Proceedings of the 3rd International Conference on Green Energy, Environment and Sustainable Development (GEESD2022), X. Zhang et al. (Eds.)

doi:10.3233/ATDE220340

Comparison of Protective Measures Against Wind Blown Sand on Railway

Wenbo WANG[1]
China Railway First Survey and Design Institute Group Ltd., Lanzhou 730000, Gansu, China

Abstract. In the flat area of Northwest China, the subgrade engineering, as a more economical and efficient structural form, plays a leading role in railway engineering. Therefore, the wind sand prevention engineering of railway subgrade engineering needs to be studied. To prevent and control sand damage scientifically, we must correctly understand the types and principles of wind sand prevention and control measures. At present, the main measures to protect the railway from wind and sand are vegetation control measures, such as planting grass and cultivating forests; engineering sand control measures, such as high vertical sand barrier, stone (grass) grid or high density polyethylene Anti-sand net; chemical sand fixation measures, such as spraying chemical agents for sand fixation. In order to compare which kind of wind sand protection project is more suitable for use in the environment of Shashangou landform, according to the mechanical principle of wind sand protection project and the design review opinions of the former Ministry of railways, we have designed a new test section at the small mileage side of Shashangou Bridge on Dunhuang to Golmud railway, and adopted a variety of wind sand protection measures in the test section. In this paper, based on the case observation of the sand hazard prevention and control test section of Shashangou section of Dunhuang to Golmud railway, the effects of various sand prevention measures are compared. At the same time, the bridge engineering (replacing the road with the bridge) is also included in the comparison as a sand prevention measure, and the more suitable sand prevention measures and structural forms in the sand environment are qualitatively compared and popularized. The protection measures based on the fixed principle are the most reasonable; in the typical desert environment, the structural form of bridge engineering is more suitable. In the whole life cycle, the economy of bridge engineering is better than that of subgrade engineering.

Keywords. Dunhuang to Golmud railway, railway sand control, bridge, subgrade, environmental protection

1. Classification of Common Sand Control Measures and Practical Application Effect in Test Section

At present, there are two main mechanisms of wind sand control measures: the first is to reduce the intensity of wind sand flow by reducing the wind speed. Plant protection measures or engineering protection measures are mainly used to increase the movement resistance of wind sand flow, reduce energy and make sand particles deposit; The second is to consolidate the surface of sand source to control the wind erosion process,

[1] Corresponding Author, Wenbo WANG, China Railway First Survey and Design Institute Group Ltd., Lanzhou 730000, Gansu, China; Email: 412049210@qq.com.

mainly by spraying chemical agents on the surface of sand particles to consolidate them, so as to reduce wind erosion (Figure 1).

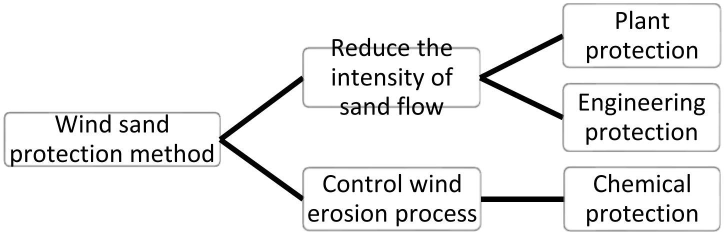

Figure 1. Main wind sand protection methods.

Some scholars believe that it is more reasonable to classify the wind sand protection engineering from the principle of mechanical action. The basic functions of the wind blown sand control project can be summarized as follows: The first is the inhibition of sand initiation; The second is the control of surface wind erosion; The third is the strengthening of the movement of wind sand flow; The fourth is to reduce the wind speed and force the deposition of wind sand flow; The fifth is to control the direction of sand flow artificially; The sixth is to change the overall wind sand flow movement into the dispersed wind sand flow movement. According to these classifications, the corresponding mechanical principles of wind sand protection can be summarized as the following six points: (1) Isolate the contact between gas and solid at the interface; (2) restrain the interaction (coherence) between gas and solid at the interface; (3) increase the local resistance of wind sand fluid movement; (4) reduce and overcome the resistance along the way and local resistance of wind sand fluid; (5) guide the wind blown sand fluid to change direction; (6) reduce and eliminate various resistance of sand dunes in the process of propulsion [1-9].

Table 1. Mechanical classification of wind sand control engineering.

Type	Purpose	Principle of action	Methods
close	Close the active sand surface and change the surface properties of sand dunes	Cut off the contact between gas and solid at the interface	Soil plastering, surface pressing, asphalt emulsion spraying, open tunnel
fixed	Fixed movable sand surface, variable bed is fixed bed	Suppression of gas-solid two-phase interaction at the interface	Spray crude oil, lay grass, seal sand for grass cultivation, grass grid, clay sand barrier
Block	Block and intercept the passing sand flow	Increase the movement resistance of wind blown sand flow and make it slow down to deposit	Fence, high vertical sand barrier, forest belt, sand retaining wall
Dredge	Promote and accelerate the smooth passage of wind sand fluid through the reserve	Reduce the movement resistance of sand flow and prevent separation	Lower wind guide, sand transport bridge, Flat section
change direction	Forcing the sand flow to change its direction	Increase the head-on resistance and force it to flow laterally	Sand guide wall
Dissipation	Change the overall movement of sand dunes into dispersed transport of aeolian sand flow	Reduce sand dune shape resistance and increase sediment transport intensity	Sand jetty, downward wind guide, wind pull

In order to compare which kind of wind sand protection project is more suitable for use in the environment of Shashangou landform, we designed and built a new test section at the small mileage side of Shashangou Bridge of Dunhuang to Golmud railway (Figure 2). Table 1 lists the classification of sandstorm prevention and control works. In the test section, we have set up a variety of prevention and control measures. In addition, we have also adopted the method of replacing roads with bridges to prevent the threat of sandstorm disasters [10]. The application effect of these measures in railway engineering will be analyzed and discussed in combination with actual engineering.

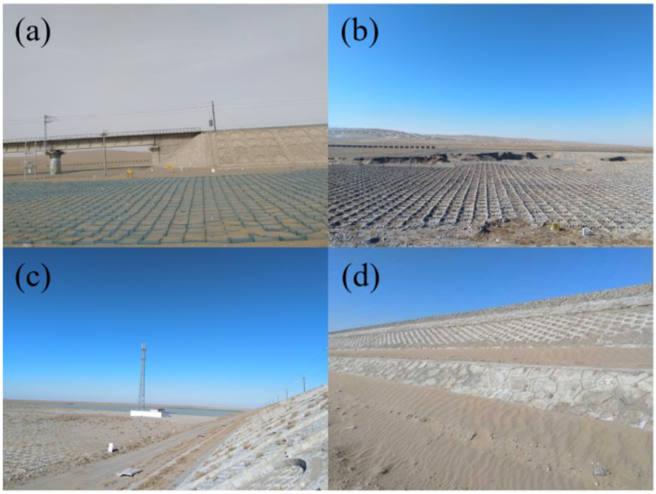

Figure 2. Comparison of wind sand protection measures and effects at abutment side. (a): PE grid at east side of abutment; (b): Stone square on the west side of abutment; (c): DK79 subgrade slope is free of sediment (November, 2019); (d): DK79 subgrade slope sand deposition (May, 2015).

1.1. Application and Effect Analysis of Sand Fixation Measures

The principle of sand fixation measures is to block the contact between wind and sand particles, restrain the generation of wind sand flow and endanger railway safety. For example, the first two protection methods in Table 1 are to prevent the contact and coherence of gas-solid two-phase fluid, so as to achieve the purpose of wind sand protection. There are two main measures: one is to use HDPE net or grass, stone grid, etc. to be laid on both sides of the railway project to achieve the purpose of sand fixation; Second, chemical agents are sprayed on the surface of sand source near the railway to make it crust to control the wind erosion process.

The test section of DK77+700-DIK80+300 section of Dunhuang to Golmud railway is set up. The test section includes wind and sand protection measures such as PE wind proof and sand fixing mesh grid, stone grid sand fixing barrier, plant fiber grid sand fixing barrier, and comprehensive sand fixing grid (sand + curing agent), At the same time, the Key Laboratory of desert and desertification, Northwest Institute of ecological environment and resources, Chinese Academy of Sciences (hereinafter referred to as “desert laboratory”) sprayed chemical agents on the sand dunes on the west side of pier 20-23 of Shashangou Bridge to make the sand surface crust to prevent and fix sand.

In May, 2015, we measured the wind field at the small mileage pier of Shashangou Bridge. At this time, the wind sand protection test section has not been formally completed. On the project site, we can observe that there is obvious sand deposition at the toe of the slope, slope and inspection steps on the windward side (West Side) of the subgrade of the road bridge transition section. After measurement, the depth of sand deposition at the toe of the slope is 17 cm, and the thickness of sand deposition at the inspection ladder shows a decreasing trend with the height, with a thickness of 3-0.5 cm. The filling of this section of road was started in July, 2013, and was completed to the design elevation in April, 2015. It can be concluded that there was obvious sand accumulation at the toe of railway subgrade slope in only 21 months without setting subgrade sand protection works.

The wind sand protection test section was completed in the second half of 2015. It was observed at the same place for many times until November 2020 that there was basically no obvious sand accumulation in the road base section with square grid protection (it was cleaned up during the selection of the national high quality project award in June 2018, and there was no obvious sand accumulation from June 2018 to November 2020). It can be seen that sand fixation measures such as square grid have obvious protective effect on railway subgrade.

However, in desert areas such as Shashangou, the cost of spraying chemical agents for sand fixation is relatively high. As there are continuous sand sources in such areas, the chemical agents are sprayed to fix the sand within a certain range near the railway, and the sand sources outside the spraying range will still be driven by the wind to the fixed sand range, causing harm to the railway. Therefore, it is necessary to increase the sand fixation range. The spraying protection range is difficult to control, and the sand fixation cost is difficult to control. At the same time, this sand fixation method is fragile. Once there is an external force, it is easy to damage the crust, with weak fatigue resistance and poor reliability. Especially at the edge of spraying protection, if the protection thickness is insufficient, it is easy to form a weak surface, resulting in large-scale failure of sand fixation protection.

In 2015, the desert Office of the Chinese Academy of Sciences sprayed chemical sand fixing agent on the sand hill on the west side of 20-23 piers of Shashangou, and protected the spraying area with a protective net to prevent people or animals from entering and damaging. In the year of spraying, it was observed that the crusts were in good condition and played a role in sand fixing. However, it was found that the crusts had been basically damaged and lost their role in sand fixing when it went to the site again in December 2019 (Figure 3). Through the above observation and analysis, it can be seen that the method of spraying chemical reagent for scaling is not applicable as a sand fixation measure under the landform similar to Shashangou.

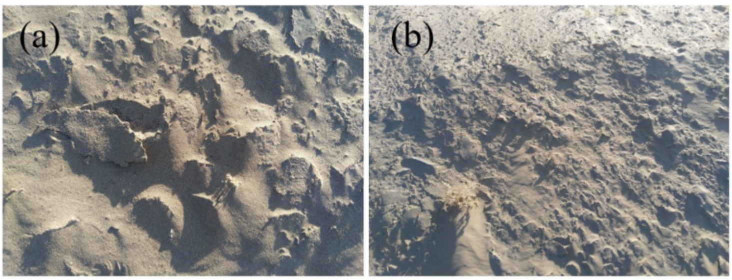

Figure 3. Sand source crust damage on the west side of pier 20. (a): Gradual destruction of crusts (May, 2018); (b) In the later stage, the crust has been basically damaged and the sand fixation effect has been lost (December, 2019).

1.2. Application and Effect Analysis of Sand Control Measures

The main source of the project hazards is the wind blown sand flow. The sand blocking measures are to set up sand barriers and other engineering measures in the forward direction of the wind blown sand flow, increase the movement resistance of the wind blown sand flow, and reduce the speed of the wind blown sand flow to achieve the purpose of sand deposition at the protective measures.

In the wind sand protection test section of Shashangou Bridge, a high vertical sand barrier was set up on the west side of the bridge, which was completed in 2015. In November, 2019, it was observed that there was obvious sand accumulation on the windward side of the sand barrier, some of the sand barriers had been basically buried, and the highest part of the sand accumulation measured on site was 1.8 M (Figure 4). It can be concluded that the high vertical sand barrier can play an obvious role in blocking sand. However, with the increase of sand accumulation in front of the sand barrier, the railway maintenance department needs to clean it regularly to prevent the sand barrier from losing its function due to excessive sand accumulation.

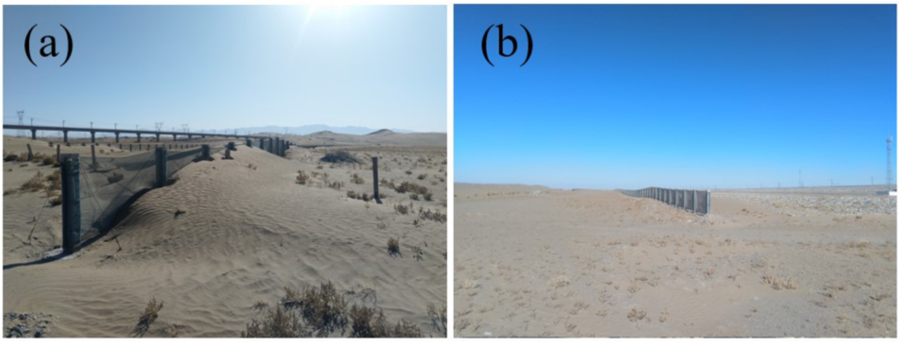

Figure 4. Sand blocking engineering measures on the west side of abutment. (a): HDPE high vertical sand barrier; (b): Comprehensive protective measures for high vertical sand barrier + stone grid.

1.3. Application and Effect Analysis of Sand Dredging Measures

The principle of sand prevention measures is to reduce the velocity of wind sand flow and increase its movement resistance so that sand particles can be deposited. On the contrary, the measures to reduce the movement resistance of the sand flow, prevent the separation of the fluid and solid phases in the sand flow, and accelerate the sand flow through the project area are the sand diversion measures.

This measure is subdivided into “drainage” and “guiding”. The former is to adopt some shape designs that are conducive to the smooth passage of fluid through the project to achieve the purpose of “drainage”. For example, G215, which is also located in Shashangou, has been operating in Shashangou for decades, and there has been no serious wind sand blocking the road. There are three main reasons: (1) The optional range of curve radius of the highway is large, and small radius curve can be selected to maximize the adaptability to the terrain in the Sand Mountain gully. The G215 line basically passes through the center of the gully, a certain distance from the sand mountains on both sides, occupying a more favorable terrain; (2) G215 within the scope of this section, the subgrade filling is very low, the slope is relatively gentle, and the cross section form is a good bypass design, which is conducive to the smooth passage of wind sand flow through the highway, that is, the “sparse” sand design. The windward side of the railway subgrade at the entrance of Shashangou in the same section has serious sand accumulation before the completion of the construction of sand hazard protection measures. The reason is that the subgrade of the national railway project is high, the slope rate (1:1.5) is steeper than the highway slope (1:6), and the wind sand flow will form obvious eddy current at the toe of the subgrade slope, resulting in large energy loss; (3) The highway pavement is cement concrete pavement, and the Z0 value is small, which is also conducive to the smooth passage of wind sand flow.

The “guide” is to set up some wind guide works, such as the following wind guide works, to guide the fluid within the wind guide panel to pass under the plate. Due to the formation of a new flow field distribution, the fluid passing through the lower end of the wind guide plate obtains additional kinetic energy, which can accelerate the wind sand flow through the protected area and reduce the deposition of sand particles. Wind guide works are required for wind guide. The most common is the lower wind guide works, whose mechanical model is the flow around a flat plate. However, the railway ballast has greatly increased the Z0 value, and the track structures such as sleepers and rails have a certain height, which hinders the smooth passage of wind and sand flow through the railway. In conclusion, the wind guide works are not suitable for the sand hazard protection of railway projects. According to the requirements of “guiding” wind, that is, increasing the flow of wind sand can make it pass through the protected area smoothly and guide the wind sand to the predetermined direction as required, it can be achieved by setting sand guiding dikes. Therefore, we have set up a feather shaped sand guide dike at the west side of Dunhuang terrace of Shashangou Bridge (Figure 5). The length of the sand guide dike is 200 m (DK79+300-DK79+500), and a sand guide (retaining) ditch and dike (DK79+100-DK79+300) are set at the side of small mileage (subgrade). The main purpose is to guide the sand blown to the subgrade to pass through the bridge works, so as to prevent sand from damaging the subgrade.

Figure 5. Sand guide dike at windward side of abutment.

According to the actual use effect on site, there is obvious sand accumulation in the sand retaining ditch at the small mileage side of the sand guiding dike, but there is no sand accumulation within the scope of the sand guiding dike. It can be concluded that in this transition area of Gobi desert with rich sand sources, the sand guiding dike has the function of guiding sand, which can guide the wind sand to the bridge works to achieve the purpose of protecting the subgrade works. But this kind of sand guiding dike also has obvious limitations: (1) The sand guiding dike is made of masonry, with large weight and high requirements for the bearing capacity of the base, which is only applicable to the Gobi (sand hazard) area with good geological conditions; (2) In order to guide the sand smoothly, the sand guiding dike is only applicable to the flat terrain area, and cannot be used in the continuous sand dune area with large topographic relief; (3) The height of Railway Subgrade in China is generally high, and the ballast has greatly increased the value of Z0. Like the lower wind guide works, the sand guide dike is not suitable for the wind sand protection of railway subgrade works. It can only be used for wind sand protection in a small range of road bridge transition section (to guide the wind sand in the subgrade range of road bridge transition section to the bridge range); (4) The overall structure size of the sand diversion dike is large, the cost is high, and the economy is poor.

Combined with the example of wind-blown sand subgrade protection engineering measures for Shashangou section of Dunhuang to Golmud railway, through the qualitative comparison of the effects of the above various wind-blown sand protection measures, it is determined that the protection measures based on the fixed principle (square grid + high vertical sand barrier) are the most reasonable in the wind-blown sand subgrade section (Table 2). However, there are many forms of grid and sand barrier measures. In order to determine which measures are most suitable for wind sand protection in areas similar to Shashangou, the applicability and economy of various fixed measures are further discussed in combination with the observation results of the test section and analysis.

Table 2. Comparison of protective measures for sand blown Subgrade in Shashangou section.

Sand fixation principle	Sand fixation mode	Conclusion
close	Sand fixation by spraying chemicals	High cost, difficult to control the scope of use, easy to destroy, and low service life
fixed	Square grid + high vertical sand barrier	This kind of protection method can be adopted in the section of sandy subgrade
Dredge	Sand guiding dike	The scope of application is small, and it is not applicable to the prevention and control of sand damage of Railway Subgrade

2. Comparison of Subgrade Sand Protection and Fixation Measures

Sand damage of railway subgrade is mainly caused by wind sand flow. The area along the Dunhuang to Golmud railway is an arid climate area with small precipitation, great evaporation, deep groundwater level and low soil moisture content, which makes it difficult for plants to survive. According to the climatic and environmental characteristics and hydrogeological characteristics of the section where the line is located, a plane grid sand barrier shall be set on the surface near the line to reduce the surface wind speed and make the sand deposit, so as to prevent the surface near the line from harming the operation of the line in case of wind and sand; A straight plate ventilated sand retaining wall is set outside the plane grid sand barrier to intercept external sand sources. After the implementation of the project, it can also create favorable conditions for the natural growth of local plants, so as to naturally produce sparse vegetation and surface biological crusts, so as to achieve the goal of reducing wind and sand hazards and sand prevention and control.

In view of the above principles, combined with the characteristics of the railway, the engineering sand control measures such as reed handle, branch fence, stone grid and HDPE net are compared and analyzed.

2.1. Economic Comparative Analysis

The plane sand barrier is compared according to the protection area of 100 m^2, as shown in Table 3.

Table 3. Economic comparison of sand control measures of the project.

Protective measures		**Unit**	**Index (yuan)**	**Material service life**
Plane sand blocking grid (1 × 1 × 0.2m)	Stone sand control grid	m^2	12.82	10-15 year
	Branch sand control grid	m^2	10.36	3-5 year
	Reed sand control grid	m^2	5.94	2-5 year
	HDPE sand control grid	m^2	9.09	6-10 year

It can be seen from Table 3 that the reed grid has the lowest index in the plane sand blocking grid, followed by the HDPE grid, and the branch grid and stone grid have higher prices. However, the reed has a shorter service life, twice the service life of the HDPE grid, and the comprehensive service life of the HDPE grid has the lowest index.

2.2. Advantages and Disadvantages Analysis

(1) Stone checkered sand barriers are rigid materials. When the wind blows on the ground, it can not effectively reduce the surface wind speed. When the wind sand flow meets a rigid object, it will increase the head of quicksand (Tangyulong, 2011). For the wind sand flow with small wind speed, it crosses the rigid object to form sand accumulation on the other side, which can play a certain role in sand prevention. When the wind speed is large, it will lose its role or play a small role, and then it will be submerged by wind sand for many years;

(2) The wind blown sand subgrade section is mainly Gobi. The wheat straw square, tree branch square and reed square shall be excavated and buried on the surface first, which will seriously disturb the surface and increase the material source of wind blown sand flow. At the same time, grass squares, branch squares and reed squares are lack of material sources in the gobi region;

(3) Setting the HDPE grid sand barrier on the ground of the active Gobi sand flow can effectively reduce the wind speed passing through the HDPE grid sand barrier, and control the wind speed of the surface layer below the starting wind speed of the surface sand particles, so that the sand particles in the sand fixation area can not move under the wind force, and will no longer become the sand source of the sand flow. A small amount of sand particles jumping along the surface can be intercepted by the HDPE network, so that the ground in the HDPE grid sand barrier will not produce sand. So as to stabilize the desert surface, block the passage of wind and sand flow, and effectively prevent wind and fix sand.

2.3. Construction and Maintenance

HDPE wind proof and sand fixation net has the characteristics of standardized materials and relatively long service life. In addition, HDPE wind proof and sand fixation net is convenient for maintenance, construction and transportation. If the windbreak and sand fixation net is buried by sand during use, the maintenance personnel can regularly clean up the accumulated sand or lift the wedge pile of the buried HDPE windbreak and sand fixation net, which can still achieve the effect of windbreak and sand fixation and reduce the cost to a certain extent. Once the stone square, branch square, reed square, etc. are buried by sand, no trace can be found, and the secondary setting needs to invest manpower and cost again.

2.4. Comparison of Test Section Measures

The construction of wind-blown sand subgrade protection test section of DK 77+700-dik80+300 section of Dunhuang to Golmud railway was completed in 2015. The test section is mainly provided with engineering measures such as HDPE high vertical sand barrier, aluminum plated zinc mesh high vertical sand barrier, PE wind proof sand fixing mesh sand barrier, plant fiber mesh sand barrier, stone lattice sand barrier, combined sand barrier (sand soil + curing agent). According to the use of the test section, the effect of air permeable plane sand barriers such as wind proof and sand fixation net and plant fiber net on Dunhua Georgia railway is better than that of stone grid combined sand barrier (sand soil + curing agent). The plant fiber net sand barrier is a degradable material, but its cost is high and its service life needs further verification. The combined sand barrier is a square grid made of sand and soil mixed with curing agent, which can be easily constructed in areas with abundant sand sources by using local materials. HDPE high vertical sand barrier adopts concrete column steel wire rope to bind the sand prevention net. During use, the sand barrier is easy to be worn and damaged at the joint of the sand barrier and the column under the action of strong wind.

Compared with other sand barriers in Gobi area with abundant sand sources, such as in front of Shashangou gully, HDPE sand barrier is superior to other sand barriers in terms of economy, convenient construction, reducing wind speed, sand resistance and sand fixation. At present, the HDPE sand barrier and sand fixation grid in the test section are in good condition (Figure 6).

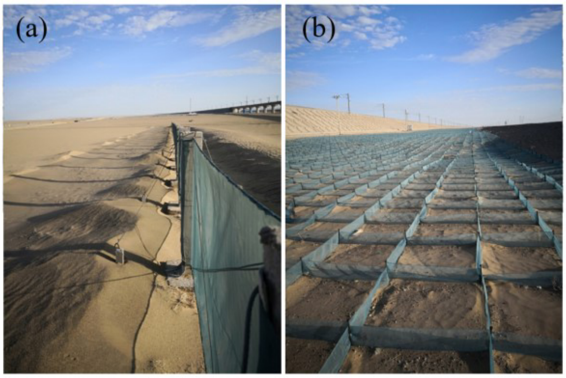

Figure 6. Effect of wind sand protection measures in test section. (a): HDPE high vertical sand barrier in test section; (b): Windbreak and sand fixation net grid in test section.

According to the above analysis, reeds and branches have few material sources in typical Gobi Desert areas, so they need to be purchased and transported from other places. Trenching during construction is easy to damage the surface and generate new sand sources. Moreover, they have a short service life in desert areas with strong wind and are difficult to maintain. HDPE net plane sand blocking grid and high vertical sand blocking fence have the advantages of low economic index, good sand prevention performance, convenient construction and maintenance, and are generally superior to other sand prevention measures in terms of cost performance. At the same time, combined with the experience and opinions of railway public works and operation departments, HDPE network is superior to other protection forms in terms of protection effect, operation and maintenance. Therefore, it is economical and reasonable to adopt HDPE network for wind blown sand subgrade protection in Dafeng Gobi desert area.

3. Effect of Passing through Shashangou by Bridge Instead of Road

3.1. Actual Effect Evaluation of Bridge Leading Road

The above two sections qualitatively compare the application effects of various wind blown sand subgrade protection measures in combination with the test section of Dunhuang to Golmud railway, and conclude that the use of HDPE network in the wind blown sand subgrade section is the most economical and reasonable protection measure. However, bridge engineering is often better than Subgrade Engineering in the wind and sand environment. Therefore, this section evaluates the application effect of bridge engineering through qualitative analysis of field observation after bridge engineering construction.

The Shashangou section of Dunhuang to Golmud railway proposed for the first time that bridges should be used instead of roads to fundamentally prevent sand hazards from threatening railway operation safety. The main works of Shashangou Bridge were completed in 2015 and have been in operation for more than five years. A large number of piers of the bridge are located on the half slope of the sand mountain. According to the field observation in recent 5 years (Figure 7), there is no obvious sand deposition or wind erosion within the bridge.

For example, No. 140 pier to No. 150 pier of Shashangou Bridge are located on the half slope of sand dune, and the height of sand hill is greater than the height of bridge rail surface. If the sand particles are biased or sliding on one side of the pier, resulting in a large amount of leakage of pier pile foundation, the bending moment of pier body will increase and the displacement of pier top will exceed the limit, seriously threatening the safety of railway operation. During the bridge design, special attention has been paid to the piers located on the half slope of the sand mountain, and the design has been carried out according to half flow and half pressure. In November, 2020, the field observation was carried out again for piers 140 to 150. Within the scope of these piers, neither single side sediment deposition bias nor quicksand foundation exposure occurred (Figure 8).

Figure 7. Aerial photo of 140-160 piers of Shashangou Bridge.

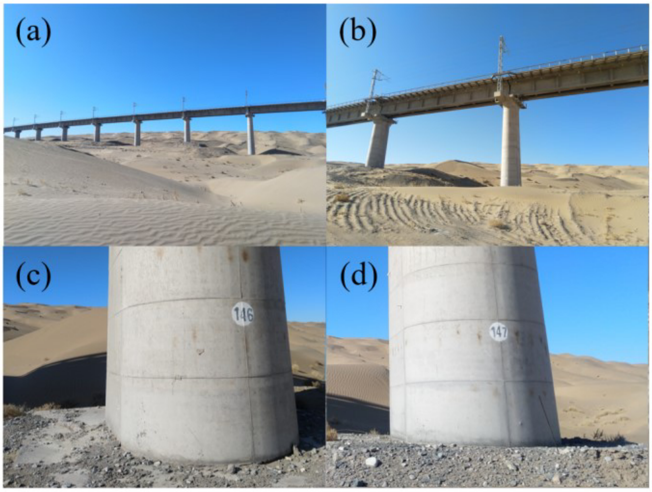

Figure 8. Current situation of 140-147 piers of Shashangou Bridge (December, 2019). (a): Current situation of 140-145 pier; (b): Current situation of 145-147 pier; (c): Detail of 146 pier bottom; (d): Detail of 147 pier bottom.

Since the operation of Shashangou Bridge, the feedback from the construction unit and the maintenance unit and the field observation show that the bridge works have good adaptability to typical desert areas, no sand damage occurs within the bridge range, and the bridge works have no great impact on the sand dune morphology.

3.2. Economic Evaluation of Replacing Roads with Bridges

For railway engineering, generally, the height of 15-16 m is the inflection point of subgrade and bridge investment, that is, the cost of subgrade engineering below this height is lower than that of bridge engineering; The cost of bridge works above this height is lower than that of subgrade works. During the design of railway engineering, most bridges are erected at 8-10 m, and the overall cost of bridge engineering is higher than that of subgrade engineering. The previous qualitative analysis combined with the field observation of the project shows that compared with the subgrade project, the structural form of bridge project is more suitable in the wind and sand environment.

However, good protection effect can also be achieved by setting reasonable wind sand protection works for railway subgrade works. Therefore, it is necessary to make economic comparison between bridge works and subgrade works (including wind sand protection measures).

The design service life of China's national railway project is 100 years. Accurate economic evaluation needs to be conducted according to the whole life cycle of the project. According to the construction drawing budget and Completion Final Accounts of Shashangou Bridge of Dunhuang to Golmud railway, the project cost is 391527843 yuan. In order to make an accurate comparison, we collected the relevant wind and sand protection data of the Jiayuguan Public Works section of Lanzhou Bureau of China Railway, the operation unit of the Liugou Dunhuang railway and the maintenance unit. Liudu Dun railway was completed in August, 2006. After operation, some sections were threatened by wind and sand disasters. In 2014, PE grid protection was added in corresponding sections. However, due to the extreme drought in the region, the temperature difference between summer and winter and between day and night was great, resulting in poor durability of the protection network. In 2018, some protective nets were damaged and even hung on the OCS with the wind, seriously threatening the safety of railway operation. Therefore, the operation and maintenance unit shall reinforce and replace the protective net of the invalid part. The investment of protection works is calculated by replacing 50% of the protection net every 4 years. At the same time, about 500000 yuan of maintenance costs such as ballast cleaning and screening are collected for the wind sand protection of liudun railway every year, and related costs are listed.

According to the landform of Shashangou, the average height of this section is 12 m if subgrade works are adopted. Taking the 12 m high subgrade as the comparison object, 3 culverts/km are considered to be set for flood discharge or surface water, with an average culvert length of 20 m; A necessary bridge of 1 km (more than 16 m high or crossing the main ditch) shall be set in the entire 10.7 km comparison section. According to the above project settings, the subgrade cost index (including culverts and bridges) is calculated to be 23.5 million/km. Combined with the investment in sand storm protection project, through comparative calculation, the subgrade project cost has exceeded the bridge project in the 51st year.

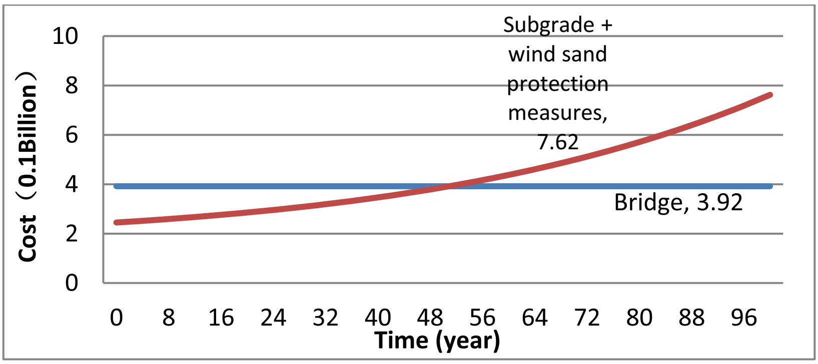

Figure 9. Comparison of investment in bridge engineering, subgrade construction and sand storm protection.

Figure 9 shows the investment comparison between bridge works and subgrade works + wind sand protection works. The zero point of the coordinate is the one-time construction investment of the two. In terms of wind sand prevention, the bridge works do not need to be maintained, while the subgrade works need to be regularly replaced with consumables for wind sand protection works and maintained continuously. From the above analysis, it can be concluded that although the one-time cost of the bridge project is higher than that of the subgrade project, the adaptability of the bridge project to the wind sand environment is better than that of the subgrade project. There is no need to set up wind sand protection facilities, carry out a lot of maintenance work, and there is no aging replacement of wind sand protection materials. According to the comparison of the whole life cycle of the project, the bridge project is also better than the subgrade project in terms of economic evaluation.

4. Conclusions and Recommendations

Since the 1960s, many scholars have studied the wind sand protection engineering, and summarized the advantages and disadvantages of various wind sand protection measures. However, the most suitable protection measures should be selected according to the test results in different environments. For this reason, we have designed and built a new test section of wind and sand protection engineering at the small mileage side of Shashangou Bridge of Dunhuang to Golmud railway. Combined with the actual use effect of the test section, we have made a qualitative evaluation on the applicability of various wind and sand protection measures. Finally, taking bridge instead of road as a kind of wind sand protection measure, the actual protection effect and economy are evaluated. The results show that:

(1) For railway subgrade engineering under wind and sand environment, various sand fixing measures (HDPE windbreak net, stone grid, sand fixing agent sand barrier, etc.) have obvious protective effect on railway subgrade;

(2) The method of sand fixation by spraying chemical agents has high cost, the spraying range is difficult to control, is easy to be damaged by external forces, and is easy to form a weak surface at the edge of sand fixation by spraying, resulting in protection failure. Without the combination of plant sand fixation and other measures, the protection effect is poor, and it is not suitable for sand fixation measures under the terrain and landform similar to Sand Mountain gully;

(3) The high vertical sand barrier can effectively reduce the velocity of wind sand flow and achieve the effect of sand deposition at the sand barrier;

(4) The sand guiding dike has certain sand guiding function, which can guide the sand to the bridge works and protect the subgrade works from the threat of sand, but it has obvious limitations;

(5) For the sand blown subgrade, the protection measures based on the fixed principle (square grid + high vertical sand barrier) are the most reasonable, and the comprehensive effect of HDPE grid plane sand barrier and high vertical sand barrier is the best;

(6) In the typical desert environment, the structural form of bridge engineering is more suitable. There is no sand damage and wind erosion within the scope of the bridge. In the whole life cycle, the economy of bridge engineering is better than that of subgrade engineering.

It should be pointed out that the above main conclusions are based on the field test section of Shashangou section of Dunhuang to Golmud railway and the actual effect observation and analysis after the completion of Shashangou Bridge, and have certain regional characteristics. For example, the protection method of HDPE net plane sand blocking grid and high vertical sand blocking fence is suitable for the subgrade works in this area, but if there are abundant reeds, branches and other materials nearby, or there are certain water sources that can be used for irrigation, the reed branch square grid protection has more advantages. Therefore, it is suggested that the new railway project in the area with serious wind and sand disasters should pass through in the form of bridge project; For the protection of the existing railway sand blown subgrade or the subgrade protection of the railway that is really not suitable for building bridges (such as low-grade railway special line), it is necessary to select the sand prevention engineering measures according to local conditions on the basis of understanding the basic principles.

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