Comparison Between PCI and Box Girder in Bridges Prestressed Concrete Design

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Abstract. This research is done by comparing PCI and Box Girder types of prestressed concrete design. The method used is load balance. Previous studies have just discussed the differences in terms of effectiveness and economics. In this study, the researchers want to know the design process by comparing the working forces, the resulting moment, and the losses of the prestressed. As the case in this study, the researchers used the bridge with the span of 31 meters. The tendon pulling system was conducted with post-tensioning system. The analysis result showed that prestressed of the Girder box type sustained the greatest moment due to the combination of its own weight, additional dead load, lane load, and wind load of 44,029 kNm, while the biggest moment of PCI Girder was 7,556.75 KNm. The Girder beam box experiences greater moment and shear force than PCI Girder. This is the effect of the weight of its own Girder box was larger than PCI Girder. The losses of prestressed style of Girder box and PCI Girder type were 24.85% and 26.32%, respectively. Moreover, it showed that the type of Girder box is cheaper, easier, and more efficient than PCI Girder.

1. Introduction
The prestressed concrete is essentially a concrete in which the internal stresses of magnitude and the corresponding distribution are given so that the voltages caused by external loads are held up to a desired level. The strategies include the addition of compressive force to the structure to reduce or even to eliminate internal tensile strength and in this case, the cracks in the concrete can be removed. Externally prestressed concrete structure is broadly applied in the highway bridges, urban bridges, and railway bridges with the development of external prestress technology. In the design and construction process of externally prestressed concrete bridge, the prestress force is often determined according to the theory formula [1]. Precast Concrete-I girder (PCI girder) and Box Girder are structural blocks that directly receive the traffic load after the slab, which then distribute the load to the columns and forwarded to the foundation.

Losses of prestress is a characteristic of all prestressed concrete members wherein the level of prestress force first applied to the member is reduced over time due to short- and long-term conditions [2]. Steinberg showed that prestress losses are consistently calculated lower (by about 33 percent) when using deter-ministic or nominal parameters than when including statistical variability [3]. Measured prestress losses included elastic shortening losses and time-dependent losses due to concrete shrinkage and creep. A coefficient to account for the relationship between the
prestress losses from the measured prestressing forces and the actual prestress losses from concrete compressive strains is proposed [4]. Similar results were found for other prestress loss estimation methods and when using the box beam example [5].

The purpose of this plan is to know the difference of two prestressed concrete models in the construction world used. The observed differences will be focused on the loss force of prestressed and tendon trajectories. This research is planned to use bridge with the same middle span, which is 31 meter. Several previous studies have shown that the use of Girder boxes is more effective than PCI Girder. In this study, the researchers wanted to find out the differences in the design process, especially in the total estimation of the losses of prestress. In the calculation of the losses of prestressed, many factors are interrelated. Thus the researchers assess the estimation with lump sum loss more appropriately used. This research will be used for designers/planners in choosing bridge type. More importantly, the losses of prestress of PCI and Box Girder play a big role in the designer’s ability.

The productivity and the efficiency of construction are measured not only by the requirements for the project, but also by the durability of the project [6]. According to Kromel E. Hanna, George Morcous, and Maher K. Tadros (2009), Prestressed concrete Box Girder has several advantages [7]:

- The easy and speedy construction because of eliminating concrete forming and placing operations (forexample, the Arbor Rail Line Bridge in Nebraska City, Neb., was erected and opened to traffic within 72 hrs)
- A shallow superstructure depth, which is often necessary to maintain the required vertical clearance (forexample, an interstate bridge in Colorado has a span-to-depth ratio of 39)
- Low construction cost compared with I-girder bridges and other competing systems
- Hollow portions inside the box girders that reduce the self-weight of the girders and provide space for gaslines, water pipes, telephone ducts, storm drains, and other utilities
- Improve bridge aesthetics because of the flat soffit and slender superstructure
- High torsional stiffness which is ideal for curved bridge construction

Vishal U. Misal, N. G. Gore, P. J. Salunke (2014) analyzed about the "Analysis and Design of Prestressed Concrete Girder". In their study, which was observed by extracting result, they concluded that Box Girder is costlier than I girder. It also revealed that the losses is more in I girder as compared to Box Girder [8].

2. Materials and Methods

This research used bridge with the same middle span, which is 31 meter. The methods utilized in this study were by designing, analyzing and comparing the result from estimation of loss of prestress, bending moment and concrete cost.

a. Section Properties of Prestressed Concrete Beam

The prestressed concrete section used is a Box Girder and PCI Girder with planned dimensions. Images and data of girder dimensions box are as follows:

| Code | Dimension (m) |
|------|--------------|
| B1   | 6.25         |
| t1   | 0.35         |
| B2   | 0.10         |
| t2   | 0.25         |
| H    | 1.6          |
| t3   | 0.4          |
| t4   | 0.4          |
| B3   | 4.00         |
| t5   | 0.25         |

(a). Type of Box Girder and Dimensions.
Figure 1. The differences of prestressed concrete models and dimensions used.

From the results of planning, it was obtained that the girder beam area is \( A = 9.849 \text{ m}^2 \) and the area of the Box Girder is \( 0.6523 \text{ m}^2 \).

b. The planned Material Quality
The material used for Box Girder and slab of this bridge floor is the concrete with the quality of K-500 (f'c 50 Mpa). Prestressed steel tendons used in high quality steel types consist of wire, strands, or bar. For planning, it used Type strands which is the standard strands cable VSL (Vorspam System Losinger), which is uncoated 7 Wire Super Strands ASTM A-416 grade 270 with a cross-sectional area of 12.7 mm and ultimate tensile strength is 1860 Mpa\[9\]. The tendon withdrawal system is implemented by post tensioning system. In this method, the concrete first printed with prepared holes (duct) or grooves for the placement of cable / strands. When the concrete is strong enough, then the cable/strands are pulled, the ends are buried, then the hole is grouted. The researchers used each respective reference for details in calculating losses according to AASHTO LRFD\[10\] and Standard Specifications \[1\]. The AASHTO LRFD method is commonly used in estimating deflection and cracking moment during the bridge design process, and the time step method has been considered a more accurate method when compared to measured losses \[11\].

3. Result and Discussion

a. The Position and Tendon Plotting
From the calculation results, it showed that the most number of tendons in the type of Girder Box is 21 tendons with 20 strands/tendon, whereas Girder PCI only requires 4 tendons with 19 strands / tendon. However, if it was seen from the shape and number of girder that must be provided for one bridge construction, then the Box Girder is more efficient in construction. In one segment of the bridge, it required two box girders, while for PCI Girder takes ten pieces. The Girder Box placement adds the aesthetics of the bridge especially for use as a fly over. Thus, in Indonesia, with the densely urban population and the increasing traffic, the use of girder box is felt very effective.

b. Moment, Shear Force and Combination of Load Beams
Based on the forces acting on the girder beam, the bridge will affect the maximum moment and shear force. The shear force and moment in the prestressed beam are the functions of the distance \( x \) which is measured along the longitudinal axis. One of step to find out is to draw a graph which shows how the Moment and Style Shear against X.
The picture above shows that the two types of prestressed concrete experienced the greatest moments due to a combination of their own weight, additional dead load, lane load and wind load. Box Girder prestressed experienced the greatest moment of 44,029 kNm, while in PCI Girder the biggest moment was 7,556.75 KNm.

The prestressed Girder box experienced the largest shear force of 5,467.52 kNm, while on PCI Girder experienced the largest shear force of 913.53 KNm. The shear force was experienced by the Girder box is far above PCI Girder.

c. Lump Sum Estimates for Prestress Loss
The initial prestressed force which was applied to the concrete element undergoes a reduction process therefore it was determined the prestressed force stages such as loading, transfer to concrete, workload conditions to reach ultimate. The loss of the prestressed force in terms of the result of the overall calculation of the prestressed force was derived from the loss of prestressed force as in the following table. The loss of prestressed in terms of: prestress due to elastic deformation of concrete, Relaxation of stress in steel, Shrinkage of concrete, Creep of concrete, Friction, Anchorage slip [12-16].
Table 1. Loss of each prestressed force.

| Losses of Prestress                  | Type of PCI Girder Force (kPa) | Type of Box Girder Force (kPa) | The percentage of prestressed force |
|--------------------------------------|-------------------------------|--------------------------------|-----------------------------------|
| Loss of stress due to friction       | 606.277                       | 9,998.824                     | 0.05                              |
| Loss due to anchorage slip           | 37,354.839                    | 37,354.839                    | 2.87                              |
| Loss due to deformation of concrete  | 82,793.364                    | 25,685.178                    | 6.36                              |
| Loss due to creep of concrete        | 20,351.012                    | 82,192.310                    | 1.56                              |
| Loss due to shrinkage of concrete    | 92,930.588                    | 92,930.589                    | 7.14                              |
| Loss due to relaxation of stress in steel | 108,588.755                  | 75,447.197                    | 8.34                              |
| Lumpsum of the loss of prestressed force | 26.32                      | 24.85                           |

From the table above, it can be seen that the Box Girder was less experience the total losses of prestress force that is 24.85%, while PCI Girder is 26.32%. Relaxation in steel is the biggest cause of losses of prestress in PCI Girder by 8.34%. This is because the fixed voltage that occurs in PCI Girder is greater than that in Box Girder. BoxGirderexperienced the greatest losses of prestress due to the shrinkage of concrete. The concrete shurb on the prestress of concrete causes the shortening of the drawn wires (Stands) moreover it contributes to the loss of voltage. Concrete losses are influenced by cement type, aggregate and treatment methods. To reduce the prestress loss due to the shrinkage on prestressed concrete, it is advisable to use high quality concrete with low water/cement ratio. Gilbertson[11]recommended total loss of prestress form Box Girder about 15.2% and I Girder about 27.1%.

d. The Construction Cost

In the term of the construction, PCI Girder requires a lower cost than Girder Box. In this case, the cost of Box Girder construction is twice as much as the PCI Girder type. However, in its implementation, Box Girder is very effective if it is constructed in narrow areas and heavy traffic. This cause that Box Girder is more preferable by the contractor in working on long-span bridges.

4. Conclusions

Based on the results of the parametric study and the comparison of Box and PCI Girder Prestressed, several conclusions are drawn below:

a. The larger the fixed voltage occurs, the greater the losses of prestress due to the relaxation of the prestressing concrete. This occurs in the type of PCI Girder which lost the prestressed force due to relaxation in the larger steel that is 8.34%.

b. The shrinkage on the prestressed concrete can cause the surface cracks so the proper concrete treatment is essential to prevent cracking. This is experienced by both types of prestressed concrete namely PCI and Box Girder. The percentage loss of the same prestressedforce is shown by both of these types of 7.14%.

c. The moment and the shear force that occurs are larger on the Box Girder than PCI Girder. This is as a result of its own weight from a large girder box material. Therefore, the number of tendons and the reinforcement of the Box Girder also becomes more numerous.
d. There are many other things that show the effectiveness of Box Girder used even though the required cost for construction is greater. From the side of Lump Sum Estimates for Prestress Loss, Box Girder shows better result.

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