STRUCTURAL BEHAVIOR OF WIND FRAME TRUSSES IN BRIDGES AFTER CRASHES USING LISA V8 FEA

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Abstract. A trailer towing large machinery struck the Pondok Gong truss bridge in Samboja, East Kalimantan, at 80 km/h, seriously damaging the 60-meter steel structure. By utilizing Finite Element Analysis (FEA) with LISA v.8, the research seeks to close the knowledge gap about the post-collision behavior of the bridge elements. With an emphasis on the wind bar frame and bracing that underwent ripping and distortion, the study simulates the impact to assess stress distribution and deformation patterns in the impacted structural components. The impact stress on the wind bracing elements was found to be 567,066 kN/m² in the simulation, which is far more than the permitted stress of 246,670 kN/m² for the steel. This discovery calls attention to significant structural flaws and demands quick response. It is advised to reinforce the impacted areas to stop further failures and replace the damaged sections with new steel components made to tolerate higher loads. Maintaining the structural integrity and safety of the bridge during the replacement process requires constant observation and monitoring.

Keywords: *bridges, crashes, LISA, simulation, stress*

Introduction

Bridge structures are critical elements in transportation networks, often subjected to various types of loading, including vehicular impacts. Such incidents can significantly affect a bridge's structural integrity, necessitating thorough investigation and analysis. This paper investigates the Pondok Gong bridge, a 60-meter steel truss bridge of Australian design, which was struck by a trailer carrying heavy machinery. The impact resulted in significant damage to the bridge's wind bracing system, posing potential risks to its stability. The identified research gap of this investigation resides in the lack of a comprehensive simulation study using Finite Element Analysis (FEA) to assess the post-collision behavior of bridge elements in an actual collision scenario, as depicted by a heavy truck carrying an excavator. Although initial on-site inspections showed significant damage to the wind braces and diagonal members of Pondok Gong Bridge, there was a need to model and analyze the stress distribution and deformation patterns in the affected structural components. This gap highlighted the absence of detailed post-impact stress and behavior analysis, which could be effectively simulated using LISA V.8 FEA to better understand how the bridge structure responded under such dynamic loading conditions. By simulating the collision between the trailer and the bridge's upper structure, the study aims to accurately predict the critical stress zones and evaluate the residual strength of the impacted elements. The investigation will provide insights into the structural integrity of the damaged bridge and inform necessary repair or reinforcement strategies, ensuring the continued safety of the bridge for public use, shown in *Figure 1*.

Figure 1. *Crash simulation.*

Review of literature

Bridge incident overview

The Pondok Gong truss bridge wind bar frame located in Samboja, East Kalimantan was hit by a heavy vehicle transporting heavy equipment where the heavy equipment arm hit the horizontal wind bar frame of the truss bridge directly, the vehicle travelled at a speed of 80 km/h, hitting the entire horizontal wind bar frame and bracing on the Pondok Gong truss bridge. The heavy equipment transported by the trailer exceeded the allowable height, so the impact caused severe deformation of some wind tie bracing and tearing of the structural elements of the horizontal wind bar frame on the Pondok Gong truss bridge. investigation focuses on understanding the impact force, structural damage, and the extent of deformation, shown in *Figure 2*.

Figure 2. *Damaged elements after a crash.*

Finite element modeling

To simulate the bridge and the impact, LISA v.8 FEA (Finite Element Analysis) software was employed. LISA V.8 FEA is a versatile and accessible tool for finite element analysis, offering engineers a practical solution for simulating complex structural behaviors under various loading conditions. Its user-friendly interface, combined with powerful analysis capabilities, allows for accurate modeling of stress distribution, deformation, and post-impact responses in structural elements. For projects involving critical infrastructure like bridges, LISA V.8 provides invaluable insights into the structural integrity of components after incidents such as collisions, enabling engineers to make informed decisions regarding repairs and reinforcements, shown in *Figure 3* (Babichev et al., 2024; Efendi, 2024; 2023a; 2023b; Efendi and Weijia, 2023; Efendi et al., 2022). The model is a 60-meter span truss bridge, designed according to Australian standards, subjected to various load conditions: (1) Self-Weight (MS): The self-weight of the bridge components, including the steel structure and the slab, was modeled [Slab weight: 7.41 kN/m for the 60-meter span]; (2) Additional Dead Load (MA): Includes the weight of the asphalt layer and potential water pooling due to drainage failures [Additional load: 1.65 kN/m]; (3) Traffic Load (TD): Represented by a uniformly distributed load (UDL) and a Knife Edge Load (KEL) of intensity 6.75 kPa and 49.00 kN/m, respectively; (4) Truck Load (TT): Modeled as a dual-wheel load of 112.50 kN with a Dynamic Load Allowance (DLA) factor of 0.30, resulting in a total of 146.25 kN; and (5) Collision Load: The impact force from the trailer was modeled based on the mass of the trailer and the heavy equipment (assumed at 30 tons) and its velocity (80 km/h). The impact duration was set at 0.01 seconds to capture the high-speed collision dynamics.

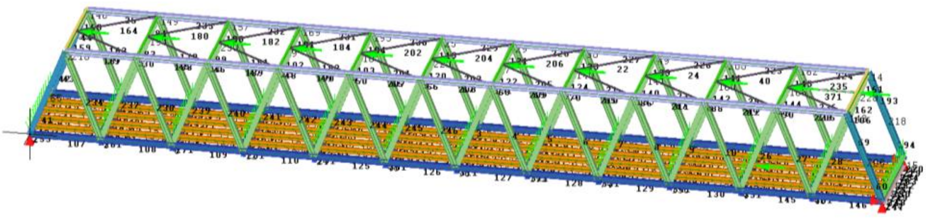
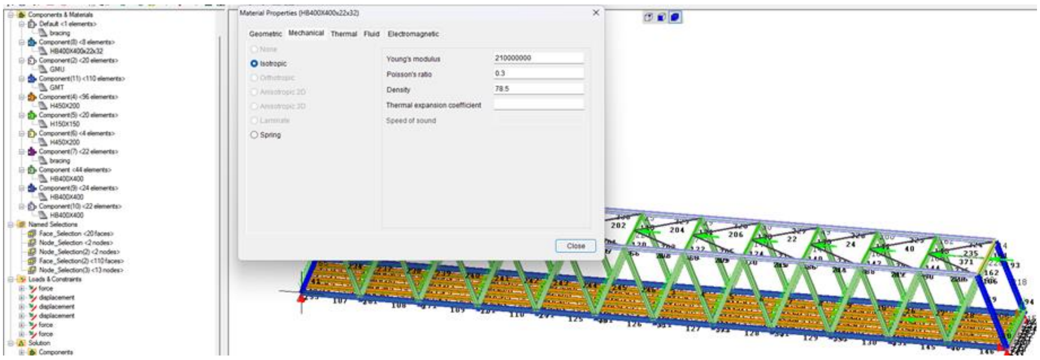


Figure 3. *Bridge Modesling on LISA.*

Materials and Methods

The material properties shown in the image indicate that the structural elements of the bridge are modeled with isotropic material characteristics. The Young’s modulus is set to 210,000,000 Pa, representing the material’s stiffness and ability to resist deformation under load. The Poisson’s ratio of 0.3 reflects the material's behavior in relation to lateral strain when subjected to axial stress. The density is set at 78.5, likely in units of kN/m³, which suggests that the material is a type of steel commonly used in structural applications, shown in *Figure 4*. These properties are essential for accurately simulating the structural response and stress distribution in finite element analysis, ensuring reliable results in the assessment of the bridge's integrity. The steel used in the wind bracing had an allowable stress of 246.670 kN/m². The FEM model was set to evaluate stress distributions during the collision and identify areas where stresses exceeded material limits (Cercone et al., 2021; Miri et al., 2021; Pu et al., 2021; Shi et al., 2021; Dai et al., 2020; El-Sisi et al., 2020; Jayaprakash, 2020; Rahnavard et al., 2019; Sadeghnejad et al., 2019; Tao et al., 2018).



Material Properties (HB400X400x22x32)

Mechanical: ● Isotropic

Young's modulus: 210000000

Poisson's ratio: 0.3

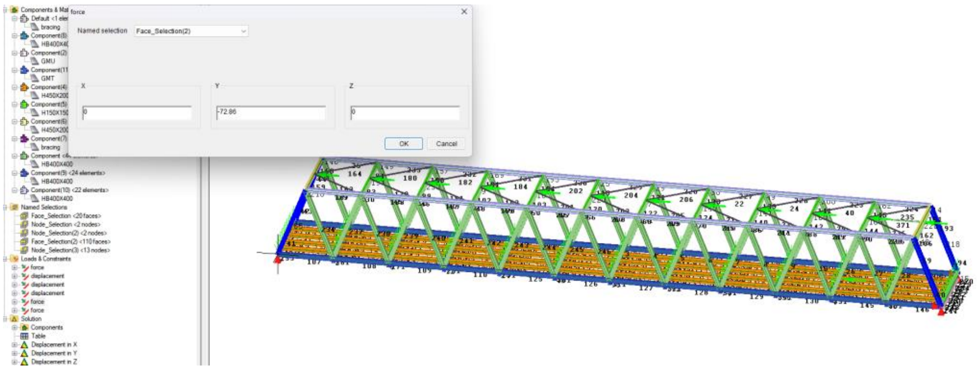
Density: 78.5

Thermal expansion coefficient:

Figure 4. *Material properties.*

Results and Discussion

The applied load shown in the image represents a uniformly distributed load (UDL) acting on each transverse girder of the steel truss bridge. The load is defined as 72.86 kN in the Y-direction, which corresponds to the vertical force applied across the girders. This load likely includes both the dead load, accounting for the bridge's self-weight, and the live load, representing the traffic and dynamic forces exerted by vehicles crossing the bridge. Such loading conditions are critical for evaluating the structural performance, ensuring that the design can withstand operational stresses while maintaining safety and serviceability, shown in *Figure 5* (Riso and Cesnik, 2023; Chang et al., 2020; Kashif et al., 2020; Koutsovasilis, 2020; Okoye et al., 2019; Falayi et al., 2018; Brown et al., 2015; Liu et al., 2014; DaBreo et al., 2013).



force

Named selection: Face_Selection(2)

X: 0

Y: -72.86

Z: 0

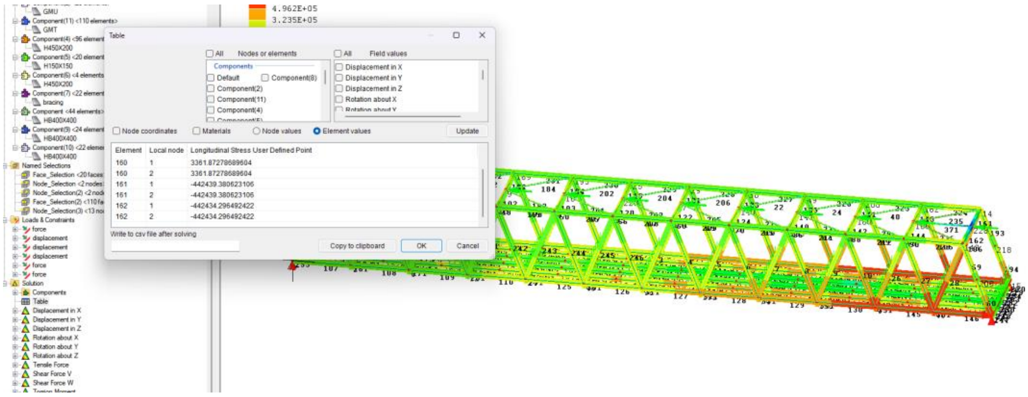
Figure 5. *The load is defined.*

Stress analysis

When the arm of a heavy machine mounted on a trailer collides with a bridge frame, the impact force can be calculated by considering the speed of the trailer and the mass of the heavy machine. For instance, if the trailer is moving at a speed of 80 km/h, we can convert this speed to meters per second. A speed of 80 km/h is equivalent to 22.22 m/s. To calculate the impact force, we need to know the mass of the machine's arm. In this example, we assume the mass of the heavy machine is 30 tons, or 30,000 kg. The impact force can be calculated using the formula (Eq. (1):

$$f = \frac{m.v}{\Delta t} \qquad \text{Eq. (1)}$$

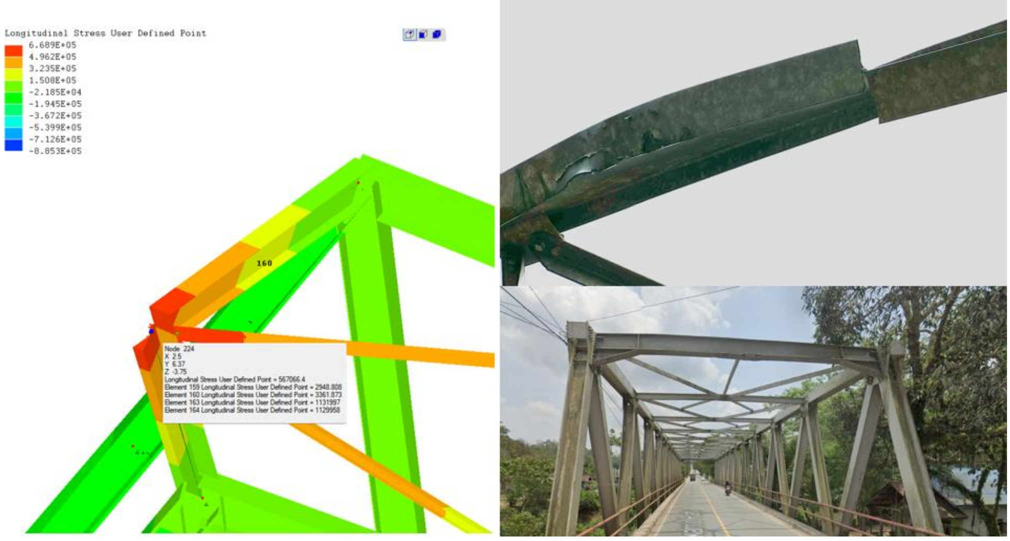
Where; m is the mass, v is the velocity, and Δt is the contact time. For collisions that happen very quickly, as is common with hard objects like steel, the contact time can be very short. For example, if the contact time is 0.01 seconds (10 milliseconds), the impact force is approximately 66,660 kN. The FEM analysis revealed that the impact generated stress far exceeding the steel's yield stress, particularly in the wind bracing system. Key findings from the analysis include that the impact-induced stress was 442,434 kN/m², which is significantly higher than the allowable stress of 246,670 kN/m² for steel, shown in *Figure 6*. Additionally, post-collision field measurements revealed that the actual stress in the damaged wind bracing sections reached 567,066 kN/m², indicating a critical failure in these areas. This substantial exceedance of both the allowable stress and the actual measured stress underscores the severity of the damage and the need for immediate structural remediation. Researchers compare the impact stress with the previously computed permitted stress in order to ascertain whether the stress resulting from the impact of the heavy machinery 442,434 kN/m^2 exceeds the allowable stress for steel. Under the assumption that the permitted stress for steel is 246,670 kN/m² when a safety factor of 1.5 is applied, the comparison demonstrates that the impact stress is far higher than the allowable limit. In particular, 442,434 kN/m² is significantly more than 246,670 kN/m², suggesting that forces are applied to the material that are higher than what is safe.



Element	Local node	Longitudinal Stress User Defined Point
160	1	3361.87278689604
160	2	3361.87278689604
161	1	-442439.380623106
161	2	-442439.380623106
162	1	-442434.296492422
162	2	-442434.296492422

Figure 6. *Stresses that occur.*

The force applied to the structure from the collision of the heavy machinery is greater than the safe capacity of the material, as evidenced by the impact stress of 567,066 kN/m², which is higher than the permissible stress for steel of 246,670 kN/m². This implies that there is a considerable risk of structural failure or damage since the stress placed on the steel structure is higher than its intended tolerance. In these situations, the integrity of the building can be jeopardized, necessitating a rapid assessment and either reinforcing or replacing the damaged components to guarantee long-term performance and safety shown in *Figure 7*. The research showed that multiple parts had exceeded their yield limits, compromising the bridge's structural integrity as a result of the incident. If structural failure is not addressed, there is a high possibility of failure due to this degree of stress. As a result of the wind bracing's tearing and irreversible distortion upon contact, stress concentrations spread to nearby structural components. According to analysis, these damaged sections could buckle under extra stresses from the environment or from traffic. It is advised to replace the damaged wind bracing elements with new steel parts made to bear impact loads in order to solve these problems and stop structural collapse. Furthermore, reinforcing the impacted sections will aid in preventing similar failures from being brought on by future impacts or load increases. In order to ensure the overall safety of the bridge and confirm the integrity of the new components, constant inspection and monitoring are necessary during the replacement process. Restoring the damaged or torn elements is the suggested course of action to address the stress from impacts that exceed steel's allowed stress capacity. New steel components with the mechanical capacity to sustain the associated loads and stresses should be used in place of these components. By replacing the structure, possible structural failures will be avoided by ensuring that it satisfies safety and performance criteria. Conducting comprehensive inspections and applying extra reinforcements if needed are essential to preserve the overall structural integrity and reduce dangers in the future during the replacement (*Figure 8*).



```
Node 224
X 2.5
Y 6.37
Z -3.75
Longitudinal Stress User Defined Point = 567066.4
Element 159 Longitudinal Stress User Defined Point = 2948.808
Element 160 Longitudinal Stress User Defined Point = 3361.873
Element 163 Longitudinal Stress User Defined Point = 1131997
Element 164 Longitudinal Stress User Defined Point = 1129958
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Figure 7. *Damage simulation on LISA.*

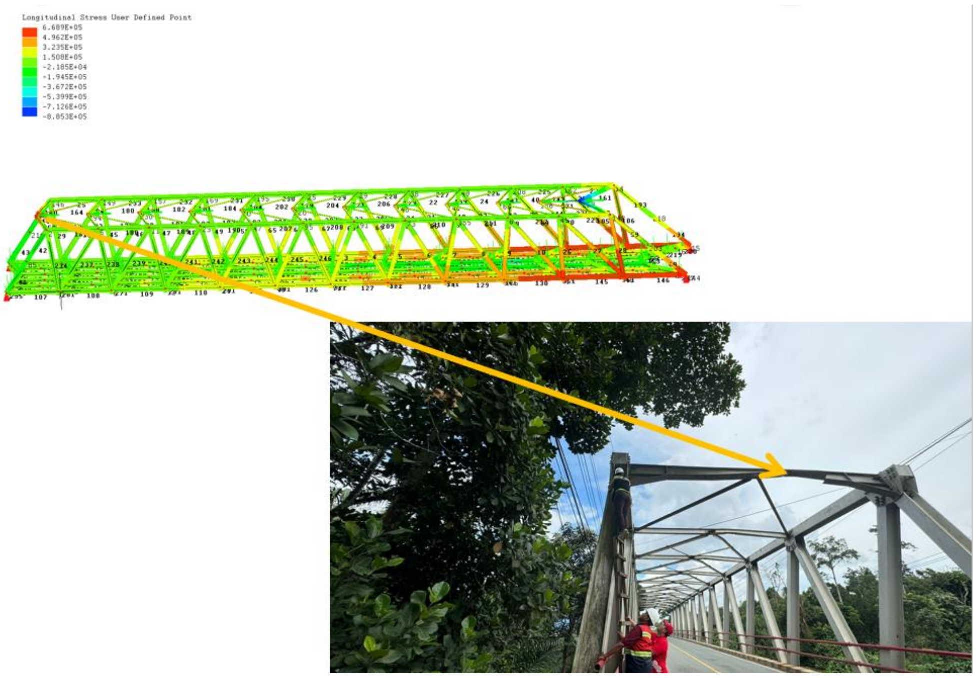

Figure 8. *Damage simulation.*

Figure 8(b). *Field damage conditions.*

Conclusion

The Pondok Gong truss bridge in Samboja, East Kalimantan, experienced significant damage when a heavy vehicle, with an arm exceeding the allowable height, collided with the horizontal wind bar frame at a speed of 80 km/h. This impact caused severe deformation and tearing of the wind bracing elements, resulting in an impact stress of 567,066 kN/m². This value significantly exceeds the allowable stress of 246,670 kN/m² for the steel components. The Finite Element Analysis (FEA) using LISA v.8 accounted for various loading conditions, including a self-weight of 7.41 kN/m for the slab, an additional dead load of 1.65 kN/m, a traffic load of 6.75 kPa, and a truck load of 146.25 kN, which highlighted that the impact force greatly surpassed the material's yield stress. It is advised to replace the broken wind bracing elements with new steel parts made to withstand impact loads in order to solve this problem and stop structural collapse. To be more precise, parts that tore should be replaced with new steel that can bear stresses higher than 567,066 kN/m². Furthermore, strengthening these areas will guarantee that they can withstand additional loads or impacts without failing. In order to assure the long-term performance and structural stability of the bridge, as well as to confirm the integrity of the new components, constant inspection and monitoring are essential during the replacement process.

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Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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