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MODIFICATION OF MECHANICAL ENGINEERING POSTGRADUATE BUILDING STRUCTURE OF STATE POLYTECHNIC OF MALANG USING PRESTRESSED BEAM

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ABSTRAK

Gedung Pascasarjana Teknik Mesin, Politeknik Negeri Malang terdiri dari 4 lantai yang difungsikan sebagai kegiatan belajar mengajar. Pengembangan dan inovasi kampus membutuhkan penambahan fasilitas dan kapasitas gedung dengan menambah jumlah lantai menjadi 6 lantai. Salah satu fasilitas yang ditambahkan adalah kantin. Perencanaan gedung menggunakan balok prategang sepanjang 12 meter di lantai 4, yaitu aula pertemuan sehingga kolom penumpu pada tengah lantai 3 bisa dihilangkan. Perencanaan ini bertujuan untuk mendesain dan menganalisis elemen-elemen struktur termasuk balok prategang. Metode pelaksanaan menggunakan sistem rangka pemikul momen khusus dengan ketahanan terhadap gempa sesuai aturan terbaru perencanaan struktur, yaitu SNI 2847-2019. Mutu beton serta baja yang digunakan adalah berturut-turut 30 MPa dan 400 MPa. Mutu beton 42 MPa digunakan untuk balok prategang. Hasil analisis perencanaan prategang pasca-tarik mengindikasikan bahwa balok prategang mengalami kehilangan gaya friksi 6,37%, pengangkuran 5,04%, rangkak 4,99%, susut 0,07%, dan relaksasi baja 9,07%. Kehilangan gaya prategang total yang didapat sebesar 25,53%. dengan gaya prategang 3000 kN dapat bekerja pada struktur. Penggunaan balok prategang di lantai 4 dapat menghilangkan kolom lantai 3 dan menambah luas area untuk fasilitas pendukung yang direncanakan.

Kata kunci : struktur tahan gempa; sistem rangka pemikul momen khusus (SRPMK); balok prategang pasca-tarik.

ABSTRACT

The Postgraduate Mechanical Engineering Building, Malang State Polytechnic consists of 4 floors which function as teaching and learning activities. Campus development and innovation requires additional facilities and building capacity by increasing the number of floors to 6 floors. One of the added facilities is the canteen. The building planning uses a 12-meter pre-stressed beam on the 4th floor, which is the meeting hall so that the supporting column in the middle of the 3rd floor can be eliminated. This plan aims to design and analyze structural elements including prestressed beams. The implementation method uses a special moment-bearing frame system with earthquake resistance according to the latest structural planning rules, namely SNI 2847-2019. The quality of concrete and steel used was 30 MPa and 400 MPa, respectively. Concrete quality of 42 MPa was used for prestressed beams. The results of the post-tensile prestressing planning analysis indicated that the prestressed beams experienced a frictional force loss of 6.37%, anchorage of 5.04%, creep of 4.99%, shrinkage of 0.07%, and steel relaxation of 9.07%. The total prestress force loss obtained is 25.53%. with a prestress force of 3000 kN can work on the structure. The use of prestressed beams on the 4th floor can eliminate the 3rd floor columns and increase the area for the planned supporting facilities.

Keywords : *earthquake resistant structure; special moment resisting frame (SRMF); post-tensioned prestressed beam*

1. PREFACE

Background

"Gedung Kuliah Bersama" of State Polytechnic of Malang functions as a teaching and learning activity for mechanical engineering and postgraduate majors. This building has three main blocks, namely mechanical engineering workshops and laboratories, postgraduate buildings, and the main building which has 8 floors. This joint lecture building was built using conventional methods and structural modifications will be made to the 4th floor hall of the graduate building using pre-stressed concrete so that the load can be carried with a wide beam span without any columns in the room.

Prestressed concrete systems are not the only planning measures available. Due to certain advantages of this system, it is worth considering. The advantages of this system include that for relatively long-span beams and heavy loads, prestressed beams generally require a smaller size than ordinary reinforced concrete beams. This means that the weight of the structure can be lighter. This building uses a Special Moment Bearing Frame System (SRPMK) structural system.

Based on the book "Design of Prestressed Beam Structures" by (T.Y Lin and NED H. Burns, there are 2 types of prestressing, namely pre-tensile which is used to describe the prestressing method where after the withdrawal of steel tendons is carried out then the concrete is cast, while the post-tensile method of steel tendons is withdrawn after the concrete has hardened. Then the post-pull method is more suitable to be used because the implementation method is easier to apply to the 4th floor of the Postgraduate building.

In the case study that will be discussed in this research, re-planning with modeling and structural analysis will be carried out with Etabs software. Thus the re-planning of the design of the Joint Lecture building can meet the standards and become a building that uses prestressed beams more efficiently and meets structural safety requirements.

Problem Formulation

In this research, the formulation of problems in planning the structural design modification of the Postgraduate Building of Malang State Polytechnic includes, among others:

1. How is the preliminary design of beam and column of the Postgraduate building of Malang State Polytechnic?
2. How is the preliminary design of secondary structure of the building such as slab and stair?
3. How is the model design and structural analysis of the building using ETABS v20.0.0 software?
4. How to plan the prestressed beam structure and its implementation method?

Problem Limitation

To limit the scope of the research conducted, there are limitations that have been described as follows:

1. The structural elements planned using prestressed concrete are only beams.
2. Does not discuss the lower structure of the building and cost planning.
3. Structural analysis only uses ETABS v20.0.0 software.
4. The regulations used in building planning are SNI 2847-2019, SNI-1726-2019, SNI 1727-2020.

Research Purposes

The purpose of this research is:

1. To plan the preliminary design of beam and column of the Postgraduate building of Malang State Polytechnic.
2. To plan the preliminary design of secondary structure of the building such as slab and stair.
3. To perform model design and structural analysis of the building using ETABS v20.0.0 software.
4. To perform prestressed beam structure planning and implementation methods.

Research Benefits

Based on the research objectives, it is hoped that the results of this study can provide benefits, including:

1. As a reference for planning building structures using the post-tensioned beam method.
2. Adding and deepening the author's insight in the study of structural science, especially the prestressing method on beams.

2. METHOD

The physical data of this building are as follows:

a. Overall Building Data (Department of Mechnical Engineering and Postgraduate Building)
   - Number of Floors : 8 floors
   - Total Floor Area : 22,705 m^2
   - Basement 1 : 2.196 m^2
   - Basement 2 : 2.426 m^2
   - 1st Floor : 4.192 m^2
   - 2nd & 3rd Floors : 7.616 m^2 (3.808 m^2 /floor)
   - 4th Floors : 1.951 m^2
   - 5th – 8th Floors : 4.342 m^2
   - Type/ Structural System : SMRF
   - Project Location : Soekarno-Hatta 09, Mlg

b. Postgraduate Building Data
   - Building Height : ± 21 meters
   - Number of Floors : 5 Floors
   - Total Floor Area : 3.439 m^2
   - 1st – 3rd Floors : 2.322 m^2 (774 m^2/ floor)
   - 4th Floors + Auditorium : 1.117 m^2
   - Type/ Structural Sytem : SMRF

c. Material Quality/ Standards

Concrete:

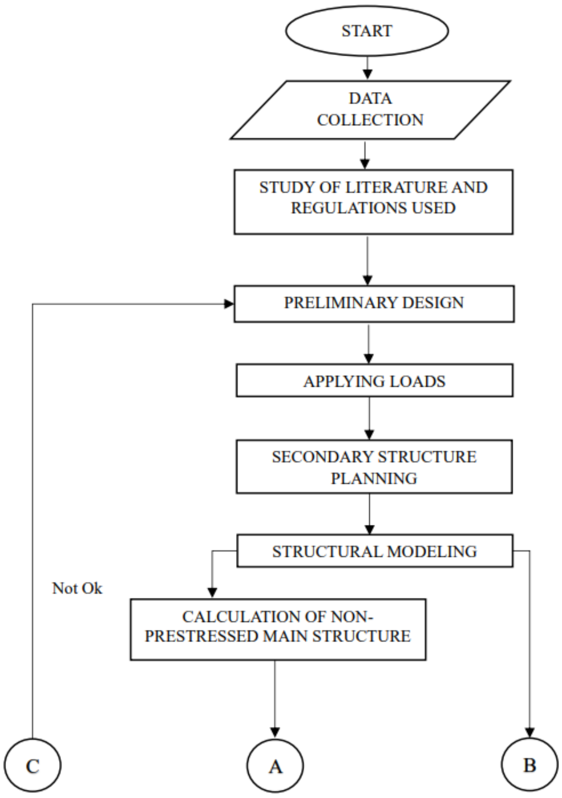
Based on the concrete strength at 28 days as follows:

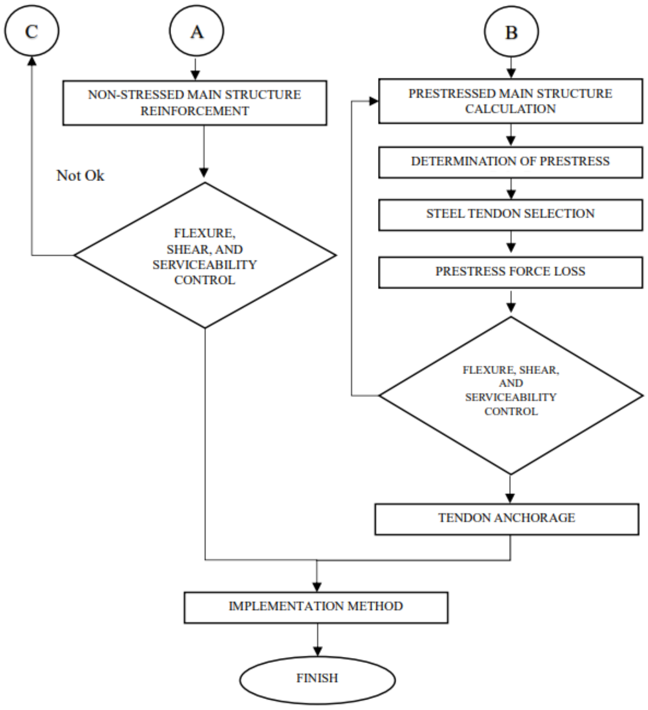
- Shear Walls : 30 MPa
- Tie Beams, Pile Caps : 30 MPa
- Slabs : f'c = 30 MPa
- Beams : f'c = 30 MPa
- Prestressed Beams : f'c = 40 MPa
- Columns : f'c = 30 MPa

Reinforcement:

- Mild Steel : 240 MPa (BJTP 24) for diameter <10 (diameter 8 mm)
- Deformed Steel : 400 MPa (BJTD 40) for diameter >10 (diameter 10mm, 13mm, etc.)

The flow of the planning stages is necessary to streamline the process for the planning the Postgraduate Building. The stages that will be utilized are as follows:





3. RESULT AND DISCUSSION

Preliminary Design

Preliminary design of structural elements is carried out to obtain dimensions that are sufficient for the building to be planned. These are the structural elements dimension:

Table 3. 1 Preliminary Design of Column

No.	Column Type	Width (mm)	Height (mm)
1	K1	400	800
2	K2	600	600

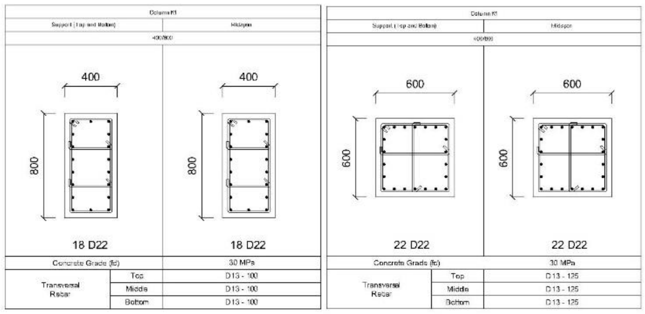


Table 3. 2 Preliminary Design of Beam

No.	Beam Type	Width (mm)	Height (mm)	Span (mm)
1	B1	350	700	8000
2	B2	400	800	9000
3	B3	350	500	8000

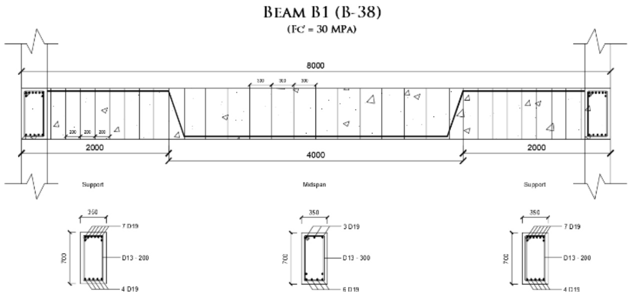


Figure 3.1 Detail of Beam B1

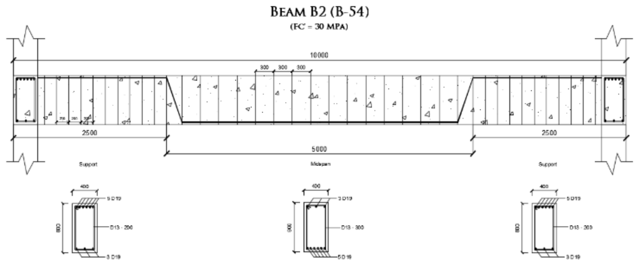


Figure 3.2 Detail of Beam B2

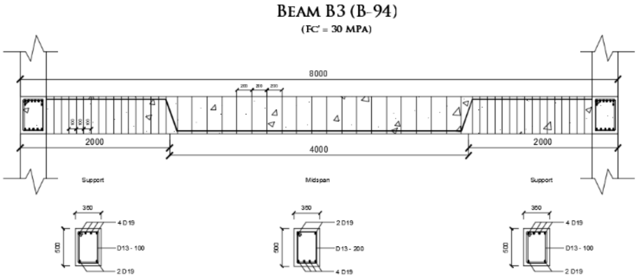


Figure 3.3 Detail of Beam B3

Load Combination

Loads must be considered using combinations for structural design. According to SNI 1726-2019, the load combinations are as follows:

1. 1,4 D
2. 1,2 D +1,6 L + 0,5 (L_r or R)
3. 1,2 D + 1,6 L (L_r or R) + (L or 0,5W)
4. 1,2 D + 1,0 W + L + 0,5 (L_r or R)
5. 0,9 D + 1,0 W
6. 1,2 D + E_v + E_h + L
7. 0,9 D - E_v + E_h

Description:

Eh = horizontal seismic influence = ρQE

Ev = vertical seismic influence = 0,2 $S_{DS}D$

QE = influence of horizontal seismic forces from V

ρ = redundancy factor, which can be taken as 1.0 for KDS A, B and C, and 1.30 for KDS D, E and F.

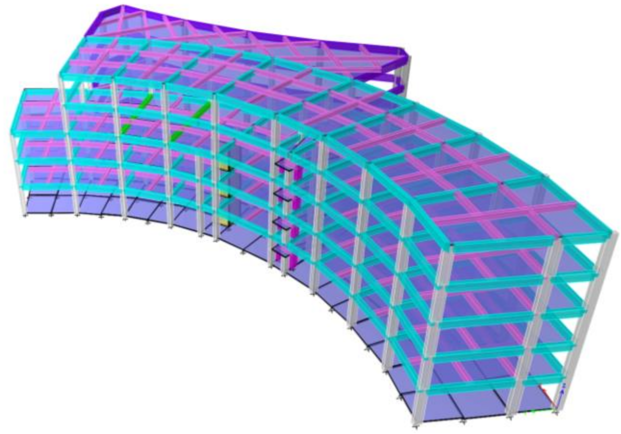


Figure 3.4 Building Model ETABS V.20.0.0

Prestressed Beam Design

Prestressed concrete is planned with the following data:

1) Concrete grade (fc') = 42 MPa.
2) Beam width (bw) = 400 mm
3) Beam height (h) = 1000 mm
4) Beam length (L) = 12000 mm
5) Beam length (net) (Ln) = 11600 mm
6) Beam T-wings thickness T (hf) = 200 mm
7) Span between beam (s) = 4000 mm
8) Composite cross-sectional area = 563200 mm2
9) Modulus of Elasticity (Ec pelat) =
$4700.\sqrt{fc'} = 4700.\sqrt{30} = 25743$ MPa
10) Modulus of Elasticity (Ec balok) =
$4700.\sqrt{fc'} = 4700.\sqrt{42} = 30459$ MPa
11) fci (14 days) = 0,88 x 42 = 37 MPa

Prestressing Force Analysis

The analysis was carried out in two conditions, namely the condition immediately after the distribution of prestress force and the service load condition. Both conditions are performed assuming that the beam structure is a simple beam. Then the F value is assumed to be given an initial stress of 3000 kN.

The structural analysis data for loading is as follows:

- Dead Load Moment (Slab + Beam + SIDL) (MG)
M_G = 586,83 kNm = 586830000 Nmm
- Dead and Live Load Moment (M_G) + (M_L)
M_L = 994,90 kNm = 994900000 Nmm
- Eccentricity design = 350 mm (below cgc)

After that, the calculation of the prestress force in the transfer and service conditions or when the load works as follows:

a. Calculating Transfer Condition Prestress Force

The calculated moment here is the self-weight of the beam (M_{balok})

1) Top fiber

$$\sigma_{tt} \geq -\frac{F_o}{A} + \frac{F_o \,.\, e}{W_t} - \frac{M_{Balok}}{W_t}$$

$$1{,}52 \text{ MPa} \geq -\frac{3000000}{780000} + \frac{3000000 \,.\, 350}{186104054} - \frac{172800000}{186104054}$$

$1{,}52 \text{ MPa} \geq 0{,}87 \text{ MPa} \rightarrow \text{OK}$

2) Bottom fiber

$$\sigma_{ct} \leq -\frac{F_o}{A} - \frac{F_o \cdot e}{W_b} + \frac{M_{Balok}}{W_b}$$

$$-22{,}18 \text{ MPa} \leq -\frac{3000000}{780000} - \frac{3000000 \cdot 350}{95762280} + \frac{172800000}{95762280}$$

$$-22{,}18 \text{ MPa} \leq -13{,}01 \text{ MPa} \rightarrow \text{OK}$$

b. Calculating Service Condition Prestress Force

At the time of service load, the calculated moments are (MG) and (ML) and are considered to have experienced a loss of 20% (post tension).

1) Top fiber

$$\sigma_{tt} \leq -\frac{F_o}{A} + \frac{F_o \cdot e}{W_t} - \frac{M_G + M_L}{W_t}$$

$$-25{,}20 \text{ MPa} \leq -\frac{2400000}{780000} + \frac{2400000 \cdot 350}{186104054} - \frac{994900000}{186104054}$$

$$-25{,}20 \text{ MPa} \leq -3{,}91 \text{ MPa} \rightarrow \text{OK}$$

2) Bottom fiber

$$\sigma_{ct} \geq -\frac{F_o}{A} - \frac{F_o \cdot e}{W_b} + \frac{M_G + M_L}{W_b}$$

$$4{,}02 \text{ MPa} \geq -\frac{2400000}{780000} - \frac{2400000 \cdot 350}{95762280} + \frac{994900000}{95762280}$$

$$4{,}02 \text{ MPa} \geq -1{,}46 \text{ MPa} \rightarrow \text{OK}$$

Determination of Tendon Usage

Tendons are planned to be ASTM-416 grade 270 (1860 MPa) Strand Stress Relieved Standard 7 wire type. The allowable stress due to the post-tensile tendon anchorage force acting on the cable is taken not to exceed 0.70 f_{pu}.

1) $f_{pmax} = 0{,}70\, f_{pu} = 0{,}70 \cdot 1860 = 1302 \text{ MPa}$
2) Tendon Area need

$$A_{perlu} = \frac{Fo}{f_{pmax}} = \frac{3000000}{1302} = 2304{,}15 \text{ mm}^2$$

3) Amount of strand (n)

$$\frac{A_{perlu}}{A_{strand}} = \frac{2304{,}15}{140} = 16{,}46 \approx 17 \text{ buah}$$

4) *Wobble* Coefficient (K) = 0,0000016/mm
5) Curvature Coefficient (μ) = 0,15
6) Tendon specification
   - Nominal Diameter = 15,24 mm
   - Breaking strength = 260,7 kN
   - Strand nominal Area = 140 mm^2
   - Minimum limit of expansion 1% = 221,5 kN
7) Tendon area used

$$A_{ps} = A_{strand} \cdot n = 140 \cdot 17$$

$$A_{ps} = 2380 \text{ mm}^2 > 2304{,}5 \text{ mm}^2 \rightarrow \text{OK}$$

$$A_{ps} = 2380 \text{ mm}^2$$

8) Minimum Breaking Load = $60{,}7 \cdot n = 260{,}7 \cdot 17 = 4431{,}9 \text{ kN}$
9) Tension control after tendon installation

$$\frac{F_o}{A_{pakai}} = \frac{3000000}{2380} = 1260{,}5 \text{ MPa} < 1302 \text{ MPa} \rightarrow \text{OK}$$

Prestressing Force Loss Analysis

Prestress loss is the reduction in the force acting on the tendons at loading stages. The following is the loss of prestress force:

1) Loss due to Elastic Shortening of Concrete

   In post-pull construction with only one tendon, the loss due to concrete elasticity is very small and tends to be ignored, because the cable pull only occurs once and there is no initial tendon shortening and loss due to the last tendon pull, the loss due to elastic shortening of concrete is not taken into account
2) Loss due to friction or shear and Wobble Effect

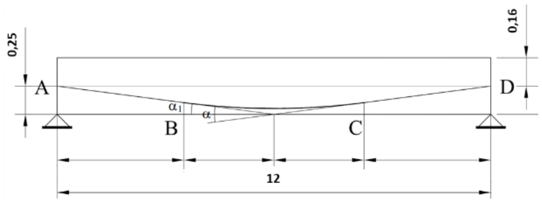


Figure 3.5 Prestressed Beam

Loss due to friction:

$$\Delta f_{fr} = 1260{,}5 \left(1 - (0{,}35)^{-((0{,}15 \,.\, 0{,}26)+(0{,}0000016 \,.12000))}\right)$$

$$\Delta f_{fr} = 80{,}28 \text{ MPa}$$

3) Loss due to anchorage.

$$\Delta f_{anc} = 2\, E_s\, \frac{g}{X}$$

$$\Delta f_{anc} = 2 \cdot 200000\, \frac{2{,}5}{15734} = 63{,}55 \text{ MPa}$$

4) Loss due to Creep in concrete.

$$\Delta f_{cr} = K_{cr} \cdot \frac{E_S}{E_C} \cdot (f_{cir} - f_{cds})$$

$$\Delta f_{cr} = 1{,}6 \cdot \frac{200000}{30459} \cdot (8{,}69 - 2{,}71) = 62{,}85 \text{ MPa}$$

5) Loss due to shrinkage.

$$\Delta f_{sh} = 8{,}2 \cdot 10^{-6} \cdot 0{,}77 \cdot 200000 \cdot \big(1 - 0{,}06(71{,}52)\big) \cdot (100 - 80)\%)$$

$$\Delta f_{sh} = 0{,}83 \text{ MPa}$$

6) Loss due to Steel Relaxation

$$\Delta f_{re} = C\,(K_{re} - J(\Delta f_{sh} + \Delta f_{cr} + \Delta f_{es})$$

$$\Delta f_{re} = 0{,}89\,(138 - 0{,}15(0{,}83 + 62{,}85 + 0)$$

$$\Delta f_{re} = 114{,}32 \text{ MPa}$$

The total prestress force loss is:

$$80{,}28 + 63{,}55 + 62{,}85 + 0{,}83 + 114{,}32 = 321{,}84 \text{ MPa}$$

$$\text{Total loss percentage} = \frac{321{,}84}{1260{,}5} \cdot 100\% = 25{,}53\%$$

$$\text{Effective prestress force} = \frac{25{,}63}{100} \cdot 3000000 \text{ N} = 2234019 \text{ N}$$

Force Control after Loss

Prestress force control after total loss with maximum earthquake loading (1,34 D + 1 L + 1,3 Spec Ex + 0,39 Spec Ey) as follows:

- Ultimate Moment = 1122,227 kN = 1122227013 N

a. Calculating Prestress Force for Service Condition

   Prestressing force control after total prestress loss (25,53%)

1) Top fiber

$$\sigma_{tt} \leq -\frac{F_o}{A} + \frac{F_o \cdot e}{W_t} - \frac{M_{lapangan}}{W_t}$$
$$-25{,}20\ MPa \leq -\frac{2234019}{780000} + \frac{2234019 \cdot 350}{186104054} - \frac{1122227013}{186104054}$$
$$-25{,}20\ MPa \leq -4{,}69\ MPa \rightarrow OK$$

2) Bottom fiber

$$\sigma_{ct} \geq -\frac{F_o}{A} - \frac{F_o \cdot e}{W_b} + \frac{M_{lapangan}}{W_b}$$
$$4{,}02\ MPa \geq -\frac{2234019}{780000} - \frac{2234019 \cdot 350}{95762280} + \frac{1122227013}{95762280}$$
$$4{,}02\ MPa \geq 0{,}69\ \text{MPa} \rightarrow \text{OK}$$

So after checking the earthquake loading reaction, the design of the prestressed structure has been fulfilled.

Method of Implementation

The prestressed beam method used is post tension or post tensile. The method of implementing prestressed concrete in the Postgraduate Mechanical Engineering building of Malang State Polytechnic is carried out by cast in site or casting in place which is none other than as follows:

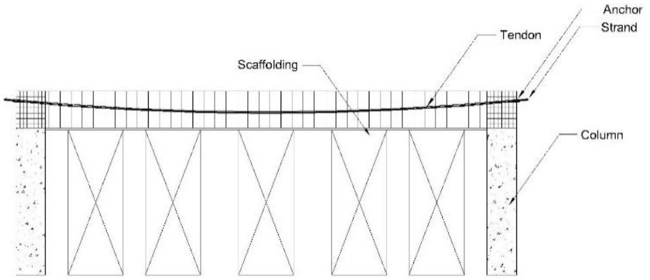


Figure 3.6 Installation of Prestressed Beam

1) Supporting columns for the prestressed beams must be completed as the main structural elements of the building. After the construction of the column structure on the 4th floor has been completed, the installation of scaffolding and secondary beams is initiated.
2) Subsequently, the formwork and installation of the planned partial prestressed concrete reinforcement are prepared.
3) Post-tensioning ducts or tendon ducts are installed in a curved configuration according to the design.
4) Strands are inserted into the tendon ducts and positioned.
5) Following that, concrete casting is performed, followed by a curing process lasting for 14 days.
6) After the final curing phase, when the concrete has gained sufficient strength to bear the prestressing force, dead-end anchors are installed on one side of the beam, while live-end anchors are installed on the other side. This is followed by the application of prestressing force or jacking.
7) The grouting process is then carried out.
8) Shear stud installation is done for the slab as per the effective width.
9) The slab is cast in place.
10) The implementation is completed.

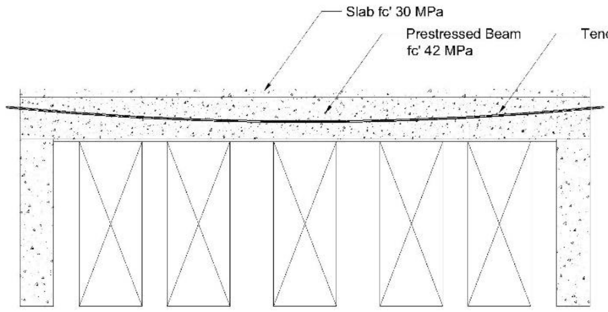


Figure 3.7 Prestressed Composite Beams

4. CONCLUSION

Based on the analysis and design of structural elements of the Postgraduate building at the State Polytechnic of Malang, as discussed earlier, the following conclusions can be drawn:

1. The design of staircase structures with concrete strength of 30 MPa and steel strength of 400 MPa is concluded to use an inclined thickness of 210 mm, with reinforcement of D10-175 for the slope and D12-100 for the landing.
2. The design of roof and floor slab structures with concrete strength of 30 MPa and steel strength of 400 MPa is concluded to use a thickness of 120 mm, with D13-75 reinforcement in the X direction (Axis 1-1) and D16-100 reinforcement in the Y direction (Axis 2-2).
3. Design of main beam B1 structures with concrete strength of 30 MPa and steel strength of 400 MPa:
   a. Width = 350 mm
   b. Height = 700 mm
   c. Longitudinal Reinforcement (Support)
      - **7D19** (As = 1901 mm^2) in the tensile region.
      - **4D19** (As = 1140 mm^2) in the compression region.
   d. Longitudinal Reinforcement (Field)
      - **6D19** (As = 1701 mm2) in the tensile region.
      - 3D19 (As = 851 mm2) in the compression region.
   e. Transverse Reinforcement (Support) = D13-200
   f. Transverse Reinforcement (Field) = D13-300
4. Design of main beam B2 structures with concrete strength of 30 MPa and steel strength of 400 MPa:
   a. Width = 400 mm
   b. Height = 800 mm
   c. Longitudinal Reinforcement (Support)
      - **5D19** (As = 1418 mm^2) in the tensile region
      - **3D19** (As = 851 mm^2) in the compression region.
   d. Longitudinal Reinforcement (Field)
      - **5D19** (As = 1418 mm^2) in the tensile region.
      - **3D19** (As = 851 mm^2) in the compression region.
   e. Transverse Reinforcement (Support) = D13-200
   f. Transverse Reinforcement (Field) = D13-300

5. Design of secondary beam B3 structures with concrete strength of 30 MPa and steel strength of 400 MPa:
   a. Width = 350 mm
   b. Height = 500 mm
   c. Longitudinal Reinforcement (Support)
      - **4D19** (As = 1134 mm^2) in the tensile region.
      - **2D19** (As = 567 mm^2) in the compression region.
   d. Longitudinal Reinforcement (Field)
      - **4D19** (As = 1134 mm^2) in the tensile region.
      - **2D19** (As = 567 mm^2) in the compression region.
   e. Transverse Reinforcement (Support) = D13-100
   f. Transverse Reinforcement (Field) = D13-200
6. Design of column K1 structures with concrete strength of 30 MPa and steel strength of 400 MPa:
   a. Width = 400 mm
   b. Height = 800 mm
   c. Longitudinal Reinforcement
      - **9D22** (As = 3421 mm^2) in the tensile and compression regions.
   d. Transverse Reinforcement (Support)
      - **D13-100** at a height 700 mm from the top and bottom faces of the column (all floors)
   e. Transverse Reinforcement (Field)
      - **D13-100** along a length of 1700 mm for columns from the 3rd floor on the roof and 2200 mm for columns on the 2nd floor.
7. Design of column K2 structures with concrete strength of 30 MPa and steel strength of 400 MPa:
   a. Width = 600 mm
   b. Height = 600 mm
   c. Longitudinal Reinforcement
      - **11D22** (As = 4181 mm^2) in the tensile and compression regions.
   d. Transverse Reinforcement (Support)
      - **D13-125** at a height 700 mm from the top and bottom faces of the column (all floors)
   e. Transverse Reinforcement (Field)
      - **D13-125** along a length 1700 mm for columns from the 3rd floor to the rood and 2200 mm for columns on the 2nd floor.
8. Prestressed Beam Structural Design:
   a. Concrete Strength fc'= 42 MPa
   b. Slab Strength fc' = 30 MPa
   c. Slab Dimensions
      - **Effective** Width= 4733 mm
      - **Slab** Height = 200 mm
   d. Prestressed Beam Dimensions
      - **Beam** Width = 400 mm
      - **Beam** Height = 1000 mm
   e. For a prestressed beam with a span of 12 meters, the effective prestressing force acting on the beam is 2400 kN, considering prestress losses due to friction of 6.37%, anchorage slip of 5.12%, creep of 3.64%, shrinkage of 0.07%, and steel relaxation of 9.54%, resulting in a total prestress loss of 24.73%
   f. Reinforcement design for the partially prestressed concrete system uses **8D22** reinforcement in the tensile zone and **4D22** reinforcement in the compression zone, along with transverse stirrups **D13-100** and **D13-200** for support and field zones, respectively.

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