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PARTIAL STRESSING METHOD EFFECTIVENESS IN POST TENSION PRESTRESSED CONCRETE SYSTEM

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ABSTRACT

Concrete material has moderately strong in compression but relatively weak in tension. To overcome this problem, three types of systems can be applied, i.e., reinforced concrete (R/C) system, composite concrete (C/C) system, and prestressed concrete (P/C) system. In prestressed concrete system, a compressive force is applied to annihilate the tension region in the concrete section. Unfortunately, this compression force creates upward displacement, called camber, with such magnitude that may not be overcome by downward displacements due to the gravity loads. To reduce the magnitude of the troublesome camber, the camber can be decreased by reducing the magnitude of the prestressing force, by assigning some of the total moment to be resisted by additional mild steel. This kind of system, which is called the partial stressing system, is the main concern of this study. The objective of this study is to investigate the effectiveness of partial stressing method in reducing the camber due to the fully stressing method in post tension prestressed concrete system. The research deals with the partial stressing system applied to two cases i.e., rectangular and box girder types based on the real project of bridge girders. The maximum total moment is divided into two portions, one portion is carried out by prestressing tendon, and the other portion is carried out by mild steel. The results of this study indicated that the application of the partial system effectively reduces the magnitude of the cambers due to the fully stressing system. The linear reduction of prestressing force results in linear reduction of the camber for both cases of the rectangular and the box girder types. The box girder has better performance in reducing the stresses and the camber. Since the camber has been reduced significantly by the application of the partial stressing system, hence reduces the construction cost of bridge girders considered.

Keywords: Bridge girder; camber; fully stressing; partial stressing

ABSTRAK

Material beton memiliki kuat tekan yang cukup kuat tetapi relatif lemah terhadap gaya tarik. Untuk mengatasi masalah ini, dapat diterapkan tiga macam sistem, yaitu sistem beton bertulang (R/C), sistem beton komposit (C/C), dan sistem beton prategang (P/C). Dalam sistem beton prategang, gaya tekan diterapkan untuk menghilangkan daerah tegangan di bagian beton. Sayangnya, gaya tekan ini menciptakan perpindahan ke atas, yang disebut camber atau kelengkungan, dengan besarnya sedemikian rupa sehingga tidak dapat diatasi oleh perpindahan ke bawah karena beban gravitasi. Untuk mengurangi besarnya camber yang bermasalah, kita dapat mengurangi camber dengan mengurangi besarnya gaya prategang, dengan menetapkan sebagian momen total yang harus ditahan oleh baja tulangan tambahan. Sistem semacam ini, yang disebut sistem tegangan parsial, menjadi perhatian utama dari studi ini. Tujuan dari penelitian ini adalah untuk mengetahui efektivitas metode tegangan parsial dalam mereduksi camber akibat metode tegangan penuh pada sistem beton prategang pasca tarik. Penelitian ini membahas tentang sistem tegangan parsial yang diterapkan pada dua kasus yaitu tipe gelagar persegi panjang dan gelagar kotak berdasarkan proyek nyata dari gelagar jembatan. Momen total maksimum dibagi menjadi dua bagian, satu bagian dilakukan oleh tendon prategang, dan bagian lainnya dilakukan oleh baja ringan. Hasil penelitian ini menunjukkan bahwa penerapan sistem parsial efektif mengurangi besarnya kelengkungan akibat sistem tegangan penuh. Pengurangan linier dari gaya prategang menghasilkan reduksi linier dari camber untuk kedua kasus tipe persegi panjang dan gelagar kotak. Gelagar kotak memiliki kinerja yang lebih baik dalam mengurangi tegangan dan camber. Karena camber telah berkurang secara signifikan dengan penerapan sistem tegangan parsial, konsekuensinya dapat mengurangi biaya konstruksi gelagar jembatan tersebut.

Kata kunci: Gelagar jembatan; camber; tegangan penuh; tegangan parsial

1. INTRODUCTION

Concrete is one of the most oftenly applied materials in constructing infrastructures such as buildings, bridges, transportation, and irrigation systems so that they stand strong and sturdy. Concrete consists of coarse aggregate (gravel), fine aggregate (sand and cement), and water mixed in one material and designed in different concrete designs. This conventional concrete has a quality of concrete known as characteristic compressive strength, meaning that the concrete is able to withstand relatively high compressive stress.

Unfortunately, concrete has a relatively weakness to the tension, a central problematic case that must be taken care in the design. To overcome this condition, it may have applied three kinds of concrete systems. In the first system, reinforcing steel bars are used to compensate for the crack region of the concrete section. In this system, which is so-called reinforced (R/C), the crack region still exists even though replaced by the steel bars. The amount of steel reinforcement is limited, usually up to about 2 % for beams and 6 % for columns. For a higher percentage of steel needed, a concrete composite system (C/C) can be applied, in which a steel profile may be embedded in the concrete. The amount of this steel is almost the same as the amount of concrete. In this system, however, the crack region still exists.

The third sub-system is called prestressing concrete system (P/C). A prestressed concrete system can be defined as concrete that is given compressive stress with a certain distribution and magnitude of stress so that it can neutralize several tensile stresses caused by external loads (Wijiastuti & Fatniawati, 2003). There are two sub-systems in this system, i.e., pre-tensioning and post-tensioning sub-systems. In the first sub-system, a high tensile strength wire or cable is stressed, and then the concrete is poured. After the concrete is hardened enough and connected with the cable along the periphery of the cable, then the cable is cut at its two ends. The cable then tends to return to its original shape, and this creates the compression in the concrete through a bond between the cable and the concrete.

In the post-tensioning sub-system, a cable is put freely inside a hose or duct, and the hose is positioned on the component according to the shape that intended to, by hanging it on the stirrups or longitudinal steel bars. The concrete is poured and waited until reached a certain strength. Then the cable is stressed, and the two ends are jacked into the component ends, and then are cut. The cable tends to return to its initial shape, and this tendency creates compression through the force exerted by the cable through the jacks.

In both sub-system cases, the application of the prestressing force creates some advantages as well as disadvantageous problems. The presence of precompression eliminates the tensile region that would be created by moments due to dead and live loads, so a full section of the component is effective. That is why the prestressing components tend to be shallower compared to that in the reinforcing concrete case.

The prestressing force would create a negative bending moment that overcomes the moments due to the dead and live loads, but unfortunately, the negative bending moment would create upward displacement, referred to as camber. The dead load and the live load create downward displacements of the girder, but extremely large prestressing force will create a negative bending moment that creates upward displacement. For example, if the dead load creates – 5 cm and live load creates – 5 cm downward displacement at mid-span, while prestressing force creates + 15 cm; so, at rest, the mid-span displacement is + 15 – 5 – 5 = + 5 cm (upward) at mid-span. If the thickness of the floor slab of the bridge is 25 cm, and to have an even slab surface, then it will have only 25 cm – 5 cm = 20 cm slab thickness of the slab at midspan.

To overcome the problematic case mentioned above, it may reduce the magnitude of the camber by reducing the magnitude of the prestressing force. Some ordinary reinforcing bars may be used to take some portion of the total moment; hence, the moment taken by the prestressing will be reduced, resulting in smaller prestressing force and smaller camber as well. This method is referred to as a partial stressing system, which is the main topic in this thesis. However, it should be pointed out at this stage that, to make the additional reinforcing bars effective, some degree of tension must be permitted to occur on the cross-section of the component.

The goal of the research is to investigate the effectiveness of partial stressing method in reducing the camber due to the fully stressing method in post tension prestressed concrete system. Hope that the method may be applied in the design of girders for buildings and other infrastructure components such as bridges. This study is conducted in correlation to the great progress in transportation infrastructure development such as elevated tolls and highways that really need to have the safe serviceable structural systems; in this case, girders with minimized uncomfortness due to excessive cambers.

2. RESEARCH METHOD

Major defect of fully prestressed concrete is its low ductility; it may produce fewer alarming signs than ordinary reinforced concrete via smaller deflection and limited cracking prior to the failure. Therefore, partial prestressing is considered an intermediate design between the two extremes. So, combining high strength concrete with partial prestressing will result in a considerable development in the use of prestressed concrete structures regarding

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serviceability durability (Choudary & Akhtar, 2019; Hariandja, 2016; Lin, 1963; Nawy, 2001; Precast/Prestressed Concrete Institute, 2008).

Another aspect that should be brought into attention is the apparatus and the cost needed to readily be prepared in the application of the prestressing method. The system requires the use of relatively high strength steel materials and yet with relatively small relaxation (Karschner & Scanlon, 2012); and therefore, needs relatively higher construction cost. Minimizing the camber means minimizing the cost by optimizing the use of steel materials and equipment.

Prestressed concrete has upward deflection by stressed strand which is also known as camber (Figure 1). It is caused by the prestressing force located with downward eccentricity that creates negative bending moment (Honarvar et al., 2015; Tadros et al., 2011; Nainggolan, 2018). Camber has only serviceability effect on the performance of the structure. However, camber has an effect on the thickness of the floor above, because it can cause unevenness in the surface of the pavement of the slab above the span. So, if the thickness of slab floor should be constant and the surface is kept level, then the thickness of slab floor at mid span becomes smaller. On the other hand, if the thickness of the slab eccentricity (e) is kept constant, the evenness of the slab surface is sacrificed and this will cause uncomfortness to the users (Nainggolan, 2018).

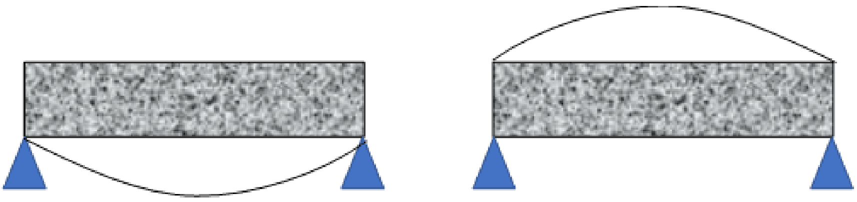

Figure 1. The camber of prestressed concrete (Hariandja, 2015)

Partial stressing method has been applied (Choudary & Akhtar, 2019; Wijiastuti & Fatniawati, 2003; Bruggeling, 1985) in the reduction of the camber caused by eccentric prestressing force. The camber may be reduced by reducing the prestressing force or increasing modulus of elasticity for constant cross section imension and eccentricity. In this study, the first option will be explored.

In partial stressing method, some portion of the moment due to the total load is given to be carried out by additional ordinary steel. The rest will be carried out by tendon or cable. Therefore, we may use smaller prestressing force that may cause smaller camber. The portion may be investigated in such a way that we may obtain smaller camber and cheaper design.

As prestressed concrete was introduced in the 1930s (Lin, 1963), the design philosophy is to find a new type of material by placing the concrete in such a compression state that no part of the concrete in tension, at least at the work load stage. In the late 1940s, observations of earlier structures revealed extra strength to the structure. Therefore, some experts believe that a certain amount of tensile stress can be allowed in the design.

In contrast to the previous criterion which does not allow for the presence of tensile stresses, called “full prestressing”, design methods that allow for a certain amount of tensile stress are often termed “partial prestressing.”

For the purpose of the serviceability, the surface of the slab on top of a girder is made even during the construction, then the existence of the camber would reduce the thickness of the slab. If the slab is cast at constant thickness, the camber will make uneven surface of the slab and then reduces the comfortless of the users. So, this study intention is to reduce the magnitude of the camber by reducing the magnitude of the prestressing force by making use of additional mild steel.

Analysis of post tension cross section

In the analysis of post tension cross section, the stages that control the design is the stage which own weight of beam and superimpose dead loads effective, and the stage which all loads effective. At the first stage, the dead load moment M_d consists only due to the own weight or the beam if the stressing of the cable is carried out before the placing of the superimposed dead loads. But it consists also superimposed load M_s moment if the stressing is carried out after superimposed loads are already at place. At this stage, the concrete stress f_{ct} at the top fiber and f_{cb} at lower fiber are given by Equations 1-2.

$$f_{ct} = \frac{F_0}{A_c} + \frac{F_0 e}{I_{zz}} y_t + \frac{M_d}{I_{zz}} y_t \geq \bar{f}_t \quad (1)$$

$$f_{cb} = \frac{F_0}{A_c} + \frac{F_0 e}{I_{zz}} y_b + \frac{M_d}{I_{zz}} y_b \leq \bar{f}_b \tag{2}$$

in which F_0 is initial prestressing force, e eccenticity of the cable, M_d dead load moment, A_c area of concrete cross section, I_{zz} moment of inertia of section with respect to $z-$axis that passes thugh cetnetavity of the section, y_t distance of the top fiber from ceneter of gravity and y_b distance of lower fiber from center of gravity.

For the stage of all loads effective, the controlling inequalities are indicated in Equations 3-4.

$$f_{ct} = \frac{F_e}{A_c} + \frac{F_e\, e}{I_{zz}} y_t + \frac{M_d}{I_{zz}} y_t + \frac{M_\ell}{I_{zz}} y_t \leq \bar{f}_b \tag{3}$$

$$f_{cb} = \frac{F_e}{A_c} + \frac{F_e e}{I_{zz}} y_b + \frac{M_d}{I_{zz}} y_b + \frac{M_\ell}{I_{zz}} y_b \geq \bar{f}_t \tag{4}$$

in which F_e is the effective prestressing force after all prestresses losses have taken place, and M_ℓ is the moment due to the live load, and the total moment is $M_d + M_\ell = M_t$.

Before determining the magnitude and the eccentricity of the cable, first determine the upper and lower limits of the lay out of the cable. If for the time being, it does not allow tensile stress to occur, then the lower limit is given by Equation 5.

$$e \geq -k_b - \frac{M_d}{F_0} \tag{5}$$

in which k_b is the lower bound of Kern region, and the upper limit is given by Equation 6.

$$e \geq -k_t - \frac{M_t}{F_0} e \geq -k_b - \frac{M_d}{F_0} \tag{6}$$

in which k_t is the upper bound of Kern region.

Generally, at practice, it may confront three cases of conditions between the upper and the lower limit as depicted in Figure 2. In Figure 2(a), it is shown that the upper limit is too far from the lower limit. This means that the section is too conservative. The second case in Figure 2(b), the lower and upper limit intersect each other. This means that the section is not enough and has to be enlarged. The ideal effective case is shown in Figure 2(c).

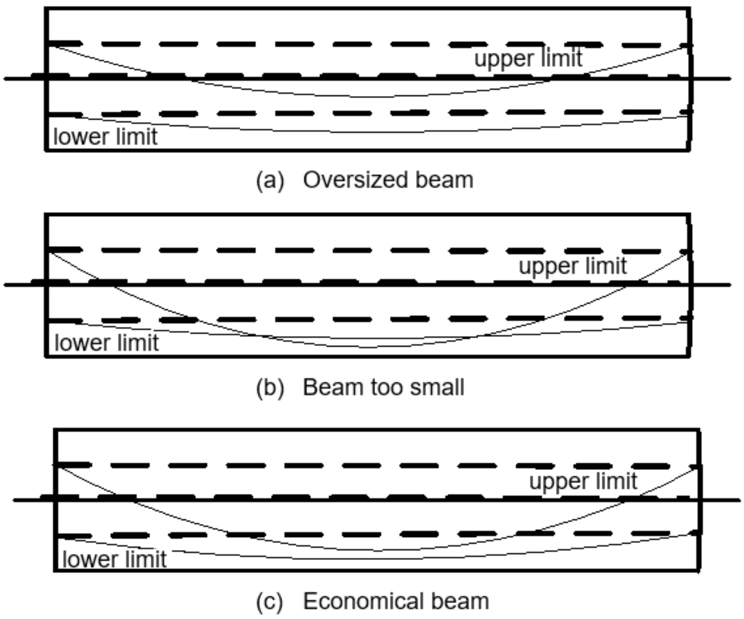

Figure 2. Three conditions of cable lay-out (Hariandja, 2016)

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Magnel's procedure

Having considered the cable lay-out region, i.e., upper and lower limit of the lay-out of the cable for assumed cross section and moments due to the dead and live loads, the remaining task is to determine the magnitude and the eccentricity of the prestressing force. This may be done by trial and error scheme for finding F_0 and e that satisfy Equations 1-4 at controlling design section. Magnel proposed a procedure in determining F_0 and e as follows. From Equations 1-4, after rearranging the terms, we get the following expressions Equations 7-11.

$$\frac{1}{F_0} \geq \frac{\alpha_b e - 1}{A_c \bar{f}_t + \alpha_b M_d} \tag{7}$$

$$\frac{1}{F_0} \geq \frac{\alpha_t\, e + 1}{-A_c \bar{f}_c + \alpha_t M_d} \tag{8}$$

and

$$\frac{1}{F_0} \leq \frac{R(\alpha_b e + 1)}{-A_c \bar{f}_t + \alpha_b M_T} \tag{9}$$

$$\frac{1}{F_0} \leq \frac{R(\alpha_t\, e - 1)}{A_c \bar{f}_t + \alpha_t M_T} \tag{10}$$

in which

$$\alpha_t = \frac{y_b}{I/A_c}; \alpha_b = \frac{y_t}{I/A_c} \tag{11}$$

Equations 7-11 are used to draw lines in Magnel's diagram such as seen in Figure 3. The four lines contain a four-side region that gives the feasible area. Selecting a point on that area will give the prestressing force and eccentricity.

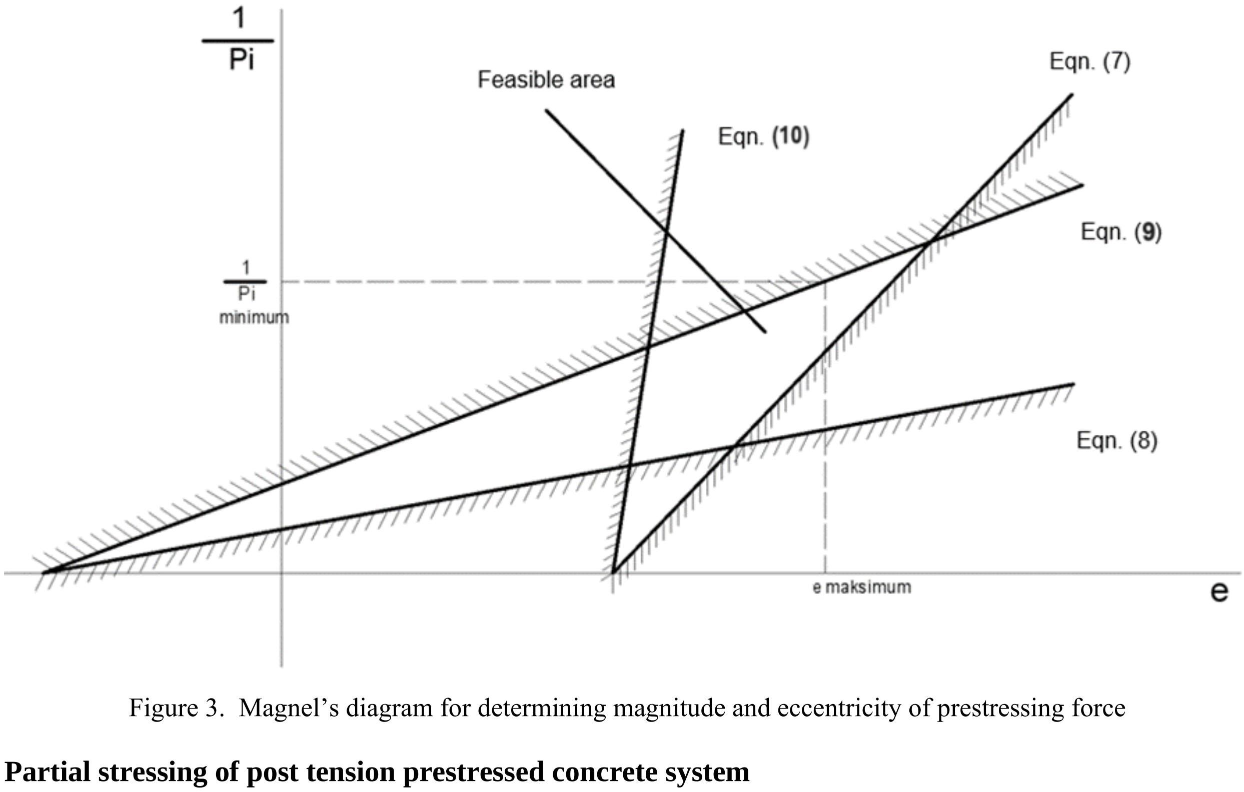

Figure 3. Magnel's diagram for determining magnitude and eccentricity of prestressing force

Partial stressing of post tension prestressed concrete system

The critical conditions that should be taken care of, in terms concrete crack, is that the top fiber of section in the stage of own weight of beam and superimpose dead loads effective, and low fiber of section in the stage of all loads effective, may not experience crack. But, since the two cases only happen in a relatively short time, i.e., in transfer of prestressing force and in the maximum load condition, then the crack may be allowed to a certain limited degree. In relation with lowering the prestressing force to reduce the camber, then in the two cases, some portion of the moment may be carried out by additional mild steel.

In the first case, in carrying the dead load moment, the portion of the moment may be carried by additional top mild steel, and hence lowering the prestressing force. But since the prestressing force is reduced, the possibility of tension at top concrete fiber diminishes, so this step may be abandoned. For the second case, the reduction in prestressing force and addition of mild steel may be considered with respect to ultimate condition at mid span.

The analysis of the partial stressing system of post tension prestressed concrete system, the intention is to reduce the magnitude of the camber. The equation of the camber in the case of post tension system as given in Equation 12.

$$e = \frac{5F_e e_0 L^4}{48\,EI} \tag{12}$$

It is clear that the reduction of the camber can be done by several ways. First, it can be reduced by finding a new design mix so as to increase the modulus of elasticity E. The second way is to enlarge the dimension of cross section so as to increase the value of moment of inertia I and eccentricity e_0.

A way to reduce the camber is to decrease the prestressing force F_e. This may be achieved by reducing the moment that will be taken by prestressing force, and the remaining moment taken by additional mild steel. In this scheme, a portion μ of the total moment M_t is taken by additional ordinary reinforcing bars, i.e. Equation 13.

$$M_a = \mu\, M_t \tag{13}$$

in which μ is the factor representing the portion of moment taken by prestressing force. The corresponding reduced prestressing force becomes Equation 14.

$$F_\mu = (1-\mu)\, F_e \tag{14}$$

The nominal moment is Equation 15.

$$M_n = \frac{M_u}{\emptyset} = \frac{1.2\, M_d + 1.6 M_\ell}{\emptyset} \tag{15}$$

The additional mild steel will be designed by ultimate strength condition. The shape factor of characteristic compression strength is Equation 16 (Hariandja, 2013).

$$\begin{aligned} \beta &= 0.85 - 0.008\,(f_c' - 30) = 0.61\ [if\ f_c' \le 55\ MPa] \\ &= 0.65\ if\ f_c' \le 55\ MPa \end{aligned} \tag{16}$$

Equilibrium of axial forces dictates that Equation 17.

$$\beta\, f_c'\, b\, c - F_\mu + A_s f_y = 0 \tag{17}$$

in which c is the depth of compression zone, A_s is the area of additional tension steel, and f_y is the yielding strength of mild steel. Equilibrium of moments is taken with respect to the location of additional mild steel so the number of unknowns in the obtained equation is reduced. This equilibrium of moment gives Equation 18.

$$M_n = \beta\, f_c'\, b\, c\left(h - \frac{c}{2}\right) + F_\mu\left(\frac{d}{2} - s + e_0\right) \tag{18}$$

Equation 18 is quadratic form in c and may be solved for c, in Equation 19.

$$\bar{c} = h\left[1 - \sqrt{1 - \frac{2}{\beta b h^2 f_c'}\left\{M_n - F_\mu\left(\frac{d}{2} - s + e_0\right)\right\}}\right] \tag{19}$$

The computation procedure is as follows. For selected value of μ, we compute F_μ from Equation 14, then compute M_n in Equation 15. For β considered in Equation 16, $\bar{c}$ is computed by Equation 19. The obtained value of $\bar{c}$ is then substituted in Equation 17 to find the value of mild steel area A_s, as seen in Equation 20.

$$A_s = \frac{F_\mu - \beta f_c' b \bar{c}}{f_y} \tag{20}$$

3. RESULTS AND DISCUSSION

The application of the method to rectangular bridge girder cross section and box bridge girder cross section with relatively the same cross-sectional area as follows. The design of full stressing system is presented first, and then the design of partial stressing afterward. The two designs are then compared to demonstrate the effectiveness of partial stressing system.

The design is based on the applicable codes (RSNI T-12 & RSNI T-02). This application is related to a real project namely the I–section girder of elevated toll road, Becakayu, connecting Bekasi and Jakarta. Due to monetary crisis in 1998, the project was behind the schedule. Moreover, the delay of the project completion was prolonged due to the excessive of the camber in the field. This section deals with the design of rectangular and box girder type cross section of bridge. Two methods area considered, i.e., fully stressing system and partial stressing system.

The properties of the materials that used in this study, i.e., concrete, prestressing cable and mild steel area as follows. The characteristic compressive strength of concrete, $f_c' = 60\,MPa$ (at service); the prestressing steel yield strength, $f_{py} = 1200\,MPa$; the mild steel yield strength, $f_y = 400\,MPa$ (longitudinal steel); $f_y = 350\,MPa$ (stirrup); and the modulus of elasticity: E_s = 200,000 MPa. In this study, the bridge girder is considered. The geometrical properties of the structure are as follows (Figure 4). The span length of the girder L is 35.00 m and the cross section with width b is 0.60 m and the height d is 1.75 m. The Magnel's diagram for fully stressing system of rectangular girder cross section and box girder cross section as shown in Figure 5 and Figure 6, respectively.

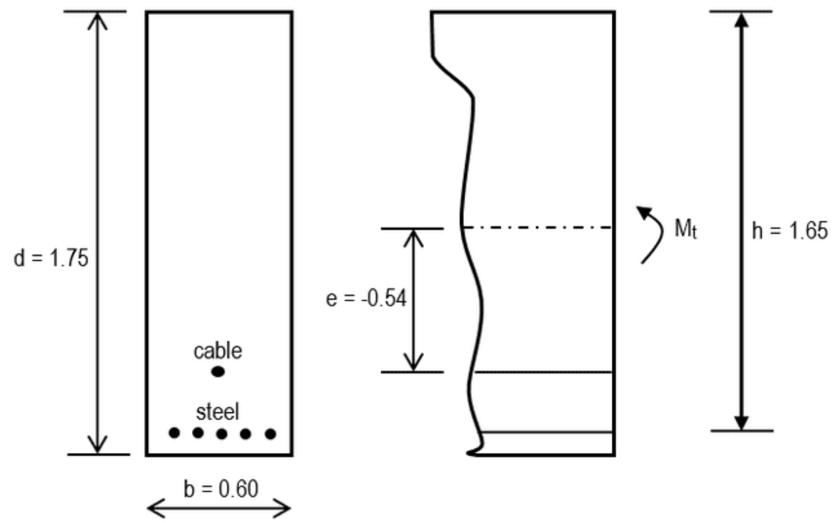

Figure 4. The partial stressing of prestressed concrete system (geometry unit in m) for rectangular cross section of bridge girder

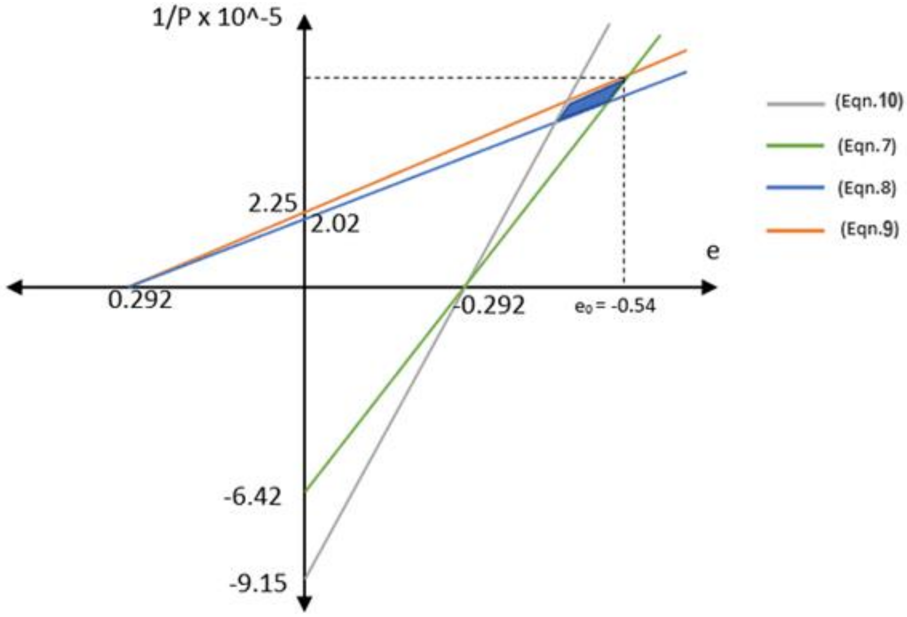

Figure 5. Magnel's diagram for fully stressing system of rectangular girder cross section

In order to reduce the camber, the partial stressing system was introduced by reducing the prestressing force F_e by 20%, 40%, and 60%. The reduction of prestressing force will leave portion of moment that will be resisted by mild steel, such as shown in Figure 4. The comparison of the camber for fully stressing system and the partial stressing of prestressed concrete system can be seen in Table 1.

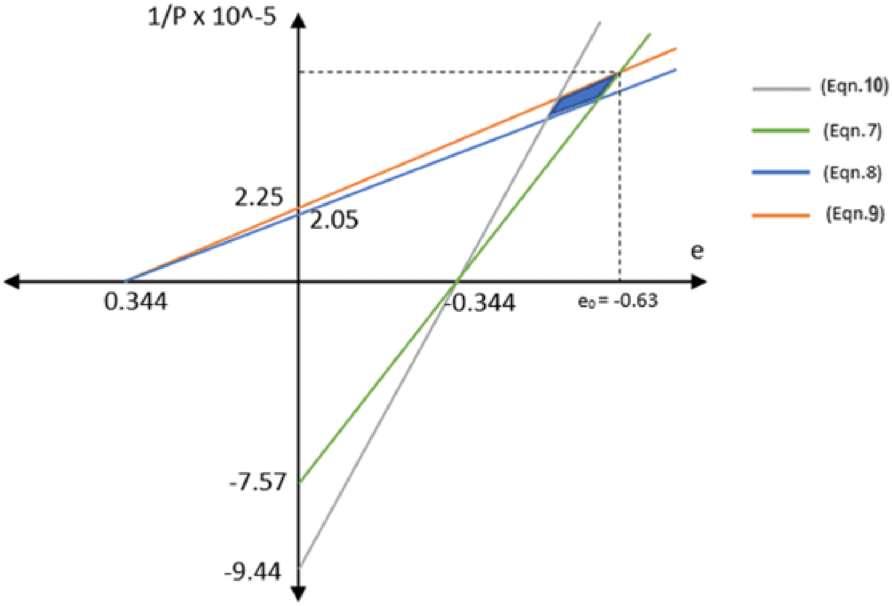

Figure 6. Magnel's diagram for fully stressing system of box girder cross section

Table 1. The comparison of the camber

No.	μF	Rectangular girder			Box girder		
		F (kN)	A_s (cm^2)	Camber (cm)	F (kN)	A_s (cm^2)	Camber (cm)
1	1.0F	13210	-	16.98	11193	-	14.58
2	0.8F	10568	88.40	13.58	8954	116.78	11.66
3	0.6F	7926	139.69	10.18	6716	160.58	8.75
4	0.4F	5284	191.45	6.79	4477	204.57	5.83

In Table 1, the partial stressing system with the reduction of the prestressing force F_e by 20%, indicate the reduction of the camber about 20% to the fully stressing system for both cases of the rectangular girder cross section and the box girder cross section. For the reduction of 40% and 60% of the prestressing force, both cases give relatively same results as 40% and 60% of the camber reduction, respectively. These results indicate that the application of this partial system can reduce the stresses and the amount of camber by reducing the volume of cable tendons used and replacing them with reinforcing steel. In other words, the implementation of this partial system can be cheaper than the fully stressed system. Based on the results of this analysis, the partial stressing system can be applied well in terms of reducing stress and camber which has more economical consequences than the fully stressing system.

With relatively the same cross-sectional area, and thus the same own weight, the moment of inertia of box girder is larger than the rectangular area, and hence stronger in carrying external moments. Since it has relatively larger moment of inertia with relatively the same height of cross sections, the magnitude of the upper and lower limits of Kern area are larger, so as to have more ample region to place the tendons. As further consequence, the prestressing force in box girder is smaller than prestressing force needed in rectangular section, so producing smaller stresses and camber.

4. CONCLUSION AND RECOMMENDATION

This study has investigated the effectiveness of partial stressing method in post tension prestressed concrete system for reducing camber due to a fully stressing system. Based on the findings in this research work, some conclusions are made as follows.

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The partial stressing system effectively reduce the camber due to the fully stressing system. The linear reduction of prestressing force results in linear reduction of the camber. With the same area and height of the two types of cross section, the box girder has better performance in reducing the stresses and the camber.

As benefits of this study, the method may be applied in the field, since the camber has been reduced significantly by the application of the partial stressing system, consequently reduces the construction cost of bridge girders.

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REFERENCES

Badan Standardisasi Nasional. (2004). *Perencanaan struktur beton untuk jembatan* (RSNI T-12).

Badan Standardisasi Nasional. (2005). *Pembebanan untuk jembatan* (RSNI T-02).

Bruggeling, A. (1985). Partially prestressed concrete structures - A design challenge. *PCI Journal*, *30*(2), 140-171.

Choudary, K., & Akhtar, S. (2019). Application of partial prestressing for crack control in reinforced concrete structures. *AIP Conference Proceedings* 2158, 020027. https://doi.org/10.1063/1.5127151

Hariandja, B. (2013). *Analisis dan perencanaan struktur beton bertulang*, Universitas Pancasila.

Hariandja, B. (2015). *Mekanika rekayasa III: Analisis struktur dengan metoda gaya dan metoda perpindahan*, Institut Teknologi Bandung.

Hariandja, B. (2016). *Analisis dan desain struktur beton prategang*, Institut Teknologi Bandung.

Honarvar, E., Nervig, J., He, W., Sritharan, S., & Rouse, J. M. (2015). *Improving the accuracy of camber predictions for precast pretensioned concrete beams, final report* (IHRB Project TR-625). Bridge Engineering Center, Iowa State University.

Karschner, K. A., & Scanlon, A. (2012). *Effects of creep and shrinkage on time-dependent strain and curvature of R/C members*. [Master Thesis, The Pennsylvania State University].

Lin, T.-Y. (1963). *Design of prestressed concrete structures*, John Wiley & Sons, Inc.

Nainggolan, T. M. (2018). *Investigasi kegagalan balok beton prategang tol Becakayu*. Institut Teknologi Bandung.

Nawy, E. G. (2001). *Beton Prategang* (3rd ed.). Erlangga.

Precast/Prestressed Concrete Institute (2008). *PCI Design Handbook, Precast and prestressed concrete* (7th ed.). Precast/Prestressed Concrete Institute.

Tadros, M. K., Fawzy, F., and Hanna, K. E. (2011). Precast, prestressed girder camber variability. *PCI Journal*, *56*(1), 135–154.

Wijiastuti, Y., & Fatniawati, N. (2003). *Analisis lendutan beton prategang parsial pada gelagar jembatan dengan metode approximate time step* [Thesis, Universitas Islam Indonesia].