Study on the improvement of the torsional bracing system designing process for steel shaped I simply supported beam bridge

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Abstract. For a long time, the steel bridge structure has been concentrated in the highway and bridge construction industry because of several advantages like high strength material, simple manufacture, and rapid construction. However, this structure still has a few remarkable disadvantages when designing the bridge structure and one of them is the overall stability of the main girders in the construction stage. This research illustrates that a system of discrete bracing along the girders’ length adopted to handle the problem effectively. From the result, the optimally designing process of the bracing system for Steel I girder simple span bridges verified against the finite element method (FEM). However, the frame forming the bracing system has not been checked by the specific process yet, especially the compression member, which can cause the instability of each bracing appurtenance in both the construction and exploitation stage. Therefore, the continuing research significantly adds checking the load capability and buckling of compression frames. The expected result in this research is as follows: 1) Checking members of the bracing system added in the design process. 2) The members of the bracing system promote their ability of resisting the lateral-torsional displacement of girders, and their strength ensured. 3) Designing the intermediate bracing system (IBS), which based only on the overall stability of bridge structure without caring about the strength of its members, is not enough.

1. Introduction
Nowadays, the steel bridge structure is widely used due to many outstanding merits such as high strength material, light structure, convenience in transportation, and fast construction. Besides, the application of steel bridges needs a stringent requirement for safety and quality. The bracing system design in the steel bridge has attracted many researchers for decades because of playing many vital roles in the steel bridge. Mainly, the bracing system provides stability for the main girder as it improves lateral-torsional resistance and strength of the steel bridge structure in both the construction and exploitation stages. A miscalculation or ignoring the bracing system may cause a part or all of the structure collapsing due to the instability. Moreover, if an intermediate bracing system designed excessively, the specific stiffness will be larger than the required one, and then it is too redundant in both the material and installation process. In the exploitation stage, this also leads to cracks at which
vehicles repetition of the live load causing local stress. Therefore, the critical role of the bracing system in general and the appurtenance design, in particular, that recognized. IBS worked as a damper dissipating seismic energy through yielding in tension and compression without buckling under reversed cyclic loading. Besides providing high lateral stiffness to control lateral displacements on structures, IBS controlled local plastic deformations to lengthen the fracture life. Notably, Huynh [1] demonstrated the trustworthy design process by using FEM to determine the critical moment values in the construction stage and total displacement in the main girder and the total stress in each appurtenance of IBS. The proposed process in that paper ensured two crucial requirements, such as the stability of the whole construction stage and non-destruction in the working stages of the structure. However, the stability of each bracing frame, which is a critical factor affecting the quality of the steel bridge, was still unchecked. For example, the MacRobertson Bridge, initially constructed in 1934, was one of two bridges in the world that used welded steel trusses. Kimpton [2] discussed a variety of damage in that bridge that occurred in the exploitation stage. These defects consisted of bent and distorted members, overstrained fastenings, cracks, and nicks (Figure 1). They happened in batten plates, bracing, and connections. These defects could lead to larger cracks and defects in the future if not addressed and might result in a critical reduction of structural capacity. Hence, each bracing member’s stability seems to be a big major and should be concerned sharply. For analyzing this stability, different models are classified based on the demands and complexity of the calculated appurtenance.

Some research types about the stability of each appurtenance were performed, especially the study of Okazaki [3]. The model in this study was composed of rigid elements, internal hinges, and elastic end restraints. After comparing to the elastic-perfectly plastic model and the alternative buckling mode, a simplified version of the buckling model used to predict the out-of-plane buckling strength and buckling mode of the buckling-restrained braces. Similarly, Lui [4] study, a simple mechanistic model, which includes two rigid links hinged together at the braced point and supported by a translational spring (Figure 2), used to account for the ideal stiffness for a geometrically perfect elastic column [5]. This model changed to consist of an initial deflection in the system to calculate the effect of geometrical imperfections. Through two models, geometrical imperfection and inelastic effects considered to investigate the behavior of compression members. The instability of steel shaped X frame in the bridge structure was also attracted [6]. Deformed shapes near buckling as combinations of the three basic modes $M_0$, $M_1$, and $M_2$. Where $M_0$, global lateral deformation mode, took place during the small amplitude, elastic frame lateral displacement cycles, before buckling of the discontinuous brace occurred. Moreover, buckling happened primarily along with mode $M_1$, out-of-plane deformations concentrating in only one segment. $M_2$, out-of-plane antisymmetrical deformation, developed in the opposite directions on either side of the continuous brace. Overall, these studies above pointed out the importance of each bracing frame’s stability. However, calculating the stability of models in the previous studies is moderately tricky, complicated, painful, and time-consuming. Simultaneously, these types of research do not indicate the design process for the appurtenance,
particularly the IBS bridge design. To solve this issue, this study carried out. The research stems from the previous paper [1], besides checking the stability of each bracing system that can ensure the quality of the bridge is high-graded. The frame considered as the truss element, and the bolt seems to be a rigid link that analyzed by using a simple model (Figure 3). By this method, calculating the stability of each frame will be easier, and it always ensures more capacity of the initial force of model when using the rigid link than others. Hence, this study demonstrates the lateral-torsional bracing system designing process for the simply supported steel I beam particularly and comprehensively. This study aims to: 1) Ensuring requirements in the previous study [1] including stability during construction stage and non-destruction in the whole working stages of the bridge structure; 2) As the amendment, the design process in this study ensures lateral-torsional resistance of each frame, and 3) Improvement in the proposed design brings the efficiency and more details that ensures not only the stability of the whole structure but also the stability of each frame.

2. Methodology

2.1. Scope of the study and assumption
Following this research, structure stability can be determined [7]. For safer and more straightforward when designing the bracing system and when auditing critical buckling moment, the author ignored the torsional-lateral resistance of IBS. The displayed process in this article recognized and followed by the previous studies of Huynh [1] by adding and auditing the axial force of members.

2.2. Stiffness of bracing system
This study only considers the cases of IBS. The distance of the horizontal interaction is selected from the ultimate internal moment value of girder in such the way that \( M_0 \) is more substantial than \( M_u \) (with \( M_u \) is the largest moment value in girder in the construction stage. The ultimate internal moment value, \( M_0 \), calculated as stated by the standard AASHTO.

\[
M_0 = \pi E \left( \frac{L_w}{L_b} \right) \left[ \frac{2GJ}{E\left(\frac{L_w}{L_b}\right)} + \pi^2 \left( \frac{d}{L_b} \right)^2 \right]^{1/2}
\]

\[
M_{cr} = \left( C_{bc} M_0^{2/3} + n C_{bc}^{2/3} E L_{eff} \right)^{1/2}
\]

Figure 2. Centrally braced elastic column model

Figure 3. Compressed truss model
The required value of overall stiffness $\beta_T$ is given as

$$\beta_T = \frac{2C_{bc}LM^2}{\phi_C C_{bb}nEI_y}$$  \hspace{1cm} (3)

Where:

- $C_{bc} = C_b$: factor corresponding to the unbraced girder.
- $C_{bb} = C_b$: factor corresponding to the full braced girder.
- $C_t$: factor corresponding to applying the load place, $C_t = 1.2$ top flange loading factor.

The required value of overall stiffness $\beta_T$ demonstrates the coworking of the whole system including the main girder and IBS. Specifically, this expressed by:

$$\beta_T = \frac{1}{\beta_b} + \frac{1}{\beta_g} + \frac{1}{\beta_{sec}}$$  \hspace{1cm} (4)

Where:

- $\beta_b$: specific stiffness of IBS. This analysis puts the specific stiffness of the twin-girder system into practice (Table 1). When using the different specific stiffness of other types of structure, the error will occur that be debated later.
- $\beta_g$: stiffness in bending plane of the main girder is reckoned by $\beta_g = \frac{24(n_g - 1)}{n_g L^3} S^2 EI_y$ \hspace{1cm} (5)
- $\beta_{sec}$: stiffness of girder cross-section which Yura and Phillips suggest using the function below to estimate

$$\beta_{sec} = \frac{1}{\beta_c} + \frac{1}{\beta_s} + \frac{1}{\beta_t}$$ \hspace{1cm} (6)

$\beta_c, \beta_s, \beta_t$: can be determined by the following equation: $\beta_i = \frac{3.3E_i}{h_i} \left[ \frac{1.5h_i t_i}{12} + \frac{t_i}{12} \right]; i = \{c, s, t\}$ \hspace{1cm} (7)

After $\beta_{req'd}, \beta_g$ and $\beta_{sec}$ are determined from Equation (3), Equation (5) and Equation (6) respectively, $\beta_b$ ($A_b$) preliminarily determined from equations in Table 1.

| Table 1. Stiffness formulas for cross frames and diaphragms |
|-----------------------------------------------|-----------------------------------------------|
| Type of IBS | Shape | Specific stiffness $\beta_b$ | Area of members $A$ (mm$^2$) |
| Z | | $\beta_b = \frac{ES^2h_b^2}{2L_c^2 + S^3} \frac{A_c}{A_b}$ | $A_c = A_b = \frac{\beta_b(2L_c^3 + S^3)}{ES^2h_b^3}$ |
| X | | $\beta_b = \frac{A_c ES^2h_b^2}{L_c^3} \frac{A_c}{A_b}$ | $A_c = \frac{\beta_b L_c^3}{ES^2h_b^3}$ |
| K | | $\beta_b = \frac{2ES^2h_b^2}{8L_c^3 + S^3} \frac{A_c}{A_b}$ | $A_c = A_b = \frac{\beta_b(8L_c^3 + S^3)}{2ES^2h_b^3}$ |
| Cross beam | | $\beta_b = \frac{6EI_b}{S}$ | $I_b = \frac{S\beta_b}{6E}$ |
\[ \beta_b = \frac{2EI_b}{S} \]
\[ I_b = \frac{8\beta_b}{2E} \]

Where:
- \( S \): Girder spacing
- \( h_b \): Height of cross frame
- \( A_b \): Area of horizontal members
- \( A_c \): Area of diagonal members
- \( h_b \): Height of cross frame
- \( L_c \): Length of diagonal members
- \( I_b \): Diaphragm moment of inertia

### 2.3. Bearing capacity

The IBS moment value has linear proportions to the original error skew angle at the system’s joint point. Many previous scientific types of research conclude this result and that is used to determine the rotation angle at the joint, \( \phi_T \), as same as the moment value in IBS.

\[
\phi_T = \frac{\phi_0}{1 - \frac{\beta_{T, M}}{\beta_T} M_r}
\]

\[ M_{cr} = \beta_T (\phi_T - \phi_0) \]  

(9)

As can be seen from Equation (8), if only the IBS gains more stiffness that equals to the minimum overall stiffness of the girder determined in Equation (2), the girder’s moment value will touch the infinite point and the deflection angle contemporaneously reaches infinite that result in the huge moment value in IBS. The AISC LRFD standard suggests making the stiffness of overall IBS larger than the minimum twice. From Equation (2), after pruning some ultimate internal moment values, since it considered very small when comparing to the IBS’s work, the following equation used to calculate the overall stiffness system:

\[
\beta_T = \frac{2.4LM^2}{\phi nC_{bb}EI_{eff}}
\]

(10)

In terms of moment values in IBS when working, the initial error skew angle hypothetically equal to \( L_b/(500d) \) radians where \( L_b \) is the distance between the IBS and \( d \) is the girder’s height. Therefore, the moment values in the IBS can be written as

\[
M_{se} = \frac{0.024LM_n}{nC_{bb}L_b}
\]

(11)

From the result of Equation (10), the stress of each different appurtenance in IBS reckoned.

### 2.4. Tension and compression members

According to AASHTO 2017 specifications, the factored tensile or compressive resistance calculated by Equation \( P_r = \phi P_n \)

(12)

The nominal tensile resistance: \( P_0 = F_yA_g \)

The nominal compressive resistance calculated as follows.

For compression members with nonslender element cross-sections, \( P_n \) can be determined as

\[
\text{If } \frac{P_n}{P_0} \geq 0.44, \text{ then: } P_n = P_0 \times 0.658 \left( \frac{P_n}{P_0} \right)
\]

(13)

\[
\text{If } \frac{P_n}{P_0} < 0.44, \text{ then: } P_n = 0.877P_e
\]

(14)

Limiting slenderness:
Limiting slenderness ratio for tension members specified in AASHTO as \( \frac{l_{bu}}{r_{min}} < 240 \) (15)

Limiting slenderness ratio for tension members specified in AASHTO as \( \frac{l_{bu}}{r_{min}} < 140 \) (16)

Where

- \( P_n \): nominal compressive resistance
- \( F_y \): specified minimum yield strength (kN/m²)
- \( A_g \): gross cross-sectional area of the member (m²)
- \( \phi \): resistance factor for yielding: factor for tension members \( \phi_t = 0.95 \)
- \( \phi_c \): factor for compression members \( \phi_c = 0.9 \)
- \( F_y \): specified minimum yield strength (kN/m²)
- \( P_e \): elastic critical buckling resistance (kN), \( P_e = \frac{\pi^2EI}{(Kl/r)} = A_g \) (17)
- \( l_{bu} \): unbraced length (m)
- \( r_{min} \): minimum radius of gyration (m)

2.5. Theoretical basis for finite element method (FEM)

The finite element method is the theoretical basis for analyzing the stability of the steel bridge structure without IBS. The static equilibrium equation of structure at a deformed state performed as:

\[
[K]\{U\} + [K_G]\{U\} = \{P\}
\] (18)

Where: \([K]\): elastic stiffness matrix; \([K_G]\): geometric stiffness matrix; \([U]\): resulting displacements of structure vector; \([P]\): applied load vector.

Set \( \lambda_{cr} \) as a critical buckling factor. From equation (17), the state of equilibrium equation is:

\[
[K + \lambda K_G]\{U\} = \{P\}
\] (19)

Set the equation \([K + \lambda K_G]\) as equivalent stiffness matrix. When analyzing the stability of the structure, there divided into three cases:

- **Case 1:** \([K_{eq}] < 0 (\lambda > \lambda_{cr})\): Unstable equilibrium state.
- **Case 2:** \([K_{eq}] = 0 (\lambda = \lambda_{cr})\): Unstable state.
- **Case 3:** \([K_{eq}] > 0 (\lambda < \lambda_{cr})\): Stable state.

Equation \([K_{eq}] = 0\) can be contracted to an eigenvalue analysis solution when the results are the eigenvalue \( \lambda = \lambda_i \) called the critical buckling factor of the structure [8]. Where, each pair of eigenvalues–eigenvector called a buckling mode of the structure. The critical buckling factor, the scale factor, multiplies by the loads \([P]\) to cause buckling in the given mode, \( \{P_{cr}\} = \lambda_{cr}\{P\} \) (where \( \{P_{cr}\}\): critical load vector). It seems like a safety factor when considering the buckling: if \( \lambda_{cr} \) is more than one, the critical load value is greater than the applied one or in other words, the applied load value has not reached the critical one. This means that the system structure is stable. In contrast, if it is less than
or equal to one, the applied load value has reached or exceeded the critical one. This time the system structure is unstable.

2.6. Process of design IBS

For safer and simpler design philosophy is to construct the below process of design IBS. The actual moment in the construction stage, calculated for the single girder with simple supports. The resistance factor, dynamic load allowance taken according to specification. As the number of IBS is chosen to $M_0 > M_u$, it can make sure the critical buckling moment is larger than the actual moment $M_{cr} > M_u$. Then, the method for twin-girder applied for the Luong Thuc Bridge.

For the strength limit state, initial imperfection assumed as $\theta_0 = \frac{L_b}{500d}$; where: $L_b$ is the unbraced length, $d$ is the girder depth. Then, the torsional coupling moment and force applying the girder are calculated as $M_x = \frac{0.024LM_b}{nC_{bs}C_{h_b}}$, $F_x = \frac{0.005L_nLM_b^2}{nE_{s}C_{bs}h_b}$ in the construction stage, respectively [6].

Stress in members of the construction stage is calculated from the torsional coupling force: $\sigma_1 = \frac{F_x}{A_c}$.

Stress in members in the exploitation stage analyzed by Midas/Civil. The chosen section of IBS based on AISC Shapes Database v15.1. The process of checking tension and compression members is entirely according to AASHTO specification. The factored tensile resistance and compressive resistance is taken by equation (12). Furthermore, the limiting slenderness ratio for tension members and compression members is calculated as equation (15) and (16), respectively. Besides, the bending moment of flexural members (cross beam) is proposed checking by a formula: $\sigma_1 + \sigma_2 < 0.6F_y$ [3].

In general, the flowchart (Figure 4) describes the process of design IBS step by step.
Design parameter:
1. Information of steel bridge structure:
   - Dimension of slab deck, span length, girder, etc. \((S, n_g)\)
   - Girder geometry
   - Weight of steel, concrete,
   - Ability of material \((E, G, F_y, f_c)\)
2. Design specifications
3. Assume that self weight of IBS equals to 15% of that of main girder.

Generate spacing among IBS - \(L_b\) and the number of IBS - \(n\):
1. Choose \(L_b\) and \(n\)
2. Calculate
   \[
   M_0 = \pi E \left[ \frac{I_{nc}}{I_{nb}} \right] \left[ \frac{2G}{E} \right] \left[ \frac{J}{I_{nb}} \right] + \pi \left[ \frac{d}{I_{nb}} \right] > M_s
   \]

Calculate stiffness
1. Required generate stiffness: \(\beta_{Req} = 2.4LM_0^2 \times (\phi_n E I L)\)
2. In-plane girder stiffness: \(\beta_y = 24(n_i - 1) S'EI_n (n_i L')^2\)
3. Web distortional stiffness: \(\beta_{sec} = \beta_y + \beta_i + \beta_z\)
   \[
   \beta = 3.3Eh_i h_j (1.5h_i t_w + t_i b_i) / 12; i = \{c, t, s\}
   \]

Condition 1: Ensuring overall stability
1. Required stiffness of bracing system \(\beta_{max} = (\beta_{Req} - \beta_i - \beta_z)\)
2. Choose type of bracing system and calculate \(A_{c Req} \& A_{b Req}\)

Choose section \(A_c > A_{c Req}, A_b > A_{b Req}\)

1. Calculate torsional coupling force: \(F_t = \frac{0.005L_b LM_0^2}{\text{nEI}_L C h h_s}\)
2. Determine axial stress of each member: \(\sigma_i\)
3. Stress in the exploitation stage by Midas/Civil: \(\sigma_e\)

Condition 2: Ensuring force axial resistance

Tension members
1. Check strength limit state: \(\sigma_i + \sigma_e \leq \phi_i F_y\)
2. Check slenderness ratio \(\lambda = L_m / t_{sec} < 240\)

Compression members
1. Check slenderness ratio \(\lambda = L_m / t_{sec} \leq 140\)

1. \(\gamma = \sigma_i / F_y \geq 0.44; \sigma_i = \pi^2 E \lambda^2\)
2. \(\sigma = \sigma_i, \sigma_e \leq 0.658 \phi_i F_y\)
3. \(\sigma = \sigma_i, \sigma_e \leq 0.877 \phi_i F_y\)

Figure 4. Process of IBS design
3. Analysis cases

3.1. Analysis object
Luong Thuc Bridge has a structure of the traditional girder system, with a horizontal bracing system of I-shaped steel beams (Figure 5). In this study, Luong Thuc Bridge has chosen as the research object [9]. The bridge has a total length of 90m, including three spans, maximum span length is 35.4m, with a beam length of 35.9 m. The bridge width is 6m, and the distance between the closest two main beams is 1.5m. Horizontal beams at the bearings are 0.6m high, and the intermediate bracing system uses horizontal I-shaped 400 steel beams.

![Cross-section of Luong Thuc bridge](image)

Figure 5. Cross-section of Luong Thuc bridge

3.2. Numerical model of steel bridge
IBS of Luong Thuc bridge will be substituted by four different types of IBS in Table 2 (except the last one) to evaluate the reliability of the proposed process objectively. The structural component of IBS is modeled by the truss element, and the slab deck in the exploitation stage is modeled by solid element. The cross-section size of each structure appurtenance and the height of the bracing system obtained from the proposed design process applied in these simulations [10]. The bridge structure for each IBS analyzed in the whole working stages. Analysis result from the construction stage is used to evaluate the critical moment determined from the proposed process. The one from the exploitation stage applied to check the bearing capacity of each structural component in each type of IBS. Input data based on the realistic model with simply supported I girder is suitable for AASHTO specification. Besides, the main girder, cross girder, and steel plate simulated by the plate element with four nodes for assessing the overall performance of components in a structural system. The text of your paper should be formatted as follows:

Table 2. Properties of the simulated steel bridge structure

| Shape | Main girder | Horizontal beam | IBS | Cross beam |
|-------|-------------|-----------------|-----|------------|
| Size (mm) | 1385×(300~350)×(20~25) | 600~200×25 | - | 1050×200×25 |
| Top flange | Wed | Bottom flange | Top flange | Wed | Bottom flange | - | - |
| Structure element | Plate | Plate | Plate | Plate | Plate | Truss | Plate |
3.3. Design loading
The strength I limit state and the service I used to assess the stability and the displacement of the bridge structure, respectively [11]. Therefore, the load acting on the bridge in the construction stage includes dead load-self weight (Table 3) of all appurtenances in the structure and the construction live load (Figure 6).

Table 3. Applied load

| Applied load          | Load factor | Value       | Description                  |
|-----------------------|-------------|-------------|------------------------------|
| Dead load             |             |             |                              |
| Main girder           | 1.25        | Automatically calculated by MIDAS/CIVIL | Self-weight |
| Cross beam            | 1.25        |             |                              |
| IBS                   | 1.25        |             |                              |
| Fresh reinforced concrete | 1.25   | 5 (kN/m²)  | Uniformly distributed load on steel form plate |
| Construction live load | 1.75        | 0.48 (kN/m²) |                              |

In addition, the live load – HL 93 (Figure 4), the asphalt surface, concrete railing are applied during the exploitation stage.

4. Result and discussion

Table 4 compares the chosen section to the required section. Where, the required section considered based on condition 1 in the design process (Figure 5) for only ensuring the total stability. Nevertheless, the chosen section, based on condition 2 in Figure 5, satisfies two demands 1. Ensuring the lateral-torsional of the structural system. 2. Ensuring the resistance of compression members and tension members compression in both construction and exploitation stage under the effect of cyclic load HL-93 (Figure 6). According to Table 5, it can be seen that the ratio of the area required and chosen section is too large (at least larger than 4.0), that expresses the sharp disparity when choosing the section following the condition 2. For the steel I cross beam, the required initial moment for the total stability is \( I_{\text{req}} = 538 \times 10^6 \text{(mm}^4\text{)} \). However, the chosen section for ensuring the condition 2 is W510x400m, and the initial moment is \( I = 1378 \times 10^6 \text{(mm}^4\text{)} \) [2]. The initial moment value of the chosen section is more substantial 2.56 times than the required section. Through these analyses, the resistance of members plays a vital role in the structure’s stability. If designing IBS only concerns overall stiffness resisted lateral-torsional displacement, the structure may be damaged [12], which is very dangerous for the structural capability of the bridge. Therefore, the resistance of members in this study will be calculated and indicated below. Table 6 shows the factored tensile and compressive resistance of three types of shaped steel, \( P_r \). The axial force, \( P \), is compared to \( P_r \), and the difference between them is performed. The percentage of the difference between \( P \) and \( P_r \) in X-Shaped steel is quite big. Generally, all \( P_r \) values are much higher than \( P \). It means the structure has enough tensile and compressive resistance. Moreover, the slenderness ratio of tension and compression members, shown in Table 7, is smaller than the limit value 140. Therefore, these structures are satisfied with the requirement specified in AASHTO 2017 specification.
### Table 4. Axial force combination

|       | K     | X    | Z   |
|-------|-------|------|-----|
| $F_h$ (kN) | 66.54 | 70.98 | -39.04 |
|        | -52.44 | - | -47.64 |
| $F_d$ (kN) | -94.91 | -49.30 | - |
|        | 94.91  | 59.80 | 139.89 |

As for the case of the cross beam, a maximum bending moment is combined as $M = 615.63$ (kNm)

Note: $F_h$, $F_d$: maximum tensile or compressive force in horizontal and diagonal members, respectively.

### Table 5. Chosen section

|       | K     | X    | Z   |
|-------|-------|------|-----|
| Required section | $A_{c\text{Req}} = A_{b\text{Req}}$ | 85.47 | 51.03 | 130.12 |
| Chosen section | AISC label | L51x51x7.9 | L51x51x3.2 | L51x51x6.4 |
|       | $A_c = A_b$ | 748 | 317 | 609 |
| Ratio | $A/A_{\text{Req}}$ | 8.75 | 6.21 | 4.68 |

### Table 6. Check strength limit state IBS members

|       | Axial resistance | Tension members | Compression members |
|-------|------------------|-----------------|---------------------|
| K     | $P_r$            | 173.05          | 107.52              |
|       | $P$              | 94.91           | 94.91               |
|       | $\Delta(\%)$    | 45.16%          | 11.73%              |
| X     | $P_r$            | 103.90          | 85.28               |
|       | $P$              | 70.98           | 39.60               |
|       | $\Delta(\%)$    | 31.68%          | 53.57%              |
| Z     | $P_r$            | 152.73          | 57.81               |
|       | $P$              | 139.89          | 32.44               |
|       | $\Delta(\%)$    | 8.41%           | 43.89%              |

### Table 7. Check slenderness ratio

|       | Horizontal members | Diagonal members |
|-------|--------------------|------------------|
| K     | 49.34              | 84.89            |
| X     | 95.54              | 58.31            |
| Z     | 96.77              | 118.13           |

For flexural members, checking bending moment of cross beam: $\sigma_1 + \sigma_2 = 183695$ (kN/m²) < 0.6$F_y = 207000$ (kN/m²)

### 5. Conclusion

According to this study, the IBS design process built base on the process design in the previous research [1] with the proposed modification. This process ensures not only two initial requirements, such as stability during construction stage and non-destruction in the whole working stages of the bridge structure, but also checks the stability and the strength of each frame. Lateral-torsional
resistance of each frame ensured. Hence, the structure has enough stability of each member and more safety. The purpose of this research is extremely meaningful since it expresses that checking the stability of each member is necessary. When designing, only choosing a section according to the specification of critical buckling moment may not ensure the specification of tensile or compressive force. Therefore, designing the structure only depending on overall stability is not enough.

6. References

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