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Performance Analysis of Composite Steel I-Girder Bridge under Overloading Conditions

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ABSTRACT

Composite bridges are generally a combination of steel girders (steel I-girders) and reinforced concrete, where steel acts as the primary load-resisting element, while reinforced concrete serves as the deck slab. This structural system requires careful consideration of strength, durability, and economic efficiency aspects. Along with population growth, economic development, and increasing traffic intensity and loading, the performance of existing bridges may deteriorate over time, necessitating a thorough evaluation of their load-carrying capacity. The main issue addressed in this study is whether the originally designed bridge is still capable of accommodating increasing loads or requires structural strengthening. This study aims to evaluate the structural capacity and deflection behavior of a composite steel I-girder bridge. The adopted method is the Load and Resistance Factor Design (LRFD) approach, supported by numerical modeling using SAP2000 software and based on loading provisions specified in SNI 1725:2016. The analysis results show that under the 8-truck loading condition, the capacity ratio reaches 1.052 (>1.00), indicating an unsafe condition. This finding indicates that the strength limit state governs the structural safety of the bridge, while the serviceability limit state (deflection) remains satisfied even under overload conditions. The deflection value of 21.2495 mm (<25 mm) still satisfies the serviceability limit; however, some girder elements fail to meet safety requirements. The maximum axial force, shear force, and bending moment under the 8-truck loading condition are 1890.717 kN (tension), 97.424 kN, and 690.3965 kN·m, respectively.

Keywords: Composite Bridge, Structural Capacity, Deflection, Serviceability, Steel Girders

INTRODUCTION

Infrastructure development is one of the primary indicators supporting economic growth, regional connectivity, and equitable national development. Land transportation infrastructure, particularly roads and bridges, plays a strategic role as it serves as the backbone of human mobility and goods distribution [1]. In Indonesia, the dominance of land transportation modes has led to a continuous and significant increase in traffic loads on road and bridge networks over time. Bridges, as an integral part of the transportation system, function to connect regions separated by physical barriers such as rivers, valleys, and other infrastructures [2]. The reliability of bridges plays a crucial role in ensuring smooth traffic flow and the economic stability of a region. In the case of the Pengidam Karang Baru Bridge, no specific economic data are available; however, general references on bridge economics support this statement. Therefore, bridge design and evaluation must consider various aspects, such as structural strength, material durability, user safety, as well as the cost efficiency of construction and maintenance [3]. With advancements in construction technology, the use of composite structural systems has been increasingly adopted in bridge engineering [4]. Composite bridges, which combine steel and reinforced concrete, offer advantages such as high strength, material efficiency, and ease of construction implementation [5]. In this study, the composite action between the steel I-girder and the concrete deck slab is achieved through shear connectors, specifically headed studs, which are assumed to be fully effective in transferring horizontal shear forces. Steel has excellent tensile strength, while reinforced concrete is highly effective in resisting compressive forces; therefore, the combination of both materials results in an optimal structural system [6]. However, the increasing number of vehicles, economic growth, and the development of the transportation industry have led to the emergence of heavier vehicle loads [7]. This condition often does not fully correspond to the loading assumptions used in the initial bridge design. As a result, bridge structures may experience increased internal forces, greater deformations, and a reduction in structural performance [8]. If this condition is not regularly evaluated, it may increase the risk of structural damage or even failure, which can ultimately compromise user safety [9]. Therefore, a comprehensive analysis is required to evaluate the capacity and performance of existing bridges under actual field loading conditions. This evaluation is not only intended to ensure structural safety but also to serve as a basis for determining the need for structural strengthening or rehabilitation. A bridge is a civil engineering structure designed to support and transfer loads from the traffic above to its supporting elements, such as piers and abutments [10]. Based on their structural systems, bridges can be classified into several types, including beam bridges, truss bridges, arch bridges, suspension bridges, and composite bridges [11]. A composite bridge is a type of structural system that combines two or more materials to act together in resisting loads. In general, composite bridges utilize steel girders as the primary flexural load-resisting elements, combined with reinforced concrete deck slabs. The interaction between steel and concrete is achieved through shear connectors, allowing both materials to act compositely and thereby enhancing the overall structural capacity [12]–[14]. In bridge design and analysis, loading is a primary factor influencing structural behavior. The considered loads include dead loads, live loads, as well as additional loads such as wind, seismic, and thermal effects. In Indonesia, bridge loading is regulated by SNI 1725:2016, which accounts for actual traffic conditions and developments in transportation technology [15].

The design method used in this study is the Load and Resistance Factor Design (LRFD), a probabilistic-based approach that accounts for uncertainties in both loads and material resistance [16]. In this method, loads are multiplied by load factors, while material resistance is multiplied by resistance factors. The structure is considered safe when the factored resistance exceeds the factored loads [17]. Modern bridge structural analysis is generally performed using finite element method-based software, such as SAP2000 [18]. This numerical approach enables detailed structural modeling, including the simulation of various loading conditions and the analysis of structural responses. The parameters evaluated include internal forces (axial force, shear force, and bending moment), deflection, and structural member capacity [19]. Deflection is an important parameter in evaluating the serviceability limit state. Excessive deflection may cause user discomfort and damage to non-structural elements [20]. In addition, the capacity ratio is used as an indicator of structural safety, where a value less than one indicates a safe condition, whereas a value greater than one indicates that the structural member has exceeded its capacity and is potentially prone to failure [21]. The progressive rise in traffic loading, particularly due to the increasing use of heavy vehicles, places additional demand on existing bridge structures beyond their originally assumed design conditions. This situation may induce higher internal force effects and amplified deformation responses, which can ultimately compromise structural performance and serviceability [22]. The main problem addressed in this study is the load-carrying capacity of composite bridges under overload conditions and the structural response, particularly deflection and member capacity, to increasing load levels. It should be noted that this study focuses on static strength and serviceability performance under increasing traffic loads. Fatigue and dynamic effects are beyond the scope of this paper and are recommended for future research. In addition, it is necessary to determine the maximum safe loading threshold that can still be tolerated by the structure before reaching an unsafe condition. This study aims to analyze the performance of the composite steel I-girder bridge superstructure in relation to increasing traffic loads. Specifically, it seeks to determine the structural capacity based on the LRFD method, evaluate the deflection resulting from varying load conditions, and identify the safe limit state of the structure. This study is expected to contribute to the field of structural engineering, particularly in the analysis of composite bridge performance under overload conditions. In addition, the findings may serve as a reference for practitioners in assessing existing bridge conditions. From a practical standpoint, this research can be used as a basis for decision-making regarding bridge maintenance, strengthening, or rehabilitation, thereby improving user safety and extending the service life of the structure. Furthermore, this study also supports the development of sustainable and reliable infrastructure in response to future traffic growth.

MATERIALS AND METHODS

This study was conducted through a systematic and structured procedure to obtain accurate and scientifically reliable analytical results. The initial stage involved problem identification, focusing on the existing condition of the bridge and the potential reduction in structural performance due to increased traffic loads. This identification was carried out through field observations, particularly concerning the growth in traffic volume and the tendency of heavier vehicle loads passing over the bridge. Subsequently, a comprehensive literature review was undertaken to establish a robust theoretical framework. This review encompasses fundamental principles governing the behavior of composite bridge systems, design methodologies based on the Load and Resistance Factor Design (LRFD) approach, as well as relevant national standards and regulatory provisions in Indonesia. Furthermore, the literature also incorporates findings from prior studies to enable methodological comparison and validation of analytical outcomes, thereby ensuring a solid scientific foundation and supporting the originality of this research. In general, a structural system is deemed safe when it satisfies the following condition:

$$\emptyset R_n \geq \sum \gamma_i . Q_i \tag{1}$$

The subsequent stage involves data collection, comprising both primary and secondary data. Primary data were obtained through direct field surveys with the objective of capturing the actual condition of the bridge, both in terms of geometric dimensions and structural physical condition. This activity included measurements of structural components, visual inspections to identify damage or deformation, and documentation of the study site. Meanwhile, secondary data were collected from relevant agencies, technical documents, and pertinent scientific literature, including material specifications, loading data, and design parameters used in bridge planning. After all data have been collected, structural modeling is performed using SAP2000 software. This modeling aims to numerically represent the bridge structure so that its response to various load combinations can be analyzed. The resulting outputs, including internal forces, deflection, and other parameters, are then processed using Microsoft Excel to facilitate result interpretation and evaluation. The final stage of the study involves drawing conclusions based on the analytical results, followed by formulating technical recommendations that may serve as references for future bridge management and development.

Study Location

This study was conducted on the Pengidam Karang Baru Bridge, located in Bandar Pusaka District, Aceh Tamiang Regency, Aceh Province. This site was selected due to the bridge's strategic role in supporting community mobility and inter-regional logistics distribution. In addition, relatively high traffic conditions and the presence of heavy vehicles make this bridge highly relevant for evaluating its structural capacity and performance. Geographically, the study area is situated in a region characterized by environmental influences such as relatively high wind exposure and rainfall intensity. These environmental factors are therefore considered in the load analysis. By accounting for these conditions, this study is expected to provide a realistic representation of the bridge structural behavior under actual field conditions.

Types and Sources of Data

The data used in this study consist of two main types, namely primary data and secondary data. Primary data are obtained directly from the study site through field survey activities. These data include the bridge's geometric dimensions, the physical condition of structural components, and other parameters that can be directly observed. Primary data collection is carried out using appropriate measuring instruments and is systematically documented to ensure data accuracy and reliability. Meanwhile, secondary data are obtained from various sources such as government agencies, design documents, and scientific literature. These data include the bridge's technical specifications, material properties, loading standards, and other design parameters. In addition, secondary data also cover information on design vehicle speeds and road classification used in traffic load analysis. The use of both primary and secondary data in this study aims to produce a comprehensive analysis, where primary data provide an actual representation of field conditions, while secondary data establish the theoretical basis and calculation parameters in accordance with applicable standards.

Research Object

The object of this study is the Pengidam Karang Baru Bridge, which is a composite steel I-girder bridge with a span length of 20 meters. The bridge structure consists of steel girders as the primary load-resisting elements and a reinforced concrete slab as the roadway deck. This composite system enables interaction between steel and concrete in resisting loads, thereby improving structural efficiency and capacity. In this study, the analysis is focused on the bridge superstructure. Structural components such as longitudinal girders, transverse girders, and bracing systems are analyzed based on the assumption that these elements behave in accordance with applicable design standards. This approach is adopted to simplify the analytical model without compromising the accuracy of the obtained results.

Analysis Procedure

Structural analysis is carried out in stages using SAP2000 software, supported by data processing in Microsoft Excel. These stages include structural modeling, load analysis, incremental load application, and evaluation of the analysis results.

A. Structural Modeling

Structural modeling is the initial stage of numerical analysis aimed at representing the bridge condition in a three-dimensional model. This model includes all main structural components, such as primary girders, diaphragms, and the bridge deck slab. The dimensions used in the modeling consist of a 20-meter bridge span, a 7-meter roadway width, and 1-meter-wide sidewalks on both sides. The main girders are modeled using IWF steel sections, which are capable of effectively resisting bending moments and axial forces. Meanwhile, the diaphragm elements are modeled using channel (C) sections, which function as bracing members to enhance structural stability. The materials used in the model consist of BJ 40 steel for the primary structural components and concrete with a specified compressive strength of 30 MPa for the deck slab. The yield strength (fy) of BJ 40 steel is 400 MPa, and the modulus of elasticity assumed for steel is 200,000 MPa, while for concrete it is 25,700 MPa (based on f'c = 30 MPa). This modeling is performed by considering boundary conditions, connections between structural elements, and load distribution acting on the structure. The girders are modeled as simply supported with pin supports at one abutment and roller supports at the other, allowing longitudinal movement and rotation while restraining vertical and lateral displacements. Thus, the resulting model is expected to realistically represent the structural behavior under field conditions.

B. *Load Analysis*

Load analysis is carried out in accordance with applicable bridge loading standards. The loads considered in this study include dead loads, superimposed dead loads, traffic loads, and environmental loads such as wind [23], [24]. Dead loads consist of the self-weight of the structure, which is automatically calculated by the software based on material properties and element dimensions. Superimposed dead loads include asphalt layers, rainwater accumulation, and other non-structural components such as railings and parapets. Traffic loads consist of lane loads and truck loads modeled as moving loads. Lane loads include uniformly distributed loads and concentrated line loads, while truck loads are represented using standard design vehicles with specified capacities. These loads are applied along designated traffic lanes to simulate actual traffic conditions. In addition, wind loads are considered based on the design wind speed corresponding to the site conditions of the study area. All loads are then combined using load factors in accordance with the LRFD method to obtain the most critical loading conditions affecting the structure. For further details, see Table 1 below.

Table 1. Design Loads for the Bridge

Load Group	**Loading Case**
Permanent Load	Dead Load
	Superimposed Dead Load
Traffic Load	Uniformly Distributed Lane Load
	Line Lane Load
	Braking Load
	Pedestrian Load
Environmental Load	Wind Load
	Earthquake Load

Wind and earthquake loads were included in the load combinations as per SNI 1725:2016. However, their contribution to the overall structural response was negligible compared to traffic loads, consistent with typical short-span bridge behavior. The truck load used in this study is a three-axle heavy truck with a total gross vehicle weight of 50 tons (approximately 490 kN), representing the maximum legal limit for heavy vehicles in Indonesia based on SNI 1725:2016.

C. *Load Increment*

The load incrementing stage is carried out to evaluate the maximum capacity of the bridge structure. In this stage, live loads in the form of heavy vehicles are gradually increased until the structure reaches its limit state or experiences failure. This load increment is performed by simulating an increase in the number of heavy vehicles crossing the bridge, particularly trucks with specified load capacities. The objective of this stage is to determine the extent to which the structure can sustain increasing loads and to identify the most critical structural members that are prone to failure.

D. Structural Analysis

The final stage of this study is structural analysis conducted using SAP2000 software. This analysis produces various key parameters, such as axial forces, shear forces, bending moments, and structural deflections. The analysis results are then evaluated by comparing the structural capacity with the applied loads. In addition, the resulting deflections are checked to ensure compliance with the allowable limits specified in the applicable standards. This evaluation aims to determine the level of structural safety and to identify whether the bridge remains serviceable or requires strengthening measures. Based on the evaluation results, conclusions can be drawn regarding the structural performance of the bridge, along with technical recommendations that may serve as references for future bridge infrastructure management and development.

RESULTS AND DISCUSSION

The analysis results were obtained through numerical modeling using SAP2000 software, considering various load combinations in accordance with applicable standards. The discussion is conducted comprehensively to evaluate the performance of the bridge structure under increasing traffic loads, particularly heavy vehicle loads.

Analysis Results Using SAP2000

The numerical analysis results obtained using SAP2000 provide a comprehensive overview of the bridge structural response under applied loading conditions [25]. The main parameters analyzed include structural weight, capacity ratio, deflection, and internal forces (axial force, shear force, and bending moment). The analysis is carried out using a staged loading approach to simulate the increasing traffic load conditions occurring in the field. This approach is consistent with modern studies emphasizing the importance of software-based numerical simulations in bridge performance evaluation, particularly in addressing overloading conditions that are increasingly common due to transportation growth [26].

A. Bridge Self-Weight

Based on the analysis results, the total self-weight of the analyzed composite bridge structure is 131.3475 tons. This value is automatically obtained from the SAP2000 model, which accounts for all structural components, including steel girders, concrete deck slabs, and other additional elements. Structural self-weight is a critical parameter in structural analysis, as it directly contributes to the dead load acting on the bridge. This dead load influences the internal force distribution as well as the overall structural deformation. Recent studies indicate that accurate estimation of structural weight is essential in composite bridge analysis, as it can affect capacity evaluation results by approximately 10–15% [27].

B. Capacity Ratio

The capacity ratio is a key indicator in assessing structural safety. A structural member is considered safe when the capacity ratio is ≤ 1, whereas a value greater than 1 indicates an unsafe condition. For further details, see Table 2 below.

Table 2. Capacity Ratio at Mid-Span

Moving Load	Capacity Ratio	Acceptance Criteria (Capacity Ratio ≤ 1.0)	Description
1 Truck	0.132	1	Safe
2 Trucks	0.261	1	Safe
3 Trucks	0.391	1	Safe
4 Trucks	0.521	1	Safe
5 Trucks	0.652	1	Safe
6 Trucks	0.782	1	Safe
7 Trucks	0.912	1	Safe
8 Trucks	1.052	1	Not Safe

The analysis results indicate that the capacity ratio increases progressively with the addition of traffic loads. Under loading conditions of 1 to 7 trucks, the capacity ratio remains within the safe limit. However, at the 8-truck loading condition, the capacity ratio reaches 1.052, indicating that it has exceeded the safety threshold. For further details, see Figure 1 below.

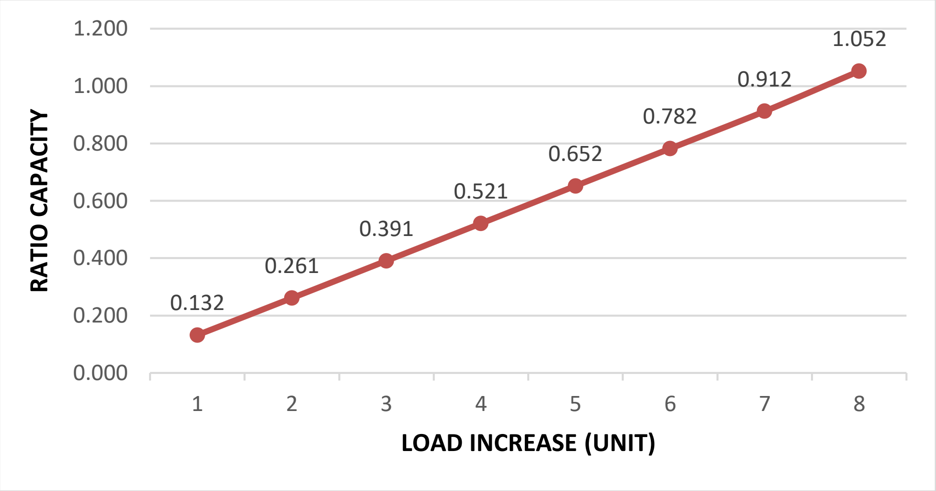


Figure 1. Relationship between Load Increment and Capacity Ratio

This phenomenon indicates that the girder elements at mid-span represent the most critical part of the structure. This is consistent with structural mechanics theory, which states that the maximum bending moment in simply supported bridges occurs at mid-span. Other studies also show that in composite bridges, failure due to overloading generally initiates in the main girders at mid-span, as a result of the combined effects of maximum bending moment and high tensile stresses [28]. The analysis results show that the capacity ratio increases consistently with the increment of vehicular loading. This indicates that the bridge structure has a defined capacity limit that cannot be exceeded without the risk of failure [29]. Under the loading condition of eight trucks, the capacity ratio exceeds the safety limit, indicating that the structure is no longer capable of sustaining additional loads. This condition reflects an overloading phenomenon that is commonly observed in bridges in developing countries. Other studies have reported that overloading is one of the primary causes of reduced bridge service life and may even accelerate deterioration by up to 30% [30]. Field observations on the Pengidam Karang Baru Bridge revealed visual evidence of overloading, including minor cracks in diaphragm connections and tire marks consistent with heavy mining trucks, although weigh-in-motion data were unavailable.

C. Structural Deflection

Deflection is a critical parameter in evaluating the serviceability performance of a structure. Based on the analysis results, the maximum deflection occurs at the mid-span of the bridge. The deflection value increases linearly with the addition of load. At the maximum loading condition (8 trucks), the deflection reaches 21.2495 mm, which is still below the allowable limit of 25 mm (L/800). For further details, see Table 3 and Figure 2 below.

Table 3. Mid-Span Deflection

Moving Load	Deflection	Deflection Limit (Serviceability Criteria) (L/800)	Unit	Description
1 Truck	2.6562	25	mm	Safe
2 Trucks	5.3124	25	mm	Safe
3 Trucks	7.9686	25	mm	Safe
4 Trucks	10.6247	25	mm	Safe
5 Trucks	13.2809	25	mm	Safe
6 Trucks	15.9371	25	mm	Safe
7 Trucks	18.5933	25	mm	Safe
8 Trucks	21.2495	25	mm	Safe

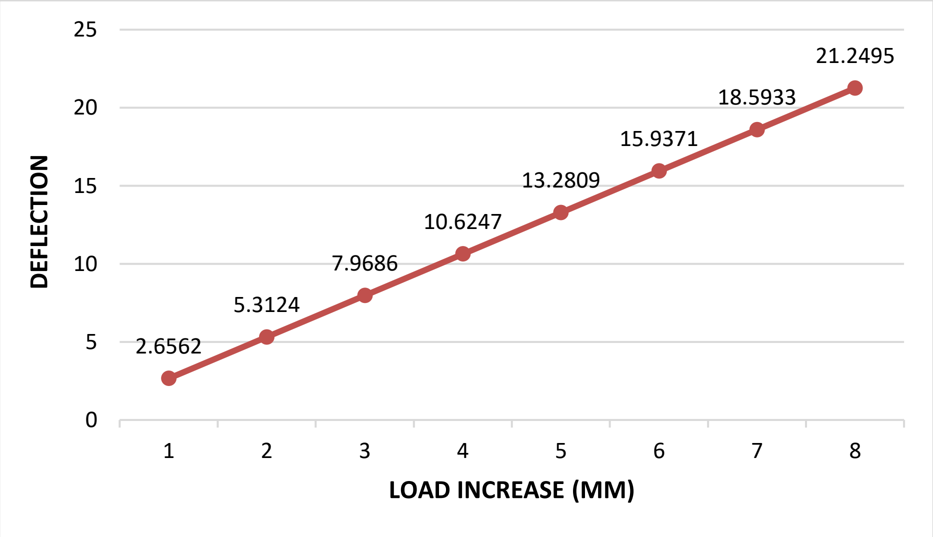


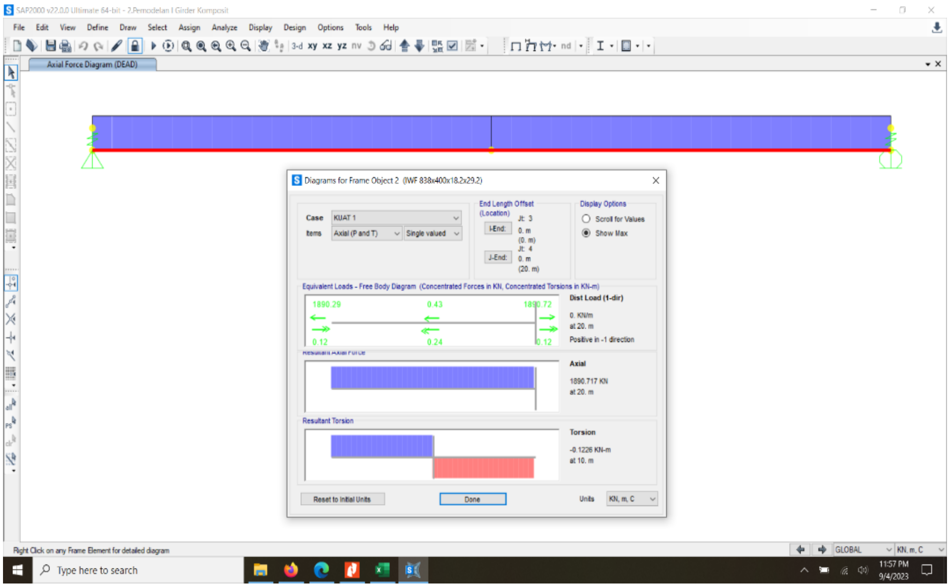
Figure 2. Relationship between Load Increment and Deflection

Nevertheless, although the deflection remains within the allowable limits, the structure already exhibits indications of insufficient safety in terms of its load-carrying capacity. This finding indicates that the strength limit state is more critical than the serviceability limit state. This finding is consistent with previous studies, which indicate that in many cases of composite steel bridges, structural failure is more frequently governed by strength capacity rather than deflection limits [31]. The reason deflection remains within the allowable limit despite strength failure is attributed to the relatively short span (20 m) and high flexural stiffness of the composite steel I-girder section. In such bridges, the strength limit state often governs over serviceability, particularly under overload conditions. The deflection occurring in the bridge structure shows a linear increasing trend with the increment of traffic loading. This pattern indicates that the structure is still behaving within the elastic range, where the relationship between load and deformation remains proportional. In other words, up to a certain loading stage, structural elements such as steel girders and concrete slabs are still capable of responding to loads without experiencing permanent damage [32].

Nevertheless, the analysis results indicate that although the deflection remains within the specified allowable limits, the capacity ratio of certain structural elements has exceeded the safe threshold. This condition signifies that, from a strength perspective, the structure is already in a critical state, even though it still appears acceptable in terms of deformation. This highlights a discrepancy between the serviceability limit state and the strength (ultimate) limit state, where both criteria must be evaluated concurrently [33]. Therefore, the assessment of structural performance cannot rely solely on deflection. Deflection reflects only the aspects of serviceability and functional performance, whereas the capacity ratio represents the structure’s ability to safely resist applied loads. Consistent with previous studies, bridge evaluations that consider deflection alone may lead to less accurate conclusions. Accordingly, a comprehensive analysis that incorporates both parameters is essential to ensure the overall safety and reliability of the bridge structure [34].

D. Internal Forces (Axial Force, Shear Force, and Bending Moment)

The analysis results indicate that the maximum axial force occurring in the girder is 1890.717 kN (tension). The presence of a large axial tensile force (1890.717 kN) in a simply supported composite girder, which is typically subjected primarily to bending, requires clarification. This axial tension arises from the specific load combination including braking forces and longitudinal load distribution effects, as well as the staged loading condition at 8 trucks, which induces membrane action in the deck slab and restraint from the bracing system. Under overload conditions, the composite section experiences not only bending but also significant axial tension due to the interaction between the steel girder and the concrete deck through shear connectors, leading to a combined flexural-tensile stress state. In addition, the maximum shear force is 97.424 kN, while the maximum bending moment is 690.3965 kN·m. For further clarification, these results are presented in Figure 3 and Figure 4 below.



Diagrams for Frame Object 2 (IWF 838x400x18.2x29.2)

Case: KUAT 1
Items: Axial (P and T) – Single valued
End Length Offset (Location): I-End: Jt: 3, 0. m (0. m); J-End: Jt: 4, 0. m (20. m)
Display Options: ○ Scroll for Values ● Show Max

Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Torsions in KN-m)

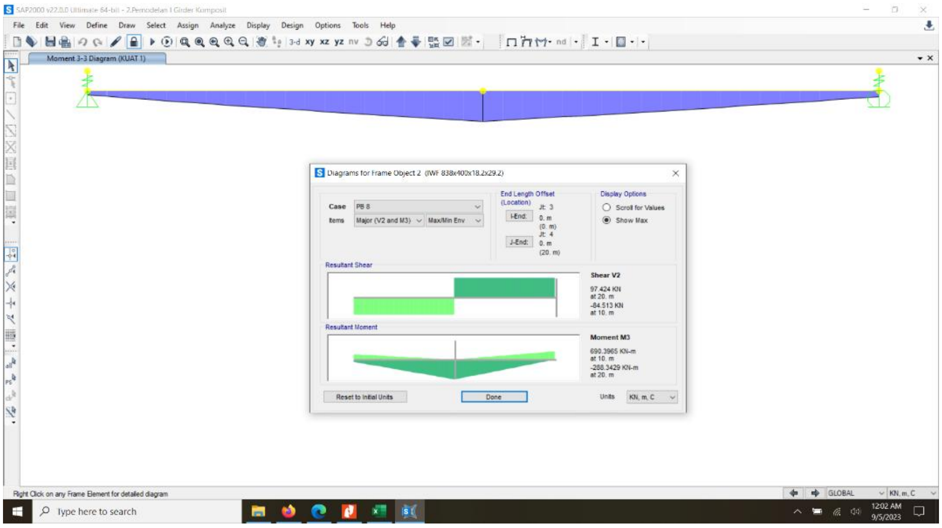
Dist Load (1-dir): 0. KN/m at 20. m, Positive in -1 direction

Resultant Axial Force — Axial: 1890.717 KN at 20. m

Resultant Torsion — Torsion: -0.1226 KN-m at 10. m

Reset to Initial Units | Done | Units: KN, m, C

Figure 3. Maximum Axial Force Occurring in the Girder



Diagrams for Frame Object 2 (IWF 838x400x18.2x29.2)

Case: PB 8
Items: Major (V2 and M3) – Max/Min Env
End Length Offset (Location): I-End: Jt: 3, 0. m (0. m); J-End: Jt: 4, 0. m (20. m)
Display Options: ○ Scroll for Values ● Show Max

Resultant Shear — Shear V2: 97.424 KN at 20. m; -84.513 KN at 10. m

Resultant Moment — Moment M3: 690.3965 KN-m at 10. m; -288.3429 KN-m at 20. m

Reset to Initial Units | Done | Units: KN, m, C

Figure 4. Shear Force and Bending Moment Occurring in the Girder

These values indicate that the girder elements are subjected to a complex combination of forces, namely axial tensile force, shear force, and bending moment acting simultaneously. This condition is commonly observed in composite bridges subjected to dynamic vehicular loading. Other studies have reported that the interaction between axial force and bending moment in composite bridges may accelerate local failure if it is not properly accounted for in the design process [35]. The internal forces indicate that the girder elements are subjected to a dominant combination of tensile forces and bending moments, which is a characteristic behavior of composite bridges. In this system, steel primarily resists tensile forces induced by bending moments, while concrete is responsible for resisting compressive forces, thereby allowing both materials to work synergistically in efficiently distributing the applied loads [36]. The magnitude of the obtained axial force indicates that the structure is still capable of effectively transferring loads in accordance with the intended design mechanism. However, the increase in axial force due to additional traffic loading may lead to critical conditions, particularly because of the interaction between axial force and bending moment, which can amplify stresses in the girder elements [35].

In addition, the non-uniform distribution of internal forces may lead to stress concentration in certain regions, particularly at midspan where the maximum bending moment occurs. This condition makes these sections the most vulnerable to failure. Consistent with previous studies, an uncontrolled increase in axial force may potentially induce local buckling in steel elements, especially in members with relatively small thickness [37]. Thus, although the structure is still performing effectively in distributing loads, the increase in internal forces due to excessive loading should be a primary concern. Therefore, traffic load control and periodic evaluation are necessary to ensure the long-term safety and reliability of the bridge structure.

CONCLUSION

Based on the analysis conducted, it can be concluded that the structural performance of the bridge exhibits a clear capacity limit with respect to increasing traffic loads. The capacity ratio increases in line with the number of vehicles, reaching a value of 1.052 under the eight-truck loading condition, which exceeds the safety threshold (>1.00). This indicates that the structural elements, particularly the midspan girder, are in an unsafe condition in terms of strength. On the other hand, the maximum deflection of 21.2495 mm remains below the allowable limit of 25 mm, meaning that the structure still satisfies the serviceability requirements. However, the loading process was terminated at this stage due to the occurrence of structural instability, indicating that the strength limit state is more critical than the deflection criterion. In addition, the internal force analysis shows that the bridge girder experiences a maximum axial force of 1890.717 kN (tension), a shear force of 97.424 kN, and a bending moment of 690.3965 kN·m. These values indicate that the structure is subjected to a complex combination of loading and is approaching its capacity under the maximum loading condition. Therefore, this study provides important implications for the public, particularly in enhancing understanding of the safe loading limits of bridges and the importance of traffic load control. The findings can also serve as a reference for relevant authorities in performing bridge evaluation, maintenance, and strengthening design to ensure user safety and the sustainability of transportation infrastructure functions. If the bridge is expected to regularly accommodate 8-truck loading conditions, the following strengthening methods are recommended based on the observed failure mode (excessive bending moment and axial tension at midspan): (1). Addition of steel cover plates bonded or bolted to the bottom flange of the I-girder to increase flexural capacity, (2). External post-tensioning (unbonded tendons) to introduce compressive prestress and reduce net tensile forces, and (3). Increasing concrete deck thickness with additional shear connectors to enhance composite action.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Bunyamin Bunyamin: conceptualization, methodology, supervision. **Khaidir Khaidir:** data curation, writing-original draft preparation. **Munirul Hady:** visualization, investigation, software, validation. **Heru Pramanda:** writing-reviewing and editing.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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