Effect of reinforcement layers on tailings sand with mud interlayer

Xiugui Yang [a], Changshu Pan [a,b*], Xu Hu [a]

[a]Chongqing GaoXin engineering Survey and Design Institute Ltd., Co., Chongqing 401120, China

[b]College of Safety Engineering, Chongqing University of Science & Technology, Chongqing 401331, China

* Corresponding Author: Changshu Pan

E-mail addresses: 8780276@qq.com (Xiugui Yang), pcsqsl@163.com (Changshu Pan), huxu_12315@163.com (Xu Hu)

Abstract. In order to understand the influence of reinforcement layers on the mechanical properties of tailings sand with mud interlayers, tailings sand from a tailings pond in Yunnan were used as the main experimental material, and mesh glass fiber was used as the reinforcement material. The effects of reinforcement density and reinforcement position on the tailings sand with mud interlayers were analyzed through different reinforcement schemes. The results show that: (1) The existence of mud interlayer reduces the shear strength of tailings sand, and the influence of mud interlayer on the cohesion of tailings sand is greater than that on the internal friction angle; (2) Regardless of where the reinforcement layers are placed in the test specimens, the shear strength and peak deviator stress of the test specimens increase with the increase of reinforcement density, while the peak pore pressure of the test specimens decreases with the increase of reinforcement density. Moreover, the increament in shear strength and peak deviator stress, as well as the reduction amplitude in peak pore pressure, will vary depending on the location of the reinforcement; (3) The improvement degree of the reinforcement layers on the shear strength, peak deviator stress, and peak pore pressure of the test specimens is shown as follows: at the interface>inside the interlayer>inside the tailings fine sand. The research results can not only provide scientific basis for the rational layout of the reinforcement layers of the tailings dam reinforcement engineering, it can also provide reference for the reinforcement scheme of slope with weak zone, and even provide reference for the reinforcement of other structures with weak interlayer.

Keywords: mud interlayer; reinforcement layers; reinforced position; reinforcement density; tailings sand

1 Introduction

Tailings pond is a man-made site where is used to store the tailings discharged from metal and non-metallic mines after beneficiation. It has the risk of dam collapse and is

Q. Gao et al. (eds.), *Proceedings of the 2024 7th International Conference on Structural Engineering and Industrial Architecture (ICSEIA 2024)*, Atlantis Highlights in Engineering 30,
https://doi.org/10.2991/978-94-6463-429-7_32

a high potential debris flow hazard source constructed by humans[1-2]. Once a dam breach occurs, it will inevitably endanger the life and property safety of downstream residents, and cause serious pollution to the ecological environment. In 2008, a dam breach accident occurred in Xiangfen County, Shanxi Province, resulting in 277 deaths, 4 missing persons, and 33 injuries, with a direct economic loss of 96.192 million yuan[3]. Therefore, it is necessary to reinforce the tailings dam to reduce economic losses. The reinforcement techniques used by Ramli Nazir[4] and Galvo[5] can both be used for the reinforcement of tailings dam slopes. However, the reinforcement of slopes does not necessarily mean that the tailings dam is stable. More importantly, the dam body needs to be reinforced, such as adding geogrids geotextiles or anchor plate in the dam body to enhance the tensile, shear strength, and overall stability of the dam body.

For this reason, some scholars have conducted research on the reinforcement of tailings dams. Among them, in terms of large-scale reinforcement (dam body reinforcement), Wang Yue[6] borrowed from roadbed engineering to use anchor plates to reinforce dry tailings dams, and analyzed the seepage characteristics and stability of reinforced tailings dams under different rainfall conditions. Yin Guangzhi[7] and Yu Guo[8] reinforced tailings dams with geosynthetic materials, studied the stability of reinforced tailings dams through model experiments and numerical simulations, and compared and analyzed the failure modes of reinforced and unreinforced tailings dams. Wei Zuoan[9] proposed a reinforcement method using end scroll geogrids to address the shortcomings of geosynthetic materials in reinforcing geotechnical structures. The feasibility of using this reinforcement method for tailings dam reinforcement was studied using horizontal slice method and numerical simulation. It was found that this reinforcement method can improve the stability of tailings dams by 14% -17%, and has good development prospects. Lin Jie and Li Dongze used geosynthetic mats as reinforcement materials and analyzed the seepage control effect of geosynthetic mats in tailings dams using saturated seepage finite element method. They also applied strength reduction method to analyze the stability of dam slopes and the stabilization mechanism of geosynthetic mats[10-11]. Wang Yunqing and Chen Hao studied the stability of reinforced tailings dams under rainfall and earthquake effects through numerical simulation[12-13].

In terms of small-scale reinforcement (tailings sand reinforcement), Yi Fu[14] and Jin Hongsong[15] conducted direct shear tests on reinforced tailings sand using geosynthetic materials, studied the effects of load and tailings sand moisture content on the initial shear stiffness of the reinforced tailings interface, and analyzed the slope anti-slip stability of the reinforced tailings dam. Zhang Liyang[16] conducted tensile tests on reinforced tailings using geotextiles and geogrids as reinforcement materials, and compared and analyzed the interface mechanical properties of reinforced tailings under different reinforcement materials. It was found that the reinforcement effect of geotextiles was better than that of geogrids. Luo[17] used Paragrid unidirectional polyester fiber and HDPE TGDG100 high-density polyethylene as experimental geotechnical materials to study the interface mechanical properties between these two materials and tailings dams. The research results can provide good guidance for the selection of reinforcement materials. Yang Han and Yang Yonghao conducted direct shear, consolidation, and permeability tests on reinforced tailings using basalt fibers as reinforcing materials, and analyzed the improvement effect of basalt fibers on the mechanical properties of tailings[18-19].

It can be seen that a large number of scholars have conducted in-depth research on reinforced materials, the stability of reinforced tailings dams, and the characteristics of the reinforcement soil interface, and have achieved good results. However, in reality, there are a large number of mud interlayers in tailings dams, which usually exist in the form of lenses within the dam body and have a significant impact on the stability of the dam body. For this reason, Chen Peng[20] used a combination of indoor experiments and numerical simulations to study the mechanical properties of tailings sand containing mud interlayers, and analyzed the influence of mud interlayers on the seepage field and stability of tailings dams. Zhang Xiaoshun[21] studied the influence of mud interlayers on the strength of tailings through geotechnical tests and found that mud interlayers reduce the mechanical properties of tailings. Li Zhiping[22] studied the influence of mud interlayers on the stability of tailings dams by changing their size, aspect ratio, horizontal and vertical positions, bonding force, and friction coefficient. Qiangui Zhang[23] studied the mechanical properties of tailings containing mud interlayers through macroscopic and microscopic experiments.

In summary, there has been little research on the mud interlayers in tailings dams in the past, mainly focusing on the research of Chen Peng and four others. However, there is almost no research on the reinforcement of tailings with mud interlayers. To fill this gap, this paper analyzed the influence of reinforcement position and quantity on tailings with mud interlayers through triaxial shear tests, using reinforcement density and position as variables. The research results can provide scientific basis for the reinforcement engineering of tailings dams with mud interlayers.

2 Materials and Methods

The experimental materials were taken from a tailings pond in Yunnan, and the tailings were sorted into tailings medium sand, tailings fine sand, tailings silt, and tailings silt through particle size classification. The tailings fine sand and tailings silt were used as the experimental soil. The physical and mechanical parameters were obtained through indoor geotechnical tests, as shown in Table 1. As is well known, glass is a brittle material that is hard and fragile, but after being drawn into fibers, glass fibers have strong tensile strength and low elongation. If fiberglass is made into a mesh structure, the strength of the fibers will be greater and the elongation will be lower. Therefore, referring to the research of Ben Leshchinsky[24] and Jing Xiaofei[25], a mesh glass fiber was used as the reinforcing material, and it was made into a circular material with a diameter of 39.1mm, as shown in Fig.1 (a), to be embedded in the experimental body for mechanical testing; The performance parameters of mesh glass fiber are shown in Table 2.

Table 1. Physical parameters of the experimental materials

Parameter / Material	Dry density ρ/(g/cm^3)	Cohesive force c/kPa	Internal friction angle φ/(°)	Permeability coefficient K/(cm/s)	Compressibility factor $a_{1\text{-}2}$/kPa^{-1}
Tailings fine sand	1.93	10.16	32.68	1.32×10^{-3}	1.73×10^{-4}
Tailings silt	1.82	13.23	31.11	1.26×10^{-4}	2.10×10^{-4}

Table 2. Strength indexes of unidirectional glass fiber

Parameter / Material	Ultimate tensile strength /(KN/m)	Tensile strength at different strains (%) /(KN/m)	
		2	5
Glass fibre	50	15	30

The experimental body is composed of tailings fine sand, tailings silt, and mesh glass fiber. The tail fine sand is used as the main part of the test body, the tail silt is inserted as a mud interlayer in the test body, and the mesh glass fiber is embedded as a reinforcement layers in the test body. Finally, the compaction method is used to prepare the test body through the sampling device shown in Fig.1 (b). The specific method is to use a sampling device to compact the test material in layers. To ensure good contact between soil layers, a small knife needs to be used to roughen the compacted soil layer before compacting the next layer of soil.

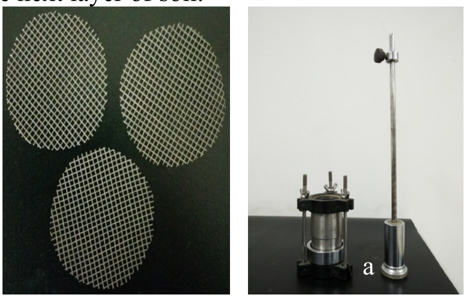


Fig. 1. Physical diagram of glass fiber(a) and device for striking samples(b)

The test method is a consolidated undrained shear test, with confining pressures of 100kPa, 200kPa, and 300kPa, and a shear rate of 0.4mm/min. Before the experiment, the specimen is subjected to confining pressure to measure its pore pressure. When the initial pore water pressure coefficient reaches 0.95, the specimen is drained and consolidated until the degree of consolidation reaches 0.95. Stress is applied at a rate of 0.4mm/min until the axial strain reaches 10-15%. This is consistent with the deformation requirements after pure tailings develop peak softening behavior without reinforcement.

The experiment scheme: (1) Add mud interlayers with different thicknesses (d=1,2cm) to the tailings fine sand for strength testing; (2) Add different quantities (n=1, 2 layers) of mesh glass fibers to the tailings fine sand containing a 2cm thick mud interlayer for strength testing; (3) Conduct strength tests on the reinforcement positions of 2cm clay interlayer tailings fine sand with different numbers of reinforcement layers. A total of 30 experiments were conducted to obtain strength parameters and peak deviatoric stress to analyze the influence of the number and position of reinforcement layers on the mechanical properties of tailings containing mud interlayers. The experimental scheme of this article is shown in Table 3, and the schematic diagram of the scheme is shown in Fig.2.

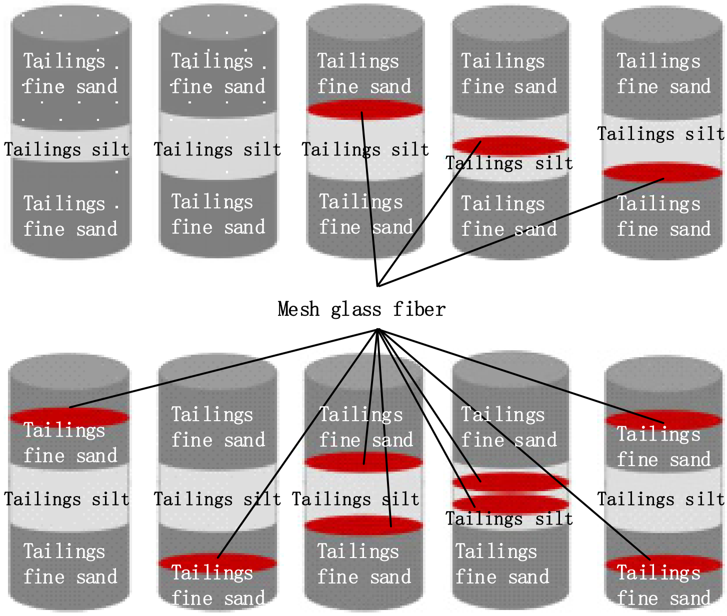


Fig. 2. Schematic diagram of the test scheme

Table 3. The experiment scheme

Serial number / Test conditions	1	2	3	4	5	6	7	8	9	10
Mud interlayer thickness *d*/cm	1	2	2	2	2	2	2	2	2	2
Reinforcement quantity *n*/layer	0	0	1	1	1	1	1	2	2	2
Reinforcement position	/	/	Upper interface	Lower interface	Middle of the interlayer	Middle of upper tailings fine sand	Middle of lower tailings fine sand	At the upper and lower interfaces	Within the interlayer	Middle of the upper and lower tailings fine sand

3 Results and Analysis

3.1 Shear strength parameters

The shear strength parameters of different test specimens were obtained through consolidated undrained shear tests, as shown in Table 4. By comparing and analyzing the shear strength parameters of the pure tailings fine sand test body with the tailings fine sand test body containing a 1cm thick mud interlayer (d=1, n=0) and the 2cm thick mud interlayer test body (d=2, n=0), it can be concluded that:

(1) The cohesive force of the tailings fine sand test body with mud interlayers is smaller than that of the pure tailings fine sand test body, and the cohesive force of tailings fine sand test body with mud interlayers is about half of that of the tailings silt test body, which is consistent with the research results of Qiangui Zhang[20]. The internal friction angle of the tailings fine sand test body with mud interlayers is smaller than that of the pure tailings fine sand test body, but greater than that of the tailings silt test body. Based on the above phenomenon, it indicates that the mud interlayers reduces the shear strength of the tailings fine sand.

(2) When the thickness d of the mud interlayer is d=0cm, 1cm, and 2cm, the cohesive force and internal friction angle of the test body are 10.16kPa, 32.68°, 6.56kPa, 32.29°, 6.96kPa, and 31.44°, respectively; When the thickness of the mud interlayer is d=1, the cohesive force of the tailings fine sand decreases by 3.6kPa, and when d=2, it decreases by 3.2kPa; When the thickness of the mud interlayer is d=1, the internal friction angle of the tailings fine sand decreases by 0.39 °, and when d=2, it decreases by 1.24°; Based on the above phenomena, it can be concluded that the presence of mud interlayers has a different degree of influence on the cohesion and internal friction angle of tailings fine sand, with a greater impact on cohesion than on internal friction angle; At the same time, it also indicates that the decrease in internal friction angle of tailings increases linearly with the increase of interlayer thickness, while the decrease in cohesion is not the same, which is consistent with the research results of Qiangui Zhang[23].

By comparing and analyzing the shear strength parameters of the test specimens (d=2, n=0, 1, 2) containing 2cm thick mud interlayers with different reinforcement densities and positions of tailings fine sand, it can be concluded that:

(1) The cohesive force and internal friction angle of the unreinforced test specimen (d=2, n=0) are 6.96kPa and 31.44°, respectively; The test specimen with one layer of reinforcement (d=2, n=1) varies in cohesive force between 8.55-9.23kPa and internal friction angle between 31.6-31.95° due to different reinforcement positions; The test specimen with two layers of reinforcement (d=2, n=2) has a cohesive force ranging from 12.18 to 12.70kPa and an internal friction angle ranging from 32.15° to 32.51° due to different reinforcement positions. Based on the above phenomenon, it can be concluded that regardless of the location of the reinforcement, the cohesive force and internal friction angle of the clay sandwich test body will increase with the increase of reinforcement density (within a certain range), and the influence of reinforcement density on the shear strength parameters of the test body is greater than that of the reinforcement location.

(2) When a test body containing 2cm thick mud interlayered tailings fine sand is laid with a layer of reinforcement (d=2, n=1), compared to the situation without reinforcement (d=2, n=0), the increase in shear strength parameters of the test body varies due to different reinforcement positions, manifested as reinforcement positions at the upper interface>lower interface>middle of the interlayer>middle of the upper tailings fine sand>middle of the lower tailings fine sand; When a test body containing 2cm thick mud interlayered tailings fine sand is laid with 2 layers of reinforcement (d=2, n=2), compared to the situation without reinforcement (d=2, n=0), the increase in shear strength parameters of the test body also varies due to different reinforcement positions, manifested as reinforcement positions at the upper and lower interfaces>within the interlayer>in the middle of the upper and lower tailings fine sand; The best improvement effect on the shear strength of the test body is achieved by placing the reinforcement belt at the interface, followed by placing it in the interlayer, and finally placing it in the tailings fine sand.

Table 4. The shear strength parameters of different test specimens

Test conditions / Test results	Tailings fine sand	Tailings silt	*d*=1, *n*=0	*d*=2, *n*=0	*d*=2, *n*=1	*d*=2, *n*=1	*d*=2, *n*=1	*d*=2, *n*=1	*d*=2, *n*=1	*d*=2, *n*=2	*d*=2, *n*=2	*d*=2, *n*=2
	/	/	/	/	Middle of the interlayer	Upper interface	Lower interface	Middle of upper tailings fine sand	Middle of lower tailings fine sand	Within the interlayer	At the upper and lower interfaces	Middle of the upper and lower tailings fine sand
Cohesive force c/kPa	10.16	13.23	6.56	6.96	8.72	9.23	9.16	8.63	8.55	12.38	12.70	12.18
Internal friction angle φ/(°)	32.68	31.11	32.29	31.44	31.69	31.95	31.87	31.64	31.6	32.28	32.51	32.15
Change amplitude of cohesive force c/kPa	/	/	/	/	1.76	2.27	2.2	1.67	1.59	5.42	5.74	5.22
Change amplitude of internal friction angle φ/(°)	/	/	/	/	0.25	0.51	0.43	0.20	0.16	0.84	1.07	0.71

3.2 Peak deviatoric stress

The relationship between the thickness of the interlayer and the peak deviatoric stress of the test body is shown in Fig.3. From the figure, it can be seen that the mud interlayers reduces the peak deviatoric stress of the pure tailings fine sand test body, and the peak deviatoric stress decreases with the increase of mud interlayers thickness and increases with the increase of confining pressure; From the figure, it can also be seen that the slope of the line with interlayer thickness between 0-1cm is smaller than the slope of the line with interlayer thickness between 1-2cm, indicating that the peak deviatoric stress of the pure tailings fine sand test body decreases due to the mud interlayer, and the magnitude of the decrease increases with the increase of mud interlayer thickness.

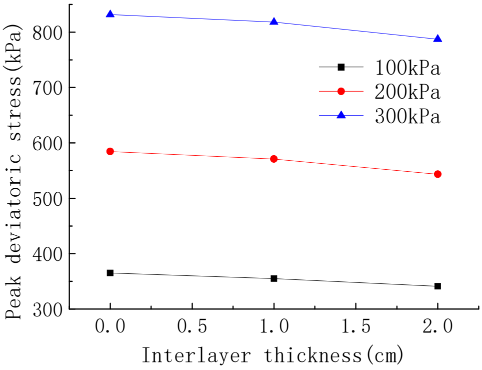
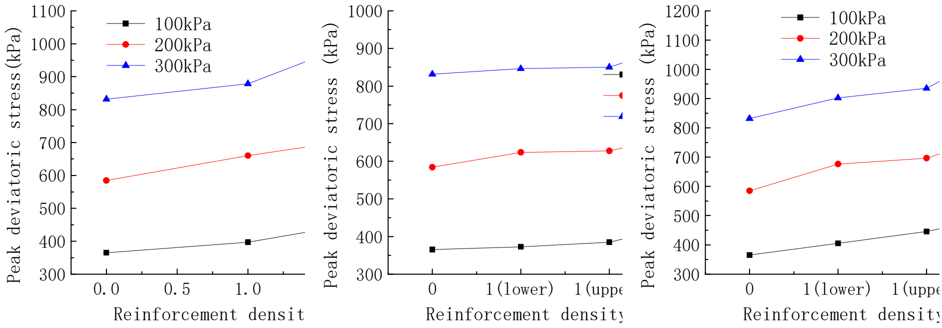


Fig. 3. Relationship between interlayer thickness and peak deviator stress

The relationship between the density and position of the reinforcement and the peak deviatoric stress of the test body with 2cm thick mud interlayered tailings fine sand is shown in Fig.4 and Fig.5, respectively. In Fig.4 (b), 1(upper) represents a layer of reinforcement arranged in the middle of the upper tailings fine sand, and 1(lower) represents a layer of reinforcement arranged in the middle of the lower tailings fine sand; In Fig.4 (c), 1(upper) represents a layer of reinforcement arranged at the interface between the tailings fine sand and mud interlayer, while 1(lower) represents a layer of reinforcement arranged at the interface between the tailings fine sand and mud interlayer. From Fig.4 and Fig.5, it can be seen that adding reinforcement to the tailings fine sand with a 2cm thick mud interlayer can improve its peak deviatoric stress, but the improvement effect varies depending on the density and position of the reinforcement; The peak deviatoric stress increases with the increase of reinforcement density (within a certain range), and there is not much difference in the peak deviatoric stress due to different reinforcement positions under the same reinforcement density, as shown in Fig.4.

When laying a layer of reinforcement, the difference in peak stress values between the middle of the upper tailings fine sand and the middle of the lower tailings fine sand, as well as between the upper and lower interfaces, is relatively small. Compared with the unreinforced test body containing 2cm thick mud interlayered tailings fine sand, the growth amplitude of the peak deviatoric stress in the reinforced test body varies depending on the position of the reinforcement, as shown in Fig.5 (a): the upper interface of the tailings fine sand and the tailings silt>the lower interface>the middle of the interlayer>the middle of the upper tailings fine sand>the middle of the lower tailings fine sand; When two layers of reinforcement are laid, the growth amplitude of the peak deviatoric stress of the reinforced test body is as follows: at the upper and lower interfaces>within the interlayer>in the middle of the upper and lower tailings fine sand, as shown in Fig.5 (b). In summary, regardless of whether one or two layers of reinforcement are laid, the growth amplitude of the peak deviatoric stress of the reinforced test body is as follows: at the interface>inside the interlayer>inside the tailings fine sand. From Fig.5, it can also be seen that regardless of where the reinforcement is placed, the peak deviatoric stress of the reinforced test body will increase with the increase of confining pressure. That is, when the reinforced test body is subjected to greater confining pressure, its ultimate shear strength will increase, and the test body is less prone to failure compared to when subjected to smaller confining pressure.

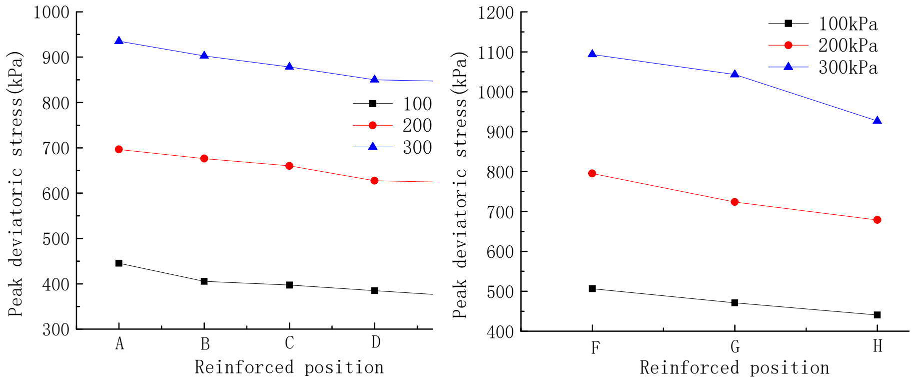


(a) middle of the interlayer

(b) middle of the tailings fine sand

(c) at the interface

Fig. 4. Relationship between reinforcement density and peak deviator stress



(a) 1-layer reinforcement

(b) 2-layer reinforcement

Fig. 5. Relationship between reinforcement position and peak deviator stress

Notes: A represents the upper interface, B represents the lower interface, C represents the middle of the interlayer, D represents the middle of the upper tailings fine sand, E represents the middle of the lower tailings fine sand, F represents the interface, G represents inside the interlayer, H represents the middle of the upper and lower tailings fine sand

3.3 Peak pore pressure

The peak pore pressure of different test specimens was obtained through consolidated undrained shear tests, as shown in Table 5. Comparing and analyzing the peak pore pressure of pure tailings fine sand test body with tailings fine sand test body containing

1cm thick mud interlayer (d=1, n=0) and tailings fine sand test body containing 2cm thick mud interlayer (d=2, n=0), it can be concluded that:

(1) The presence of mud interlayers increases the peak pore pressure of the pure tailings fine sand test body, while the addition of reinforcement reduces the peak pore pressure of the tailings fine sand test body containing mud interlayers. Under the confining pressures of 100kPa, 200kPa, and 300kPa, the peak pore pressure of pure tailings fine sand increases by 6kPa, 12kPa, and 28kPa respectively by adding a 1cm thick mud interlayer. By adding a 2cm thick mud interlayers, the peak pore pressure increases by 11kPa, 20kPa, and 39kPa respectively; The influence of mud interlayers on the peak pore pressure of pure tailings fine sand is greater under higher stress, but relatively smaller under lower stress.

(2) After laying reinforcement on the test body containing 2cm thick mud interlayer tailings fine sand, under the confining pressure of 100kPa, 200kPa, and 300kPa, the change amplitude of the peak pore pressure due to the reinforcement density is 3-8kPa, 14-20kPa, and 14-38kPa, respectively. The change amplitude of the peak pore pressure due to the reinforcement position of one layer of reinforcement is 3-5kPa, 15-17kPa, and 14-29kPa, respectively. The change amplitude of the peak pore pressure due to the reinforcement position of the two layers of reinforcement is 5-8kPa, 17-20kPa, and 33-38kPa, respectively, The influence of the density n of the reinforcement and the position of reinforcement on the peak pore pressure of the test body containing 2cm thick mud interlayered tailings fine sand is more prominent under larger confining pressure compared to smaller confining pressure.

(3) Under the confining pressure of 300kPa, when a layer of reinforcement is laid, the decrease in peak pore pressure of the reinforced test body is as follows: upper interface between the tailings fine sand and tailings silt>lower interface>middle of the interlayer>middle of the upper tailings fine sand>middle of the lower tailings fine sand. When two layers of reinforcement are laid, the decrease in peak pore pressure of the reinforced test body is as follows: at the upper and lower interfaces > within the interlayer > middle of the upper and lower tailings fine sand. Regardless of the reinforcement density, the effect of the reinforcement position on the peak pore pressure is as follows: at the interface>inside the interlayer>inside the tailings fine sand.

Table 5. The peak pore pressure of different test specimens

Test conditions / Test results		Tailings fine sand	Tailings silt	*d*=1, *n*=0	*d*=2, *n*=0	*d*=2, *n*=1	*d*=2, *n*=1	*d*=2, *n*=1	*d*=2, *n*=1	*d*=2, *n*=1	*d*=2, *n*=2	*d*=2, *n*=2	*d*=2, *n*=2
		/	/	/	/	Middle of the interlayer	Upper interface	Lower interface	Middle of upper tailings fine sand	Middle of lower tailings fine sand	Within the interlayer	At the upper and lower interfaces	Middle of the upper and lower tailings fine sand
Peak pore pressur	100 kPa	14	28	20	25	21	20	20	22	22	18	17	20
	200	30	56	42	50	35	33	34	35	36	32	30	33

e u/kPa	kPa 300 kPa	40	90	68	79	55	50	52	64	65	43	41	46

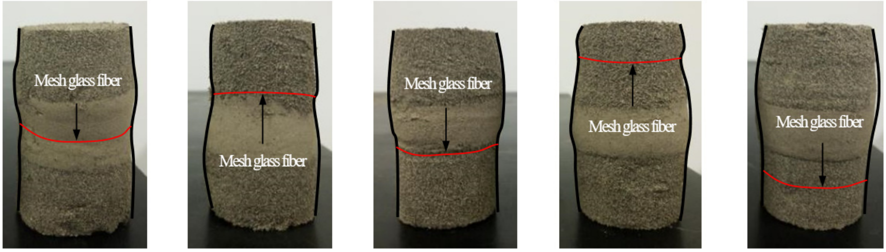
3.4 Deformation mode

Fig.6 shows the deformation of the test body containing 2cm thick mud interlayer tailings fine sand after triaxial shear. It can be seen from the figure that due to the mud interlayer located in the middle, the deformation of the test body is mainly concentrated in the middle, showing a weak expansion trend, showing a "convex in the middle and concave at both ends" shape; Fig.7 and Fig.8 respectively show the deformation diagrams of the test body containing 2cm thick mud interlayered fine sand after triaxial shear under the action of one layer and two layers of reinforcement.

By comparing Fig.6, Fig.7 (a), and Fig.8 (a), it can be seen that when the reinforcement is placed in the middle of the mud interlayer, the deformation in the middle of the test body will shrink inward, and the degree of inward shrinkage of the test body increases with the increase of reinforcement density; When the reinforcement is placed in the middle of the interlayer, it increases the shear strength of the mud interlayer in the middle of the test body, causing the specimen to expand and deform outward at a faster speed than the middle under triaxial pressure, presenting a "concave in the middle and convex at both ends" shape.

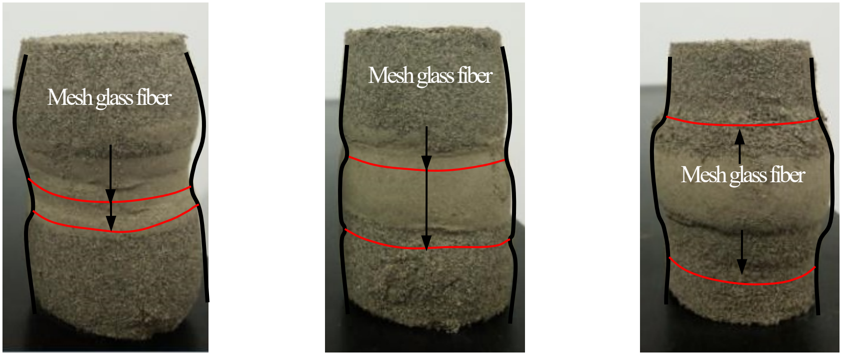
Fig. 6. Deformation of tail fine sand containing 2cm thick mud interlayer

From Fig.7 and Fig.8, it can be seen that regardless of how many layers of reinforcement are added and where they are placed, the expansion degree of the soil at the location of the reinforcement in all test specimens is lower than that of the soil in other parts. This is because the frictional resistance of the reinforcement and the interlocking ability of the grid limit the ability of the soil to expand laterally under load, resulting in relatively small soil deformation. Especially, when the double-layer reinforcement is placed at the interface between the tailings fine sand and mud interlayer, the morphology of the test body after triaxial shear is the most complete, as shown in Fig.8 (b).



(a) middle of the interlayer (b) upper interface (c) lower interface (d) middle of upper tailings fine sand (e) middle of lower tailings fine sand

Fig. 7. Deformation of test specimens strengthened with 1-layer mesh glass fiber



(a) within the interlayer (b) at the upper and lower interfaces (c) middle of the upper and lower tailings fine sand

Fig. 8. Deformation of test specimens strengthened with 2-layer mesh glass fibers

4 Discussion

According to the experimental results, regardless of where the reinforcement is placed, the shear strength and peak deviatoric stress of the specimen will increase with the increase of the number of reinforcement layers (within a certain range). Moreover, regardless of whether one or two layers of reinforcement are placed, the improvement effect of cohesion is shown as follows: the reinforcement is placed at the interface between tailings fine sand and tailings silt>inside the tailings fine sand>inside the interlayer. This may be because:

(1) The soil with reinforced bands has a strong shear strength due to the frictional resistance between soil particles and the reinforcement layers, which limits the tendency for particles to sway.

(2) When reinforced soil is subjected to a load, the first area where failure occurs is the unreinforced part; The deformation continues to develop, and when it reaches the reinforcement layers, it will be blocked by the reinforcement layers, causing the deformation to stop or change direction, effectively restraining the deformation and failure of the specimen.

(3) The particle size of tailings fine sand is larger than that of tailings silt (interlayer), so the degree of interlocking between particles is smaller in tailings fine sand than in tailings silt (interlayer).

(4) The laying of reinforcement layers can increase the biting force between particles and reduce the tendency of particle bouncing. Due to the high biting force of tailings particles, the addition of reinforcement layers has a relatively small effect on improving their cohesion. Conversely, the biting force of tailings fine sand particles is poor, so the effect of improving their cohesion is more significant after laying reinforcement layers.

(5) The interface is a composite of tailings fine sand and tailings silt, and it is a non-uniform mixture. It is more prone to bouncing at the interface between the two materials, so the improvement of cohesion at the interface is the best.

The shear strength parameters and peak deviatoric stress both represent the ability of tailings with mud interlayers to withstand shear stress. The higher the shear strength parameters and peak deviatoric stress, the greater the shear stress that tailings with mud interlayers will bear during failure. This study found that reinforcement can improve the ability of tailings with mud interlayers to resist shear failure by reinforcing them. Tailings dams are composed of many tailings with mud interlayers, therefore, reinforcement can improve the ability of tailings dams to resist shear failure.

According to the experimental results, the reinforcement of tailings dams should focus on the interface between tailings sand and mud layers. Through many on-site drilling of tailings dams, it has been found that mud interlayers often exist in the form of lenses within the dam body, without obvious patterns. Moreover, the reinforcement of tailings dam bodies is generally carried out during operation, such as laying a layer of geogrid every 5m of the dam body elevation.

However, the impact of reinforcement density on tailings dams is not a quantitative superposition effect, as reinforcement not only enhances the shear strength of the dam body, but also affects the seepage field of the dam body. This is manifested as the infiltration rate of tailings in the reservoir area gradually decreases with the increase of reinforcement density. If the tailwater cannot be discharged from the reservoir area in a timely manner, it will raise the infiltration line of the tailings dam, making it prone to overflow or dam failure accidents. Therefore, when reinforcing, both the seepage field and the position of the interlayer should be considered, and the position and quantity of reinforcement should be reasonably arranged in order to effectively improve the stability of the dam body. Therefore, this study only focuses on the reinforcement of newly constructed tailings dams.

We propose the following hypothetical process for the reinforcement of the newly constructed tailings dam:

(1) Identify the surrounding terrain conditions of the proposed tailings dam and determine its ore drawing process.

(2) Find existing tailings dams with similar terrain conditions (90% similarity is sufficient) and the same ore drawing process (ore drawing speed, slurry concentration, ore drawing pipeline diameter, etc.). Carry out drilling work on the tailings dam to determine the distribution of mud interlayers.

(3) In areas with dense distribution of mud interlayers, locate the interface between the mud interlayers and tailings, determine the height difference between the interface and the initial dam, and determine its relative position.

(4) According to the relative position of the interface between the mud interlayer and tailings in similar existing tailings dams, carry out reinforcement engineering with reasonable reinforcement density for the proposed tailings dam. Thus effectively improving the stability of tailings dams with mud interlayers.

5 Conclusions

(1) The presence of mud interlayers reduces the cohesive force and internal friction angle of pure tailings fine sand, and the interface is prone to sliding due to differences in soil quality. Therefore, the mud interlayer reduces the shear strength of pure tailings fine sand, and the presence of the mud interlayer has a greater impact on the cohesion of tailings fine sand than on the internal friction angle.

(2) Regardless of where the reinforcement is placed, the cohesive force and internal friction angle of the test body with mud interlayers will increase with the increase of reinforcement density (within a certain range), and the influence of reinforcement density on the shear strength parameters of the test body is greater than that of the reinforcement position.

(3) Regardless of whether one or two layers of reinforcement are laid, the shear strength and peak deviatoric stress of the reinforced test body increase with the increase of reinforcement density, while the peak pore pressure decreases with the increase of reinforcement density; The degree of improvement in shear strength, peak deviatoric stress, and peak pore pressure of the reinforcement belt is as follows: at the interface>inside the interlayer>inside the tailings fine sand.

(4) The influence of mud interlayers on the peak pore pressure of pure tailings fine sand is greater under higher stress, but relatively smaller under lower stress. The influence of reinforcement density n and reinforcement position on the peak pore pressure of the test body with 2cm thick mud interlayer tailings fine sand is more prominent under larger confining pressure compared to smaller confining pressure.

References

1. Liang Bing, Zeng Yong, Yi Fu, et al. Research progress on seepage stability of tailings dams[J]. Journal of Yangtze River Scientific Research Institute, 2024, 1-9.
2. Qiu Ziyuan, Wang Ruiqi, Yang Na, et al. A three-dimensional numerical simulation study on the downstream impact of a tailings dam failure[J]. Metal Mine, 2024, 1-9.
3. Yu Guangming, Song Chuanwang, Pan Yongzhan, et al. Review of new progress in tailing dam safety in foreign research and current state with development trent in China[J]. Chinese Journal of Rock Mechanics and Engineering, 2014, 33(S1): 3238-3248.
4. Ramli Nazir, Soheil Ghareh, Mansour Mosallanezhad, Hossein Moayedi. The influence of rainfall intensity on soil loss mass from cellular confined slopes. Measurement 81 (2016) 13-25.

5. T.C.D.B. Galvão, A.R. Pereira, M.G. Parizzi, H. Alves Da Silva, Bioengineering techniques associated with soil nailing applied to slope stabilization and erosion control, Nat. Hazards Rev. 11 (2010) 43-48.
6. Wang Yue. Technical research on anchoring plate reinforcement of dry tailings dam[D]. Beijing: North China University of Technology, 2021.
7. Yin Guangzhi, Wei Zuoan, Wan Ling, et al. Study on stability of fine grained tailings dam in geo-grid reinforcement situation[J]. Chinese Journal of Rock Mechanics and Engineering,2005,24(06):1030-1034.
8. Yu Guo. Model experiment and numerical simulation of fine-grained tailings accumulation dam[D]. Chongqing: Chongqing University, 2005.
9. Wei Zuoan, Xu Jiajun, Chen Yulong, et al. Reinforcement method of both ends scroll geosynthetics in tailings dam[J]. Journal of Northeastern University (Natural Science),2014,35(6):880-884.
10. Lin Jie, Shen Zhenzhong, Man Jianming, et al. Research on the influence of geotextile mats on improving the stability of tailings dams[J]. Mining Research and Development, 2020, 40 (11): 28-32.
11. Li Dongze, Niu Ben. Analysis of seepage stability of reinforced tailings dam[J]. Opencast Mining Technology, 2022,37(04):23-26.
12. Chen Hao. Stability analysis of a tailings dam under rainfall and earthquake effects and research on reinforcement measures for increasing seepage of the dam body[D]. Jiangxi: Jiangxi University of Science and Technology, 2023.
13. Wang Yunqing. Dynamic response analysis and reinforcement measures of high tailings dams under earthquake action[D]. Yunnan: Kunming University of Science and Technology, 2023.
14. Yi Fu, Jin Hongsong, Yu Huize, et al. Macro and micro analysis of shear strain bands in reinforced tailings based on particle flow program[J]. Journal of Yangtze River Scientific Research Institute, 2022, 39 (04): 116-121.
15. Jin Hongsong, Yi Fu, Qi Xupeng, et al. Stability and interface shear model of reinforced tailings[J]. China Safety Science Journal, 2022, 32(04): 86-92
16. Zhang Liyang, Yi Fu, Li Junyuan, et al. Experimental study on the mechanical properties of the interface between geotextile reinforced tailings sand[J]. Journal of Yangtze River Scientific Research Institute, 2020, 37(05): 145-150+156.
17. Luo Minjie, Fu Zhilong, Wang Dongmei. Research on interface mechanical characteristics of geogrid reinforced tailings dams[J]. China Energy and Environmental Protection, 2022, 44 (12): 272-277.
18. Yang Han. Experimental study on mechanical properties of basalt fiber reinforced tailings[D]. Chongqing: Chongqing University, 2018.
19. Yang Yonghao. Study on the mechanical properties of polymer materials for improving the storage of tailings[D]. Chongqing: Chongqing University, 2019.
20. Chen Peng. Research on Mechanical Properties of Clay Interlayer Lenticle and Its Influence on the Stability of Tailings Dam[D]. Chongqing: Chongqing University, 2014.
21. Zhang Xiaoshun, Jing Xiaofei, Pan Changshu, et al. Study on the strength characteristics of tailings under the influence of lens body[J]. Science Technology and Engineering, 2017, 17 (11): 188-191.
22. Li Zhiping, Peng Zhenbin, He Zhongming, The law and simplified method of the influence of lens on the safety of tailings dams[J]. Journal of Central South University (Science and Technology), 2017, 48 (05): 1326-1334.

23. Qiangui Zhang, Guangzhi Yin, Zuoan Wei, et al. An experimental study of the mechanical features of layered structures in dam tailings from macroscopic and microscopic points of view. Engineering Geology, 195 (2015): 142-154.
24. Ben Leshchinsky, T. Matthew Evans, Jordan Vesper. Microgrid inclusions to increase the strength and stiffness of sand. Geotextiles and Geomembranes, 2016, 44 :170-177.
25. Jing Xiaofei, Zhou Xiao, Zhao Yishu, et al. Study on influence of reinforcement density on overtopping failure of tailings dam[J]. Journal of Safety Science and Technology, 2016, 12(08): 68-74.