The Planning and Design of the 2nd Namhae Bridge

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Abstract: *In this paper, The 2nd Namhae bridge connecting Namhae to Hadong is introduced. The 2nd Namhae bridge is innovative technique and unique suspension bridge. The bridge consists of a suspension span with a 50m-890m-50m span arrangement. In order to overcome restriction of anchorage location and increase wind stability, the main cables have a 3-dimensional profile in the main span, not in a vertical plane. The pylons are inclined to the side spans and comprised of pre-stressed concrete. Streamline-shaped stiffening box girders are used for the superstructure.*

Keywords : 2nd Namhae bridge, Inclined Pylon, 3-Dimensional Cable, Streamline-shaped stiffening box girder

1. INTRODUCTION

The 2nd Namhae Bridge which is constructed on the general national road is the main artery between Kohyon and Hadong IC2. The main purpose of constructing this bridge is to promote a balanced development of nation, regional development and the function of main road on the general national route

19. And further, the 2nd Namhae Bridge construction lead to demand for travel and reinvigorate regional economy.

The total length of the bridge reaches 990m, which has a single-span suspension bridge with main span 890m and approaching bridge with 50m.

This bridge which has 3-Dimensional cable and the streamlined-shaped stiffening girder will be constructed in the Hanryeo Marine National Park. So pylons are located in the land in order to reduce pollution of marine.

Figure 1. An Air View of the 2nd Namhae Bridge

The pylon is inclined towards the back spans as 8 degrees, which makes the direction of resultant cable force on the top of pylon be the same as pylons axis. The 3-Dimensional arrangement of main cable with inclined hanger ropes will improve the wind stability.

2. THE PLANING OF BRIDGE

The 2nd Namhae Bridge was placed an order for the alternative plan of construction on the general national road between Kohyon and Hadong IC2 by Busan Regional Construction and Management Administration.

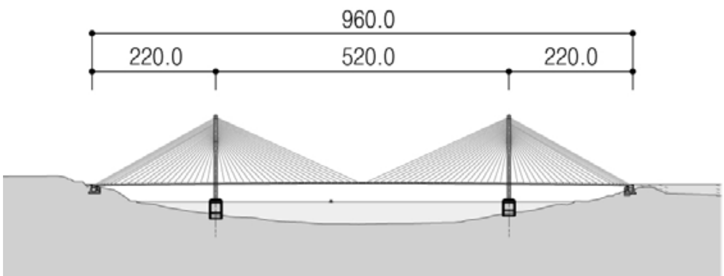

Figure 2. The Original Plan

The original plan was designed to the cable stayed bridge of which the total length reaches 960m and the main span is 520m and had controversial points which are disharmony with Namhae Bridge and pollution of the sea by construction of cassion in the marine.

The alternative plan must be considered by controversial points and various conditions of surrounding situations.

The 2nd Namhae Bridge was designed to the earth-anchored single span suspension bridge in order to increase the main span, apply pylons which are located in the ground and reduce pollution of the sea in the Hanryeo Marine National Park.

The 2nd Namhae Bridge improved on the constructive ability and visual harmony with Namhae Bridge because it solved controversial points and various conditions of surrounding situations.

3. THE DESIGN OF MAIN STRUCTURAL ELEMENTS

3.1 Inclined Pylon

The 2nd Namhae bridge project have introduced the world's first the inclined pylon system to reduce side span ratio, improve structural efficiency including the selection of anchorage positions, and improve cable slip safety ratio at the top of pylons. As shown in Figure 3, the design concept of inclined pylon is to equalize both the angle of incidence(θ_c) and the angle of reflection(θ_b) of the cable, that is, to apply horizontal forces(H) of the resultant force by main and side span tension force T_c and T_b in the longitudinal direction of inclined pylon.

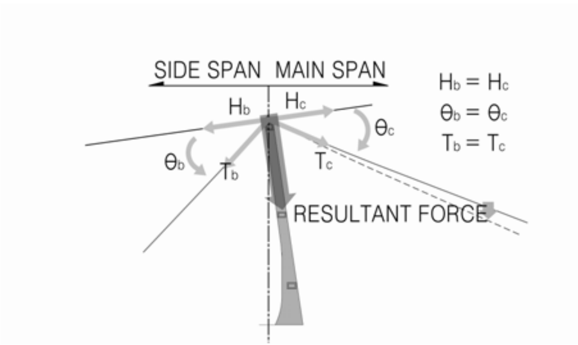

Figure 3. The Principle of Inclined Pylon

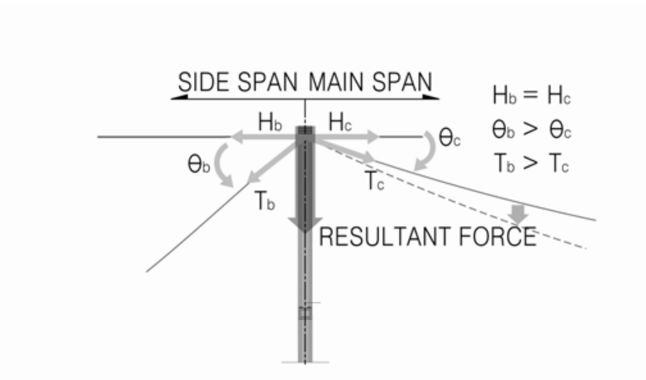

Figure 4. The Principle of Perpendicular Pylon

By introducing the inclined pylon system, the difference of cable forces between main and side span became smaller, which has led to saving extra cables. And, according to the decrease of tensile force over the side spans, the size of anchorage could reduce about 11% as compared with the case of equivalent perpendicular pylon. Also, it could be improve the structural efficiency, such as minimizing setback during the cable installation.

The main cable forces of the inclined pylons are Ts=113MN and Tc=118MN with Ts/Tc=0.96 as shown in Figure 5, which means a decrease of about 15% than those of perpendicular pylons. The main cable slip safety ratio at the top of pylon was confirmed as 10.1, which is about 7.3 times higher than the cable slip safety ratio of 1.38 for the perpendicular pylons.

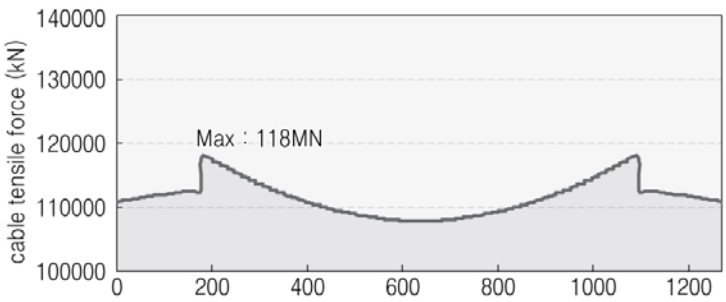

Figure 5. The Cable force of Inclined Pylon

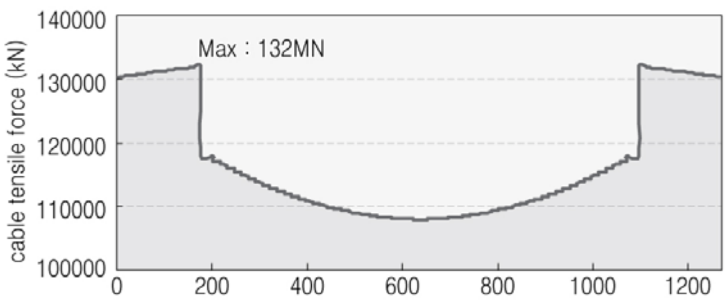

Figure 6. The Cable force of Perpendicular Pylon

By the application of inclined pylon system, the vertical displacement of stiffening girders have seen about 7.7% decrease in figures, from 2.6m to 2.4m as compared with that of perpendicular pylon system. In case of long-term behavior, have seen about 14.3% decrease from 0.42m to 0.36m. This results was due to decrease of transversal displacement of the inclined pylon.

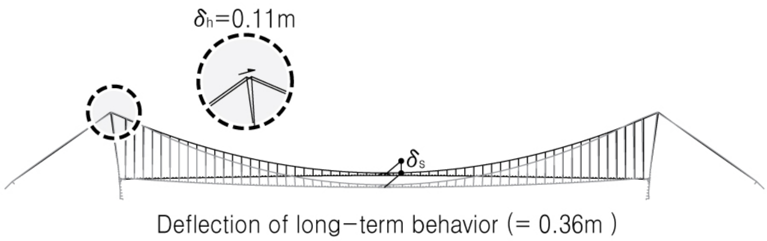

Figure 7. The Displacements of Inclined Pylon

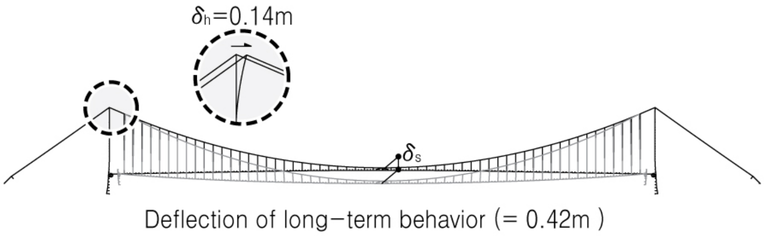

Figure 8. The Displacements of Perpendicular Pylon

At the 2nd Namhae bridge, in order to reduce or prevent cracks during construction of pylon, a eccentric prestressed force is imposed in the longitudinal direction of the pylon. Also, structural stability was secured by the offsetting moments between the resulting moment induced by inclination of the pylon and the moment induced by tensile force of main cables after construction.

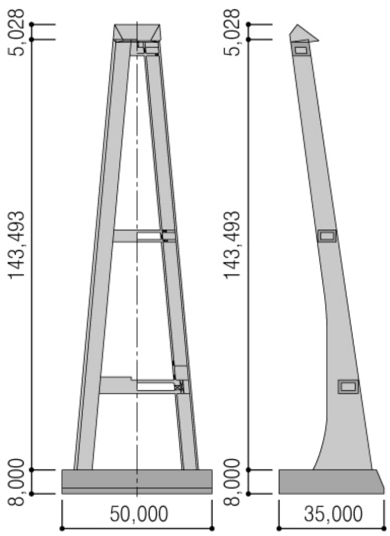

Figure 9. General View of Inclined Pylon

Each pylon consist of two inclined shafts that join together cross beams. The Pylon shafts are hollow reinforced concrete sections of varying rectangular cross sections that are connected together at elevations 31.95 meters and at elevation 81.95 (top of cross beams) in addition to the one at the top.

The pylons are postensioned with external tendons that are anchored in the spread footings at one end and in the interior pylon wall that faces the suspended span.

The external postensioning is designed to overcome the high tension in the concrete walls (facing the water) that will occur during the erection of the pylon itself due to its inclination from the vertical that creates large dead load bending moments and shears.

The postensioning operation must be performed at various stages of casting concrete lifts in order to control concrete tensile stresses in the pylon shafts.

The shafts are envisioned to be casted in approximately 4.0 meter lifts, which is a reasonable height for casting hollow sections with similar dimensions. It is expected that each lift will take 7 working days

to complete using steel jump forms.
The transverse cross beams are 4.00 meter deep and approximately 6.60 meters wide made of reinforced and postensioned concrete hollow sections.

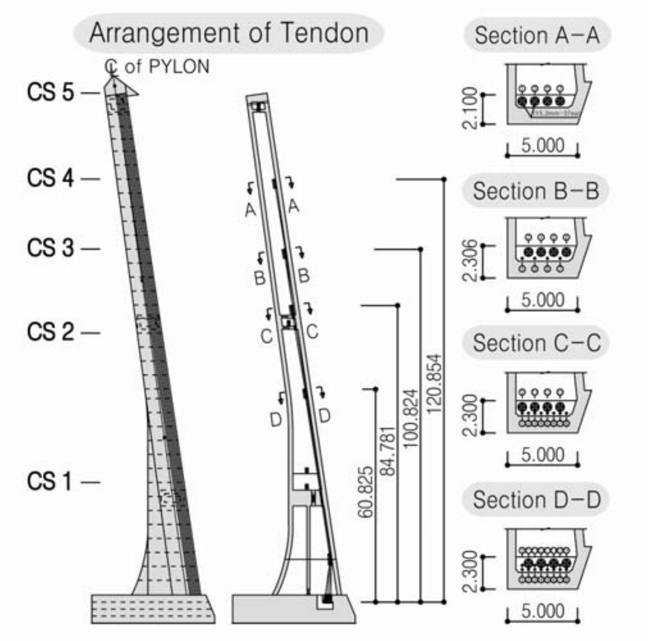

Figure10. Construction Stage of Inclined Pylon

The cross beam below the deck is designed to carry vertical loads via bearings and transverse loads via shear keys from the suspended as well as the side spans. Modular expansion joints are located at deck level over the cross beam.

3.2 Three-Dimension Cable

Considering the bridge areas where No-Ryang Intersection and No-Ryang Tunnel were located before the bridge approach and Mi-Bup Intersection was lied at the bridge-end, both beginning and ending points of the bridge could not avoid requiring change of horizontal alignment of road and expansion of road breadth.

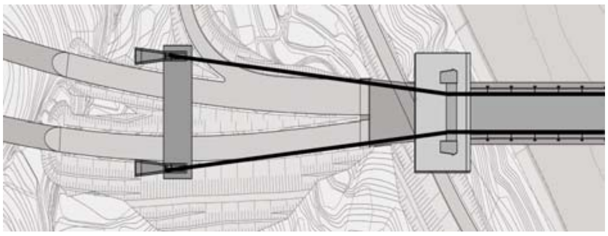

Figure11. 3-Dimensional Cable of Side Span

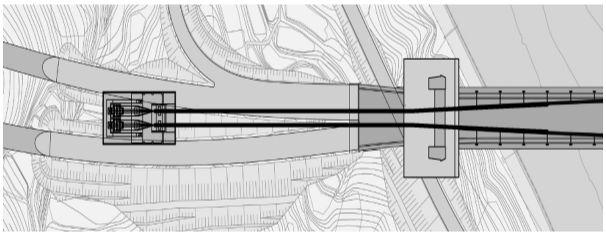

Figure 12. 3-Dimensional Cable of Main Span

In view of such topography and condition of horizontal alignment, it was impossible to follow two-dimensional cable configuration of general suspension bridge. Therefore, three-dimensional configurations of main and side spans as shown in Figures 11 and 12 were reviewed comparing each other to select optimum cable configuration with best structural stability.

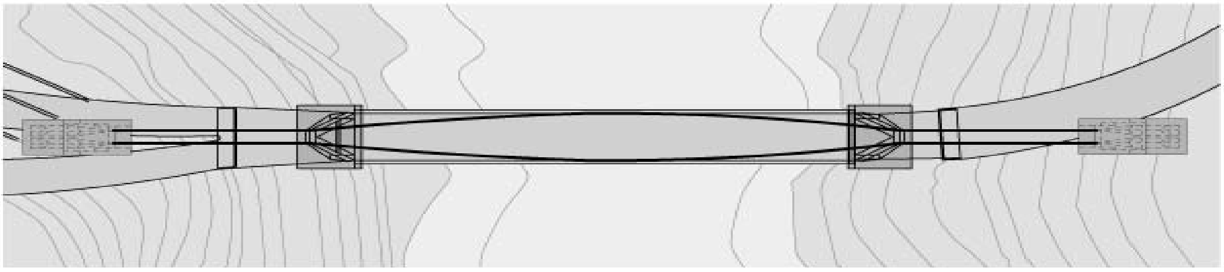

Figure13. 3-Dimension Cable Arrangem

When arranging the cables in two-dimensional way for central span and three-dimensional way for side spans as shown in Figure 11, the horizontal force was developed greatly with the increase of cable bending angle at tower saddle, which accordingly caused increase of excavation due to enlargement of anchorage dimension. Also, this made big difference between anchorages at starting and ending points, thereby forcing the suspension bridge to be non-symmetrical structure. Therefore, as shown in Figure 12, the side span cables were erected straight in center, the cables in main span were arranged in three-dimensional method, the dimension of anchorages were made smaller, and cable's horizontal force was controlled to raise structural stability and horizontal resistance of hangers, and wind stability and landscape symbol were improved.

3.3 High Tensile Strength Cable System

Main cable that is the most important element in suspension bridge transmits load that occurs in stiffening girder to pylon and anchorage.

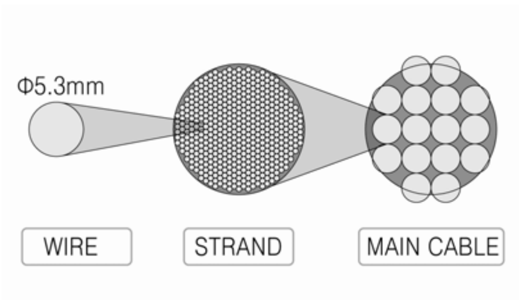

Figure 14. Cross Section of Main Cable

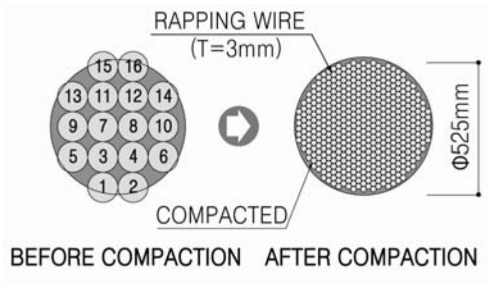

Figure 15. Compaction of Cable

The main cable of 2nd Namhae bridge consists of 16 strands (480 wires) of 5.30mm diameter. It apples to the high tensile strength cable with 1,960MPa and is planned to guarantee structural stability, economical efficiency, durability and efficient maintenance.

The cable will have s-wire wrapping and a total diameter including the s-wire of 525mm after compaction. The strands will be erected with the air-spinning method which had many domestic construction experiences.

The suspenders are typical CFRC type of 85mm and 90mm in diameters. The suspenders are socked at both ends connected to the deck by means of pins.

3.4 Streamline-Shaped Stiffening Girder

As for the 2nd Namhae bridge, streamline-shaped stiffening box girder was selected, which has numerous cases of applications among middle-sized suspension bridges having main span of less than 1,000 m and excellent performance in wind resistant stability.

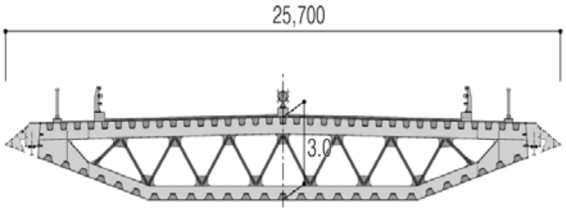

Figure 16. Streamline-Shaped Stiffening Girder

As for the stiffening girder, the upper and lower longitudinal ribs were all applied with U-ribs, and effort was made for lightening steel weight and increase stiffness by comparing with I-ribs. Also, wind stability for whole suspension bridge system was secured as it was confirmed that the girder is safe (Vcr=68.8m/s) up to flutter speed of 80m/s (angle of attack 0 degree) through two-dimensional wind tunnel test and CFD (Computational Fluid Dynamics) analysis.

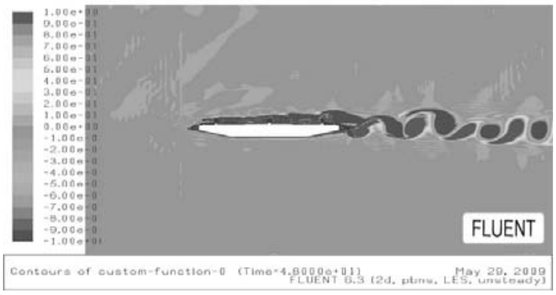

Figure 17. CFD Analysis

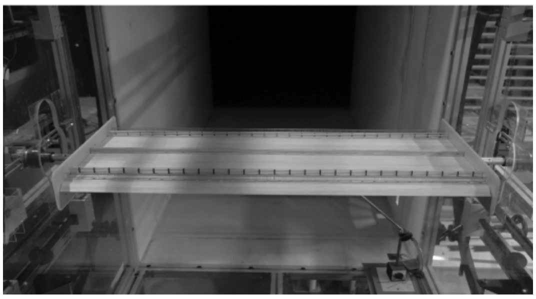

Figure 18. Wind Tunnel Test

3.5 Anchorage System

The 2nd Namhae bridge where gravity anchorage system that was supported cable force by bodily self-weight, designed to satisfy bearing capacity and overturning stability of structure.

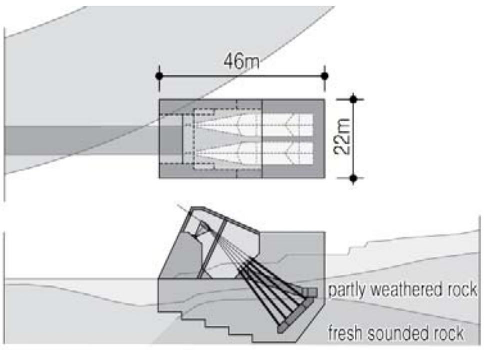

Figure 19. Gravity Anchorage System

Front side of anchorage was designed for stairway foundation and minimizing of rock and ground excavation. Also, it gives careful consideration for maintenance of anchor chamber.

4. The Planning of Erection

The 2nd Namhae bridge was designed with various conditions of surrounding and erection site, will be constructed using a sequence described as follows, that is, the construction stage are anchorage, pylon, main cable(Air Spinning method), stiffening girder, cable lapping and removing of constructional equipment.

The form types of the inclined pylon is designed with general Climbing Form(straight section) and Auto-Climbing Form(curve section).

The pylon footings are 50.0m*35.0m*8.0m massive concrete elements using 35MPa concrete. So it will be required that is crack control method.

The placing for the pylon footings with massive concrete is designed by 4th separate placing method in order to prevent thermal cracks by hydration heat.

The main cable erection is planned the A/S method that had wide experiences. The types of construction methods used are shown in Figure 20.

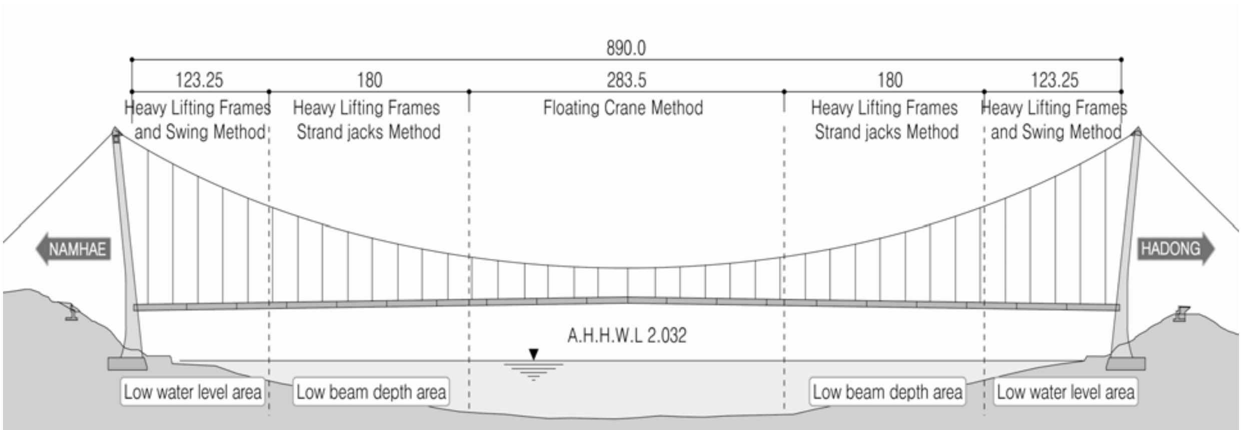

Figure 20. Erection of Stiffening Girder

The stiffening girder will be fabricated with 15.0m per a segment for a final field assembly. The centeral stiffening girder is planned to be erected by a 1,200ton floating crane, and the other stiffening girders are erected by the other methods.

Heavy Lifting Frames method is very efficient construction method, which used in unavailable position with the floating crane. Heavy Lifting Frames method is planned to erect the segments close to the pylon. And then the segment connected by hanger with the repeated.

If stiffening girder constructed from main span to pylon, the cable would occur serious moving away and twisting. Therefore, it must be erected by opposite direction, which planned with structural stability and durability.

5. CONCLUSION

This study is mainly concerned with the design concept of simple span suspension bridge with inclined pylon. In this paper, specified planning, design, and erection for the 2nd Namhae bridge that is constructed on the general national road between Gohyeun and Hadong. This bridge was designed with world's first 3-dimensional cable system by the originative and innovative techniques.

It is necessary to discuss and have interesting for the 2nd Namhae bridge in order to have a successful construction.