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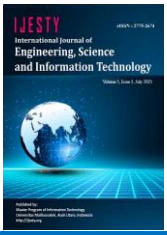

Design of Semujur Bridge with Diagonal Steel Box Arch Bridge

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Abstract

Transportation is an integral part of social life. One of the structures that can support transportation is the bridge. The construction of the Semujur Bridge will be planned to meet and support transportation needs. This bridge is expected to be a new connecting bridge to cut travel time in Pangkal Pinang City. Semujur Bridge, with a width of 20 meters and a total length of 100 meters, is planned to use a steel arch bridge because the arch bridge can reduce the bending moment on the bridge. The bridge uses a box girder cross-section because the arch bridge with a steel box cross-section is considered more economical and has higher flexural strength and torsional stiffness. Semujur Bridge will also have a diagonal arch. With the new construction design, it is expected to be a structurally strong bridge, both against earthquake loads and bridge dynamic loads. As a result, in this study, it was found that the longitudinal girder WF 600x300x14x23, transverse girder GIRDER 1500x400x30x30, tie beam BOX GIRDER2500x2000x40x40, and Macalloy 520 (M100) hanging cable with a diameter of 97 mm.

Keywords: *Box Girder, Girder, Arch Bridge, Diagonal Arch Bridge.*

1. Introduction

In the current era of globalization, transportation is an integral part of social life. Most aspects of people's lives today require transportation activities. According to KBBI, transportation can be defined as transporting or moving people or goods by various vehicles with technological advances from one place to another. To support this, the central aspect that supports the transportation process is infrastructure, such as roads, bridges, and others [1]. Transportation as an essential sector always requires renewal to continue to improve the safety, security, and comfort of transportation services for its users [2].

A bridge is a structure built to cross or pass over a lower obstacle, such as a strait, river, railroad, or highway. Bridges have a variety of design forms, materials, and functions [3]. With the increase in human activities as well as meeting and supporting transportation needs, the construction of the Semujur Bridge will be planned [4]

In addition to being an iconic architectural bridge in Pangkal Pinang City, the Semujur Bridge is considered strategic because it can cut travel time and become a new connecting bridge in Pangkal Pinang City. Pangkal Pinang City planned the construction of the Semujur Bridge to advance the area around the bridge, which is less developed and underdeveloped, and the Pangkal Pinang City wants to make the area a tourist area.

The Semujur Bridge, with a width of 20 meters and a total length of 100 meters, is planned to use a steel arc bridge because the arc bridge can reduce the bending moment on the bridge compared to a regular girder bridge [5].

According to [6], an effective steel arc bridge for a span of 100 meters uses a steel box section because arc bridges with steel box sections are considered more economical and have higher flexural strength and torsional stiffness than frame sections. In addition, from an architectural point of view, the arc bridge with a steel box section has a higher value and can become an iconic bridge [7].

Considering the subgrade and river conditions on the Semujur River, the arc bridge planning will use the vehicle floor below. Semujur Bridge will also be designed with a diagonal arc. With the new construction design, it is expected to be a structurally strong bridge, both against earthquake loads and bridge dynamic loads.

2. Methods

2.1. Arch Bridge

A bridge is valuable for continuing a road over a lower obstacle. This obstacle can be in the form of a road over water or a regular traffic road) The bridge consists of the lower part (substructure) and the upper part (superstructure). The lower part of the bridge bears or supports the upper part and passes the load of the upper part along with the traffic load to the subgrade. The type of bridge that is often used is the arc bridge [3].

In general, the arch bridge is a semicircular arch bridge with abutments on both sides. The arch bridge is a bridge that includes good bridge construction because the arc construction can provide a horizontal reaction due to the vertical load that works. It can reduce the bending moment on the bridge more efficiently than parallel girders [8]. Semujur Bridge is planned using the diagonal arch method with a steel box with a vehicle floor type below (Through Arch). A special steel box arc bridge review is needed to design the Semujur bridge.

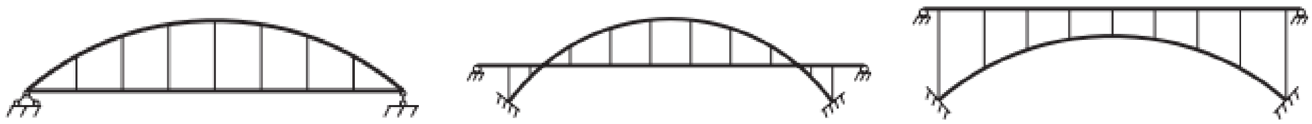

Fig 1. Type of arch bridge [9]

This type of arc bridge has the location of the vehicle floor above, which directly supports the traffic load and is at the top of the arc. This type of bridge is often used and is ideal for crossing valleys with rock soil types on the walls. The type of arc bridge with the vehicle floor below or where the vehicle is located right at the arc spring line. This type of arc bridge can reduce the horizontal thrust received by the arch and distribute it to the bridge girders. Therefore, it can result in a smaller bridge foundation. This type of arc bridge has the vehicle floor in the middle of the location of the vehicle floor between the spring line and the middle of the bridge arc. This type of arc bridge is the type that works better than other types [9].

2.2. Curved Bars

When viewed from the transverse direction, the arch bridge's curved bars generally consist of 2 parallel arcs placed respectively on the sides of the bridge. However, many modern bridges modify this shape to add to the aesthetic value of the bridge [10]. The types of curved bars can be seen in Figure 2.

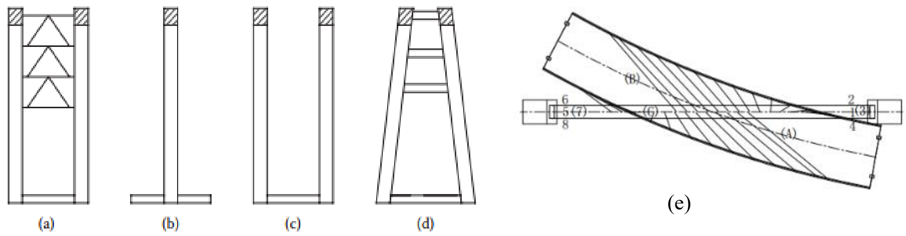

Fig 2. Type of arch bridge [10]

Several types of curved rods from bow bridges have been built today. Here are the kinds of curved rods from bow bridges: Parallel Rod, Single Rod, Open Parallel Rod, Non-Parallel Rod, and Diagonal Rods. Arch bridges that are often built are bridges with parallel bars. However, some bridges are built with a single rod or as an open parallel rod without bracing for a through or a half-through bridge. The bow bridge must sometimes have sufficient stiffness or increase lateral stability by using a rigid hanger with the vehicle floor to form a half frame in the transverse direction. Bow bridges are also built tilted inward, called non-parallel bars [11]. In addition, there are also special arc bridges with diagonal arcs. This bridge is rare because it requires more complex force analysis [12].

3. Methods

The methodology used in this study is to simulate the bridge model with a Diagonal Steel Box Arch Bridge. The model was made using a structural analysis program called MIDAS Software. The methodology can be seen in Figure 3.

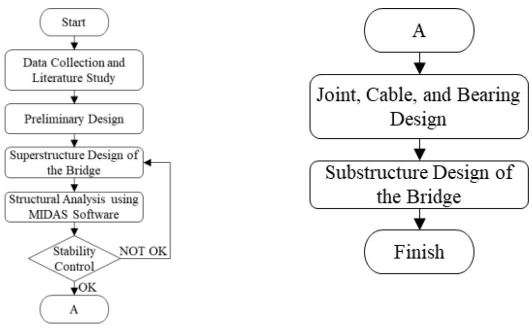

Fig 3. Methodology

1. SNI 1725-2016, Loading for Bridges.
2. SNI 1729-2015, Specification for Structural Steel Building.
3. SNI 2833-2016, Earthquake Resistance Planning Standards for bridges.
4. SNI 1726-2019, Procedures for earthquake resistance planning for building and non-building structures

4. Result and Discussion

4.1. Bridge Technical Data

The Semujur Bridge, located in Pangkal Pinang City, is a diagonal steel arch bridge known for its sturdy design and architectural appeal. The bridge is designed to accommodate significant traffic flow, spanning a length of 100 meters and a width of 2 x 10 meters. Its underbuilding structure consists of two abutments, providing essential support and stability. The bridge's design and foundation are well-suited to the local soil conditions, ensuring durability and long-term performance. Top and side views can be seen in Figure 4.

Fig 4. Top and Side View of The Semujur Bridge

4.2. Bridge Loading

4.2.1. Permanent Loads

Permanent loads consist of material-specific gravity, self-weight, and additional dead load. Material-specific gravity for dead load is based on SNI 1725-2016 Article 7.1. Self-weight is the weight of the bridge's parts or other structural elements; nonstructural elements are considered fixed. Self-weight is based on SNI 1726-2016 Article 7.2. Additional dead load is the weight of all materials that form a load on the bridge, which is a nonstructural element, and its magnitude can change during its lifetime.

4.2.2. Traffic Loads

Traffic loads for bridge planning consist of "D" lane loads and "T" truck loads. The "D" lane load acts on the entire width of the vehicle lane and exerts an influence on the bridge equivalent to an actual motorcade. The total amount of lane load "D" acting depends on the width of the vehicle lane itself.

1. "D" lane loads
   According to SNI 1725-2016 Article 8.3, lane load "D" consists of evenly divided load (BTR) and line load (BGT).
   a. Divided load (BTR)
      According to SNI 1725-2016 Article 8.3.1, the equally divided load (BTR) has an intensity of q kPa with the amount of q depending on the total loaded length L can be seen in Equations 1 and 2:
      If $L \leq 30$ m: $q = 9$ kPa ……………………………………………………………………………..(1)
      If $L > 30$ m: $q = 9 \cdot (0{,}5 + 15/L)$ kPa …………………………………………………………………..(2)
      Where:
      q is the intensity of divided load (BTR) in the longitudinal direction of the bridge (kPa)
      L is the total length of the loaded bridge (meter)
   b. Line load (BGT)
      According to SNI 1726-2016 Article 8.3.1, the centered line load (BGT) with intensity p kN/m must be placed perpendicular to the direction of traffic on the bridge. The intensity p is 49.0 kN/m. An illustration of the "D" lane load can be seen in Figure 5.

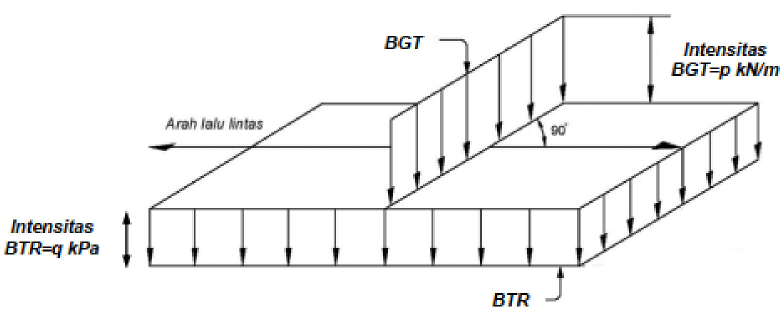

Fig 5. Illustration of "D" lane loads

2. "T" truckloads
   There is another traffic load, the "T" truckload. According to SNI 1725-2016 Article 8.4, truckload "T" cannot be used together with load "D." Truck loads can be used for floor structure calculations. An illustration of the "T" truckload can be seen in Figure 6.

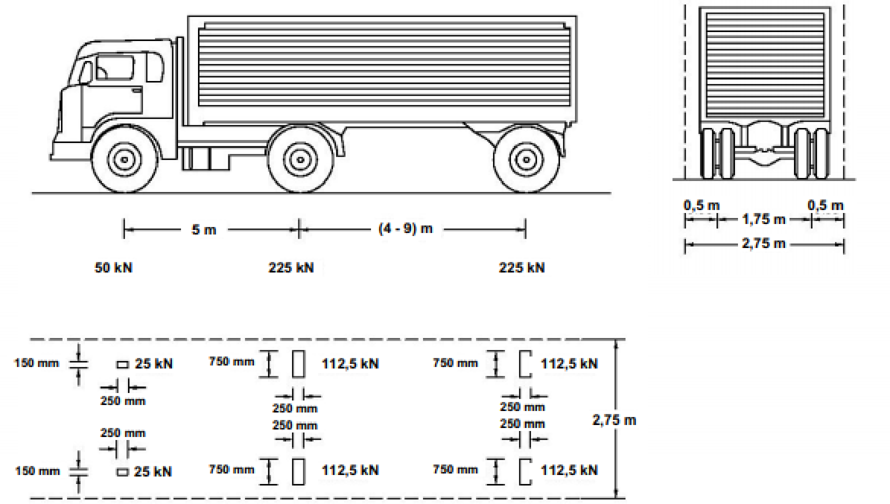

Fig 6. Illustration of "T" truckloads

3. Brake Force (TB)
   According to SNI 1725-2016 Article 8.7, the brake force shall be taken as the largest of :
   a. 25% of the design truck axle weight or,
   b. 5% of the plan truck weight plus the load of the equally divided lane (BTR).
   The brake force shall be applied to all loaded plan lanes containing traffic in the same direction. This force shall be assumed to act horizontally at a distance of 1800 mm above the road surface in each longitudinal direction and shall be selected as the most decisive.
4. Pedestrian loading (TP)
   According to SNI 1725-2016 Article 8.9, all sidewalk components wider than 600 mm must be planned to carry pedestrian loads with an intensity of 5 kPa and are considered to work simultaneously with vehicle loads in each vehicle lane.

4.2.3. Environmental Burden

1. Temperature Load
   According to SNI 1725-2016 Article 9.3.1, deformation due to uniform temperature changes can be calculated using the procedure described in this article. This procedure can be used for bridge planning using girders made of concrete or steel. The difference between the minimum or maximum temperature and the nominal temperature assumed in the planning shall be used to calculate the deformation effect due to the temperature difference. The minimum and maximum temperatures shall be used as Tmindesign and Tmaxdesign.
   The deformation range due to temperature load (Δ_T) shall be based on the maximum and minimum temperatures defined in Equation 3.

$$\Delta_T = \alpha L \left(T_{max\ design} - T_{min\ design}\right) \quad \text{…(3)}$$

   Where:
   L is the length of the bridge component (mm)
   α is the coefficient of temperature expansion (mm/mm/ºC)

2. Wind Load
   The wind pressures specified in this article are assumed to be caused by a planned wind with a basic velocity (VB) of 90 to 126 km/h. Wind loads shall be deemed to be uniformly distributed on surfaces exposed to the wind. The area considered is the area of all components, including flooring and railing systems, taken perpendicular to the wind direction. This direction should be varied to obtain the most harmful effect on the bridge structure or its components. Areas that do not contribute can be ignored in the planning.

$$V_{DZ} = 2{,}5\, V_o \left(\frac{V_{10}}{V_B}\right) \ln\left(\frac{Z}{Z_o}\right) \quad \text{.....(4)}$$

   Where:
   V_{DZ} = Plan wind speed at plan elevation (km/h)
   V_{10} = Wind speed at Elevation 10 m above ground level or plan water level (km/h)
   V_B = Plan wind speed of 90-126 (km/h)
   V_o = Wind friction speed depending on bridge conditions (km/h)
   Z = Elevation of the structure measured from the ground or water surface where wind loads are considered (mm)
   Z_o = Friction length upstream of the bridge (mm)
3. Earthquake Load
   Bridges should be planned to have a low probability of collapse but can suffer significant damage and disruption to service due to earthquakes. Partial or complete replacement of the structure is required in some cases. The competent authority may specify higher performance, such as operational performance.

4.2.3. Combination Loads

The load combination used according to SNI 1726-2019 is as follows:
1. Strong 1: 1.1 MS + 2MA + 1.8 LL + 1EUn
2. Strong 2: 1.1 MS + 2MA + 1.4 LL + 1EUn
3. Strong 3: 1.1 MS + 2MA + 1.4 Ews + 1EUn
4. Strong 4: 1.1 MS + 2MA + 1EUn
5. Strong 5: 1.1 MS + 2MA + 0.4 Ews + 1EUn
6. Extreme 1: 1.1 MS + 2MA + 0.5 LL + 0.3 Eqx + 1 Eqy
7. Extreme 2: 1.1 MS + 2MA + 0.5 LL + 1 Eqx + 0.3 Eqy
8. Serviceability 1: 1MS + 1MA + 1 LL + 1EWs + 1EUn
9. Serviceability 2: 1MS + 1MA + 1.3 LL + 1EUn
10. Serviceability 3: 1MS + 1MA + 0.8 LL + 1EUn
11. Serviceability 4: 1MS + 1MA + 0.7 Ews + 1Eun

4.3. Superstructure Design

Superstructure design is calculated based on the loading found on the bridge. The upper structure of the bridge is considered as Floor Slab, Longitudinal Girder, Transverse Girder, and Wind Ties.

4.3.1. Floor Slab

Calculating moments due to "D" or "T" load and dead load on the vehicle floor using the auxiliary program analysis obtained the results in Figure 7.

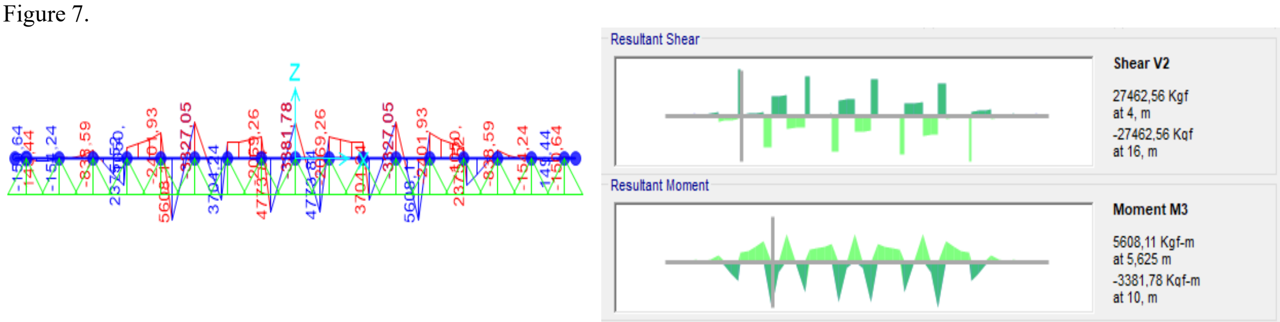

Fig 7. Moment in Floor Slab

Force
   Mu Minimum = -3381.78 ton.m
   Mu Maximum = +5608.11 ton.m
Dimension
   Slab Thickness = 250 mm
   Asphalt thickness = 50 mm
Floor Slab Moment Reinforcement
   ρ = 0.002
   As = 450 mm^2
   D10-150 mm reinforcement is used

Floor Slab Shrinkage Reinforcement

AS = 384 mm^2

D10-200 mm reinforcement is used

Shear Pons Control

ØVc ≥ Vu

554.6 kN > 292.5 kN (OK)

3.3.2. Longitudinal Girder

Force

Mu = 41.38 ton.m

Vu = 18.2 ton

Profile

WF 600x300x14x23

Moment Capacity

Ø Mn ≥ Mu

108.37 ton.m > 41.38 ton.m (OK)

Shear Capacity

Ø Vn ≥ Vu

107.78 ton > 18.19 ton (OK)

Deflection Control

δallowable ≥ Deflection due to "T" Load

0.625 cm > 0.141 cm (OK)

4.3.3. Transverse Girder

Force

Mu = 1204.18 ton.m

Vu = 214.72 ton

Profile

Girder 1500x400x30x30

Moment Capacity

Ø Mn ≥ Mu

1436.65 ton.m > 1204.18 ton.m (OK)

Shear Capacity

Ø Vn ≥ Vu

583.2 ton > 214.72 ton (OK)

Deflection Control

δallowable ≥ Deflection due to "T" Load

2.5 cm > 1.44 cm (OK)

4.3.4. Wind Ties

Force

Pu = 13.52 ton

Profile

L 175x175x15

Moment Capacity

Ø Pn ≥ Pu

17.85 ton > 13.52 ton.m (OK)

4.4. Structure Analysis

Bridge modeling using MIDAS software. The loading is inputted in the MIDAS software. For modeling can be seen in Figure 8.

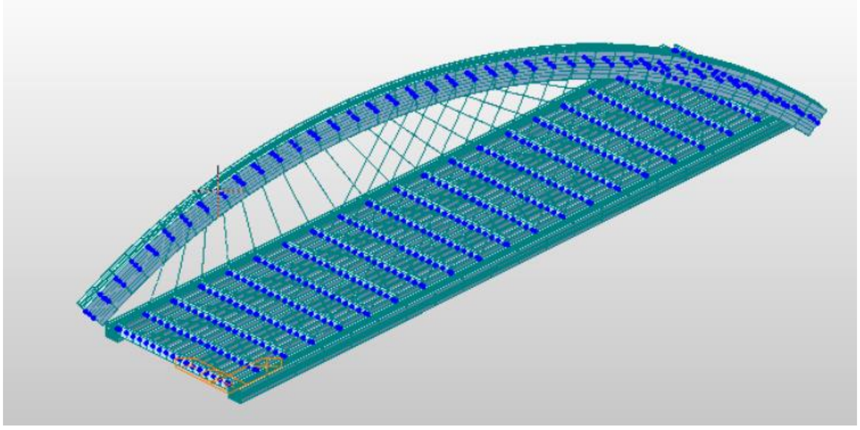

Fig 8. Structure Analysis with MIDAS Software

The results of the structural analysis under combined loading conditions, conducted using MIDAS software, will yield internal forces such as axial forces, shear forces, and bending moments. These forces will be the primary basis for determining the appropriate dimensions and reinforcement requirements of structural elements, specifically, the tie beams and arches, to ensure they meet strength and serviceability criteria following relevant design standards.

4.4.1. Tie Beam

The box girder tie beam profile uses Box Girder 2000x2000x40x65 with stiffeners using BJ-37 steel grade, which has cross-sectional parameters, as shown in Figure 9.

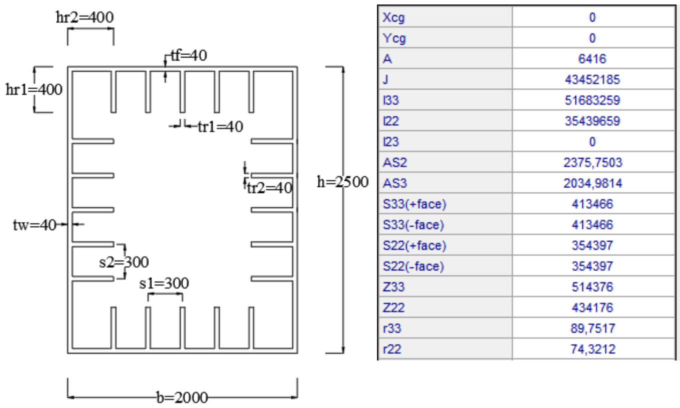

Fig 9. Tie Beam Box Girder 2000x2000x40x65

Table 1. Tie Beam Box Girder Control Capacity

Loads		Ultimate	Capacity	Status
Axial	Tension (kN)	22403.98	135952.5	OK
	Compression (kN)	22403.98	132560	OK
Shear	X-Way (kN)	7614.91	10594.8	OK
	Y-Way (kN)	1640.43	8475.84	OK
Moment	X-Way (kN.m)	18151.54	108944.2	OK
	Y-Way (kN.m)	65140.85	92000.16	OK
Torsi (kN.m)		8877.17	47414.29	OK

4.4.1. Box Girder

The box girder arch profile uses Box Girder 2500x4000x40x40 with stiffeners using BJ-37 steel grade which has cross-sectional parameters as shown in Figure 10.

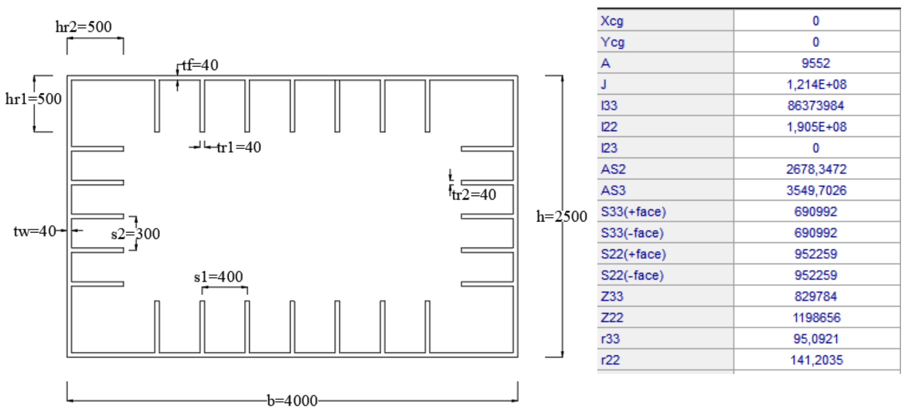

Fig 10. Box Girder 2500x4000x40x40

Table 2. Arch Bridge Box Girder Control Capacity

Loads		Ultimate	Capacity	Status
Axial	Tension (kN)	61600.62	202403.1	OK
	Compression (kN)	61600.62	197897.6	OK
Shear	X-Way (kN)	6154.33	10594.8	OK
	Y-Way (kN)	5710.17	16951.68	OK
Moment	X-Way (kN.m)	90476.16	175827.9	OK
	Y-Way (kN.m)	42895.4	2539904.1	OK
Torsi (kN.m)		56193.44	95828.3	OK

4.5 Stability Control

In planning a bridge, one of the main requirements that must be met is that the deflection must not exceed the required allowable deflection.

Deflection Allowable

δallowable = L/1000 = 10 cm

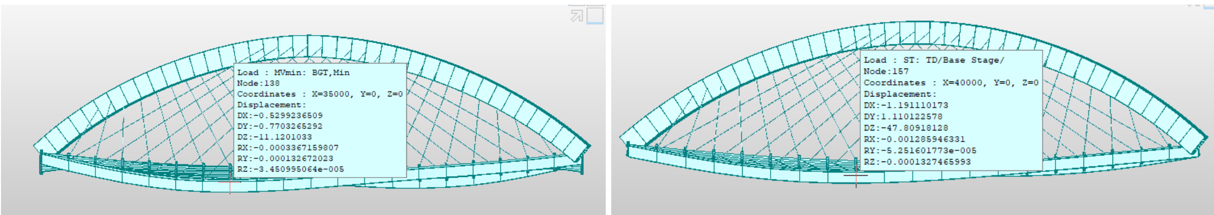

Fig 11. Deflection due to “D” Load

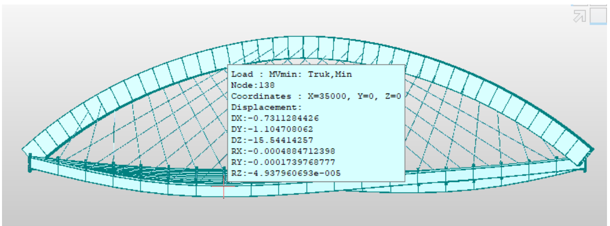

Fig 12. Deflection due to “T” Load

Deflection

Deflection due to “D” Load = 5.89 cm ≤ δallowable = 10 cm (OK)
Deflection due to “T” Load = 1.55 cm ≤ δallowable = 10 cm (OK)

4.6 Joint, Cable, and Bearing Design

4.6.1. Joint

Longitudinal Girder to Transverse Girder Connection

Connection bolt diameter	= 16 mm
Bolt area	= 201.06 mm^2
Hole diameter	= 16 + 2 = 18 mm
Bolt quality	= A325 (Fnv = 4570 kg/cm^2)
Connector Plate	= L100x100x10
Number of Bolts	= 5 pieces

Transverse Girder to Box Girder Tie Beam Connection

Connection bolt diameter	= 24 mm
Bolt area	= 452.34 mm^2
Hole diameter	= 24 + 2 = 26 mm
Bolt quality	= A325 (Fnv = 4570 kg/cm^2)
Connector Plate	= L250x250x25
Number of Bolts	= 20 pieces

Wind Ties Connection

Connection bolt diameter	= 16 mm
Bolt area	= 201.06 mm^2
Hole diameter	= 16 + 2 = 18 mm
Bolt quality	= A325 (Fnv = 4570 kg/cm^2)
Connector Plate	= L175x175x15
Number of Bolts	= 4 pieces

Box Girder Tie Beam Connection

Connection bolt diameter	= 36 mm
Bolt area	= 1017.88 mm^2
Hole diameter	= 36 + 2 = 38 mm
Bolt quality	= A325 (Fnv = 4570 kg/cm^2)
Connector Plate	= 30 mm (2 Shear Planes)
Number of Bolts	= 50 pieces for Web Plates and 112 Pieces for Wing Plates

Cable Connection

Connection bolt diameter	= 32 mm
Bolt area	= 804.25 mm^2

Hole diameter = 32 + 2 = 34 mm
Bolt quality = A325 (Fnv = 4570 kg/cm^2)
Connector Plate = 30 mm (2 Shear Planes)
Number of Bolts = 12 pieces

Box Girder Arch Bridge Connection
Connection bolt diameter = 36 mm
Bolt area = 1017.88 mm^2
Hole diameter = 36 + 2 = 38 mm
Bolt quality = A325 (Fnv = 4570 kg/cm^2)
Connector Plate = 30 mm (2 Shear Planes)
Number of Bolts = 144 pieces for Web Plates and 108 Pieces for Wing Plates

3.6.2. Cable

In the calculation of the cable force, the worst simulation is also carried out if one of the cables breaks (fails). The following is an analysis of the cable style according to the simulation performed. Case 1 (All Cables Working), Case 1 is controlled when all cables are working. Case 2 (Center Cable Broken), Case 2 is controlled if the center cable is broken. Case 3 (Long End Cable Broken), Case 3 is controlled when the long end cable is broken. Case 4 (Short End Cable Broken), Case 4 is controlled when the short end cable is broken.

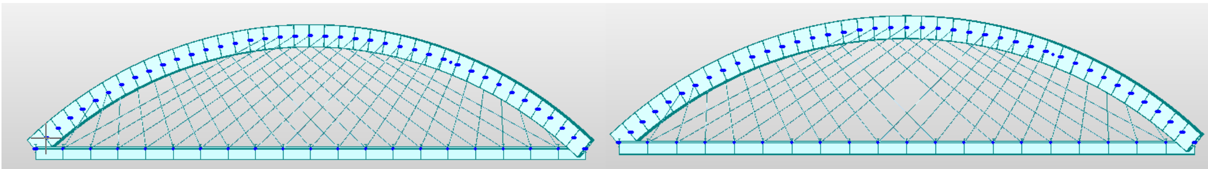

Fig 13. Case 1 (Left) and Case 2 (Right)

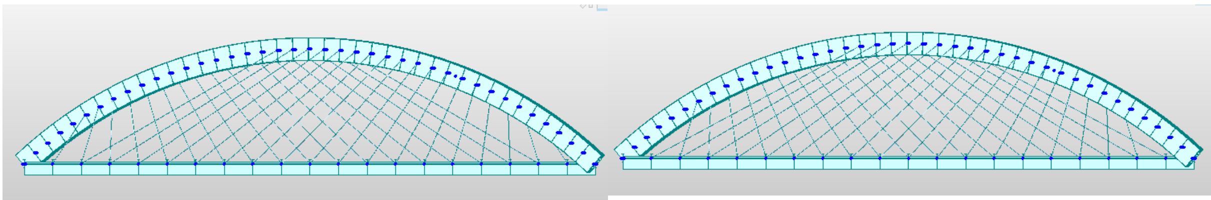

Fig 14. Case 3 (Left) and Case 4 (Right)

In the Semujur Bridge design, tension rods and hanging cables are used, Macalloy production is the Macalloy 520 (M90), and carbon steel is used, as shown in Fig.

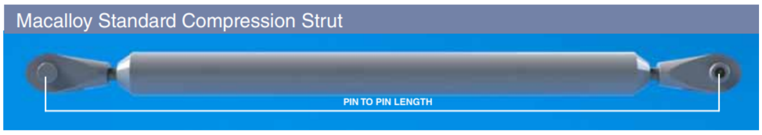

Fig 15. Macalloy 520 Hanging Cable

Hanger data
Ø rod = 97 mm
W of cable = 46.7 kg/m
V total = RA Total + Hanger Self Weight = 125.73 + 238.53 + 1.28 = 365.54 tons
Hanger Strength Control
Vtotal = 365.54 tons < Minimum Break Load = 463.9 tons (OK)

3.6.3. Bearing

The bearings used for the vehicle floor on this bridge are pins and roll joints. This bearing is designed to withstand horizontal and vertical loads due to the loads acting on the bridge. The planning of the vehicle floor platform is illustrated in Figure 16.

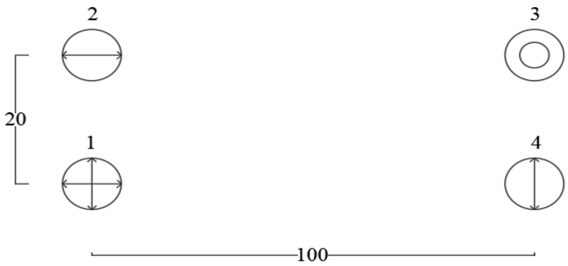

Fig 16. Bearing Design

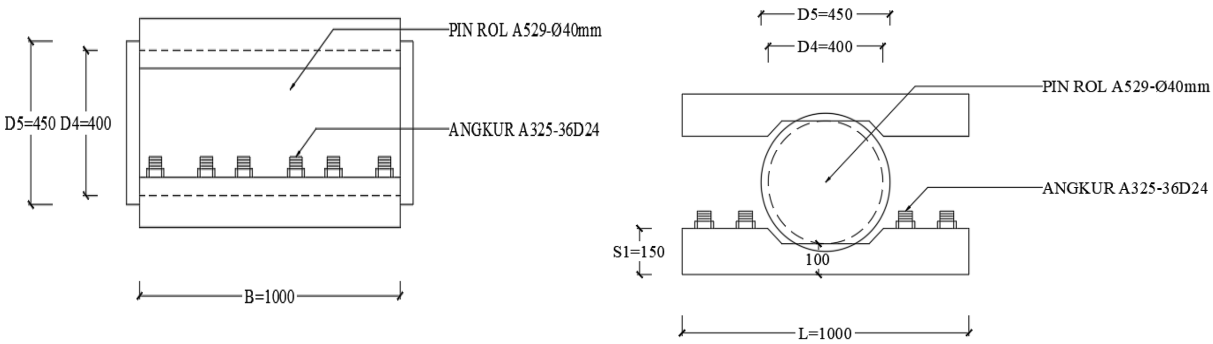

Fig 17. Roll Joint

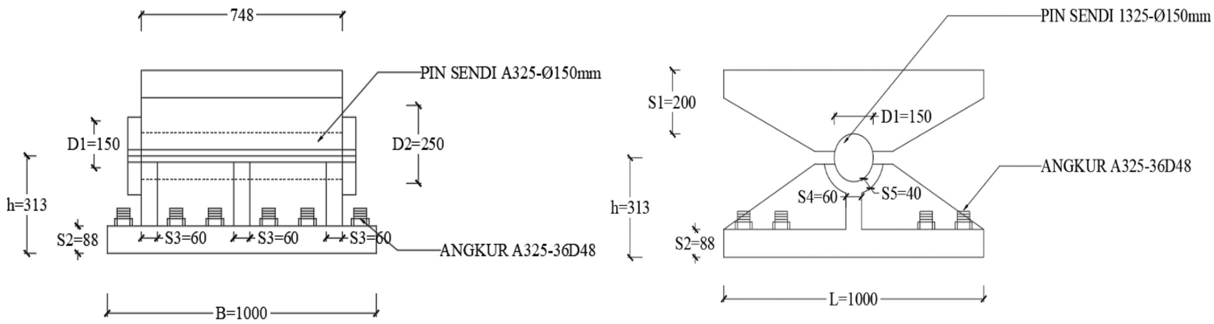

Fig 18. Pins Joint

3.7. Substructure Design

The soil bearing capacity is calculated by first processing N-SPT data obtained from soil data. After obtaining N-SPT Correction, soil bearing capacity is calculated using the Terzaghi & Peck formula. The piles are 120 cm in diameter with a cross-sectional area of 113.097 cm^2 of 30 MPa concrete.

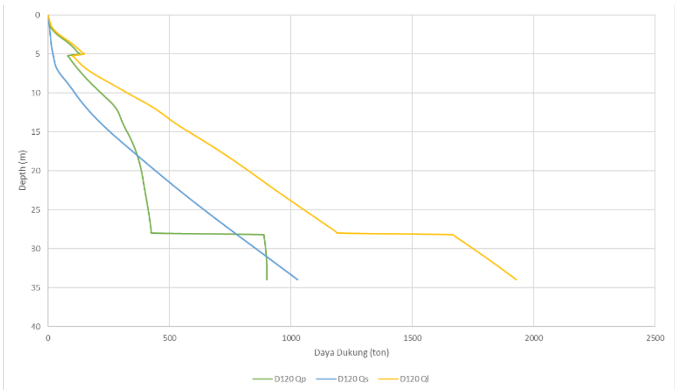

Fig 18. Bearing Capacity Bored Pile 120 cm

Based on the soil bearing capacity calculation results, the dimensions and specifications of the structural elements were obtained as follows. The pilecap is planned to have a length and width of 18 meters each with a thickness of 1.5 meters. 36 planted piles support this foundation system to support the building load evenly. To strengthen the pilecap, top and bottom reinforcement with 36 mm diameter reinforcing steel (D36) specifications is used, and 150 mm between bars is installed in the X and Y directions. This design aims to ensure the rigidity and stability of the structure in resisting vertical and lateral loads following the available soil-bearing capacity.

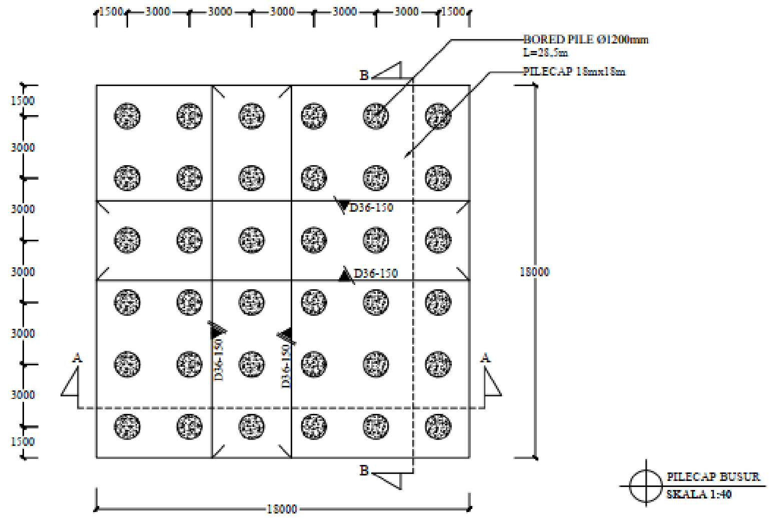

Fig 19. Pilecap for The Bridge

4. Conclusion

Based on the overall results of the analysis that has been carried out in the design of the Semujur Bridge with a diagonal steel box bridge, the following conclusions can be drawn:

1. The span of Semujur Bridge is 100 m long and 20 m wide. Vehicle floor width 14 m for four vehicle lanes @3.5 m and sidewalk width @3 m on each side.
2. Based on the calculation of the superstructure of the arc bridge, obtained:
   a. The vehicle floor plate uses f'c 35 MPa concrete with a thickness of 0.25 m with reinforcement for negative moments using D13-300, reinforcement for positive moments using 1241 mm2 cross-sectional area bondeks, reinforcement for shrinkage using D10-200 and asphalt with a thickness of 0.05 m.
   b. Longitudinal girder using BJ37 steel with profile WF600x300x14x23
   c. Transverse girder using BJ37 steel with GIRDER1500x400x30x30
   d. Tie beam using BJ37 steel with BOXGIRDER2500x2000x40x40 with longitudinal stiffeners and transverse stiffeners.
   e. Hanging cables using Macalloy 520 (M100) with a diameter of 97 mm and a minimum break load of 4551 kN.
3. Modeling of arch bridge structure using MIDAS Software.
4. Cross section of the arc using BJ37 steel with BOXGIRDER2500x4000x40x40 with longitudinal and transverse stiffeners.
5. The joint for the Arch Bridge uses pins joint, and the Vehicle Floor uses pins and roll joint.
6. The substructure uses an 18 m x 18 m pilecap with a thickness of 1.5m and uses 36 bored piles with a 1.2m, 22 m deep diameter.

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