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Analysis of Girder Deflection in a Simulated Bridge Using SAP 2000: Study Case of Nongsa Pura Bridge

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ABSTRACT: Within structural engineering, bridges demonstrate how the practical import of scientific hypotheses becomes clear to humanity. Engineers use computer simulations and models to anticipate how the bridge will react under various stresses and what its response is likely given all sorts of environments over its life span. The construction of the Nongsa Pura Bridge in Batam, which showcases cutting-edge civil engineering accomplishments customized to local requirements, represents a critical turning point in the region's infrastructure improvement. This paper aims to analyze the deflection of a Nongsa Pura Planning Simulation using SAP2000 software. This research uses secondary data and the author's assumptions as necessary data to design a bridge. The results of this research are deflection values for the main girder, transverse girder, and longitudinal girder. In the main girder, the most considerable deflection value is 0,0778724 m. In contrast, in the transverse girder, the most considerable deflection value is 0,034118 m, and the longitudinal beam has the most considerable deflection value of 0,077809 m.

Keywords: Bridge Planning, SAP2000, Girder Deflection

INTRODUCTION

Within structural engineering, bridges demonstrate how the practical import of scientific hypotheses becomes clear to humanity. The project involves thorough knowledge of geology to guarantee solid foundations, hydrodynamics to control water flow around piers, and aerodynamics to withstand wind forces. Engineers use computer simulations and models to anticipate how the bridge will react under various stresses and what its response is likely--given all sorts of environments over its life span. The invention of materials like high-performance concrete, corrosion-resistant alloys, and seismic isolation bearings has greatly improved bridge safety and longevity (Snijder et al., 2021). The design process comprises a thorough analysis of such forces as tension, compression, and torsion, among others, and the choice of materials that can provide the most powerful and flexible options. Today's bridges are irreplaceable masterpieces in their function and reflect significant technological and engineering achievements.

Indonesian bridge development is a dynamic, multifaceted industry distinguished by creative responses to regional and environmental problems. Designing bridges that can endure Indonesia's varied topography, intense rainfall, and regular seismic activity is challenging for its engineers. Utilizing deep foundation systems and flexible structures to withstand seismic forces, such as the Suramadu Bridge, are prime examples of sophisticated engineering methods. Collaborative efforts with international experts and institutions ensure the adoption of global best practices, enhancing the resilience and functionality of these critical structures (Kiraga & Wicaksono, 2020). Incorporating contemporary design software facilitates accurate simulations and optimizations, guaranteeing efficiency and safety.

Bridge structural development in Kepulauan Riau is an example of bridge innovations and planning presented by the region's complicated topography and environmental circumstances. The Barelang Bridge system, which consists of six individual bridges, is an excellent example of how different structural engineering techniques, such as cable-stayed and arch bridge designs, can be strategically applied. These structures were designed to endure the dynamic loads and stresses of solid winds, seismic activity, and humid tropical weather. Efficient design and construction procedures are made possible by sophisticated modeling and simulation tools, guaranteeing that the bridges satisfy performance and safety requirements and facilitate smooth transportation and economic integration throughout the archipelago (M. Tapley, 2024).

The construction of the Nongsa Pura Bridge in Batam, which showcases cutting-edge civil engineering accomplishments customized to local requirements, represents a critical turning point in the region's infrastructure improvement. This bridge was built to support growing traffic demands and boost the local economy in the nearby area. To increase stability and longevity, its design includes elements like flexible joints and deep foundation systems (Yusuf & Hermawan, 2023). The Nongsa Pura Bridge was built using steel as materials and has a planned service life of 50 years. It spans approximately 100 meters, connecting two lands separated by sea.

This paper aims to analyze the deflection of a Nongsa Pura Planning Simulation. Considering the condition of the current bridge structure, the author will plan a replacement bridge using secondary data. This paper aims to develop bridge planning using software to analyze bridge structure. As a result, the deflection analysis will be shown with the assistance of SAP 2000 software.

Literature Review

Bridge Structural Planning

A comprehensive feasibility study is the first step in the rigorous and iterative process of bridge structural planning (Polley et al., 2015). Engineers perform thorough site evaluations, including geotechnical surveys and environmental assessments, to choose the best location and bridge type. Selecting the correct type of bridge requires careful consideration of many factors, including traffic volume, site topography, soil conditions, and hydrological considerations (F. Colarossi, 2019). Possible bridge types include beam arch suspension and cable-stayed. Environmental impact assessments are essential for minimizing ecological disturbance and guaranteeing adherence to regulations, especially in water bodies or sensitive habitats.

After finishing the feasibility study, engineers move on to the conceptual and preliminary design stages. Here, they investigate different structural layouts and materials, simulating and optimizing the bridge performance under various loading scenarios with cutting-edge computer-aided design (CAD) and modeling software. Structural engineers work closely with architects and environmental specialists to incorporate sustainability practices, community needs, and aesthetic considerations into the bridge design (Matos & Lourenço, 2019). To ensure the bridge design satisfies local expectations and requirements, this phase also involves stakeholder engagement to obtain feedback and address concerns about accessibility, visual impact, and socioeconomic factors.

Engineers move on to the detailed design stage after deciding on the best design concept. Thorough computations and structural analysis are done to polish the design and guarantee that the bridge can securely sustain expected loads for its design life. During this stage, construction materials are specified, structural components are detailed, and comprehensive construction documents, including drawings, specifications, and technical reports, are prepared (Tang, 2018; Wheeler et al., 2010). While adhering to project timelines and budget constraints, engineers develop construction methodologies and sequencing plans to minimize disruptions to surrounding environments and traffic during construction.

Getting permit approvals from authorities and environmental clearances is the last step in the structural planning of bridges before construction can start (Mitrović & Mašović, 2023; Y. Yu, 2023). Engineers, in collaboration with government agencies and environmental authorities, closely monitor safety codes, environmental regulations, and permitting requirements (Ciotta et al., 2021). After careful planning, the result is a structurally solid and aesthetically beautiful bridge that improves transportation efficiency, fosters economic development and satisfies community needs.

Beam Deflection

In the structural design of bridges, beam deflection plays a crucial role in affecting the structure's serviceability and safety (Brinissat et al., 2024; Kraváriková, 2022). A bridge beam will bend or distort when a load is placed. The span, length, material properties of the beam itself, the magnitude and distribution of the load, and other factors all affect the amount of deflection. Engineers compute beam deflection to ensure passenger comfort and structural integrity to guarantee that the bridge satisfies design requirements like the maximum permissible deflection limits.

Engineers apply the theory of elasticity and the equations of static equilibrium from structural mechanics to analyze beam deflection for bridge structures. Depending on the intricacy of the bridge's structural behavior and loading conditions, the beam's deflection is usually calculated using mathematical models such as the Timoshenko beam theory or the Euler-Bernoulli beam theory ￼￼. Factors such as shear forces, bending moments, and beam stiffness are considered to predict these theories' deflection accurately.

Engineers perform in-depth structural analysis during the design phase to determine the expected deflections under various load scenarios. By simulating the bridge's response to loads and optimizing the beam dimensions and material choice to minimize deflection while maintaining structural safety, finite element analysis (FEA) tools and computer-aided design (CAD) software are essential. Engineers can make educated judgments about the beam's geometry reinforcement and support conditions and improve the design through this iterative process.

In addition to maintaining structural stability, regulating beam deflection is crucial to guarantee the comfort and security of bridge users. Because of the uneven surfaces, excessive deflection can result in structural failure or discomfort for cyclists, pedestrians, and drivers (Wright & Walker, 1971). Engineers establish deflection criteria based on standards and laws to guarantee that the bridge operates dependably under anticipated loads and environmental circumstances for its service life. Engineers support effective transportation networks and sustainable infrastructure development by closely examining and controlling beam deflection and enhancing bridge structures' longevity, usefulness, and safety.

SAP2000 COMPUTER PROGRAM

Because of its sophisticated features and intuitive interface, SAP2000, a popular structural analysis and design program, has dramatically impacted bridge structural planning (Chaitanya & Ramakrishna, 2018; Ramakrishna, 2018). Several studies in the literature demonstrate how well SAP2000 models intricate bridge structures perform thorough structural analysis and optimize design parameters. The software facilitates accurate simulation of real-world conditions by handling various bridge types, such as beam arch suspension and cable-stayed bridges (Nagose & Prasad, 2018; Savaliya et al., 2015). To guarantee that bridge designs adhere to safety regulations and standards, this capability is essential for analyzing structural integrity, assessing load distribution, and forecasting performance under various loading scenarios.

Engineers can simulate the behavior of bridges subjected to static dynamic and seismic loads thanks to SAP2000s extensive functionality, including tools for finite element analysis (FEA), nonlinear analysis, and dynamic analysis. Research has shown how valuable SAP2000 is for examining how bridges react to environmental elements like wind, earthquakes, and temperature changes. This analysis can reveal necessary information about the behavior of the structure and possible weak points. Furthermore, the software's ability to integrate with Building Information Modeling (BIM) platforms improves multidisciplinary teams' ability to collaborate by allowing for smooth data exchange and coordination during the planning and construction stages of the bridge (Bhusar & Akhare, 2014).

The literature also highlights how SAP2000 can optimize bridge designs by evaluating various structural configurations, material selections, and construction techniques (Zaheer et al., 2022). Engineers use software optimization algorithms and parametric modeling features to improve designs iteratively, cut construction costs, and increase efficiency. In addition, SAP2000 facilitates the assessment of bridge projects' feasibility and economic viability by offering comprehensive reports, visualizations, and performance metrics. Incorporating SAP2000 into bridge structural planning improves engineering precision and efficiency and helps build resilient and sustainable bridge infrastructures that adapt to changing community and transit demands.

RESEARCH METHODOLOGY

This research uses assumed data to simulate the bridge structure to be analyzed. The assumptions referred to are the dimensions of the bridge and the assumed loads that occur on the bridge. In addition, secondary data are needed to provide information such as wind velocity, precipitation depth, etc. The research was conducted at the Nongsa Pura Bridge in Nongsa, Batam, Riau Islands.

The calculation of the bridge structure is carried out using a finite element-based computer for various combinations of loads, including self-weight, additional dead load, vehicle traffic load (lane load, pedestrian brakes), and environmental loads (temperature, wind, earthquake) with 3-D structural modeling (space-frame). The method used is a linear analysis of the direct stiffness matrix method with small structural deformation and isotropic material. The computer program used for the study is SAP2000. In this program, the self-weight of the structure is calculated automatically.

Figure 1. *Research Location*

RESULT AND DISCUSSION

This analysis refers to SNI 1725:2016 about Loads on Bridges, SNI 2833:2016 about Bridge Planning Against Earthquake Loads, and SNI 1729:2020 about Specifications for Structural Steel Elements. The following are necessary information for the simulated bridge:

Table 1. *General Information*

Description	Measurement
Total Length	100 meters
Total Width	12 meters
Type of Road	2/2 UD
Lane Width	3.5 meters
Sidewalk Width	1 meter
Roadside Width	0.5 meter

This research uses the software SAP2000 v 24.0.0 to carry out an analysis of bridge design. The data that has been provided will be input into the application, such as loading, girder profile, etc. The following is the steel girder profile data used in this bridge simulation:

Table 2. *Steel Profile of Bridge*

Element	Profile
Longitudinal Girder	WF 500X200X10X16
Transverse Girder	WF 800X300X14X22
Main Girder	BOX 800X600X45X45

The bridge superstructure is modeled in 3D for analysis with SAP2000 software. The frame structure and floor girders are modeled as frame elements. The connections between the frames are released against the moment to obtain pin connections between frames/about connections. In the modeling process, the frames are given clear numbering because the frame members will be analyzed individually according to the load to be applied. The member numbering can be seen in Figure 2.

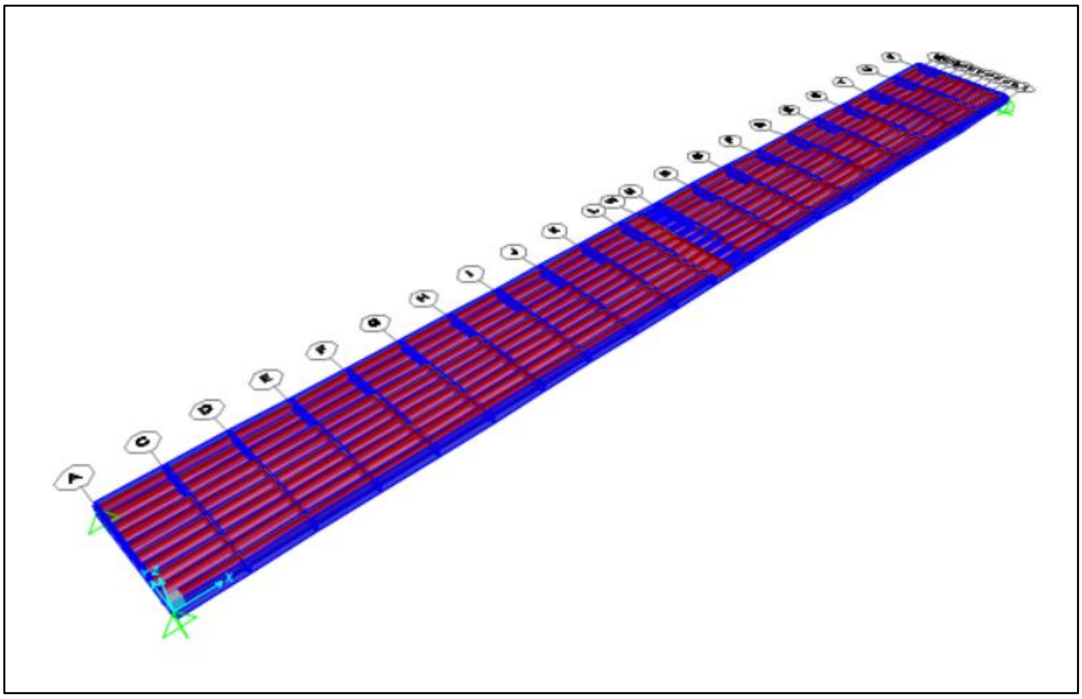

Figure 2. *Bridge Structure Using by SAP2000*

Structural analysis was carried out using a combination of SNI 1725:2016 loads. The results displayed are the structural reaction to the envelope combination. The following tables show the deflection values of the main girder, longitudinal girder, and transversal girder; see Table 3, Table 4, and Table 5.

Table 3. *Deflection Value of Main Girder*

Span (m)	Deflection (m)
97,5	0,021617
92,5	0,034027
87,5	0,044946
82,5	0,054314
77,5	0,06212
72,5	0,068368
67,5	0,073051
62,5	0,076175
57,5	0,077743
52,5	0,077872
47,5	0,077743
42,5	0,076175
37,5	0,073051
32,5	0,068368
27,5	0,062122
22,5	0,054314
17,5	0,044946
12,5	0,034027
7,5	0,021617
2,5	0,007717

The following calculation results from bridge simulation in horizontal conditions were done using SAP2000 software. Figure 2 shows the deflection that occurs on the bridge. In manual calculations, entering the desired maximum deflection value can be used to calculate the tension on the cable, but in this simulation, it is done the other way around. The horizontal tension value on the cable must be entered first, then after running, the deflection value that occurs will be obtained. So, it is necessary to repeat entering the tension value to obtain the deflection value towards the z-axis (-). Table 3 is a trial of entering the horizontal tension value that the author did to find the cable tension value needed in horizontal conditions with one load so that the maximum deflection that occurs can be seen in the following table.

Table 4. Deflection value of Transversal Girder

Span (m)	Deflection (m)
100	0,034118
95	0,018577
90	0,010682
85	0,007136
80	0,00466
75	0,002787
70	0,001387
65	0,000412
60	0,000777
55	0,001063
50	0,001082
45	0,001063
40	0,000777
35	0,000412
30	0,001387
25	0,002787
20	0,00466
15	0,007136
10	0,010682
5	0,018577
0	0,034118

From the table above, it can be seen that there is a relationship between stress and deflection in the girder stress column and vertical deflection (z). The greater the stress given, the smaller the deflection in the cable. And vice versa, the smaller the stress is given, the greater the deflection in the cable. The initial plan for the simulation was to carry out static and dynamic analysis. Still, there was an obstacle where moving and wind loads in the simulation could not be applied to the girder. Girder simulation in SAP2000 is used to analyze building and bridge structures, not to analyze transportation equipment on bridges. Therefore, the loading on the cable is done statically. As seen in the table, the difference in the required stress value from the manual calculation results and the simulation results can be caused by rounding and assumptions made during the calculation. However, the difference between the calculation and simulation results is close.

Table 5. *Deflection Value of Longitudinal Girder*

Span (m)	**Deflection (m)**
97,5	0,007107
92,5	0,020796
87,5	0,033973
82,5	0,044909
77,5	0,054314
72,5	0,062095
67,5	0,068383
62,5	0,073022
57,5	0,076199
52,5	0,077809
47,5	0,076199
42,5	0,073022
37,5	0,068383
32,5	0,062095
27,5	0,054314
22,5	0,044909
17,5	0,033973
12,5	0,020796
7,5	0,007107
2,5	0,007589

It can be seen that the most significant tension in the cable occurs when two loads load it. This can be caused by the amount of load imposed on the cable. In addition, if calculated, as shown in the image above, the tension with one and two loads can be compared. If the angles α and β in the image are the same, then the tension when loaded by two loads is more significant than when given one load. However, the difference in results is not too far. This can be caused by the deflection in the cable, which is very small compared to the cable's length. So that the value of half the angle α will approach the value of sine β.

CONCLUSION

This research was conducted on the Nongsa Pura Bridge case study with a bridge length of 100 meters and a width of 12 meters. The data used is secondary data and assumptions, which are then modeled using SAP2000 software. The results of this research are deflection values for the main girder, transverse girder, and longitudinal girder. In the main girder, the most considerable deflection value is 0,0778724 m. In contrast, in the transverse girder, the most considerable deflection value is 0,034118 m, and the longitudinal beam has the most considerable deflection value of 0,077809 m.

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