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Effect of Steel Truss Configuration on Bridge Structural Strength and Seismic Response

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Abstract. Located within the Pacific Ring of Fire, Indonesia experiences high seismic intensity, posing a risk of structural damage to bridges; thus, seismic load considerations are imperative in bridge engineering. Although bridge seismic analysis has been conducted, comparative studies of truss configurations under seismic loads remain limited. This study analyzes the influence of truss configurations, including Howe, Pratt, Warren, Quadrangular Warren, Whipple, Camel Back, Baltimore, K-Truss, and Petit Truss, under seismic loads through deflection and Demand Capacity Ratio (DCR) parameters. The analysis was performed using Midas Civil, a Finite Element Method software, while seismic loading was applied using the response spectrum method. The results show that the Camel Back Truss achieves the highest structural efficiency, yielding the lowest DCR, with a maximum of 0.064693 and 0.1503 for the mean. Regarding serviceability, Petit Truss exhibited the minimum deflection values of 0.02735 m, 0.02482 m, and 0.02493 m for Service I (TD), Service I (TT), and Extreme I, respectively. Overall, Camel Back Truss provides the best structural performance by maintaining the lowest stress ratio and the second-lowest deflection, recorded at 0.02725 m and 0.03897 m under Service I and 0.02818 m under Extreme I loads, respectively.

Keywords: bridge frame type, seismic load, bridge strength, SNI 2833:2016, bridge structural analysis

INTRODUCTION

Bridges are important for regional connectivity, facilitating the mo mobility of people, goods, and services across natural and man-made obstacles. According to Law No. 38 of 2004 on Roads, bridges serve as strategic elements for national transportation and equitable economic growth. Structurally, bridges are categorized by form (e.g., slab, girder, arch, truss, cable stayed) and material (e.g., bamboo, wooden, masonry, steel, concrete) [1]. Steel truss bridges are particularly prominent in Indonesia, totaling 17,160 units, accounting for 12% of the total existing bridges. [2]. Steel structure has advantages in strength and flexibility. The strength-to-cost ratio of steel is higher under tensile conditions and slightly lower under compressive conditions. In bridge construction, structural steel is an efficient and economical material. Additionally, steel is often chosen because its components can be prefabricated and assembled on site. Steel bridges also tend to be more effective at withstanding earthquake forces and have a longer service life compared to concrete bridges [3].

During the planning process, the bridge must be designed with various technical considerations to ensure it functions optimally and safely throughout its service life. These aspects include structural strength, stability, user comfort, and ease of maintenance. In addition, the planning phase must incorporate environmental conditions, such as soil characteristics, hydrology, and potential external loads that may affect the bridge's performance. According to the Circular Letter of the Minister of Public Works and Housing No. 07/SE/M/2015, the planning of the bridge structure must meet fundamental design requirements, one of which is structural strength capable of supporting all applied loads, both permanent and temporary loads [4]. Permanent loads include the self-weight of the structure and other additional elements, while temporary loads include traffic loads and wind loads; these loads must be thoroughly analyzed to ensure that the bridge can operate safely.

As a country located on the Pacific Ring of Fire (Ring of Fire), Indonesia experiences high earthquake intensity and seismic vulnerability; it is imperative to incorporate seismic load analysis into the bridge planning phase. Earthquakes caused by continental plate movements, active faults, and local faults can generate vibrations that the bridge must withstand [5]. Earthquakes can cause lateral forces on bridge structures, leading to excessive deformation, structural damage, and even total collapse. The collapse of bridges during earthquakes not only caused significant material losses but also threatened human lives and paralyzed regional transportation networks. Bridges must be designed in such a way that they have a very small probability of collapse, yet still allow significant damage and disruption of service functions in the event of an earthquake with a 7% probability within 75 years [6]. In the design process, selecting the appropriate truss configuration is one of the important factors in enhancing the bridge's resistance to seismic loads.

Various truss configurations have different capabilities in responding to various loads, including seismic loads. These differences in truss configuration *cause variations in structural behavior, particularly in terms of stiffness, stability, and* the ability to distribute loads evenly. Truss types have been extensively developed in various configurations and categories. Some bridges are classified as truss bridges with parallel chords, including Howe Truss, Whipple Truss, Pratt Truss, and Warren Truss; curved or inclined chord bridges, such as Camel Back Truss; and subdivided truss bridges, such as Baltiomre Truss, Petit Truss, and K-Truss. In bridge design, the truss configuration is a critical aspect, as each type has distinct characteristics that require careful planning to determine the optimal configuration for the site conditions. Due to seismic loading, the bridge structure is subjected not only to static forces but also to dynamic forces, thereby requiring the structure to dissipate energy and maintain stability. The differences in the characteristics of each truss require selecting an appropriate configuration. This is an important factor in improving the bridge's performance under seismic loads.

In the design of earthquake-resistant bridges in Indonesia, SNI 2833:2016 provides guidelines for calculating seismic loads on bridge structures using the response spectrum method. A response spectrum is a curve that describes the maximum dynamic response of a single degree of freedom (SDOF) system subjected to a specific dynamic load, expressed as a function of the natural frequency and damping ratio [7]. Although this standard provides a comprehensive analytical framework, studies comparing the performance of different truss configurations under seismic loading in accordance with SNI 2833:2016 remain limited.

Several studies have conducted comparative analyses of various trusses. A study by Putri & Nindyawati Nindyawati (2024) analyzed the influence of Warren, Pratt, Howe, and K-truss configurations to evaluate their structural behavior based on DCR values (*Demand Capacity Ratio*), indicating that the K-truss bridge is the most efficient, with the minimum deflection and the lowest structural weight compared to other types [8]. Research by Sari et al. (2025) also compared four types of truss, consisting of Warren, Pratt, Howe, and K-Truss, showing that Howe exhibits low deflection and superior stiffness [9]. Vasava & Nath (2024) reviewed the application of Linear Time History (LTHA) to truss bridges subjected to near-source earthquakes and emphasized the need for realistic dynamic analysis. However, this study remains a general review and lacks a comprehensive comparison across diverse truss configurations [10]. Shinde & Patil (2021) compared Part, Warren, and Howe Trusses using STAAD Pro and showed that each type offers different advantages depending on the parameters evaluated [11].

Despite extensive academic discourse on truss bridges, a comparative study of nine truss configurations specifically focused on seismic loads remains under-researched. Previous studies have generally compared only three to four truss configurations, focusing predominantly on static efficiency, material consumption, or general structural behavior. There is limited research evaluating a wide range of truss configurations under seismic loads in accordance with Indonesian bridge standards, particularly in high-seismic areas such as Magelang Regency.

This study aims to quantitatively evaluate the seismic resilience of nine different steel truss configurations—Howe, Pratt, Warren, Quadrangular Warren, Whipple, Camel Back, Baltimore, K-Truss, and Petit Truss—using the Response Spectrum Method based on SNI 2833:2016. Unlike previous studies that often focus on limited typologies, this research identifies the optimal configuration based on measurable structural indicators, including the Demand Capacity Ratio (DCR) value and structural deflection under both service and extreme load combinations. The primary contribution of this work is the establishment of a comprehensive performance hierarchy among these nine types under local seismic hazards conditions of Magelang Regency. This research offers a practical decision-making framework for engineers to select a high-performance, earthquake-resistant truss system in high-risk zones.

METHODOLOGY

This research employs numerical analysis using Midas Civil, a Finite Element Method (FEM) computational platform, to evaluate the influence of various truss configurations on the strength and performance of a bridge under seismic loads. This approach was chosen because it can present the structure's behavior in detail and approximate actual conditions through mathematical modeling. The bridge structure is modeled as a three-dimensional frame, with 3D beam elements representing the truss members. This numerical framework is essential for calculating the structural response, specifically internal forces and joint displacement, which serve as the primary data for evaluating the Demand Capacity Ratio (DCR) and structural deflection.

The modeling is conducted by considering material properties, structural geometry, boundary conditions, and loading types in accordance with applicable design standards. The variations in truss types are modeled under uniform conditions and parameters to ensure the results can be compared objectively. The analysis focuses on the structural response, including deflection and internal forces, as the primary indicators for evaluating the performance and strength of each truss type under seismic loads. The seismic response was quantified based on the maximum structural deflection and the Demand Capacity Ratio (DCR) derived from the seismic load combination. The maximum deflection indicates the global stiffness of the structure in resisting earthquake forces. In contrast, the DCR value indicates the capacity utilization of structural elements under the internal forces generated by seismic activity.

The study is located along the Progo River, Borobudur District, Magelang Regency, specifically on the Keprekan–Borobudur road section at coordinates -7.602560, 110.221950. The selection of this location is based on the area's significant seismic potential, making it relevant for analyzing the resilience of bridge structures under seismic loading. Therefore, the results of the study are expected to reflect real conditions and provide an overview of the performance of steel truss bridges in earthquake-prone areas.

Research variables and indicators are established to ensure a systematic analysis and to maintain objective comparisons across all structural models. The independent variable in this study is the truss configuration consisting of nine models: Howe, Pratt, Warren, Quadrangular Warren, Whipple, Camel Back, Baltimore, K-Truss, and Petit Truss. The dependent variables represent the structural responses derived from numerical analysis, including the maximum Demand Capacity Ratio (DCR), the mean DCR, and the maximum deflection of the structure. The DCR values indicate structural element safety, while deflection is used to evaluate structural stiffness.

To ensure consistency, the controlled variables are kept uniform across all models, comprising a bridge span of 50 meters, a width of 7 meters, and a truss height of 6 meters. The material properties were defined based on the BJ41 grade for steel elements and f ’c = 30 MPa for concrete. The environmental and design parameters are defined by the Site Class Stiff Soil (SD) condition. The same load combinations are applied to all models. The study location is in Magelang Regency, as shown in Figure 1.

FIGURE 1. Research Location
(Source: Google Maps, 2026)

Research Stages

This research follows a systematic, structured approach to ensure the accuracy of the analytical results. The initial phase involves collecting primary data on material properties, bridge geometry, soil conditions, and seismic parameters of the research area. In addition, a literature review of SNI planning standards, scientific journals, and relevant studies on truss bridge structures and seismic analysis was conducted. This stage establishes the theoretical foundation and provides the necessary parameters for subsequent modeling and analysis.

The subsequent stage involves preliminary design, during which initial configurations for several bridge-truss alternatives are established. The initial dimensions of the structure are determined based on preliminary assumptions and design standards. This stage serves as a foundational model for further analysis; it must be sufficiently representative of the final structure while remaining flexible for subsequent optimization and adjustments.

The loading phase involves determining all primary loads acting on the bridge structure in accordance with SNI, including both static and dynamic loads. The analysis accounts for self-weight, superimposed dead loads, live loads, and environmental actions such as wind and seismic loads. Seismic loads are derived from soil conditions at the study site and subsequently analyzed using response spectrum analysis.

The next stage is structural element verification. Following the initial analysis, each structural element is evaluated for compliance with strength and stability requirements. If any element fails to meet these criteria, design refinements are implemented, such as modifying sectional profiles or selecting alternative material grades. This process continues until all structural members meet the criteria or are deemed safe.

The next stage is data analysis, which involves processing and evaluating the analysis results from the various bridge configurations under study. The performance indicators, including internal member forces and structural deflections, are compared across the different bridge types. The analysis identifies the optimal truss configuration for seismic resistance and overall structural performance.

The final stage comprises the formulation of conclusions and recommendations based on the preceding analysis and discussion. This section synthesizes the findings regarding the influence of truss configuration on structural performance under seismic loads. Specifically, it identifies the most effective truss configuration for enhancing seismic performance and provides a comparative assessment of structural capacity across all evaluated configurations.

General Bridge Data

General bridge data constitutes the foundational information used as a reference in the structural design and analysis process. This data includes the primary structural characteristics, including bridge type, total span length, deck width, roadway and sidewalk dimensions, vertical clearance, alongside other supporting elements that influence the structural configuration. These specifications serve as the baseline parameters for determining the geometric modeling, loading system, and the overall analytical methodology applied in the bridge planning phase.

The availability of accurate general data is important because it serves as the foundation for determining assumptions, developing analysis methods, and evaluating the performance of the bridge structure. Inaccurate data can lead to calculation errors and affect analysis results. Therefore, general data must be compiled systematically and based on actual conditions and applicable planning standards.

Types of bridges	: Through Howe Truss, Pratt Truss, Warren Truss, Quadrangular Warren Truss, Whipple Truss, Camel Back Truss, Baltimore Truss, K-Truss, and Petit Truss
Bridge span	: 50m
Bridge width	: 7m
Pavement width	: 6m
Bridge height	: 6m
Pedestrian width	: 1m
Concrete deck thickness	: 25cm

Bridge Material Data

Bridge material data consists of information regarding the types and properties of materials used in structures, such as steel and concrete, which are the primary components of the bridge structure system. This data includes steel and concrete grades, along with parameters such as modulus of elasticity, Poisson ratio, specific gravity, yield strength, tensile strength, and other properties that influence the material's response to loading. Each of these parameters plays a crucial role in describing the material's behavior under force, both in elastic conditions and as it approaches its capacity limits.

The accuracy of material data is crucial because it directly determines the strength, stiffness, and resistance of the bridge structure to various types of loads, including static and dynamic loads such as seismic loads. Material properties influence the structure's ability to withstand seismic loads. The ability of the structure to withstand seismic loads is a key aspect in bridge design.

The steel used in this study is BJ 41. The steel material used has the following characteristics.

Density	= 78.5 kN/m³
Modulus of elasticity (E)	= 2 × 105 MPa
Poisson ratio (μ)	= 0.3
Thermal expansion coefficient (α)	= 1.17×10^{-5} /°C
Shear Modulus (G)	= 76923 MPa
Yield Stress (Fy)	= 250 MPa
Ultimate tensile tension (Fu)	= 410 MPa

Meanwhile, the concrete used has a compressive strength of f'c = 30 MPa. The concrete material data used have the following characteristics.

Density	= 24 kN/m^3
Modulus of elasticity (E)	= 25742.96 MPa
Poisson ratio (μ)	= 0.2
Thermal expansion coefficient (α)	= 9.9×10^{-6} /°C
Shear Modulus (G)	= 10726.233 MPa

Bridge Profile Data

Bridge profile data refers to information regarding the dimensions and cross-sectional shapes of structural elements used in design. This data includes the profile type and geometric dimensions of the cross-section, such as height (H), width (B), web thickness (tw), and flange thickness (tf), for each structural element. Selecting the appropriate profile significantly influences the structure's ability to resist internal forces, including tensile, compressive, and bending forces, acting on the bridge. Additionally, profile selection influences structural stiffness, thereby controlling the magnitude of deformation or deflection under loading.

In the design of steel truss bridges, the use of efficient profiles is crucial to achieving a balance between structural strength and economical material usage. Profiles that are too large can increase self-weight, while profiles that are too small may fail to meet the required strength capacity. Therefore, each structural element is designed using an appropriate profile. The material data used are shown in Table 1 below.

TABLE 1. Bridge Material Data

Rod	Profile	H (mm)	B (mm)	t_w (mm)	t_f (mm)
Stringer	IWF 500.200.10.16	500	200	10	16
Cross Girder	IWF 600.300.30.30	600	300	30	30
Bottom Chord	HB 400.400.13.21	400	400	13	21
Diagonal Chord	HB 400.400.13.21	400	400	13	21
Vertical Chord	HB 400.400.13.21	400	400	13	21
Top Chord	HB 400.400.13.21	400	400	13	21
Top Bracing	L 150.100.15.15	150	100	15	15

RESULT AND DISCUSSION

Loading

The structural analysis incorporates various loading conditions per SNI 1725:2016, Loading for Bridges. The dead load (DL) consists of the self-weight of structural and non-structural components, treated as an integrated unit and evaluated using nominal, maximum, and minimum load factors. Specifically, self-weight encompasses the steel truss members, the concrete deck slab, and the structural connections. Superimposed dead loads, which account for non-structural elements subject to change over the bridge's service life, include the asphalt wearing surface, rain, and railings.

Furthermore, traffic load also influences the structural response and the effective mass for seismic analysis. Traffic loads, including lane load consisting of Uniformly Distributed Load (UDL) and Knife Edge Load (KEL). In addition, there are Truck Load, Braking Forces, and Pedestrian Live Load. For serviceability limit state evaluations, the maximum vertical deflection is determined by the governing case between a single design truck or the UDL component of the lane load.

In addition to dead loads and traffic loads, environmental action loads include the influence of temperature, wind, floods, earthquakes, and other natural causes. In this study, the environmental action loads considered are wind load and seismic load. In accordance with SNI 1725:2016, wind loads act on structures and vehicles.

Seismic loads are also considered in the bridge analysis to represent more realistic loading conditions. Each type of load is calculated in accordance with the regulations and combined in accordance with SNI 2833:2016. The results of the load analysis serve as a basis for modeling and structural analysis to evaluate the bridge's response to the different types of trusses under consideration.

TABLE 2. Bridge Loading

Load Type	Load Value	Units
Superimposed Dead Load of Asphalt and Rain Load (MA)	1.5905	kN/m^2
Superimposed Dead Load of Railing (MA)	0.0385	kN
Uniformly Distributed Load (UDL)	7.2	kN/m^2
Knife Edge Load (KEL)	68.6	kN
Truck Load (TT)	35	kN
Truck Load (TT)	157.5	kN
Braking Forces (TP)	2.8636	kN
Pedestrian Load (TP)	5	kN/m^2
Wind Pressure Load (EWs)	4.4	kN/m
Wind Suction Load (EWs)	2.2	kN/m
Wind Load on Vehicles (EWl)	1.5	kN/m

Superimposed Dead Load (SIDL), including asphalt wearing surfaces and rain loads, along with Uniformly Distributed Load (UDL) and pedestrian loads, are modeled as area loads on the deck and sidewalks. Conversely, the Knife Edge Load and truck load are applied as line loads on girders. According to SNI 1725:2016, a dynamic load factor of 40% is applied to vehicular loading for a 50 m span. The dynamic load factor results from the interaction between a moving vehicle and a bridge. It is excluded from calculations on centrifugal force, Uniformly Distributed Load (UDL), pedestrian load, and brake force. The brake force is modeled as a point load on the stringers. Brake force should be determined based on the greatest value between 25% of the axle weight of the design truck or 5% of the weight of the combined weight of the design truck and UDL. The braking force should be assumed to act horizontally at a height of 1800 mm above the riding surface across all design lanes.

Pursuant to SNI 1725:2016, the wind loads are assumed to be uniformly distributed on the structural surface directly exposed to the wind flow. This is used to simplify loading modeling without reducing the level of analytical accuracy of the influence of wind on bridge structures. In this analysis, the wind load is modeled as a uniform load applied horizontally to the vertical and diagonal truss members. This orientation accurately represents the lateral forces exerted on the bridge frame.

Wind action comprises two primary components: positive pressure on the windward face and suction (negative pressure) on the leeward face, driven by atmospheric pressure differentials. Based on a design wind speed (V_{DZ}) of 100 km/h as specified by the standard, the calculated wind pressure (P_D) is 4.4 kN/m on the windward side, while the suction load on the leeward side is 2.2 kN/m.

Seismic Load Analysis

Earthquake load calculations using the Response Spectrum Analysis (RSA) method in accordance with SNI 2833:2016. The response spectrum was determined based on the study site's coordinates and soil site classification at the Borobudur site in Magelang Regency, which is classified as Stiff Soil (SD). Following the Peak Ground Acceleration (PGA) map and the 0.2-second and 1-second acceleration response spectra at bedrock were established for a 1000-year return period, corresponding to a 7% probability of exceedance in 75 years. The determined values include a Peak Ground Acceleration (PGA) of 0.292 g, short-period spectral acceleration (Ss) of 0.639 g, and one-second spectral acceleration (S1) of 0.261 g. The spectrum response graph is shown in Figure 2.

The location amplification factor is determined from the SNI 2833:2016 table, yielding FPGA values of 1.216, Fa = 1.289, and Fv = 1.878. Then, the design spectral acceleration is calculated as: As = FPGA × PGA = 0.355 g; SDS = Fa × Ss = 0.824 g; SD1 = Fv × S1 = 0.491 g. The characteristic period is Ts = SD1/SDS = 0.596 seconds and T0 = 0.2 × Ts = 0,1192 seconds. The resulting response spectrum is applied to each bridge model in both longitudinal (X) and transverse (Y) directions.

The design response spectrum values at ground level for the stiff soil site class are shown in Table 3 and the following figure.

TABLE 3. Spectrum of Design Response at Ground Level

T	CSM	T	CSM	T	CSM
0	0,355	1,5	0,327	2,8	0,175
0,119	0,824	1,6	0,307	2,9	0,169
0,2	0,824	1,7	0,289	3	0,164
0,596	0,824	1,8	0,273	3,1	0,158
0,7	0,701	1,9	0,258	3,2	0,153
0,8	0,613	2	0,245	3,3	0,149
0,9	0,545	2,1	0,234	3,4	0,144
1	0,491	2,2	0,223	3,5	0,14
1	0,491	2,3	0,213	3,6	0,136
1,1	0,446	2,4	0,204	3,7	0,133
1,2	0,409	2,5	0,196	3,8	0,129
1,3	0,377	2,6	0,189	3,9	0,126
1,4	0,35	2,7	0,182	4	0,123

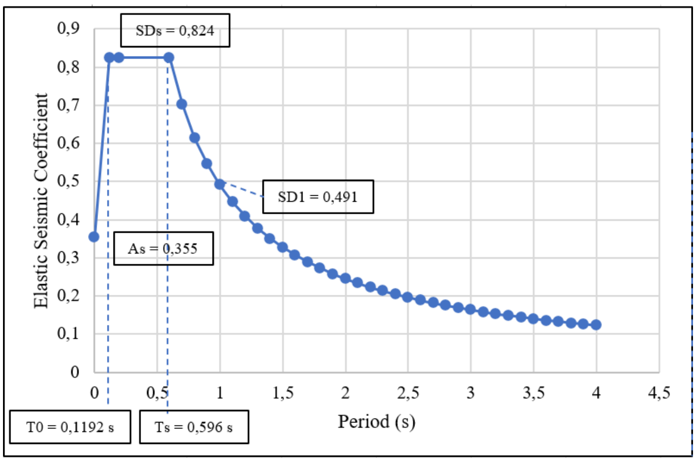

FIGURE 2. Spectrum response graph

Load Combinations

The combination of loads in bridge analysis refers to the provisions of SNI 1725:2016, which account for various possible loading conditions that may occur during public service. The purpose of load combinations is to ensure that the bridge structure has an adequate level of safety, stability, and performance against the most critical conditions that may occur. Each combination is arranged according to a specific boundary state. Load combinations are arranged by combining different types of loads, such as dead, live, and seismic loads. The purpose of applying a combination of loads is to ensure that the structure can withstand the worst conditions during its service life, thereby guaranteeing the bridge's safety and performance.

The load combinations used in this study are shown in Table 4 below.

TABLE 4. Load Combinations

Keadaan Batas	MS MA TA PR PL SH	TT TD TB TR TP	EU	EW_s	EW_L	BF	EU_n	TG	ES	Gunakan salah satu		
										EQ	TC	TV
Kuat I	γ_p	1,8	1,00	-	-	1,00	0,50/1,20	γ_{TG}	γ_{ES}	-	-	-
Kuat II	γ_p	1,4	1,00	-	-	1,00	0,50/1,20	γ_{TG}	γ_{ES}	-	-	-
Kuat III	γ_p	-	1,00	1,40	-	1,00	0,50/1,20	γ_{TG}	γ_{ES}	-	-	-
Kuat IV	γ_p	-	1,00	-	-	1,00	0,50/1,20	-	-	-	-	-
Kuat V	γ_p	-	1,00	0,40	1,00	1,00	0,50/1,20	γ_{TG}	γ_{ES}	-	-	-
Ekstrem I	γ_p	γ_{EQ}	1,00	-	-	1,00	-	-	-	1,00	-	-
Ekstrem II	γ_p	0,50	1,00	-	-	1,00	-	-	-	-	1,00	1,00
Daya layan I	1,00	1,00	1,00	0,30	1,00	1,00	1,00/1,20	γ_{TG}	γ_{ES}	-	-	-
Daya layan II	1,00	1,30	1,00	-	-	1,00	1,00/1,20	-	-	-	-	-
Daya layan III	1,00	0,80	1,00	-	-	1,00	1,00/1,20	γ_{TG}	γ_{ES}	-	-	-
Daya layan IV	1,00	-	1,00	0,70	-	1,00	1,00/1,20	-	1,00	-	-	-
Fatik (TD dan TR)	-	0,75	-	-	-	-	-	-	-	-	-	-

Catatan : - γ_p dapat berupa $\gamma_{MS}, \gamma_{MA}, \gamma_{TA}, \gamma_{PR}, \gamma_{PL}, \gamma_{SH}$ tergantung beban yang ditinjau

- γ_{EQ} adalah faktor beban hidup kondisi gempa

(Source: SNI 1725:2016, 2016)

DCR Analysis

In this study, the Demand Capacity Ratio (DCR) parameter is used to determine the steel element for each truss configuration. The DCR value is a comparison between the factored internal forces (demand) and the design strength (capacity) of the elements. Based on the requirements that have been stated in SNI 1725:2016, an element is considered adequate if the D/C ratio is less than 1.0. Conversely, a D/C ratio≥ 1 indicates that the member is overstressed and is categorized as structurally unsafe.

The DCR values used to compare the nine truss types were the maximum and average DCRs. The maximum DCR serves as the primary indicator for safety and integrity. Since a structural system is only as strong as its weakest link, the maximum DCR identifies the critical member most susceptible to failure. Truss configurations with the lowest maximum DCR values exhibit a higher safety margin, as no element member is near its ultimate capacity. Furthermore, the average DCR value quantifies the global efficiency or force distribution. The lower average value indicates uniform force distribution.

The results of the DCR analysis for the nine frame types are shown in the following table.

TABLE 5. DCR Analysis Results

Bridge Type	Ratio Max	Average Ratio	Remarks
Camel Back Truss	0.647	0.150	Safe
Baltimore Truss	0.826	0.342	Safe
Warren Truss	0.854	0.174	Safe
Through Howe Truss	0.860	0.395	Safe
K-Truss	0.887	0.177	Safe
Petit Truss	0.914	0.340	Safe
Whipple Truss	0.914	0.400	Safe
Pratt Truss	0.938	0.227	Safe
Quadrangular Warren Truss	0.950	0.210	Safe

The results show that the Camel Back Truss exhibits the best performance, with a maximum DCR of 0.647. This indicates that even the most critical member of this truss utilizes only 64.7% of its total capacity, providing a safety reserve. Not only did it achieve the lowest maximum DCR, but it also. Camel Back Truss exhibits the lowest average values of 0.150. proving that their configuration are highly effective in distributing internal forces. This indicates that, in addition to safer critical elements. The force distribution on the structure is also quite uniform. This behavior is influenced by geometric shapes' chord upper, which can produce uniform stress distribution among chord members and efficient load transfer [3].

Based on the maximum DCR, the second-lowest value for the Camel Back Truss is 27.6% higher than that for the Baltimore Truss. Compared to the Quadrangular Warren Truss, the least efficient model with a maximum DCR of 0.95, the Camel Back Truss is 31.9% more efficient at managing peak stress. Based on the average DCR, the second-lowest value is recorded by K-Truss. These results indicate that, between K-Truss and Baltimore Truss, despite both employing subdivision systems, the Baltimore configuration tends to provide a more uniform fore distribution, resulting in a lower maximum DCR.

The disparity between maximum and average values reveals the presence of stress concentrations. Configurations with a high Max-to-Average ratio (such as the Howe or Pratt types) indicate a suboptimal load path, with some members heavily taxed while others remain underutilized. In contrast, the Camel Back's superior performance is attributed to its optimized geometry, which minimizes these disparities, resulting in a more 'harmonious' structural response. This uniform utilization is a key characteristic of high-performance seismic design, as it ensures that no single component becomes a premature failure point for the entire bridge.

All analyzed models achieved a DCR below 1.0, indicating they are safe, and confirming that every configuration can sustain the designated seismic loads without localized failure.

Structural deflection analysis

According to SNI 1725:2016. Structural deflection was evaluated under the Service I Limit State combination in this study. Deflection analysis was performed for both combinations of Service 1 and Extrem 1 load combinations. Service I was selected because it represents the most frequent operational conditions throughout the bridge's service life. encompassing dead loads. superimposed dead loads. and vehicular loads under normal traffic conditions. The evaluation of deflection in this combination aims to ensure the comfort of bridge users and prevent excessive deformation that could impair serviceability or cause damage to non-structural components such as the wearing surface and utilities.

Meanwhile, the Extreme 1 combination was incorporated to account for seismic loads, which are critical in bridge planning in areas with high seismic activity at the study site. The evaluation of deflection at this extreme combination aims to ensure that the bridge maintains its structural integrity and avoids catastrophic failure. Furthermore, this analysis verifies that the structure does not undergo excessive permanent deformation under the maximum earthquake load during its design life.

The results of deflection analysis for the combination of serve 1 and extreme 1 are shown in the following table.

Table 6. Deflection Analysis Results

Bridges	Deflection (m)		
	Service I (TD)	Service I (TT)	Extreme I
Petit Truss	0.02735	0.02482	0.02593
Camel Back Truss	0.02725	0.03807	0.02818
Through Howe Truss	0.03675	0.03471	0.03516
Whipple Truss	0.0326	0.03855	0.0364
K-Truss	0.04017	0.03647	0.03858
Quadrangular Warren Truss	0.04568	0.04099	0.04321
Warren Truss	0.04409	0.04489	0.04455
Baltimore Truss	0.04783	0.04374	0.04472
Pratt Truss	0.0555	0.05097	0.05112

The deflection limit of a beam is determined based on the service load. This requirement is specified in RSNI-T-03-2005. Beams are supported on a continuous girder or between two supports. have a maximum deflection limit of 1/800 × span length. For bridges with a span of 50 m. The allowable deflection for service 1 is 0.0625 mm, ensuring that all deflection results have met the specified requirements.

The results of the deflection analysis provide a performance hierarchy for each truss configuration under both service and extreme load combinations. Based on the analysis carried out. The Petit Truss exhibited the minimum deflection in all load combinations. with values 0.02735 m for Service I TD, 0.02482 m for Service I TT, and 0.02593 for Extreme I. This superior performance is attributed to the integration of sub-struts and sub-ties. which effectively partitions the main panels and enhances the structural stiffness. By reducing the effective panel length. These supplementary members facilitate a more efficient redistribution of internal forces, thereby minimizing global structural deformation compared to alternative truss geometries [12].

The Camel Back Truss ranks second in deflection results, with deflection for the Service I TD. Service I TT. and Extreme I load combinations of 0.02725 m. 0.03807 m. and 0.02818 m. respectively. Camel Back Truss produces greater deflection under Service I TT combination due to the polygonal configuration of the top chord high in the middle of the span. causing the chord and web members in the center to withhold a greater axial force compared to the other members. The bending moment distribution that depends on the span length causes the chord members in the center to bear a greater force and the diagonal members to bear shear force. resulting in the total deformation becoming greater [3][13].

The Pratt Truss exhibits the greatest deflection for all load combinations. which is 0.0555 for the Service I TD combination. 0.05097 for Service I TT, and 0.05112 for Extreme I load combination in Pratt Truss configurations. Diagonal members generally operate under tension. In contrast, vertical members withstand compressive forces. The absence of subdivision elements could increase the structural stiffness. causing the effective length of the members to be relatively large, causing axial deformation to be greater [9]. In addition. The constant height of the frame along the span reduces the distribution of the maximum bending moment at the midspan, thereby increasing the axial force at the midspan [3].

A smaller configuration yields the minimum deflection due to its higher number of element subdivisions, effectively resulting in shorter effective number lengths. This characteristic enhances the axial stiffness of individual members, thereby increasing the global stiffness of the entire structure. Despite its high stiffness, the Petit configuration does not produce the lowest DCR values. This suggests that an increase in stiffness may lead to an elevation of internal forces in specific members due to a less uniform distribution, thereby increasing the demand relative to the member's capacity.

Consequently, it can be concluded that structural efficiency is not solely determined by stiffness, but also by the configuration's capacity to achieve a uniform distribution of internal forces. The Camel back configuration demonstrates better force distribution, whereas the Petit configuration remains superior at controlling structural deformation.

CONCLUSION

A comparative analysis of nine truss configurations under seismic loads using the Response Spectrum Method shows that truss type significantly influences the performance and strength of the bridge structure. Each truss configuration exhibits distinct behaviors regarding internal force distribution and deflection. The study identifies the Camel Back Truss configuration as the most efficient in terms of stress distribution (lowest DCR), while the Petit configuration provided superior control over structural deformations.

Overall, the Camel Back configuration is identified as the most optimal overall design. It achieved the highest material efficiency with the lowest DCR and, simultaneously, demonstrated excellent serviceability performance as the second-stiffest configuration, trailing only slightly behind the Petit Truss. While the Petit configuration remains superior at strictly controlling structural deformation, its higher DCR values suggest a less efficient stress distribution than the Camel Back.

The findings provide a strategic guide for bridge engineers, particularly in high-seismic regions. Furthermore, as these findings are derived from numerical simulations based on idealized structural parameters, the models may not fully capture the complex physical behaviors in actual seismic events. Therefore, it is highly recommended that future research conduct experimental testing using small-scale models to validate the numerical findings by observing the actual structural behavior and failure mechanisms under seismic simulations.

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