Analisis Teknikal Kehilangan Prategang pada Girder Jembatan Y: Sistem Pascatarik

[Technical Analysis of Prestress Loss in Y Bridge Girders: Post-Tensioning System]

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ABSTRACT

This study investigates the prestress loss in Girder Y of Bridge Y, which experienced structural inefficiency suspected to be caused by significant prestress loss in its post-tensioning system. The objective is to analyze the magnitude of prestress loss and assess how different influencing factors—such as elastic shortening, friction, anchorage slip, shrinkage, creep, and tendon relaxation—affect it. The analysis was conducted using a technical evaluation approach by varying key parameters including tendon configuration (curved and straight), concrete grade (K-500 and K-600), and web width (0.2000 m and 0.3000 m). Results showed that the total prestress loss ranged from 21.35% to 17.67%, with curved tendons generally experiencing higher loss. However, despite lower losses in straight tendon configurations, the resulting compressive stress during force transfer exceeded permissible limits. Therefore, the curved tendon configuration is considered more suitable for the prestressed concrete design of Girder Y as it meets stress compliance criteria.

Keywords: *concrete grade; curved tendon; girder; post-tensioning; prestress*

ABSTRAK

Penelitian ini mengkaji kehilangan gaya prategang pada Girder Y Jembatan Y yang mengalami indikasi ketidakefisienan struktur akibat besarnya kehilangan gaya prategang pada sistem pascatarik yang digunakan. Tujuan dari penelitian ini adalah untuk menganalisis besarnya kehilangan prategang serta pengaruh enam faktor utama, yaitu perpendekan elastis beton, gesekan, slip angkur, susut, rangkak, dan relaksasi tendon. Analisis dilakukan secara teknikal dengan memvariasikan beberapa parameter penting, seperti konfigurasi tendon (melengkung dan lurus), mutu beton (K-500 dan K-600), serta lebar badan girder (0,2000 m dan 0,3000 m). Hasil menunjukkan bahwa total kehilangan prategang berkisar antara 21.35% hingga 17.67%, dengan konfigurasi tendon melengkung cenderung mengalami kehilangan lebih besar. Namun, meskipun konfigurasi tendon lurus menghasilkan kehilangan yang lebih rendah, tegangan tekan saat transfer gaya melampaui batas izin. Oleh karena itu, konfigurasi tendon melengkung dinilai lebih sesuai untuk desain beton prategang pada Girder Y karena memenuhi kriteria batas tegangan yang diizinkan.

Kata kunci ***:*** *girder; mutu beton; pascatarik; prategang; tendon lengkung*

INTRODUCTION

The rapid development of construction science and technology has encouraged many countries, including Indonesia, to utilize prestressed concrete in various buildings, such as high-rise buildings and bridges. Prestressed concrete has advantages over ordinary concrete because of its ability to withstand tensile forces through the provision of initial tension (Nawy and Suryoatmono, 2001; Lin, 2000). One example of its application is in the Y Bridge Girder.

The Y Bridge Girder is 626.75 meters long, consisting of 14 spans of 35 meters and 3 spans of 15 meters, supported by 16 pillars standing on well foundations. This structure reflects the use of prestressed concrete in providing an efficient solution for long spans (Ilham, 2008).

Prestressed concrete, as explained in SNI 2847:2019, is reinforced concrete that is given initial tension to reduce tensile stress due to external loads (Badan Standardisasi Nasional, 2019). The resulting internal stress helps improve the weakness of concrete in resisting tensile forces, resulting in stronger elements with minimal cracks and significantly reduced deflection (ACI Committee 363, 1992; Raju, 1986). The concrete mixture consists of cement, water, aggregates, and additives, where the proportions of the materials are designed to produce certain characteristics, such as durability and ease of workability, namely high quality above K-500 (Badan Standardisasi Nasional, 2004; Budiandi, 2008).

However, prestressed concrete also has limitations. The manufacturing process requires strict supervision, additional costs for transportation, and the loss of prestressing force is a major challenge (Soetoyo, 2001). Loss of prestressing force, or loss of prestress, is the difference between the initial prestressing force and the remaining force after some time. This loss is influenced by several factors, including elastic shortening of the concrete, friction, anchor slippage, shrinkage, creep, and tendon relaxation (Darmawan, 2008; Sutarja, 2006; ASTM, 2006).

The process of tensioning reinforcing steel in prestressed concrete creates a compressive force that reduces or eliminates internal tensile forces, increasing the strength of the structural element (ACI Committee 318, 1995). However, the calculation of prestress losses is crucial to determine the amount of prestress required for the structure to carry the load effectively. Mistakes in estimating these losses can have a significant impact on the performance and serviceability of prestressed concrete structures (Lin, 2000; Darmawan, 2008).

In this context, the research on the Y Bridge Girder aims to study the loss of prestressing force and determine the optimal solution so that the prestressed concrete structure can meet the planning standards with maximum efficiency and safety.

METHOD

This research was conducted with several main stages, starting from literature study to technical calculations using systematic methods. The research flowchart describes the work process flow, starting from data collection, analysis, to interpretation of results.

Literature Study

The literature studies reviewed include theories related to bridges, prestressed concrete, constituent materials, types of prestressed concrete, and prestressing force loss factors. This basic understanding is used to build a strong theoretical foundation in research.

Modulus of Elasticity, Compressive Strength and Tensile Strength

To calculate the modulus of elasticity of concrete, two formulas are used: for concrete with a certain density and for normal concrete. The value of the modulus of elasticity of concrete (Ec) can be calculated using the two formulas below:

$$\boldsymbol{Ec = In_c^{1,5}\ x\ 0,043\ \sqrt{f'c}} \quad (1)$$

$$\boldsymbol{Ec = 4700\ \sqrt{f'c}} \quad (2)$$

The compressive strength of concrete is determined based on the SNI 03-2847-2002 standard, with testing using cylindrical and cube-shaped test objects. The allowable stress of concrete is calculated based on the prestressing force transfer conditions (3) and service conditions (4) calculated using the formula:

$$\boldsymbol{Allowable\ compressive\ stress\ =\ 0.60\ xf'_{There}} \quad (3)$$

$$\boldsymbol{Allowable\ compressive\ stress\ =\ 0.45\ xf'_{c}} \quad (4)$$

Tensile strength according to RSNI T-12-2004 at the time of prestressing force transfer (5) and service conditions (6) can be calculated using the formula:

$$\boldsymbol{Tensile\ stress\ =\ 0.50\ x\sqrt{f'_{There}}} \quad (5)$$

$$\boldsymbol{Tensile\ stress\ =\ 0.50\ x\sqrt{f'_{c}}} \quad (6)$$

Girder Cross Section and Prestressing Force

Calculation of girder cross-section properties includes the location of the center of gravity, moment of inertia, and moment resistance. Calculations are made based on the shape of a rectangular or triangular cross-section using standard formulas. Initial prestressing force calculations are made using formulas referring to the ACI-318 standard. Jacking force is calculated from the breaking load of tendons or strands, which are then correlated with the initial prestressing force to determine the number of tendons or strands required.

According to ACI-318, the magnitude of the initial prestressing force due to jacking force is:

$$\boldsymbol{Fj = 80\%\ x\ Pu} \quad (7)$$

Loss of Prestressing Force

The loss of prestressing force is calculated as the difference between the initial prestressing force and the actual force after some time. Factors causing the loss, such as elastic shortening of concrete, friction, anchor slippage, shrinkage, creep, and tendon relaxation, are analyzed in detail for each girder configuration. This approach allows the study to provide a quantifiable evaluation of the loss of prestressing force, which is then used to optimize the design of prestressed concrete in bridge girder structures. This systematic methodology ensures the validity of the results and the relevance of the recommendations to field applications.

RESULTS AND DISCUSSION

Planning Data

To analyze prestress loss in the Y Bridge girder, several key planning data are required, as listed in Table 1.

The bridge span length (40 m) affects tendon length and the extent of friction and relaxation losses.

The spacing between girders (1.8 m) determines the load each girder must support, influencing the required prestressing force. The thickness of the bridge floor plate (0.2 m) contributes to the

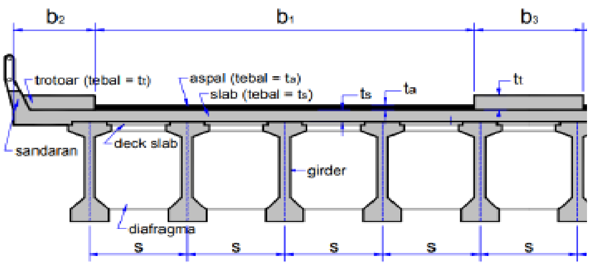

Figure 1. Cross Section of Y Bridge in planning.

dead load, impacting stress levels during prestress transfer.

The specific gravity of prestressed concrete (2550 kg/m³) is used to calculate the girder's self-weight, which relates to creep and shrinkage losses. Additionally, the concrete grade (K-500) is essential in determining the elastic modulus and compressive strength, which are critical for calculating losses due to elastic shortening and verifying if the resulting stresses remain within allowable limits. Together, these data form the foundation for accurately modeling the prestress behavior and evaluating all six loss factors in the post-tensioning system. The Planning data illustrated in Table 1 and Figure 1.

Table 1. **Planning Data**

Data	Mark	Unit
Bridge Span Length	40	m
Jarak Antar Girder, s	1,8	m
Thickness of Bridge Floor Plate, ho	0,2	kg/m^3
Specific Gravity of Prestressed Concrete	2550	h4
Concrete Quality on Girder	K-500	
Bridge Floor Slab Concrete Quality	K-500	

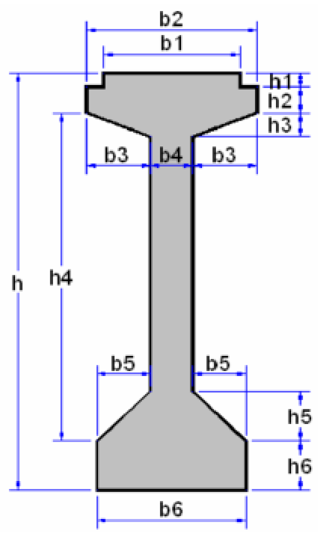

Figure 2. Sketch *Cross Section* Girder

Figure 2 shows the cross-sectional sketch of the Y Bridge girder, illustrating the overall geometry and layout of the structural elements, including the flange, web, and base dimensions. Table 2 complements this by providing detailed measurements of each part of the girder section, such as the width and thickness of various segments, which are essential for calculating cross-sectional properties like area, moment of inertia, and stress distribution in the prestressing analysis.

Table 2. **Girder Dimensions**

Code	Width (m)	Code	Tebal (m)
b1	0,64	h1	0,07
b2	0,80	h2	0,13
b3	0,30	h3	0,12
b4	0,20	h4	1,65
b5	0,25	h5	0,25
b6	0,70	h6	0,25
		h	2,10

Moment of Inertia and Moment of Resistance

Figure 3 illustrates the position of tendons at the support and mid-span of the girder, showing how the tendon paths are arranged along the length of the beam. Table 3 provides the calculated values of key cross-sectional properties, such as the location of the centroid, moment of inertia, and moment resistance, which are critical for evaluating the structural capacity and stress behavior of the girder under prestressing forces.

Table 3. **Moment of Inertia and Moment of Resistance**

Data	Mark	Unit
Place the emphasis, yac	1,004	m
Moment of inertia about the base, Ibc	2,331	m^4
Moment of inertia about the center of gravity, Ixc	0,669	m^4
Top moment resistance of beam, wac	0,381	m^4

Tendon Configuration

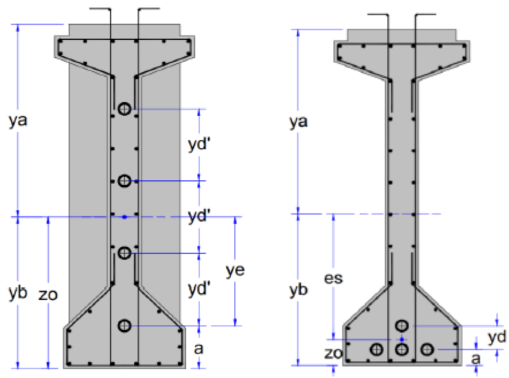

Figure 3. Position of tendon at the support (a) and at the
mid-span (b)

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A strand is a component of a tendon made up of high-strength steel wires used to transfer prestressing force in concrete. Each strand may differ in position and length depending on the tendon configuration. The differences between strands are usually caused by their geometric placement within the girder, particularly in terms of path length and curvature. Strand 1 shows a different pattern compared to the others, especially at positions where x > 15, because it follows a straighter path with less curvature and friction. As a result, the prestress loss in Strand 1 is more stable and tends to be lower in that section than in other strands that follow more curved trajectories. This difference is clearly illustrated in Table 4 and Figure 4.

Table 4. **Tendon configuration at the support and in the middle**

Position	Line	Number of Tendons	Number of Stands
Support Position	1	1	12
	2	1	18
	3	1	18
	4	1	18
		Total	66
Middle Span	1	1	12
	2	3	18
		Total	66

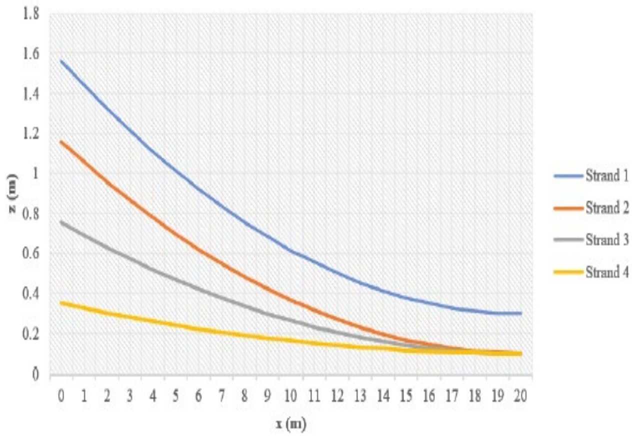

Figure 4. Path of each strand

Loss of Tension in Arched Tendons

The loss of prestressing force in the Y Bridge girder is summarized in the following Table 5:

Table 5. **Loss of tendon prestressing force curved**

Losses	(N/mm2)	% Losses
Elastic Shortening	34,73	2,34
Friction	133,69	9,02
Anchor Derailment	12,06	0,81
Shrink	6,35	0,43
Crawl	111,15	7,50
Tendon Relaxation	21,68	1,46
Total	319,66	21,56

The total loss of prestress is 21.56%. This loss still exceeds the prestress loss limit of post-tension concrete which has a value of 20%. The percentage of prestress loss can be changed by changing the eccentricity. The largest percentage of prestress loss is caused by friction, the value of which can be reduced by reducing friction, namely by changing the tendon configuration from curved to straight. To calculate the amount of prestress loss with a straight tendon configuration, a recalculation is needed.

Loss of Tension in Straight Tendons

The loss of prestressing force in the Y Bridge girder is summarized in the following Table 6.

Table 6. **Loss of prestressing force**

Losses	(N/mm^2)	% Losses
Elastic shortening	34,73	2,34
Friction	94,89	6,40
Anchor Derailment	12,06	0,81
Shrink	6,35	0,43
Crawl	111,15	7,50
Tendon Relaxation	21,68	1,46
Total	280,86	18,94

The magnitude of this loss is already below the limit of prestressing force loss of post-tensioned concrete which has a value of 20%, so the problem of prestressing force loss has been resolved.

CONCLUSION

The loss of prestressing force in girders with curved and straight tendon configurations showed significant influence from various factors, namely elastic shortening, friction, anchor slippage, shrinkage, creep, and tendon relaxation. In girders with curved tendons, the total loss of prestressing force reached 21.56%, consisting of 2.34% due to elastic shortening, 9.02% due to friction, 0.81% due to anchor slippage, 0.43% due to shrinkage, 7.50% due to creep, and 2.46% due to tendon relaxation. On the other hand, in girders with straight tendons, the total loss of prestressing force was lower, which was 18.94%, which included 2.34% due to elastic shortening, 6.40% due to friction, 0.81% due to anchor slippage, 0.43% due to shrinkage, 7.50% due to creep, and 2.46% due to tendon relaxation.

Tendon eccentricity changes have a significant effect on prestressing force loss. In curved tendons, eccentricity changes affect the amount of loss due to elastic shortening, friction, creep, and tendon relaxation. The smallest loss occurs at an eccentricity of 0.8920 m, with a total loss of 21.46%. Meanwhile, in straight tendons, eccentricity changes affect the loss due to elastic shortening, creep, and tendon relaxation, with the smallest loss of 18.97% at the same eccentricity, which is 0.8920 m. These results indicate that the design of tendon eccentricity greatly affects the efficiency of the girder structure in maintaining prestressing force. By optimizing the eccentricity value, prestressing force loss can be minimized, thereby improving the overall performance of the girder structure.

Although the straight tendon configuration produces a smaller prestressing force loss, this configuration cannot be applied to the Srandakan Bridge girder design because the compressive stress that occurs during the transfer of prestressing force exceeds the allowable stress limit. On the other hand, in the curved tendon configuration, the tensile and compressive stresses produced are within or equal to the allowable stress limit, so it is considered safe to use.

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