Construction cost effectiveness comparison on I-girder bridge and box culvert

Irpan Hidayat, Made Suangga, Felix Hartanto

Civil Engineering Department, Faculty of Engineering, Bina Nusantara University
Jakarta, Indonesia 11480

Corresponding author: irpan@binus.edu

Abstract. One of the most important aspects in bridge construction is cost. A study case has been carried out in Balikpapan-Samarinda highway STA 45+990.946. In that specific location, a bridge is needed as a local road. The ongoing project is constructing a 90 m long I-girder concrete bridge. In this research, as opposed to I-girder concrete bridge, box culvert is designed and then calculate the cost. The budget calculation for bridge construction costs refers to the Unit Price Analysis Guidelines (AHS) in the Public Works Sector and General Specifications. Under the AHS Guidelines, work items are divided into 10 job divisions. The recapitulation of the construction cost budget shows that box culvert construction costs are less than I-girder bridge. In earthworks and structural works, it is the most significant cost difference between box culvert and I-girder bridge. In earthworks, the costs required to the box culvert construction is higher than the I-girder bridge construction. Meanwhile, the construction cost of the box culvert in structural works is less than the I-girder bridge.

Keywords: cost comparison, box culvert, I-girder bridge

1. Introduction

A country’s economic growth is correlated with its infrastructure growth as well. One of the Indonesia’s infrastructures used to improve the people’s accessibility and the economic growth is the freeway. Generally, a freeway is a used to ease up traffic of transportation and distribution of product. Based on Indonesian Road Capacity Manual, freeway is defined as a continuous traffic with a full control access, either a divided or an undivided road. The importance of a sufficient can be seen by the number of infrastructures in one nearby location. For instance, highway that is installed vertically on another existing roads due to the traffic demand or when a tunnel is built beneath an operating road. The addition of highway can be defined as higher demand on highway; therefore, existing operating highway cannot be omitted.

In the practice, some vertically installed highway is made from various kinds of bridges such as: girder structured, box culverts, tunnels, slab bridges. The three basic analysis and design on which is the most suitable alternatives are the quality, time, and cost. For this research, the options opted are I-girder bridge and box culvert. The design itself is based on some standards and some literature such as, SNI 1725:2016 Loading for Bridge Construction[1], and NYSDOT (New York State Department of
To specify the scope of research, the case for this research is the Balikpapan–Samarinda freeway (STA 45+990.946). For the project, I-girder bridge was planned which on this research will be compared with the box culvert cost of construction, and finally to decide the more economic structure for the study case.

2. Study Literature

2.1 Loadings

The loadings used in this research are permanent loads, traffic loads, and environmental loads. Permanent loads consist of self load and superimposed dead load. Traffic loads consist of UDL, knife end load (KEL), braking force, and pedestrian load. Environmental loads consist of wind load and lateral earth pressure. The load combinations are based on SNI 1725:2016 [1].

| Load Combination | Types of Load |
|------------------|---------------|
| MS   | MA | TA | TD | TD | TB | TP | EW | EQ |
| ultimate I      | 1.3 | 2  | 1.25 | 1.8 | 1.8 | 1.8 | 1.8 |
| ultimate II     | 1.3 | 2  | 1.25 | 1.4 | 1.4 | 1.4 | 1.4 |
| ultimate III    | 1.3 | 2  | 1.25 |       |       |       | 1.4 |
| ultimate IV     | 1.3 | 2  | 1.25 |       |       |       |       |
| extreme I       | 1.3 | 2  | 1.25 | 0.5  | 0.5 | 0.5 | 0.5 | 1   |
| extreme II      | 1.3 | 2  | 1.25 | 0.5  | 0.5 | 0.5 | 0.5 | 0.3 |
| serviceability I | 1   | 1  | 1   | 1   | 1   | 1   | 1   | 0.3 |
| serviceability II | 1   | 1  | 1   | 1.3 | 1.3 | 1.3 | 1.3 |
| serviceability III | 1   | 1  | 1   | 0.8 | 0.8 | 0.8 | 0.8 |
| serviceability IV | 1   | 1  | 1   |       |       |       |       |

Table 1 describes the load combination used on this research. It is based on SNI 1725:2016 [1], with each loading abbreviation; MS (self-load), MA (superimposed dead load), TA (lateral earth pressure), TD (“D” lane load), TB (braking force), TP (pedestrian load), EW (wind force), and EQ (earthquake load).

2.2 Permanent Loads

Permanent Loads in box culvert consist of self-load and superimposed dead load. The self-load for both I-girder bridge and box culvert for this research are made from reinforced concrete. To calculate the self-weight of each structure can be done by multiplying the area of an element with its length and the unit weight of reinforced concrete, which is 25 kN/m³. Whereas the superimposed dead load consists of asphalt and water puddle. With both asphalt and water puddle thickness are 5 cm.

| Asphalt weight |
|----------------|
| Thickness (m) | Width (m) | Length (m) | Unit Weight (kN/m³) | Dead load (kN/m²) |
| 0.05          | 7         | 32         | 22                  | 1.1               |
Table 3. Water dead load

| Water weight | Depth (m) | Width (m) | Length (m) | Unit Weight (kN/m³) | Dead load (kN/m²) |
|--------------|-----------|-----------|------------|---------------------|------------------|
|              | 0.05      | 7         | 32         | 9.8                 | 0.49             |

2.3 Traffic Loads

Traffic loads consists of uniformly distributed load (UDL) and knife end load (KEL). The value of UDL load for span of 16 m is 9 kPa (9 kN/m²). The knife end load (KEL) is 49 kN/m.

Table 4. UDL and KEL of box culvert

| Uniform Load UDL dan KEL | L (m) | UDL q (kN/m³) | KEL (kN/m) | Width of 1 lane (m) | UDL load for 1 lane (kN) |
|--------------------------|-------|---------------|------------|---------------------|-------------------------|
|                          | ≤30   | 9             |            |                     |                         |
|                          | >30   | 9*(0.5 + 15/L) | 49         | 3.5                 | 504                     |

For Breaking force for span of 16 m is 25% of axle load (0.25 x 225 KN = 56.26 kN). Whereas pedestrian loads is 5 kN/m².

2.4 Wind Load

Wind load acted on box culvert structure are the pushing and the suction wind pressure. The details are as follows.

Table 5. Pushing wind pressure on box culvert

| Pushing wind load (Y-direction) | Length (m) | Q pushing wind (N/mm) | Number of nodes | P pushing wind (N) |
|--------------------------------|------------|-----------------------|-----------------|-------------------|
|                                | 32         | 4.4                   | 37              | 3805.40           |

Table 6. Suction wind pressure on box culvert

| Suction wind load | Length (m) | Q pushing wind (N/mm) | Number of nodes | P suction wind (N) |
|-------------------|------------|-----------------------|-----------------|-------------------|
|                   | 32         | 2.2                   | 444             | 158.55            |

2.5 Lateral Earth Pressure

Table 7 is the data obtained from the project. The data is then processed using the correlation of N-SPT and other soil parameters. Based on the N-SPT, the value of angle of internal friction can be obtained using the following equation. angle of internal friction is $15,4 \times N_{SPT} + 20$ [2].
Table 7. Soil data

| No | Layer Thickness (m) | Description                      | N-SPT | c (t/m²) | t/m' | alpha |
|----|---------------------|----------------------------------|-------|----------|------|-------|
| 1  | 1                   | Clayey sand, high water          | 0     | 4.5      | 5    | 0.58  |
| 2  | 1                   | Clayey sand, high water          | 2     | 4.5      | 5    | 0.58  |
| 3  | 1                   | Clayey sand, high water          | 2     | 4.5      | 5    | 0.58  |
| 4  | 1                   | Clayey sand, high water          | 4     | 4.5      | 5    | 0.58  |
| 5  | 1                   | Clayey sand, high water          | 4     | 4.5      | 5    | 0.58  |
| 6  | 1                   | Clayey sand, high water          | 7     | 4.5      | 5    | 0.58  |
| 7  | 1                   | Clayey sand, high water          | 8     | 4.5      | 5    | 0.58  |
| 8  | 1                   | Clayey sand, white colour        | 9     | 4.5      | 5    | 0.58  |
| 9  | 1                   | Clayey sand, white colour        | 12    | 4.5      | 5    | 0.58  |
| 10 | 1                   | Clayey sand, white colour        | 15    | 4.5      | 5    | 0.58  |
| 11 | 1                   | Clayey sand, white colour        | 24    | 4.5      | 5    | 0.58  |
| 12 | 1                   | Compact sand, white colour       | 33    | 4.5      | 5    | 0.58  |
| 13 | 1                   | Compact sand, white colour       | 45    | 4.5      | 5    | 0.58  |
| 14 | 1                   | Compact sand, white colour       | 53    | 4.5      | 5    | 0.58  |
| 15 | 1                   | Compact sand, white colour       | 60    | 4.5      | 5    | 0.58  |
| 16 | 1                   | Compact sand, white colour       | 60    | 4.5      | 5    | 0.58  |
| 17 | 1                   | Compact sand, white colour       | 60    | 4.5      | 5    | 0.58  |
| 18 | 1                   | Compact sand, white colour       | 60    | 4.5      | 5    | 0.58  |
| 19 | 1                   | Compact sand, white colour       | 60    | 4.5      | 5    | 0.58  |
| 20 | 1                   | Compact sand, white colour       | 60    | 4.5      | 5    | 0.58  |

After obtaining the *angle of internal friction*, to get the value of $\alpha$, convert the value of angle of internal friction into radian. Then using the value of $\alpha$, the value of $ka$ can be obtained using the equation below.

$$ka = \frac{1-\sin(\alpha)}{1+\sin(\alpha)}$$  \hspace{1cm} (1)

Followed by calculating the lateral earth pressure with the design of vertical earth load has a height of 6 m. So, the lateral earth pressure can be obtained using the equation below [3].

\[
q \text{ (vertical earth load)} = H_{vertical} \times \gamma_{vertical} = 6 \text{ m} \times 17.2 \text{ kN/m}^3 = 103.2 \text{ kN/m}^2
\]

Lateral earth Pressure \[
= (ka \times \gamma' \times H) + (kw \times \gamma w \times H) + (ka \times q)
\]
Table 8. Lateral earth pressure

| H (m) | Description                  | $\gamma_{\text{submerged}}$ (kN/m$^3$) | Ka | $\gamma_{W}$ (kn/m$^3$) | kw | q  | Lateral Earth Pressure (kN/m$^3$) |
|-------|------------------------------|----------------------------------------|----|--------------------------|----|----|---------------------------------|
| 1     | Clayey sand, high water     | 0                                      | 0.490 | 10                        | 1  | 103.2 | 60.598                           |
| 2     | Clayey sand, high water     | 7.85                                   | 0.397 | 10                        | 1  | 103.2 | 67.243                           |
| 3     | Clayey sand, high water     | 7.85                                   | 0.397 | 10                        | 1  | 103.2 | 80.362                           |
| 4     | Clayey sand, high water     | 5.7                                    | 0.363 | 10                        | 1  | 103.2 | 85.763                           |
| 5     | Clayey sand, high water     | 5.7                                    | 0.363 | 10                        | 1  | 103.2 | 97.833                           |
| 6     | Clayey sand, high water     | 7.25                                   | 0.328 | 10                        | 1  | 103.2 | 108.150                          |
| 7     | Clayey sand, high water     | 8.0333                                 | 0.319 | 10                        | 1  | 103.2 | 120.828                          |
| 8     | Clayey sand, white colour   | 8.8167                                 | 0.310 | 10                        | 1  | 103.2 | 133.882                          |
| 9     | Clayey sand, white colour   | 7.61                                   | 0.288 | 10                        | 1  | 103.2 | 139.374                          |
| 10    | Clayey sand, white colour   | 8.075                                  | 0.269 | 10                        | 1  | 103.2 | 149.428                          |
| 11    | Clayey sand, white colour   | 9.47                                   | 0.225 | 10                        | 1  | 103.2 | 156.703                          |
| 12    | Compact sand, white colour  | 8.005                                  | 0.193 | 10                        | 1  | 103.2 | 158.500                          |
| 13    | Compact sand, white colour  | 10.825                                 | 0.161 | 10                        | 1  | 103.2 | 169.171                          |
| 14    | Compact sand, white colour  | 10.4                                   | 0.143 | 10                        | 1  | 103.2 | 175.583                          |
| 15    | Compact sand, white colour  | 10.4                                   | 0.130 | 10                        | 1  | 103.2 | 183.601                          |
| 16    | Compact sand, white colour  | 10.4                                   | 0.130 | 10                        | 1  | 103.2 | 194.949                          |
| 17    | Compact sand, white colour  | 10.4                                   | 0.130 | 10                        | 1  | 103.2 | 206.298                          |
| 18    | Compact sand, white colour  | 10.4                                   | 0.130 | 10                        | 1  | 103.2 | 217.646                          |
| 19    | Compact sand, white colour  | 10.4                                   | 0.130 | 10                        | 1  | 103.2 | 228.994                          |
| 20    | Compact sand, white colour  | 10.4                                   | 0.130 | 10                        | 1  | 103.2 | 240.342                          |

3. Methodology

The research started by identifying the problems to achieve the research purpose. The data obtained are design engineering drawing of I-girder bridge, soil data, and contour data of the construction site. By using the data obtained, a box culvert structure is designed and modelled with the aid of Midas Civil computer program under the rules of SNI 1725:2016 [1]. The output of Midas Civil computer program is then used to calculate the volume of rebar reinforcement needed for box culvert. After the structure of box culvert is considered as capable to withstand the design loads, the volume of the materials is then being summarized and its values are then used to obtain the price of box culvert structure using the (BOQ) from the Public Works. As for the I-girder bridge, the required material volume is calculated, and its values are then being input using the similar BOQ [4] [5]. The total price of both structures is then being compared to get the more economic structure for this research. The research flowchart can be seen below.
4. Results and Discussion

The research results were loading design for box culvert structure based on SNI 1725:2016 [1], box culvert dimension, rebar reinforcement requirements and moment capacity for box culvert, cost estimation for both I-girder bridge and box culvert structure, and finally the comparison of both structures construction cost.

4.1 Analysis on Box Culvert

The design on box culvert structure for this study is by the aid of Midas Civil computer program. The initial step of research is the DED phase, then by trial and error, author will obtain the most suitable dimension. A box culvert is basically made from 2 horizontal slabs and 2 vertical slabs. Box culvert structure on this research must also fit with the previously planned freeway beneath the box culvert. The box culvert’s material is reinforced concrete with f’c of 40 MPa.
Figure 2. Elements on box culvert

- Top Slab: 16 m (span), 12 m (width), 0.8 m (thickness)
- Bottom Slab: 16 m (span), 12 m (width), 0.8 m (thickness)
- Sidewall: 12 m (length), 0.8 m (width), 6 m (height)
- Midwall: 12 m (length), 1 m (width), 6 m (height)
- Wingwall: 10 m (length), 1.5 m (thickness), 8.5 m (height)

4.2 Cost Estimation

The cost estimation for bridge construction refers to the Unit Price Analysis Guidelines (AHS) in the Public Works Sector and General Specifications [6]. The divisions are divided into 10 divisions and can be seen as follows.

Table 9. Bridge construction division

| Division | Description                          |
|----------|--------------------------------------|
| 1        | General                              |
| 2        | Drainage                             |
| 3        | Soil work                            |
| 4        | Pavement Widening                    |
| 5        | Non-Asphalt pavement                 |
| 6        | Asphalt pavement                     |
| 7        | Structure                             |
| 8        | Minor work                           |
| 9        | Daily work                           |
| 10       | Routine maintenance work             |

After calculating the volume of material for both I-girder bridge and box culvert structure, the total construction cost can be obtained. The total construction cost recap can be seen below [6] [7] [8].
Table 10. Box culvert construction cost recap

| Division | Description                  | Total Work Cost (Rupiah) |
|----------|------------------------------|--------------------------|
| 1        | General                      | 1,152,122,719            |
| 2        | Drainage                     | 0                        |
| 3        | Soil work                    | 2,893,770,293            |
| 4        | Pavement Widening            | 479,880,638              |
| 5        | Non-Asphalt pavement         | 117,593,421              |
| 6        | Asphalt pavement             | 1,148,539,242            |
| 7        | Structure                    | 6,106,385,317            |
| 8        | Minor work                   | 412,289,532              |
| 9        | Daily work                   | 32,005,630               |
| 10       | Routine maintenance work     | 398,482,954              |

(A) Total Work Cost (includes general cost and profit) 12,741,069,746
(B) Value Added Tax (VAT / PPN) = 10% x (A) 1,274,106,975
(C) Total Work Cost = (A) + (B) 14,015,176,721

Table 11. I-girder bridge construction cost recap

| Division | Description                  | Total Work Cost (Rupiah) |
|----------|------------------------------|--------------------------|
| 1        | General                      | 1,152,122,719            |
| 2        | Drainage                     | 0                        |
| 3        | Soil work                    | 1,602,931,848            |
| 4        | Pavement Widening            | 479,880,638              |
| 5        | Non-Asphalt pavement         | 0                        |
| 6        | Asphalt pavement             | 1,148,539,242            |
| 7        | Structure                    | 13,049,348,230           |
| 8        | Minor work                   | 412,289,532              |
| 9        | Daily work                   | 32,005,630               |
| 10       | Routine maintenance work     | 398,482,954              |

(A) Total Work Cost (includes general cost and profit) 18,275,600,793
(B) Value Added Tax (VAT / PPN) = 10% x (A) 1,827,560,079
(C) Total Work Cost = (A) + (B) 20,103,160,872

Based on table 10 and table 11, can be concluded that the construction cost for box culvert is less than that of I-girder bridge. The chart for each division of both structures can be seen on the following figure.
Based on figure 3, can be concluded that the most expensive cost component of I-girder bridge on this research is division 7 (structure) that consist of concrete, rebar reinforcement, purchasing and installation of girders, bored pile installation, and prestressed tendon. While as for box culvert, division 7 (structure) consist of concrete and rebar reinforcement.

5. Conclusion

The recapitulation of the construction cost budget shows that box culvert construction costs are less than I-girder bridge. In earthworks and structural works, it is the most significant cost difference between box culvert and I-girder bridge. In earthworks, the costs required to the box culvert construction is higher than the I-girder bridge construction. Meanwhile, the construction cost of the box culvert in structural works is less than the I-girder bridge.

References

[1]. Badan Standardisasi Nasional. Pembebanan untuk Jembatan 2016.
[2]. Hatanaka, Munenori; Uchida, Akihiko. (1996). Empirical Correlation Between Penetration Resistance and Internal Friction Angle of Sandy Soils. Soils and Foundations, Vol. 36, No. 4, P 1-9.
[3]. Krishna, S. R., & Rao, H. (2017). Study on Box Culvert Soil Interaction. International Journal of Civil Engineering and Technology (IJCET), 734-738.
[4]. Fragkais, Nikolaos, Marinelli, Marina, Lambropoulos, Sergios. (2015). Preliminary cost estimate model for culverts. ScienceDirect, 153-161.
[5]. Kattimani, K., & Shreedhar, R. (2013). Parametric Studies of Box Culverts. International Journal of Research in Engineering and Science.
[6]. Kementerian Pekerjaan Umum dan Perumahan Rakyat. Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat no. 28/PRT/M/2016 tentang Analisis Harga Satuan Pekerjaan Bidang Pekerjaan Umum. 2016
[7]. Dinas Pekerjaan Umum Balikpapan. Harga Satuan DPU Balikpapan. 2017
[8]. Mostafa, E. A. (2003). Cost Analysis for Bridge and Culvert. ResearchGate.