Case Study of ITB Cirebon GOR Building Beam Structure Checking Against Torsion Loads

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Abstract

In this analytical study, a building structure planning analysis will be carried out as well as checking the beam structure for torsional loads at the ITB Sports Arena (GOR) Building located in Cirebon. Analysis and planning refer to SNI 1726:2019, SNI 2847:2019 and SNI 2020. Modeling analysis and checking of torsion beams using the SAP2000 program as well as manual calculation analysis. Torque is almost the same as design for bending and shearing when the factored torsional moment load applied to a section exceeds the torsional resistance that can be provided by the concrete section itself. The results of the analysis and calculation of the beam structure using the SAP2000 program were obtained: from reinforcement calculations and analysis using SAP2000 software on the beam structure, as well as checking the beam for torsion, the value was taken with the largest torsion force of 91.3673 KN for beam B1A (600 x 450): Top reinforcement with supports 5D22, field 3D22, Support 3D22 ; Bottom reinforcement with support 4D22, Field 4D22, Support 4D22; Web reinforcement with support 4D16, Field 4D16, Support 4D16; using 3 foot stirrups with support D13-100, Field D13-150, Support 13-100.

***Keywords**: Beam Structure, Beam Reinforcement, Torsion Force (T).*

A. INTRODUCTION

The sports arena building (GOR) is planned to be a building for various sports activities inside by providing various kinds of facilities including a volleyball court, badminton court, futsal court, basketball building, and so on. Building structures generally consist of a lower structure and an upper structure. The lower structure is a foundation that is below the ground surface, and the upper structure is the building structure that is above the ground surface such as columns, beams, plates, stairs. In building construction planning, there are structural components that greatly influence the strength of the structure, such as beams and columns.

Beams are known as flexible elements, namely structural elements that dominantly carry internal forces in the form of bending moments and shear forces. A structure formed by placing a horizontal rigid element on top of a vertical rigid element, the beam carries a load that acts transversally from its length and transmits this load to the vertical element (column) that supports it. As for special conditions where the beam receives loads other than bending and shear loads, additional loads due to torsion cause the beam to twist.

The purpose of writing this study is: To analyze and check the planning of beam reinforcement with torsion forces in the structure. The aim of writing this study is: to understand the planning and analysis of beam reinforcement against torsional force loads on building structures.

B. LITERATURE REVIEW

1. Torsion Design in Concrete Beams

A beam is a plate support structure which aims to avoid large deflections which function to resist forces acting in a transverse direction to its axis which results in bending/deflection.

Torsion beams are reinforced beam structural components that can generally bear bending moment loads and shear forces, in addition to simultaneously receiving torsion loads which tend to twist the beam in the longitudinal axis direction.

2. Torsion Beam Design Requirements

Torque Threshold

a. Solid Cross Section:

Non-prestress component: $0.083\lambda \sqrt{f'c}\ (\frac{Acp^2}{Pcp})$

Prestressing components:

$0.083\lambda \sqrt{f'c}\ (\frac{Acp^2}{Pcp})\sqrt{1+\frac{fpc}{0{,}33\lambda\sqrt{f'c}}}$

Non-prestressed components receive axial loads:

$0.083\lambda \sqrt{f'c}\ (\frac{Acp^2}{Pcp})\sqrt{1+\frac{Nu}{0{,}33Ag\lambda\sqrt{f'c}}}$

b. Hollow Cross Section:

Non-prestress component: $0.083\lambda \sqrt{f'c}\ (\frac{Ag^2}{Pcp})$

Prestressing components:

$0.083\lambda \sqrt{f'c}\ (\frac{Ag^2}{Pcp})\sqrt{1+\frac{fpc}{0{,}33\lambda\sqrt{f'c}}}$

Non-prestressed components receive axial loads:

$0.083\lambda \sqrt{f'c}\ (\frac{Ag^2}{Pcp})\sqrt{1+\frac{Nu}{0{,}33Ag\lambda\sqrt{f'c}}}$

Factored Torque Moments and Torsion/Structure Cracks.

a. Non-prestressed structural components, the cross-section of which is less than a distance *d* from the face of the support must be designed not less than T_u calculated at a distance *d*.

$\phi\, 0.33\lambda\sqrt{fc'}\ (\frac{Acp^2}{Pcp})$

b. Prestressed structural members, which are located less than a distance *h*/2 from the support face must be designed not less than T_u calculated at a distance *h*/2.

$\phi\, 0.33\lambda \sqrt{f'c}\ (\frac{Acp^2}{Pcp})\sqrt{1+\frac{fpc}{0{,}33\lambda\sqrt{f'c}}}$

c. For non-prestressed structural components with axial tension or compression forces.

$\phi\, 0.33\lambda \sqrt{f'c}\ (\frac{Acp^2}{Pcp})\sqrt{1+\frac{Nu}{0{,}33Ag\lambda\sqrt{f'c}}}$

Torque Moment Strength

a. For solid cross section: $\sqrt{(\frac{Vu}{bwd})^2 + (\frac{TuPh}{1,7\ Aoh^2})^2} \leq \phi(\frac{Vc}{bwd}\ 0.66\ \sqrt{f'c}\ )$

b. For hollow sections:

$(\frac{Vu}{bwd})^2 + \left(\frac{TuPh}{1,7\ Aoh^2}\right)^2 \leq \phi(\frac{Vc}{bwd}\ 0.66\ \sqrt{f'c}\ )$

If T_u exceeds the torque limit, then the cross-sectional design must meet:

$\phi T_n \geq T_u$

T_n value is taken from the smallest value between:

a. $T_n = \frac{2AoAtFyt}{s} cot\ \theta$

b. $T_n = \frac{2AoAtFy}{Ph} cot\ \theta$

Minimum torsion reinforcement, T_u exceeds the torque threshold value. If torsion reinforcement is required then the minimum area of transverse closed stirrups must be calculated by:

$(A_v + 2A_t) = 0.62\sqrt{f'c}\ \frac{bws}{fyt}$ but cannot be less than $(0.35\ b_w s)/f_{yt}$

If torsion reinforcement is required then the minimum total area of longitudinal torsion reinforcement *is* $A_{t\ min}$, calculated by:

$A_{t.min} = \frac{0,42\sqrt{f'c}\ Acp}{fy} - \frac{At}{s} P_h \frac{fyt}{fy}$

with $\frac{At}{s}$ no less than

$0.175\ b_w / f_{yt}$

C. METHOD

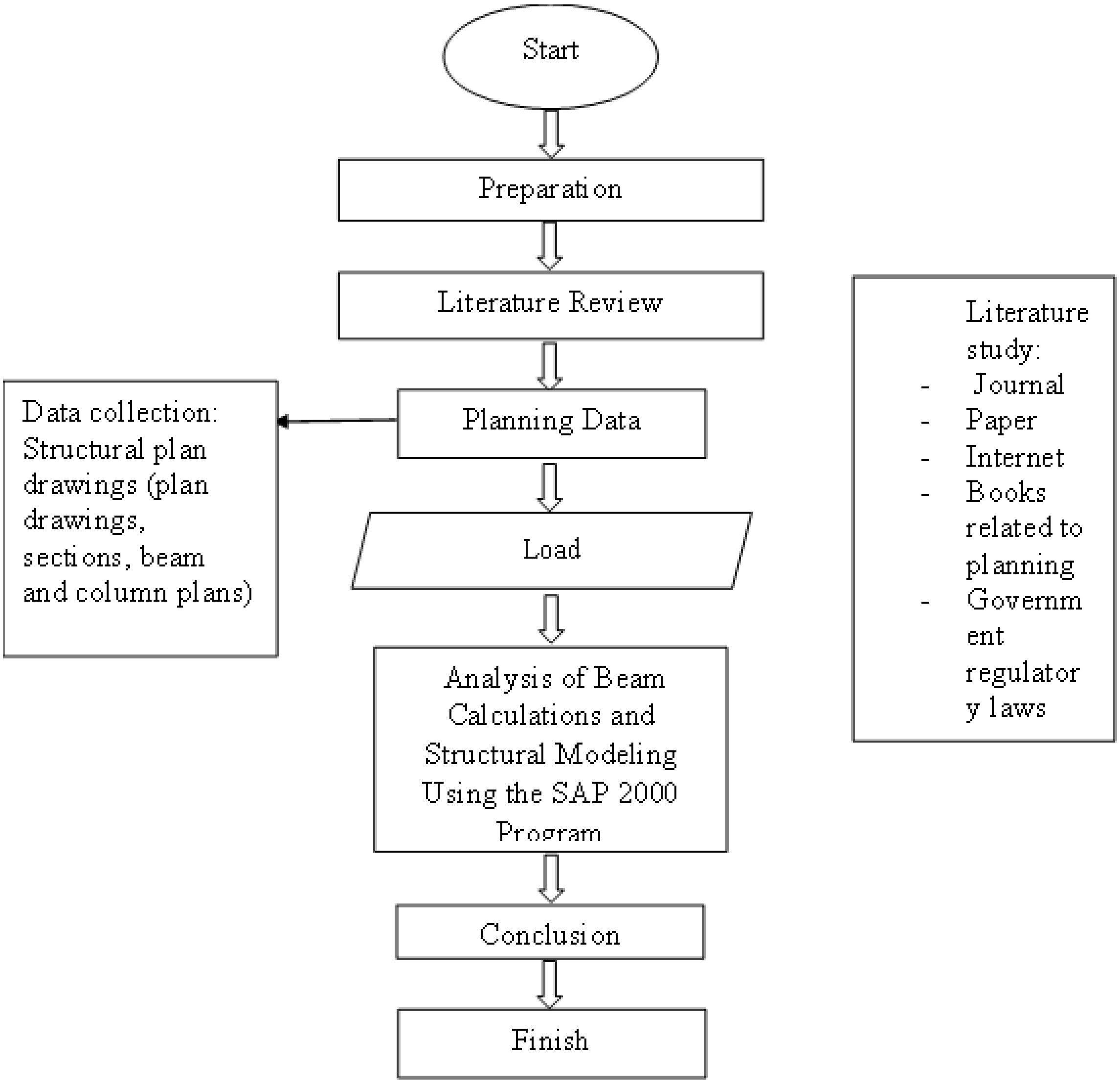

Figure 1 Analysis Methodology Flow Chart

Planning Data

1. Building Name: Sports Building, Bandung Institute of Technology, Cirebon Campus.
2. Location: Jln. Kebonturi, district. Arjawinangun, Cirebon Regency
3. Number of Floors : 2 Floors
4. Building Function : Sports
5. Building height : 18.5 m
6. Building Width : 48.4 m
7. Building Length : 36.4 m
8. Height of Each Floor
   - Basement : 3.3 m
   - 1st floor : 2.4 m
   - 2nd floor : 2.4 m

9. Material Quality
   - Concrete: *ready mix* with compressive strength fc' = 30 MPa intended for columns, beams and slabs.
   - Steel: steel reinforcement with a diameter of >10 mm using BJTD 40 (threaded), f_y = 400 MPa.
   - Steel Profile: BJ-37 with a minimum yield stress of 2400Kg/cm ^{2} and allowable stress of 1600 kg/cm^2.
   - Welding: The quality of the welding steel used is equivalent to *E70xx.* Refers to AWS A5 (*American Welding Society*).

Planning Data

a. Dead Load (DL)
   - The self-weight, columns, beams, slabs and roof trusses using concrete materials of 24 kN/m ^{3} and steel 78.5 kN/m^3, are calculated automatically by the program.
   - The additional dead load on the roof frame is evenly distributed at 0.5 kN/m ^{2} (roof covering + purlin) and the concentrated load is 0.5 kN as the load for lighting lamps and accessories.
   - Brick wall load: 2.5 kN/m^2
   - *Finishing* Load: 1.2 kN/m^2

b. Live Load (LL)

   The live load calculated is as follows:
   - Dome Roof : 0.25 kN/m^2
   - Roof Dak : 1.0 kN/m^2
   - Café Room : 2.0 kN/m^2
   - Sports Room : 3.0 kN/m^2
   - Sports Arena : 5.0 kN/m^2
   - Spectator Stand : 3.0 kN/m ^{2}
   - Stairs : 3.0 kN/m ^{2}

c. Soil Lateral Load

   The lateral soil load is 17.5 kN/m ^{3} which burdens the basement walls.

d. Earthquake Load

   The equivalent static load acting on a building mimics the effects of ground movements caused by an earthquake.
   - Regional zone: Cirebon-West Java
   - Acceleration at *Base Roc*: 0.3124g

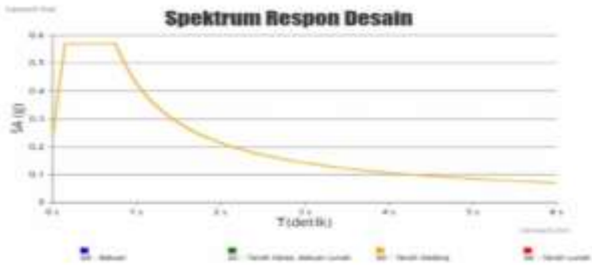

Figure 2 Spectrum Response Graph

e. Wind Load

Wind Pressure (Q)

- $Q = 0.613 \times V^2 = 3.52\ kN/m^2$
- V = D design Base wind speed (*34 m/s = 150 km/hour*).

Structural Analysis

Building structure modeling was carried out with the help of SAP2000 software. determine the structural materials used and the cross-sectional dimensions of the structural elements of the frame system. The dimensions of each structure are made according to the plan drawing, then applied to the structural model design.

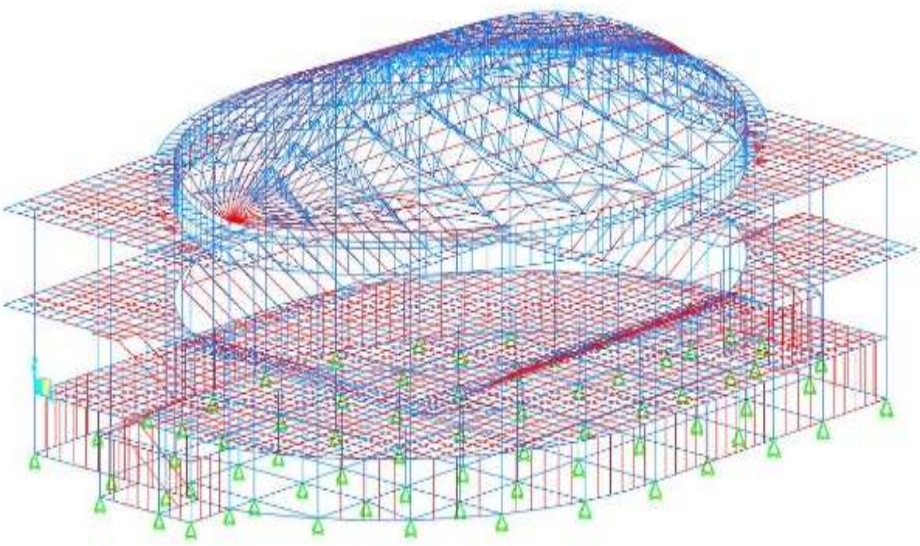

Figure 2. 3D Model of the GOR Structure Building

Beam Structure Analysis

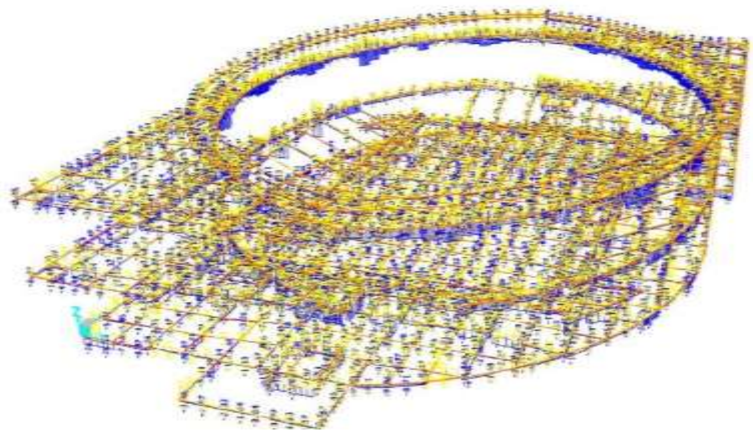

Figure 3 Torque Force Output on the Beam

From the results of structural analysis and modeling, the values of the internal forces in the building structure were obtained. The torsional forces with the largest values were taken, namely located in beam BA1. Based on the analysis table below, the largest Torque force (*Tu) value, namely 91.3673 kN,* is in Frame 477 on beam B1A.

Table 1 ***Forces Frame Elements*** **with the Largest Torque Values**

Frames	Case output	Step Type	P (KN)	V2 (KN)	V3 (KN)	Q (KN-m)	M2 (KN-m)	M2 (KN-m)
477	EnvU	Max	173.7	278.5	22.9	91.4	16.04	45.2
477	EnvU	Max	173.7	279.1	22.9	91.3	13.9	51.4
477	EnvU	Max	173.7	279.8	22.9	91.3	11.9	57.67
477	EnvU	Max	173.7	280.4	22.9	91.3	9.91	63.9
477	EnvU	Max	173.7	281.1	22.9	91.3	8.01	70.1
477	EnvU	Max	173.7	281.7	22.9	91.3	6.3	76.3
477	EnvU	Max	173.7	282.4	22.9	91.3	4.5	82.5
477	EnvU	Max	173.7	283.1	22.9	91.3	3.0	88.6
477	EnvU	Max	173.7	283.7	22.9	91.3	3.93	94.7
1368	EnvU	Min	-48.9	70.2	-10.8	-88.7	-3.99	-63.1
1368	EnvU	Min	-48.9	70.3	-10.8	-88.7	-3.80	-65.6
1368	EnvU	Min	-48.9	71.38	-10.8	-88.7	-1.26	-102.4
1368	EnvU	Min	-48.9	72.5	-10.8	-88.7	-1.46	-139.7
			956.7	381.4	108.5	91.4	62.9	257.2
			-820.1	-232.7	-116.1	-88.7	-58.8491	-332.03

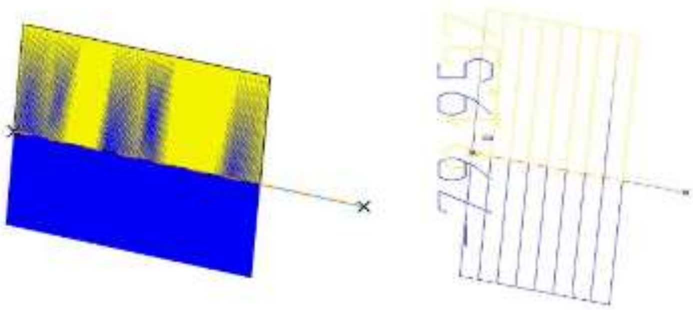

Figure 4 Diagram and Value of the Largest Torque Beam

Checking Torsion Reinforcement – Beam Shear B1A

Input Data:

Beam Width: b = *450 mm*

Beam Height: h = *600 mm*

Beam Type = Exterior

Number of Stirrup Legs: n = 3

Concrete Compressive Strength f'_c = 30 MPa

Ultimate Shear Load at Endspan: $V_{u\,es}$, Condition 1 = 431.7 kN

Ultimate Shear Load at Endspan: $V_{u\,es}$, Condition 2 = 273.2 kN

Combination of shear force in 1.2D+1.6L beam, V_e = 675.175 kN

Beam Torque Load T_u, Condition 1 = 39.05 kN.m

Beam Torque Load T_u, Condition 2 = 97.48 kN.m

Shear Torque Calculation

Shear torque at end span: $\phi = 0.75$

$h_w = 480\ mm$

$l_w = 1263\ mm$

$A_{cp} = 367500\ mm^2$

$P_{cp} = 3726\ mm$

Torque Threshold:

$T_n = \phi.\ 0.83\sqrt{f'y}\ \frac{Acp^2}{Pcp}$

$= 0.75\ x\ 0.083\ x\ \sqrt{30}x\frac{367.500^2}{3.726.0}$

$= 12.3586724\ kN.m$

$12.36\ KN.m < T_u = 97.48\ kN.m$

(Torque gain must be calculated).

Concrete Shear Capacity:

$V_c = 0.17\sqrt{f'c}b_d$

$= 0.17\ x\ \sqrt{f'c}x\ 450\ x\ 560.00$

$= 234644.34\ N$

Part capacity torque:

$T_c = \phi\frac{Vc}{bd} + 0.66\sqrt{f'c}$

$= 0.75\ \frac{234.644}{450\ x\ 560} + 0.66\ x\sqrt{30}$

$= 3.41\ MPa$

Reinforcement Covered Area:

$A_{oh} = 192400\ mm^2$

$P_h = 1780\ mm$

Axial Compressive Force Limit:

$$P_{min} = \frac{Ag\, f'c}{10} = \frac{450\ x\ 600\ x\ 30}{10} = 810\ kN$$

Torque Shear Check

- Condition 1: Maximum shear force V_{u_max} with correlated torque M_x

  $V_{u\_max} = 431.7\ KN$

  $T_{u\_cons} = 39.05\ KN.m$

  (Torque Consideration Status Considered)

Pressing Torque:

$$T_{su} = \sqrt{(\frac{Vu}{bd})^2 + (\frac{TuPh}{1.7\ Aoh^2})^2}$$

$T_{su} = 2.04\ MPa < 3.41\ MPa$

Torque Section Capacity Status → **Safe**

Nominal shear requirements:

$$V_n = \frac{Vu}{\phi} = \frac{431.705}{0.75} = 575.6\ KN$$

Shear force reinforcement requirements:

$$Vs = V_n - V_c = 340962.7\ N$$

Cross-sectional capacity:

$$\sqrt{\left(\frac{Vu}{bwd}\right)^2 + \left(\frac{TuPh}{1.7A0h^2}\right)^2}$$

$$= \sqrt{\left(\frac{347.7}{450\ x\ 560}\right)^2 + \left(\frac{39.05\ x\ 1380}{1.7.192400^2}\right)^2}$$

$= 2.04\ MPa$

$$(\phi\left(\frac{Vc}{bwd}\right) + 0.66\ \sqrt{f'c})$$

$$= 0.75\left(\frac{234.644}{450\ x\ 560}\right) + 0.66\ \sqrt{30} = 4.31\ MPa$$

$4.31\ MPa > 2.04\ MPa$

Nominal torque requirements:

$$T_n = \frac{Tu}{\phi} = \frac{39.051}{0.75} = 52.07\ KN.m$$

$$\frac{Ast}{s} = \frac{Tn}{2Aoh\ fy\ v\ Cot\theta} \quad \theta = 0.45^{o}\ (22.7.6.1.2)$$

$$= \frac{At}{s} = \frac{Tn}{2Aoh\ fy\ v\ Cot(\theta)}$$

$$= \frac{At}{s} = \frac{52.07\ x\ 100000}{2\ x\ 192{,}400\ x\ 420\ x\ (cot(45))}$$

$$= \frac{At}{s} = 0.322\ mm^2/mm$$

$$\frac{Av}{s} = \frac{Vs}{fys\ d} = \frac{340{,}962.656}{420\ x\ 560} = 1.45\ mm^2/mm$$

$$\frac{Avt}{s} = 2\frac{Avt}{s} + \frac{Av}{s} = 2\ x\ 0.32217 + 1.45000$$

$$= 2{,}094\ mm^2/mm$$

Stirrup distance requirements:

$$S_{rec} = \frac{n\,0.25\pi d2}{\frac{Avt}{s}} = \frac{3\ x\ 0.25\ x\ \pi\ x\ 13^2}{2.0940}$$

$$= 190.2\ mm$$

$$Al = \frac{At}{s} . p_h . \frac{fys}{fyv} = 0.32217\ x\ 1.780\ x \frac{420}{420}$$

$$= 573.46\ mm$$

$$Almin = 0.42\sqrt{f'c}\,\frac{Acp}{fys} - \frac{At}{s} P_h \frac{fys}{fyv}$$

$$= 0.42\ x\ (30^{05})\ x\ \frac{367500}{420} - 0.3222\ x\ 1780\ x \frac{420}{420} \quad = 1439.0\ 4\ mm^2$$

$$Almin = 0.42\sqrt{f'c}\,\frac{Acp}{fys} - \frac{175\ bw}{s} P_h \frac{fys}{fyv}$$

$$= 0.42\ x\ (30^{0.5})\ x\ \frac{367500}{420} - \frac{0.175\ \ x\ 450}{420} x\ 1780\ x\ \frac{420}{420} = 1678.75\ mm^2$$

$$Al = \frac{1678.75}{3} = 559.58\ mm^2$$

Amplified Torque Amount

$$= \frac{559.5833333}{0.25\ x\ \pi\ x\ 16^2} = 2{,}783 \rightarrow use = 4\ Rebar$$

- Condition 2: Maximum Torque M_{x_max} with Correlated Shear, F_y

  $V_{u\_max} = 273.2\ KN$

  $T_{u\_cons} = 97.48\ KN.m$

  Pressing Torque:

  $$T_{su} = \sqrt{\left(\frac{Vu}{bd}\right)^2 + \left(\frac{TuPh}{1.7\ Aoh^2}\right)^2}$$

  $T_{su} = 3.00\ MPa < 3.41\ MPa$

  Torque Section Capacity Status → **Safe**

  Nominal Shear Requirements:

  $$V_n = \frac{Vu}{\phi} = \frac{237.158}{0.75} = 364.2\ kN$$

  Shear Force Strengthening Requirements:

  $V_s = V_n - V_c$

  $= (364{,}211\ x\ 1000) - 234{,}644{,}344$

  $= 129566.7\ N$

Cross Section Capacity:

$$\sqrt{\left(\frac{Vu}{bwd}\right)^2 + \left(\frac{TuPh}{1.7A0h^2}\right)^2}$$

$$= \sqrt{\left(\frac{237.20}{450\ x\ 560}\right)^2 + \left(\frac{97.48\ x\ 1380}{1.7.192400^2}\right)^2}$$

$$= 2.99626086\ MPa$$

$$\phi\left(\frac{Vc}{bwd}\right) + 0.66\ \sqrt{f'c} = 0.75\left(\frac{234.644}{450\ x\ 560}\right) + 0.66\ (30^{0.5}) = 4.31\ MPa$$

$4.31\ MPa > 3.00\ MPa$

Nominal Torque Requirements:

$T_n = \frac{Tu}{\phi} = \frac{97.478}{0.75} = 130\ KN.m$

$\frac{Ast}{s} = \frac{Tn}{2Aoh\ fy\ v\ Cot\theta}$ $\theta = 0.45^o$ (22.7.6.1.2)

$\frac{At}{s} = \frac{Tn}{2Aoh\ fy\ v\ Cot(\theta)}$

$\frac{At}{s} = \frac{129.97\ x\ 100000}{2\ x\ 192{,}400\ x\ 420\ x\ (cot(45))}$

$\frac{At}{s} = 0.804196\ mm^2/mm$

$\frac{Av}{s} = \frac{Vs}{fys\ d} = \frac{129{,}566.656}{420\ x\ 560} = 0.551\ mm^2/mm$

$\frac{Avt}{s} = 2\frac{Avt}{s} + \frac{Av}{s} = 2\ x\ 0.80420 + 0.55100$

$= 2.159\ mm^2/mm$

Stirrup distance requirements:

$S_{rec} = \frac{n\ 0.25\pi d2}{\frac{Avt}{s}} = \frac{3\ x\ 0.25\ x\ \pi\ x\ 13^2}{2.159}$

$= 184.4\ mm$

$AI = \frac{At}{s} . p_h . \frac{fys}{fyv}$

$= 0.80420\ x\ 1.780\ x \frac{420}{420}$

$= 1431.476\ mm$

$Al_{min} = 0.42\sqrt{f'c}\frac{Acp}{fys} - \frac{At}{s} P_h \frac{fys}{fyv}$

$= 0.42\ x\ \sqrt{30} x \frac{367500}{420} - 0.80420\ x\ 1780\ x \frac{420}{420}$

$= 581.0309351\ mm^2$

$Al_{min} = 0.42\sqrt{f'c}\frac{Acp}{fys} - \frac{175\ bw}{s} P_h \frac{fys}{fyv}$

$= 0.42\ x\ \sqrt{30})\ x \frac{367500}{420} - \frac{0.175\ \ x\ 450}{420} x$

$1780 x \frac{420}{420} = 1678.75\ mm^2$

$Al = \frac{1678.75}{3} = 559.5833333\ mm^2$

Amplified Torque Amount $= \frac{559.5833333}{0.25\ x\ \pi\ x\ 16^2}$

$= 2{,}783 \rightarrow use = 4$ Rebar

In the checking analysis above, the following configuration of 4D16 torsion reinforcement in the web reinforcement is used:

Table 2 Reinforcement of Beam B1A

Balok		Tumpuan	Lapangan	Tumpuan
B1A 600x450 kuning	Tul. Atas	5D22	3D22	3D22
	Tul. Bawah	4D22	4D22	4D22
	Tul. Badan	4D16	4D16	4D16
	Sengkang 3 Kaki	D13-100	D13-150	13-100

D. CONCLUSION

Based on the results of reinforcement calculations and structural analysis using SAP2000 software on beam structures, as well as checking the beam for torsion, the value with the largest torsion force was taken, namely 91.3673 KN, located on beam B1A. Beam B1A (600 x 450), there is the addition of 4D16 torsion resisting reinforcement in the web reinforcement pair.

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