



## Simulation of Tied-Arch Bridge Design on Ibu Kota Nusantara (IKN)

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### Abstract

The relocation of Indonesia's capital to Ibu Kota Nusantara (IKN) in East Kalimantan necessitates the development of robust infrastructure, particularly bridges. This research focuses on the design simulation of a tied-arch bridge for IKN, addressing challenges such as limited skilled human resources, budget constraints, and environmental considerations. The primary objective is to create a simulation model that integrates structural durability, ecological sustainability, and aesthetics. The bridge's design was meticulously modeled and analyzed using SAP2000 software under various load conditions to ensure strength and stability. The methodology involved collecting technical and environmental data, simulating the bridge model, and evaluating its feasibility. The results indicate that the proposed tied-arch bridge design can effectively withstand dynamic and static loads, ensuring safety and functionality. The study concludes that integrating civil engineering disciplines in bridge design is crucial for achieving efficient, durable, and aesthetically pleasing structures. The simulation model provides practical guidance for stakeholders involved in the planning and constructing of bridge infrastructure in IKN, contributing significantly to the knowledge base in this field and supporting the vision of IKN as a sustainable and iconic capital city.

**Keywords:** Bridge Planning, Tied-arch bridge, Ibu Kota Nusantara, Simulation

### 1. Introduction

Bridges are one of the infrastructure facilities vital for the smooth running of the traffic system in an area. Bridges are widely used to cross rivers, valleys, and highways, becoming a connecting path between one land and another from ancient to modern times [1]. The primary purpose of a bridge is to provide a path through any obstacle, such as a river or valley [2]. Bridges and transportation infrastructure are significant assets supporting human mobility and activity. [3]. However, nowadays, bridges are used as a connecting path between roads and can also be a monumental building that characterizes an area.

Infrastructure plays an essential role in driving economic growth. Infrastructure development is vital for economic growth in both the long and short term. [4]. In Indonesia, several challenges will be faced in developing bridge infrastructure. However, despite these challenges, opportunities to overcome them and improve infrastructure development in Indonesia indeed remain. With the right solution, bridge development in Indonesia can be optimized to achieve national development goals.

Indonesia is moving the capital city from Jakarta to the Ibu Kota Nusantara (IKN), located in East Kalimantan province. In this new IKN, bridge construction will undoubtedly be

one of the main aspects that will be the main focus of connecting regions. However, there will be challenges in preparing to increase the capacity of Indonesia's new capital city, such as limited skilled human resources, budget limitations, knowledge and skills gaps, coordination between stakeholders, and technological changes. [5]. However, the bridge's construction in IKN is expected to boost economic growth through improved connectivity and mobility, encouraging investment and trade. The bridge can also become an iconic landmark that attracts tourists and promotes the tourism sector in IKN.

The development of bridge infrastructure in IKN must not only be functional but must also consider aesthetic and sustainability factors. Therefore, arch bridges are one of the design options that can fulfill these criteria. Arch bridges, with their historical significance and aesthetic appeal, are an essential part of transportation infrastructure [6]. The technical planning of arch bridges involves optimizing geometric parameters, understanding structural behavior, and ensuring quality control to achieve efficient, durable, and visually pleasing designs.

In the design of arch bridges in Indonesia, cost, stability, and environmental conditions such as seismic loads and the risk of natural disasters are vital considerations. In a case study in Bireuen Regency, Indonesia, construction cost was the dominant criterion in prioritizing bridge construction [7]. Preservation methods, including maintenance and rehabilitation, are needed to increase the structural capacity of old bridges and ensure continued service for the next 100 years [8]. Preservation methods, including maintenance and rehabilitation, are also needed to improve the structural capacity of old bridges and ensure sustainable service for the next 100 years.

This research will design a simulation model that can consider various factors such as structural durability, environmental sustainability, and aesthetic aspects when planning arch bridges in IKN. By integrating civil engineering disciplines, this research aims to develop a simulation method that can be used for the technical planning of arch bridges in IKN by considering various factors such as structural durability, environmental sustainability, and aesthetic aspects. This research is expected to provide practical guidance for stakeholders in the planning and construction of bridge infrastructure in IKN and contribute to the development of knowledge in this field.

## **2. Literature Review**

### **2.1 Bridge Infrastructure Design**

The increased emphasis on Sustainable Development Goals (SDGs) has led government authorities worldwide to develop initiatives that promote sustainability as a critical component of regional development plans [9]. Infrastructure development is the foundation for all activities and growth in a country. According to Hansen, infrastructure encompasses all facilities provided to the public in the form of essential services, including public utilities such as roads, bridges, and transportation, clean water supply, waste management, energy, and housing. Due to its crucial role, countries around the globe are increasingly competing to invest in infrastructure projects [10].

One of the continuously developed national infrastructures is public facilities such as bridges. A bridge is a structure that connects two areas separated by a ravine, river, valley, or sea over a long distance, facilitating land transportation access. The presence of bridges makes transportation activities easy and smooth [11]. In constructing a bridge, it is crucial to consider the primary safety factor. All load conditions must also be accounted for to ensure the bridge's maximum strength in bearing loads, prioritizing user safety and security. It is essential to assess the feasibility of bridge construction so that it can be classified according to the level of service and its ability to handle loads [12].

The existence and construction of bridges have continuously evolved to the present day, encompassing designs such as cable-stayed bridges, suspension bridges, steel truss arch bridges, and concrete arch bridges. Cable-stayed bridges utilize key elements characterized by

their lightweight, low damping, and high flexibility. These cables are subject to continuous vibrations with varying amplitudes caused by different dynamic loads over time, leading to fatigue and potential cable failure, which can compromise bridge safety. Therefore, mitigation measures are necessary, including creating surface profiles, cross-binding, and implementing structural vibration control systems to enhance the dynamic performance of cable-stayed bridges [13].

Suspension bridges play a crucial role in civil infrastructure. To maximize design freedom, giga-scale computational morphogenesis procedures are employed to identify new design concepts [14]. Suspension bridges utilize artificial neural networks to predict the critical flutter speed in suspension bridges with closed-box deck sections. The neural network model is derived and trained using an essential dataset of flutter speeds, with calculations performed based on experimental flutter derivatives and variations in geometric and mechanical parameters [15].

## 2.2 Tied-arch Bridge

An arch bridge is a structural element with a large span, typically used in its pure form without a transverse stabilizing system [16]. Professor Tweit recommends designing network arches with attention to optimizing cost efficiency. The arch should be a part of a circle, with the curvature near the supports being part of another circle with a reduced radius. The curvature near the supports should have a radius of about 80% of the primary curvature radius. The cross-section of the arch should be a universal column, as this type of column appears slender, provides a streamlined network arch, and requires less welding and more straightforward detailing [17].

This type of bridge is commonly found in Asia, South America, and Europe. For example, the Capriogliola arch bridge spans the Magra River and was established in the early 1900s. The Capriogliola bridge is one of the first reinforced concrete (RC) bridges built in Italy and is the longest bridge in the world. It serves as a critical infrastructure for the local economy, connecting the towns of Albiano Magra and Capriogliola, as well as the regions of Liguria and Tuscany [18]. Another example in Europe is the prevalence of arch bridges in road and railway networks. Over 40% of the 220,000 railway and 25% of highway bridges in Europe are stone arch bridges. However, stone arch bridges no longer meet modern usage and design criteria and are structurally deemed unsafe. This is because modeling and analyzing the behavior of stone arch bridges require extensive information, including geometry, material properties, morphology, and bridge behavior [19].

Tied-arch bridges have various hanger configurations. Typically, hanger layouts have been enhanced through advancements in modern technology. Understanding the structural behavior of these bridges involves addressing several static uncertainties facilitated by computer advancements. A tied-arch bridge features a deck suspended by an arch and connected by hangers known as suspenders. Unlike typical suspension bridges, the hangers in tied-arch bridges do not need to be vertical. The hangers function to transfer the load from the deck to the upper arch, which then distributes it to the supports [20].

In tied and regular arches, loads can cause significant bending in the arch. This bending requires larger cross-sections and materials with higher strength, which increases structural costs and overall weight. One technique involves placing hangers at an angle rather than vertically to achieve material savings and a sleek aesthetic. Inclined hangers in a tied arch help distribute some forces along the span, referred to as shear forces. One such configuration is the "V" configuration, commonly known as a Nielsen Bridge. While live loads can be relatively higher than dead loads, there is potential for compression forces to develop in some hangers, which are designed to withstand tensile forces [21].

## 2.3 Ibu Kota Nusantara

Ibu kota Nusantara is the focus of Indonesia's development and a target in achieving its vision of becoming a developed country by 2045. The construction of the national capital, with

a national identity, aims to shift the development orientation to an Indonesia-centric approach and accelerate the country's economic transformation [22]. The capital city serves as the spearhead for all activities related to state administration. It is projected to host the country's central government. As a state governed by law, there are procedural requirements for relocating the capital based on existing legal provisions. The foundation for relocating the capital is based on Article 4, paragraph (1) of the 1945 Constitution. This provision states that the governmental power referred to is executive power. Executive power and government operations are distinguished between general administrative and specific operational authorities [23].

The relocation of Ibu Kota Nusantara will be carried out to the island of Kalimantan, precisely in Penajam Paser Utara and Kutai Kartanegara, where later this move will have an impact on the formation of a new epicenter with long-term development in underdeveloped areas. On the other hand, this will also be one of the efforts to overcome the problem of economic centralization and development in the context of regional structuring. In addition, the Ibu Kota Nusantara program also aims to assist in reducing various issues, including financial, political, and population density issues, which continue to increase, especially on the island of Java. The development of the Ibu Kota Nusantara carries the concept of a green, inclusive, innovative, and sustainable city in the context of realizing the national capital with a new civilization and becoming a model city [23].

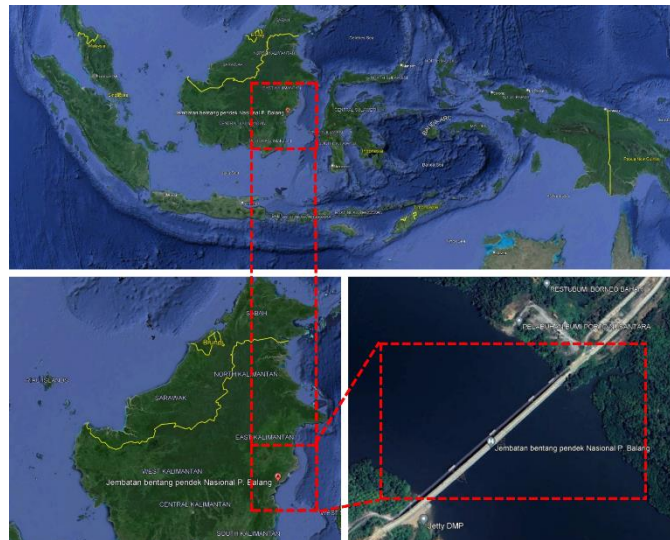
Naming the new capital city "Nusantara" is one of the choices given by the community. However, in choosing the name, the President held discussions with historians and linguists about the name Nusantara, which provides an overview of the Republic of Indonesia. Other factors also motivate the relocation of the capital out of Java, namely the concern over ecosystem and social disasters in big cities on the island of Java. Agricultural land that has three times the fertility of land outside Java is narrowing and turning into industrial areas, property projects, and new cities. Through this development model, the rural poor are relegated to the status of urban poor and do not experience development. Kalimantan has advantages as the location of the center of the Nusantara, starting from the vast land that is still available so that the spatial planning of the capital city will be carried out ideally [24].

The development of the Ibu Kota Nusantara certainly impacts all aspects, including economic, political, social, and cultural development, as well as the role of the community in various aspects of social life. Developing the Ibu Kota Nusantara with the concept of a forest city aims to ensure environmental resilience so that at least 50 percent of the area is green. The idea of the primary plan with minimizing risks to the natural ecology that has been formed, social systems, and the environment that will be built through the development of a modern city with international standards is innovative, progressive, and competitive in all aspects of life. The Ibu Kota Nusantara will also have world-class infrastructure linked to various international urban centers. According to the Deputy for Regional Development of the Ministry of National Development Planning/Bappenas, the relocation of the Ibu Kota Nusantara is intended to become a new economic growth magnet through six economic clusters and supported by two clusters as drivers of the economic change process. Ibu Kota Nusantara has a regional form of government. Still, Ibu Kota Nusantara is centralized so that in passing regulations, there is no connection between the legislature and the executive at the regional level [25].

### **3. Methodology**

In this research, the method used has various stages, starting from collecting information and references related to the design of tied-arch bridges, collecting technical and environmental data through the study of study documents, using SAP2000 software to model the bridge and perform simulations, and analyzing the simulation results to evaluate the strength and stability of the bridge. The data that has been collected is then used to create a

bridge model that will be made and analyzed to determine whether this bridge is feasible or not.



**Figure 1.** Research Location  
 Source: Google Earth, 2024

This research was conducted in 2024 using the coordinates 1°07'55.5 "S 116°43'23.0 "E as the research location. This research uses a quantitative approach with simulation methods to design a tied-arch bridge in the Ibu Kota Nusantara (IKN). The simulation was chosen because it allows the analysis of various design variables and environmental conditions more efficiently and accurately.

## 4. Result and Discussion

### 4.1 Data Planning

The planning data in this project includes relevant technical and location specifications obtained from the author's simulations. The bridge to be designed is a tied-arch bridge, with the location selected at Pantai Lango, Penajam, Penajam Paser Utara, Kalimantan Timur. The detailed data are as follows:

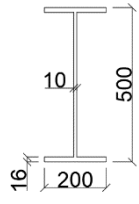
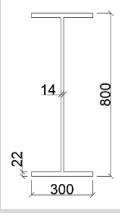
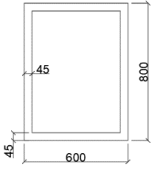
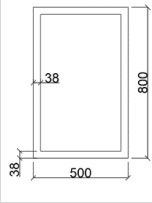

Table 1. General Data of Bridge Planning

No.	Parameter	Detail
1	Bridge Length	100 m
2	Bridge Width	12 m
3	Bridge Height	18 m
4	Road Class	2/2 UD
5	Road Width	2 x 3,5 m
6	Sidewalk Width	2 x 1 m
7	Shoulder Width	2 x 0,5 m

Source: Personal Processed Results, 2024

The material specifications used in the bridge construction are also essential to ensure the structure's strength, durability, and sustainability. The prominent arches of the bridge will be constructed using BJ 52 grade steel with a yield strength ( $F_y$ ) of 360 MPa and a tensile strength ( $F_u$ ) of 520 Mpa, thus able to withstand extreme stresses and strains and provide the necessary structural stability. The suspension cables will be made of galvanized steel to prevent corrosion and extend service life, while the bridge deck will use high-grade concrete with a compressive strength ( $F_c$ ) of 30 MPa to cope with live and dead loads effectively.

Table 2. Material specifications

No	Component	Specification	Drawing
1	Longitudinal girder (WF 500x200x10x16)	A: 114,2 cm <sup>2</sup>	
		Zx: 2090 cm <sup>3</sup>	
		Ix: 47800 cm <sup>4</sup>	
		W: 89,69 kg/m	
		Zy: 332 cm <sup>3</sup>	
		Iy: 2140 cm <sup>4</sup>	
2	Transverse Girder (WF 800x300x14x22)	A: 243,4 cm <sup>2</sup>	
		Zx: 7040 cm <sup>3</sup>	
		Ix: 254000 cm <sup>4</sup>	
		W: 191 kg/m	
		Zy: 1027 cm <sup>3</sup>	
		Iy: 9930 cm <sup>4</sup>	
3	Main Girder (BOX 800x600x45x45)	A: 1179 cm <sup>2</sup>	
		Zx: 31727,25 cm <sup>3</sup>	
		Ix: 1038878,3 cm <sup>4</sup>	
		W: 925,51 kg/m	
		Zy: 25832,25 cm <sup>3</sup>	
		Iy: 655148,3 cm <sup>4</sup>	
4	Arc (BOX 800x500x38x38)	A: 930,24 cm <sup>2</sup>	
		Zx: 24437,34 cm <sup>3</sup>	
		Ix: 792421,2 cm <sup>4</sup>	
		W: 730,23 kg/m	
		Zy: 17460,54 cm <sup>3</sup>	
		Iy: 373442,4 cm <sup>4</sup>	
5	Hanger (Macalloy 520 (M100) (Carbon Steel)	D: 97 mm	
		W: 58 kg/m	
		MBL: 4551 kN	
		Iy: 46,54 m	

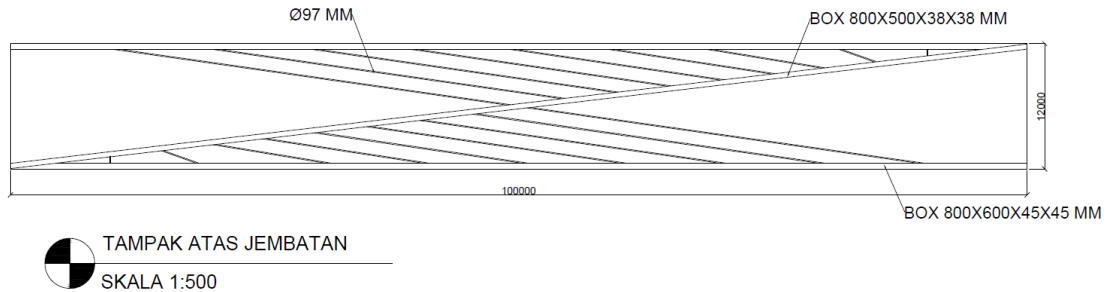
Source: Personal Processed Results, 2024

The table above details the material specifications used for the various bridge components. The longitudinal girders support the vertical load from the bridge deck and transmit it to the transverse girders and pillars. The transverse girder spreads the load from the bridge deck to the longitudinal girder and increases the overall stiffness of the bridge structure. The main girder is the main element that supports the overall bridge structure, ensuring its stability and strength. The arc (Arch Box) is the main component that supports the load from the bridge deck through compressive forces. The hanger is made of highly durable carbon steel to support the bridge load. Meanwhile, the specification information from the table above is (A) = profile area; (Zx) = x-axis plastic modulus; (Ix) = X-axis inertia; (W) = profile weight; (Zy) = y-axis plastic modulus, (Iy) = y-axis inertia; (D) = Thread; (MBL) = Min. Break Load.

#### 4.2 Design Modeling

The modeling design for this tied-arch bridge was carried out using SAP2000 and Autocad Autodesk software, which allows detailed structural analysis. The modeling included

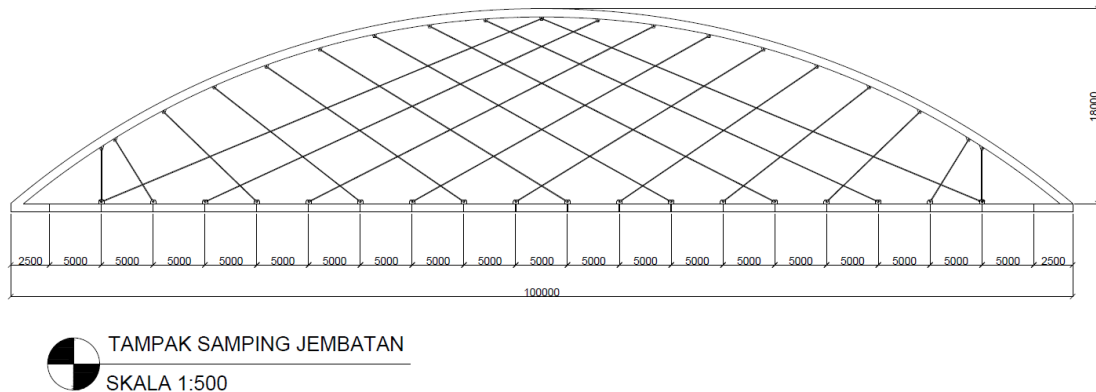
significant elements such as longitudinal transverse girders, arcs, and hangers and their interactions under various load conditions. This process involves material strength testing, load distribution analysis, and deformation simulation to ensure the bridge can withstand dynamic and static loads effectively. As such, the modeling design aims to optimize the bridge's safety, stability, and efficiency while considering environmental and aesthetic factors relevant to the construction site in Ibu Kota Nusantara.



Source: Personal Processed Results, 2024

**Figure 2.** Top View of The Bridge

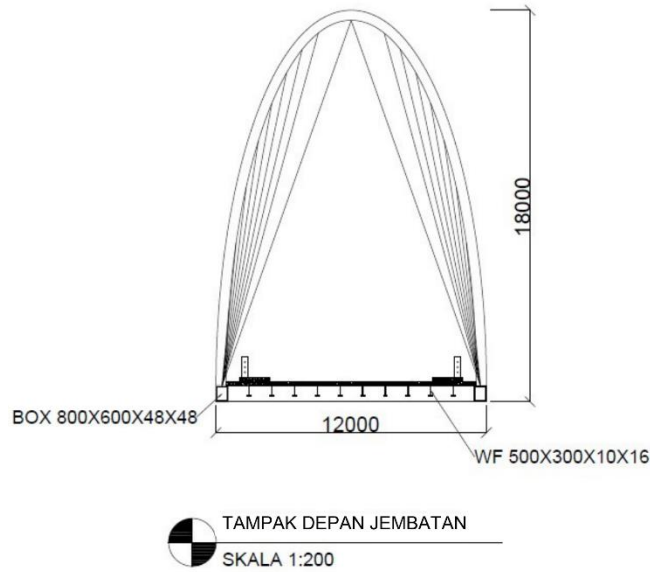
The result shown in Figure 2 is a top view of the bridge, showing the overall layout of the proposed bridge. The top view was designed using Autodesk Autocad software as a tool. This figure shows how structural elements such as longitudinal and transverse girders, bridge deck, and bow positions are strategically positioned to support optimal load distribution. This layout ensures the bridge can withstand traffic loads and other forces acting on the structure.



Source: Personal Processed Results, 2024

**Figure 3.** Side View of The Bridge

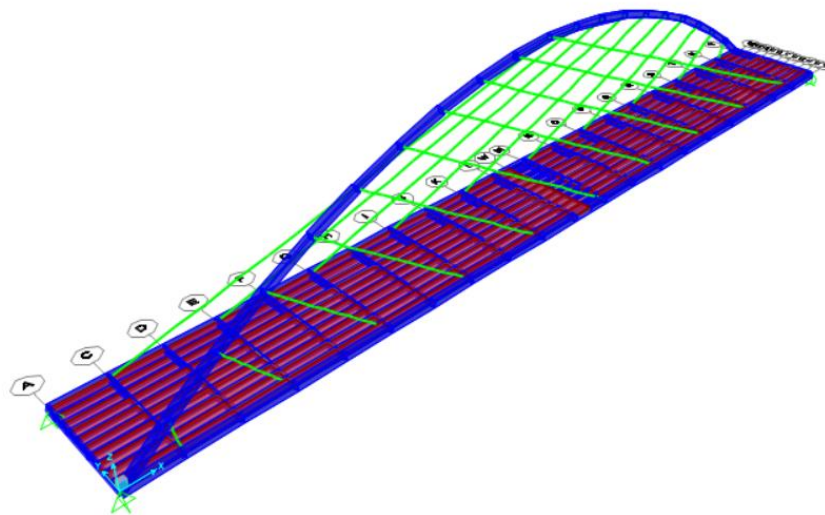
The result shown in Figure 3 is a side view of the bridge. It shows the longitudinal profile of the bridge, including the bow height, hanger position, and bridge deck. This image shows how the bow supports the deck through the hanger, designed to withstand vertical loads from traffic. This design ensures the structural strength and stability of the bridge, especially against compressive and flexural forces acting on the bow and deck.



Source: Personal Processed Results, 2024

**Figure 4.** Front View of The Bridge

The result shown in Figure 4 is the front view of the bridge. This image displays a frontal view of the bridge structure, including the main arc and the hangers that hang the bridge deck. This image provides a perspective on the height and width of the bridge, as well as how these structural elements are integrated to provide optimal stability and strength. This front view also shows the aesthetic design of the bridge, which has become an architectural icon at the construction site.



Source: Personal Processed Results, 2024

**Figure 5.** Structural Modeling

The results shown in Figure 5 represent structural modeling using SAP2000 software to analyze and simulate bridge behavior under various load conditions. This figure shows a three-dimensional model of the bridge, including the main structural elements such as girders,

arcs, and hangers. This simulation evaluates how stress distribution and deformation occur on the bridge, ensuring an optimal and safe design for use in actual conditions.

### 4.3 Planning Analysis

#### 4.3.1 Floor Plate Planning

##### a. Material specifications

- Thickness of concrete floor slab (ts): 0.2 m
- Concrete specific gravity: 2400 kg/m<sup>3</sup>
- Asphalt specific gravity: 2200 kg/m<sup>3</sup>

##### b. Dead load calculation

Weight of concrete slab: The weight of the concrete slab is calculated by multiplying the specific gravity of concrete by the thickness of the concrete slab. Where the specific gravity of concrete is 2400 kg/m<sup>3</sup>, and the thickness of the slab is 0.2 m, the weight of the concrete slab per square meter is 4.8 kN/m<sup>2</sup>.

$$w_{concrete} = 2400 \text{ kg/m}^3 \times 0.2 \text{ m} = 480 \text{ kg/m}^2 = 4.8 \text{ kN/m}^2$$

Weight of Asphalt: The asphalt weight is calculated by multiplying the asphalt-specific gravity by the asphalt layer thickness. Where the specific gravity of asphalt is 2200 kg/m<sup>3</sup>, and the thickness of asphalt layer is 0.05 m, the weight of asphalt layer per square meter is 1.1 kN/m<sup>2</sup>.

$$w_{asphalt} = 2200 \text{ kg/m}^3 \times 0.05 \text{ m} = 110 \text{ kg/m}^2 = 1.1 \text{ kN/m}^2$$

Total dead load: Total dead load is the sum of concrete slab and asphalt dead load. The total dead load per square meter of the floor slab is 5.9 kN/m<sup>2</sup>.

$$w_{total} = 4.8 \text{ kN/m}^2 + 1.1 \text{ kN/m}^2 = 5.9 \text{ kN/m}^2$$

##### c. Live load calculation

- Standard Truck Load: 112.5 kN
- Impact Factor: 30%

Total vehicle load: The total live load is calculated by multiplying the standard truckload by the shock factor. Hence, the total vehicle load, including the shock factor, is 146.25 kN.

$$P_{vehicle} = 112.5 \text{ kN} \times 1.3 = 146.25 \text{ kN}$$

##### d. Floor plate reinforcement

Dead load moment (M<sub>D</sub>): The dead load moment is calculated using the moment formula for a distributed load on a simple beam. Hence, the maximum moment due to dead load is 106.5 kNm.

$$M_D = w_{total} \times \left( \frac{L_{span}^2}{8} \right)$$

$$M_D = 5.9 \text{ kN/m}^2 \times \left( \frac{12^2}{8} \right) = 106.5 \text{ kNm}$$

Live load moment (M<sub>L</sub>): The live load moment is calculated using the moment formula for the centered load on a simple beam. Hence, the maximum moment due to live load is 219.42 kNm.

$$M_L = P_{vehicle} \times \left( \frac{L_{span}^2}{8} \right)$$

$$M_L = 146.25 \text{ kN} \times \left( \frac{12^2}{8} \right) = 219.42 \text{ kNm}$$

Total moment ( $M_u$ ): The total moment is the sum of the moment due to dead load and the moment due to live load. Hence, the total moment acting on the floor plate is 325.92 kNm.

$$M_u = M_D + M_L$$

$$M_u = 106.5 \text{ kNm} + 219.42 \text{ kNm} = 325.92 \text{ kNm}$$

Reinforcement ( $A_s$ ): Reinforcement is calculated using the formula for the required cross-sectional area of steel reinforcement. The reinforcement of steel needed cross-sectional area is 4500 mm<sup>2</sup>, with d (effective plate height) = 0.2 m and  $F_y$  (yield stress of steel) = 360 MPa.

$$A_s = \frac{M_u}{0.9 \times d \times F_y}$$

$$A_s = \frac{325.92 \text{ kNm}}{0.9 \times 0.2 \text{ m} \times 360 \text{ MPa}} = 4500 \text{ mm}^2$$

### 4.3.2 Longitudinal Girder

#### a. Material specifications

- Profile: WF 500x200x10x16
- Cross-sectional area (A): 114.2 cm<sup>2</sup>
- Section modulus (Zx): 2096 cm<sup>3</sup>
- Moment of inertia (Ix): 47000 cm<sup>4</sup>
- Steel yield strength ( $F_y$ ): 360 Mpa

#### b. Load calculation

Dead load per meter of girder: The dead load per meter of the girder is calculated by dividing the total dead load by the length of the rafter. Which is the dead load per meter of the girder is 5.9 kN/m

$$w_{dead\_girder} = \frac{w_{total} \times B}{L_{girder}}$$

$$w_{dead\_girder} = \frac{5.9 \text{ kN/m}^2 \times 12 \text{ m}}{12 \text{ m}} = 5.9 \text{ kN/m}$$

Live load per meter of girder: The live load per meter of the girder is calculated by dividing the total vehicle load by the length of the rafter. This means the live load per meter of the girder is 12.19 kN/m.

$$w_{live\_girder} = \frac{P_{vehicle}}{L_{girder}}$$

$$w_{live\_girder} = \frac{146.25 \text{ kN}}{12 \text{ m}} = 12.19 \text{ kN/m}$$

#### c. Moment and shear calculation

Maximum moment due to dead load: The maximum moment due to dead load is calculated using the moment formula for a supported beam with a distributed load. The maximum time due to dead load on the longitudinal girder is 106.5 kNm.

$$M_{dead} = w_{dead\_girder} \times \left( \frac{L_{girder}^2}{8} \right)$$

$$M_{dead} = 5.9 \text{ kN/m} \times \left( \frac{12^2}{8} \right) = 106.5 \text{ kNm}$$

Maximum moment due to live load: The maximum moment due to live load is calculated using the moment formula for a supported beam with a distributed load. The maximum moment due to the living load on the longitudinal girder is 219.42 kNm.

$$M_{live} = w_{live\_girder} \times \left( \frac{L_{girder}^2}{8} \right)$$

$$M_{live} = 12.19 \text{ kN/m} \times \left(\frac{12^2}{8}\right) = 219.42 \text{ kNm}$$

Total moment ( $M_u$ ): The total moment is the sum of the moments due to dead load and live load. The total moment acting on the longitudinal girder is 325.92 kNm.

$$M_u = M_{dead} + M_{live}$$

$$M_u = 106.5 \text{ kNm} + 219.42 \text{ kNm} = 325.92 \text{ kNm}$$

d. Section strength check ( $M_n$ )

Nominal moment ( $M_n$ ): The nominal moment is calculated by multiplying the section modulus with the steel yield strength. The nominal moment of the longitudinal girder is 753.6 kNm.

$$M_n = Z_x \times F_y$$

$$M_n = 2096 \text{ cm}^3 \times 360 \text{ MPa} = 753.6 \text{ kNm}$$

Factored moment strength ( $\phi M_n$ ): The factored moment strength is calculated by multiplying the nominal moment with the strength reduction factor. Assuming that strength reduction factor ( $\phi$ ) = 0.9. So, the factored moment strength of the longitudinal girder is 678.24 kNm.

$$\phi M_n = 0.9 \times 753.6 \text{ kNm} = 678.24 \text{ kNm}$$

Check  $M_n$  &  $M_u$ : If the factored moment strength ( $\phi M_n$ ) is greater than the total moment ( $M_u$ ), indicating that the longitudinal girder design is safe, if it is not, planning calculations must be reviewed.

$$\phi M_n = 678.24 \text{ kNm} > M_u = 325.92 \text{ kNm} \Rightarrow OK$$

### 4.3.3 Transverse Girder

a. Material specifications

- Profile: WF 800x300x14x22
- Cross-sectional area (A): 243.4 cm<sup>2</sup>
- Section modulus ( $Z_x$ ): 7040 cm<sup>3</sup>
- Moment of inertia ( $I_x$ ): 254000 cm<sup>4</sup>
- Steel yield strength ( $F_y$ ): 360 Mpa

b. Load calculation

Dead load per meter of girder: The dead load per meter of the girder is calculated by dividing the total dead load by the length of the rafter. Which is the dead load per meter of the girder is 5.9 kN/m

$$w_{dead\_girder} = \frac{w_{total} \times B}{L_{girder}}$$

$$w_{dead\_girder} = \frac{5.9 \text{ kN/m}^2 \times 12 \text{ m}}{12 \text{ m}} = 5.9 \text{ kN/m}$$

Live load per meter of girder: The live load per meter of the girder is calculated by dividing the total vehicle load by the length of the rafter. This means the live load per meter of the girder is 12.19 kN/m.

$$w_{live\_girder} = \frac{P_{vehicle}}{L_{girder}}$$

$$w_{live\_girder} = \frac{146.25 \text{ kN}}{12 \text{ m}} = 12.19 \text{ kN/m}$$

c. Moment and shear calculation

Maximum moment due to dead load: The maximum moment due to dead load is calculated using the moment formula for a supported beam with a distributed load. The maximum time due to dead load on the longitudinal girder is 106.5 kNm.

$$M_{dead} = w_{dead\_girder} \times \left( \frac{L_{girder}^2}{8} \right)$$

$$M_{dead} = 5.9 \text{ kN/m} \times \left( \frac{12^2}{8} \right) = 106.5 \text{ kNm}$$

Maximum moment due to live load: The maximum moment due to live load is calculated using the moment formula for a supported beam with a distributed load. The maximum moment due to the living load on the longitudinal girder is 219.42 kNm.

$$M_{live} = w_{live\_girder} \times \left( \frac{L_{girder}^2}{8} \right)$$

$$M_{live} = 12.19 \text{ kN/m} \times \left( \frac{12^2}{8} \right) = 219.42 \text{ kNm}$$

Total moment ( $M_u$ ): The total moment is the sum of the moments due to dead load and live load. The total moment acting on the longitudinal girder is 325.92 kNm.

$$M_u = M_{dead} + M_{live}$$

$$M_u = 106.5 \text{ kNm} + 219.42 \text{ kNm} = 325.92 \text{ kNm}$$

d. Section strength check ( $M_n$ )

Nominal moment ( $M_n$ ): The nominal moment is calculated by multiplying the section modulus with the steel yield strength. The nominal moment of the transverse girder is 2534.4 kNm.

$$M_n = Z_x \times F_y$$

$$M_n = 7040 \text{ cm}^3 \times 360 \text{ MPa} = 2534.4 \text{ kNm}$$

Factored moment strength ( $\phi M_n$ ): The factored moment strength is calculated by multiplying the nominal moment with the strength reduction factor. Assuming that strength reduction factor ( $\phi$ ) = 0.9. So, the factored moment strength of the longitudinal girder is 2280.96 kNm.

$$\phi M_n = 0.9 \times 2534.4 \text{ kNm} = 2280.96 \text{ kNm}$$

Check  $M_n$  &  $M_u$ : If the factored moment strength ( $\phi M_n$ ) is greater than the total moment ( $M_u$ ), indicating that the longitudinal girder design is safe, if it is not, planning calculations must be reviewed.

$$\phi M_n = 2280.96 \text{ kNm} > M_u = 325.92 \text{ kNm} \Rightarrow OK$$

#### 4.3.4 Bridge Loading

a. Dead load of concrete slab and asphalt

Weight of concrete slab ( $q_{D1}$ ): The weight of the concrete slab is a critical factor in the overall dead load of the bridge. It is calculated by multiplying the unit weight of concrete, 3120 kg/m<sup>3</sup>, by the gravitational acceleration (9.81 m/s<sup>2</sup>) to convert it to kN/m<sup>2</sup>. This gives us a concrete slab weight per square meter. The weight of the concrete slab per square meter is calculated to be 30.58 kN/m<sup>2</sup>. This value is significant as it contributes to the dead load that the bridge must support.

$$q_{D1} = 3120 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 = 30.58 \text{ kN/m}^2$$

Weight of asphalt ( $q_{D2}$ ): Similar to the concrete slab, the weight of the asphalt layer is calculated. The unit weight of asphalt is 715 kg/m<sup>3</sup>. We obtain the asphalt weight per square meter by multiplying this with the gravitational acceleration. The weight of the asphalt layer per square meter is 7.01 kN/m<sup>2</sup>. This is a crucial component of the dead load calculation for the bridge deck.

$$q_{D2} = 715 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 = 7.01 \text{ kN/m}^2$$

Weight of sidewalk slab: The weight of the sidewalk slab is calculated similarly, considering its unit weight. The weight of the sidewalk slab is calculated to be 30.58 kN/m<sup>2</sup>, contributing to the overall dead load of the bridge.

$$q_{sidewalk} = 3120 \text{ kg/m}^2 \times 9.81 \text{ m/s}^2 = 30.58 \text{ kN/m}^2$$

Pedestrian load: The pedestrian load is considered by calculating the weight per square meter. The pedestrian load is calculated as 24.53 kN/m<sup>2</sup>. This load is essential for ensuring the bridge can safely support pedestrian traffic.

$$q_{sidewalk} = 2500 \text{ kg/m}^2 \times 9.81 \text{ m/s}^2 = 24.53 \text{ kN/m}^2$$

#### b. Live load

Uniformly Distributed Load (UDL): The uniformly distributed load (UDL) represents the load distributed uniformly across the bridge deck. This is a standard live load considered in bridge design. The uniformly distributed live load is 5.85 kN/m<sup>2</sup>. This load simulates the typical loads the bridge will encounter during its use.

Concentrated Live Load: The concentrated live load represents localized loads, such as vehicles, that the bridge must support. Narration: The concentrated live load is calculated to be 127.4 kN/m. This load is critical for ensuring that the bridge can support heavy, localized loads such as vehicles.

#### c. Wind load

Arch wind load: The wind load acting on the arch is 76.8 kN, ensuring the bridge can withstand lateral forces due to wind. The suction wind load is calculated to be 38.4 kN, which accounts for the uplift forces due to wind.

Wind Load on Vehicles: The wind load on vehicles is 2.628 kN/m. This load ensures the bridge can handle wind forces acting on vehicles crossing it.

#### d. Seismic load

Seismic Response Coefficient (C<sub>s</sub>): The seismic response coefficient is directly as C<sub>s</sub> = 0.0699. Which indicates the expected seismic force levels based on the location and conditions. Base Shear in X Direction: The base shear force in the X direction is 996.8 kN, with a factored shear force of 847.28 kN. These values ensure the bridge can withstand seismic forces along the X-axis.

$$V_{static, x} = 996.8 \text{ kN}$$

$$\phi V_{static, x} = 847.28 \text{ kN}$$

Base Shear in Y Direction: The base shear force in the Y direction is 664.5 kN, with a factored shear force of 564.8 kN. These values ensure the bridge can withstand seismic forces along the Y-axis.

$$V_{static, y} = 664.5 \text{ kN}$$

$$V_{static, y} = 564.8 \text{ kN}$$

Dynamic Seismic Load Control in X Direction: The dynamic seismic load in the X direction is 2824.27 kN, significantly higher than the static load, indicating the bridge design is robust against seismic forces.

$$V_{dynamic, x} = 2824.27 \text{ kN}$$

$$V_{static, x} < V_{dynamic, x} = 996.8 \text{ kN} < 2824.27 \text{ kN} \Rightarrow OK$$

Dynamic Seismic Load Control in Y Direction: The dynamic seismic load in the Y direction is 2215 kN, indicating the bridge design can safely handle seismic forces along the Y-axis.

$$V_{dynamic, y} = 2215 \text{ kN}$$

$$V_{static, y} < V_{dynamic, y} = 664.5 \text{ kN} < 2215 \text{ kN} \Rightarrow OK$$

## 5. Conclusion

This research aimed to develop a simulation model for designing a tied-arch bridge in Indonesia's new capital, Ibu Kota Nusantara (IKN), integrating structural durability, environmental sustainability, and aesthetic considerations. The primary findings indicate that the proposed bridge design can effectively withstand dynamic and static loads, ensuring safety and functionality. By utilizing SAP2000 software for detailed structural analysis, the study contributes to existing literature by providing a robust framework for bridge design in challenging environments. However, the research is limited by the availability of real-world data and potential variations in environmental conditions. Future research should incorporate real-time data and explore innovative materials and technologies to enhance the bridge's resilience and sustainability. The findings offer practical guidance for stakeholders and support the vision of IKN as a sustainable and iconic capital city, promoting economic growth and connectivity.

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