Application of Pile-sheet wall in the slop reinforcement project

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Abstract. The Pile-sheet wall has been widely used In the roadbed slope reinforcement project of railway and highway engineering, Due to the high slope and inadequate foundation bearing capacity, the Pile-sheet wall has been adopted for slope reinforcement in the rebuilding engineering of a railway station in northern Shaanxi. After comparing the plans in three aspects—technology, economy, and implementation—the proposed technique is feasible, thrifty, and the results are satisfactory. This paper introduces the practice and experience in the design of the Pile-sheet wall. However, traditional limit equilibrium calculating methods have some shortcomings, such as the inability to simulate material behavior, soil-structure interaction, construction sequences, and conditions. Therefore, the finite element method was used to optimize the design. Additionally, some construction operations were introduced. This information is expected to be useful for future reference in similar projects.

Keywords: Pile-sheet wall, design, finite element method, slope reinforcement project

1 Introduction

Pile-sheet wall is often used in high slope treatment and landslide treatment of railway and highway subgrade main works at home and abroad, and some mature theories and experiences have been obtained[1]. It can be used for both shoulder retaining wall and embankment retaining wall. In some sections where high embankment or high shoulder retaining wall is needed, the pile-sheet wall has certain technical advantages when the local foundation conditions are not good enough.

A railway station in northern Shaanxi is located in the northern edge of northern Shaanxi Plateau, in the loess hilly and gully region, where the valleys are steep and narrow, and the hillsides on the top of the mountain are mostly covered by fixed and semi-fixed sand dunes. At present, there is a trunk secondary highway parallel to the railway line at the lower left side of the railway station. The height difference between the railway track top and the highway pavement is 14.0 meters, and the horizontal distance between the center line of the special railway line and the highway is 22.38 meters. Most of the existing railway and highway embankment fillers are silty fine

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sand. In order to build a new special railway line for coal mines, the existing railway stations must be reformed and tracks must be added. In order to prevent the foot of the railway embankment slope from encroaching on the highway and ensure the stability of the railway embankment slope after adding tracks, a retaining project must be set up for treatment. Considering the low bearing capacity of the foundation of this project, it can not be used as the natural bearing layer of gravity retaining wall, and the high slope of the embankment, in order to ensure the safety of railway stations and the smooth flow of highways, through technical and economic comparison of various schemes, the pile-sheet retaining wall is selected as a retaining engineering form, and 40 reinforced concrete piles are used to reinforce the slope, which has achieved good results.

2 Site engineering geological conditions

The area where the site is located has a simple structure, and the stratum structure is a gentle monoclinic structure with a strike of NE and a tendency of NNW. The dip angle of rock strata is 1 ~ 30, generally 1.50, and there are extremely gentle fluctuations along the dip and strike. The basic earthquake intensity in this area is six degrees. The lithologic characteristics of the strata involved in this project are as follows:

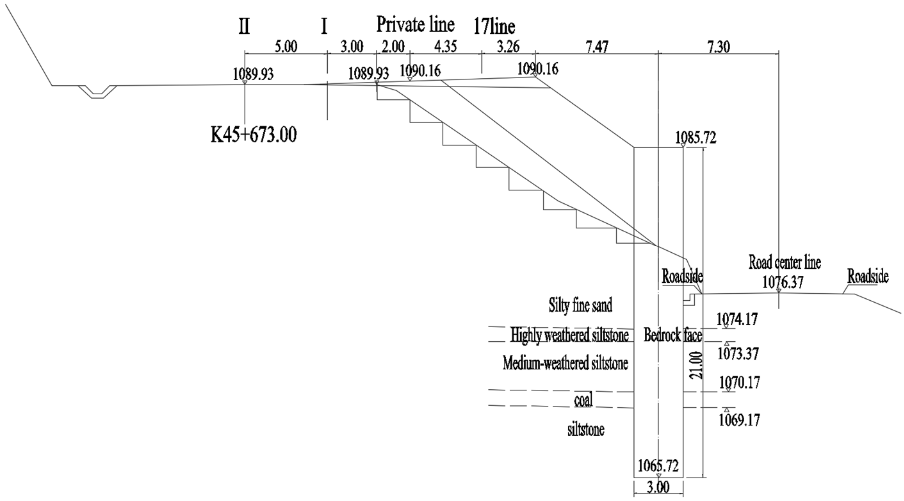

Fig. 1. l Structure of the project (sketch of retaining structure and calculating mode for Pile-sheet wall)

(1)Powder and fine sand (Q_4^{eol}): Dark yellow, loose, slightly wet ~ wet, mainly composed of feldspar particles, with scattered round gravel at the bottom. Widely distributed. The top of this layer is about 0.6 meters for highway subgrade. The thickness is 1.5 ~ 5.3 m. The basic bearing capacity [σ]= 100Kpa.

(2)Round gravel soil(Q_4^{al+pl}): variegated, loose and slightly wet. The composition is mainly sand and mudstone, generally with a grain size of 0.5 ~ 2.0 cm, containing pebbles, which are filled with sand and have poor sorting performance. The thickness is 0.3 ~ 1.0 m. The basic bearing capacity [σ] = 250Kpa.

(3)Silt-stone (J):Light yellow, gray. Thin-thick layer structure, fine-grained structure, mainly argillaceous cementation, with local coal line and mudstone thin layer. The thickness of strong weathering layer is 0.0 ~ 2.0m, and the thickness of moderate weathering layer is 2.9~6.7 m. Basic bearing capacity: strongly weathered siltstone [σ_o]=500Kpa, moderately weathered siltstone [σ_o]=1800Kpa. Shear strength of moderately weathered siltstone: C=3.2Mpa, $\phi = 40^0$.Uniaxial compressive strength (saturation) R=18.2Mpa.

(4)Coal seam(J):Black, good coal quality, block. The thickness is 0.6 ~ 1.0 m. The basic bearing capacity [σ]=400KPa.

(5)Silt-stone (J):Gray, dark gray, gray-white, fine grain Structure, argillaceous and calcareous cementation, local coal line and mudstone thin layer. The thickness is 1.3 ~ 6.7 m. The basic bearing capacity [σ] = 3000Kpa. Shear strength: C=3.5Mpa、$\phi = 40^0$, uniaxial compressive strength (saturation) R=34.7Mpa.

Groundwater in the worksite is mainly replenished by atmospheric precipitation, which is small in water quantity and poor in water level continuity. Groundwater is non-corrosive to concrete.

This area has a temperate continental climate. It is cold in winter and hot and dry in summer. The annual average temperature is 7.3~9.0℃, the lowest temperature is-26℃, and the coldest month is January, with an average temperature of-12.7℃ ~-6.5℃. The maximum frozen depth of soil in this area is 1.5m.

3 Design scheme selection

3.1 Gravity retaining wall

Because the slope is as high as 14m and the natural bearing capacity of silty fine sand is very low, it can not be used as the natural bearing layer of gravity retaining wall, so it must be treated to improve the bearing capacity of foundation. For the section with large slope height, this method is not economical. At the same time, due to the high gravity retaining wall, its cross-section size is very large, and the horizontal distance between highway and railway subgrade is very close, so the excavation of retaining wall foundation may lead to the instability of the original railway subgrade, which will inevitably affect the safe operation of railway stations. There is a lack of stone in materials, and transportation from a distance will increase the construction cost.

3.2 Anchor slab retaining wall[2]

This kind of retaining wall has light structure, large flexibility, small land occupation and less masonry. However, the railway and highway subgrade fillings are mostly fine sand, which requires high construction technology and complex technology, and may also affect the safe operation of railway stations.

3.3 Pile-sheet wall

After adopting the construction technology of excavating pile foundation with concrete thin-wall support, special machines and tools are not needed, the construction progress is fast and safe, and the construction can be carried out at intervals at the same time, with more working faces and less interference, and little damage to the original railway subgrade, so as not to cause deterioration of slope conditions; If problems are found in construction, they can be easily remedied. At the same time, waste rails of railway can be used in construction, so as to reuse waste and reduce project cost.

Through the above comparison, the pile-sheet wall is used in engineering practice to reinforce the railway subgrade slope.

4 Design load and design calculation of Pile-sheet wall

4.1 Design and calculation of traditional pile-sheet wall[3~5]

(1) The earth pressure: which includes the lateral pressure caused by the train load converted to the soil column and the earth pressure generated by the soil behind the wall, is calculated according to the Coulomb or Rankine active earth pressure formula.

(2) The internal force calculation of pile and slab, the load acting on pile, take the earth pressure behind the wall with half of the distance between piles on both sides, the load acting on slab, take the earth pressure stress value behind the wall where the slab is located, and distribute it according to uniform load. In the internal force calculation of pile, firstly, the deformation coefficient of pile is calculated to judge whether it is rigid pile or elastic pile. There are many calculation methods for rigid piles. At present, the reduction of external load is considered according to whether there is or not the resistance of sliding body and its size on the sliding surface in front of the pile. All forces above the sliding surface are regarded as external loads. Landslide thrust and resistance of sliding body in front of the pile are converted into bending moment and shear force acting on the sliding surface as external loads, while the medium around the pile below the sliding surface is regarded as elastic body to calculate lateral stress and soil resistance. For elastic pile, it is considered that the stiffness ratio between pile body and surrounding rock, the pile is weak, and the axis of pile body buried in surrounding rock changes continuously after being stressed. The usual calculation methods include common method and simplified method (dimensionless coefficient method), which are divided into "m" method and "k" method.

(3) Strength calculation of pile and plate: The strength calculation of pile and plate can adopt limit state method and consider flexural members.

The cross-section size of pile body of pile-sheet wall should be determined according to internal force calculation, but if digging pile is used, several forms of pile cross-section size such as 1.5×2.5m and 2×3m (width×height) can be adopted according to the height of pile top exposed to the ground, and then adjusted appropriately according to checking calculation. At present, there is no mature calculation method for pile spacing. Generally, the pile spacing is 6~10m. In determining the pile spacing, the weight of retaining plate and the lifting capacity of hoisting equipment should be considered. The buried depth of pile should be determined according to the lateral allowable compressive stress of foundation. For the convenience of calculation, it can be selected according to experience first. Generally, 1/3 of the pile length is taken for rock foundation and 1/2 of the pile length for soil foundation, and then adjusted appropriately according to the checking calculation.

According to the structural form of railway and highway subgrade engineering in the section where the project is located (schematic diagram of supporting structure and calculation diagram of pile-sheet wall) (as shown in Figure 1), C25 reinforced concrete is used for pile body in design, and the cross-section size is 2 × 3 m. According to the lithologic characteristics of stratum, the anchorage section below the medium weathered sandstone surface is taken as the stress section, and the pile length is set to be 21m and the pile spacing is 6m. The piles are connected by retaining plates. C20 reinforced concrete precast members are used for arch slab, each slab is 0.5 m high, 0.2 m thick and the span of retaining slab is 4.40 m.

In the concrete calculation, the simplified method "m" method of elastic pile under the traditional limit equilibrium theory is adopted to calculate the internal force of pile. The calculation process can refer to the paper "3 ~ 5", and the calculation results are shown in Figure 2 and Table 1. By checking the strength of the pile, the data show that the assumptions of the pile fully meet the requirements.

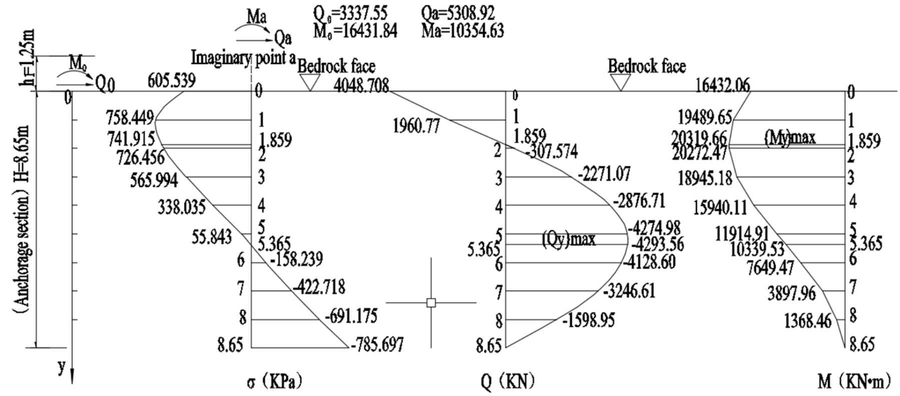

Fig. 2. Distribution of Lateral stress & internal force in pile

Table 1. lateral stress & internal force result

y(m)	y'(m)	α*y'	AP3.28	BP3.28	AQ3.28	BQ3.28	AM3.28	BM3.28	Py'	σy' (KPa)	Qy' (KN)	My' (KN•m)	Remark
0	1.25	0.403	0.7737	0.4602	0.8262	-0.1013	0.3779	0.9852	1816.618	605.539	4048.708	16432.064	
1	2.25	0.725	1.0330	0.4746	0.5271	-0.2511	0.5972	0.9313	2275.346	758.449	1960.770	19489.652	
1.86	3.11	1.001	1.0536	0.3956	0.23481	-0.3737	0.7036	0.8420	2225.745	741.915	0.000	20319.662	(My')max
2	3.25	1.047	1.0398	0.3743	0.1875	-0.3907	0.7120	0.8242	2179.367	726.456	-307.574	20272.468	
3	4.25	1.369	0.8686	0.1986	-0.1237	-0.4842	0.7209	0.6818	1697.983	565.994	-2271.068	18945.183	
4	5.25	1.691	0.5905	0.0044	-0.2170	-0.5172	0.6409	0.5190	1014.104	338.035	-2876.707	15940.109	
5	6.25	2.013	0.2069	-0.1734	-0.4982	-0.4889	0.4994	0.3555	167.528	55.843	-4274.979	11914.912	

5.37	6.62	2.130	0.1447	-0.2303	-0.5177	-0.4634	0.4387	0.3001	0.000	0.000	-4293.565	10339.533	(Qy)max
6	7.25	2.335	-0.0757	-0.3216	-0.5221	-0.4069	0.3316	0.2108	-474.718	-158.239	-4128.604	7649.471	
7	8.25	2.657	-0.4616	-0.4462	-0.4338	-0.2829	0.1745	0.0985	-1268.154	-422.718	-3246.611	3897.956	
8	9.25	2.979	-0.8620	-0.5588	-0.2246	-0.1219	0.0634	0.0312	-2073.524	-691.175	-1598.954	1368.461	
8.65	9.90	3.188	-1.0208	-0.5701	0	0	0	0	-2357.092	-785.697	0	0	

4.2 Numerical simulation and optimization of design by finite element method

The traditional pile-sheet wall calculation uses limit equilibrium theory to calculate the internal forces of pile and slab under various pile bottom boundary conditions through many simplified assumptions about soil, structure and load properties. This method can provide bearing capacity and successfully predict the failure load of retaining structure, but it can not effectively simulate the geometric shape, load conditions and material characteristics of the site, and can not predict the deformation related to the limit load, nor can it give the situation before the limit state [6-8]. However, the finite element method can meet the needs of this aspect.

In the finite element analysis, the finite element method synthesizes the three-dimensional solid element of soil or rock and structure and the interface element at the contact between structure and soil, fully considers the properties of various materials, especially the nonlinear material properties of soil, and simulates the construction program by establishing the constitutive model of soil and structure, so as to find out the mechanical state and characteristics of the analyzed object, and provide technical personnel with numerical and theoretical basis for optimal design, construction and research and development. Now a lot of finite element analysis tools, such as ANSYS Civil FEM geotechnical engineering module SAP2000, etc., can be well applied in geotechnical engineering, which has great practical significance for the design and optimization of cross-section size, spacing and reinforcement of pile-sheet wall piles.

In the concrete design, we use the finite element method to simulate the actual engineering, use the Civil FEM geotechnical engineering module of ANSYS to optimize the design, use Duncan-Chang nonlinear elastic model for filling soil, use linear elastic model for concrete and siltstone bedrock, and use hyperbolic model for contact surface between concrete pile and filler, filler and foundation. The contact surface element is used for the contact surface of the two materials, and the solid element is used for the filling, concrete pile and bedrock. The parameters of various material models are obtained by Duncan-Chang E-u model of indoor test except the value of the contact surface between concrete and bedrock[9,10].

The filling process is divided into several working conditions, that is, the filling work is divided into four layers according to the construction procedure, and the double-track train load is considered (converted into the filling height). Finally, the effect of filling increment in each working condition is analyzed in sequence, and the results of each increment are superimposed on the previous results to obtain the accumulated stress and displacement conditions, so as to complete the simulation of construction procedures well, and the bending moment and displacement of piles, filling pressure, filling settlement and displacement are calculated.

From the calculation results, it can be seen that the fill pressure is the main load of the structure, and its magnitude is affected by the stiffness of pile plate. The calculation results show that the earth pressure increases with the thickness of fill (wall height), but it is not a linear relationship of theoretical earth pressure. In most sections of the wall, the earth pressure is between Rankine active earth pressure σ_a and static earth pressure σ_0. This shows that the displacement of fill does not reach the displacement required by active earth pressure because the stiffness of pile plate has a certain limiting effect. The maximum displacement of the top of the pile is 6.3 cm at the working condition 5, which is similar to the displacement of the top of the pile calculated by the elastic constrained foundation coefficient method, which is 5.1cm. The maximum bending moment of pile body appears in the working condition 5, which is 14462kN·m. When designing the reinforcement of pile body, the design optimization is carried out with reference to this value, so as to achieve the purpose of saving investment.

4.3 Reinforcement of piles and plates

The reinforcement of pile and slab is based on the limit state theory[11,12], adopting "Code for Design of Concrete Structure" and referring to "Code for Design of Railway Subgrade Retaining Structure"[13]. Material: 43kg/m old rail is used as the main reinforcement, and the design value of tensile strength f_y=340000kPa. The cross-sectional area of rail is 85% and the weight is 95%. Hot rolled steel bars are used for steel bars, and C25 grade is used for concrete. Rail joints shall be connected by fishplate and bolts, and then welded. The joint positions shall be staggered. If there are joints within the same section length, the area shall not exceed 25% of the total area of the stressed bars in this section. In addition, rail joints are not allowed near the bedrock surface and the maximum bending moment (12.35m and 14.2m below the pile top). Calculation of reinforcement of pile plate is omitted.

5 Engineering construction process

(1)Because the project is close to the highway, in order to ensure the stability of excavation pile foundation pit and smooth road, C20 concrete retaining wall is set in soil layer and broken rock layer, and the retaining wall is embedded 0.5 m below bedrock surface.

(2) A 0.4×0.4m (width×height) drainage ditch is set in front of the pile-sheet wall to introduce water into the nearby culvert or connect with the existing highway side ditch, and the longitudinal slope at the bottom of the ditch is not less than 3 ‰. The drainage ditch is built with M7.5 cement mortar and rubble.

(3) The retaining plate is a prefabricated member, and the ground on the pile side shall be leveled and tamped during installation. In the section with steep longitudinal slope of the ground, mortar rubble cushion block is set as the foundation of retaining plate. The fill on the inside of pile and slab can't be reached by mechanical rolling and compaction. Use small rammer or manual rammer for compaction.

(4) In order to ensure the safety of foundation pit excavation and construction without greatly affecting the original railway subgrade, the pile foundation shall be excavated at intervals. The construction sequence is the first batch of 1#, 3#, 5#, 7#, 9#...; The second batch of 2#, 4#, 6#, 8#, 10#….

(5) After the pile position is put in place, level the surface according to the construction requirements, and do a good job of temporary drainage. Although the groundwater volume here is small, it is widespread. Pumping equipment is prepared during construction to prevent water accumulation in the pile, and drainage around the pile is done at the same time to prevent surface water from entering the well.

(6) The reinforced concrete members of pile body strictly abide by the relevant provisions in the Quality Control Regulations for Concrete and Precast Concrete Members (CES40: 92). Before use, rust removal and cleaning of old rails should be carried out to ensure clean appearance, and flaw detection and sampling test should be carried out to eliminate rails with dark injuries and cracks.

6 Conclusions

This project adopts pile-sheet retaining wall, which has been built after careful construction. After years of operation and testing, it completely meets the design requirements and meets the needs of the project. This kind of pile-sheet retaining wall composed of reinforced concrete piles and slabs can be used in the main subgrade works of newly built or rebuilt railways, which can be used for both shoulder retaining wall and embankment retaining wall. Its main advantages are that its height is not limited by the height of general retaining walls, and the foundation strength is insufficient, which can be compensated by the depth of piles. In some sections where high shoulder retaining walls or high embankment retaining walls are needed, and the foundation conditions are not good enough, pile-sheet retaining walls are adopted, which has its special advantages:

(1) It can be used alone or in conjunction with other retaining works;

(2) It can be constructed at intervals at the same time, with more working faces and less interference, and less broken sliding bodies, so as not to cause deterioration of landslide conditions;

(3) After adopting the construction technology of excavating pile foundation with concrete thin-wall support, special machines and tools are not needed, and the construction is fast and safe;

(4) It is easy to build all the projects and make them play a role quickly;

(5) It is especially beneficial to rectify the landslide on the operation line and the landslide in the slow sliding stage;

(6) If problems are found during construction, they are easy to remedy.

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