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# Design Process of the Fixing Pipes in the Guide Pipe Anchor System for Cable-Stayed Bridges

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***Abstract*—**For the efficient and safe use of the cable-stayed bridge, a design based on the detailed local analysis of the cable anchor system is required. Also, a theoretical design process for the anchor system should be prepared and reviewed. Generally, the size of the fixing pipe in the anchor system is decided according to the specifications prepared by cable-manufacturing companies, and accordingly, there is difficulty determining the initial inner diameters of the fixing pipes. As such, there is no choice but to use the products with the existing sizes. In this study, the existing design process of the fixing pipe, is a type of guide pipe anchor in the cable anchor system, is reviewed, a formula determining the thickness of the fixing pipe is proposed, and the convenience and validity of the suggested equation is compared with the results of the existing designs to verify its convenience and validity.

***Keywords*—**Cable-stayed bridge; Guide pipe anchor system; Fixing pipe; Theoretical design process.

## I. INTRODUCTION

THE construction of long-span bridges such as cable-stayed and suspension bridges has dramatically increased of late worldwide. In particular, many cable-stayed bridges, including Sutong Bridge in China, with a center span of 1,088m, and Russky Bridge in Russia, with a center span of 1,104m, are under construction or are now in use. The design and construction technology of cable-stayed bridges has remarkably developed since Strőmsund Bridge, the first modern cable-stayed bridge, was constructed in 1955.

The cable-stayed bridge has a structure that transfers the fixed loads applied to the bridge to the pylons via cables, and accordingly, long-span bridges can be constructed due to the minimized effects of fixed loads on the stiffening girder, and due to the effective resistance against other loads. The design of the cable anchor system of cable-stayed bridges is usually conducted through a theoretical design considering the load flow or the pathway of the tensile force to the members to decide the cross-section and then to confirm the design validity by investigating the stress via finite element analysis and experiments. In the loading process of a dead, live, and secondary load onto the stiffening girder to the cable, and further to the cable anchor system, not only the local-stress concentration in the cable anchor system resulting from the large tensile force on the cable but also severe stress disturbance develops. To ensure safety, critical examinations such as a design based on a detailed local-stress analysis, and analysis of the effects of the live load on the fatigue, are required.

The common criteria on the design process of the cable anchor system include restrictions on deciding the cross-section of the fixing pipe, but a theoretical approach to deciding the cross-section for the initial design has yet to be prepared. Accordingly, the criteria used in practical designs are usually those of the cable-manufacturing companies. Therefore, when designing the fixing pipe of the cable anchor system, the specifications of the existing products are used, and as a result, it is difficult to conduct economic and rational designs. To propose the initial design values of the cable-fixing pipe, the mean values of the inner diameter of the anchor system according to the cable tensile force are prepared in the CEB-FIP design criteria [1].

In this study, a guide pipe anchor system was selected from cable anchor systems to show the existing design flow, and an equation theoretically deciding the initial thickness of the fixing pipe is suggested. In addition, a compensation design of the fixing pipe of the anchor system is also suggested using design criteria and equations. Moreover, a three-span continuous cable-stayed bridge with a 240-m-long main span with streamlined steel decks was selected to verify the convenience and validity of the compensation design, which was based on the initial thickness of the fixing pipe decided by the suggested equation.

## II. ANCHOR SYSTEM OF THE GUIDE PIPE ANCHOR

According to the anchor system of the guide pipe anchor which was recently used, a fixing pipe is completely welded onto a lateral web for integrated structural behavior. As a result, the concentrated local stress developed by the cable tensile force is effectively distributed and transferred to the structural members of an initial steel girder, and the resistance against fatigue is excellent. By virtue of the integrated structure, the reinforcing structures can be simple and economic, and the minimized exposure provides a beautiful landscape. In addition, as the distance between the damper and cable anchor is long, it is easy to control the cable vibration [2], [3], [11]. Accordingly, the integrated structure can be applied to long-span cable-stayed bridges with a longer than 500 m main span. In South Korea, the structure was used for the bridges of

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Yeongheung, Wando, and Incheon [4], [5]. Fig. 1 shows the concept of an anchor system of the guide pipe anchor with steel girders.

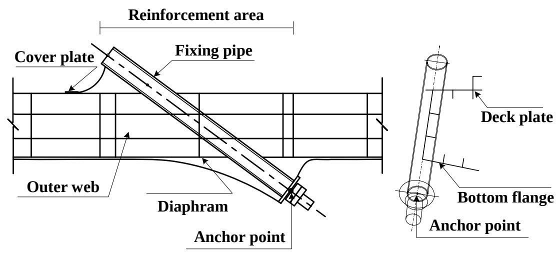


Fig. 1 Explanatory diagram of the guide pipe anchor system

At the area where the fixing pipe is exposed on and beneath the steel girder, stiffeners were welded for easy transfer of stress to the steel girder. The cover plate, which is welded thicker than the upper flange of the steel girder, plays the role of compensating the cross-section loss caused by the fixing pipe [6]. The lateral web integrated with the fixing pipe is thicker than the other areas to reduce the stress burden, and a diaphragm is established to match the centroid of the fixing pipe for even stress distribution. The tensile force of the cable anchored in the guide pipe anchor is transferred via anchor point → bearing plate → fixing pipe → lateral web → lower flanges and diaphragm → bearing plate → upper flanges. Fig. 2 shows the details of the fixing pipe area [12].

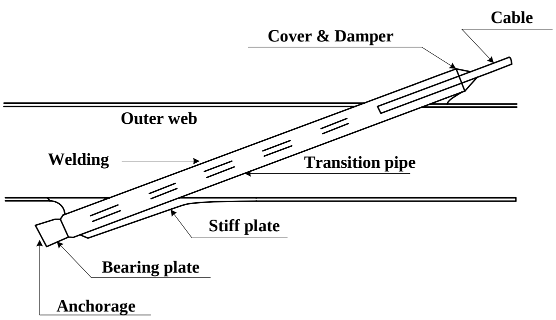


Fig. 2 Detailed drawing of the fixing pipe

## III. Design of the Fixing Pipe in the Guide Pipe Anchor

### A. Existing Design Method

As the fixing pipe of the guide pipe anchor directly and primarily bears the cable tensile force, the stress distribution to the other structural members is significantly affected according to the design stability.

The fixing pipe bears axial compression due to the cable tensile force. Accordingly, the compressive and shear stresses at the direction of the fixing pipe are considered in the design, and the combined compressive-shear stress is finally examined [5].

Fig. 3 shows a flowchart of the existing theoretical design based on the methods and processes applied to the design of the fixing pipe of the guide pipe anchor in South Korea.

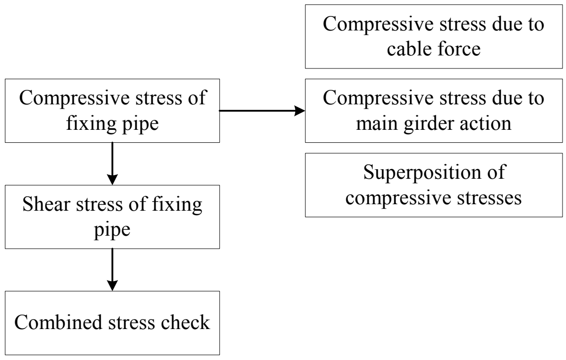


Fig. 3 Existing design of the fixing pipe

### B. Compressive Stress of the Fixing Pipe

1) Compressive Stress Due to the Cable Tensile Force

Fig. 4 is a diagram showing the compressive stress of the fixing pipe caused by the cable tensile force.

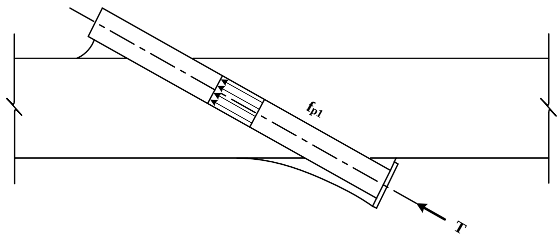


Fig. 4 Compressive stress due to the cable tensile force

$$f_{p1} = P_{p1} \cdot \frac{T}{A_p} \qquad (1)$$

The compressive stress of the fixing pipe due to the cable tensile force can be calculated using equation (1). In the equation, $P_{p1}$ represents the stress concentration factor, $T$ the designed cable tensile force, and $A_p$ the cross-sectional area of the fixing pipe. The compressive stress at the fixing pipe ends, where the cable is anchored, is shown, and the cable tensile force is divided by the cross-sectional area of the fixing pipe. A stress concentration factor can be additionally applied on top of the standard value of 1.0 according to the decision of the engineers, or according to the results of the comparison via finite element analysis [5]. Based on the results of the finite element analysis, Park (2010) reported that the stress concentration factor could be 1.0[7]. Designers, of course, should choose the stress concentration factor considering safety and economic feasibility [8].

2) Compressive Stress Due to the Main Girder Action

Fig. 5 is a diagram showing the compressive stress of the fixing pipe due the main girder action.

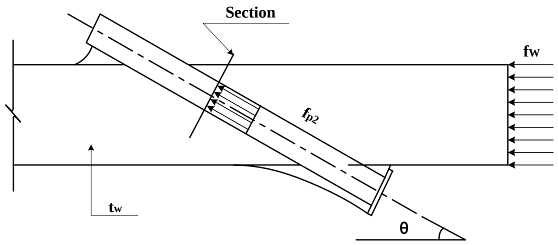


Fig. 5 Compressive stress due to the main girder action

$$f_{p2} = P_{p2} \cdot f_w \cdot \cos^2\theta \cdot \frac{t_w}{t_p} \quad (2)$$

The compressive stress due to the main girder action can be calculated using equation (2). In the equation, $P_{p2}$ represents the stress concentration factor, $f_w$ the stress due to the main girder action, $\theta$ the fixing pipe angle, $t_w$ the thickness of the lateral web, and $t_p$ the thickness of the fixing pipe. The product of the vertical-stress level and thickness of the lateral web obtained from the stress due to the main girder action was assumed to have the same value as the compressive stress of the fixing pipe due to the main girder action, and the thickness of the fixing pipe, and is shown as $f_{p2}$. A stress concentration factor can be additionally applied on top of the standard value of 1.0 according to the decision of the engineers, or based on the results of the comparison via finite element analysis [4].

3) Superposition of Compressive Stress

$$f_p = f_{p1} + f_{p2} \le f_a \quad (3)$$

The superposition of compressive stress can be calculated using equation (3). In the investigation of the superposition of compressive stress based on the allowable stress design, the sum of the cable tensile force and the stress due to the main girder action should be designed not to exceed the allowable stress level of the steel used in the fixing pipe.

*C. Shear Stress of the Fixing Pipe*

Fig. 6 is a diagram of the shear stress of the fixing pipe due to the cable tensile force.

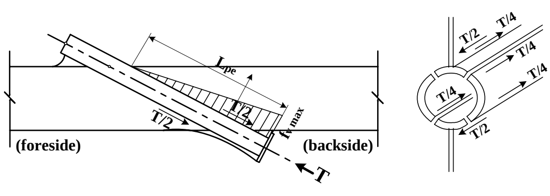


Fig. 6 shear stress due to the cable tensile force

$$v_p = P \cdot \frac{T}{2 \cdot L_{pe} \cdot t_p} \le v_a \quad (4)$$

The shear stress of the fixing pipe can be calculated using equation (4). In the equation, $P$ represents the stress concentration factor, $T$ the design cable tensile force, $L_{pe}$ the net anchoring length of the steel pipe (rear side), $t_p$ the thickness of the fixing pipe, and va the allowable shear stress. The cable tensile force on the fixing pipe is assumed to transfer to the lateral web and weld point, and consequently, the tensile force is divided by two. A stress concentration factor can be additionally applied on top of the standard value of 1.0 according to the results of the comparison via finite element analysis [4].

*D. Combined Compressive-Shear Stress*

$$\left(\frac{f_p}{f_a}\right)^2 + \left(\frac{v_p}{v_a}\right)^2 \le 1.2 \quad (5)$$

The combined stress can be calculated using equation (5). In the equation, $f_a$ represents the allowable stress level of steel, $v_a$ the allowable shear stress of steel, $f_p$ the compressive stress of the fixing pipe, and $v_p$ the shear stress of the fixing pipe. For reviewing the combined stress of the weld point, the equation of the full-face joint-penetration groove weld was used. The combined stress coefficient was regulated at 1.2 or lower [8].

## IV. Design Compensation for the Fixing Pipe of the Guide Pipe Anchor

As the existing design process is not sufficient for securing the safety of the fixing pipe, additional items for compensation are suggested considering the design criteria in South Korea and abroad.

*A. Establishment of the Cross-Section of the Fixing Pipe*

1) Fixing pipe Limitation of the Outer Diameter

$$D = D \cdot \cos\theta \le \frac{1}{2} \cdot h \cdot \cos\theta \quad (6)$$

Equation (6) is proposed considering the fixing pipe angle and lateral web height. In the equation, $D$ represents the outer diameter of the fixing pipe, $D$ the penetration depth of the lateral web, $h$ the lateral-web height, and $\theta$ the angle (refer to Fig. 7).Limitation of the outer diameter of the fixing pipe is required for the efficient stress distribution of the cable tensile force. $D$ is set at 1/2 or less of the lateral-web height to restrict as much cross-section loss of the lateral web as possible, which is penetrated by the fixing pipe, and then welded [6]. This is to prevent structural defects, which may develop due to the cross-section loss caused by welding.

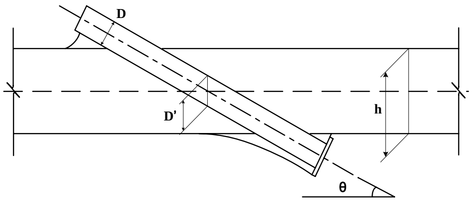


Fig. 7 Outer-diameter limit of the fixing pipe

2) Minimum Inner Diameter of the Fixing Pipe

When the minimum inner diameter of the fixing pipe is determined, not only the size of the cross-section according to the number of cable strands but also the damper margin caused by the live loads should be considered. The size of the inner diameter of the fixing pipe is usually based on that used by cable-manufacturing companies and imported products are preferred in the South Korean market due to quality issues. Table I shows the inner-diameter specifications of the cable anchor system of Freyssinet Company, which has most actively participated in manufacturing cable products for cable-stayed bridges for the South Korean market.

TABLE I
INNER-DIAMETER STANDARDS OF THE CABLE ANCHOR SYSTEM

| Max. Strand | Formwork Tube (mm) | | | |
|---|---|---|---|---|
| | Fixed end | | Live end | |
| | Inner diameter | Thickness | Inner diameter | Thickness |
| 12 | 177.8 | 6.3 | 219.1 | 6.3 |
| 19 | 219.1 | 6.3 | 244.5 | 6.3 |
| 27 | 244.5 | 6.3 | 298.5 | 8 |
| 31 | 244.5 | 6.3 | 298.5 | 8 |
| 37 | 273 | 6.3 | 323.9 | 8 |
| 48 | 323.9 | 8 | 368 | 8 |
| 55 | 323.9 | 8 | 368 | 8 |
| 61 | 355.6 | 8.8 | 406.4 | 8.8 |
| 75 | 368 | 8.8 | 445 | 10 |
| 91 | 419 | 10 | 482.6 | 11 |
| 109 | 431.8 | 10 | 530 | 12.5 |
| 127 | 457.2 | 10 | 558.8 | 12.5 |
| 169 | 530 | 12.5 | 635 | 12.5 |

3) Criteria for the Determination of the Thickness of the Fixing Pipe

According to the design criteria on the guide pipe anchor of cable-stayed bridges, the thickness of the fixing pipe is as follows [6];

- Regarding the weld structure, plates as thin as possible are good for lowering effects such as restraint stress and weld transformation. In the case of the fixing pipe, a thin and large-diameter pipe shows a better cross-section performance than a thick and short pipe, even in the case of the same cross-sectional area. In terms of the quality of the centrifugally cast steel pipe, a thin steel pipe with a large diameter is better, and the possible manufacturing sizes range from Ø300mm (t=9mm) to Ø1200mm (t=65mm).
- The weld point between the steel pipe and the anchor diaphragm is an important area-bearing shear force, and accordingly, the steel pipe thickness should not be less than that of the anchor diaphragm.

4) Suggested Equation for Determining the Thickness of the Fixing Pipe

Table II shows the thickness of the fixing pipe in the guide pipe anchor system applied to the South Korean cable-stayed bridges.

TABLE II
DESIGN OF THE DOMESTIC FIXING PIPE THICKNESS

| Target bridge | Yeongheung | Wando | Incheon |
|---|---|---|---|
| Thickness of fixing pipe (mm) | 30, 32 | 30, 32, 34 | 26, 28, 30, 32, 34, 36, 38, 40, 44 |

Nevertheless, criteria on thickness, which are important initial values in fixing pipe design, have not yet been prepared. The values are usually determined on a trial-and-error basis, using past construction cases or the results of finite element analyses.

As seen, equations for determining the initial thickness of the fixing pipe are suggested through the design process. The items included in equation (3) for calculating the superposition of the compressive stress of the fixing pipe can be expressed as equation (7). In the equation, $P_{p1,2}$ represents the stress concentration factor, $T$ the design cable tensile force, $A_v$ the fixing pipe cross-sectional area, $f_w$ the stress due to the main girder action, $\theta$ the fixing pipe angle, $t_w$ the thickness of the lateral web, and $t_p$ the thickness of the fixing pipe.

$$P_{p1} \cdot \frac{T}{A_v} + P_{p2} \cdot f_w \cdot \cos^2\theta \cdot \frac{t_w}{t_p} \leq f_\alpha \quad (7)$$

The equation is based on the allowable stress design, and $f_\alpha$ represents the allowable stress level of steel. Considering the step of determining the initial thickness of the fixing pipe, all the stress concentration factors are assumed to be 1.0. The cross-sectional area of the fixing pipe, $A_v$ , can be expressed as equation (8) using $D_i$, and thickness $t_v$ can be expressed as equation (6), within the scope of the limitation of the outer diameter, and considering the inner-diameter criteria prepared by cable-manufacturing companies. The outer diameter of the fixing pipe is $D_0 = (D_i + 2t_v)$ .

$$A_p = \frac{\pi}{4} \cdot (D_0{}^2 - D_i{}^2) = t_p \cdot (t_p + D_i) \cdot \pi \quad (8)$$

As all the items except $t_p$ are decided through the existing design process in equation (7), equation (9) can be expressed with $t_p$ as an unknown quantity.

$$t_p{}^2 + (D_i - \frac{A}{210})t_p - \frac{0.4T + A \cdot D_i}{210} \geq 0 \quad (9)$$

For the consideration of the allowable stress levels of the main cable and hanger in erection, the product of the cable tensile force and the incremental coefficient 1.25 was reflected[8]. In addition, the allowable stress level of SM520, which is widely used for the cable anchor system, was used as a standard, and the same items were substituted $(A = f_w \cdot \cos^2\theta \cdot t_w)$ to simplify to the quadratic inequality for $t_p$. The positive solution is suggested as an initial thickness $t_p$ of the fixing pipe in the guide pipe anchor.

*B. Lateral Load to the Axis of the Fixing Pipe*

Fig. 8 is a diagram of the lateral load to the axis of the fixing pipe.

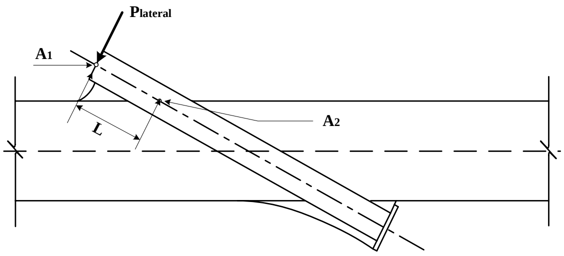


Fig. 8 Lateral load to the axis of the fixing pipe

In the diagram, $L$ represents the upper exposed length of the fixing pipe, $A_1$ the point of load application, $A_2$ the intersecting point of the fixing pipe and upper flanges, and $P_{lateral}$ the lateral load to the axis. The loads on the upper tip of the fixing pipe, which cause cable vibration, include a load due to the changes in the bridge structure; the changes in the cable sag due to the construction load; the loads due to the changes in the wind load, traffic load, and temperature; and a load due to the cable vibration itself [1].

Reasonable deviation of the cable vibration angle due to these loads is suggested at $\alpha = \pm 1.4^\circ (\pm 25 mrad)$, and 2.5% of the cable tensile force is assumed as the working load in designing the fixing pipe [9]. Equations (10) and (11) are for shear stress and bending stress, respectively.

- Shear stress due to the lateral load to the axis

$$v_{lateral} = \frac{P_{lateral}}{A_p} \leq v_\alpha \quad (10)$$

In the equation, $P_{lateral}$ represents the lateral load of the fixing pipe axis $A_p$, $v_\alpha$ the cross-sectional area of the fixing pipe, and $v_{lateral}$ the allowable shear stress.

- Bending stress due to the lateral load to the axis

$$\sigma_{lateral} = \frac{M_{lateral}}{I_{x,p}} \cdot y \leq \sigma_\alpha \quad (11)$$

In the equation, $M_{lateral}$ represents the lateral moment to the fixing pipe axis ($P_{lateral} \cdot L$), $I_{x,p}$ the secondary moment of the fixing pipe cross-section, $y$ the lateral radius of the fixing pipe, and $\sigma_\alpha$ the allowable bending stress.

*C. Cold Bending Allowance*

When round steel pipes are formed using plates, residual stress develops in the steel upon curvature introduction. As suggested in equation (12), the inner diameter of the steel pipe is restricted at five times or more the steel pipe thickness to minimize the damage from the residual stress developing upon curvature introduction [10]. In the equation, $r_{inner}$ represents the inner diameter of the fixing pipe and $t_p$ the thickness of the fixing pipe.

$$\frac{r_{inner}}{t_p} \geq 5 \quad (12)$$

*D. Compensation Design Process of the Fixing Pipe in the Guide Pipe Anchor*

Fig. 9 is a summary of the items that should be additionally considered for the existing design process based on the design criteria in South Korea and abroad.

## V. Application to the Design of the Fixing Pipe in the Guide Pipe Anchor

*A. Summary of the Subject Bridge*

The subject bridge is a three-span continuous cable-stayed bridge with two diamond-shaped steel pylons, and is the first cable-stayed bridge designed entirely with domestic technology. The major specifications of the subject bridge are shown in Table III, and the vertical cross-section is shown in Fig. 10.

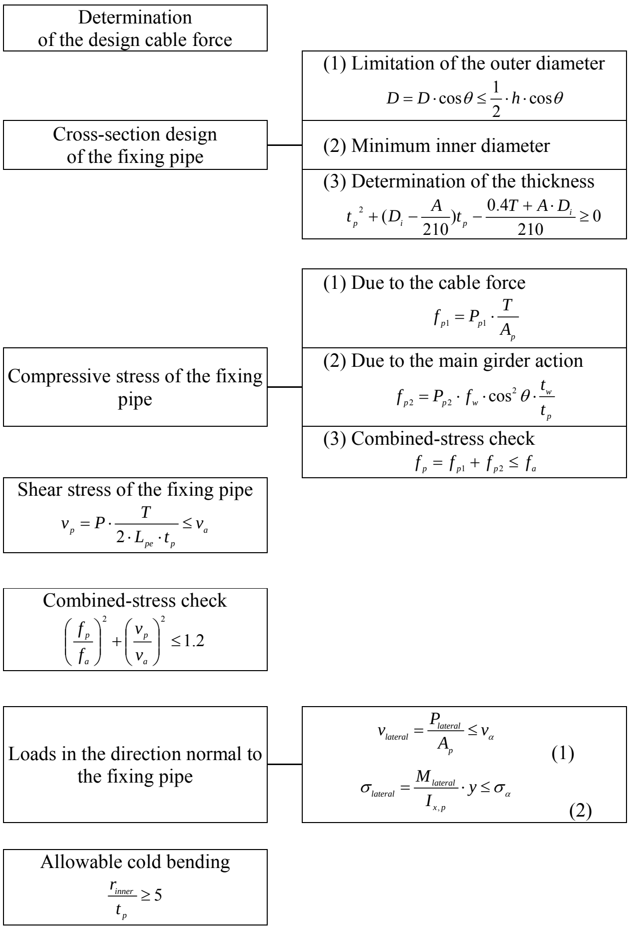


Fig. 9 Complement design process of the fixing pipe

TABLE III
MAJOR SPECIFICATIONS OF THE TARGET BRIDGE

| | |
|---|---|
| Bridge type | Three-span continuous steel cable-stayed bridge |
| Span, width | 460m (110+240+110m), 17.6m |
| Steel girder | Trapezoindal three-cell steel deck |
| Pylon | Diamond-shaped steel pylon (77.4m) |
| Cable | Two-plane array (total 64ea), semi-harp type |
| Design method | Allowable stress method(DB-24, DL-24) |

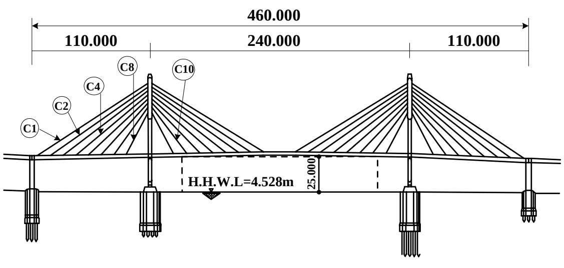


Fig. 10 Longitudinal cross-section of the bridge

*B. Specifications and Selection of the Fixing Pipe in the Guide Pipe Anchor*

MS type was used as a cable type. Considering the esthetic visual quality and the segment weight of the 102-ton steel girder, a 12mspace was evenly arranged. The anchor system was symmetric against C1-C16, and a total of five pipes were selected according to the location of the anchor system, the strength of the cable tensile force, and the number of used steel wires. The major specifications of the fixing pipe are shown in Table IV.

TABLE IV
MAJOR SPECIFICATIONS OF THE FIXING BRIDGE

| Cable no. | C1 | C2 | C4 | C8 | C10 |
|---|---|---|---|---|---|
| Design force (kN) | 5800(5060) | 5060 | 2740 | 2740 | 2320 |
| Degree (Deg) | 26.22 | 27.83 | 32.42 | 56.87 | 45.42 |
| Inner diameter (mm) | 464 | 464 | 370 | 370 | 322 |
| Inner diameter (mm) | 400 | 400 | 310 | 310 | 262 |
| Thickness (mm) | 32 | 32 | 30 | 30 | 30 |
| Length (mm) | 4537.5 | 4276.9 | 3686.6 | 2296.9 | 2951.5 |

*C. Selection of the Cross-Section of the Fixing Pipe*

Application was conducted based on the compensation design process, and the major specifications were the same as the existing values. Table V shows the limitation of the outer diameter based on equation (6), the minimum inner diameter, and the items needed for the suggested equation.

TABLE V
DETERMINING THE INITIAL THICKNESS OF THE FIXING PIPE

| Cable no. | C1 | C2 | C4 | C8 | C10 |
|---|---|---|---|---|---|
| Design force (kN) | 49615.0 | 49615.0 | 26875.7 | 26875.7 | 22739.3 |
| Outer-web stress (MPa) | 18.42 | 61.05 | 97.06 | 69.38 | 75.23 |
| Degree of fixing pipe (Deg) | 26.2 | 27.83 | 32.42 | 56.87 | 45.42 |
| Thickness of the outer web (mm) | 14 | 14 | 14 | 12 | 12 |
| Diameter limit of the fixing pipe (mm) | 636.8 | 637.8 | 599.2 | 388.0 | 498.2 |
| Standard inner diameter at the live end (mm) | 368 | 368 | 298.5 | 298.5 | 298.5 |
| Allowable stress (MPa) | 210 | 210 | 210 | 210 | 210 |

Through the suggested equation (9), and by substituting the figures in Table V, the initial thickness of the fixing pipe was calculated. Table VI shows the cross-section factors of the fixing pipe, which were decided considering the workability.

TABLE VI
MAJOR SPECIFICATIONS OF THE FIXING PIPE BASED ON THE SUGGESTED EQUATION (9)

| Cable no. | C1 | C2 | C4 | C8 | C10 |
|---|---|---|---|---|---|
| Inner diameter (mm) | 418.0 | 422.0 | 340.5 | 334.5 | 330.5 |
| Outer diameter (mm) | 368.0 | 368.0 | 298.5 | 298.5 | 298.5 |
| Thickness (mm) | 25 | 27 | 21 | 18 | 16 |

### *D. Review of the Compensation Design for the Fixing Pipe*

The design elements, which were decided using the suggested equations, were applied to the compensation design of the fixing pipe to obtain the values of the compressive stress, shear stress, combined stress, and lateral load to the axis, and the cold bending allowance of the fixing pipe, as shown in Table VII. As a result of the design, all the criteria on the items were satisfied.

TABLE VII
RESULTS OF THE FIXING PIPE DESIGN BASED ON THE SUGGESTED EQUATION (9)

| Cable no. | C1 | C2 | C4 | C8 | C10 | Limit |
|---|---|---|---|---|---|---|
| Compressive stress due to the cable force (MPa) | 160.74 | 148.08 | 127.50 | 150.16 | 143.84 | - |
| Compressive stress due to the main girder action (MPa) | 8.30 | 24.76 | 46.11 | 13.82 | 27.80 | - |
| Superposition of the compressive stress (MPa) | 169.04 | 172.84 | 173.61 | 163.98 | 171.64 | 210 |
| Shear stress of the fixing pipe (MPa) | 24.40 | 23.94 | 18.85 | 34.31 | 29.21 | 120 |
| Combined-stress check | 0.6893 | 0.7172 | 0.7081 | 0.6915 | 0.7273 | 1.2 |
| Load in the direction normal to the fixing pipe (shear) (MPa) | 5.02 | 4.63 | 3.98 | 4.69 | 4.50 | 120 |
| Load in the direction normal to the fixing pipe (bending) (MPa) | 78.36 | 67.96 | 62.23 | 45.76 | 49.50 | 210 |
| Allowable cold bending | 7.36 | 6.81 | 7.11 | 8.29 | 9.33 | 5 |

### *E. Comparison of the Existing Design and Compensation Design for the Fixing Pipe*

1) Thickness of the Fixing Pipe

A reasonable decision on the thickness of the fixing pipe is the most important factor in initial design and influences the follow-up design process. The existing thickness of the fixing pipe of the subject bridge was formed at 32 and 30mm. Using the suggested equation, the thickness was determined to be 16-27mm, and the thickness could be reduced up to 47% of that in the existing design. Accordingly, the manufacturing difficulty, amount of steel used, and construction cost can be reduced. Table VIII and Fig. 11 include the relevant information.

TABLE VIII
FIXING PIPE THICKNESS COMPARISON

| Cable no. | C1 | C2 | C4 | C8 | C10 |
|---|---|---|---|---|---|
| Target bridge (mm) | 32 | 32 | 30 | 30 | 30 |
| Proposed method (mm) | 25 | 27 | 21 | 18 | 16 |
| Reduction ratio (%) | 22 | 16 | 30 | 40 | 47 |

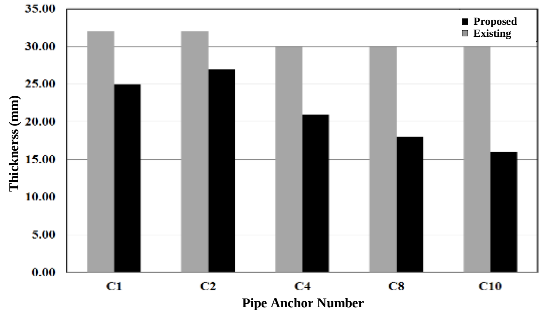


Fig. 11 Fixing pipe thickness comparison

2) Combined Stress of the Fixing Pipe

As a result of the review of the existing combined stress of the fixing pipe, a minimum value of 0.3689 was calculated at C8, and a maximum value of 0.7267 was calculated at C2. According to the review using the suggested thickness, a minimum value of 0.6893 was calculated at C1, and a maximum value of 0.7273 was calculated at C10, showing an up to 92% increase in combined-stress coefficient.

All the standard values of the combined-stress coefficient were satisfied, but in the existing design, a mean of 0.4613 or 38% of the allowable level was reported, except for the C2 anchor system. This may be due to the lack of reliability on the design, the insufficient use of the steel performance, and the excessive design. The mean of the combined-stress coefficient of the proposed design is 0.7067 or 59% of the allowable level of 1.2, confirming a sufficient use of the steel performance and the rationality of the design compared with the existing design. Fig.12 and Table IX include the relevant information.

TABLE IX
COMPARISON OF THE COMPOSITE STRESSES OF THE FIXING PIPE

| Cable no. | C1 | C2 | C4 | C8 | C10 |
|---|---|---|---|---|---|
| Existing composite stress factor | 0.5865 | 0.7267 | 0.5113 | 0.3689 | 0.3784 |
| Composite stress factor through the proposed method | 0.6893 | 0.7172 | 0.7081 | 0.6915 | 0.7273 |
| Limit of composite stress factor | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Increase ratio (%) | 17 | -1 | 38 | 87 | 92 |

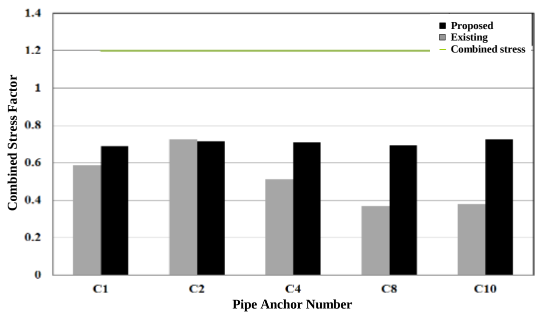


Fig. 12 Comparison of the composite stresses of the fixing pipe

## VI. Conclusions

In this study, the theoretical design of the fixing pipe directly bearing the cable tensile force in the guide pipe anchor of the anchor system of a cable-stayed bridge was reviewed. Equations for determining the thickness of the fixing pipe were suggested, and compensation of the design process was conducted to compare with the existing bridge designs. Based on the results, the following conclusions were drawn:

1) Additional items considered necessary for the design of the fixing pipe are summarized according to the design criteria in South Korea and abroad, and a compensation design flow is suggested.
2) Based on the initial thickness determined by the suggested equations, application to the compensation design flow was conducted and reviewed. As a result, all of them satisfied the allowable level. As a result of the comparison with the existing design, the thickness of the fixing pipe decreased by up to 47%, and the combined-stress coefficient increased by up to 92%.
3) By using the suggested equation for the thickness of the fixing pipe in the guide pipe anchor system, and the compensation design, engineers can secure safety in a convenient and reasonable way, without depending on the past design cases or on the results of finite element analyses conducted prior to the initial design.
4) In the future, comparison with the results of finite element analysis may be necessary to confirm the validity of the anchor system, through mutual compensation between the theoretical design and the results of the finite element analysis.

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