

Effect of Bottom Bracing Configuration on Mid-Span Deflection of Tied Steel Arch Bridge

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Article Information	ABSTRACT
Article History Received : December 17, 2025 Revised : January 07, 2026 Published : January 16, 2026	Tied steel arch bridges are commonly used due to their structural efficiency and aesthetic value; however, excessive mid-span deflection remains a critical design issue. While previous studies indicate that bottom bracing can enhance stiffness, the optimization of bracing configurations at the mid-span has not been sufficiently investigated. This study evaluates the influence of different bottom bracing configurations on mid-span deflection in tie-beam steel arch bridges. Numerical analysis based on the finite element method was conducted using SAP2000 v.22 on four bridge models with identical geometry, loading conditions, and a total bottom bracing weight of 10 kg. The bridge span was 4 m with an allowable deflection limit of 5 mm. The results show that all configurations satisfy the deflection criteria, with the X-bracing configuration yielding the smallest mid-span deflection. These findings contribute to the understanding of optimal bottom bracing configurations in steel arch bridge design, supporting efficient structural performance in engineering applications.
Keywords: <i>Tied Arch Bridge; Deflection; Mid-Span; Configuration; Bottom Bracing.</i>	

INTRODUCTION

Bridge infrastructure is a vital component of interregional connectivity, contributing to accessibility and connectivity design, and supporting economic growth (Putri & Suwitri, 2024; Lindawati et al., 2022). Effective bridge design contributes to transportation efficiency, reduced logistics costs, and increased mobility. Furthermore, selecting the right bridge type and construction materials is crucial to ensure sustainability and structural efficiency. In this regard, steel-girder arch bridges offer a range of structural, economic, and aesthetic advantages, offering excellent effectiveness and stability across a wide range of span lengths, particularly when compared to other bridge configurations (Greco et al., 2019; Shao et al., 2021).

Arch bridges using bracing can increase the overall system stiffness and reduce the risk of lateral buckling (Pan et al., 2024). Furthermore, research has shown that optimally designed bracing configurations can improve the out-of-plane stability and structural performance of arch bridges (Zhao et al., 2024; Wang et al., 2022). Furthermore, research conducted by Abedin & Mehrabi (2020) indicates that the addition of bottom cross members can reduce excessive deformation and significantly increase flexural stiffness compared to bridges without bracing. Therefore, further studies on the various configurations and amounts of bottom bracing are important to provide substantive knowledge in designing more efficient and durable steel-braced arch bridges, especially in the context of sustainable and long-term performance-oriented designs.

In this regard, Sulasmono et al (2024) conducted research on modifying the variation in the number and spacing of the lower transverse elements on bridges, but it turned out to be ineffective in reducing deflection. This is due to the fact that increasing the number of lower transverse bracing actually contributes to an increase in the dead weight of the bridge structure. Furthermore, in the previous study, all model variants tested still had the lower transverse bracing at the center of the bridge span. Accordingly, existing studies have not specifically investigated the influence of optimized transverse members or bottom bracing configurations model at the mid-span on the deflection behavior of steel arch bridges. On the other hand, the mid-span is known to be the location of maximum deflection in steel arch bridges (Liu et al., 2024). This research gap is the basis for this study, which focuses on optimization through various modification models of bottom bracing or transverse bracing at the mid-span of the bridge span with the objective of evaluating their effect on bridge deflection. Furthermore, the objectives of this study are to identify the most effective bottom bracing configuration for enhancing structural performance with more efficient material utilization, thereby supporting the principles of sustainable bridge design.

RESEARCH METHODS

Enhancing structural stability and stiffness can effectively reduce deflection, making it a key approach for optimizing the performance of steel arch bridges (Wang et al., 2024). Bottom bracing plays a critical role in distributing loads uniformly to other structural components (Shi et al., 2023). Therefore, selecting an appropriate bracing configuration is essential to achieve optimal deflection performance (Rosyidi et al., 2022). Within the methodological framework of this study, the authors developed the flowchart presented in **Figure 1** to evaluate a smaller-scale bridge model incorporating various types of bottom bracing. Throughout the literature review process, the authors identified and utilized several methodological similarities across existing studies as a basis for advancing the present research.

This study examines various bridge configurations through modeling, specifically focusing on different types of bottom bracing at mid-span. In addition, the modeling procedure incorporates the determination of loading combinations and the determine of the applied loads. To facilitate the structural analysis and bridge design modeling, all the process are conducted using SAP2000 v.22. Structural validation must also be conducted after the modeling process is completed in SAP2000 v.22. Two references are employed for this analysis, SNI 1729:2020 “Spesifikasi Bangunan Baja Struktural” and RSNI T-03-2005 ‘Perencanaan Struktur Baja untuk Jembatan’. SNI 1729:2020 is used to ensure that the steel capacity ratios do not exceed the permissible limits, while RSNI T-03-2005 is applied to verify that the deflection values remain within the allowable deflection limits.

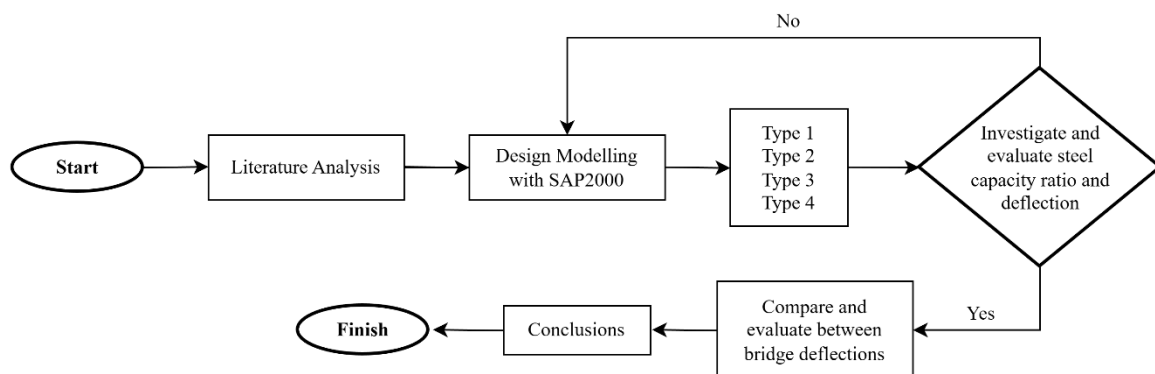


Figure 1. Flowchart of Research Methodology for Effect of Bottom Bracing Configuration on Mid-span Deflection of Tied Steel Arch Bridge

Based on the preceding analyses, the final stage of this study involves a comprehensive evaluation. All deflection values obtained from each bridge model type are compared to assess their relative performance. Through this methodological approach, the various model

configurations are expected to reveal the effect of bottom bracing on deflection behavior in tied steel arch bridges.

Materials

The primary material used for all bridge components in this study is structural carbon steel. This material was applied to the top chord, bottom chord, hanger, upper tie chord and bottom bracing elements because it has sufficient strength and stiffness characteristics to support the performance of a steel arch bridge.

Tabel 1. Specifications of Material Grades for the Bridge Model

Specifications	SS304	SS400
Yield Strength (Fy)	215 MPa	245 MPa
Ultimate Stress (Fu)	505 MPa	400 MPa
Density	8000 Kg/m ³	7850 Kg/m ³
Young's Modulus	193000 MPa	200000 MPa

Source: (JIS G3101, 2021)

Modelling of Arch Bridge Structures

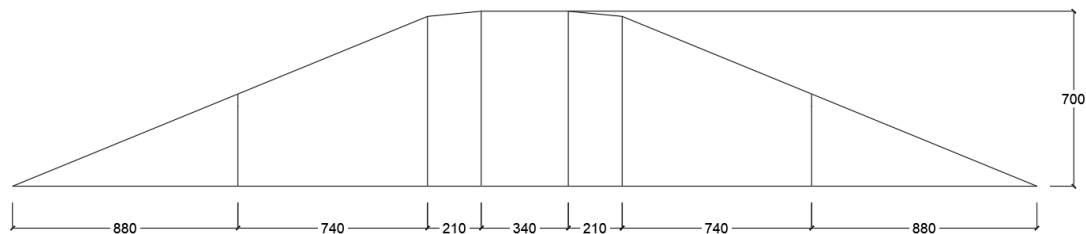


Figure 2. Model Bridge Size Specifications

In this study, the geometric dimensions of the bridge are fixed to ensure that the varying influence of the bottom bracing system on the structural response can be objectively analyzed. The bridge length, height, and width remain unchanged during the modeling process. The bridge will be modeled with a span of 4 meters, a structural height of 0.7 meters, and a width of 0.6 meters, as shown in **Figure 2**. The bearing conditions of the bridge structure are represented as roll-support joints to model the support behavior that allows for certain translational movements. By setting uniform dimensions and boundary conditions throughout the model, various bottom bracing types and configurations can be optimized and directly compared. The structural performance evaluation focuses on the maximum deflection response at mid-span, so that the effect of each bottom bracing type on the global stiffness and the structure's ability to control deflection can be clearly identified.

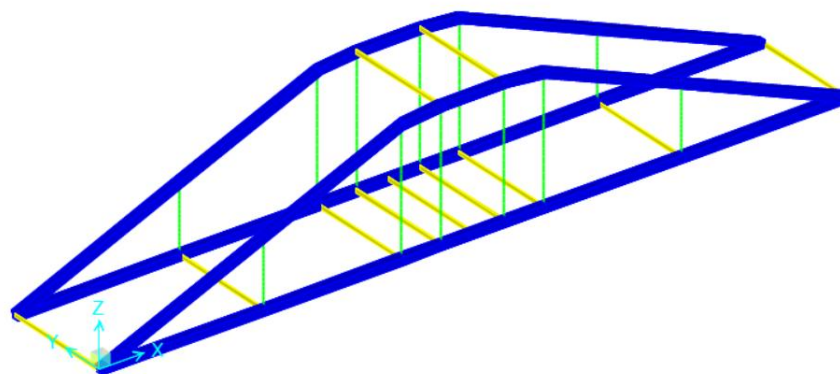


Figure 3. Example of 3D View of Bridge Model using SAP2000 v.22 Software

This research uses a scaled model bridge to simplified modelling and accelerate analysis. In addition, the uses of FEM (Finite Element Method) based on SAP2000 v.22 software program can simplify and facilitate the analysis process (Zhu et al., 2023). The structural profiles used in this study as a result of trial and error. The top chord uses a 40.40.2 mm hollow section, while the bottom chord is designed using a 40.40.1,5 mm hollow section. In addition, the hanger system is used by an SS304 steel cable with a nominal diameter of Ø6 mm. The tied steel arch bridge to be studied uses of following bridge profile specifications.

Tabel 2. Bridge Profile Specifications

Structures Elements	Specifications
Top Chord	Carbon Steel Hollow
Bottom Chord	Carbon Steel Hollow
Bottom Bracing	Carbon Strip Steel
Hanger	SS304 Steel Cable

Bottom Bracing Configuration

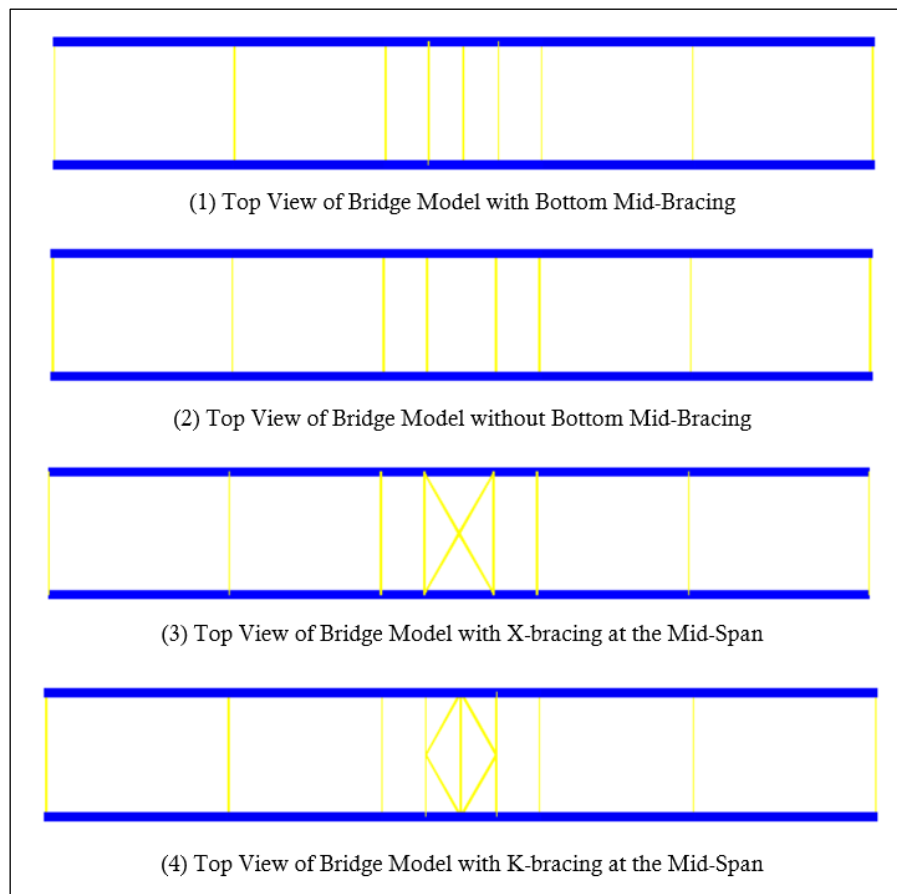


Figure 3. Various Bridge Model Typologies

Each model bridge will use bottom bracing with a 40 mm width strip steel profile and a total bottom bracing weight of 10 kg. These two factors will be the control variables in this study. In addition, the upper tie chord profile is adjusted from the profile adjustments obtained from each model. Furthermore, the optimization carried out is in the form of using the bottom bracing type shown in **Figure 3**. The variation is based on previous studies that have not optimized the variation of the bottom bracing elements at the mid-span in testing the effect of bridge deflection. In addition, the thickness of the strip steel profile used in the bottom bracing will also be optimized to adjust to the total weight of 10 kg, as shown in **Table 3**.

Tabel 3. Optimization of the Thickness of the Bottom Bracing Steel Strip

Type of Bridge Model	Strip Steel Thickness (mm)
Type (1)	5,90 mm
Type (2)	6,63 mm
Type (3)	5,15 mm
Type (4)	4,69 mm

Bridge Loading

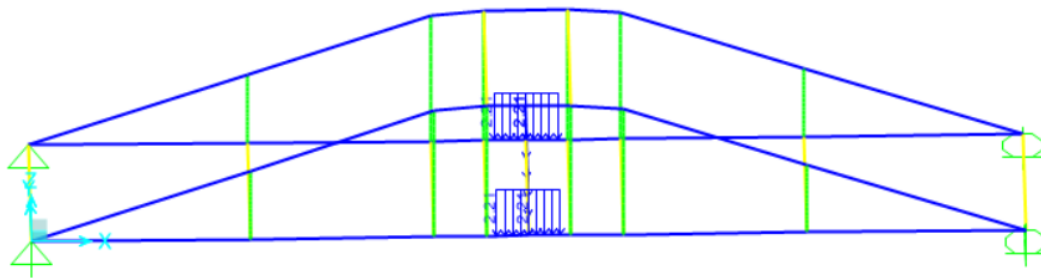
The bridge loading process only involves dead load (DL) and live load (LL). Dead load including the weight of the structure itself and live load will be applied at 250 kg as a tributary load at mid-span, which refers to SNI 1725:2016 (Badan Standardisasi Nasional, 2016). A load combination of 1.1 (DL) + 1.8 (LL) will be used in the loading stage, without considering wind load and earthquake load. In this analysis, the author only examines the deflection at mid-span as a comparison to the effect of bottom bracing. The boundary conditions and load distribution are visualized in the **Figure 4** which presents the placement and loading limits at mid-span of the model bridge.

$$1.1 \text{ DL} + 1.8 \text{ LL} \quad (1)$$

Explanation:

DL = Dead Load (kg)

LL = Live Load (kg)

**Figure 4.** Illustration of Type 1 Visualization of Load Conditions

Deflection

According to the RSNI T-03-2005 provisions, the maximum allowable deflection for bridge structures is specified as $1/800 \times \text{span}$, which corresponds to 5 mm for the bridge model used in this study. Consequently, all bridge configurations analyzed must comply with this deflection limit. If any model exhibits a deflection value exceeding 5 mm, it is deemed to fail the performance requirement. In such cases, modifications or strengthening of the structural member dimensions are necessary to ensure that the resulting deflection falls within the permissible limit and that the design can be considered acceptable.

$$\Delta = \frac{1}{800} \times L \quad (2)$$

Explanation:

Δ = maximum deflection (mm)

L = length span (mm)

RESULTS AND DISCUSSION

The research data were obtained through numerical analysis SAP2000 v.22. The results of the analysis were then presented in the form the bar charts to facilitate comparison between models. Each bridge model was analyzed separately against the applied load. The deflection values that occurred in each model were then collected and evaluated comprehensively to identify the effect of applying various bottom bracing configurations on the structural performance of the arch bridge, especially in improving the structure ability to control deflection.

Deflection Analysis

Based on the analysis of the SAP2000 v.22 software, the deflection results for each type of bridge structure model were obtained based on the type of bottom bracing configuration. The following is a comparison of the deflection analysis results shown in **Figure 5**.

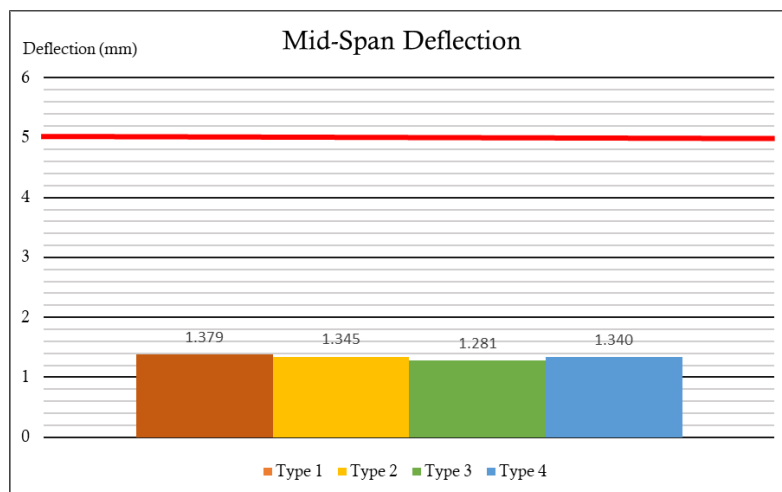


Figure 5. Comparative Chart of Mid-Span Deflection of Various Bridge Types

Based on the analysis results, all types of bridge models meet the deflection allowance limit of 5 mm. As shown in **Figure 5**, the smallest mid-span deflection occurs in type 3, which uses an X-bracing configuration with a deflection value of 1,281 mm. This value is sequentially followed by type 4 (1,340 mm), type 2 (1,345 mm), and type 1 (1,379 mm), indicating differences in the level of structural stiffness between configurations. The X-bracing configuration at mid-span (type 3) proved to be the most efficient configuration in reducing deflection and increasing structural stiffness compared to other types. However, a comparison between type 1 and type 2 indicates that the presence of transverse bracing at mid-span had a significant effect on the magnitude of bridge deflection. In addition, type 2, which does not use bottom bracing or transverse bracing at mid-span, shows a deflection value that is almost equivalent to the K-bracing configuration, thus indicating that the addition of transverse bracing at mid-span does not contribute significantly to reducing deflection.

The differences in deflection values obtained in each model indicate that the bottom bracing configuration at mid-span has a significant influence on the structural stiffness level of the steel arch bridge. The X-bracing configuration in type 3 provides the best deflection performance because it is able to form a more effective force distribution system through diagonal elements, so that deformation in areas with maximum bending moments can be minimized. In contrast, configurations with a single transverse bracing (type 1) or without bottom bracing (type 2) at mid-span do not show a significant increase in stiffness, indicating that the presence of bracing elements must be accompanied by an appropriate configuration to work optimally. These results are in line with the findings of Rosyidi et al (2022) who emphasized that selecting the right bracing configuration is a key factor in achieving optimal deflection performance.

Evaluation and Discussion

Based on the deflection analysis results, the effectiveness of the X-bracing configuration in Type 3 can be attributed to its ability to form a more stable triangular truss system, which promotes a more uniform distribution of axial forces among structural members and significantly reduces deformation caused by bending loads. This finding is consistent with the theory that cross-bracing systems exhibit superior performance in enhancing structural stability and stiffness compared to other bracing configurations (Pan et al., 2024). Furthermore, the results of this study are in agreement with the findings of Zhao et al (2024) and Wang et al (2022), which confirm that the application of cross-bracing in steel arch bridges effectively reduces deflection and improves out-of-plane structural performance.

In contrast, the comparison between type 1 and type 2 indicates that the presence of transverse bracing at the midspan does not have a significant effect on deflection reduction. Despite differences in configuration, the deflection values obtained for both types are relatively similar. This finding suggests that the addition of structural elements without considering the structural mechanism and optimal load path does not necessarily lead to a meaningful improvement in structural performance. In other words, the orientation and configuration of the bracing system play a more dominant role than the number of structural elements alone (Greco et al., 2019).

These results directly address the research objective, which is to evaluate the effect of various bottom bracing configurations at the midspan on the deflection response of steel arch bridges. The findings indicate that optimization of the bottom bracing configuration significantly influences deflection behavior, particularly through the use of X-bracing, which is more effective in controlling deflection than conventional approaches involving the addition of transverse bracing. From a sustainable design perspective, the X-bracing configuration enhances structural performance without requiring excessive additional elements, thereby supporting sustainable bridge design and material efficiency. Moreover, these findings are consistent with the study conducted by Sulasmono et al (2024), which reported that increasing the number of transverse elements in steel arch bridges may lead to higher dead loads without providing a meaningful reduction in deflection.

This research demonstrates that the design of steel arch bridges can be optimized through the selection of appropriate bracing configurations rather than merely increasing the number of structural elements, as also reported by Bruno et al (2016). Nevertheless, this study has certain limitations, as the analysis was conducted numerically under specific loading conditions and parameter assumptions. Therefore, further research incorporating a wider range of loading scenarios, different span lengths, and experimental validation is recommended to strengthen the generalizability of the findings.

CONCLUSION

The results of the study indicate that the bottom bracing configuration has a significant influence on the mid-span deflection of the bridge. Based on the four configurations studied, type 3 showed the smallest mid-span deflection, which was 1,281 mm, indicating the maximum stiffness of the structure. In contrast, type 1 (1,379 mm), type 2 (1,345 mm), and type 4 (1,340 mm) had larger deflection values, resulting in relatively lower stiffness compared to type 3. This finding highlights the important contribution of the bottom bracing configuration to the global structural stiffness of the bridge. This study also confirms that optimizing the bottom bracing configuration type is an effective strategy to reduce mid-span deflection, and type 3 was identified as the most efficient configuration among those evaluated. For further research, it is recommended to conduct studies with variations in span length, more complex loading conditions (including dynamic and earthquake loads), or experimental validation to strengthen the numerical consistency obtained.

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