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Prestressed beam system due to the addition of a long-span beam in building infrastructure

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ABSTRACT

Prestressed concrete is the perfect composite consisting of high-strength concrete and strands with reinforcement with high yield strength Prestressed concrete beam is one of the concrete innovations that have been used in many constructions. The advantage of prestressed concrete particularly using the post-tensioning method, in designing and applying prestressed concrete beam for the building is that the tensioning can be carried out in stages, for all tendons in a member, or some of them Prestressed concrete beam using post-tensioning method can be an alternative to increase the span of the building when removing the existing column in the center of the building is required. In this paper, the use of prestressed concrete beam will be designed in Nyitdah Hospital-Tabanan, Bali. The prestressed beam is designed with 60/90 cm dimension and 1 tendon unit with 12 strands unit. Based on the design and result, the prestressed beam can be used as the alternative to increase spans in a building room of the Nyitdah hospital.

Keywords: increase spans; post-tensioning; prestressed beam

1 Introduction

The safety factor is the embodiment of the elastic method but is still relevant to be used as a comparison to the ultimate method which is usually used in planning analysis with reinforced concrete [1]. Prestressed concrete is a concrete construction technology that integrates high-performance concrete with high-performance reinforcement inactive way [2]. Prestressed concrete is also an ideal combination of two modern high-strength materials [3]. The prestressed concrete beam is one of the concrete innovations that have been used in many constructions. The use of prestressed concrete beam can produce slimmer dimension and resistance to shear, and higher tensile strength compare to the reinforced concrete beam. Prestressed concrete beams have usually low deflection. One of the essential benefits of prestressed over reinforced concrete is that, for specified length and loading, a smaller prestressed concrete member is preferred [4]. Using prestressed concrete beam due to implicit long-term reduction is important, as less maintenance is required, which means longer service life due to better quality control of the concrete and lower weight of the superstructure [5, 6].

Post-tensioning is one of prestressing concrete methods in designing and applying prestressed concrete beams for buildings. The prestress constrain is put in this case by jacking reinforcement tendons against an already-cast concrete member [7]. Nearly cast-in-place prestressing is executed using this procedure. Prestressed concrete beam using the post-tensioning method can be an alternative to increase the span of the building by removing the existing column in the center of the building [8].

In this paper, the use of prestressed concrete beam will be designed in Nyitdah Hospital-Tabanan, Bali. Nyitdah hospital is located in Banjar Tegal Antungan, Nyitdah Village, Kediri Distric, Tabanan Regency, Bali. This 3-floor hospital's primary structure has been designed with reinforced concrete. The prestressed concrete beam will be designed on the 3rd floor of this building by removing 2 columns in one span of the designed prestressed beam. After the alternate columns are removed, the spacing of the column is increased to 18 m instead of the existing 7.2 m. Also, in this case not every beam on the 3rd floor is changed to be a prestressed concrete beam. The use of prestressed beams is specifically due to the addition of the 4th floor which functioned as hall space. It allows to withstand the stress combination (bending, shear, or torsional stresses) caused by loads and extended beam spans, therefore, cracks can be avoided.

2 Data and Methods

In designing prestressed concrete beams, there are several references used such as, SNI 2847:2019 [9] and SNI 7833:2012 [10] for concrete structure and prestressed concrete beam, the load used in design complies to SNI 1727:2020 [11] and related to anticipating earthquake hazards, one of which was SNI 1726:2019 Procedures for planning earthquake resistance for building and non-building structures located in earthquake-prone areas [12, 13]. The analysis and design of prestressed beams are using ETABS'17 software. The structure system is designed as special moment resisting frame, where the dimensions and detailing of its structural elements are generated with performance-based design concept with the direct displacement method, which can meet the "Strong Column Weak Beam" requirement.[14]

2.1 Methods of prestressing

The prestressed concrete elements, in this paper, are using post-tensioning method. The prestress constrain is put in this case by jacking reinforcement tendons against an already-cast concrete member [7]. Nearly cast-in-place prestressing is executed using this procedure. The tendons are threaded through ducts cast into the concrete, or in some cases pass outside the concrete section [4]. One benefit of post-tensioning over pretensioning is that the tensioning can be carried out in stages, for all tendons in a member, or for some of them [15]. This can be effective where the load is put in well-defined stages.

An essential different between pretensioned and post-tensioned systems is that it is easy to incorporate curved tendons in the latter [4]. The flexible ducts can be held to a curved shape while the concrete is poured around them (Figure 1)

Figure 1. Post-tensioning

2.2 Allowable stresses

Based on SNI 2847-2019 to calculate extreme concrete fiber stress in compression immediately after transfer of prestress, but before time-dependent prestress losses, shall not exceed the limits on Table 1 [9].

Table 1. Concrete compressive stress limits immediately after transfer of prestress [9]

Location	Concrete compressive stress limit
End of simply-supported members	$0.70f_{ci}'$
All other locations	$0.60f_{ci}'$

For class U and T members, the calculated extreme concrete fiber stress in compression at service loads, after allowance for all prestress losses, shall not exceed the limits in Table 2 [9].

Table 2. Concrete compressive stress limits at service loads [9]

Load condition	Concrete compressive stress limit
Prestress plus sustained load	$0.45f_c'$
Prestress plus total load	$0.60f_c'$

Table 3. Concrete tensile stress limits immediately after transfer of prestress, without additional bonded reinforcement in tension zone for initial condition [9]

Location	Concrete tensile stress limit
End of simply-supported members	$0.50\sqrt{f_{ci}'}$
All other locations	$0.25\sqrt{f_{ci}'}$

2.3 Prestress Losses

Prestressed losses are classified into two types [16]:

1. Short-term or intermediate losses
   a. Elastic Shortening
   The loss in the prestressing steel stress due to elastic shortening is expressed as:

   $$\Delta f_{pES} = 0,5\frac{E_s}{E_c}\sigma_c \quad (1)$$

   b. Anchorages Slip
   The loss in the prestressing steel stress due to anchorages slip is expressed as:

   $$\Delta f_{pA} = \frac{\Delta_a}{L}E_s \quad (2)$$

   c. Friction and Wobble Effect
   The loss in the prestressing steel stress due to friction and wobble effect is expressed as:

   $$\Delta f_{pF} = f_1(\mu\alpha + KL) \quad (3)$$

2. Long-term or Time Dependent Losses
   a. Relaxation of Steel
      The loss in the prestressing steel stress (i.e., the change in stress) due to relaxation of steel over time interval (t; tj) is expressed as:

$$\Delta f_{pR} = f_{pi}(\frac{logt_2 - logt_1}{45})(\frac{f_{pi}}{f_{py}} - 0{,}55) \quad (4)$$

   b. Shrinkage of Concrete
      The loss in the prestressing steel stress due to shrinkage of concrete over a time interval (t; tj) is expressed as:

$$\Delta f_{pSH} = 8{,}2 \times 10^{-6} K_{SH} E_{ps}(1 - 0{,}0236\frac{V}{S}) \times (100 - RH) \quad (5)$$

   c. Creep of Concrete
      The stress loss in the prestressing steel due to creep of concrete over a time interval (t; tj) is expressed as:

$$\Delta \boldsymbol{f_{pCr}} = \boldsymbol{nK_{CR}(f_{cir} - f_{csd})} \quad (6)$$

2.4 Allowable deflection

Based on SNI 2847:2019, allowable deflection can be seen on Figure 2 about maximum permissible calculated deflections.

Member	Condition		Deflection to be considered	Deflection limitation
Flat roofs	Not supporting or attached to nonstructural elements likely to be damaged by large deflections		Immediate deflection due to maximum of L_r, S, and R	$\ell/180$[1]
Floors			Immediate deflection due to L	$\ell/360$
Roof or floors	Supporting or attached to non-structural elements	Likely to be damaged by large deflections	That part of the total deflection occurring after attachment of nonstructural elements, which is the sum of the time-dependent deflection due to all sustained loads and the immediate deflection due to any additional live load[2]	$\ell/480$[3]
		Not likely to be damaged by large deflections		$\ell/240$[4]

[1]Limit not intended to safeguard against ponding. Ponding shall be checked by calculations of deflection, including added deflections due to ponded water, and considering time-dependent effects of sustained loads, camber, construction tolerances, and reliability of provisions for drainage.

[2]Time-dependent deflection shall be calculated in accordance with 24.2.4, but shall be permitted to be reduced by amount of deflection calculated to occur before attachment of nonstructural elements. This amount shall be calculated on basis of accepted engineering data relating to time-deflection characteristics of members similar to those being considered.

[3]Limit shall be permitted to be exceeded if measures are taken to prevent damage to supported or attached elements.

[4]Limit shall not exceed tolerance provided for nonstructural elements.

Figure 2. The maximum permissible calculated deflections [9]

2.5 Cracking moment

Based on SNI 2847:2019, for minimum flexural reinforcement in prestressed beams, total quality of A_s and A_{ps} shall be adequate to develop a factored load at least 1.2 times the cracking load calculated based on f_r bellow [9]:

$$f_r = 0{,}62\lambda\sqrt{f_c{}'} \quad (7)$$

The cracking moment can be calculated as,

$$M_{cr} = \left(\frac{F_e}{A} \times \frac{I}{y_b}\right) + \left(\frac{F_e \times e \times y_b}{I} \times \frac{I}{y_b}\right) + \left(f_r \times \frac{I}{y_b}\right) \quad (8)$$

2.6 Minimum reinforcement

Based on SNI 2847:2019 for beams with unbonded tendons, the minimum area of bonded deformed longitudinal reinforcement, $A_{s,min}$ shall be [9]:

$$A_{s,min} = 0{,}004A_{ct} \quad (9)$$

where: A_{ct} is the area of that part of the cross section between the flexural tension face and the centroid of the gross section.

2.7 Shear Design

Based on SNI 2847:2019, for prestressing components, the value of V_c is allowed to be teken the smallest between V_{ci} and V_{cw} [9].

$$V_{ci} = 0{,}05\lambda\sqrt{f_c'}b_w d_p + V_d + \frac{V_i M_{cre}}{M_{max}} \quad (10)$$

$$V_{ci} = 0{,}14\lambda\sqrt{f_c'}b_w d \quad (11)$$

$$V_{cw} = (0{,}29\lambda\sqrt{f_c'} + 0{,}3f_{pc})b_w d_p + V_p \quad (12)$$

3 Results and Discussions

The prestressed beam in this case will be design using post tension method with curved tendon. The analysis and design of prestressed beams in this case using ETABS'17 software. The following is the data for design the prestressed concrete beam:

1. Section and material properties:
   a. The width of the beam (b): 600 mm.
   b. The height of the beam (h): 900 mm.
   c. The length of the beam (L): 18000 mm.
   d. Specified compressive strength of concrete (fc'): 41.5 MPa.
   e. Type of strand: Low relaxation, Seven-Wire Steel Strand for Prestressed Concrete (A416/A416M-16).
   f. Grade of the strand: Grade 270.
   g. Nominal diameter of strand: 12.7 mm.
   h. Minimum breaking strength of strand: 184 kN.
   i. Steel area of strand: 98.7 mm^2.
   j. Type of tendon : (5-27) unit strand

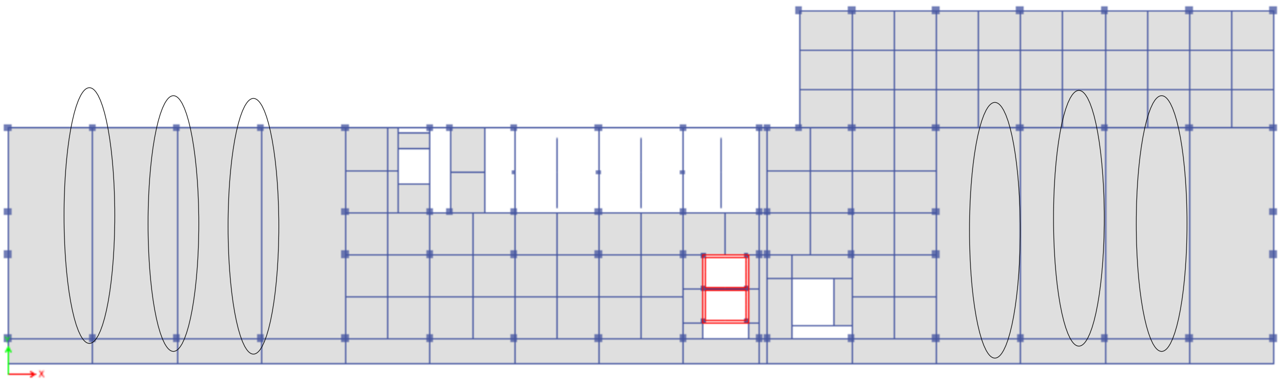

Figure 3. The 4th floor plan, section circled by prestress on ETABS

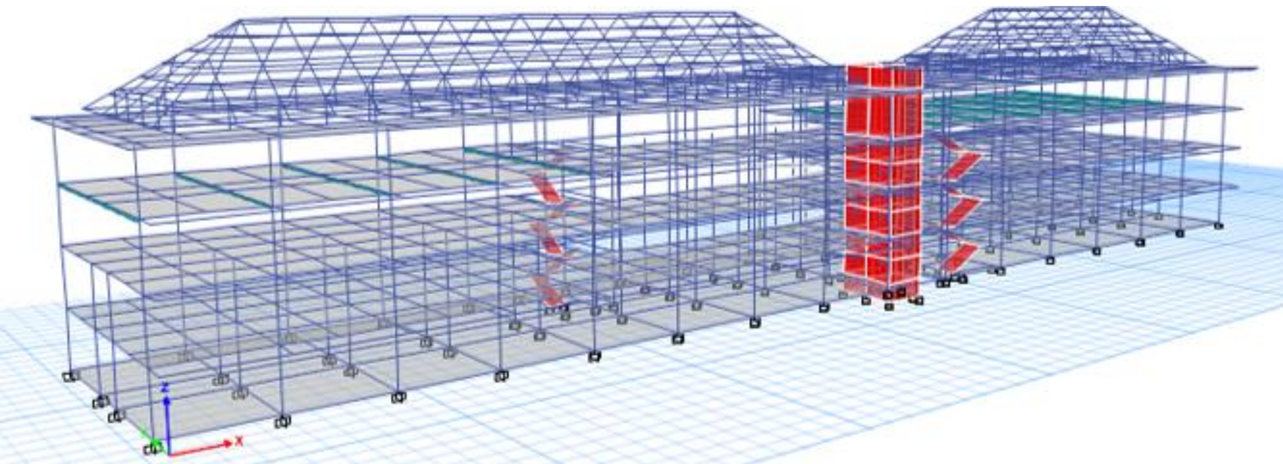

Figure 4. 3D view of existing structures and 4th floor additional structures using ETABS

The view of the modelling structure and prestressed concrete beam using ETABS can be seen on the Figure 3 and Figure 4.

2. Design parameters
   The result of the design parameters is the determination of the prestressing force at end of jacking, the number of tendon and strand.
   a. Prestressing force at and of jacking (Fo): 1500 kN
   b. The number of tendons: 1 unit
   c. The number of the strands: 12 units
3. Prestressed losses
   The result of calculation prestressed losses on beam can be seen in the table below:

Table 4. Recapitulation of the prestress losses

Prestress losses	Result (MPa)
Elastic shortening	0
Anchorages slip	0
Friction and wobble effect	75.09
Creep of concrete	6.93
Shrinkage of concrete	61.63
Relaxation of steel	25.60
Total losses	169.24

Based on Table 4, the percentage of total prestressed losses is 13% and it is smaller than the limit of prestressed loss for post tensioning that is 20%.

4. Total stress after prestress losses
   a. The initial stress for top section σ_{top} = -6.27 MPa
   b. The allowable compression for concrete σ_{ciall} = 24.9 MPa
   c. The initial stress for bottom section σ_{bottom} = 2.02 MPa
   d. The allowable tension for concrete σ_{tiall} = 3.22 MPa
   Based on the stress result above, both top and bottom section is qualified.
5. Deflection control
   Maximum permissible calculated deflections:
   $\delta_{all} = \frac{L}{480} = \frac{18000}{480} = 75\ mm$
   Based on analysis result, total deflection that occurs due to service load is 23.05 mm. It can be concluded that deflection that occurs is smaller than maximum permissible deflection.
6. Cracking moment control
   Based on analysis result modulus of rupture, f_r is 3.1. The result of cracking moment is 1185.34 kNm.

The control calculation:

$\emptyset M_n > 1{,}2\ M_{cr}$

$2155{,}68\ kNm > 1185{,}34$ kNm

Based on the calculation above, the cracking control moment is qualified.

7. Reinforcement design

The design of reinforcement addition on beam is using 8D25 and 6D25 for longitudinal reinforcement and 2D13 of shear stirrups. The view of the reinforcement addition on beam can be seen in Figure 4.

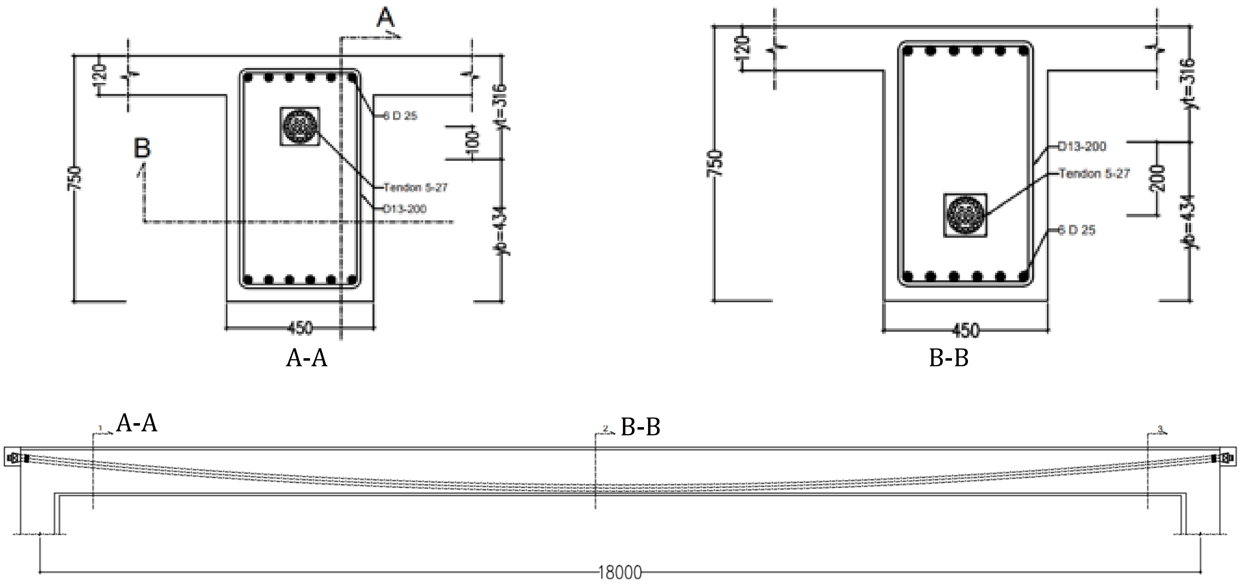

Figure 5. Details of prestressed beam design

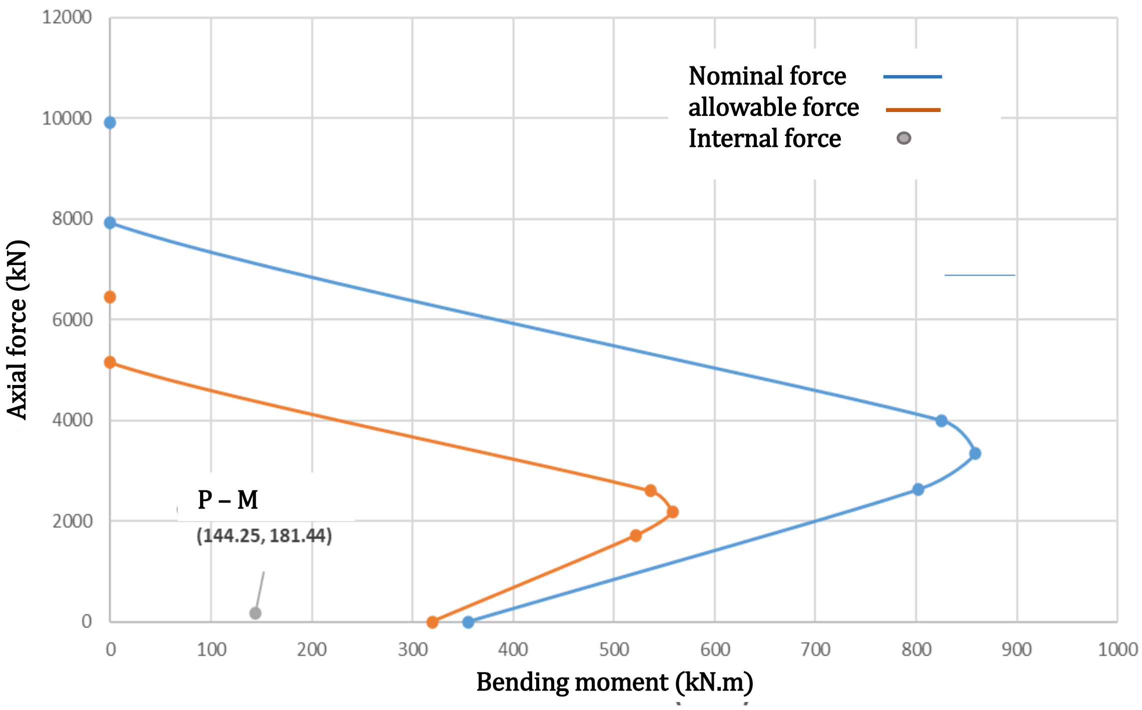

Figure 5. P-M K4 interaction diagram (60 x 60)

Analysis of Column Longitudinal Reinforcement on Supplementary Floors, The longitudinal reinforcement of the K4 column (60 x 60) is shown in the form of the P-M interaction diagram (Figure 5).

Based on the Figure 5, the value of internal force or R derived from the results of the ETABS program analysis (Mu = 144.25 kNm, Pu = 181.44 kN) is in the area of the design strength interaction diagram. So based on the diagram, it can be concluded that column K4 (60 x 60) is still able to withstand the working load for prestressed beam.

4 Conclusion

Based on the design and result mention above, prestressed beam on Nyitdah Hospital can be using as the alternative of increasing the spans in a building room. The deflection that occurs in the use of prestressed beams with long span is proven smaller than maximum permissible deflection. The reinforcement addition on the beam is needed to support the beam due to earthquake load and before the beam applied to the prestressing force.

Therefore, in conclusion, prestressed beam can also be an alternative and effectively used for increasing the spans in a building room. The benefit of using post-tensioning method is that the tensioning can be execute in stages, for all tendons in a member, or for some of them.

Planning of prestressed beams on additional floors with dimensions (450 x 750 cm) and length of 18 meters and using 1 tendon with 24 strands in each prestressed beam. The prestress loss in the planned beam is 18.71%.

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