Reinforcement Design of Transfer Beams in a three-Story Residential Building

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ABSTRACT

Residential buildings are buildings that are used as residences, for example, houses. In residential buildings that carry modern aesthetics will make the shape of the plan tend to be irregular, so it is necessary to adjust structural elements such as slender columns and transfer columns. A transfer column is a column that rests on a beam (grows across the beam), so the column is not continuous from the bottom floor to the top, while the beam is called a transfer beam. Transfer beams allow load distribution from the upper floors to the structural elements below. This study was conducted to determine the reinforcement requirements of transfer beams in a three-story residential building in accordance with SNI 2847: 2019. Structural analysis was carried out with the ETABS v9.7.1 program and manual calculations to determine the reinforcement configuration of the transfer beam. The result of the research is that the transfer beam with dimensions of 350 mm x 650 mm has a reinforcement configuration, namely 4D19 tensile and 6D19 compressive reinforcement in the support area, and 12D19 tensile and 6D19 compressive reinforcement in the field area, for stirrup reinforcement used 3D12 - 100 mm and for torsion reinforcement used 2D16. As for the deflection that occurs, which is 7,782 mm, this value is still within the permit limit according to SNI 2847: 2019. It can be concluded that the transfer beam is safe to use.

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1. INTRODUCTION

Limited residential land, especially in big cities, along with the increasing demand for housing, has encouraged the construction of high-rise residential buildings [1]. In some residential building designs, especially those that adopt a modern style, the plan form often becomes irregular, so it is necessary to adjust the structural elements used, for example, transfer columns. A transfer column is a column that rests on a beam so that the column cannot be continued to the ground floor or shifted in position. This challenge adds complexity to structural planning, especially in terms of how to distribute loads from the upper floors to the foundations. Transfer beams are a type of beam used to solve load distribution problems caused by the presence of non-continuous columns in a building. These transfer beams serve as an important solution to ensure the stability and safety of the building structure [2]. In addition, the use of transfer beams allows the design of buildings with more space and freedom from columns on the lower floors, providing greater flexibility in interior design. [3].

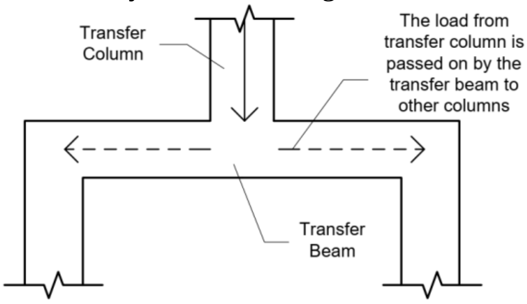


Figure 1. Transfer Beam

Beams with centralized loads can be determined based on the slenderness of the beam. The slenderness of a beam is the ratio between the distance of the centralized load (a) and the effective height of the beam (d) [4]. If the ratio a/d < 1, the beam is a deep beam [5]. A deep beam is a structural component that is loaded on one side and supported on the opposite side, so that a compressive component such as a strut can be formed between the load and the support. At least a deep beam must have one of two conditions, namely (i) The clear span does not exceed four times the height of the beam ($L_n \leq 4h$) and (ii) The centered load is within 2h of the face of the support ($a \leq 2h$) [6].

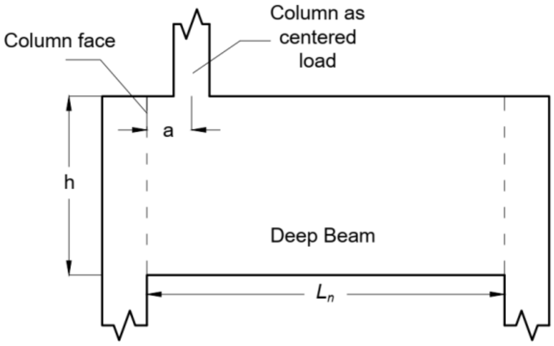


Figure 2. Deep Beam

The stress distribution in deep beams is a non-linear stress distribution, so the completion of structural elements requires special methods, one of which is the strut and tie method [7], but simplified methods in the calculation of shear forces for deep beam can also be applied [8]. But if a beam with a centralized load is not categorized as a deep beam, then the structural solution is like an ordinary beam, except that the beam receives a large load [9].

The use of transfer beams in the construction world has generally been widely used, several previous studies on transfer beams in buildings have been carried out to determine the reinforcement requirements used. Research has been conducted by Fahmi & Buwono (2020), namely modeling a three-story residential building with the use of transfer beams on the 2nd floor using the ETABS program. The resulting transfer beam dimensions are 400 mm x 800 mm with a reinforcement configuration of 4D25 tensile and 3D25 compressive reinforcement in the support area and 3D25 tensile and 6D25 compressive reinforcement in the field area, for stirrup reinforcement used 2D10-100 [10]. Another research conducted by Alvandi et al (2019) is modeling a 12-story high rise building with the use of transfer beams on the 6th and 7th floors using the ETABS program. The results obtained are the dimensions of the transfer beam used are 600 mm x 700 mm with a reinforcement configuration of 8D16 compressive and 6D19 tensile reinforcement, the stirrup reinforcement used is 2D13 – 100 [11].

Beams are structural elements that are usually installed horizontally and function to distribute gravity loads into column elements. The bending moment, shear force and torsion moment are internal forces on the beam due to the loading that occurs, for which reinforcement is needed to bear these internal forces, namely bending reinforcement, shear reinforcement and torsion reinforcement [12].

a. Flexural Reinforcement

Flexural reinforcement in beams, also known as longitudinal reinforcement, is a type of reinforcement that is installed parallel to the long axis of the beam to resist bending moments. The installation of this flexural reinforcement can be done singly or in multiples, depending on the magnitude of the moment that the beam must resist. The nominal moment strength of the beam is calculated based on the following equation [13]:

$$M_n = A_s\, f_y \left(d - \frac{a}{2}\right) \quad (1)$$

Description :

M_n : Nominal bending moment (Nmm)
A_s : Reinforcement area (mm)
f_y : Yield strength of reinforcement (Mpa)
d : Effective height of the beam (mm)
a : Height of beam compression block (mm)

b. Shear Reinforcement

Shear reinforcement in beams is a reinforcement that functions to withstand the latitudinal forces that are large enough to cause oblique cracks in the beam. Shear reinforcement is installed by enclosing the longitudinal reinforcement of the beam. The nominal shear force of the beam is calculated based on the following equation [14] :

$$V_n = V_c + V_s \quad (2)$$

Description :

V_n : Nominal shear strength (N)
V_c : Shear strength of concrete (N)
V_s : Shear strength of reinforcement (N)

c. Torsion Reinforcement

The torsional moment acting on the longitudinal axis of the beam will be resisted by torsion reinforcement distributed around the beam cross section. The nominal torsional moment of the beam is calculated based on the following equation [15] :

$$T_n\ (shear) = \frac{2\ x A_o\ x\ A_t\ x\ f_{yt}}{s} \cot 45° \quad (3)$$

$$T_n\ (flexural) = \frac{2\ x\ A_o\ x\ A_l\ x\ f_y}{P_h} \tan 45° \quad (4)$$

Description :

T_n : Nominal torsion moment (Nmm)
A_o : 0,85 x perimeter of the beam (mm)
A_t : Area of stirrups (mm)
f_{yt} : Yield strength of stirrups (Mpa)
s : Spacing of stirrups (mm)
A_l : Flexural reinforcement area (mm)
f_y : Yield strength of flexural reinforcement (Mpa)
P_h : Cross sectional area of the beam (mm^2)

The deflection of the transfer beam is checked in accordance with SNI 2847:2019 Article 24.2.2, which is the deflection that occurs due to the service level gravity load [6]. The deflection that occurs must not exceed the limit as per table 1.

Table 1. Maximum allowable deflection [6]

Conditions	Deflection Limit
Does not bear nonstructural elements	L_n / 360
Bears nonstructural elements	L_n / 480

2. METHODS

2.1 Research Data

This study was conducted on a three-story residential building located in Kalimantan with SRPMM structural system. The transfer beam under review is located at the 2nd floor with dimensions of 350 mm x 650 mm (B15), carrying loads from the slab, columns above it and 3,5 meter high wall loads. The concrete compressive strength used is K300 with reinforcement grades BjTS 280 and BjTS 420B. The following is the beam plan that will be reviewed.

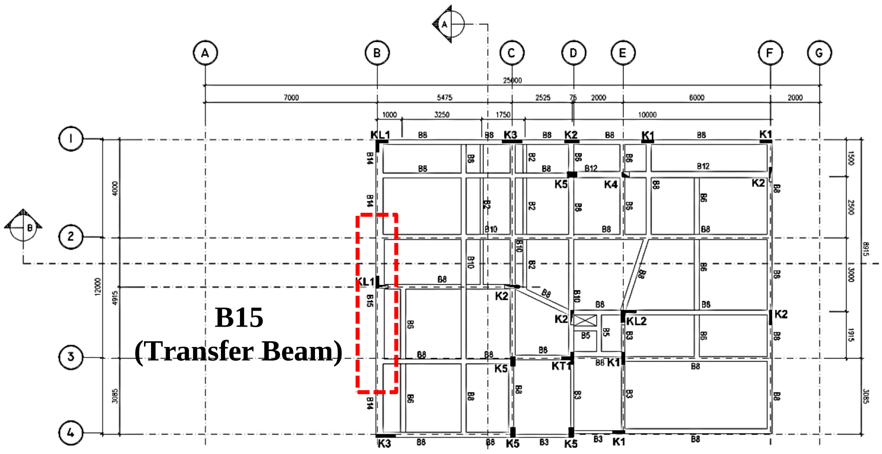


Figure 3. Floor Plan 2

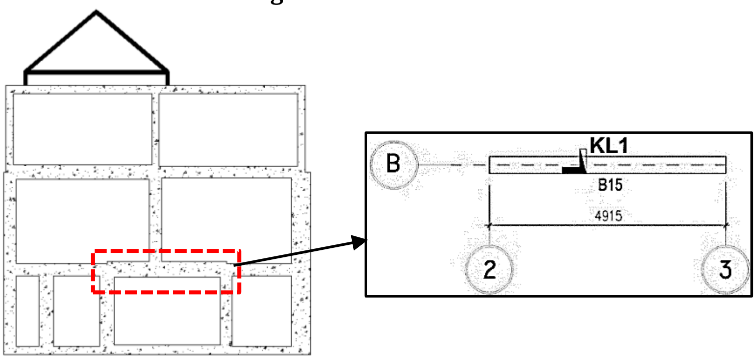


Figure 4. Transfer Beam Location (B15)

2.2 Research Procedure

In general, there are two stages of research carried out, namely structural modeling using the ETABS program and manual calculation of transfer beams based on SNI 2847: 2019. An illustration of the research procedure is presented in Figure 5.

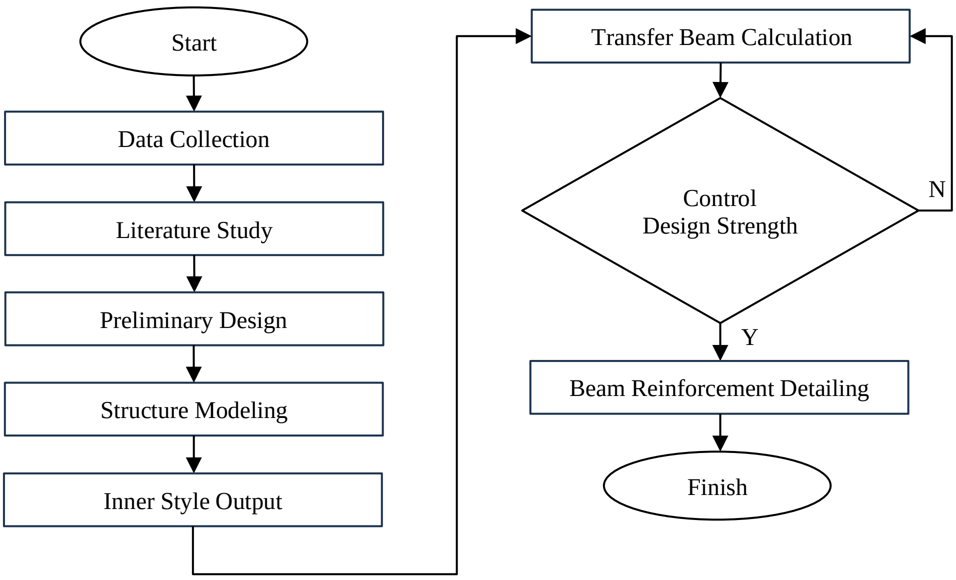
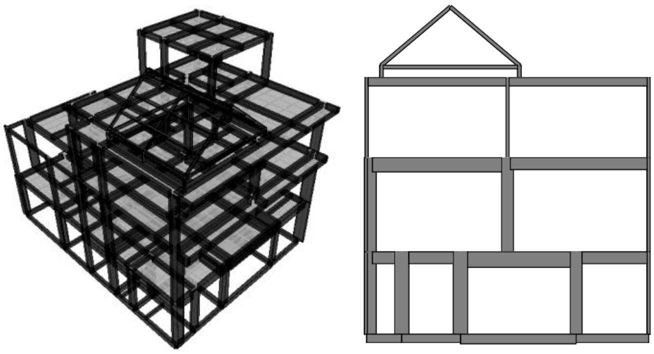


Figure 5. Flowchart of Research Procedure

a. Structure Modeling
   In this section begins with making column and beam plans based on working drawings, the initial dimensions of columns, beams and plates (*preliminary design*) are calculated according to SNI 2847: 2019. The stage is continued by modeling the building in the ETABS program according to the data that has been determined. Then input the loads according to SNI 1727: 2020 [16], continued with the analysis of the structural period, shear force and building mode shape according to SNI 1726: 2019 [17].
b. Transfer Beam Calculation
   The transfer beam under review is the transfer beam with the largest internal force. Next, the beam type is determined, whether it is a deep beam or an ordinary beam, which will determine the beam reinforcement calculation procedure. Then the nominal strength is checked to see if the beam is able to carry the working loads. The last step is to make beam reinforcement detailing (drawings) based on SNI 2847: 2019.



Gambar 6. Modeling of Buildings

3. RESULTS AND DISCUSSION

3.1 Force In Transfer Beam

The following is the force in the transfer beam (B15) based on the results of the structural modeling performed.

Table 2. Force In Beam B15

Beam	Negative Moment (kNm)	Positive Moment (kNm)	Shear Force (kN)	Torsion Moment (kNm)	Load Comb.
B15 (Support)	241,54	348,5	552,6	54,27	*Envelope*
B15 (Midspan)	0	663,53	509,11	54,27	*Envelope*

3.2 Determining Beam Type

As a first step in calculating beam reinforcement, the type of beam will be determined, whether it is a deep beam or not. The following is an image of the longitudinal cross section of beam B15.

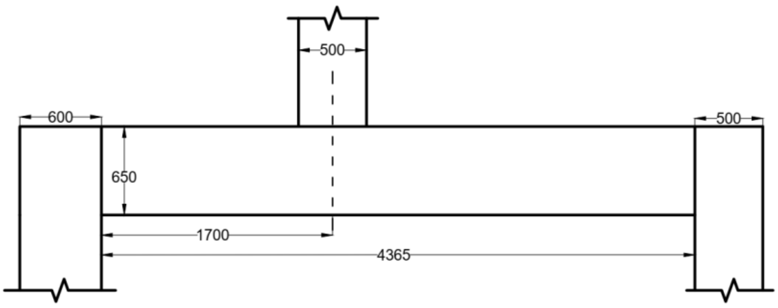


Figure 7. Longitudinal Cross Section of Beam B15

Based on the picture, it can be seen :
Beam height (h) = 650 mm
Net span of beam (L_n) = 4365 mm
Centralized load distance to nearest column face (a)= 1700 mm
Based on Article 9.9 SNI 2847: 2019 deep beam is determined based on the following 2 conditions[6]:

a. $L_n \leq 4h$ = $4365 \leq 4 \times 650 = 4365 \leq 2600$ (Does not meet)
b. $a \leq 2h$ = $1700 \leq 2 \times 650 = 1700 \leq 1300$ (Does not meet)

Since none of the conditions are met, beam B15 is not a deep beam, so the method used in determining the reinforcement of beam B15 is in the same way as in general beams.

3.3 Check Beam Deflection Against Clearance Deflection

The following is the amount of deflection in the transfer beam obtained through the program.

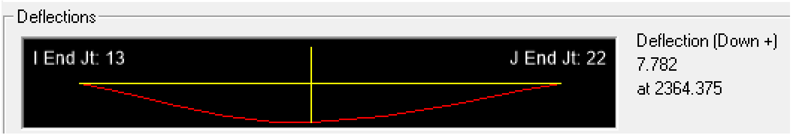


Figure 8. Beam Deflection B15 (Comb. 1,2 D + 1,6L) (mm)

The beam is a beam that will carry nonstructural elements, so the allowable deflection is :
Permitted deflection = L_n / 480 = 4365 mm / 480 = 9,094 mm
Deflection of beam B15 = 7,782 mm < 9,094 mm
Since the deflection of the beam is below the limit of the allowable deflection, the deflection of the beam is qualified.

3.4 Flexural reinforcement

For example, the following describes the calculation of flexural reinforcement in the positive field section (largest bending moment).

Checking whether compressive reinforcement is required or a single reinforcement is sufficient

Assumed value of c/d_t = 0,3 (Assumed to be tensile controlled ($c/d_t \leq 0,375$))
Main reinforcement (ØP) = 19 mm
Reinforcement stirrup (Øs) = 12 mm
Effective height ($d = d_t$) = h – ts – Øs – 0,5 x ØP
= 650 – 30 – 12 – 0,5 x 19 = 598,5 mm
Neutral axis height (c) = 0,3 x 598,5 = 179,550 mm
Pressure block conversion factor (β_1) = 0,850 (f'c < 28) (Article 22.2.2.4.3)
Press block height (a) = c x β_1 = 179,550 x 0,85 = 152,618 mm
Concrete compressive force (C_C) = 0,85 x f'c x b x a
= 0,85 x 24,9 x 350 x 152,618 = 1130552,3 N
Nominal moment (M_{n1}) = C_C x (d – a/2)
= 1130552,3 x (598,5 – 152,618/2)
= 590364511,2 Nmm = 590,365 kNm
Moment strength reduction factor (ϕ) = 0,9 (Assumed to be tensile controlled)
Ultimate Moment (M_u) = 663,53/0,9 = 737,256 kNm

Since 590,365 (M_{n1}) < 737,256 (M_u), compressive reinforcement (double) is required. Furthermore, the assumption of tensile controlled collapse will be re-examined.

Calculating the value of M_{n2} dan the compressive reinforcement stress (f_s')

Remaining M_n required (M_{n2}) = M_u – M_{n1} = 737,256 - 590,365
= 146,891 kNm = 146891044,3 Nmm
Compressive reinforcement used (ØP') = 19 mm

d' (assumption of 1-layer) $= ts + Øs + 0,5 \times ØP$
$= 30 + 12 + 0,5 \times 19 = 51,5$ mm

Strain of compressive reinforcement ($Ɛ_s$') $= \frac{0,003\,(c - d')}{c} = \frac{0,003\,(179,55 - 51,5)}{179,55}$
(Article 21.2.2.1) $= 0,0021$

Compressive reinforcement stress (f_s') $= E_S \times f_s' = 200000 \times 0,0021 = 427,903$ Mpa

Because $f_s' > 400$ Mpa (f_y) the compressive reinforcement has yielded, so it is used $f_s' = f_y = 420$ Mpa

Calculating Reinforcement Area and Reinforcement Spacing

Compressive reinforcement area required (A_S') $= \frac{M_{n2}}{f_s' \times (d - d')} = \frac{146891044,3}{420 \times (598,5 - 51,5)} = 639,379\ mm^2$

Tensile reinforcement area required (A_S) $= A_{S1} + A_S' = 2691,791 + 639,379 = 3717,468\ mm^2$

Used 4D19 (A_S') $= 4 \times 0,25 \times \pi \times 19^2 = 1134,115\ mm^2$

Used 12D19 (A_S) $= 12 \times 0,25 \times \pi \times 19^2 = 3402,345\ mm^2$

Spacing between compressive reinforcement (s') $= \frac{b - 2 \times ts - 2 \times Øs - n \times ØP}{(n - 1)}$
(Article 25.2.1)
$= \frac{350 - 2 \times 30 - 2 \times 12 - 4 \times 19}{(4 - 1)} = 63,33$ mm > 25 mm

Spacing between tensile reinforcement (s) $= \frac{b - 2 \times ts - 2 \times Øs - n \times ØP}{(n - 1)}$
(Article 25.2.1)
$= \frac{350 - 2 \times 30 - 2 \times 12 - 12 \times 19}{(12 - 1)} = 3,45$ mm < 25 mm

Since the tensile reinforcement spacing is < 25 mm, the tensile reinforcement needs to be installed in 2 layers (6 pieces per layer).

Spacing of reinforcement in layers 1 and 2 $= \frac{350 - 2 \times 30 - 2 \times 12 - 6 \times 19}{(6 - 1)} = 30,4$ mm > 25 mm

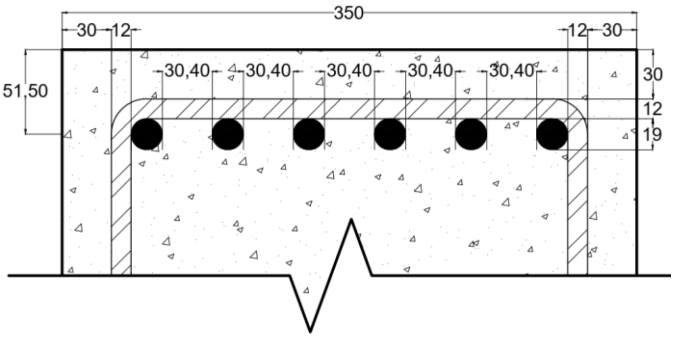


Figure 9. Spacing Distance Between Reinforcements

Because the tensile reinforcement is made in 2 layers, the effective height (d) must be recalculated

Reinforcement cross-sectional area (A_S) $= 0,25 \times \pi \times 19^2 = 283,5\ mm^2$

Bottom layer distance to tensile fiber (l_1) = h – d assumption 1 layer = 650 – 598,5 = 51,5 mm

Net distance of layer 2 and layer 1 (s) = 25 mm (SNI 2847 : 2019 Article 25.2.1)

Top layer distance to tensile fiber (l_2) $= l_1 + 0,5 \times ØP + s + 0,5 \times ØP$
$= 51,5 + 0,5 \times 19 + 25 + 0,5 \times 19 = 95,5$ mm

Point of weight 2 ply to tensile fiber (y) $= \frac{(n_1\ A_S\ l_1) + (n_2\ A_S\ l_2)}{(n_{total}\ A_S)}$
$= \frac{(6 \times 283,5 \times 51,5) + (6 \times 283,5 \times 95,5)}{(12 \times 283,5)} = 73,5$ mm

So the new effective height (d) = h – y = 650 – 73,5 = 576,5 mm

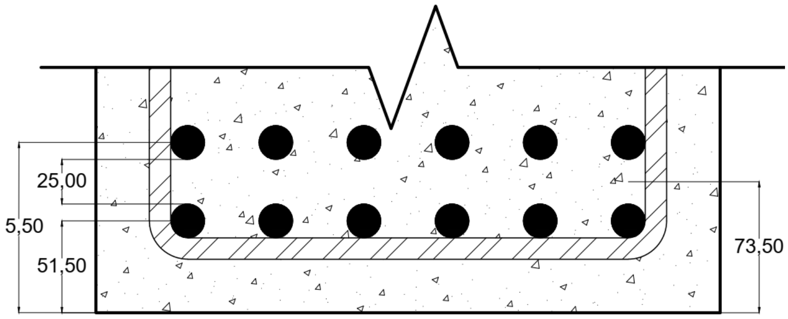


Figure 10. Vertical Spacing Distance Between 2 Rows Of Reinforcement

Calculating the compressive block height (a) and neutral axis height (c)

Press block height (a) *(Article 22.2.2.4.1)*
$$= \frac{A_S \times f_y - A_S' \times f_s'}{0{,}85 \times f'c \times b}$$
$$= \frac{3402{,}345 \times 420 - 1134{,}11 \times 420}{0{,}85 \times 24{,}9 \times 350} = 128{,}603 \text{ mm}$$

Neutral axis height (c) *(Article 22.2.2.4.1)* $= a / \beta_1 = 128{,}603 / 0{,}85$
$= 151{,}297$ mm

Check collapse type *(Article 21.2.2)* $= c / d_t = 151{,}297 / 598{,}5$
$= 0{,}253 < 0{,}375$ (Controlled tensile)

Tensile reinforcement strain (ε_s) *(Article 21.2.2.1 and 21.2.2)*
$$= \frac{0{,}003 \times (d - c)}{c} = \frac{0{,}003 \times (576{,}5 - 151{,}297)}{151{,}297}$$
$= 0{,}0084 > 0{,}005$ (Controlled tensile)

Since the type of collapse is controlled tensile or ductile, the moment strength reduction factor (ϕ) used is equal to 0,9 (Article 21.2.2).

Calculating nominal strength and checking beam capacity

Nominal Moment (M_n) *(Article 22.3.1.1)*
$= C_C \times (d - a/2) + C_S \times (d - d')$
$= (A_S \times f_y - A_S' \times f_s') \times (d - a/2) + A_S' \times f_s' (d - d')$
$= (3402{,}345 \times 420 - 1134{,}115 \times 420) \times (576{,}5 - 151{,}297/2) + 1134{,}115 \times 420 (576{,}5 - 51{,}5)$
$= 738021754{,}1$ Nmm $= 738{,}022$ kNm

$\phi\ M_n$ $= 738{,}022 \times 0{,}9 = 664{,}220$ kNm

Ultimate Moment (M_u) $= 663{,}530$ kNm

Because $\phi\ M_n > M_u$, the beam with **12D19** tensile reinforcement and **4D19** compressive reinforcement can be said to be sufficient and safe to bear the positive moment in the field area.

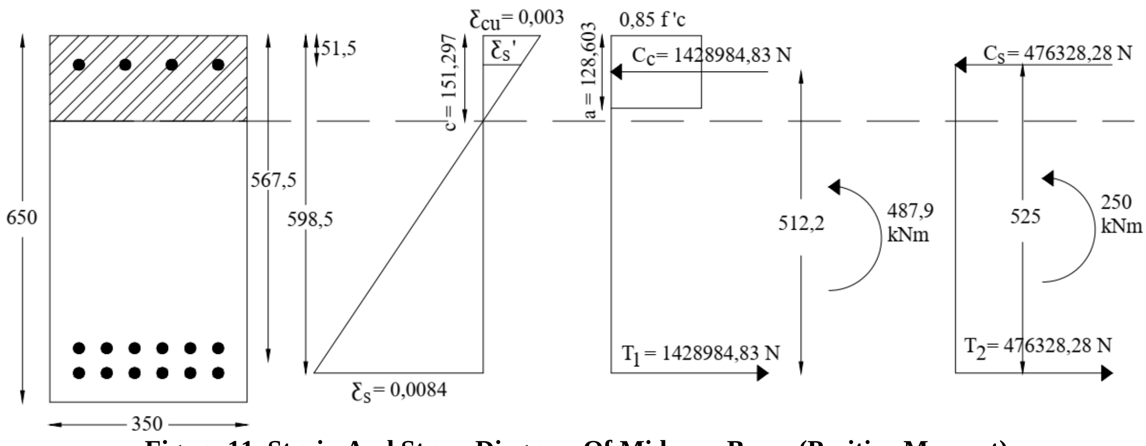


Figure 11. Strain And Stress Diagram Of Midspan Beam (Positive Moment)

In the same way, the number of longitudinal reinforcements required at the support and field areas is obtained. The reinforcement configuration is presented in Figure 12.

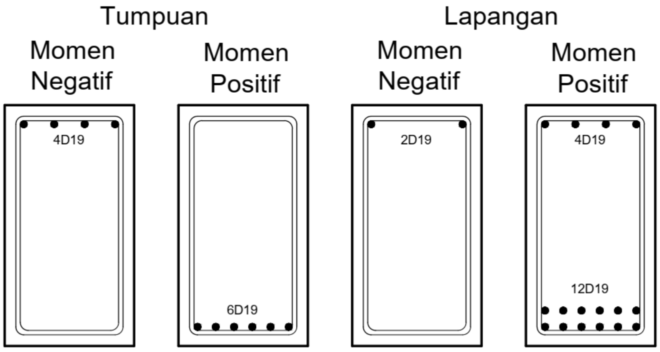


Figure 12. Longitudinal Reinforcement Configurations At The Support And The Midspan

3.6 Calculation of Shear Reinforcement

Based on SNI 2847: 2019 Article 9.4.3.2 the shear force value at the pedestal is sufficiently taken at a distance d (effective beam height) from the face of the column [6]. Based on the modeling results obtained:

V_u at the support (d distance) = 544963,67 N
V_u in the field (1/4 span) = 524683,26 N

Calculating the concrete shear strength V_c

Concrete modification factor (λ) = 1 ; normal concrete (Article 19.2.4.2)
Concrete shear strength (V_c) = $0{,}17 \times \lambda \times \sqrt{f'c} \times b \times d$
(Article 22.5.5.1) = $0{,}17 \times 1 \times \sqrt{24{,}9} \times 350 \times 598{,}5 = 177697{,}29$ N
ϕV_c = $0{,}75 \times V_c = 133272{,}96$ N

Check the requirement for the ability of the cross section to accept shear loads

Maximum V_u = 544963,67 N
Requirement = $\phi\,(V_c + 0{,}66\sqrt{f'c}\,bd)$
(Article 22.5.1.2) = $0{,}75\,(177697{,}29 + 0{,}66\sqrt{24{,}9} \times 350 \times 598{,}5) = 650685{,}7$N
Since 650685,7 > 544963,67 the cross section is sufficient.

Classification of V_u values (Article 10.6.2.1, Article 22.5.10.1 and Article 22.5.10.5.3)

Support Area = 133272,96 > 544963,67 ($\phi V_c < V_u$, shear reinforcement required)
Field Area = 133272,96 > 524683,26 ($\phi V_c < V_u$, shear reinforcement required)

Calculating the plan shear strength of reinforcement (V_s) (Article 22.5.10.1)

V_s Support area = $(V_u - \phi V_c)/\phi = (544963{,}67 - 0{,}75 \times 177697{,}29)/0{,}75 = 548920{,}9$ N
V_s Field Area = $(V_u - \phi V_c)/\phi = (524683{,}26 - 0{,}75 \times 177697{,}29)/0{,}75 = 521880{,}4$ N

Calculating shear reinforcement spacing (Article 9.7.6.2.2)

Support area = s = d/4 = 598,5/4 = 149,625 mm, used 100 mm (< 300 mm)
Field Area = s = d/4 = 598,5/4 = 149,625 mm, used 100 mm (< 300 mm)

Calculating V_s (Article 22.5.10.5.3)

A_v used (2 legged Ø12 mm) = $2 \times 0{,}25 \times \pi \times 12^2 = 226{,}195\ mm^2$

V_s Support area = $\frac{A_v \times f_y \times d}{s} = \frac{226{,}195 \times 420 \times 598{,}5}{100} = 568585{,}5$ N

V_s Field Area = $\frac{A_v \times f_y \times d}{s} = \frac{226{,}195 \times 420 \times 598{,}5}{100} = 568585{,}5$ N

Nominal shear strength check (ϕV_n) (Article 9.5.1.1)

Support area

V_n = $V_c + V_s$ = 177697,29 + 568585,5 = 746282,83 N

$\phi V_n \geq V_u$ = 0,75 x 746282,83 = 559712,12 N > 544963,67 N....**OK**

Field Area

V_n = $V_c + V_s$ = 177697,29 + 568585,5 = 746282,83 N

$\phi V_n \geq V_u$ = 0,75 x 746282,83 = 559712,12 N > 524683,26 N....**OK**

So that the stirrup reinforcement is used as follows :

Support area = **2D12 mm – 100 mm**

Field Area = **2D12 mm – 100 mm**

3.7 Torsion Reinforcement

Checking whether torsion reinforcement is required

Torsional moment (T_u) = 54270000 Nmm

Beam perimeter (P_{cp}) = 2 (b + h) = 2 (350 + 650) = 2000 mm

Area of beam (A_{cp}) = b x h = 350 x 650 = 227500 mm^2

Torsional moment of the beam (T_n) = $0{,}033 \times \lambda \times \sqrt{f'c} \times (A_{cp}^2/P_{cp})$

(Article 22.7.4) = $0{,}033 \times 1 \times \sqrt{24{,}9} \times (2275002^2/2000)$

= 42613422,87 Nmm

Check if torsion reinforcement is req. = $\phi T_n / 4$ = 0,75 x 42613422,87 / 4

(Article 22.7.1.1) = 7990016,788 Nmm < 54270000 Nmm (Need torsion bars)

ϕT_u = 0,75 x 42613422,87 =31960067,15 Nmm

Check cross-sectional capacity (Article 22.7.7.1)

A_{oh} = (b – 2ts) x (h – 2ts) = (350 – 2 x 30) x (650 – 2 x 30) = 171100 mm^2

P_h = 2 ((b – 2ts) + (h – 2ts)) = 2 ((350 – 2 x 30) + (650 – 2 x 30)) = 1760 mm

Check the cross section $= \sqrt{\left(\frac{V_u}{b\ d}\right)^2 + \left(\frac{T_u\ P_h}{1{,}7\ A_{oh}^2}\right)^2} \leq 0{,}75\left(\frac{V_c}{b\ d} + 0{,}66\sqrt{f'c}\right)$

$= \sqrt{\left(\frac{544963{,}7}{350 \times 598}\right)^2 + \left(\frac{31960067{,}15 \times 1760}{1{,}7 \times 171100^2}\right)^2} \leq 0{,}75\left(\frac{177607{,}29}{350 \times 598} + 0{,}66\sqrt{24{,}9}\right)$

= 2,836 < 3,106 (The cross-sectional dimensions of the beam are sufficient)

Determining transverse reinforcement due to torsion (Article 22.7.6.1)

A_o = 0,85 A_{oh} = 0,85 x 171100 = 145435 mm^2

A_t $= \frac{T_u \times s}{\phi \times 2 \times A_o \times f_y} \tan 45° = \frac{31960067{,}15 \times 100}{0{,}75 \times 2 \times 145435 \times 420} \tan 45° = 34{,}882\ mm^2$

A_v previously = 226,195 mm^2 (2D12 mm – 100 mm)

New stirrup area = $A_v + 2\ A_t$ = 226,195 + 2 x 34,882 = 295,958 mm^2

Number of legs req. $= \frac{4 \times A}{\pi \times d^2} = \frac{4 \times 295{,}958}{\pi\ 12^2} = 2{,}62 \approx 3$ legged

So the new stirrups are 3D12 - 100 mm (along the span)

Stirrup area (A_t) = 3 x 0,25 x π x 12^2 = 339,292 mm^2

Determine the longitudinal reinforcement due to torsion (Article 22.7.6.1)

A_l $= \frac{T_u \times P_h}{\phi \times 2 \times Ao \times fy} \cot 45° = \frac{31960067{,}15 \times 1760}{0{,}75 \times 2 \times 145435 \times 420} \cot 45° = 613{,}919\ mm^2$

A_l min $= 0{,}42\sqrt{f'c}\,\frac{A_{cp}}{f_{yt}} - \frac{0{,}175\ b}{f_{yt}} P_h \frac{f_{yt}}{f_y} = 878{,}556\ mm^2$

Since 613,919 < 878,556, A_l of 878,556 mm^2 is used

$A_l/3$ = 878,556 / 3 = 292,852 mm^2

Wearable torsion bars $= 292{,}852 / (0{,}25 \times \pi \times 116^2) = 1{,}457 \approx 2$ pieces 16 mm

Check capacity (Article 9.5.1)

$T_u = 31960067$ Nmm

$$\phi T_n \text{ (shear)} = 0{,}75\,\frac{2 \times A_o \times A_t \times f_{yt}}{s}\cot 45° = 0{,}75\,\frac{2 \times 145435 \times 339{,}292 \times 420}{100}\cot 45°$$

$= 310873077{,}8$ Nmm $> T_u$ …**OK**

$$\phi T_n \text{ (flexural)} = 0{,}75\,\frac{2 \times A_o \times A_l \times f_y}{P_h}\tan 45° = 0{,}75\,\frac{2 \times 145435 \times 878{,}556 \times 420}{1760}\tan 45°$$

$= 45736854{,}4$ Nmm $> T_u$ …**OK**

So longitudinal reinforcement for torsion **2D16** is used, and the new stirrup reinforcement is **3D12 - 100 mm**. The following is the detailing of the beam section.

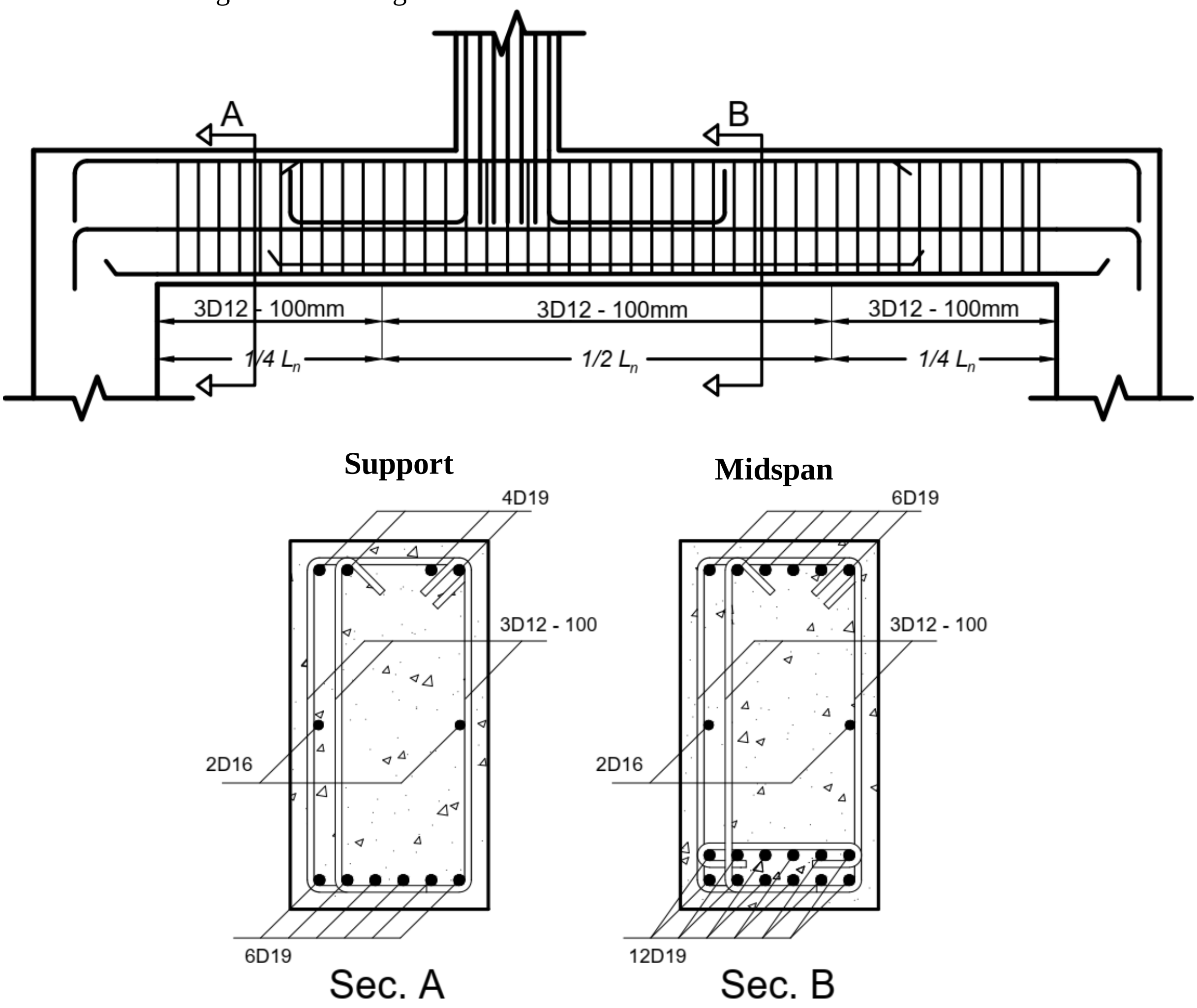


Figure 13. Detailing of Beam Reinforcement

4. CONCLUSION

Based on the results of the analysis, it can be concluded that to determine the reinforcement of transfer beams in residential buildings is done by determining the type of beam first, if the beam is an ordinary beam type, then the reinforcement design is carried out by the usual method (beams in general), while if the deep beam, the reinforcement design is carried out by the finite element method or the strut and tie method. In this study, the transfer beam is an ordinary beam type, the reinforcement configuration is obtained, namely 4D19 tensile and 6D19 compressive reinforcement is used in the support area and

12D19 tensile and 6D19 compressive reinforcement in the midspan area, the stirrup reinforcement used is 3D12 - 100 mm and the torsion reinforcement used is 2D16 along the span. The deflection of the transfer beam that occurred was 7,782 mm, this deflection is still within the permitted limit of 9,094 mm.

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