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Analysis of Control Behaviour of Arch on Through Arch Bridge Construction

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ABSTRACT

Bridges are structures that need to be well-planned to function optimally. Bridges come in various shapes and sizes, one of them is an arch bridge. Through this thesis preparation the author tried to plan the upper structure of a bridge with an arch type on Tukad Ayung Bridge. The initial planning data includes a length of the existing bridge of 64 m and a width of 15 m. The planning method using LRFD and SAP2000 for the software. The arch rib dimensions in the planning of the through arch steel bridge on Tukad Ayung is 900.600.30.40 box profile with a cross-sectional height. It is using steel material of special type of structural steel for bridges with ASTM A 709 grade 50 specifications. From the analysis result, the stress melting point is fy= 345 MPa and the modulus of elasticity steel is E= 200000 MPa. The cross-sectional height is 900 mm, cross-sectional width is 600 mm, the body thickness (tw) is 30 mm and the wing thickness (tf) is 40 mm.

Keywords: Bridge; Through Arc Bridg; Steel Frame Bridge; Upper Building Structure

1 Introduction

Bridges are structures that need to be well-planned to function optimally [1]. As infrastructure, bridges must be designed to meet technical requirements in terms of safety so that the bridge structure can be used safely and provide a sense of security for its users [1]. One factor that can provide a sense of safety and comfort for users is the composition material of a bridge.

In general, the materials used in bridges are concrete and steel. The selection of materials is based on ease of technical construction processes, material durability, and economic considerations [2]. Using steel as the main material in making bridges has advantages that other common structural materials do not have. It is because steel has strength to withstand heavy loads, strong tensile, good ductility, and faster construction time so that it can be used to build long bridges and reduce the needs for bridge pillars in rivers [3].

Tukad Ayung Bridge is a bridge located on Gatsu Timur Street, Denpasar City which connects the Cokroaminoto intersection with the Ayung intersection. This bridge has a length of 64 meters and a width of 15 meters. Through this study, the author tried to plan the construction of Tukad Ayung Bridge using an arch bridge structure. The arch shape itself is intended to reduce bending moments on the bridge so that material usage becomes more efficient. In addition, arch bridges have more architectural value than other types of bridges with different structural types.

2 Data and Methods

This bridge design project is located on Gatot Subroto (Gatsu) Timur Street, Denpasar Timur District, Denpasar City, Bali Province. This bridge has a length of 64 meters and a width of 15 meters. The first thing of planning a through arch steel frame bridge on Tukad Ayung, Denpasar carried out by collecting data. The method used in collecting data are the literature study and observation method. Next, the plan drawing and initial selection of profiles for each structural component are made by searching brochures, assumptions, and trials (Preliminary Design). Structural modelling is using SAP2000 software. Calculation of the magnitude of loads refers to SNI 1725:2016 and SNI 2833:2016 which are then input into SAP2000. software and adjusted to planning needs. If there is a factored load combination, then the forces in each cross-section (Mu, Vu, Pu) caused by the load need to be summarized. After that, performing control deflection and making the drawing structure. It can be seen in Figure 1. General Planning Flowchart.

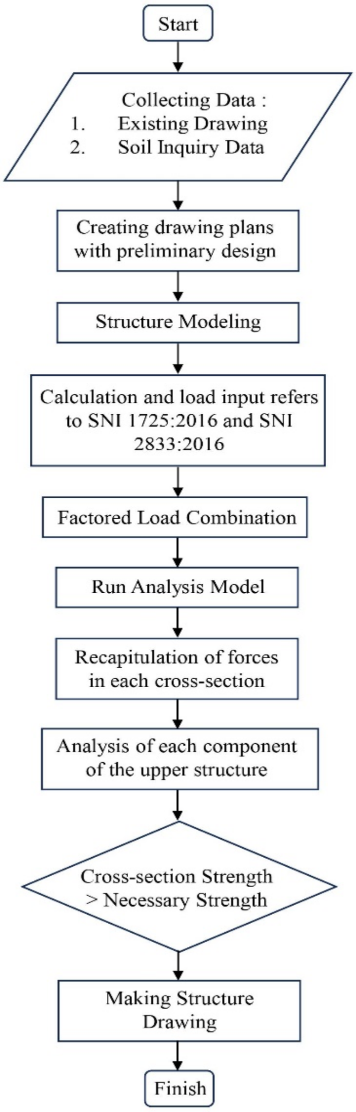

Figure 1. General Planning Flowchart

2.1 Structural Dimensioning

The dimensions of each structural element used in the planning of the through arch steel bridge was obtained from preliminary design and by trial. The arch rib dimensions in the planning of the through arch steel bridge on Tukad Ayung is 900.600.30.40 box profile with a cross-sectional height.

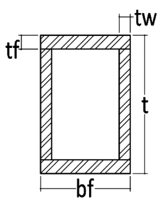

Figure 2. Arch Rib Cross Section

2.2 Upper Structure Model

The The planning of the Through Arch Bridge-Steel Arch Bridge on Tukad Ayung uses structural steel as the main material in the upper structure. The type of steel material used in this planning is a special type of structural steel for bridges with ASTM A 709 grade 50 specifications produced by PT. Gunung Raja Paksi Tbk.

The upper structure modelling in the planning of the Through Arch Bridge-Steel Arch Bridge on Tukad Ayung is modelled to match the plan drawing so that the force transfer resembles the actual condition. The 3D results from the draw model in this bridge planning are according to Figure 3.

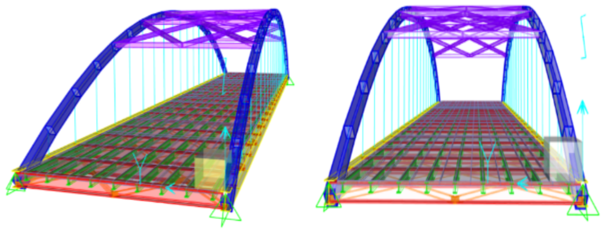

Figure 3. Upper Structure Model in 3D

The top view and floor plan of the planning of this arch bridge are according to Figure 4 and Figure 5.

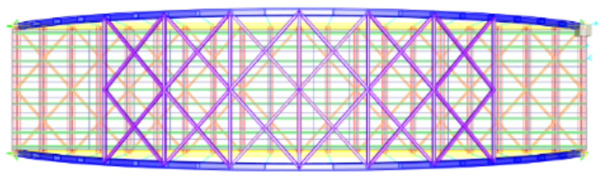

Figure 4. Top View of the Arch Bridge

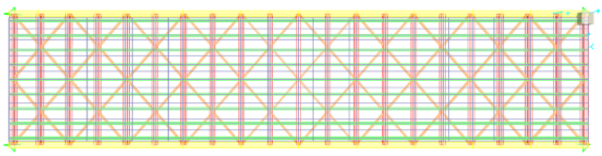

Figure 5. Slab Floor Plan of the Arch Bridge

2.3 Load Planning and Input

The loading on the upper structure of the Through Arch Bridge-Steel Arch Bridge on Tukad Ayung consists of permanent and transient load [4, 5].

Permanent Load:

1. Dead Load (MS)
   Dead load is calculated automatically in modeling on SAP2000 software. Load pattern used is dead type and the self-weight multiplier number is 1,0.
2. Super Dead Load (MA)
   The planned super dead loads can be seen on Table 1.

Table 1. Planned Super Dead Load

Super Dead Load	Concrete Railing Load	Sidewalk Load	Asphalt Load	Rainwater Load
Width	0,2 m	1,2 m	11 m	-
Height	1 m	-	-	-
Cross-Sectional Area	0,2 m^2	-	-	-
Weight	4,8 kN/m	4,8 kN/m^2	2,2 kN/m^2	0,5 kN/m^2
Thickness	-	0,2 m	0,05 m	0,05 m
Specific Gravity of Asphalt	-	-	-	-
Specific Gravity Reinforced Concrete	24 kN/m^3	24 kN/m^3	22 kN/m^3	-
Specific Gravity Water	-	-	-	10 kN/m^3

Transient Load:

1. Lane Road "D" (TD)
   Consist of evenly divided load (BTR) and centralized line load (BGT).
   a. BTR Load
   The total length of the planned through arch bridge type on Tukad Ayung is 64 meters, so the BTR load intensity is:
   $$q = 9{,}0\left(0{,}5 + \frac{15}{L}\right)\ \text{kPa}$$
   $$q = 9{,}0\left(0{,}5 + \frac{15}{64}\right) = 6{,}61\ \text{kPa}$$
   b. BGT Load
   Based on SNI 1725:2016, BGT load intensity is 49 kN/m with a dynamic magnification factor for BGT upper structure of 30%.
   BGT value = (1 + FBD) BGT
   BGT value = (1 + 0,3) 49 kN/m
   BGT value = 63,7 kN/m
2. Truck Load "T" (TT)
   Steel Arch Bridge Type Through Arch Bridge on Tukad Ayung on this planning has 3 traffic lanes. The weight of the truck axle is 25 kN on each front axle and 112.5 kN on each rear axle. Then in the loading of this "T" truck, there is a dynamic magnification factor of 30%. In this bridge modeling, the display in Figure 12 is the loading position of truck "T" multiplied by FBD by 1,3 on the load case.

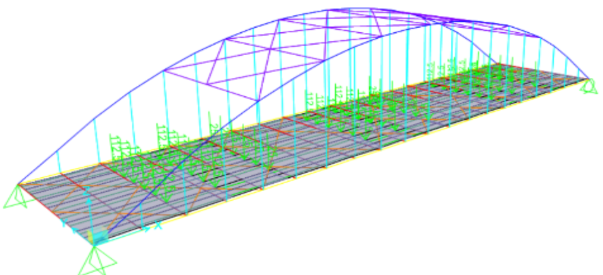

Figure 6. Truck Load "T" (Unit: kN)

3. Brake Load (TB)
   The brake load is 25% of the axle weight of the design truck and acts horizontally at distance of 1,8 m above the road surface in the longitudinal direction.
   Truck axle weight design, Wt = 112,5 kN
   25% of axle weight, Wg = 36,56 kN
   High position brake load, H = 1,8 m
   This brake force will be the moment force because there is a distance H from the contact area to the input position of the load. So, the moment that occurs (MTB) is 65,81 kNm and it is assumed that the brake force comes from the center axle on the truck, so that the input position of the brake load (TB) can be seen in Figure 7.

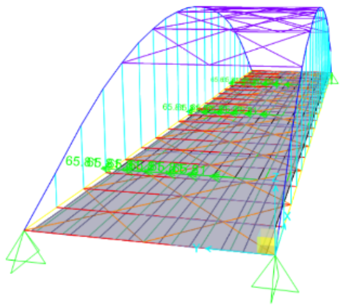

Figure 7. Break Load "TB" (Unit: kNm)

4. Pedestrian Load (TP)
   Based on SNI 1725:2016, sidewalk components more than 0,6 m must be planned to carry pedestrian loads with an intensity of 5 kPa. This loading is inputted as an even load on the pavement.
5. Wind Load on Structure (EWs)
   Wind load on structure is calculated as seen on Table 2.

Table 2. Calculation Wind Load on Structure

Frictional Wind Speed (V0)	19,3 Km/h
Wind Speed at Elevation 10 m from Ground Level (V10)	126 Km/h
Wind speed at Elevation 1 m from Ground Level (VB)	90 Km/h
Surface elevation from Ground Level (Z)	13 m
Friction length in Upstream Bridge (Z0)	2,5 m
Wind Speed Plan	
$V_{DZ}=2{,}5\,V_0\left(\frac{V_{10}}{V_B}\right)\ln\left(\frac{Z}{Z_0}\right)$ $V_{DZ}=2{,}5.19{,}3\left(\frac{126}{90}\right)\ln\left(\frac{13}{2{,}5}\right)=111{,}37\ km/h$	
Wind Pressure on The Structure (Compressive Wind)	
$P_D=P_B\left(\frac{V_{DZ}}{V_B}\right)^2$ $P_D=0{,}0024\left(\frac{111{,}37}{90}\right)^2.1000=3{,}67\ kN/m^2$ PB = 0,0024 N/mm^2	
Wind Pressure on The Structure (Suction Wind)	
$P_D=P_B\left(\frac{V_{DZ}}{V_B}\right)^2$ $P_D=0{,}0012\left(\frac{111{,}37}{90}\right)^2.1000=1{,}84\ kN/m^2$ PB = 0,0012 N/mm^2	

Width of components structures exposed to wind loads:	
Arch Rib Width (B1)	0,9 m
Tie Beam, Curb and Railing Width (B2)	2,5 m
Compressive Wind Load on Arch Rib (PD)	3,31 kN/m
Suction Wind Load on Arch Rib (PD)	1,65 kN/m
Compressive Wind Load on Tie Beam (PD)	9,19 kN/m

The input position of the wind load of this structure can be seen in Figure 8.

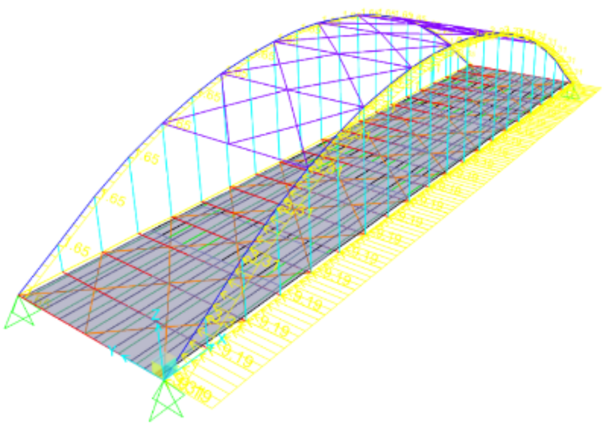

Figure 8. Wind Load on Structure "EWs" (Unit: kNm)

6. Wind Load on Vehicle (Ewl)

   The wind pressure received by the vehicle must as a continuous pressure load of 1.46 kN/m working perpendicular to the position 1.8 m above the road surface. Wind load on vehicle is calculated as seen on Table 3.

Table 3. Calculation Wind Load on Structure

The wind load on arch bridge is calculated as follows:	
Continuous Wind Pressure Load (TEW)	1,46 kN/m
Wind Load Height (H)	1,8 m
Wind Load (EWl)	2,63 kN/m
Truck Wheel Distance (x)	1,75 m
Wind Load on Contact (QEW)	1,5 kN/m

7. Vertical Wind Load (EWv)

   Vertical wind load is the longitudinal line load of the bridge which has a compressive value of 0.96 kN/m². This vertical wind load has a capture point at a quarter of the width of the bridge and works simultaneously with the horizontal wind load.

   Vertical wind pressure, Pv = 0,96 kN/m²
   Bridge width, B = 15 m
   Vertical wind force per m, Pv = 14,40 kN/m

2.4 Factored Combination Planning

1. Strength I
   $\gamma_{MS}MS + \gamma_{MA}MA + \gamma^{u}(TD\ atau\ TT) + 1{,}8(TB + TP)$
   a. Strength I TD
      1,1MS+2MA+2TD+1,8TB+1,8TP
   b. Strength I TT
      1,1MS+2MA+2TT+1,8TB+1,8TP
2. Strength II
   $\gamma_{MS}MS + \gamma_{MA}MA + \gamma^{u}(TD\ atau\ TT) + 1{,}4(TB + TP)$
   a. Strength I TD
      1,1MS+2MA+2TD+1,4TB+1,4TP
   b. Strength I TT
      1,1MS+2MA+2TT+1,4TB+1,4TP
3. Strength III
   $\gamma_{MS}MS + \gamma_{MA}MA + 1{,}4(EWs + EWv)$
   a. 1,1MS+2MA+1,4EWs+1,4EWv
4. Strength IV
   $\gamma_{MS}MS + \gamma_{MA}MA$
   a. 1,1MS+2MA
5. Strength V
   $\gamma_{MS}MS + \gamma_{MA}MA + 0{,}4EWs + EWl$
   a. 1,1MS+2MA+0,4EWs+EWl
6. Extreme Event I
   $\gamma_{MS}MS + \gamma_{MA}MA + \gamma_{EQ}(TD\ atau\ TT + TB + TP)$
   a. Extreme Event I TD (Regular)
      1,1MS+2MA+0,3TD+0,3TB+0,3TP
      1,1MS+2MA+0,3TD2+0,3TB+0,3TP
      1,1MS+2MA+0,3TD3+0,3TB+0,3TP
   b. Extreme Event I TD (Less)
      0,9MS+0,7MA+0,3TD+0,3TB+0,3TP
      0,9MS+0,7MA+0,3TD2+0,3TB+0,3TP
      0,9MS+0,7MA+0,3TD3+0,3TB+0,3TP
   c. Extreme Event I TT (Regular)
      1,1MS+2MA+0,3TT+0,3TB+0,3TP
   d. Extreme Event I TT (Less)
      0,9MS+0,7MA+0,3TT+0,3TB+0,3TP
7. Service I
   MS+MA+TD or TT+TB+TP+0,3EWs+EWl
   a. Service I TD
      MS+MA+TD+TB+TP+0,3EWs+EWl
   b. Service I TT
      MS+MA+TT+TB+TP+0,3EWs+EWl
8. Service II
   $MS + MA + 1{,}3(TD\ atau\ TT) + 1{,}3(TB{+}TP)$
   a. Service II TD
      MS+MA+1,3(TD atau TT)+1,3(TB+TP)
   b. Service II TT
      MS+MA+1,3TT+1,3TB+1,3TP
9. Service III
   $MS + MA + 0{,}8(TD\ atau\ TT) + 0{,}8(TB{+}TP)$
   a. Service III TD
      MS+MA+0,8TD+0,8TB+0,8TP
   b. Service III TT
      MS+MA+0,8TT+0,8TB+0,8TP
10. Service IV
    $MS + MA + 0{,}7(EWs + EWv)$
    a. MS+MA+0,7EWs+0,7EWv
11. Fatigue TD
    $0{,}75(TD + TB + TP)$
    a. 0,75TD+0,75TB+0,75TP

2.5 Arch Rib Analysis Formula

The following is the position of the arch rib with maximum inner force based on the recapitulation results.

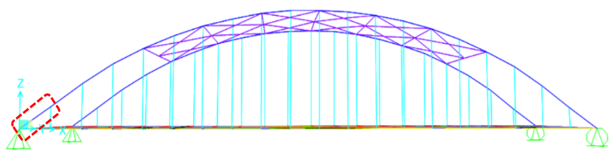

Figure 9. Arch Rib Analysed Position

In the arch rib, there is an axial inner force and a moment acting simultaneously produced by the combination of Strength I TD load, so the arch rib analysis uses the following formula that can be seen on Table 4.

Table 4. Arch Rib Analysis Formula

1. Effective Slimness Ratio	$K\frac{L}{r}<200$
2. Flexible bending on structural components without slim elements	$P_n = F_{cr} . A_g$
Critical Tension (F_{cr})	$If\ \frac{L_c}{r} \leq 4{,}71\sqrt{\frac{E}{Fy}}\left(¿\frac{Fy}{Fe} \leq 2{,}25\right), F_{cr} = \left[0{,}658^{\frac{Fy}{Fe}}\right]$
	$If\ \frac{L_c}{r} > 4{,}71\sqrt{\frac{E}{Fy}}\left(¿\frac{Fy}{Fe} > 2{,}25\right), F_{cr} = 0{,}877\,F_e$
	$F_e = \frac{\pi^2 E}{\left(\frac{L_c}{r}\right)^2}$
3. Axial Force Ratio	$\frac{Pu}{Pn}$
4. Bending M-x Ratio	$\frac{Mux}{Mn}$
5. Bending M-y Ratio	$\frac{Muy}{Mn}$
6. Ratio Combination	$\frac{Pu}{Pn}+\frac{8}{9}\left(\frac{Mux}{Mn}+\frac{Muy}{Mn}\right)$
7. Nominal Shear Strength	$Aw = 2h \times tw$

3 Results and Discussion

3.1 Arch Rib Analysis

Material Data:

1. Stress melting point, fy = 345 MPa
2. Modulus of elasticity steel, E = 200.000 MPa

Profile Data:

1. Cross-sectional height, h = 900 mm
2. Cross-sectional width, b = 600 mm
3. Body thickness, tw = 30 mm
4. Wing thickness, tf = 40 mm

Calculation of Compresive Axial Strength:

1. Effective Slimness Ratio LRFD

   $\phi Pn = 0{,}9 \times 32879858{,}97 = 29591873{,}07$

   Control:

   $$Pu \leq \phi\ Pn$$
   $$13106261{,}40 < 29591873{,}07\ (OK!)$$

2. Axial Force Ratio:

   $$\frac{Pu}{\phi\ Pn} = 0{,}443$$

Mx Flexural Strength Calculation:

1. Bending Mx Capacity

   Mn = 10600470000 Nmm

   ϕMn = 0,9 × 10600470000 = 9540423000 Nmm

   Control:

   $$Mux \leq \phi\ Mn$$
   $$4094812119 < 9540423000\ (OK!)$$

2. Bending Mx Ratio

   $$\frac{Mux}{\phi Mn} = 0{,}429$$

My Flexural Strength Calculation:

1. Bending My Capacity

   Mn = 7321590000 Nmm

   ϕMn = 0,9 × 7321590000 = 6589431000 Nmm

   Control:

   $$Muy \leq \phi\ Mn$$
   $$113385321{,}9 < 6589431000\ (OK!)$$

2. Bending My Ratio

   $$\frac{Muy}{\phi Mn} = 0{,}017$$

Ratio Combination:

1. Axial-Bending Combination Capacity

   $$\frac{Pu}{\phi\ Pn} + \frac{8}{9}\left(\frac{Mux}{\phi\ Mn} + \frac{Muy}{\phi\ Mn}\right)$$
   $$0{,}443 + \frac{8}{9}(0{,}429 + 0{,}017) = 0{,}84$$

   Control:

   $$\frac{Pu}{\phi\ Pn} + \frac{8}{9}\left(\frac{Mux}{\phi\ Mn} + \frac{Muy}{\phi\ Mn}\right) \leq 1{,}0$$
   $$0{,}84 \leq 1{,}0$$

Calculation of Shear Strength:

1. Nominal Shear Strength

   $\phi Vn = 1 \times 10184400 = 10184400$ N

   Control:

   $$Vu \leq \phi Vn$$
   $$824516{,}42 < 10184400\ (OK!)$$

4 Conclusion

The arch rib dimensions in the planning of the through arch steel bridge on Tukad Ayung is 900.600.30.40 box profile with a cross-sectional height. It is using steel material of special type of structural steel for bridges with ASTM A 709 grade 50 specifications. From the analysis result, the stress melting point is fy = 345 MPa and the modulus of elasticity steel is E = 200000 MPa. The cross-sectional Height is 900 mm, cross-sectional Width is 600 mm, the body thickness (tw) is 30 mm and the wing thickness (tf) is 40 mm.

5 Acknowledgement

Planning the structure of a bridge, especially arch bridges have many aspects and variables that should be taken into consideration in calculation. Therefore, planners are expected to be more careful and meticulous in planning this structure.

A planned bridge with a steel structure should be consider the maintenance factor, due to steel material is very susceptible to corrosion hazards thus affecting the strength of the bridge structure aforementioned.

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