Questions to be responded to by the firm submitting the application Why do you think this project should receive an award? How does it demonstrate:

- innovation, quality, and professional excellence
- transparency and integrity in the management and project implementation
- sustainability and respect for the environment

The bridge is located in the coastal high wind speed belt of China, frequently attacked by typhoon (up to Scale 13) from July to September of year, with prevailing monsoon (up to Scale 11) from November to next March. The bridge deck was designed by a reference wind speed of 55 m/s (100 year return) and a fluttering wind speed up to 79 m/s which is one of bridges with the maximum fluttering wind speed and the most stringent wind resistant requirement in the world. Also, bridge crosses the sea channel of 1513m wide, with maximum water depth of 95m and current velocity up to 3.65 m/s. The bedrock on the sea bed is exposed. The submarine isolated mounds and reefs caused strong eddy at many places and resulted in huge construction difficulty and risk.

The Xihoumen Bridge is a single span suspension bridge using steel box girders, of which main span is 1650m long. The Bridge crosses the Xihoumen channel with tower provided at Laohu Mountain and two long spans (central span and north span) pass through the north and south waterways respectively. The towers and anchors are provided onshore for avoiding influence to complicated marine environment. The arrangements of bridge main cables are 578+1650+485(m), with structural system of two spans continuous and rise span ratio of 1/10. The main span is second ranked in the world at present. It is a steel-box-girder suspension bridge with longest span in the world today.

The bridge incorporated critical technologies with separate steel box girder as core and supported by five major scientific and technological innovations. It solved three critical issues including wind resistance, material robustness of structural members, and construction serviceability for long span suspension bridge built in coastal high wind speed zones.

1. Innovation for Wind Resistance

① New type separate steel box girder was researched, developed and implemented for the first time in a super-long span suspension bridge and the difficulties of structure wind resistance stability were solved. A new law was found that the critical fluttering wind speed is varied with the separation width, and derived the analytical formula of critical fluttering wind speed. Through the wind tunnel test of the whole bridge using air elastic model and large scale segment model, it was determined that the optimized separation width 6m is the optimum with overall consideration of wind resistance performance and economic indicators, which is not only solved the problem that the single piece steel box girder can hardly meet the wind resistance requirements, but also lead to reduced steel consumption, simplified repair and maintenance compared to steel truss girder. It is a new generation of stiffening girder with superior comprehensive performance.

② For the first time, the new law was found that the critical fluttering wind speed is varied with girder segment erection rate, which is different from single steel box girder. For a super long span suspension bridge, the stiffening girder wind resistance performance during erection is not as good as that of a completed bridge. In a strong wind zone, the safe erection of stiffening girder is the most critical. Under influence by meteorological condition at bridge site, the bridge can only be safely and efficiently constructed in 72 days of one year. The erection of stiffening girders would last for at least 150 days. Therefore, the girders can only be erected crossing the typhoon period. According to the new law of wind resistance stability evolution during construction stage, that is, the fluttering stability will reduce after the completion of erection of 50% girder segments in mid span. Therefore, the construction sequence was developed that the erection was stopped after the completion of erection of 50% girder segments and girder segment erection was resumed after safe transition of the typhoon.

③ The movable wind break with variable form was created to ensure the safety of driving on the bridge deck and the wind resistance of structures. For the Xihoumen Bridge, the closing days resulting from wind were reduced by 35 days per year, which may remarkably increase economic and social benefits. There are average 43 days, and maximum 69 days, per year that wind of scale 8 and above are present over the Xihoumen Bridge (the wind speed on the bridge deck may be up to 28.4 m/s). According to the current applicable codes, a bridge must be closed if the wind speed on the bridge deck exceeds 25 m/s, which will cause serious adverse social and economic impact. The wind break must be provided to improve wind environment of driving in order to ensure driving safety on the bridge deck and increase traffic capacity. Five 200×80 mm rectangular-section cross-bar wind break were optimally selected through appraisal to 15 options of wind break in numerical simulation and wind tunnel test methods. The measured results showed that the wind environment of driving on the bridge deck is efficiently improved. After the wind breaks are provided, the critical fluttering wind speed may still meet the wind resistance requirements, but, the stiffening girder has a resistance coefficient up to 1.79 and the bridge structure is under heavy static wind load. Therefore, the wind load is creatively reduced through change in form of wind break, that is, when the bridge is attacked by strong typhoon, the vertical wind break is horizontally placed, with resistance coefficient is greatly reduced to 1.28 to ensure structure wind resistant safety and remarkably increase economic benefits.

2. Innovation on Robustness of Structural Members

The law and transmission mechanism of longitudinal and transverse forces applied on the separate steel box girder were revealed. The fatigue mechanism, fatigue resistance design and maintenance of steel bridge deck were systematically researched for accomplishment of technical innovation in steel box stiffening girder. The construction and force applied on the separate steel box girder are different from the single steel box girder. The large scale model test was researched for a suspension model with scale of 1:2 and total weight of 60 tons. The multi-point synchronous hydraulic loading system and bearing method was researched and developed to solve the problems of complete and accurate simulation of complex structures, suspension system and boundary conditions, and to show the law and transmission mechanism of forces applied on the separate steel box girder. Through fatigue load investigation and based on investigation results of 200 million vehicles, the simplified model of vehicle load on steel bridge deck fatigue design was proposed. The fatigue tests were carried out for 15 test pieces with respect to construction details of orthotropic steel bridge deck. Full scale model fatigue tests of dual-point opposite-phase loading were performed for 10 million times of simulated movable wheel loads, along with static and dynamic load tests on actual bridge. The fatigue mechanism and fatigue resistance design method were systematically researched.

3. Innovation on Material Robustness

Φ5mm series of high tensile steel wires for cable were researched and developed, reaching the international state of the art, filling the gap in China, and successfully applied in Xihoumen Bridge, forming large scale production, and leading to huge economic benefits in the future. With micro-alloying technology, super clean steel smelting technology, special controlled rolling and controlled cooling technology and other advanced techniques, special B82MnQL coil rods for high tensile steel wire were researched, developed and produced, breaking the foreign technology monopoly, replacing the past S82B duplicated coil rod. Based on special B82MnQL coil rod, "three-dimensional control" hot-galvanized process, "dual-tensioning + diameter-limit mould" stabilization process and other independently innovative technologies were used. The manufactured Φ5mm series of 1770 MPa high tensile steel wire for cable reached the international state of the art, promoted the technological progress of the Chinese high tensile steel wire and coil rod industries. The B82MnQL coil rods and 1770-MPa steel wires were firstly applied in the Xihoumen Bridge, a super long span suspension bridge. Subsequently, they were applied in Nanjing Yangtze River No.4 Bridge and Maanshan Yangtze River Bridge and other Chinese super long span suspension bridges, showing that China's manufacturing technology of high tensile steel wires for cables of super long span suspension bridges had reached the advanced level in the world.

4. Innovation on Construction Applicability

① Innovation was adopted in the construction control method for super long span suspension bridges under marine environment. Refined control was achieved in the whole process of construction, ensuring that the bridge construction accuracy reached the international standard. The superstructure construction of super long span suspension bridges began with PPWS method. For a super long span suspension bridge under marine environment, the main cable temperature field nonlinearity, sustainable action of gentle wind, etc. have serious adverse influence on strand measurement and control accuracy. The conventional construction control method can hardly ensure accuracy of main cable erection. Therefore, theoretical model and calculation formula was established for the single strand linearly varied with temperature and span using new cable strand module theoretical model and cable segment model tests, and, "dynamic point-finding control technology" was firstly proposed. Based on the accurate control of the reference cable strand, "inter-layer distance quantification and positioning control technology" was firstly proposed, breaking through the past qualitative control method. The strands formed main cable after tensioning. The flexural rigidity and cable saddle restraint can have direct influence on main cable linearity. The 2-node and 3-node "main cable combined new module" was firstly introduced with consideration of influence of main cable flexural rigidity and cable saddle to ensure that the bridge main cable construction reached world's highest precise level for more than 1000m span suspension bridges at that time.

② In China, the ship dynamic positioning technology was introduced into construction field of suspension bridges, solving the problems of stiffening girder installation. The stiffening girders were lifted after the construction of main cable was completed. The girder segments were shipped to the bridge site for lifting. The barge carrying girders was very difficult to be positioned in Xihoumen channel with strong wind, deep water, rapid current, and exposed bedrock on sea bed. By introducing ship dynamic positioning technology into bridge construction, the secondary cable which was fixed onto the main cable was creatively used to increase ship positioning accuracy to ensure that the barge carrying girders had a positioning error less than 0.3 m and duration longer than 40 min, which safely and efficiently solved the problems that a ship was unable to be positioned in conventional anchoring technology at sea with super deep water and without overburden.

For the Xihoumen Bridge, the innovative technologies of construction ensured high quality of bridge. ① The Bridge was designed with effective bridge deck width of 21 m, and width-span ratio of 1/79 only. The separate steel box girder with central channel of 6 m is used to ensure that the bridge critical fluttering wind speed exceeds 90 m/s, but, the 13.9 t/m steel consumption indicator is slightly higher than that of single steel box girder, achieving the balance between wind resistance performance and economic performance. ② By research on steel box girder erection sequence and safety guaranteeing measures during typhoon period, the bridge was able to successfully withstand attack by typhoons such as Wipha and Krosa, without any accidents, and final closure was successfully implemented in the end of 2007. ③ Compared to the steel wires on Japan Honshu-Shikoku Bridge, the steel wires developed for the Xihoumen Bridge has linearity, tensile strength, yield strength higher than Japanese standard, except number of twists was properly reduced due to Chinese assessment of slackness, and with addition of other indicators including bending, slackness, elastic modulus, number of copper sulfate, etc. ④ With innovative construction control technology, the main cable had an absolute elevation error less than the 1/12000 span. The maximum relative difference of elevation between right and left is 2.6cm approximately. The suspension cable force and main cable strand tensile force accuracies were controlled within 5%. The measured bridge tower deviation was less than 2 cm under action of temperature. Duration of main cable erection was reduced by 3 month. The construction control reached the world's highest accuracy at that time. During construction, the bridge quality is always under control. No fail in quality incident occurred. Within 6 years since the bridge was put into service, 23501030 vehicles have passed through the bridge. And, all indicators met the design requirements with very high qualities. The former president of IABSE Mr. Jacques Combault commented on the Xihoumen Bridge, said, "You conquered various challenges from the harsh environment such as the wind and tides, completed a tremendous construction work which represents the bridge engineering level of China. Hardly any words can express my congratulation." International renowned bridge expert and Denmark Science & Technology University Professor Niels J. Gimsing commented and said, "The separated steel box girder technology was first researched, developed and applied to the long span suspension Xihoumen Bridge, it sets an outstanding model and reference for other bridges in the world. Undoubtedly, this technology can be promoted to the sea crossing bridges in other areas."

During the bridge construction, the project construction was used for the researches of one major State Science and Technology project, one Ministry of Transport technology program project, and eleven projects of Zhejiang Provincial Department of Transport. More than 112 million yuan was invested for research expenditures, solving many world level technical problems, making a lot of world-leading achievements and breakthroughs, including 7 books of specialized work published, 7 sets of software for design, construction and analysis for long-span suspension bridge researched and developed, 120 papers issued, 4 items of new product and new equipment developed, 9 patents for invention and 17 patents of utility model awarded, 6 processes and construction methods obtained, 2 production lines formed, and 13 standards and guidelines developed. For the technical achievements, 4 reached the leading world level, 21 reached the advanced world level, 5 at the leading Chinese level, 17 awarded with science and technology prizes issued by government at all levels, China Highway and Transportation Society and Zhejiang Provincial Highway and Transportation Society, because of the bridge outstanding achievements with respect to engineering structures, aesthetic value, harmonious environment, etc. The Gustav prize was awarded to the Xihoumen Bridge of the Project of Zhoushan Linking Islands in 2010, International Bridge Conference (IBC).

For the Xihoumen Bridge of the Project of Zhoushan Archipelago Linking, the whole management processes of the consultancy services and project bidding fully implemented the FIDIC philosophies. Following the principles of the openness and transparency, the bidding of 29 packages was completed with contract amount of 721 million yuan. No case involving violation of discipline and no effective complaint were found. For the activities of several dozens of consultancy services, the consultant and contractor were efficiently coordinated to ensure project quality, progress, and investment control and management objectives. Emphasis was placed on enhancement of overall strength and large numbers of engineering consulting and management personnel were cultivated. During the bridge construction, non compliance to quality standards never occurred. The Employer fully complied with the honesty and self-discipline principles in FIDIC. With a good mechanism, all the builders kept good honest in performing the duties during the bridge construction. After the bridge completion, the project was audited by national and local authorities and there was not any non-compliance to the consulting engineer's professional ethics.

In the whole process of the bridge construction, the contractor always followed the principle of sustainable development for harmony with environment. The Bridge was designed as a suspension bridge with a main span of 1650m, with tower provided at Laohu Mountain. There is only single span over sea, avoided the deep foundation construction, expensive collision prevention measures and direct corrosion to foundation by sea water. The anchorages on both banks were built at the foot of the mountains, making full use of resistance of the mountain for reduction the anchorage sizes. Only 80,000m^3 of concrete was used in each anchorage. The south approach bridge was provided with horizontal curve with a radius of 1250m, avoiding disturbance to the reservoir on the back of the south anchorage and provision of mountain tunnel. The Bridge was designed with separate steel box girder. Compared to steel truss girder, it saved stiffening girder steel of 14482 tons, main cable steel of 6720 tons, and anchorage concrete of 38400m^3. The movable wind break with variable forms ensured that the closing days would not exceed 8 days per year due to wind of scale 10 and above with respect to traffic on the bridge deck (within 2 years after being put into service, only one closing day occurred due to wind), featuring good environmental adaptability. These measures not only extraordinarily contribute to energy conservation, emissions reduction and sustainable development, but also more importantly reduced the adverse influence of the bridge to the natural environment.

The successful completion of Xihoumen Bridge and project of Zhoushan Archipelago Linking Islands thoroughly changed the natural geographical status of Zhoushan, allowing the islands to become peninsula directly connected to the mainland, and have continuous influence on all respects of social, economic and cultural development. The traffic data showed that there were 1.89 million vehicles from/to Zhoushan in 2009 and 3.89 million vehicles after the bridge open, an increase of 106%. The traffic volume is up to 6.08 million vehicles in 2014, increased by 56%. The Bridge eliminated the shackles of transportation to economy, as a result, Zhoushan has become a center for rapid distribution of all kinds of resource, providing full guarantee for leapfrogging development, breaking the greatest bottleneck holding back the development of Zhoushan. The bridge cracked hard issues of geographic environment of sea islands. Therefore, in Zhoushan the society was rapidly developed, the civilians were directly benefited, and people's livelihood was greatly improved.

What services did the member firm provide to the project? Please describe briefly.

As a design consultancy of the Xihoumen Bridge of the Project of Zhoushan Archipelago Link, we were responsible for and completed all the design work of the Xihoumen Bridge. We were in charge of technology research on separate steel box girders and movable wind breaks, also implemented application of bridge research results in design, made significant contribution to successful construction of the Xihoumen Bridge.

Please use additional pages as needed. Maximum 5 pages per project.

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