Use of Rocket Traction Method to Span Pilot Rope for Long Span Suspension Bridge Construction in Mountainous Area

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Abstract

There are many pilot rope erection methods for spanning the pilot rope as a part of the suspension bridge construction; these include water towing, manual hauling and air traction. Yunnan Puli long span bridge is a 1040 meters suspension bridge in the Karsts region of China. The bridge is crossing a canyon more than 600 meters deep and is very cliffy on both sides. In addition to the very rugged terrain, the ever-changing weather in the canyon and with thick vegetation covering the ground makes it is difficult to erect the pilot rope using the traditional methods. After comparing three types of erection methods, the rocket traction method was chosen for erecting the pilot rope for this project as an innovative exploration method. Through this project, it has demonstrated that the rocket traction method possesses certain favorable characteristics, including easy reparation, fast in the erection operation, cost effective and environment-friendly, and is particularly suited for use in the mountainous region.

Keyword: Suspension bridge; Pilot rope; Rocket traction; Construction

1 INTRODUCTION

With the continued expansion of the national highway network in China, the highway construction has gradually shifted to the mountainous terrain and remote areas. Suspension bridges have been more widely used under the special geological and topological conditions of mountainous terrain. For constructing long-span suspension bridge erection of pilot rope is the first step of the superstructure construction, which provides the foundation for the load-bearing cable catwalk traction system to be constructed on the pilot rope. However, erection of pilot rope under certain mountainous terrain conditions can be extremely challenging. Thus, the pilot rope erection is often a critical point of the long-span suspension bridge construction, especially for those bridges located in deep gorges, steep dry valleys and other special terrain conditions. Therefore, various factors such as topography, hydrology, environmental effects, weather conditions at the project site and construction safety that can affect the pilot rope erection operations must be carefully considered in the course of choosing a specific pilot rope erection method and the detailed construction procedures to ensure that the overall construction schedule and the construction cost, and the environmental protection requirements can be met.

2 PILOT ROPE ERECTION METHOD FOR LONG SPAN SUSPENSION BRIDGES

In recent years, a variety of pilot rope erection methods have been adopted all over the world. Basis on the ways of spanning the pilot rope across from one side to the other side of the bridge, they can be divided into three main ways: water traction, air traction and land traction. They are briefly described in the following.

2.1 Water Traction

This method is suited for long-span suspension bridge across the river and sea. The pilot rope is pulled across the water by tugboats or barges. There are four methods according to the differences in the docking of the rope.

(1) Free-hanging traction: In this method one end of the rope connected to the hoist at one side of the shore and with the free end of the rope is towed by a tugboat to the other side and connected to the hoist rope there to complete the spanning. This method is simple and commonly used, but the river traffic has to be closed for a long time if the bridge span is very wide. This method was used in the construction of the Guangdong Humen Bridge and the Xiamen Haicang Bridge in China and the Naruto Bridge in Japan.

(2) Segmented docking traction: The pilot rope at each side of the river is connected to a tugboat and the tugboat from each side tows the rope to a temporarily docked barge sitting in the middle of the water and where these two ropes are connected together to complete the spanning operation. This method can shorten the closure time of the waterway but the operations need more vessels. This method was used in the

construction of the Yichang Yangtze River Bridge, the Wuhan Yangluo Yangtze River Bridge and the Guangzhou Huangpu Bridge in China.

(3) River bottom traction: In this method the free end of the pilot rope at one side of the shore is towed by a tugboat across the river with the rope sliding along the river bottom. After reaching to the other side of the shore, the rope is connected to the winch to complete the spanning operation. This method is also simple, but the waterway closure time is long and the riverbed must be free of obstructions. This method was used in the construction of the Jiangyin Yangtze Bridge and the Runyang Yangtze Bridge in China.

(4) Floating rope traction: The pilot rope is fixed on buoys placed at regular intervals on the water so that the pilot rope is floating on the water while being towed by the tugboat across the water. The method is applicable to the waterway full of reefs. The construction process is complex, more susceptible to the storm and the waterway closure time is long. This method was used at the construction of the Kanmon Bridge and the Innoshima Bridge in Japan.

2.2 Air Traction

Just as the name implies, the erection process of spanning the pilot rope across the river or the gorge is done in the air. There are three main ways of doing this.

(1) Helicopter traction: The pilot rope is dragged for one side of the river or valley to the other side by a helicopter. Due to the highly maneuverability and high payload capacity of the helicopter, it can easily adjust the flying direction and speed and the weight of the rope to adapt to the varying site conditions. However, this method requires a higher release cable rack rate and anti-pull cable release to account for the high flying speed of the helicopter, and the operation is more difficult. This method was used in the Akashi Strait Bridge construction in Japan.

(2) Remote controlled airship traction: This method in a way is similar to the helicopter traction, with the airship balloon filled with helium to provide the uplifting and the airship's propelling mechanism to provide the thrust and steering, the pilot rope can be delivered across the river or valley and the head of the rope be dropped from the airship via an automatically controlled releasing mechanism at a predetermined location to achieve the spanning operation. The advantages of this method are safe, cost less and environmental friendly. The drawbacks include the limited load carrying capacity and the need of multi-level conversion. This method was used in the Guizhou Baling River Bridge construction in China.

(3) Rocket traction: The pilot rope is tied of the rocket tail and the rocket is fired and carries the rope to the other side to complete the spanning of the rope. The advantage of this method is the spanning operation is fast while the disadvantage is greater placement errors up to 50-80 meters. This method is more suited for rugged mountains terrain. This method was used in the Hubei Siduhe Bridge construction in China.

2.3 Land Traction

This method is to drag the pilot rope from one side of the project site to the other side along the ground by using human labor. It is more suitable for flat, wide terrains or narrow, shallow valleys. The disadvantage is that a longer construction time is needed. Furthermore, the method is not suitable with terrain covered with dense forests and crops and the presence of high-voltage lines.

Table 1 lists the pilot rope erection methods used by the top ten suspension bridges in the world. In summary, for the current long-span suspension bridges at sea or across rivers at plain terrains the water traction is the primary method used for erecting the pilot rope, while the air traction and the land traction methods are used mainly for erecting the pilot rope at the mountainous areas. With the increasing civil-military cooperation in recent years, rocket traction was gradually used into the mountainous area for pilot rope erection for the construction of long span suspension bridges and was used successfully in the Siduhe Bridge in China.

This paper will discuss the selection and the operation of using the rocket traction pilot rope erection method for the construction of the long-span suspension bridge across the Puli Canyon in China to illustrate the various relevant features of using this method. It is hope that such information will help to promote and advance the use of this method.

TABLE 1 Pilot rope erection methods of World's top ten suspension bridges

No.	Name	Span(m)	Nation	Completion	Erection Method
1	Akashi Strait Bridge	1991	Japan	1998	Helicopter
2	Zhoushan Xihoumen Bridge	1650	China	2008	Helicopter
3	Great Belt East Bridge	1624	Danmark	1996	Free-hanging traction
4	Runyang Yangtze River Bridge	1490	China	2005	River bottom traction
5	Humber Bridge	1410	UK	1981	Free-hanging traction
6	Jiangyin Yangtze River Bridge	1385	China	1999	River bottom traction
7	HK Tsing Ma Bridge	1377	China	1997	Free-hanging traction
8	Verrazano Narrows Bridge	1298	U.S.A.	1964	Free-hanging traction
9	Golden Gate Bridge	1280	U.S.A.	1937	Free-hanging traction
10	Wuhan Yangluo Yangtze River Bridge	1280	China	2007	Segmented docking traction

3 PILOT ROPE ERECTION OF PULI LONG SPAN SUSPENSION BRIDGE

3.1 Project Introduction

Puli to Xuanwei highway (Puxuan highway for short) is a section of the highway from Hangzhou in Zhejiang Province to Ruili in Yunnan Province, which is part of China's 7918 National Highway Network ("7918" network - that is, 7 radiation lines from Beijing, 9 N-S lines across China from north to south and 18 E-W lines run across from east to west). The total length of the Puxuan highway is 85.71km and the construction budget was 8.5 billion yuan (about 1.4 billion USD). It took 48 months to complete the entire project.

Puli long span suspension bridge, as shown in Figure 1, is the key of the Puxuan highway project. The bridge across the Puli Canyon is 1040m in length, 24.5m standard roadbed width and with the design speed of 80km/h. The main part of the bridge is a twin towers single span steel box girder suspension bridge consisting of three spans (166 + 628 + 166 m). The transverse spacing between the two main cables is 26 m and the spacing between the vertical hanging cables is 12m. The 628m main span is made of 8.1m +51×12m + 6.6 m, a total of 53, segments of 3m high and 28.5 m wide steel box girder. The weight of the standard 12m length steel box girder is 140 tons. The two main towers are frame structures with the height of 153.5m and 138.5m respectively for the high tower and the low tower. The distance from the top of the tower to the bottom of the valley is 450 meters. There are three same height spans of prestressed concrete box beams settled on the bridge The main tower foundation is a separate pile foundation, 11.5 × 18 × 7 meters in size, and the foundation is rested on 6 of 3.0m diameter digging holes embedded rock piles. The main cable anchorage was the former prestressing strand anchor. Puli shore anchorage was tunnel anchor with plugged body length of 35 meters and inclination 42°. Xuanwei shore anchorage was gravity anchor, 56.7 meters long, 41 meters wide, inclination 43.5 °.

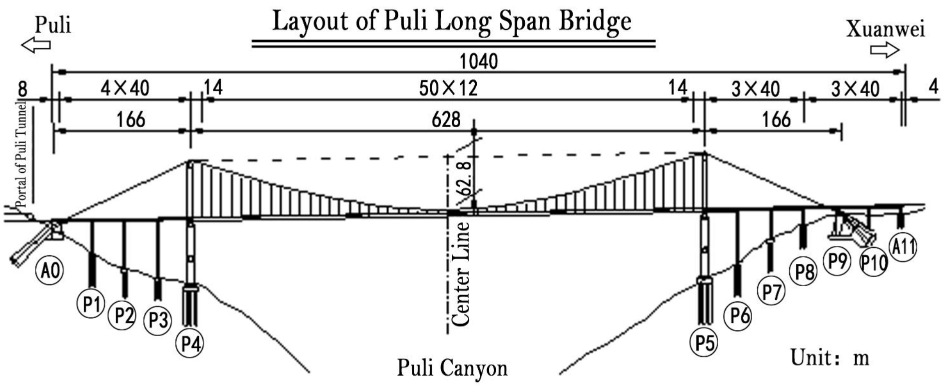

FIGURE 1 Layout of Puli long span bridge.

The bridge is located in a very rugged terrain and complex geology conditions and with ever-presence of stiff wind, unpredictable weather in the canyon. All of these added to the complexity of the construction of the bridge and required high technology and skill, and the budget cost reached 440 million yuan (about 71 million USD).

3.2 Comparison of Pilot Rope Erection Methods

Due to the long span length, great height (450m from the top of the main tower to the bottom of the valley) and the rugged cliffy terrain and particularly with no navigation conditions that limit the choice for the pilot rope election to using air traction and possibly land traction. The following summarizes the evaluation and comparisons of each of the air traction methods and land traction method:

(1) Helicopter traction: Using this method would need to meet the following requirements: ① the permission for using the helicopter is needed, and the procedures for getting the approval are complicated and time consuming. The request for using the helicopter and the specific designed route must be submitted to the government for approval at least one month in advance; ② at least $2000m^2$ of a flat landing site must be provided, and the height of any ground facilities must be lower than 2m within the $5000m^2$ landing site; ③ the costs for hiring pilots, aircrew and ground personnel, and the purchase of high accident insurance would be quite high.

(2) Airship traction: The costs for using Airship traction method could be much less compared with that for using the helicopter method, but Puli valley is often foggy and the weather is always variable, so it is difficult to control the airship in such complex conditions. Furthermore, it is also very difficult to meet the technical requirements for the airship to carry a pilot cable with multi-level converter capability, and due to the limited payload capacity the airship traction can only carry the pilot ropes with small diameter and weights.

(3) Rocket-traction method: The method can only be done by the professional rocket launching company and using of a civilian rocket. The drawback is the landing error can be in the range of 50m.

(4) Manual traction: Puli valley's elevation difference is about 400 meters and the two sides of the valley are cliffy with the slopes between 60 ° ~ 75 °. There is dense vegetation on both sides of the valley and thus it would require to manually open a 0.8 meter wide path for the rope to be dragged through. The construction of such a path would be difficult to carry out and, furthermore, it would be difficult to get approved by the environmental agencies.

3.3 Program Selection

Table 2 summarizes the comparisons of the various options for erecting the pilot rope across the Puli valley. Due to the ever-presence of stiff wind in the valley and the lack of suitable helicopter land site on both side of the valley the option for using the helicopter method was not viable and such option was ruled out. Regarding the use of the airship traction method, the current techniques were unable to meet the requirements and thus was also been ruled out. Due to the high mountains, steep slopes and dense forests on the surrounding terrain, it would incur extensive efforts, high construction costs, longer construction time for using the traditional manual pull method across the valley and thus the use of land traction method was not workable. The only viable option remained was using the rocket throw method. The comparative advantages of using this method were: low-cost, environmentally friendly, safer and reliable and, more importantly, it can save three months of the precious construction time.

Therefore, after carefully evaluating the various options and with intense discussions, the highly technical-intense rocket traction method was finally chosen.

TABLE 2 Comparisons of pilot rope erection methods for Puli long-span suspension bridge

Items	Manual Traction	Helicopter Traction	Rocket Traction
Equipment And Details	Worker:15 Duration:>3 months	Helicopter:1 (From Kunming airport) Duration: 1 day Pilot: 2	Rocket:2 Duration: 4hours Personnel: 3
Economy	Labor Cost: 2000 yuan/month *3months*15 =90000 yuan Land Acquisition Compensation Cost: 1000m2*0.75yuan/m2=750yuan Trees Compensation cost: 1000m2*2trees/m2*15yuan/tree=30000yuan Revegetation Cost: 1000m2*8yuan/m2= 8000yuan Insurance、contingency cost: 100000yuan Total: 90000+750+30000+8000+100000=228750 yuan	Labor Cost: 10000yuan *2 person=20000 Rental Expense: 20000yuan/hr*8hr=160000 Insurance Expense: 5000yuan Total: 20000+160000+5000= 185000 yuan Rent time including: Kunming airport take-off、landing, refuel and all operation process	Rocket: 50000yuan Launcher: 4000yuan *1 Administration and other cost: 50000yuan Total: 50000+4000+50000= 104000 yuan
Advantage and disadvantage	(1) long construction period; (2) effects on the environment protection; (3) high construction risk.	(1) valley bottom is more than 450 meters deep from the main tower, steep terrain and turbulent flow is bad for the safety of flight, (2) No helicopter lift site available on both sides	(1) fast construction speed; (2) less effected by weather and terrain; (3) controllable error

3.4 Program Implementation

(1) Specifications and parameters of rocket traction device

Puli long span suspension bridge rocket pilot rope traction system included the following: rocket engine, traction rope, buffer-rope, lead rope composition, launchers and other parts, see Figure 2.

① Towing Rocket

The total length of the rocket was 1.1m (including 0.95m of the charge), the diameter of the rocket was 155mm, and the rocket engine weighed 43kg (including 18kg of propellant). The thrust generated after rocket ignition was 500kg and the rocket engine operating time was 3.6 seconds and the total rocket flying time was about 10 seconds. When the initial velocity of the rocket launchers reached 50m/s the maximum flight speed was about 130m / s and the maximum flight speed occurred at the 1/3 ascent position.

(a) (b)

FIGURE 2 Towing rocket: (a) rocket launchers and (b) traction system.

② Materials and specifications of pilot rope

As shown in Figure 3 and Figure 4, the rope assembly consisted of the pilot rope which ws connected to the buffer rope, which in turn was connect to the tow rope and the front end of the tow rope was then connected to the rocket tail. The pilot rope was made of polyamide rope (nylon rope) with 14mm in diameter, maximum tension of 2.7 tons, 1350m long length and with a total weight of 149kg. The buffet rope was also made of polyamide, 14mm in diameter and 11m long and 9kg in weigh. The tow rope was made of steel wires, 14mm in diameter and 6m long and 4kg in weigh. The tow rope was needed to prevent the buffer rope from being burn out by the rocket flame.

FIGURE 3 Pilot rope parts.

(2) Key points and important considerations of rocket launch

① Equipment handling and connection: The operator follows the schematic diagram below, Figure 4, to install and connect the various parts. The entire process should be handled carefully and avoid any bumping. The length of the polyamide rope free end should be greater than 20m to play a buffer function. Polyamide rope length must be 1000m.

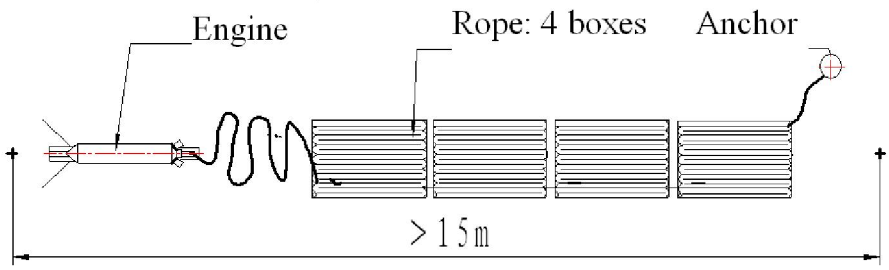

FIGURE 4 Rocket traction parts assemble diagram.

② Launcher, rocket engine, connecting cables and the other parts should be assembled correctly and adjusting the launcher angle to meet the requirements;

③ Ignition operator should report the preparations in accordance with the strict procedures and launch the ignition upon the permission was granted;

④ Tracking the impact point, measuring distance and deviation and used that to adjust the parameters for the second-round emission.

⑤ Launch the second rocket 20 minutes later (to allow for equipment installation time) if no abnormal circumstances were encountered. However, postpone the second ignition if there were large deviations in the first lunch or with a sudden change of the wind conditions.

Though careful preparations and execution, the rocket towing pilot rope program for the Puli long-span suspension bridge project was successfully. Two rockets were fired: The first rocket had 32° vertical angle and 0° horizontal angle (along the bridge direction) and the rocket was dropped at 56 meters away from the preset dropping point. The wind speed was 2.7 m / sec. and the wind direction was 41° to the right of the bridge direction. The operation parameters for the second rocket were adjusted to have 30° vertical angle and 2° horizontal angle to the left of the bridge and that resulted in the rocket dropped at 23.7 meters away from the preset point.

4 CONCLUSION

Using rocket technology to erect pilot rope on Puli bridge construction is an innovation for erecting pilot rope for long-span suspension bridge construction in the mountainous areas in the less developed region in China. Through this project, it has demonstrated that the rocket traction method possesses certain favorable characteristics, including easy preparation, fast construction, environment-friendly, and low-cost and therefore it deserves favorable consideration to promote this pilot rope erection method.

This rocket pilot rope erection system is not only suited for the suspension bridge construction in mountainous areas, it can also be extended to the field of power line construction. We strongly believe that as the technology of this method becomes more mature, it can bring another significant technical advancement to the suspension bridge construction.

REFERENCES

1. Xun Dongliang, Wang Min, Pan Guilin, etc. Innovation and progress of lead rope suspension bridge erection method in our country [J]. *Urban Roads Bridges & Flood Control*, 2009, (1) :24-28.
2. Wang Zongren, Wang Chongxu, etc. Program Selection of Siduhe Pilot Rope Erection[J]. *Highway*, 2006 (3): 184 - 187.
3. Liu Jianxin, He Pizhuang. Prelude to the Large Bridge Construction-New Challenges to the Technicians [M]. Beijing: Beijing People's Transportation Press, 2002.
4. Yan Guomin. Modern Suspension Bridge [M] Beijing: People's Communications Press, 2001.
5. Lei Junqing, Zheng Mingzhu, Xu Gong Yi. Suspension Bridge Design [M] Beijing: People's Communications Press, 2002.
6. Xu Junlan. Suspension [M] Beijing: People's Communications Press, 2001.
7. Zhang Jianping, Chen Kaili. Pilot Rope Erection Method in Aizhai Bridge [J]. *World bridge*, 2010, (4) :20-23.
8. Liu Guoqing, Xue Xiang. Construction Technology Research of Mountainous Suspension [J]. *Engineering Technology*, 2009 (34): 42.