Model Simulation of Steel Frame Bridge with Deck Type Truss 5 meters Span

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**Abstract.**  Colonial occupation in Indonesia left behind various infrastructures, one of which is the lori-bridge at Sambirejo, Madiun Regency. Currently, this bridge has been repurposed as a two-wheeled vehicle bridge. According to data from the Central Statistics Agency, there has been an increase in private vehicles in Madiun by 4.375% per year (2018–2020), necessitating a redesign of the bridge to meet highway bridge standards. This study redesigns the steel frame bridge model (truss bridge) due to its strengths: being strong, lightweight, and easy to assemble. The design also considers local wisdom values so that the bridge can function as a regional icon. The methodology involves designing the bridge structure with a Parker-Warren Truss system, using hot-rolled steel (BJ 37). Analysis and simulation were conducted using software to ensure that the bridge meets load and deflection standards. The results show that the steel frame bridge model, weighing 78.22 kg, can support a test load of 400 kg, with a deflection of 2.87 mm, close to the target of 3 mm and below the allowable deflection of 6.25 mm. Thus, the designed bridge is not only safe and efficient but also meets local infrastructure needs while considering cultural aspects.

# Keywords: Bridge, Simulation-model, Frame, Steel, Parker-Warren

# INTRODUCTION

Colonial occupation in Indonesia left many legacies, one of which is the lori-bridge infrastructure at Sambirejo Bridge in Madiun Regency. Although it has endured to this day, the bridge has been repurposed as a bridge for two-wheeled vehicles. Bridge planning needs to consider effectiveness and efficiency to ensure that the construction meets the specifications required to ensure the safety and comfort of bridge users [1]. Additionally, bridge planning needs to consider serviceability, design innovation, construction, and maintenance to ensure that it functions ideally according to the bridge's intended lifespan [2]. This is raised as part of the issue of national development equity, which requires transportation infrastructure to connect one region to another. Additionally, innovation is needed in the design and simulation of bridge constructions that are strong, easy to implement, and environmentally friendly, in line with the theme of the Indonesian Bridge Competition 2024.

According to the Central Statistics Agency from 2018 to 2020, the average increase in the number of private vehicles in Madiun was 4.375%. Based on this data, it is necessary to redesign the railway bridge to meet the standards of a highway bridge to support community movement. A truss bridge is a bridge composed of steel members, distributing loads by resolving them into axial forces through the joints [3].

A steel truss bridge is used as a highway bridge because of its strong, lightweight structure and ease of assembly, making it an ideal choice for roadways [4]. Additionally, the advantage of steel material is its durability in all weather conditions, and its shape can be varied according to needs [5]. These aspects should be applied in bridge construction planning to create effective and efficient structures. Additionally, in bridge planning, it is important to consider cultural aspects that can serve as landmarks or icons, reflecting the local wisdom of the region.

The Indonesia Bridge Competition XIX 2024 aims to innovate in designing practical and realistic solutions to address infrastructure issues in Indonesia. Therefore, it is expected to design bridges that align with the theme "Design and Build a Robust and Optimal Bridge Considering Local Wisdom."

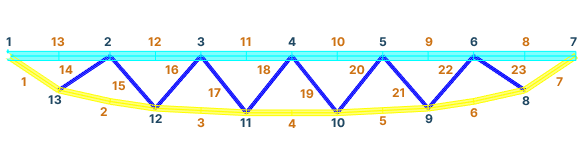
# METHODS

The methodology for planning this steel frame bridge model begins with a literature review and data collection. The data required for planning includes bridge specifications based on the Indonesia Bridge Competition 2024 guidelines, material specifications, and connection specifications. Next, loading is performed according to SNI 1725:2016 with a test load of 400 kg at the center of the span. Additionally, cross-sectional and steel connection analyses are conducted based on SNI 1729:2020. Finally, the goal is to achieve deflection close to the target deflection of 3±1 mm with the lightest possible structural weight to achieve optimal analytical results.

## STRUCTURAL SYSTEM

The structural system refers to the arrangement of elements and how the loads are distributed, making the configuration of the bridge important to consider. The bridge configuration comes in various types with different performances that affect the structural durability, aesthetics, and efficiency [6]. The Parker-type bridge is a configuration where the main framework has a curved shape, resulting in support reactions that are oriented toward the edge transitions under perpendicular loads [7].

On the other hand, the Warren-type bridge is a truss type composed of triangles combined into a structure with the characteristic of maintaining its shape, thus ensuring stability [8]. In terms of bridge performance, the Warren truss has advantages over the Pratt and Howe types, as it meets the DCR limits and adheres to the allowable deflection criteria [9]. The structural system of the Model Steel Frame Bridge integrates the Parker-Warren Truss design, combining the economical curved shape of the Parker truss with the load-distributing characteristics of the Warren truss, resulting in an economical and robust structure [10]. The structural system is shown in FIGURE 1 below.

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**FIGURE 1** Geometry model of the Steel Frame Bridge Model

## ANALYSIS OF ELEMENTS AND CONNECTIONS

The cross-sectional and connection analysis is based on the lowest strength under SNI 1729:2020. The section analysis equations are as follows.

1. Cross-Section Analysis
2. Tension Strenght, according to SNI 1729:2020 Article D.2

Tensile Yield; = ≥ (1)

Tensile Failure; = ≥ (2)

1. Compressive Strength, according to SNI 1729:2020 Article E.3, E.4, and E7.

Flexural Buckling; = ≥ (3)

Torsional Buckling; = ≥ (4)

Flexural-Torsional Buckling; = ≥ (5)

1. Connection Analysis
2. Bolt Spacing Requirements, according to SNI 1729:2020 Article J.3

Bolt spacing ; 3d ≤ S ≤ 200 (6)

Edge spacing ; 1.5d ≤ S ≤ 150 (7)

1. Connection Strength, according to SNI 1729:2020 Article J.3

Shear Strength; = (8)

Tensile Strength; = (9)

Bearing Strength; = (10)

Tear Strength; = (11)

# RESULTS AND DISCUSSION

## DATA OF MODEL

In designing a steel frame bridge model, it is essential to consider the principles and criteria that comply with the regulations. Design criteria are necessary to ensure the efficiency of the bridge as follows. The data for the steel frame bridge includes information about design characteristics and structural conditions to be utilized effectively in planning and maintenance. The planned steel frame bridge data, based on the Indonesia Bridge Competition 2024 guidelines, is provided in **TABLE 1** below.

**TABLE 1**. Steel Frame Bridge Model Data

|  |  |
| --- | --- |
| Specification | Description |
| Type of Bridge | Deck Type Truss |
| Material of Bridge | Hot Rolled Steel |
| Connection devices | Anchor Plate and Bolts |
| Span of Bridge | 5000 mm |
| Floor width of Bridge | 800 mm |
| Height of Bridge | 500 mm |

In bridge planning, it is necessary to consider optimal bridge structure technology, meaning that it should be lightweight yet capable of supporting the planned load [11]. Therefore, material is a crucial aspect in the design of the steel frame bridge model as it affects both the performance and strength of the bridge. The material specifications planned for the steel frame bridge model are detailed in **TABLE 2** and **TABLE 3** below.

**TABLE 2**. Material Specification

|  |  |
| --- | --- |
| Specification | Description |
| Types of Steel and Steel Quality | Hot Rolled Steel (ST 37) |
| Steel density | 7850 kg/m3 |
| Minimum Yield Stress (Fy) | 240 MPa |
| Minimum Tensile Strength (Fu) | 370 MPa |
| Modulus of Elasticity (E) | 200000 MPa |
| Modulus of Shear(G) | 77200 MPa |
| Poisson's Ratio (µ) | 0,3 |

Source: Procedures for Designing Steel Structures for Buildings”

**TABLE 3**. Materials for Truss Bridges

|  |  |
| --- | --- |
| Profile | |
| Steel quality | ST 37 |
| Dimensions of profile | Double L 45×20×2  Double L 30×14×1,7  L 22×22×1,4 |
| Anchor Plate | |
| Material dan Mutu | Hot Rolled Steel (ST 37) |
| Minimum Yield Stress (fy) | 240 MPa |
| Minimum Tensile Strength (fu) | 370 MPa |
| Thick of plate | 2 mm |
| Flange Bolt | |
| Bolt quality | Grade 4.6 |
| Nominal Tensile Strength (Fnt) | 400 MPa |
| Nominal Shear Strength (Fnv) | 241 MPa |
| Diameter | 6 mm |
| Length | 15 mm and 20 mm |

Source: ”Guidelines for Planning Steel Structures for Buildings”

## LOADING MODEL

Loading combinations are performed by combining the loads acting on the steel truss bridge model to ensure that the bridge can withstand the applied loads. The loads are modeled with the load applied precisely at the nodes. The loading on the steel truss bridge model is shown in **TABLE 4** and **TABLE 5** below.

**TABLE 4**. Data of Weight Structures

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| No | Element code | Type of element | Profile | Weight (kg) |
| 1 | BMB | Large cross beam | Double Angle 30 14 1,7 | 1,90 |
| 2 | BMK | Small cross beam | Angle 22 22 1,4 | 4,33 |
| 3 | BGU | Main girder beam | Double Angle 45 20 2 | 40,28 |
| 4 | BD | Diagonal beam | Double Angle 30 14 1,7 | 13,21 |
| 5 | - | Connection and bolt | Plate 2 mm thick, bolt 6 mm | 7,74 |
| 6 | - | Floor plate | Multiplek 3 mm | 4,80 |
| 7 | - | Weight of finishing | Anti-corrosion paint, stickers | 5,97 |
| Total weight | | | | 78,22 |
| Test load | | | | 400,00 |

**TABLE 5**. Data of Loading Structures

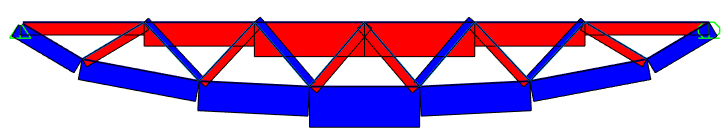
|  |  |  |  |
| --- | --- | --- | --- |
| Type of Loading | Loading Factor | Loading (kg) | Unit |
| Weight of structures | 1,1 | 2,42 | kg/node |
| Weight of connection | 1,1 | 0,33 | kg/node |
| Weight of floor plate | 1,4 | 4,80 | Kg |
| Weight of Finishing | 2,0 | 0,24 | kg/node |
| Weight of Ornament | 2,0 | 0,71 | kg/node |
| Loading test (400 kg) | 1,8 | 200,00 | kg/node |

Source: SNI 1725-2016 “Loading for Bridge”

Analysis of internal forces is necessary to ensure that the Steel Frame Model Bridge can withstand the applied loads. Additionally, internal force analysis is needed to analyze load distribution so that the Steel Frame Model Bridge can be optimally designed. The internal force analysis using software is shown in **TABLE 6** and **FIGURE 2** below.

**TABLE 6**. Analysis of Internal Forces

|  |  |  |  |
| --- | --- | --- | --- |
| Type of elements | Ultimate Force | Force values | Unit |
| Main Longitudinal Girder | Axial Compression | 6469,12 | N |
| Axial Tension | 7815,90 | N |
| Diagonal Members | Axial Compression | 2110,37 | N |
| Axial Tension | 1476,77 | N |



**FIGURE 2**. Axial Forces Diagram

## DESIGN OF COMPONENTS AND CONNECTIONS

1. **Design of Components**

The design of the cross-section of the steel frame bridge model is crucial to ensure it can support the applied loads. The analysis is conducted by considering the factors of forces acting, such as those on the main longitudinal girder and the diagonal members, as discussed below.

The analysis of the main longitudinal girder includes both compressive and tensile forces. The analysis is presented in **TABLE 7** and **TABLE 8** below.

**TABLE 7.** Compressive Force Analysis of Main Longitudinal Girder

| Criteria | References | Control | | | Description |
| --- | --- | --- | --- | --- | --- |
| Profile Clasification | SNI 1729:2020 Article B4.1a | b/t = 22,5 | > | λp = 12,99 | Slenderness |
| Flexural buckling | SNI 1729:2020 Article E.3 | θPn = 25172 N | > | Pu = 6469,12 | Safe |
| Torsional buckling | SNI 1729:2020 Article E.4 | θpn = 48916,3 N | > | Pu = 6469,12 | Safe |
| Flexural-torsional buckling | SNI 1729:2020 Article E.7 | θpn = 9359 N | > | Pu = 6469,12 | Determine |

**TABLE 8.** Tension Force Analysis of Main Longitudinal Girder

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Criteria | References | Control | | | Description |
| Tensile Yield | SNI 1729:2020 Pasal D.2 | θpn = 54432 N | > | Pu = 7815,9 N | Safe |
| Tensile Rupture | SNI 1729:2020 Pasal D.2 | θpn = 35921 N | > | Pu = 7815,9 N | Determine |

The analysis of the diagonal member girder consists of compressive and tensile forces. The analysis is shown in **TABLE 9** and **TABLE 10** below.

**TABLE 9.** Compressive Force Analysis of Diagonal Members

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Criteria | References | Control | | | Description |
| Profile Clasification | SNI 1729:2020 Table B4.1a | b/t = 17,647 | > | λp = 12,99 | Slenderness |
| Flexural buckling | SNI 1729:2020 Article E.3 | θpn = 9216,58 N | > | Pu = 2122 N | Determine |
| Torsional buckling | SNI 1729:2020 Article E.4 | θpn = 44597,6 N | > | Pu = 2122 N | Safe |
| Flexural-torsional buckling | SNI 1729:2020 Article E.7 | θpn = 12292 N | > | Pu = 2122 N | Safe |

**TABLE 7.** Tension Force Analysis of Diagonal Members

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Criteria | References | Control | | | Description |
| Tensile Yield | SNI 1729:2020 Article D.2 | θPn = 31065,12 N | > | Pu = 1493 N | Safe |
| Tensile Rupture | SNI 1729:2020 Article D.2 | θPn = 10919,5 N | > | Pu = 1493 N | Determine |

1. **Design of Connections**

Connections in a bridge are crucial components that ensure the safety and durability of the bridge. The choice of the type of connection for a bridge depends on various factors, such as the length of the bridge, the materials used, and the load conditions. In the Steel Frame Bridge Model, the connections used are bolt connections with the design as shown in **TABLE 11** below.

**TABLE 8**. Design of Connections

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Criteria | References | Control | | | Implemented |
| Bolt Spacing | SNI 1729:2020 Article J3 | 3d ≤ S ≤ 200 | = | 18 ≤ S ≤ 200 | 18 mm |
| Edge Spacing | SNI 1729:2020 Article J3 | 1,5d ≤ S ≤ 150 | = | 9 ≤ S ≤ 150 | 9 mm |

After designing the connections for the Steel Frame Bridge Model, it is necessary to inspect the strength of the connections to ensure their safety. The connection strength analysis is detailed in **TABLE 12** below.

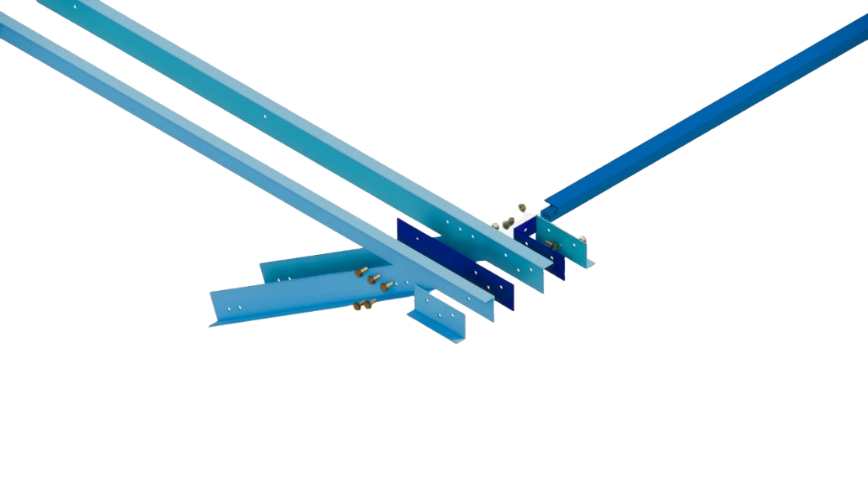
**TABLE 9**. Connections Strength Control

|  |  |  |
| --- | --- | --- |
| Inspection | References | Bolt Strenght |
| Shear strength | SNI 1729:2020 Article J.3 | θRnv = 5,11 kN/baut |
| Tension strength | SNI 1729:2020 Article J.3 | θRnt = 8,478 kN/baut |
| Bearing strength | SNI 1729:2020 Article J.3 | θRn = 23,976 kN/baut |
| Tear strength | SNI 1729:2020 Article J.3 | θRn = 11,988 kN/baut |

After performing the strength checks, the final step is to determine the number of bolts required. The bolt requirements and connection details are shown in **TABLE 13** and **FIGURE 3** below.

**TABLE 10**. Bolt Requirements

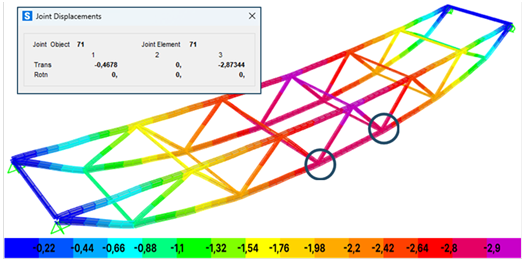
|  |  |  |
| --- | --- | --- |
| References | Parameter | Number of bolts |
| Steel Structure Design with LRFD Metode, 2008 | n = = = 1,5 units | 2 units |



**FIGURE 3.** Details of the Connection at the Support

## ANALYSIS OF DEFLECTION

Deflection is the deformation of a structure caused by the applied loads and the span of the bridge [14]. In the Indonesian Bridge Competition 2024 guidelines, the targeted deflection is 3 ± 1 mm, and the allowable deflection is 6.25 mm. From the analysis results using software, the deflection of the steel frame bridge model was obtained as 2.87 mm, as shown in TABLE 14 and FIGURE 4 below.

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**FIGURE 4.** Deflection Diagram

**TABLE 14.** Analysis of Deflection

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Allowable deflection (f-allow) | Target deflection | Deflection (f) | Control (f ≤ f-allow) | | | | | Description |
| 6 mm | 3 mm | 2,87 mm | 2,87 mm | ≤ | 3 mm | ≤ | 6,00 mm | Safe |

Based on the analysis and calculations of the truss bridge structure design, and in accordance with the results shown in **FIGURE 4** and **TABLE 14** above, the allowable deflection is 6.00 mm, while the target deflection is 3.00 mm. The deflection obtained from the load acting on the bridge structure is 2.87 mm, which is still below the target deflection of 3.00 mm and is located at the center of the span.

# CONCLUSIONS

The design of the steel frame bridge model refers to the Bridge Competition Indonesia 2024 Guidelines [16]. The steel frame bridge model uses a double angle profile of 45×20×2 for the main frame, a double angle profile of 14×30×1.4 for the diagonal members, an angle profile of 14×30×1.4 for the top edge diagonals, and an angle profile of 22×22×1.4 for the top and bottom diagonals. The model bridge weighs 78.22 kg with a test load of 400 kg at mid-span. From the analysis and cross-sectional checks, the reduced nominal strength is greater than the ultimate strength, indicating that the section is safe. Additionally, the software modeling shows that the theoretical deflection of 2.87 mm is close to the target deflection of 3 ± 1 mm and is less than the permissible deflection of L/800 = 6.25 mm, making the bridge optimal.

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