TẠP CHÍ KHOA HỌC
TRƯỜNG ĐẠI HỌC QUY NHƠN

Quy trình tính toán độ bền dầm bêtông cốt thép chịu mômen uốn - xoắn đồng thời theo TCVN 5574:2018

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TÓM TẮT

Bài báo này phân tích lý thuyết tính toán độ bền cấu kiện bêtông cốt thép chịu uốn - xoắn đồng thời theo Tiêu chuẩn TCVN 5574:2018. Từ đó đề xuất một quy trình tính toán độ bền của dầm bêtông cốt thép chịu mômen uốn – xoắn đồng thời theo tiêu chuẩn hiện hành của Việt Nam, giúp việc thiết kế kết cấu của các kỹ sư đơn giản hơn.

Từ khóa: *Dầm bêtông cốt thép, quy trình tính toán độ bền cấu kiện chịu uốn – xoắn đồng thời, dầm bêtông cốt thép chịu uốn – xoắn đồng thời.*

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Proposing a strength design process of reinforced concrete beams under combined bending and torsion based on TCVN 5574:2018 standard

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ABSTRACT

This paper analyzes the theory of calculating the strength of reinforced concrete members subject to combined bending and torsion by the TCVN 5574:2018 standard. And a strength design process of reinforced concrete beams under combined bending and torsion based on the current standard of Viet Nam will be offered, which helps construction engineers' design easier.

Keywords: *Reinforced concrete beams, strength design process for members under combined bending and torsion, reinforced concrete beams under bending and torsion.*

1. INTRODUCTION

In reinforced concrete structures, there are almost no members under pure torsion, but members under combined bending and torsion are quite common. For example, balcony support beams, side beams, etc. are members where the force acting on them is not in the plane passing through their longitudinal axis.

The torsional bearing capacity of reinforced concrete structures is much worse than their bending bearing capacity. Therefore, in many cases, although the value of the torsional moment is not great, it has a significant influence and causes the appearance of cracks. In the design of reinforced concrete members should avoid or reduce the torsional moment as much as possible.[1,2]

Section 8.1.4 of TCVN 5574:2018 standard presents principles of strength design of reinforced concrete members for torsional moments. This article will base on these principles to develop a process to apply in the design of reinforced concrete members under combined bending and torsion.

2. STRENGTH DESIGN OF REINFORCED CONCRETE MEMBERS WITH RECTANGULAR CROSS-SECTION FOR COMBINED TORSIONAL AND BENDING MOMENTS BASED ON TCVN 5574:2018 STANDARD

2.1. Basic provisions

Strength design of reinforced concrete members with rectangular cross-section for torsional moments is performed based on model of spatial sections. In the design based on model of spatial sections, we should consider sections formed by inclined lines, passing on three tensile sides of a member, and closing line passing on the fourth compressive side.

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The design of reinforced concrete members for torsional moments is performed with regard to strength of spatial sections and a member between them. Concrete strength between spatial sections is characterized by maximum values of torsional moment which is determined by axial tensile resistance of concrete considering stress state in concrete between spatial sections.

Analysis of spatial sections is performed based on equilibrium expressions of all internal and external forces about an axis in the centre of the compression zone of the spatial section. Internal moments include moment which is sustained by rebars passing along the member axis; by rebars passing across the member axis, crossing the spatial section and placed in the compression zone of the spatial section and at the tension member side opposite to the compression zone of the spatial section. Then internal forces sustained by reinforcement are determined corresponding to design values of tensile resistance of longitudinal and transverse reinforcement.

In the design, we should consider all positions of a spatial section with compression zone at bottom, lateral and top sides of a member. Analysis for combined torsional and bending moments, as well as torsional and shear forces is performed according to equilibrium expressions between the resppective force factors.

2.2. Strength design of reinforced concrete members for combined torsional and bending moments

Section 8.1.4.3 of TCVN 5574:2018 standard shows that the design of members under combined bending and torsion should comply with the following two conditions:

2.2.1. Condition on the strength of a member between spatial sections

Strength design of a member between spatial sections should comply with the condition (1):[3]

$$T \leq 0.1R_b hb^2 \quad (1)$$

Where :

T : Torsional moment due to external loads in the normal section of a member.

R_b: Design axial compressive resistance of concrete for first group limit states.

b, h : Dimensions of a cross-section ($b \leq h$).

2.2.2. Condition on the strength of spatial sections

Scheme of forces at the design of a spatial section for torsional moments is shown in Figure 1.[3]

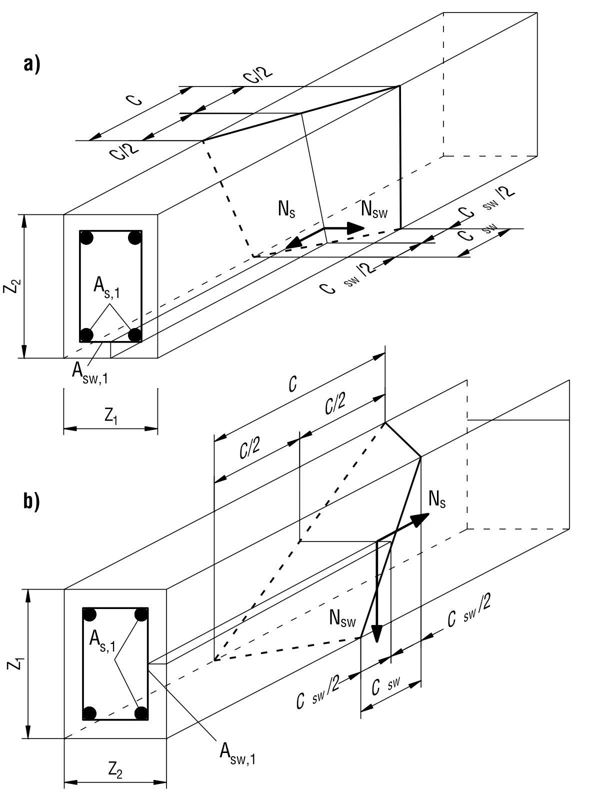

Figure 1. Scheme of forces at the design of a spatial section for torsional moments
a) Tensile reinforcement at bottom side; b) Tensile reinforcement at lateral side

Strength design of a spatial section is performed according to the condition (2):[3]

$$T \leq T_0 \sqrt{1 - \left(\frac{M}{M_0}\right)^2} \quad (2)$$

Where :

T: Torsional moment due to external load in a spatial section;

T_0: Torsional moment due to external load in a spatial section;

M: Bending moment due to external load in a normal section;

M_0: Ultimate bending moment sustained by a normal section.

For design of combined torsional and bending moments, the spatial section with tensile reinforcement should be considered, when tensile reinforcement is located at the tensile side due to the bending moment, that is at the side normal to the plane of bending moment.

Torsional moment T due to external load is determined in a normal section located in the middle of the projection length C along the longitudinal axis of a member. Bending moment M due to external load is determined in a normal section as well.

Ultimate torsional moment T_0 is determined by the formula:

$$T_0 = T_{sw} + T_s \quad (3)$$

Where:

T_{sw}: Torsional moment sustained by reinforcement with a spatial section in cross direction with respect to the axis of a member:

$$T_{sw} = 0.9N_{sw}Z_2 \quad (4)$$

T_s: Torsional moment sustained by reinforcement with a spatial section in longitudinal direction:

$$T_s = 0.9N_s \frac{Z_1}{C} Z_2 \quad (5)$$

N_{sw}: Force in reinforcement located in cross direction:

$$N_{sw} = q_{sw,1}C_{sw} \quad (6)$$

$q_{sw,1}$: Force in this reinforcement per unit length of a member:

$$q_{sw,1} = \frac{R_{sw}A_{sw,1}}{s_w} \quad (7)$$

$A_{sw,1}$: sectional area of reinforcement in the cross direction;

s_{sw} : Spacing of reinforcement in the cross direction;

C_{sw} : Projection length of the tensile side of a spatial section on the longitudinal axis of a member:

$$C_{sw} = \delta C \quad (8)$$

δ - Coefficient considering ratio of cross-section dimensions:

$$\delta = \frac{Z_1}{2Z_2 + Z_1} \quad (9)$$

C - Projection length of the compressive side of a spatial section on the longitudinal axis of a member;

N_s: Force in longitudinal reinforcement in the referred side:

$$N_s = R_sA_{s,1} \quad (10)$$

$A_{s,1}$: Sectional area of longitudinal reinforcement in the referred side;

Z_1 and Z_2: length of the cross-sectional side at the referred tensile side and the length of another cross-sectional side (Figure 1).

Note:

+ The ratio φ_w should comply with the condition:

$$0.5 \le \varphi_w = \frac{q_{sw,1}Z_1}{R_sA_{s,1}} \le 1.5 \quad (11)$$

In case exceeds the stated values, the design should consider reinforcement ($A_{s,1}$ and $A_{sw,1}$) within the stated values.

+ The design is performed for spatial sections located along the length of a member at the most critical projection length of a spatial section C on the longitudinal axis. C is determined by the method of iterative approximation, calculate the derivative of the second member of condition (3) according to C and then assumed equal to 0.

$$\Rightarrow C = \sqrt{\frac{R_sA_{s,1}(2Z_2 + Z_1)}{q_{sw,1}}} \quad (12)$$

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And C should comply with the condition:

$$C \le \begin{cases} 2Z_2 + Z_1 \\ Z_1\sqrt{2/\delta} \end{cases} \quad (13)$$

Ultimate bending moment M_0 is determined by the problem of checking the load bearing capacity of the bending members. The steps to calculate M_0 of rectangular cross-section with single reinforcement are done as follows:[1-4]

$$\text{Calculate: } \xi = \frac{R_s A_s}{R_b Z_1 (Z_2 - a)} \quad (14)$$

$$\Rightarrow \alpha_m = \xi(1 - 0.5\xi) \quad (15)$$

$$\Rightarrow M_0 = \alpha_m R_b Z_1 (Z_2 - a)^2 \quad (16)$$

2.3. Strength design of reinforced concrete members for combined torsional and shear force

Section 8.1.4.4 of TCVN 5574:2018 standard shows that the design of members under combined torsional moment and shear force should comply with the following two conditions:

2.3.1. Condition on the strength of a member between spatial sections

Strength design of a member between spatial sections should comply with the condition (17):[3]

$$T \le T_0\left(1 - \frac{Q}{Q_0}\right) \quad (17)$$

Where :

T : Torsional moment due to external load in a normal section;

T_0: Torsional moment sustained by a member between spatial sections and assumed equal to:

$$T_0 = 0.1R_b hb^2 \quad (18)$$

Q: Shear force due to external load in the same normal section;

Q_0: Ultimate shear force sustained by concrete between inclined sections and assumed equal to:

$$Q_0 = 0.3R_b bh_0 \quad (19)$$

2.3.2. Condition on the strength of spatial sections

- Strength design of a spatial section is performed according to (17) with the following values:

T: Torsional moment due to external load in a spatial section;

T_0: Torsional moment sustained by a spatial section;

Q: Shear force in an inclined section;

Q_0: Ultimate shear force sustained by an inclined section.

- In the design for combined torsional moment and shear force, the spatial section with tensile reinforcement should be considered, when tensile reinforcement is located at one tensile side due to shear force, that is at the side parallel to the plane of shear force.

- Torsional moment T due to external load is determined in a normal section located in the middle of the projection length C along the longitudinal axis of a member. Shear force Q due to external load is determined in the normal section as well.

- Ultimate torsional moment T_0 is determined according to the formula (3).

- Ultimate shear force Q_0 is determined according to the formula (20):[1-4]

$$Q_0 = Q_b + Q_{sw} \quad (20)$$

Where Q_{sw} , Q_b : shear force sustained by transverse reinforcement and concrete:

$$Q_{sw} = 0.75q_{sw}C' \quad (21)$$

Where C' should comply with the condition: $h_0 \le C' \le 2h_0$

$$q_{sw} = \frac{R_{sw}A_{sw}}{s} \quad (22)$$

Q_b is determined as follows:

If $q_{sw} \ge 0.25R_{bt}b$, Q_b is determined by the formula:

$$Q_b = \frac{1.5R_{bt}bh_0^2}{C'} \quad (23)$$

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If $q_{sw} < 0.25R_{bt}b$, Q_b is determined by the formula:

$$Q_b = \frac{6q_{sw}h_0^2}{C'} \quad (24)$$

Where $0.5R_{bt}bh_0 \leq Q_b \leq 2.5R_{bt}bh_0$ (or $0.6h_0 \leq C' \leq 3h_0$).

C' is the most critical projection length of a spatial. C' is determined by the method of iterative approximation, calculate the derivative of the second member of condition (20) according to C' and then assumed equal to 0.

$$\Rightarrow C' = \sqrt{\frac{2R_{bt}bh_0^2}{q_{sw}}} \quad (25)$$

2.4. The strength design process of reinforced concrete beams under combined bending and torsion

Problem in words: known M, T, Q, b, h, R_b, R_{bt}, R_s, R_{sc}, R_{sw}, ξ_R . Requirement: calculate and arrange the reinforcement.

Perform the following steps:

Use the problem: calculate the longitudinal reinforcement support bending moment M:[3]

1. Assume a $\Rightarrow h_0 = h - a$

2. Calculate α_m: $\alpha_m = \frac{M}{R_b bh_0^2}$ (26)

3. Calculate ξ:

$$\xi = 1 - \sqrt{1 - 2\alpha_m} \leq \xi_R \quad (27)$$

4. Calculate area of tensile reinforcement section:

$$A_s = \frac{\xi R_b bh_0}{R_s} \quad (28)$$

5. Select and reinforce the longitudinal reinforcement $\Rightarrow$ the actual value of a, a', h_0 (A'_s provided by structural requirements).

Use the problem: calculate the transverse reinforcement support shear force Q $\Rightarrow A_{sw}$, s.[3]**:**

6. Select the transverse reinforcement according to the conditions:

- $\phi_d \geq 6$ mm

- $q_{sw} = \frac{R_{sw} A_{sw}}{s}$ (29)

- $s \leq \begin{cases} s_{max} = \frac{R_{bt} b h_0^2}{Q} \\ 0.5h_0 \\ 300 \text{ mm} \end{cases}$ (30)

7. Check the condition:

$$Q \leq Q_0 \quad (31)$$

Where: Q_0 is determined according to (20)

If the condition (31) is not satisfied, reselect the transverse reinforcement according to step 6 until the condition (31) is satisfied, then move to step 8.

Design for combined torsional moment (T) and bending moment (M):

8. Check the condition (1).

If the condition (1) is not satisfied, increase the cross-sectional size (b, h) or increase the grade of compressive strength of concrete (B) until the condition (1) is satisfied, then go to step 9.

9. Check the condition (11), where: $Z_1 = b$; $Z_2 = h$ and $A_{s,1}$, $A_{sw,1}$ are tensile reinforcement at bottom side b (Figure 1a).

If the condition (11) is not satisfied, adjust $A_{s,1}$, $A_{sw,1}$ into the design until the condition (11) is satisfied, then move to step 10.

10. Calculate C according to formula (12).

11. Calculate δ according to formula (9).

12. Calculate C_{sw} according to formula (8).

13. Calculate N_{sw} according to formula (6).

14. Calculate T_{sw} according to formula (4).

15. Calculate N_s according to formula (10).

16. Calculate T_s according to formula (5).

17. Calculate T_0 according to formula (3).

18. Calculate ξ according to formula (14).

19. Calculate α_m according to formula (15).

20. Calculate M_0 according to formula (16).

21. Check the condition (2).

If the condition (2) is not satisfied, increase the cross-sectional size (b, h) or increase longitudinal reinforcement, transverse reinforcement and then repeat steps from 9 to 21 until the condition (2) is satisfied and go to step 22.

Design for combined torsional moment (T) and shear force (Q):

22. Calculate T_0 according to formula (18).

23. Calculate Q_0 according to formula (19).

24. With T_0 and Q_0 just calculated in steps 22, 23, check the condition (17).

If the condition (17) is not satisfied, increase the cross-sectional size (b, h) or increase the grade of compressive strength of concrete (B) until the condition (17) is satisfied, then move to step 25.

25. Check the condition (11), where: Z_1 = h; Z_2 = b and $A_{s,1}$, $A_{sw,1}$ are tensile reinforcement at lateral side h (Figure 1b).

If the condition (11) is not satisfied, adjust $A_{s,1}$, $A_{sw,1}$ into the design until the condition (11) is satisfied, then move to step 25.

26. Perform steps from 10 to 17.

27. Calculate Q_0 according to formula (20).

28. With T_0 and Q_0 just calculated above, check the condition (17).

If the condition (17) is not satisfied, increase the cross-sectional size (b, h) or increase longitudinal reinforcement, transverse reinforcement and then repeat steps from 25 to 28 until the condition (17) is satisfied → **Finish**.

2.5. Example

A beam with rectangular cross-section: b = 300; h = 600, h - height of rectangular. Grade of compressive strength of concrete: B20. Bending moment: M = -160 kNm, torsional moment: T = 40 kNm, shear force: Q = 120 kN. Longitudinal reinforcement: CB400-V, transverse reinforcement: CB300-T. Requirement: calculate and arrange the reinforcement.

Data: Concrete: R_b = 11.5 MPa, R_{bt} = 0.9 MPa ; longitudinal reinforcement: $R_s = R_{sc}$ = 350 MPa; transverse reinforcement: R_{sw} = 210 MPa; ξ_R = 0,583.[3]

Perform the following steps:

Use the problem: calculate the longitudinal reinforcement support bending moment M:

1. Assume a = 40; h_0 = 600 – 40 = 560 mm

2. $$\alpha_m = \frac{M}{R_b b h_0^2} = \frac{160\times10^6}{11.5\times300\times560^2} = 0.148$$

3. $$\xi = 1-\sqrt{1-2\alpha_m} = 1-\sqrt{1-2\times0.148} = 0.161 \le \xi_R = 0.583$$

4. Area of tensile reinforcement section:

$$A_s = \frac{\xi R_b b h_0}{R_s} = \frac{0.161\times11.5\times300\times560}{350} = 889 \text{ mm}^2$$

5. Provide for the longitudinal reinforcement as follows:

A_s = 4ϕ18 = 1018 mm^2; A'_s = 2ϕ16 = 402 mm^2; structural reinforcement in the middle of edge h: 2ϕ14 = 308 mm^2

Concrete cover: 25 mm

a = 25 + 18/2 = 34 mm ; h_0 = 566 mm; a' = 25 + 16/2 = 33 mm

Use the problem: calculate the transverse reinforcement support shear force Q:

6. Transverse reinforcement ϕ10 with A_{sw} = 2x78.5 =157 mm^2

Distance between stirrups s = 100 mm.

7. Check the condition (31):

$q_{sw} = R_{sw}A_{sw}/s$ = 210x157/100 = 329.7 N/mm > $0.25R_{bt}b$ = 67.5 Mpa

$$C' = \sqrt{\frac{2R_{bt}bh_0^2}{q_{sw}}} = \sqrt{\frac{2\times0.9\times300\times560^2}{329.7}} = 717 \text{ mm}$$

With: $0.6h_0 \le C' \le 3h_0$, take C' = 717 mm calculate:

$$Q_b = \frac{1.5R_{bt}bh_0^2}{C'} = \frac{1.5\times0.9\times300\times560^2}{717} = 177138\ \text{N}$$

With: $h_0 \le C' \le 2h_0$, take $C' = 717$ mm calculate:

$Q_{sw} = 0.75q_{sw}\ C' = 0.75x329.7x717 = 177296$ N

$\Rightarrow Q_0 = Q_b + Q_{sw} = 177138 + 177296 = 354434$ N = 354.434 kN

We see that Q = 120 kN < Q_0 = 354.434 kN

⇒ The reinforcement is arranged as shown in Figure 2a.

Design for combined torsional moment (T) and bending moment (M):

The scheme for the design is shown in Figure 2b.

8. Check the condition (1):

$0.1R_bhb^2 = 0.1x11.5\ x\ 600x300^2 = 62.1x10^6$ Nmm = 62.1 kNm.

So: T = 40 kNm < $0.1R_bhb^2$ = 62.1 kNm.

9. Condition on the strength of spatial sections:

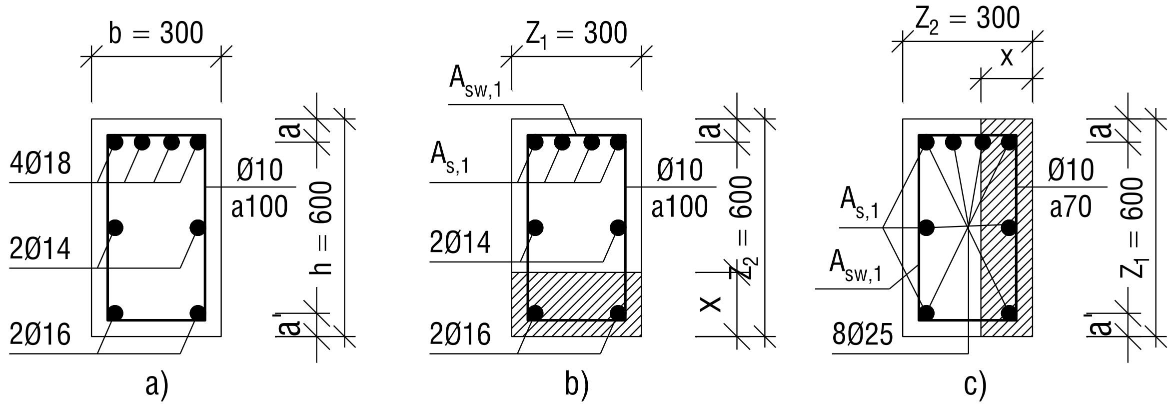

Figure 2. Beam cross section and calculation diagram

From Figure 2b, we have:

Z_1 = b =300 mm; Z_2 = h = 600 mm

$A_{s,1}$ = 4ϕ18 = 1018 mm^2 ; $A_{sw,1}$ = ϕ10 = 78.5 mm^2

$q_{sw,1} = q_{sw}/2$ = 164.85 N/mm

We see that:

$$\frac{q_{sw,1}Z_1}{R_sA_{s,1}} = \frac{164.85\times300}{350\times1018} = 0.139 < 0.5$$

So to adjust the above ratio, we reduce $A_{s,1}$ into the calculation:

Take $A_{s,1}$ = 1ϕ18 = 255 mm^2

$$\Rightarrow 0.5 < \frac{q_{sw,1}Z_1}{R_sA_{s,1}} = \frac{164.85\times300}{350\times255} = 0.554 < 1.5$$

10.

$$C = \sqrt{\frac{R_sA_{s,1}(2Z_2+Z_1)}{q_{sw,1}}} = $$

$$= \sqrt{\frac{350\times255(2\times600+300)}{164.85}} = 901\ \ \text{mm}$$

We see that:

$$C = 901\text{mm} < \begin{cases} 2Z_2 + Z_1 = 1500\text{mm} \\ Z_1\sqrt{2/\delta} = 300\sqrt{2/0.2} = 949\text{mm} \end{cases}$$

11. $$\delta = \frac{Z_1}{2Z_2+Z_1} = \frac{300}{2\times600+300} = 0.2$$

12. $C_{sw} = \delta C = 0.2C = 180.2$ mm

13. $N_{sw} = q_{sw,1}C_{sw} = 164.85x180.2 = 29705.97$ N

14. $T_{sw} = 0.9N_{sw}Z_2 = 0.9x29705.97x600 = 16.041x10^6$ Nmm

15. $N_s = R_sA_{s,1} = 350x255 = 89250$ N

16.

$$T_s = 0.9N_s\frac{Z_1}{C}Z_2 = 0.9\times89250x\frac{300}{901}\times600 =$$

$$= 16.047\times10^6\ \ \text{Nmm}$$

17. $T_0 = T_{sw} + T_s = 16.041x10^6 + 16.047x10^6 = 32.088x10^6$ Nmm = 32.088 kNm

18. $$\xi = \frac{R_sA_s}{R_bZ_1(Z_2-a)} = \frac{350\times1018}{11.5\times300\times566} = 0.182$$

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19. $\alpha_m = \xi(1-0.5\xi) = 0.182(1-0.5x0.182) = 0.166$

20. $M_0 = \alpha_m R_b Z_1 (Z_2-a)^2 = 0.166x11.5x300x566^2$ $= 183.468x10^6$ Nmm = 183.468 kNm

21. We see that:

$$T = 40 \quad kNm > T_0\sqrt{1-\left(\frac{M}{M_0}\right)^2} =$$

$$= 32.088\sqrt{1-\left(\frac{160}{183.468}\right)^2} = 15.702 \quad kNm$$

⇒ **The member does not have enough load bearing capacity.**

Re-select the longitudinal reinforcement: A_s = 4ϕ25 = 1963 mm²; A'_s = 2ϕ25 = 982 mm²; structural reinforcement in the middle of edge h: 2ϕ25 = 982 mm²

Concrete cover: 25 mm

a = 25 + 25/2 = 37.5 mm; h_0 = 562.5 mm; a' = 25 + 25/2 = 37.5 mm

Transverse reinforcement: ϕ10 with A_{sw} = 2x78.5 =157 mm².

Distance: s = 70 mm.

⇒ **Repeat from step 9 to 21:**

9. Take $A_{s,1}$ = 4ϕ25 = 1963 mm²; $A_{sw,1}$ = ϕ10 = 78.5 mm²

$q_{sw,1} = R_{sw}A_{sw,1}/s$ =210x78.5/70 = 235.5 N/mm

We see: $\frac{q_{sw,1}Z_1}{R_sA_{s,1}} = \frac{235.5\times300}{350\times1963} = 0.103 < 0.5$

To adjust the above ratio, we reduce $A_{s,1}$ into the calculation:

Take $A_{s,1}$ = 400 mm²

$$0.5 < \frac{q_{sw,1}Z_1}{R_sA_{s,1}} = \frac{235.5\times300}{350\times400} = 0.505 < 1.5$$

10.

$$C = \sqrt{\frac{R_sA_{s,1}(2Z_2+Z_1)}{q_{sw,1}}} =$$

$$= \sqrt{\frac{350\times400(2\times600+300)}{235.5}} = 944 \quad mm$$

We see that:

$$C = 944 \quad mm < \begin{cases} 2Z_2 + Z_1 = 1500 \quad mm \\ Z_1\sqrt{2/\delta} = 300\sqrt{2/0.2} = 949 \quad mm \end{cases}$$

11. $\delta = 0.2$

12. $C_{sw} = 0.2C = 188.8$ mm

13. $N_{sw} = q_{sw,1}C_{sw} = 235.5x188.8 = 44462.4$ N

14. $T_{sw} = 0.9N_{sw}Z_2 = 0.9x44462.4x600 = 24.010x10^6$ Nmm

15. $N_s = R_sA_{s,1} = 350x400 = 140000$ N

16.

$$T_s = 0.9N_s\frac{Z_1}{C}Z_2 = 0.9\times140000x\frac{300}{944}\times600 =$$

$$= 24.025\times10^6 \quad Nmm$$

17. $T_0 = T_{sw} + T_s = 24.010x10^6 + 24.025x10^6 = 48.035 x10^6$ Nmm = 48.035 kNm

18. $\xi = \frac{R_sA_s}{R_bZ_1(Z_2-a)} = \frac{350\times1963}{11.5\times300\times562.5} = 0.354$

19. $\alpha_m = \xi(1-0,5\xi) = 0.354(1-0.5x0.354) = 0.291$

20. $M_0 = \alpha_m R_b Z_1 (Z_2-a)^2 =$

$= 0.291x11.5x300x562.5^2 = 318.029x10^6$ Nmm = 318.029 kNm

21. We see that:

$$T = 40 \quad kNm < T_0\sqrt{1-\left(\frac{M}{M_0}\right)^2} =$$

$$= 48.035\sqrt{1-\left(\frac{160}{318.029}\right)^2} = 41.513 \quad kNm$$

Conclusion: So that the member has enough capacity to bear combined torsional moment and bending moment, we need the amount of reinforcement.: tensile longitudinal reinforcement A_s = 4ϕ25, CB400-V and stirrup ϕ10, CB300-T, s = 70 mm.

Design for combined torsional moment (T) and shear force (Q):

The scheme for the design is shown in Figure 2c.

22. $T_0 = 0.1R_bhb^2 = 62.1$ kNm.

23. $Q_0 = 0.3R_bbh_0 = 0.3x11.5x300x562.5 = 582187.5$ N = 582.188 kN

24. Check the condition (17):

$$T = 40 \quad kN \le T_0\left(1-\frac{Q}{Q_0}\right) = $$

$$= 62.1\left(1-\frac{120}{582.188}\right) = 49.3 \quad kN \Rightarrow \text{Satisfied}$$

25. Condition on the strength of spatial sections:

From Figure 2c, we have:

$Z_1 = h = 600$ mm; $Z_2 = b = 300$ mm

$A_{s,1} = 3\phi25 = 1473$ mm^2; $A_{sw,1} = \phi10 = 78.5$ mm^2

$q_{sw,1} = 235.5$ N/mm

We see: $\frac{q_{sw,1}Z_1}{R_sA_{s,1}} = \frac{235.5\times600}{350\times1473} = 0.274 < 0.5$

To adjust the above ratio, we reduce $A_{s,1}$ into the calculation:

Take $A_{s,1} = 800$ mm^2

$$\Rightarrow 0.5 < \frac{q_{sw,1}Z_1}{R_sA_{s,1}} = \frac{235.5\times600}{350\times800} = 0.505 < 1.5$$

26. Perform steps from 10 to 17.

$$C = \sqrt{\frac{R_sA_{s,1}\left(2Z_2+Z_1\right)}{q_{sw,1}}} = $$

$$= \sqrt{\frac{350\times800\left(2\times300+600\right)}{235.5}} = 1194 \quad mm$$

We see:

$$C = 1194 \quad mm < \begin{cases} 2Z_2 + Z_1 = 1200 \quad mm \\ Z_1\sqrt{2/\delta} = 600\sqrt{2/0.5} = 1200 \quad mm \end{cases}$$

$$\delta = \frac{Z_1}{2Z_2+Z_1} = \frac{600}{2\times300+600} = 0.5$$

$C_{sw} = \delta C = 0.5C = 597$ mm

$N_{sw} = q_{sw,1}C_{sw} = 235.5x597 = 140593.5$ N

$\Rightarrow T_{sw} = 0.9N_{sw}Z_2 = 0.9x140593.5x300 = 37.960x10^6$ Nmm

$N_s = R_sA_{s,1} = 350x800 = 280000$ N

$$T_s = 0.9N_s\frac{Z_1}{C}Z_2 = 0.9\times280000x\frac{600}{1194}\times300 = $$

$$= 37.990\times10^6 \quad Nmm$$

$\Rightarrow T_0 = T_{sw} + T_s = 37.960x10^6 + 37.990x10^6 = 75.95x10^6$ Nmm = 75.95 kNm

27. Calculate Q_0 = (20):

$$C' = \sqrt{\frac{2R_{bt}bh_0^2}{q_{sw}}} = \sqrt{\frac{2\times0.9\times300\times562.5^2}{2\times235.5}} = 602 \quad mm$$

We see that $0.6h_0 = 337.5$ mm < C' = 602 mm < $3h_0 = 1687.5$ mm

$$\Rightarrow Q_b = \frac{1.5R_{bt}bh_0^2}{C'} = \frac{1.5\times0.9\times300\times562.5^2}{602} = $$

$$= 212.865\times10^3 \quad N = 212.865 \quad kN$$

We see that $h_0 = 562.5$ mm < C' = 602 mm < $2h_0$ = 1125 mm

$\Rightarrow Q_{sw} = 0.75q_{sw}C' = 0.75x2x235.5x602 = 212.657x10^3$ N = 212.657 kN

$\Rightarrow Q_0 = Q_b + Q_{sw} = 212.865 + 212.657 = 425.552$ kN

28. We see that:

$$T = 40 \quad kNm < T_0\left(1-\frac{Q}{Q_0}\right) = $$

$$= 75.95\left(1-\frac{120}{425.552}\right) = 54.533 \quad kNm$$

Conclusion: **The member has enough capacity to bear combined torsional moment and shear force → End.**

3. CONCLUSION

From the content presented above, we see that:

Design standard for concrete and reinforced concrete structures TCVN 5574:2018 presents principles of strength design of reinforced concrete members for combined torsional and bending moments, but the formulas are quite complicated and there is no specific design procedure for this type of member. Therefore, building a process to concretize the calculation steps is applicable and can be applied more easily in the design of structures.

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Although still using the model of spatial sections according to the ultimate internal force method, but the principles of strength design of reinforced concrete members for combined torsional and bending moments provided in the TCVN 5574:2018 Standard have many changes compared to those provided in the old Standard TCVN 5574:2012.[4] Besides, the strength design process of reinforced concrete beams under combined bending and torsion based on TCVN 5574:2018 standard proposed in Section 2.4 is still quite complicated, especially the adjustment of the amount of longitudinal and transverse reinforcement ($A_{s,1}$ and $A_{sw,1}$) into the design leads to results that may still be subjective by the designer.

From the calculation example in Section 2.5, it can be seen that the torsional bearing capacity of reinforced concrete structures is much worse than their bending bearing capacity. Therefore, in many cases, although the value of the torsional moment is not great, it has a significant influence and causes the appearance of cracks. In the design of reinforced concrete members should avoid or reduce the torsional moment as much as possible. In some cases, when the value of the torsional moment cannot be limited, we need to design the strength of reinforced concrete members for combined torsional and bending moments.

The assessment of the strength design process of reinforced concrete beams under combined bending and torsion is based on TCVN 5574:2018 standard compared to TCVN 5574:2012 standard and some advanced standards in the world as well as quantifying the influence of torsional moment on the bearing capacity of the member will be presented in the next issue.

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