Application and Research of Abandoned Slurry Treatment Technologies in Metro Tunnel Construction from the Perspectives of Climate Crisis and Sustainable Development

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Abstract: With the acceleration of national infrastructure construction, more and more cities have started to build urban subways. Civil engineering works such as stations and sections inevitably generate a large amount of waste slurry during the construction process, leading to resource waste and environmental pollution. Green construction is the trend and inevitability of the development of the construction industry. The direct discharge of waste slurry causes great pollution to the environment. At the same time, the cost of transporting the slurry out is very high. Therefore, the zero-discharge treatment of separating water from waste slurry is a trend and necessity. In response to this problem, a combined process of a cyclone desander and a horizontal scroll centrifuge has been developed and adopted for the first time to treat the waste slurry from the retaining structure. This process changes the transportation of slurry out of the site into the transportation of earthwork out of the site plus the discharge of clean water. Engineering applications have shown that compared with the unit price of 110 yuan per cubic meter for the conventional transportation of waste slurry out of the site, the cost has been reduced by 66%. The project has saved a total of 280,000 yuan. It has achieved multiple goals such as cost reduction and efficiency improvement, and pollution reduction. Analyzed from both economic and social benefits, it has the conditions for widespread promotion and application.

Keywords: Climate crisis;Sustainable development;Subway tunnel;Waste slurry;Cyclone desander and horizontal scroll centrifuge

1. Introduction

With the acceleration of national infrastructure construction, more and more cities are starting to build urban subways, including civil engineering projects such as stations and sections. In terms of urban subway construction, especially for stations, it is mostly necessary to first construct the retaining structures, such as diaphragm walls and bored piles. Due to the technological requirements, a large amount of waste mud will inevitably be generated. The preparation of ready-mixed fluidized solidified soil directly from engineering waste mud was studied, providing solutions for the treatment and reuse of engineering waste mud[1]. Taking the waste mud generated from the construction of a certain bored pile in Shenzhen as the research object, a modular green building waste mud treatment system was designed. This waste mud green treatment system can effectively handle building waste mud and avoid environmental pollution[2]. By researching the multi- stage mud- water separation technology and high - efficiency harmless solidification technology for engineering waste mud, the core technology for the green treatment of waste mud was formed[3]. In order to explore the treatment and utilization of bored

pile waste mud, the basic physical properties of the mud were calculated through experiments. The orthogonal experimental method was used to set up a natural sedimentation group, an organic flocculant group, and an inorganic flocculant group. The sedimentation of each group of mud was recorded and analyzed using the gravity sedimentation method[4]. A method of directly treating a large amount of waste mud generated from the bored pile wall protection on the construction site using a plate - and - frame filter press was adopted, which effectively avoided environmental pollution, accelerated the construction progress, and ensured the project quality[5]. A new type of shield tunneling mud treatment technology was adopted, and the resource - based disposal of the separated products was analyzed[6]. Common treatment technologies for waste mud were reviewed, and the development direction of drilling waste mud treatment was proposed[7]. Through the study of waste mud solidification, it was found that compared with cement and lime, the HAS solidifying agent formed needle - rod - shaped hydrates on the mud surface, filling the pores on the surface of soil particles, and the needle - rod - shaped crystals were tightly interlocked, improving the strength and stability of the soil[8]. The circulation flow rate and total amount of mud were calculated through volume balance and mass balance formulas. The reduction treatment of waste mud adopted a three - stage treatment of screening - cyclone - centrifugation, and the effects such as the mud separation rate and COD content were analyzed by comparison[9]. The waste mud generated during construction was treated with a plate - and - frame filter press. The plate-and - frame filter press can effectively separate the solid particles and water in the waste mud, reduce the volume of the mud. The recovered water can be reused at the construction site, and the solid mud cake can be used for site leveling and other purposes, significantly reducing environmental risks and improving economic benefits[10]. The treatment of the waste mud generated during construction by a plate-and-frame filter press has been studied, and good results have been obtained[11]. The research on the reuse of wastewater through constructed wetlands is constantly evolving, covering experiments of different scales[12].It illustrates the synergistic effect between the recovery of phosphorus (P) in SSIA and the production of cementitious materials, converting waste into valuable resources[13].An energy and economic analysis of an integrated combined heat and power generation system based on sludge gasification is presented[14].The effectiveness of treating alkaline tunnel construction wastewater with CO2 and its potential influencing factors were explored[15]. A method of treating heavy metals by utilizing the purification function of plants in civil engineering projects is proposed[16].A combined three-stage system, Treat the tunnel construction wastewater[17]. For the first time, a combined process of a hydro-cyclone and a horizontal spiral centrifuge was used to treat the waste mud generated from the retaining structure. This has transformed the transportation of mud out of the site into the transportation of earthwork out of the site and the discharge of clean water, achieving multiple goals such as cost reduction, efficiency improvement, and pollution reduction. At present, the cost of transporting urban mud out is relatively high, and the environmental pollution is severe. The discharge and treatment of waste mud have become a major problem in subway construction.

2.Research motivation

Developing an effective and environmentally friendly waste slurry treatment technology can, on the one hand, reduce construction costs, and on the other hand, minimize the discharge of pure slurry. Thus, it can achieve the goals of reducing environmental pollution and enhancing the level of civilized construction.

3.Research, Development and Application of Core Technologies

This achievement is applicable to the construction safety risk monitoring during the shield construction of projects such as railway tunnels, highway tunnels, subways, and underground utility tunnels.

3.1 Innovation points

In the construction of urban subway stations, a conventional - breaking approach was adopted. For the first time, a combined process of a hydro - cyclone and a horizontal spiral centrifuge was used to treat the waste mud from the retaining structure. This transformed the transportation of mud out of the site into the transportation of earthwork out of the site plus the discharge of clean water, achieving multiple goals such as cost - reduction, efficiency - improvement, and pollution -

reduction.

In the schematic diagram of the horizontal centrifugal separation equipment, the core components are clearly visible at a glance. The drum is horizontally placed, serving as a crucial site for achieving solid-liquid separation. The motor is connected to the drum via a belt or a coupling, providing the power for the operation of the equipment and ensuring that the drum can rotate at a high speed, generating a strong centrifugal force field. Inside the drum, there is a screw conveyor, which is coaxially installed with the drum, and there is a certain rotational speed difference between the two. When the mixture to be separated enters the drum from the feed inlet, under the action of the centrifugal force generated by the high-speed rotation, the solid-phase particles with a higher density quickly settle towards the drum wall, while the liquid phase with a lower density converges in the central area of the drum. At this moment, the screw conveyor comes into play, transporting the solid-phase particles settled on the drum wall along the axial direction of the drum to the slag discharge port for discharge; the liquid phase flows out of the equipment through the overflow port, thus completing the process of solid-liquid separation. This structural design gives the horizontal centrifugal separation equipment the advantages of high efficiency and continuous operation in many fields such as industrial wastewater treatment, sludge dewatering, and mineral processing. It has greatly improved the separation efficiency and production capacity, playing an important role in promoting the process optimization and sustainable development of related industries.

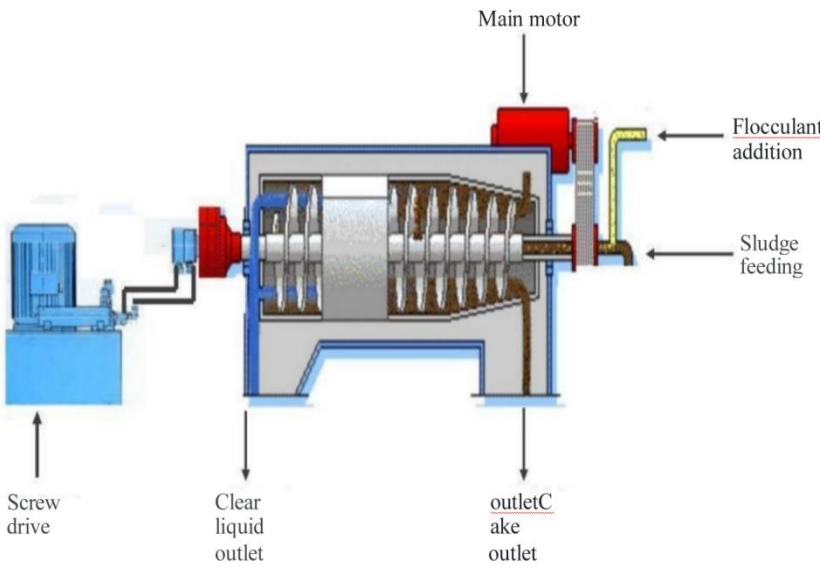

Fig. 1 Schematic Diagram of Horizontal Centrifugal Separation Equipment

3.2 Technological process

This flow chart illustrates the technological process of waste slurry treatment and separation. Firstly, the elevation of the mobile slurry separation and preparation equipment is measured to determine the slurry separation and preparation scheme. After the waste slurry enters the treatment process, it first passes through a hydrocyclone desander, which separates out the large particle construction waste from it. The remaining waste slurry with a low specific gravity then enters a centrifuge for further treatment. Under the action of centrifugal force, the waste slurry achieves solid-liquid separation. The separated water is recycled as reclaimed water, while the remaining solids are treated as construction waste. This process can effectively realize the resource utilization and reduction treatment of waste slurry, and it helps to improve the environmental

benefits and resource utilization rate in construction projects.

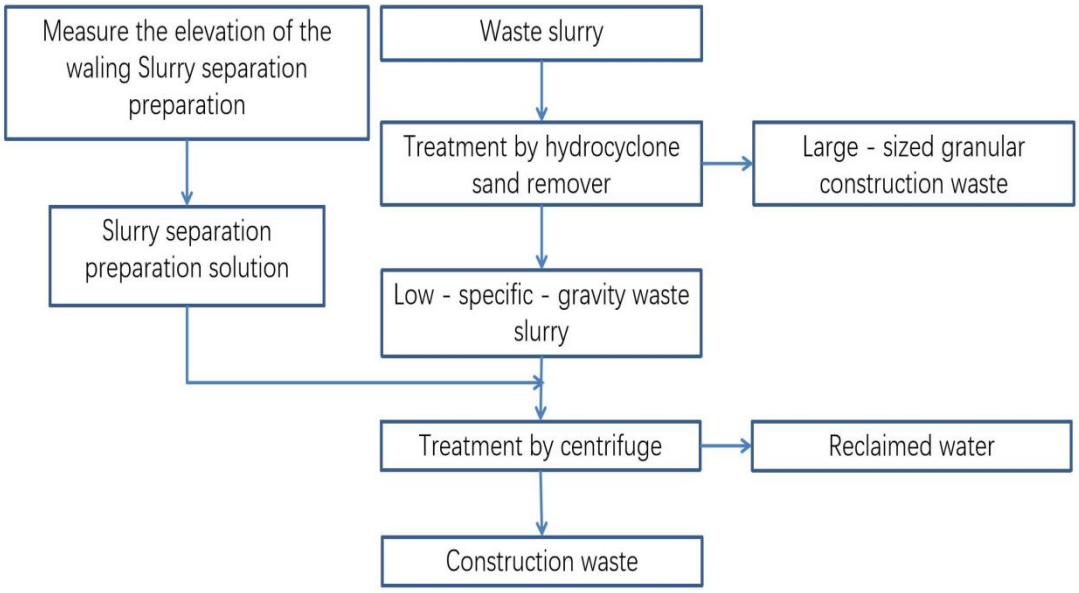

Fig. 2 Flowchart of the technological process

3.3 Operation Key Points

The hydro - cyclone sand remover is made based on the screening principle of solid particles in the fluid when they rotate inside the sand remover. Integrating swirling flow and filtration, it can achieve sand removal, turbidity reduction, and solid - liquid separation in the field of water treatment.

When water flow enters the equipment tangentially from the sand - removal water inlet under a certain pressure, a strong rotational motion is generated. Due to the different densities of sand and water, under the combined action of centrifugal force, centripetal force, buoyancy, and fluid drag force, the water with a lower density rises and is discharged from the water outlet, while the sand grains with a higher density are discharged from the sewage outlet at the bottom of the equipment, thus achieving the purpose of sand removal.

The greater the inlet pressure of the sand remover, the higher the sand - removal rate. Multiple sand removers can be used in parallel. It has advantages such as a high sand - removal rate, space - saving installation, a low rate of missing individual tiny solids, and stable working conditions. The hydro - cyclone can separate slag materials with a particle size above 0.075 mm, which will then enter the horizontal spiral centrifuge for further processing.

(1) Equipment Name

The cyclone desander used in this project is the ZX - 200(250) mud treatment device from Sanchuan Deqing Company (formerly Black Cyclone Company). It consists of a vibrating screen, a slurry pump system, a cyclone, etc.

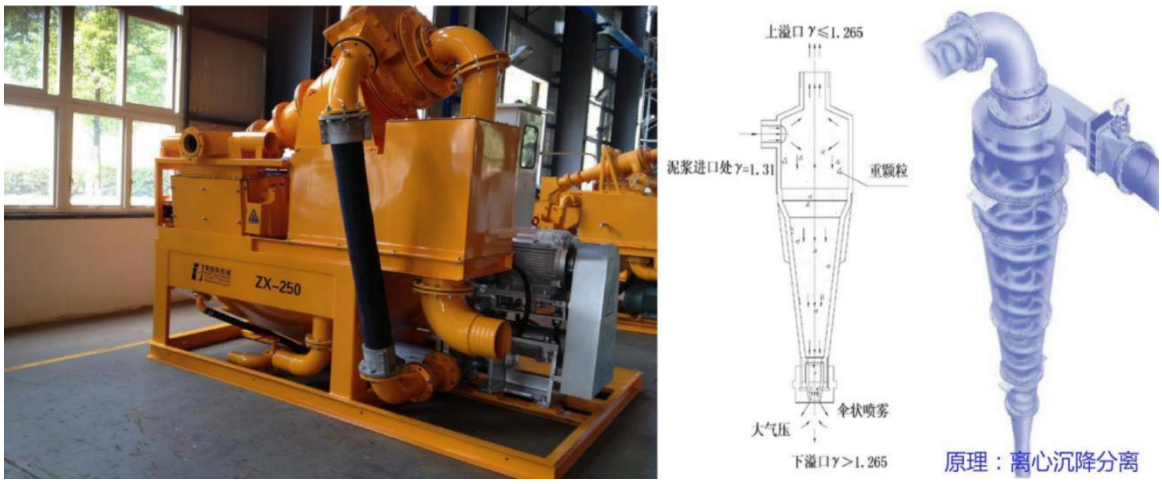

Fig. 3 Schematic diagram of hydro - cyclone sand - removal treatment equipment

① Vibrating Screen

The vibrating screen is composed of two vibrating motors, one vibrating box, one set of coarse sieve plates, one set of fine sieve plates, four groups of vibration - isolation springs, and two groups of adjustment s hims. The vibrating motors are the excitation sources of the vibrating screen. The motors directly drive the eccentric device to generate centrifugal force. The two vibrating motors operate synchronously in opposite directions, causing the vibrating screen to produce linear vibration. The excitation force can be adjusted by changing the angle between the eccentric blocks. At the time of leaving the factory, the excitation force is adjusted to 100% of the maximum value.

The vibrating screen box is of a frame - type welded structure and is supported by four groups of vibration - isolation springs. Its good structural rigidity enables it to reliably withstand the excitation force transmitted by the vibrating motors installed on its top. The coarse and fine sieves are installed in two layers in the vibrating screen box through the connection and fastening of the two - way inclined - plane wedge - tightening mechanism and standard parts. Both the coarse and fine sieve plates are made of polyurethane sieve plates or stainless - steel slotted sieve plates. The sieve pore size of the coarse sieve is 3 ×40mm, and that of the fine sieve is 0.4 ×40mm.

② Slurry Pump System

The slurry pump system consists of a slurry pump and a drive motor. The slurry pump is of a horizontal centrifugal type with a secondary impeller shaft seal. During operation, it is necessary to add grease and lubricating packing in a timely manner. The slurry pump is prohibited from running idle to avoid burning and damaging the packing.

③ Hydro - cyclone

The hydro - cyclone determines the final purification effect of the entire mud purification device on the mud. Its key index is particle separation, which is mainly reflected in the separation degree of the - 0.075mm particle size range.

(2) Centrifugal Treatment

The horizontal spiral centrifuge used in this project is the Chengdu Tiansheng environmental - protection centrifuge, and its core technology is the Centrisys (Paladin) centrifuge technology from the United States. The Paladin centrifuge is a counter - current horizontal spiral discharge sedimentation centrifuge. The centrifuge mainly consists of three key components: the screw body, the drum, and the hydraulic differential. The working principle of the centrifuge is mainly the sedimentation separation principle. Driven by the main drive motor, it rotates at a high speed to form a centrifugal force. Due

to the action of the centrifugal force, the solid particles with a high density in the material are deposited on the inner wall of the drum.

During operation, the screw body is driven by the hydraulic differential to make a relative motion at a non-uniform speed with the drum. The screw body continuously scrapes off the solid particles deposited on the inner wall of the drum and pushes them out from the slag discharge port. The separated clear liquid is discharged from the overflow port of the drum through the inner liquid layer channel of the screw of the screw body. Thus, the solid-liquid separation process is achieved.

To achieve the effect of reclaimed water that meets the standards for stormwater and sewage discharge, the general dosage during centrifugal separation is usually 3 - 8 ppm. That is, it is more appropriate to add 3 - 8 grams of polyacrylamide (PAM) per ton of waste slurry.

Main chemical components: modified chitosan - acrylamide copolymer (biodegradable). Optimal concentration: 0.05% - 0.3% (mass - volume ratio, w/v). Flocculation speed - initial flocculation time is 30 - 60 seconds (visible flocs formation by visual inspection), and complete flocculation time is 2 - 5 minutes (solid - liquid separation is completed in the centrifuge). Sedimentation rate: ≥15 cm/min (under static conditions), and the turbidity of the supernatant after centrifugation: ≤10 NTU (when the centrifuge speed is 3000 rpm and the treatment time is 5 minutes).

However, the actual dosage may vary due to factors such as the characteristics of the slurry, the type of PAM, and the performance of the centrifuge. Currently, the conventional flocculants on the market have relatively poor effects. Our project uses a new type of environmentally - friendly flocculant material jointly developed with the materials company of the bureau.

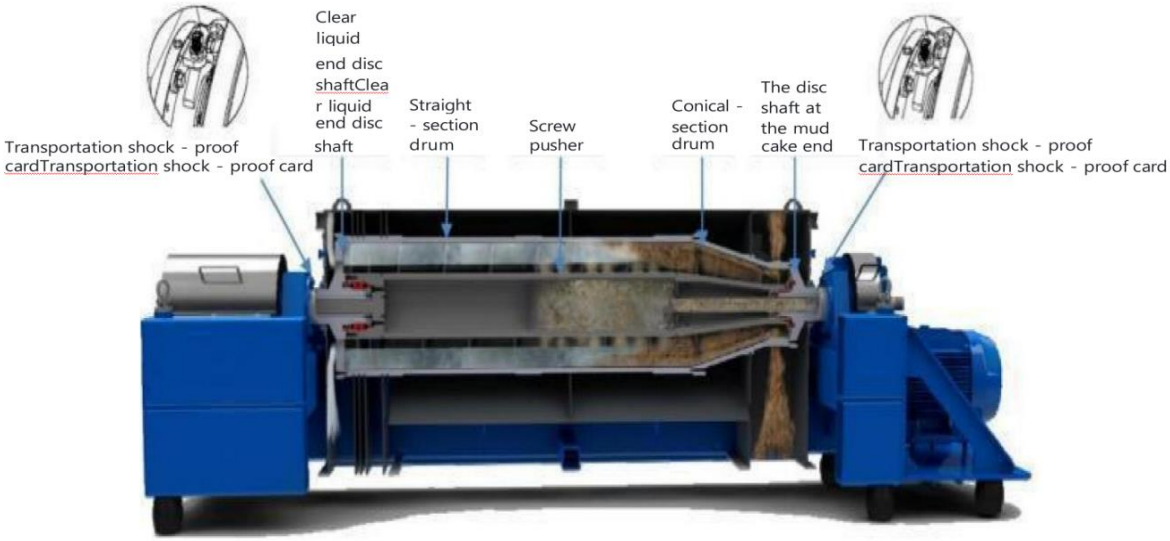

Fig. 4 Schematic diagram of centrifuge treatment equipment（1）

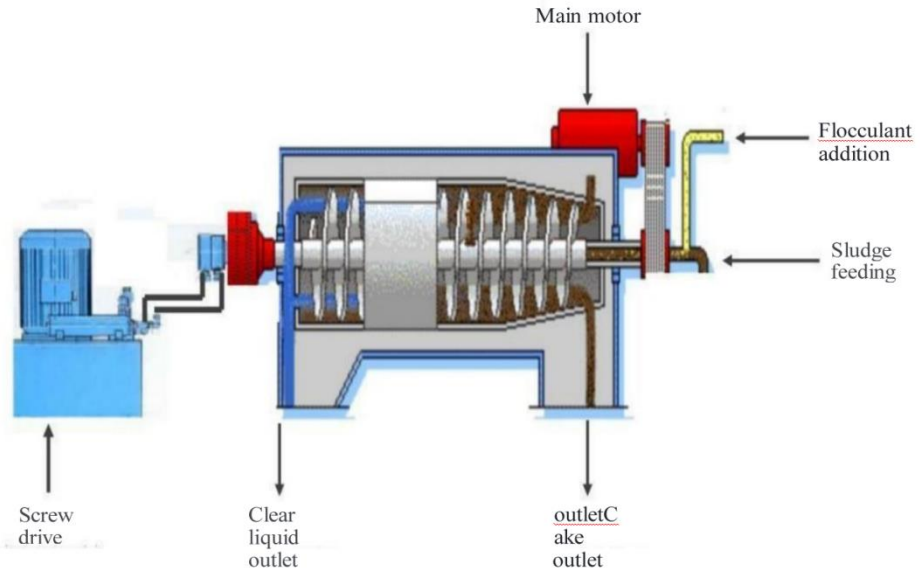

Fig. 5 Schematic diagram of centrifuge treatment equipment（2）

Table 1 Pollutant removal rate

Pollutant Type	Removal Rate (%)	Remarks
Suspended Solids (SS)	92 - 98	Dependent on the initial concentration of slurry (1 - 5%)
Heavy Metals (Pb, Cd)	85 - 93	Through adsorption - coprecipitation
Chemical Oxygen Demand (COD)	70 - 82	Requiring combined oxidation pretreatment
Petroleum - based Pollutants	65 - 78	Hydrophobic groups enhance oil droplet aggregation
Total Phosphorus (TP)	80 - 88	Better effect when compounded with calcium salts
Suspended Solids (SS)	92 - 98	Dependent on the initial concentration of slurry (1 - 5%)
Heavy Metals (Pb, Cd)	85 - 93	Through adsorption - coprecipitation
Chemical Oxygen Demand (COD)	70 - 82	Requiring combined oxidation pretreatment
Petroleum - based Pollutants	65 - 78	Hydrophobic groups enhance oil droplet aggregation

Note: The data source is organized by this study.

(3) External Transportation

After testing, if the moisture content of the dry soil separated from the waste slurry meets the requirements, it will be transported out by muck trucks. The reclaimed water separated from the waste slurry, after being tested and meeting the sewage discharge standards, will be directly discharged into the sewage pipes through the drainage ditches.

Fig. 6 Schematic Diagram of Muck

4. Application effect

4.1 Economic benefits

This technology was applied to the construction of the retaining structure of Zhenpu Road Station, Section 6 of Hangzhou Metro Line 6. According to statistics, the treatment cost per cubic mete of the waste slurry from the diaphragm wall of the station is only 39 yuan. Compared with the unit price of 110 yuan per cubic meter for the conventional external transportation of waste slurry, it has decreased by 66%. The project has saved a total of 280,000 yuan. In addition, good results have been achieved in terms of civilized construction on - site, as well as the impact on roads and the environment.

The cost control achievements brought about by this innovative process have strong reference significance for other industries. For example, in the field of mining, a large amount of waste similar to slurry is generated during the processes of ore screening and tailings treatment. If a similar high-efficiency combined treatment technology is adopted, it can significantly reduce the costs of waste treatment and transportation, freeing up a considerable amount of funds for equipment upgrades or expansion of production scale. In the ceramic manufacturing industry, the treatment of mud wastewater during the production process has always been a major cost item. If the concept of this technology is introduced to optimize the wastewater treatment process and reduce the treatment cost, it can not only increase the corporate profit margin but also make the enterprise more competitive in product pricing, thus expanding the market share.

Table 2 Surface elemental composition and weight

Time		2024/1/5-2024/10/08	
Treatment of Waste Slurry	5250m³	Cost of mud hauling	577500.0
Cost Categories	quantity	unit price（yuan）	total（yuan）
Flocculant	2875	20.0	57500.0

Electricity Consumption	18250	1.0	18250.0
Operation Personnel	2	8000.0	16000.0
Workers	1	4500.0	4500.0
Horizontal Screw Centrifuge (Joint Research, Rental Fee: 50,000 yuan)	3	50000.0	150000.0
Excavator	2	24000.0	48000.0
External Transportation of Earthwork (Included in the Diaphragm Wall Earthwork, Cost Not Calculated Separately)	1575	110.0	173250.0
Total treatment cost of horizontal spiral centrifuge			294250.0
Treatment cost per cubic meter of slurry m^3			39.0
Cost savings			283250.0
Cost reduction rate			0.49047619

Note: The data source is organized by this study.

4.2 Social benefits

(1) Significantly improving the urban environmental quality: Through the efficient treatment of waste slurry, the pollution of urban soil, water bodies and air caused by the random discharge of slurry has been greatly reduced. It effectively prevents the slurry from flowing into urban sewers and causing blockages, reduces the risk of deterioration of the water quality of urban inland rivers, and at the same time reduces the adverse impact on air quality caused by slurry dust. It creates a cleaner and healthier living environment for urban residents and significantly improves the overall ecological environmental quality of the city.

(2) Effectively ensuring the smooth flow of urban traffic: The traditional external transportation of waste slurry often causes serious interference to urban road traffic due to the large size and numerous quantity of transportation vehicles, and the frequent occurrence of slurry leakage during the transportation process, increasing the probability of traffic congestion. However, this combined process converts the slurry into earthwork and clean water, greatly reducing the number of transportation trips, alleviating the pressure on urban road traffic, ensuring the safety and smoothness of road transportation, and improving the operation efficiency of urban traffic.

(3) Actively promoting the green transformation of the industry: This innovative process provides a green and environmentally friendly example for the treatment of waste slurry in the construction industry, inspiring more construction enterprises to adopt advanced environmental protection technologies and driving the entire industry towards the direction of energy conservation, emission reduction and green sustainability. It helps to enhance the image of the construction industry in the eyes of the public, strengthen the industry's social responsibility and competitiveness, and plays a positive leading role in promoting the transformation and upgrading of the construction industry.

(4) Effectively promoting community harmony and stability: If the waste slurry during the construction process is not properly treated, it is likely to cause dissatisfaction and complaints from surrounding residents. This combined process

effectively solves the environmental pollution and other problems caused by waste slurry, reduces the conflicts and disputes between the construction party and surrounding residents, promotes the harmonious coexistence of the construction project and the community environment, maintains social harmony and stability, and improves the recognition and support of residents for urban construction projects.

5.Conclusion

(1) The hydro-cyclone utilizes centrifugal force to quickly separate the larger particles in the slurry, achieving preliminary solid-liquid separation. The horizontal spiral centrifuge further conducts a fine separation of the slurry processed by the hydro-cyclone. Through the collaborative operation of the two, compared with a single treatment device or traditional slurry treatment methods, a large amount of waste slurry can be treated in a shorter time. For example, in a certain large-scale construction project, it takes 24 hours to treat 100 cubic meters of waste slurry with the traditional process. However, with this combined process, the same workload only requires 8 to 10 hours, and the treatment efficiency is increased by approximately 60%.

(2) Compared with the unit price of 110 yuan per cubic meter for the conventional external transportation of waste slurry, the cost has decreased by 66%. The project has saved a total of 280,000 yuan, achieving multiple goals such as cost - reduction, efficiency - improvement, and pollution - reduction.

By drawing on this solution, the expenditure on slurry treatment can be significantly reduced. Take a medium-sized bridge construction project that generates 10,000 cubic meters of waste slurry per year as an example. If the conventional external transportation method is adopted, the cost will reach 1.1 million yuan. However, if a similar high-efficiency treatment technology is used and calculated based on the same cost reduction rate, the treatment cost can be reduced to approximately 374,000 yuan, directly saving 726,000 yuan. These saved funds can be used to purchase higher-quality building materials to enhance the project quality, or invested in other key construction links to ensure the smooth progress of the project.

(3) The application of the combined process of a hydro-cyclone and a horizontal spiral centrifuge in the treatment of waste slurry has promoted the development of green and environmentally friendly technologies in the construction industry, set a demonstration benchmark for energy conservation and emission reduction in related industries, and has extensive social benefits.

(4) It reduces the input of human resources and time costs. With a relatively high degree of automation, only a small number of professional personnel are required to monitor the operation of the equipment, eliminating the need for a large amount of labor for cumbersome operations such as slurry handling and mixing. Taking a medium-sized construction project as an example, the traditional slurry treatment method requires the deployment of 10 workers, while the adoption of this combined process only requires 2 to 3 operators, significantly reducing the labor cost. At the same time, the high-efficiency treatment speed shortens the project's slurry treatment cycle, enabling the project to enter the next construction phase more quickly. This saves a great deal of time costs and accelerates the overall progress of the project.

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