the same field in the design of the support system.
2. Project Introduction

2.1. General information on the project
A continuous beam bridge, with a span of (45+70+45) meters, crosses the main canal. The 2# main bridge pier is located on the north dyke of the main canal. The top surface of the secondary cushion cap is basically leveled with the top surface of the secondary platform of the dyke. The pier cap is designed as a rectangular cap with a plane dimension of 14.6m long, 10.6m wide and 3m high. Based on the needs of site construction, the length and width of the base pit of the cushion cap were set at 17.6m and 13.6m respectively, and the depth between the base pit of the cushion cap and the existing drilling platform is 4.8m.

2.2. Hydrogeological condition

| Layer number | Name of soil   | Layer thickness (m) | Weight (kN/m³) | Floating weight (kN/m³) | Cohesion (kPa) | Internal friction angle(°) | Pile friction (kPa) |
|--------------|----------------|---------------------|----------------|-------------------------|----------------|--------------------------|------------------|
| 1            | Mucky soil     | 2.70                | 18.0           | 8.0                     | 18.75          | 10.18                    | 16.0             |
| 2            | Silty Soil     | 2.00                | 18.9           | 8.9                     | 3.00           | 30.00                    | 22.0             |
| 3            | Fine sand      | 1.00                | 22.0           | 9.7                     | 3.00           | 15.00                    | 25.0             |
| 4            | Coarse sand    | 5.00                | 25.0           | 8.0                     | 3.00           | 15.00                    | 25.0             |
| 5            | Gravel sand    | 10.00               | 22.0           | 8.0                     | ---            | ---                      | 25.0             |
| 6            | Coarse sand    | 5.00                | 19.0           | 8.0                     | ---            | ---                      | 25.0             |

In winter, the region is influenced by dry and cold polar continental air mass, with very low temperature and very little precipitation. The average annual temperature in winter is -14.2°C, with January the coldest. The annual average temperature of the region in January is -19.6°C. The average annual precipitation (snow) in winter is 23.6mm, with an interannual variation between 6.6-35.4mm, a difference of nearly 5 times. Southwest wind with low wind speed prevails in winter. Blizzard hits occasionally. According to the geological longitudinal section provided by the design and the borehole of bored pile, the geological compositions of the cushion cap from top to bottom are as follows: (1) silty soil; (2) silt; (3) fine sand; (4) coarse sand; (5) gravel sand; (6) coarse sand. Specific parameters were shown in Table 1. The underground water level is as deep as 6m. In winter, there is neither surface water nor effective precipitation around the cushion cap.

3. Design of Steel Sheet Pile Supporting
As the base pit was located in the layer of mucky silty clay or silty clay, it was easy to pull the steel sheet pile. In winter when there was no surface water, the surface layer was frozen, bringing good stability to the soil layer. The base pit was 4.8m deep. Based on the above-mentioned consideration, a 9-meter long SP-IV Larsen steel sheet pile support was adopted.

3.1. Parameters of the steel sheet pile

3.1.1. Steel sheet pile parameters
SP-IV steel sheet pile is 400mm wide, 170mm high, 15.5mm thick, cross-sectional area is 96.9cm², and theoretical weight is 76.1kg/m. The steel sheet piles are inserted and connected to each other with locks.

3.1.2. Support parameters of steel sheet piles
The steel sheet piles are connected by enclosing purlin of 36b waist beam, and inclined internal support is made by steel pipes with a size of DN 351mm×16mm.
3.2. Design of the steel sheet pile
The base pit was 4.8m in depth, which fell into the category of secondary base pit. The surrounding load of the base pit was set at 15kPa above the ground. The soil parameters are shown in Table 1, and the layout form of the steel sheet pile is shown in Figure 1. The steel sheet pile is supported by a 9-meter long SP-IV Larsen steel sheet pile plus one inner support, and the enclosing purlin support is 1 meter from the ground.

3.3. Calculation of structural internal forces
The elastic force earth pressure model and the classical law earth pressure model were used to calculate the internal force of the structure. The internal force envelope diagram of the structure was calculated, as shown in Figure 2, and the surface settlement diagram was shown in Figure 3.

It can be known from Figure 2: The standard value of the maximum bending moment inside the foundation pit is 86.07kN·m by using the elastic pressure earth pressure model. The standard value of the maximum bending moment outside the foundation pit is 13.52kN·m, and the standard value of the maximum shear force is 54.55kN. The maximum displacement of the steel sheet pile is 7.51mm, and the standard value of the maximum support reaction force of the internal support is 38.16kN. The classic method of earth pressure model is used to calculate the maximum value of the maximum bending moment inside the foundation pit, which is 71.22kN·m, the standard value of the maximum bending moment outside the foundation pit is 71.81kN·m, and the standard value of the maximum shear force is 67.81kN. The maximum displacement of the steel sheet pile is 0.02mm, and the standard value of the maximum supporting reaction force of the internal support is 33.25kN.
It can be known from Figure 3 that, calculated by the triangle method, the maximum settlement amount of the foundation pit surface is 12 mm; calculated by the parabolic method, the maximum settlement amount of the foundation pit surface is 18 mm; and calculated by the index method; the maximum settlement amount of the foundation pit surface is 10 mm.

3.4 Calculation of the pier, waist beam and internal support
The internal forces of the structure were calculated using the elastic method and the classical method, respectively, and the standard value of the maximum bending moment of the foundation pit was 86.07kN·m. It can be obtained through calculation that, the design value of the maximum bending moment of the foundation pit is 91.45kN·m, the bending modulus is 2270cm³ per meter, the allowable bending stress is 215MPa, and the bending stress of the steel sheet pile is 40.285MPa, which is less than the allowable bending stress. Therefore, the steel sheet pile section meets the specification requirements.

3.5 Overall stability calculation
The overall stability calculation method adopted the Swedish slice method, and the stress state was calculated according to the effective stress method. The strip width in the stripe method was 0.40m. The specific slip surface data was: the arc radius was 9.028m, and the center coordinate was (-1.625, 4.598). When excavation depth is 11m, it was calculated that the overall stability safety factor $K_s = 1.401 > 1.30$ is calculated, which meets the specification requirements.

3.6 Internal support calculation
Take the maximum support reaction force calculated under the above working conditions in Figure 2 as the basis for the internal support design. The maximum reaction force of the internal support is 36.18kN/m, and the overall support is modeled using midas as shown in Figure 4. The internal force calculation results are shown in Figures 5, 6, and 7, respectively.

![Figure 4. Internal support model](image)

![Figure 5. Deformation of internal support](image)
Figure 6. Moment diagram of internal support
Figure 7. Composite stress of internal support

From Figure 5-7, we can know that the maximum deformation of the long side of the cofferdam is 16.8mm <\[L/400\] = 34mm, the maximum combined stress of the ring beam 36b I-beam is 142.98MPa <\[170\] MPa, and the diagonal brace DN351mm×16mm maximum combined stress is 42.7MPa <\[170\] MPa, so the internal support forces meet the requirements [10].

4. Conclusion
In this paper, the following conclusions were obtained:

- Through theoretical analysis and finite element software analysis, the paper studied the stress deformation and stability of Larsen steel sheet pile as the deep base pit support. The results showed that the stress deformation and stability of Larsen steel sheet pile support meet the requirements of the specification, making it feasible to apply Larsen steel sheet pile in supporting the base pit.

- The performance of projects showed that the Larsen steel sheet pile support can effectively shorten the construction period, save cost and land for construction in these projects, meeting the requirements of the construction of deep base pit of bridge. It has good actual effect and ensures the smooth progress of the bridges principal part. Therefore, the Larsen steel sheet pile is worth promoting as the deep base pit support.

Acknowledgment:
(1) Project of the 13th Five-Year Plan, Provincial Department of Leading Group for Educational Science Planning, Gansu, China (S[2019]GHB2065).
(2) Department of the Ministry of education of the people's Republic of China, Beijing, China (2019012733045).
(3) Project of Education and teaching research, Longdong University, Gansu, China(2019-37).

References
[1] ZHAO. Z. J., YING. H. Q. (1999)Brief design and Construction Manual of deep foundation pit engineering. M. China Architecture& Building Press, The Beijing.
[2] NIE. Q. K., LIANG. J. G. (2008)Design theory and application of double row pile supporting structure in deep foundation pit. M. China Architecture& Building Press, The Beijing.
[3] LIU. Y. P. (2014)Application of steel sheet pile in foundation pit supporting engineering of adjacent existing line. J. Journal of railway construction, 1:85-87.
[4] YANG. W., XIAO. Y. H., et al. (2014)Application of steel sheet pile in deep foundation excavation support of Zhaojiali super-large bridge. J. Construction Technology., 12: 65-68.
[5] Li. Q. L. (2018)An Lingshi. Numerical simulation study on supporting process of steel sheet pile excavation in deep ditch adjacent to Subgrade. J. Journal of low temperature building technology., 10: 68-71+81.
[6] ZHAO. X. Z., ZHUANG. J. B., et al. (2017) Study on the Support Asymmetric System of Steel Sheet Piles in Deep Foundation Excavation of a Bridge Underwater Building. J. Journal of construction technology., 46(2):84-87.

[7] LiU. X. S. (2016) Application of double row steel sheet pile cofferdam in soft soil foundation of Zhongshan area. J. Journal of water conservancy planning and design., 5: 113-115.

[8] WANG. A. X., LIU. G. B., et al. (2018) Application of AZ46-700 Lassen steel sheet pile used in the Construction of deep foundation excavation of Macao Lisboa Hotel. J. Construction Technology., 19: 75-77+115.

[9] CAO. L. Q. (2013) Finite element analysis of heave of deep foundation pit in soft soil area. J. Journal of geotechnical engineering., 35:819-824.

[10] Ministry of Housing and Urban-Rural Development of the People's Republic of China, (2017) Code for design of steel structures GB50017-2017. s. China Architecture& Building Press, The Beijing.