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Efficiency and Effectiveness Comparative Analysis of Wide Flange Beams and Cellular Beams in A Case Project United Tractor

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Abstract

United Tractors Company will build a sports center building consist of 3 floors using steel structures. Nowadays, limited land is one of the building development problems. The construction of multi-stored buildings is a solution to the limited land problem. The writer has analyzed beam design with a Wide Flange and Cellular system. Focused on the beam element with construction material in the form of steel with steel quality BJ-37, Fy 240 MPa, Fu 370 MPa. The strength and efficiency of the use of steel tonnage were also analyzed. E-Tabs software 2016 used to steel beam structure analysis. In this beam design planning refers to the steel structure planning following SNI 1729: 2015, SNI 1727: 2013, AISC 2010, ASCE 7-10, and also AISC Design Guide 31. The results of manual verification show that the cross-section of WF 400x200x8x13 and CB 250x125x5x8 with a span length of 6 meters is declared to be strong and safe because fill the strong requirements needs to be smaller than the strength of the plan. The efficiency of the use of Cellular Beam was compared to Wide Flange, the longer of Cellular Beam will increase steel tonnage reductions. The percentage reduction in steel weight will continue to increase when the length of steel usage also increases. This concludes that the use of steel length with steel weight reduction will move linearly. Where in this project with a steel beam length of 1439.27m reduction of steel tonnage was at 19.5%.
Keywords: Wide Flange Beam, Cellular Beam, Comparison

1. Introduction

Enthusiasme to exercise the employees of PT. United Tractor encourage management to provide sports facilities and infrastructure. Nowadays, limited land is one of building development problem. The construction of multi-storey buildings is the solution. One of important things in construction of multi-storey building is structural planning. In planning a multi-storey building structure basically must following criteria: Strong in holding planned loads, requirements of serviceability, high durability, accordance with the surrounding environment, economical and easy to maintain [5].

In structural planning, it is necessary to analyze the structure of the reaction caused by axial and lateral forces towards building structure. Structural elements must be designed to able carry an overload of a certain amount, outside of the load expected to occur of normal conditions. Spare capacity is needed to anticipate the possibility of overload factors and undercapacity factors [5]. Based of the problem, this paper analyzes the structures that only review the upper structure, which is the beam element. In this discussion, will analyze the beams with a Wide Flange and Cellular system which will be reviewed regarding the strength and efficiency of the use of steel tonnage. Cellular beam is profile steel I with openings on the body part is which is made by cutting standard profile body parts into 2 parts along the span, then separated, shifted and welded back into new shapes (J.P. Boyer, 1964). The results of this process make the steel profile has higher than the beginning, resulting in the addition of inertia. Increasing inertia will increase the ability of the steel. The economic value of profile I can increase, because with the initial profile I the dimensions are smaller and lighter can be formed into a profile that has a higher height [6]. The steel beam structure analysis is based on SNI 1729: 2015 procedures for planning steel structures for buildings. By using the help of ETABS 2016 computer software for structural analysis.

The rules used are the regulations issued are as follows:
- SNI 1729: 2015 Procedures for planning steel structures for buildings.
- SNI 1727: 2013 Minimum load for building construction planning.
- Steel Design Guide 31 - Castellated and Cellular Beam Design.

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2. Methodology

Analysis method used in building structure modeling where the planning used two system, Wide Flange beam system and the Cellular beam system. This research method uses case study analysis method. Case study method is in the form of re-planning with a model that is made in accordance with existing building conditions. The research method used has stages of input, analysis and output. At the input stage will be explained about the structure geometry, dimensions, and specifications of structural elements, the determination of the burden of working with 3-dimensional modeling. The stages of analysis include structural modeling using the 2016 ETABS software. The final stage is the output stage which discusses the strength and efficiency of using steel tonnage. The final result of this plan is to find out what is the tonnage ratio of each design and find out which design is the most efficient if applied to this project.

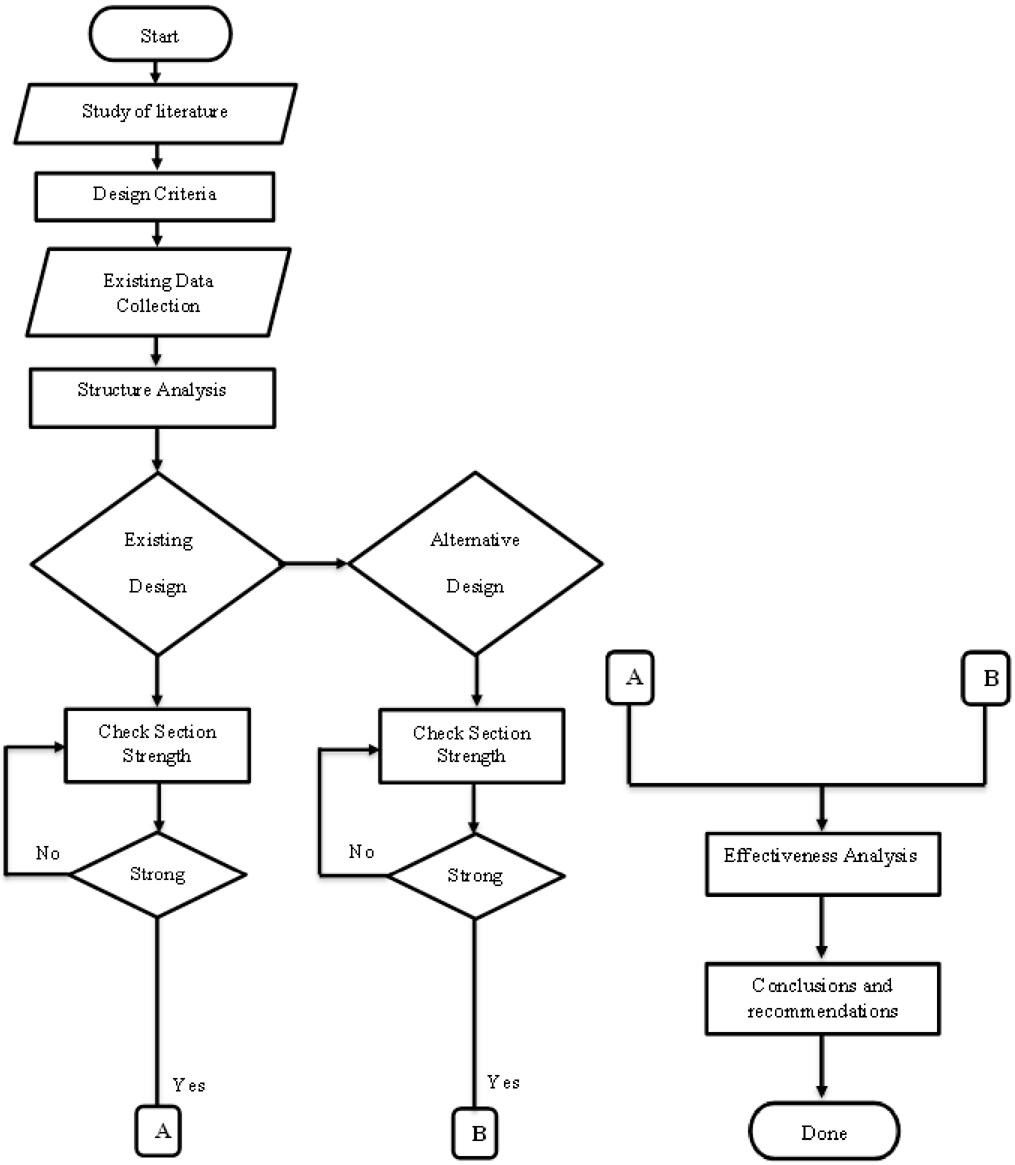


Figure 1. Research *Flowchart*
Source: Data in research, 2019

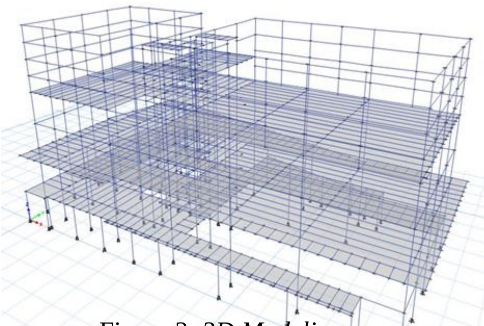


Figure 2. *3D Modeling*
Source: *ETABS Modeling*

Structural Material

Concrete Quality	: 30 Mpa
Steel Quality	: BJ-37, Fy 240 MPa, Fu 370 MPa
Geometric Structure	
Number of Floors	: 2 Floors
Floor Height	: GF-LT3 (3,5 meter)
Building Height	: 30 meter
Function	: Sport Center
Location	: Cakung, North Jakarta
Type of Soil	: Medium (SD)

In this study there are 2 types of data, primary data is existing data obtained from the project under study and secondary data from alternative design experiments. The data is then analysed following stages of the research carried out are as follows:

3. Result and Analysis

3.1 Existing Data

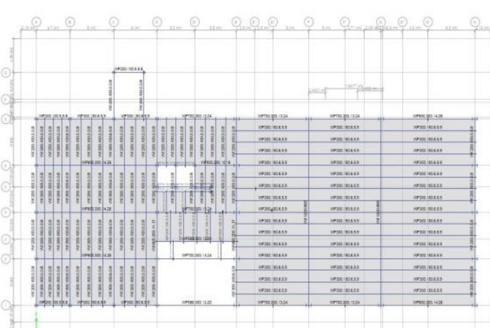
In this case referring to for construction (planning drawings) for the beam size of the Ahemce project is as follows:

Table 1. List of Beam Sizes for Construction

Beam Type	Size (mm)	Beam Type	Size (mm)
1	WF 800x300x14x26	8	WF 400x200x8x13
2	WF 700x300x13x24	9	WF 350x175x7x11
3b	WF 588x300x12x20	10	WF 300x150x6.5x 9
4	WF 600x200x11x17	11	WF 250x125x6x9
6	WF 500x200x10x16	12	WF 200x100x5.5x8

Source: Ahemce Project Documents 2019

Figure 3. Mezzanine Floor Design Figure 4. 1st Floot Design
Source: Data in research, 2019



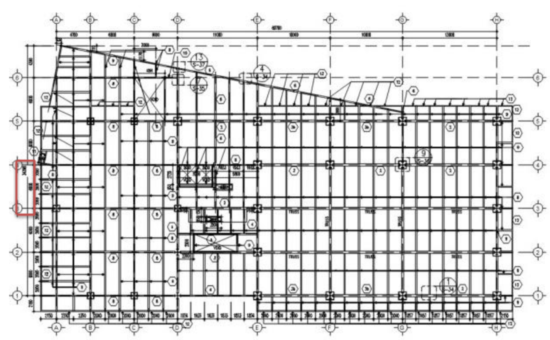


Figure 5. 2nd Floor Design Figure 6. The position of the beam being observed
Source: Data in research, 2019

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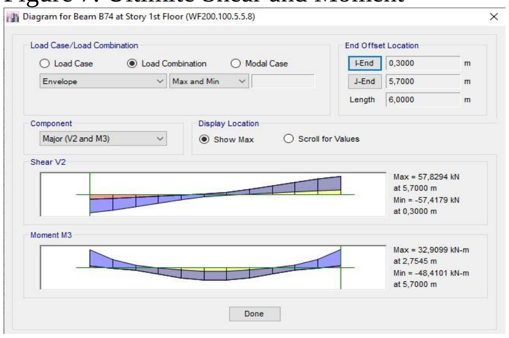
3.2 Check Section Strength

Wide Flange Beam

Material Data :
WF 400 x 200 x 8 x 13
Yield stress (fy) = 240 MPa
Height (H) = 400 mm
Width (B) = 200 mm
Thick (Flens/tf) = 13 mm
Thick (Web/tw) = 8 mm
Radius of gyration (rx) = 168 mm
Radius of gyration (ry) = 45,4 mm
Momen of inersia (Ix) = 23700 cm^4
Momen of inersia (Iy) = 1740 cm^4
Section area (A) = 8412 mm^2
Modulus of section (Zx) = 1190 cm^3
Modulus of section (Zy) = 174 cm^3
Span length (L) = 6 m
Spacing (b0) = 2 m
Concrete Strength (fc') = 30 Mpa
Thick concrete = 170 mm
Weight of decks = 240 kg/m2
tc = 70 mm
wr = 200 mm
hr = 50 mm
Ultimite Moment (Mu) = 48,4101 kN.m → 48410100 N.mm
Ultimate Shear (Vu) = 57,8294 kN → 57829,4 N

Figure 7. Ultimite Shear and Moment



Completion:

Assume a = 50 mm and d = 400 mm

As need : $\frac{M_u}{\emptyset . f_y . \left(\frac{d}{2}+t-\frac{a}{2}\right)} = \frac{48410100}{0,85.240.\left(\frac{400}{2}+170-\frac{50}{2}\right)}$

= 687,8 mm2 → 6,88 cm2
Trying to use wf 400x200x8x13
(As = 84,10 cm2)
Before the concrete hardens, the steel beam carries:
Live load during construction
= 2 x 100 = 200 kg/m
Dead load
= 2 x (240 + 66) = 612 kg/m

qu $= 1{,}2(612) + 1{,}6(200) = 1054{,}40\ kg/m$

Mu $= \frac{1}{8} q_u . L^2 = \frac{1}{8}\ (1054{,}4).(6)^2$

Cellular Beam

Material Data :
•Top Root Section : WF 250x125x5x8
Height (dtop = ht) = 250 mm
Width (bf) = 125 mm
Thick of web (tw) = 5 mm
Thick of flens (tf) = 8 mm
Radius (r) = 12 mm
Section area (A) = 3268 mm2
Moment of inertia (Ix) = 35400000 mm4
Moment of inertia (Iy) = 2550000 mm4
Radius of gyration (rx) = 104 mm
Radius of gyration (ry) = 27,9 mm
Modulus of section (Zx) = 285000 mm3
Modulus of section (Zy) = 41100 mm3
•Bottom Root Section : WF 250x125x5x8
Height (dtop = ht) = 250 mm
Width (bf) = 125 mm
Thick of web (tw) = 5 mm
Thick of flens (tf) = 8 mm
Radius (r) = 12 mm
Section area (A) = 3268 mm2
Moment of inertia (Ix) = 35400000 mm4
Moment of inertia (Iy) = 2550000 mm4
Radius of gyration (rx) = 104 mm
Radius of gyration (ry) = 27,9 mm
Modulus of section (Zx) = 285000 mm3
Modulus of section (Zy) = 41100 mm3
Section Geometry
Span (L) = 6000 mm
Spacing (s) = 1500 mm
Section Properties of Deck
Nominal height waves of steel decks (hr)
= 50 mm
Thick concrete on a wave of steel deck (tc)
= 120 mm
Concrete Strength (fc')
= 30 N/mm2
Berat jenis beton (w)
= 23,54 kN/m3
Hole Dimension
Opening Diameter (Do) = 200 mm
Space of Opening Diameter (e) = 100 mm

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Wide Flange Beam

$= 4744{,}80\ kg.m = 47448000\ N.mm$

Because wf 400x200x8x13 is a compact section, then:

Mn $= M_p = Z_x . f_y = 1190.10^3\ x\ 240$

$= 285600000\ N.mm$

Ø Mn $= 0{,}9(285600000)$

$= 257040000\ N.mm\ >$ Mu OK

Calculate Flexibility Strength of Composite Beam

After the concrete hardens, load factor borne by the composite beam is :

Mu = 48410100 N.mm (data from ETABS)

The width of the effective slab of concrete is taken from the smallest value :

bE $= \frac{1}{4} L = \frac{1}{4}(6) = 1{,}5\ m$

bE = b0 = 2 m

So the width effectively was taken by 1.5 m

Suppose a neutral plastic axis fell on a concrete plate, then the height of strength beam hit on the concrete block was :

A = $\frac{A_S\ X\ f_y}{0{,}85\ X\ f_c'\ X\ b_E} = \frac{8412\ X\ 240}{0{,}85\ X\ 30\ X\ 1500}$

= 52,78 mm < tc = 70 mm

Because a < tc, means a neutral-plastic axis fell on the concrete plate, and is on the assumption before.

Nominal Flexibility Strength of Composite Beam :

Mn $= A_s . f_y \left(\frac{d}{2} + t - \frac{a}{2}\right)$

$= 693706169{,}22\ N.mm$

ØMn = 0,85 (693706169,22)

$= 589650243{,}84\ N.mm\ >$ Mu OK

Next the beams must be checked against the shear :

Vu = 57829,4 N

ØVn $= Ø.0{,}6.f_y.h.t_w$

$= 0{,}9(0{,}6)(240)(358)(8)$

= 371174,4 N > Vu

OK

Compactness section check :

$\frac{h}{t_w} = \frac{400-2(13+8)}{8}$

$= 44{,}75\ N < \frac{1100}{\sqrt{f_y}} = 71\ N$ OK

Calculate Need of Shear Stud

Shear connection total number to cause a full composite action

For the full composite action :

C = $V_h = 0{,}85.f_c'.a.b_E = A_s . f_y = 2018880\ N$

Use the stud 3/4" - 10cm (Asc = 285mm2) One per section.

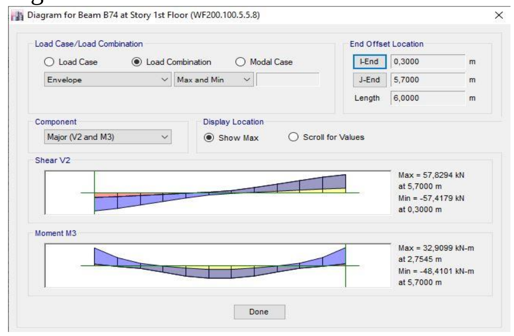
Reduction factor strength of stud, rs (Nr = 1, Hs = 10 cm)

rs $= \frac{0{,}85}{\sqrt{N_r}}\left(\frac{W_r}{h_r}\right)\left[\frac{H_s}{h_r} - 1{,}0\right] < 1{,}0$

$= \frac{0{,}85}{1}\left(\frac{200}{50}\right)\left[\frac{100}{50} - 1{,}0\right] = 3{,}4 > 1{,}0$

Cellular Beam

Figure 8. Ultimite Shear and Moment



Completion:

Hole Dimension

Opening Diameter (Do) = 200 mm

Space of Opening Diameter (e) = 100 mm

S = e + Do = 200 + 100 = 300 mm

loss = $\frac{D_o}{2} - \sqrt{\left(\frac{D_o}{2}\right)^2 - \left(\frac{S-D_o}{2}\right)^2} = \frac{200}{2} - \sqrt{\left(\frac{200}{2}\right)^2 - \left(\frac{300-200}{2}\right)^2}$

= 13,40 mm

dt-top-net $= \frac{1}{2}\left[d_{top} - \left(\frac{D_o}{2} + loss\right)\right]$

$= \frac{1}{2}\left[250 - \left(\frac{200}{2} + 13{,}40\right)\right]$

= 68,30 mm

dt-bot-net $= \frac{1}{2}\left[d_{bot} - \left(\frac{D_o}{2} + loss\right)\right]$

$= \frac{1}{2}\left[250 - \left(\frac{200}{2} + 13{,}40\right)\right]$

= 68,30 mm

dg = dt-top-net + Do + dt-bot-net

= 68,30 + 200 + 68,30 = 336,60 mm

y $= \sqrt{(0{,}5D_o)^2 - (0{,}225D_o)^2}$

$= \sqrt{(0{,}5\,.\,200)^2 - (0{,}225\,.\,200)^2}$

= 89,30 mm

dt-top-crit $= \frac{D_o}{2} - y + d_{t-top-net}$

$= \frac{200}{2} - 89{,}30 + 68{,}30 = 79\ mm$

dt-bot-crit $= \frac{D_o}{2} - y + d_{t-bot-net}$

$= \frac{200}{2} - 89{,}30 + 68{,}30 = 79\ mm$

Properties Tee Atas di Tengah Opening

Momen inersia arah x - dengan jari-jari girasi di asumsikan nol :

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Wide Flange Beam

with :
rs = is reduction factor
Nr = Is the number of shear stud on every wave on the cross section of the steel beam.
Hs = Is a high shear stud ≤ (hr + 75mm)
hr = Is nominal high waves of steel deck
wr = Is the width of the effective waves of the steel deck
take rs = 1,0. Untuk fc' = 30 Mpa, modulus of concrete elasticity :

$$Ec = 0{,}041\, w^{1{,}5}\sqrt{f_c{}'}$$
$$= 0{,}041(2400)^{1{,}5}\sqrt{30}$$
$$= 26403{,}49 \text{ MPa}$$

Shear strength a stud:

$$Qn = 0{,}5.A_{sc}\sqrt{f_c{}'}\ x\ E_c$$
$$= 0{,}5\ (285).\sqrt{30\ x\ 26403{,}49}$$
$$= 126771{,}29 \text{ N}$$
$$A_{sc}.f_u = 285\ (450)$$
$$= 128195{,}31\ N > \text{Qn} \qquad \text{OK}$$

The number of stud required :

$$N = \frac{V_h}{Q_n} = \frac{2018880}{126771{,}29} = 15{,}93 \rightarrow 16 \text{ stud} \qquad \text{(for ½ the span)}$$

For the total lenght it takes 32 stud for the full composite action to occur. If every 2 waves are installed a stud, then the distance between the stud is 2(200) = 400 mm, so the number of stud used is as much (6000 / 400) + 1 = 16 stud, or 8 stud every ½ span.

∑Qn = 8(126771,29) = 1014170,35 N

Because As. fy = 2018880 N > ∑Qn , Then there's part of the profile of steel under pressure.

The balance of force that occurred :
∑Qn + Cf = Tmaks – Cf
1014170,35 + Cf = 2018880 - Cf
2 x Cf = 1004709,65
Cf = 502354,83 N

The location of the neutral plastic axis calculated from above the flens press is :

$$\frac{C_f}{b_f x f_y} = \frac{502354{,}83}{200\ x\ 240} = 10{,}47\ mm \quad (< \text{tf} = 13 \text{ mm})$$

Ts location, measured from the underedge of steel flens :

	Area, A (cm2)	Arm, y (cm)	A * y (cm3)
Concrete slab	2550	8,5	21675
WF 400	84,12	48,5	4079,82
	2634,12		25754,82

$$\bar{y} = \frac{25754{,}82}{2634} = 9{,}78\ cm$$

Besarnya a dihitung dari persamaan :

Cellular Beam

Table 2. Properties Tee Atas di Tengah Opening

	Luas (A)	Tinjauan dari tengah flens y	Ay	Ay^2	I_o
	mm^2	(mm)	mm^3	mm^4	mm^4
Flens	1000,00	0,0	0,0	0,0	5333,3
Steem	301,51	34,2	10296,6	106020658,75	91362,5
Tee	1301,51		10296,6	106020658,8	96695,9

$$y_{0-t-top-net} = \frac{\sum Ay}{A_{t-top-net}} = \frac{10296{,}6}{1301{,}51} = 7{,}91\ mm$$

$$I_{x-t-top-net} =$$
$$\sum I_0 + \sum Ay^2 - A_{t-top-net}.{y_{0-t-top-net}}^2$$
$$= 96695{,}9 + 106020658{,}8 - 1301{,}51\ x\ 7{,}91^2$$
= 106035894,7 mm4

Properties Tee Above on the Critical Section
The moment of inertia in the x direction - with the radius of gyration assumed to be zero:

Table 3. Properties Tee Above on the Critical Section

	Luas (A)	Tinjauan dari tengah flens y	Ay	Ay^2	I_o
	mm^2	(mm)	mm^3	mm^4	mm^4
Flens	1000,00	0,0	0,0	0,0	5333,3
Steem	354,99	39,5	14021,9	196613834,29	149119,6
Tee	1354,99		14021,9	196613834,3	154452,9

$$y_{0-t-top-crit} = \frac{\sum Ay}{A_{t-top-crit}} = \frac{14021{,}9}{1354{,}99} = 10{,}35\ mm$$

$$I_{x-t-top-crit} =$$
$$\sum I_0 + \sum Ay^2 - A_{t-top-crit}.{y_{0-t-top-crit}}^2$$
$$= 154452{,}9 + 196613834{,}3 - 1354{,}99\ x\ 10{,}35^2$$
= 196623183,9 mm4

$$S_{x-min-t-top-crit} = \frac{I_{x-t-top-crit}}{d_{t-top-crit} - (y_{0-t-top-crit} + 0{,}5 t_{f-top})}$$
$$= \frac{196623183{,}9}{79 - (10{,}35 + (0{,}5\ x\ 8))}$$
= 3041344,6 mm3

Lower Tee Properties in the Middle of Opening
The moment of inertia in the x direction - with the radius of gyration assumed to be zero:

Table 4. Properties Tee Down at the Middle of the Opening

	Luas (A)	Tinjauan dari tengah flens y	Ay	Ay^2	I_o
	mm^2	(mm)	mm^3	mm^4	mm^4
Flens	1000,00	0,0	0,0	0,0	5333,3
Steem	301,51	34,2	10296,6	106020658,75	91362,5
Tee	1301,51		10296,6	106020658,8	96695,9

$$y_{0-t-bot-net} = \frac{\sum Ay}{A_{t-bot-net}} = \frac{10296{,}6}{1301{,}51} = 7{,}91\ mm$$

$$I_{x-t-bot-net} =$$
$$\sum I_0 + \sum Ay^2 - A_{t-bot-net}.{y_{0-t-bot-net}}^2$$
$$= 96695{,}9 + 106020658{,}8 - 1301{,}51\ x\ 7{,}91^2$$

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Wide Flange Beam

a $= \frac{\sum Q_n}{0{,}85\ x\ f_c'\ x\ b_E} = \frac{1014170{,}35}{0{,}85\ x\ 30\ x\ 1500} = 26{,}51\ mm$

Tentukan momen internal terhadap garis kerja Ts :

∑Qn : Mn1 $= \sum Q_n (d - \bar{y} + t_s - \frac{a}{2})$

$= 1014170{,}35(400 - 9{,}78 + 170 - \frac{26{,}51}{2})$

= 465472715,87 N.mm

Cf : Mn2 $= C_f (d - \bar{y} - \left(\frac{C_f}{b_f\ x\ f_y}\right)/2)$

$= 502354{,}83\ (400 - 9{,}78 - 5{,}23)$

$= 193401457{,}14\ N.mm$

Mn = Mn1 + Mn2 = 658874173,01 N.mm

Øb.Mn = 0,85(658874173,01)
= 560043047,06 N.mm
= 56,00 ton.m > Mu (7,44 ton.m)

Jadi, dapat dipasang 16 buah stud 3/4" - 10 cm dengan jarak 400 mm (tiap 2 gelombang dek baja).

Kontrol Lendutan

Sebelum beton mengeras

q_D = 2(240 + 66) = 612 kg/m = 6,12 N/mm

Δ1 $= \frac{5qL^4}{384EI_S} = \frac{5\ X\ 6{,}12\ x\ 6000^4}{384\ x\ 200000\ x\ 23700\ x\ 10^4}$

$= 2{,}18\ mm$

Lendutan akibat beban hidup selama konstruksi

q_L = 2(100) = 200 kg/m = 2 N/mm

Δ2 $= \frac{5qL^4}{384EI_S} = \frac{5\ X\ 2\ x\ 6000^4}{384\ x\ 200000\ x\ 23700\ x\ 10^4}$

$= 0{,}71\ mm$

Setelah beton mengeras aksi komposit mulai bekerja, momen inersia penampang komposit Itr dihitung sebagai berikut :

n $= \frac{E_S}{E_C} = \frac{200000}{26403{,}49} = 7{,}57 \rightarrow 8$

$\frac{b_E}{n} = \frac{1500}{8} = 187{,}50\ mm$

Luas A (cm2)
Pelat Beton = 225
WF 400 = 84,12
∑ = 309,12
Lengan y (cm)
Pelat Beton = 8,5
WF 400 = 48,5
A * y (cm3)
Pelat Beton = 1912,5
WF 400 = 4079,82
∑ = 5992,32
Io
Pelat Beton = 2700
WF 400 = 23700
d
Pelat Beton = 10,89
WF 400 = -29,11
Io + A * d^2

Cellular Beam

= 106035894,7 mm4

Lower Tee Properties In Critical Sections

The moment of inertia in the x direction - with the radius of gyration assumed to be zero:

Table 4.5. Lower Tee Properties In Critical Sections

	Luas (A)	Tinjauan dari tengah flens y	Ay	Ay^2	I_o
	mm^2	(mm)	mm^3	mm^4	mm^4
Flens	1000,00	0,0	0,0	0,0	5333,3
Steem	354,99	39,5	14021,9	196613834,29	149119,6
Tee	1354,99		14021,9	196613834,3	154452,9

$y_{0-t-bot-crit} = \frac{\sum Ay}{A_{t-bot-crit}} = \frac{14021{,}9}{1354{,}99} = 10{,}35\ mm$

$I_{x-t-bot-crit} =$
$\sum I_0 + \sum Ay^2 - A_{t-bot-crit} \cdot y_{0-t-bot-crit}{}^2$
$= 154452{,}9 + 196613834{,}3 - 1354{,}99\ x\ 10{,}35^2$
= 196623183,9 mm4

$S_{x-min-t-bot-crit} = \frac{I_{x-t-bot-crit}}{d_{t-bot-crit} - (y_{0-t-bot-crit} + 0{,}5 t_{f-bot})}$
$= \frac{196623183{,}9}{79 - (10{,}35 + (0{,}5\ x\ 8))}$
= 3041344,6 mm3

Properties Of Net Section at Middle of Opening

The moment of inertia in the x direction - with the radius of gyration assumed to be zero:

Table 5. Properties Of Net Section at Middle of Opening

	Luas (A)	Tinjauan dari bawah Cellular	Ay	Ay^2	I_o
	mm^2	(mm)	mm^3	mm^4	mm^4
Top tee	1000,00	324,7	324691,2	105424388518	106035894,7
Bottom tee	1000,00	11,9	11911,3	141879546,81	106035894,7
Net Section	2000,00		336602,5	105566268065	212071789,3

$y_{steel-net} = \frac{\sum Ay}{A_{net}} = \frac{336602{,}5}{2000} = 168{,}30\ mm$

$I_{steel-net} = \sum I_0 + \sum Ay^2 - A_{net} \cdot y_{net}{}^2$
$=$
$212071789{,}3 + 105566268065 -$
$2000\ x\ 168{,}30^2$
$= 1{,}05722\ x\ 10^{11}\ mm^4$

Properties Of Net Section di Bagian Kritikal

Anet-crit $= A_{t-top-crit} + A_{t-bot-crit}$
$= 1354{,}99 + 1354{,}99$
$= 2709{,}98\ mm^2$

$d_{effec-noncomp}$
$= d_g - (0{,}5 t_{f-top} + y_{0-t-top-crit}) - (0{,}5 t_{f-bot} + y_{0-t-bot-crit})$
$= 336{,}6 - ((0{,}5\ x\ 8) + 10{,}35) - ((0{,}5\ x\ 8) + 10{,}35)$

Wide Flange Beam

Pelat Beton = 546513,23
WF 400 = 23548336,7
$\sum$ = 24094849,93

ȳ = $\frac{5992,32}{309} = 19,39\ cm$

Karena struktur dianggap sebagai balok komposit parsial, maka momen inersia harus direduksi sebagai berikut :

Iefektif = $I_s + (I_{ts} - I_s)\sqrt{\frac{\Sigma Q_n}{C_f}}$

$= 23700 + (24094849,93 - 23700)\sqrt{\frac{1014170,35}{2018880,0}}$

= 17084407,59 cm4

Lendutan akibat beban hidup :
q = 2(488,4) = 976,8 kg/m = 9,77 N/mm

$\Delta 3 = \frac{5qL^4}{384EI_{tr}} = \frac{5\ X\ 9,77\ x\ 6000^4}{384\ x\ 200000\ x\ 17084407,59\ x\ 10^4}$

$= 4,82\ mm$

Lendutan jangka panjang akibat beban mati berupa partisi dihitung sebagai berikut :

$\frac{b}{2n} = \frac{1500}{2\ x\ 8} = 93,75\ mm$

Luas A (cm2)
Pelat Beton = 112,5
WF 400 = 84,12
$\sum$ = 197
Lengan y (cm)
Pelat Beton = 8,5
WF 400 = 48,5
A * y (cm3)
Pelat Beton = 956,25
WF 400 = 4079,82
$\sum$ = 5036,07
Io
Pelat Beton = 1350
WF 400 = 23700
d
Pelat Beton = 17,11
WF 400 = -22,89
Io + A * d^2
Pelat Beton = 675413,15
WF 400 = 14551208,76
$\sum$ = 15226621,91

ȳ = $\frac{5036,07}{197} = 25,61\ cm$

Iefektif' = $I_s + (I_{ts}' - I_s)\sqrt{\frac{\Sigma Q_n}{C_f}}$

$= 23700 + (15226621,91 - 23700)\sqrt{\frac{1014170,35}{2018880,0}}$

= 10798947,79 cm4

Cellular Beam

= 307,91 mm

Properties Of Net Composite in the Middle of Opening

The moment of inertia in the x direction - with the radius of gyration assumed to be zero:

Slab transformation:

The effective width of the concrete slab is taken from the smallest value between:

bE = $\frac{1}{4}.L = \frac{1}{4}.6000 = 1500\ mm$
bE = bo = 1500 mm
bE dipakai = 1500 mm

Calculating the value "n"

n = $\frac{E_s}{E_c} = \frac{200000}{4700\sqrt{fc'}} = \frac{200000}{4700\sqrt{30}} = 7,77$

Plate equivalent effective width

$\frac{b_E}{n} = \frac{1500}{7,77} = 193,07\ mm$

Table 6. Properties Of Net Composite in Middle of Opening

	Luas (A)	Tinjauan dari bawah Cellular	Ay	Ay^2	I_o
	mm^2	(mm)	mm^3	mm^4	mm^4
Transformed Slab	32822,27	421,6	13837954,2	191488976673232	464982,2
Net Section	2000,00	168,3	336602,5	113301270189,22	105721689219,3
Composite Section	34822,27		14174556,7	191602277943421	105722154201,5

$y_{tr-net} = \frac{\sum Ay}{A_{tr-net}} = \frac{14174556,7}{34822,27} = 407,1\ mm$

$I_{comp-net} =$
$\sum I_0 + \sum Ay^2 - A_{tr-net}.y_{tr-net}{}^2$
$= 105722154201,5 + 191602277943421 -$
$34822,27\ x\ 407,1^2$
= 191702230283235 mm4

Global and Local Style in the First Opening Top Tee

First opening location:

x = e + 0.5Do = 100 + 0.5 x 200 = 200 mm

Global shear force:

The shear force that exists at the distance x

Vu at a distance
x = 57418,17 N

Gaya geser nominal pada beton :

Vnc = $3\ (hr + tc).(tc).\left(4\sqrt{f_c'}\right)$
$= 3\ (50 + 120).(120).\left(4\sqrt{30}\right)$
= 1340824,82 N

Vc = $\emptyset_{cv}\ .\ V_{nc} = 0,75$ x 1340824,82
$= 1005618,62\ N$
Vnet = $V_u - V_c = 57418,17 - 1005618,62$
$= -948200,45$ N

Momen global :

Wide Flange Beam

$\Delta 5 \; = \; \frac{5qL^4}{384EI_{tr}} = \frac{5 \; X \; 9{,}77 \; x \; 6000^4}{384 \; x \; 200000 \; x \; 10798947{,}79 \; \; x \; 10^4}$

$= 0{,}01 \; mm$

Lendutan total yang terjadi :

$\Delta 1 + \Delta 3 + \Delta 5 \; = 2{,}18 + 4{,}82 + 0{,}01$

$= 7{,}01 \text{ mm} \leq \frac{L}{240} = 25 \; mm$ OK

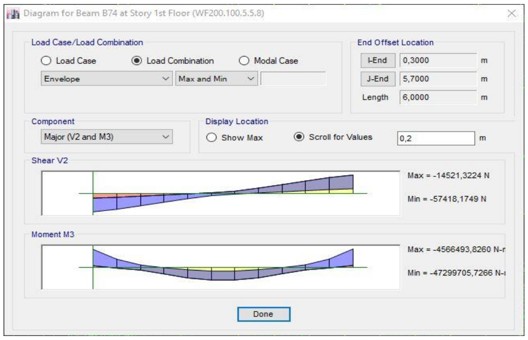
Dari hasil verifikasi perhitungan manual di atas menunjukkan bahwa penampang WF 400x200x8x13 dengan panjang bentang 6 meter dinyatakan kuat dan aman karena memenuhi syarat kuat perlu (Mu), lebih kecil dari kuat rencana (ØMn).

Cellular Beam

Momen pada jarak x

Mu pada jarak x = 47299705,7 N.mm

Gambar 9. Momen dan Geser Ultimit Pada Jarak X = 200 mm



Gaya aksial di Tee atas :

Asumsi aksi komposit sudah bekerja, sehingga kedalaman beton yang mengalami tekan, Xc sama dengan :

$\text{Xc} \; = \frac{4}{100} \, . \, t_c = \frac{4}{100} \, . \, 120 = 4{,}80 \; mm$

Kedalaman efektif balok komposit sebagai berikut :

$d_{effe-comp} = d_g - \left(0.5t_{f-bot} + y_{0-t-bot-crit}\right) + h_r + t_c - \frac{X_c}{2}$

$= 336{,}6 - (0.5 \; x \; 8 + 10{,}35) + 50 + 120 - \frac{4{,}80}{2}$

= 489,85 mm

dan gaya tekan pada beton, C1 adalah :

$\text{C1} = 0.85. f_c'. X_c. b_{eff} = \; 0.85 \; x \; 30 \; x \; 4{,}80 \; x \; 193{,}07$

= 23632,04 N

$\text{C1} = \frac{M_u}{d_{effec-comp}} = \frac{47299705{,}7}{489{,}85} = 96559 \; N$

C1 yang menentukan :

$C_{1-statisfies} \qquad = 23632{,}04 \; N$

Vierendeel momen di Tee atas :

$M_{vu-top} =$

$V_{net} \frac{A_{t-top-crit}}{A_{net-crit}} \left(\frac{D_0}{4}\right) = 948200{,}45 \; \frac{1354{,}99}{2709{,}98} \left(\frac{200}{4}\right)$

= 23705011,14 N.mm

Kuat Lentur Tee Atas di Kritikal Area

Yielding :

$\text{Mp} = M_y = F_y \, . \, S_{x-min-t-top-crit}$

$= 240 \; x \; 3041344{,}6$

= 729922699,6 N.mm

Tekuk local penampang Tee :

Persyaratan

$\frac{d}{t_w} < 0.84 \sqrt{\frac{E}{F_y}}$

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Wide Flange Beam	Cellular Beam
	(continued below)

Maka

$F_{cr} = F_y$

Momen nominal

Mn $= F_{cr}\ x\ S_{x-min-t-bot-crit} = 240\ x\ 3041344{,}6$
$= 729922699{,}6$ N.mm

Kapasitas Ratio untuk Tee Atas Area Kritikal di Opening Pertama

$\frac{M_{vu}}{\emptyset M_n} = \frac{23705011{,}14}{0{,}9\ x\ 729922699{,}6} = 0{,}04$

$\frac{M_{vu}}{\emptyset M_n} < 1$ OK

Gaya Global dan Lokal di Tee Bawah Opening ke Enam

Lokasi opening ke enam

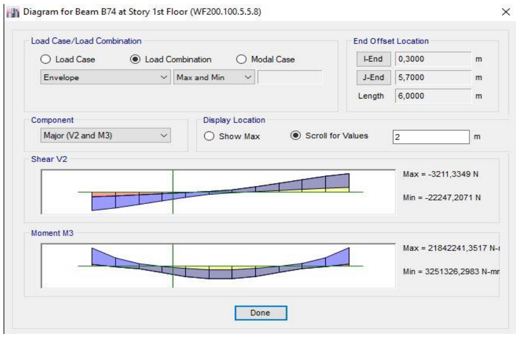
x = $e + 6S + 0.5D_0 == 100 + 6(300) + 0.5(200)$
= 2000 mm

Gaya geser global :

Gaya geser yang ada pada jarak x

Vu pada jarak x = 22247,2 N

Gambar 10. Momen dan Geser Ultimit Pada Jarak X = 2000 mm



Gaya geser nominal pada beton :

Vnc = $3\ (hr + tc).(tc).\left(4\sqrt{f_c{}'}\right)$
$= 3\ (50 + 120).(120).\left(4\sqrt{30}\right)$
= 1340824,82 N

Vc $= \emptyset_{cv} \,.\, V_{nc} = 0{,}75\ x\ 1340824{,}82$
$= 1005618{,}62\ N$

Vnet = $V_u - V_c = 22247{,}2 - 1005618{,}62$
$= -983371{,}42\ N$

Momen global :

Momen pada jarak x

Mu pada jarak x = 21842241,4 N.mm

Gaya aksial di Tee bawah :

Asumsi aksi komposit sudah bekerja, sehingga kedalaman beton yang mengalami tekan, Xc sama

<table>
<tr><th>Wide Flange Beam</th><th>Cellular Beam</th></tr>
<tr><td></td><td>
dengan :
Xc $= \frac{25}{100} \,.\, t_c = \frac{25}{100} \,.\, 120 = 30\ mm$

Kedalaman efektif balok komposit sebagai berikut :
$d_{effe-comp} = d_g - \left(0.5t_{f-bot} + y_{0-t-bot-crit}\right) + h_r + t_c - \frac{X_c}{2}$
$= 336,6 - (0.5\ x\ 8 + 10,35) + 50 + 120 - \frac{30}{2}$
= 477,25 mm

dan gaya tekan pada beton, C1 adalah :
C1 $= 0.85. f_c'. X_c. b_{eff} = 0.85\ x\ 30\ x\ 30\ x\ 193,07$
= 147700,23 N
C1 $= \frac{M_u}{d_{effec-comp}} = \frac{21842241,4}{477,25}$
$= 45766,47\ N$

C1 yang menentukan :
$C_{1-statisfies} = 45766,47\ N$

Vierendeel momen di Tee bawah :
$M_{vu-top} = V_{net} \frac{A_{t-bot-crit}}{A_{net-crit}} \left(\frac{D_0}{4}\right) = 983371,42\ \frac{1354,99}{2709,98} \left(\frac{200}{4}\right)$
= 24584285,39 N.mm

Kekuatan tarik Tee bawah di area kritikal
Pn $= F_y \,.\, A_{t-bot-crit} = 240\ x\ 1354,99 = 325198,10\ N$

Kuat Lentur Tee Bawah di Kritikal Area
Yielding :
Mp = $M_y = F_y \,. S_{x-bot-crit} = 240\ x\ 3041344,6$
= 729922699,6 N.mm
Tekuk local penampang Tee :
Persyaratan

$\frac{d}{t_w} < 0.84 \sqrt{\frac{E}{F_y}}$
Maka
$F_{cr} = F_y$

Momen nominal
Mn = $F_{cr}\ x\ S_{x-bot} = 240\ x\ 3041344,6$
= 729922699,6 N.mm

Persamaan Interaksi Untuk Tee Bawah Kritikal Area di Opening 6
Persamaan 1 :
$\frac{P_u}{\emptyset P_n} + \frac{8M_{vu}}{9\emptyset M_n} = \frac{45766,47}{0,9\ x\ 325198,10} + \frac{8\ x\ 24584285,39}{9\ x\ 0,9\ x\ 729922699,6}$
$= 0,12$
Persamaan 2 :
</td></tr>
</table>

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Wide Flange Beam	Cellular Beam

$$\frac{P_u}{2\emptyset P_n} + \frac{M_{vu}}{\emptyset M_n} = \frac{45766{,}47}{2\ x\ 0{,}9\ x\ 325198{,}10} + \frac{24584285{,}39}{0{,}9\ x\ \ 729922699{,}6}$$
$$= 0{,}04$$

Menentukan (Kontrol)
Nilai max = 0,12 < 1 OK

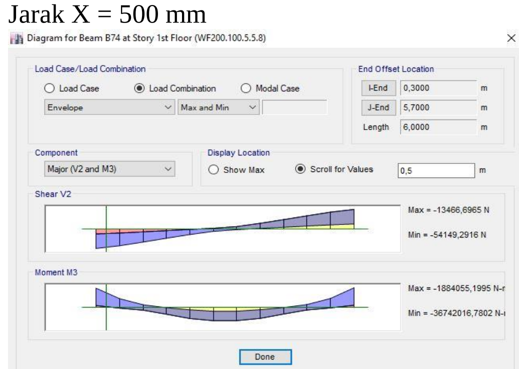
Momen Lentur di Web Post Pertama
Gaya tekan Tee bawah di opening pertama
Lihat perhitungan diatas, untuk gaya aksial yang terjadi di Tee bawah opening, Tul, adalah sebagai berikut :

Tul $= C_{1-statisfies} = 45766{,}47\ N$
Momen lentur di opening kedua :
Lokasi web kedua
x2 $= \mathrm{e} + \mathrm{S} + 0.5\mathrm{D}_0 = 100 + 300 + 0.5(200)$
$= 500\ \mathrm{mm}$

Momen global :
Momen pada jarak x

Mu pada jarak x = 36742016,8 N.mm

Gambar 11. Momen dan Geser Ultimit Pada Jarak X = 500 mm



Gaya aksial Tee bawah di opening ke 2 :
Asumsi aksi komposit sudah bekerja, sehingga kedalaman beton yang mengalami tekan, Xc sama dengan :

Xc $= \frac{9}{100}\,.120 = \frac{9}{100}\,.t_c = 10{,}80\ mm$
Kedalaman efektif balok komposit sebagai berikut :
$d_{effe-comp} = d_g - \left(0.5t_{f-bot} + y_{0-bot}\right) + h_r + t_c - \frac{X_c}{2}$
$= 336{,}6 - (0.5\ x\ 8 + 10{,}35) + 50 + 120 - \frac{4{,}80}{2}$
= 489,85 mm

dan gaya tekan pada beton, C1 adalah :
C1 =

Wide Flange Beam	Cellular Beam
	$0.85. f_c'. X_c. b_{eff} = 0.85\ x\ 30\ x\ 10{,}80\ x\ 193{,}07$ = 53172,08 N C1 $= \frac{M_u}{d_{effec-comp}} = \frac{36742016{,}8}{489{,}85} = 75006{,}02\ N$ C1 yang menentukan : $C_{1-statisfies}$ $= 53172{,}08\ N$ Gaya Geser Horisontal di Web Post : Vuh = $T_{u2} - T_{u1} = 53172{,}08 - 45766{,}47$ $= 98938{,}56\ N$ Momen Lentur di Web Post : Muh = $0{,}9 . \frac{D_0}{2} . V_{uh} = 0{,}9 . \frac{200}{2} . 98938{,}56$ $= 8904470{,}05\ N.mm$ Kuat Geser Horizontal Web Post Gaya tekan Tee bawah di opening pertama $\emptyset V_{n-horiz} = \emptyset_v . F_y . e . t_{w-top} = 0{,}6\ x\ 240\ x\ 100\ x\ 5$ $= 72000\ N$ Kuat Lentur Web Post Momen lentur elastis : Me $= \frac{t_w(s-D_0+0.564D_0)^2}{6} . F_Y$ $= \frac{5(300-200+0.564(200))^2}{6} . 240$ = 9056768 N.mm Momen tekuk : C1 $= 5{,}097 + 0{,}1464 \left(\frac{D_0}{t_w}\right) - 0{,}00174 \left(\frac{D_0}{t_w}\right)^2$ $= 5{,}097 + 0{,}1464 \left(\frac{200}{5}\right) - 0{,}00174 \left(\frac{200}{5}\right)^2$ = 8,17 C2 $= 1{,}441 + 0{,}0625 \left(\frac{D_0}{t_w}\right) - 0{,}000683 \left(\frac{D_0}{t_w}\right)^2$ $= 1{,}441 + 0{,}0625 \left(\frac{200}{5}\right) - 0{,}000683 \left(\frac{200}{5}\right)^2$ = 2,85 C3 $= 3{,}645 + 0{,}0853 \left(\frac{D_0}{t_w}\right) - 0{,}00108 \left(\frac{D_0}{t_w}\right)^2$ $= 3{,}645 + 0{,}0853 \left(\frac{200}{5}\right) - 0{,}00108 \left(\frac{200}{5}\right)^2$ = 5,33 $\emptyset_b M_{allow}$ $= 0{,}9 \left[C_1 \left(\frac{S}{D_0}\right) - C_2 \left(\frac{S}{D_0}\right)^2 - C_3\right] M_e$ $= 0{,}9 \left[8{,}17 \left(\frac{300}{200}\right) - 2{,}85 \left(\frac{300}{200}\right)^2 - 5{,}33\right] 9056768$ = 4206370,61 N.mm Geser Vertikal Tee di Opening Pertama

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<table>
<tr><th>Wide Flange Beam</th><th>Cellular Beam</th></tr>
<tr><td></td><td>
Lokasi opening pertama
x = $e + 0.5D_0 = 100 + 0.5(200) = 200\ mm$

Geser :
Geser Ultimit

Vu = 57418,17 N

$V_{u-top-tee} = \frac{A_{t-top-net}}{A_{net}} V_u = \frac{1000}{2000}.57418,17 = 28709,09\ N$

$V_{u-bottom-tee} = \frac{A_{t-bottom-net}}{A_{net}} V_u = \frac{1000}{2000}.57418,17 = 28709,09\ N$

Kuat Geser Nominal :
Persyaratan
$\frac{h}{t_w} = \frac{d_{t-top-net}}{t_{w-top}} \leq 1,1\sqrt{k_v \frac{E}{F_y}}$ maka $C_{v2} = 1.0$

$\frac{h}{t_w} = \frac{d_{t-top-net}}{t_{w-top}} = \frac{68,3}{5} = 13,66$

$1,1\sqrt{k_v \frac{E}{F_y}} = 1,1\sqrt{1,2\ x\ \frac{200000}{240}} = 34,8$

$\emptyset_v V_{n-tee-top} = \emptyset_{v.} 0,6. F_y. \left(d_{t-top-net}. t_{w-top}\right). C_{v2}$
$= 1\ x\ 0,6\ x\ 240\ x\ (68,3\ x\ 5)\ x\ 1$
= 49176,9 N

Persyaratan
$\frac{h}{t_w} = \frac{d_{t-bot-net}}{t_{w-bot}} \leq 1,1\sqrt{k_v \frac{E}{F_y}}$ maka $C_{v2} = 1.0$

$\frac{h}{t_w} = \frac{d_{t-bot-net}}{t_{w-bot}} = \frac{68,3}{5} = 13,66$

$1,1\sqrt{k_v \frac{E}{F_y}} = 1,1\sqrt{1,2\ x\ \frac{200000}{240}} = 34,8$

$\emptyset_v V_{n-tee-bot} = \emptyset_{v.} 0,6. F_y. (d_{t-bot-net}. t_{w-bot}). C_{v2}$
$= 1\ x\ 0,6\ x\ 240\ x\ (68,3\ x\ 5)\ x\ 1$
= 49176,9 N

Geser Vertikal Pada Bagian Kotor
Geser
Vu = 57829,14 N

Gambar 12. Momen dan Geser Ultimit
</td></tr>
</table>

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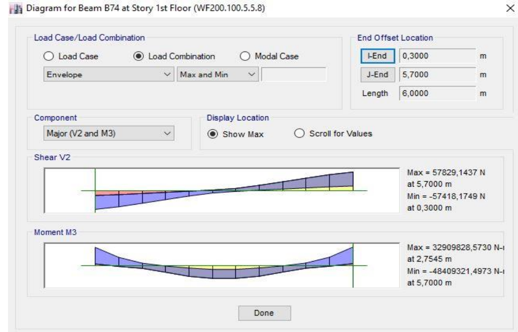
Wide Flange Beam	Cellular Beam



Kuat Geser
Membuat asumsi fillet yang sama dengan ETABS untuk bagian kotor :
Persyaratan

$$\frac{h}{t_w} \geq 1{,}1\sqrt{k_v \frac{E}{F_y}} \quad \text{maka} \quad C_{v1}$$

$$h = d_g - (t_{f-tee-top} + r_{tee-top}) + (t_{f-tee-bot} + r_{tee-bot})$$
$= 336{,}6 - (8 + 12) + (8 + 12)$
$= 296{,}6$

$$\frac{h}{tw} = \frac{296{,}6}{5} = 59{,}3$$

$$1{,}1\sqrt{k_v \frac{E}{F_y}} = 1{,}1\sqrt{1{,}2\ x\ \frac{200000}{240}} = 34{,}8$$

$$C_{v1} = \frac{1{,}1\sqrt{k_v \frac{E}{F_y}}}{h/t_w} = \frac{34{,}8}{59{,}3} = 0{,}59$$

$$\emptyset_v V_{n-gross} = \emptyset_v . 0.6 . F_y (d_g . t_w) C_{v1}$$
$= 0{,}9\ x\ 0.6\ x\ 240\ (336{,}6\ x\ 5)\ x\ 0{,}59$
$= 127902{,}8$ N

$\emptyset V_n > V_u$ = OK
$W_{dead} = 0{,}002\ x\ L = 0{,}002\ x\ 6000 = 12\ N/mm^2$
$W_{live} = 0{,}005\ x\ L = 0{,}005\ x\ 6000 = 30\ N/mm^2$

Lendutan Beban Mati

$$\delta_{dead} = W_{dead} . \frac{5L^4}{384.E.(0.9I_{steel-net})}$$

$$= \frac{12}{12}\ x\ \frac{5\ x\ 6000^4}{384\ x\ 200000\ x\ (0.9\ x\ (1{,}05722\ x10^{11})\ )}$$

= 0,11 mm

Lendutan Beban Hidup

$$\delta_{live} = W_{live} . \frac{5L^4}{384.E.(0.9I_{comp-net})}$$

$$= \frac{30}{12}\ x\ \frac{5\ x\ 6000^4}{384\ x\ 200000\ x\ (0.9\ x\ 191702230283235\ )}$$

= 0,00015 mm

Wide Flange Beam	Cellular Beam
	Lendutan total yang terjadi : $\delta_{dead} + \delta_{dead} = 0{,}11 + 0{,}00015$ $= 0{,}11015 \text{ mm} \leq \frac{L}{280} = 21{,}42\ mm$ OK

Further calculations on each cellular beam type can be seen in the appendix, while the size (type) of the beam used is as follows:

Table 7. List of Cellular Beam Size

Nama Balok	Ukuran (mm)	Tinggi (mm)	Lebar (mm)	Lubang Cellular Ø	Spasing Ø
A	250x125x5x8	334.6	124	200	300
B	300x150x5.5x8	421.2	150	240	360
C	350x175x6x9	471.2	175	280	420
D	350x175x7x11	471.2	175	280	420
E	346x174x6x9	467.2	174	280	420
F	400x200x7x11	538	200	320	480
G	400x200x8x13	538	200	320	480
H	450x200x9x14	605.9	200	360	540
I	500x200x10x16	673.2	200	400	600
J	600x200x11x17	816.5	200	500	750
K	600x300x12x20	807	300	480	720

(Source : Author)

4. Conclusions & Suggestions

4.1. Conclusions

Based on the results of the research it can be concluded that:

Table 8. Beams Checked Against The Shear

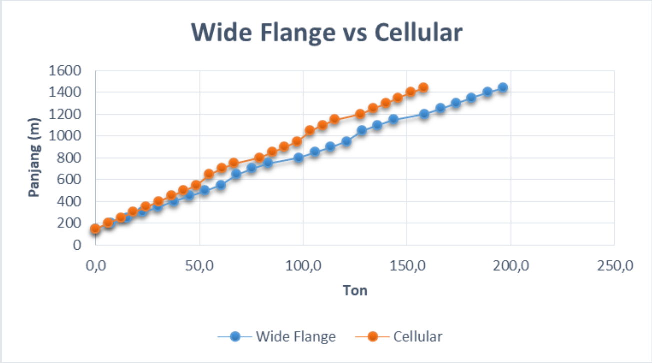
No	Steel Type	Chek Shear (*ØVn* > *Vu*)		
		Vu	*ØVn*	Status
1	WF 400x200x8x13	57829,4	371174,4	OK
2	CB 250x125x5x8	57829,14	127902,85	OK

Table 9. Beams Checked Against The Nominal Flexibility Strength

No	Steel Type	Chek Moment (*ØMn* > *Mu*)		
		Mu	*ØMn*	Status
1	WF 400x200x8x13	48410100	589650243,8	OK
2	CB 250x125x5x8	48410100	656930429,7	OK

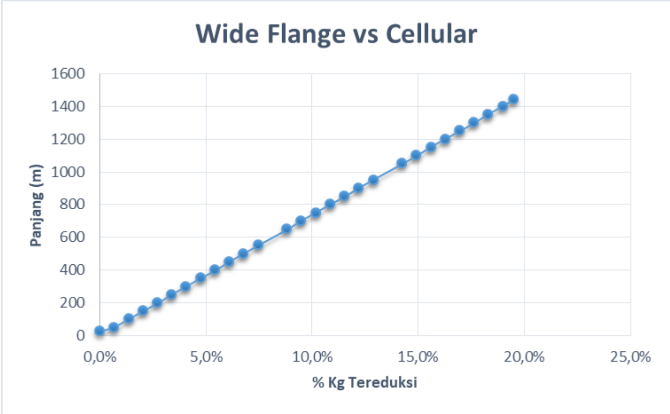
From the results of manual calculation verification, it shows that the cross section of WF 400x200x8x13 and CB 250x125x5x8 with a span length of 6 meters is declared strong and safe because it fill the necessary strong requirements, smaller than the strength of the plan.

Figure 13. Efficiency Graph of Wide Flange And Cellular Beams



From the graph above it can be seen the efficiency of using Cellular Beam compared to Wide Flange. Where the longer (m) use of Cellular Beam, will increases steel tonnage reduction.

Figure 14. Graph Percentage Of Steel Weight Reduction



From the graph above explains the percentage reduction of steel weight will continue to increase when the length of steel usage also increases. This concludes that the use of steel length with steel weight reduction will move linearly. Where in this project with a steel beam length of 1439.27m reduction of steel tonnage was at 19.5%.

4.2. Suggestions

Based on the results that have been researched can be given suggestions, including:

1. In calculating the analysis in this study using the standard burdens of existing regulations. To get a more accurate structural analysis, it is recommended to use the burdens that have been imposed on the structure design by the planner (consultant).
2. For further research, analysis of beams can use other types of blocks such as asymmetrical cellular or castellated. So that we will get a broader conclusion than other alternatives.

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Biographies

Donald Essen was a professor who, today, actively teaches at the Mercubuana University Jakarta with a concentrate on structure. He got a bachelor's degree in civil engineering from the bandung institute of technology in 2002, an Master' degree in engineering specialist from the bandung institute of technology in 2007. He is a member of the Indonesian society of civil and engineers, registered as haki professional engineer, also Class A professional for construction engineering from Dinas Pengawasan dan Penertiban Bangunan DKI Jakarta (DPPB). Currently the director of ESK Enjiniring Company.

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