

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

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Ngày nhận bài: 23/03/2021; Ngày sửa bài: 18/04/2021;

Ngày nhận đăng: 05/05/2021; Ngày xuất bản: 28/06/2021

TÓM TẮT

Bài báo này phân tích lý thuyết tính toán độ bền cấu kiện bê tông 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 bê tông 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 bê tông cốt thép, quy trình tính toán độ bền cấu kiện chịu uốn - xoắn đồng thời, dầm bê tông 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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Received: 23/03/2021; Revised: 18/04/2021;

Accepted: 05/05/2021; Published: 28/06/2021

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 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 respective 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

$$T \leq 0.1R_bhb^2 \quad (1)$$

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

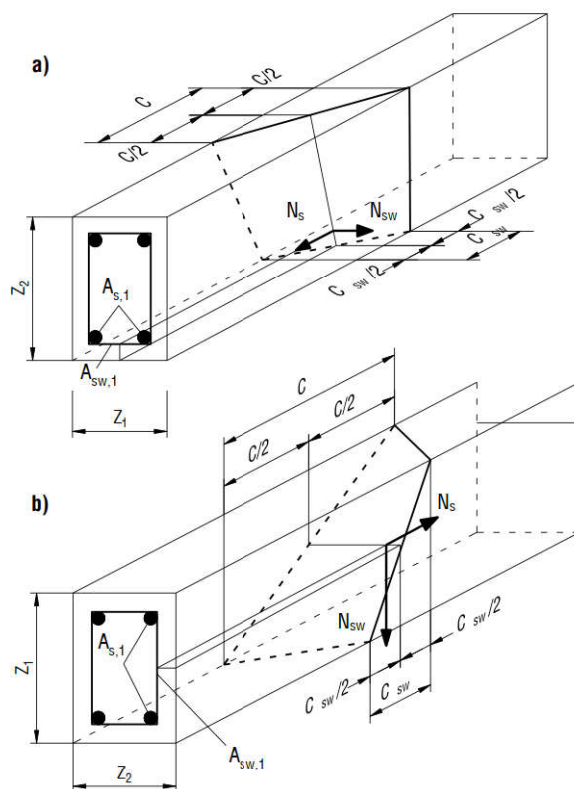


Figure 1. Scheme of forces at the design of a spatial section for torsional moments

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:

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

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

$$q_{sw,l} = \frac{R_{sw} A_{sw,l}}{s_{sw}} \quad (7)$$

$A_{sw,l}$: 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:

$$N_s = R_s A_{s,l} \quad (10)$$

$A_{s,l}$: 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:

$$0.5 \leq \varphi_w = \frac{q_{sw,l} Z_1}{R_s A_{s,l}} \leq 1.5 \quad (11)$$

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

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

And C should comply with the condition:

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

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

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

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:

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

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:

$$Q_0 = 0.3 R_b b h_0 \quad (19)$$

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:

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

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

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

Q_b is determined as follows:

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

$$Q_b = \frac{1.5 R_{bt} b h_0^2}{C'} \quad (23)$$

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 : $\alpha_m = \frac{M}{R_bbh_0^2} \quad (26)$

3. Calculate ξ :

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

4. Calculate area of tensile reinforcement section:

$$A_s = \frac{\xi R_bbh_0}{R_s} \quad (28)$$

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:

$$- \phi_d \geq 6 \text{ mm}$$

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

$$- s \leq \begin{cases} s_{\max} = \frac{R_{bt}bh_0^2}{Q} \\ 0.5h_0 \\ 300 \text{ mm} \end{cases} \quad (30)$$

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; $\xi_R = 0.583$.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

$$2. \alpha_m = \frac{M}{R_b b h_0^2} = \frac{160 \times 10^6}{11.5 \times 300 \times 560^2} = 0.148$$

3.

$$\xi = 1 - \sqrt{1 - 2\alpha_m} = 1 - \sqrt{1 - 2 \times 0.148} = 0.161 \leq \xi_R = 0.583$$

4. Area of tensile reinforcement section:

$$A_s = \frac{\xi R_b b h_0}{R_s} = \frac{0.161 \times 11.5 \times 300 \times 560}{350} = 889 \text{ mm}^2$$

5. Provide for the longitudinal reinforcement as follows:

$A_s = 4\phi 18 = 1018 \text{ mm}^2$; $A'_s = 2\phi 16 = 402 \text{ mm}^2$; structural reinforcement in the middle of edge h: $2\phi 14 = 308 \text{ mm}^2$

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 $\phi 10$ with $A_{sw} = 2 \times 78.5 = 157 \text{ mm}^2$

Distance between stirrups $s = 100$ mm.

7. Check the condition (31):

$$q_{sw} = R_{sw} A_{sw} / s = 210 \times 157 / 100 = 329.7 \text{ N/mm} > 0.25 R_{bt} b = 67.5 \text{ MPa}$$

$$C' = \sqrt{\frac{2 R_{bt} b h_0^2}{q_{sw}}} = \sqrt{\frac{2 \times 0.9 \times 300 \times 560^2}{329.7}} = 717 \text{ mm}$$

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

$$Q_b = \frac{1.5R_{bt}bh_0^2}{C'} = \frac{1.5 \times 0.9 \times 300 \times 560^2}{717} = 177138 \text{ N}$$

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

$$Q_{sw} = 0.75q_{sw} C' = 0.75 \times 329.7 \times 717 = 177296 \text{ N}$$

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

We see that $Q = 120 \text{ kN} < Q_0 = 354.434 \text{ kN}$

\Rightarrow The reinforcement is arranged as shown in Figure 2a.

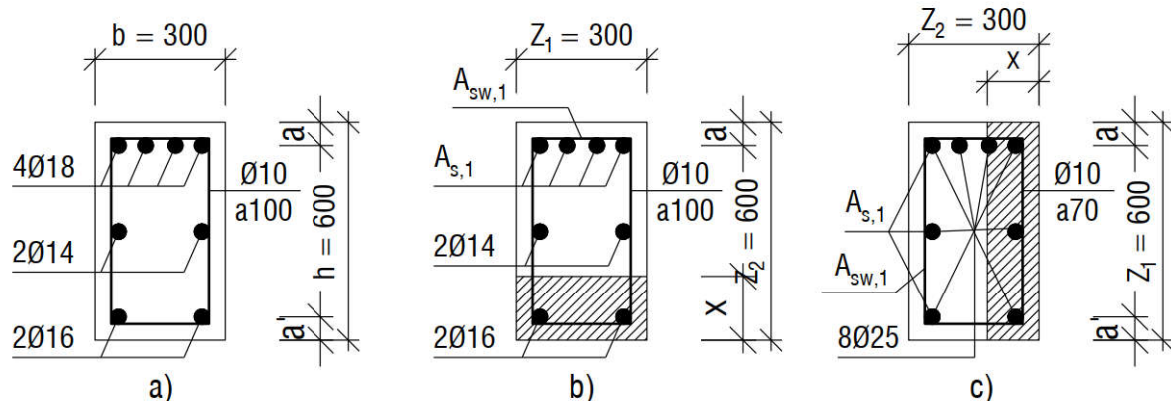


Figure 2. Beam cross section and calculation diagram

From Figure 2b, we have:

$$Z_1 = b = 300 \text{ mm}; Z_2 = h = 600 \text{ mm}$$

$$A_{s,1} = 4\phi 18 = 1018 \text{ mm}^2; A_{sw,1} = \phi 10 = 78.5 \text{ mm}^2$$

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

We see that:

$$\frac{q_{sw,1}Z_1}{R_s A_{s,1}} = \frac{164.85 \times 300}{350 \times 1018} = 0.139 < 0.5$$

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

$$\text{Take } A_{s,1} = 1\phi 18 = 255 \text{ mm}^2$$

$$\Rightarrow 0.5 < \frac{q_{sw,1}Z_1}{R_s A_{s,1}} = \frac{164.85 \times 300}{350 \times 255} = 0.554 < 1.5$$

10.

$$C = \sqrt{\frac{R_s A_{s,1} (2Z_2 + Z_1)}{q_{sw,1}}} = \sqrt{\frac{350 \times 255 (2 \times 600 + 300)}{164.85}} = 901 \text{ mm}$$

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):

$$0.1R_b hb^2 = 0.1 \times 11.5 \times 600 \times 300^2 = 62.1 \times 10^6 \text{ Nmm} = 62.1 \text{ kNm.}$$

$$\text{So: } T = 40 \text{ kNm} < 0.1R_b hb^2 = 62.1 \text{ kNm.}$$

9. Condition on the strength of spatial sections:

We see that:

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

$$11. \delta = \frac{Z_1}{2Z_2 + Z_1} = \frac{300}{2 \times 600 + 300} = 0.2$$

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

$$13. N_{sw} = q_{sw,1} C_{sw} = 164.85 \times 180.2 = 29705.97 \text{ N}$$

$$14. T_{sw} = 0.9N_{sw} Z_2 = 0.9 \times 29705.97 \times 600 = 16.041 \times 10^6 \text{ Nmm}$$

$$15. N_s = R_s A_{s,1} = 350 \times 255 = 89250 \text{ N}$$

16.

$$T_s = 0.9N_s \frac{Z_1}{C} Z_2 = 0.9 \times 89250 \times \frac{300}{901} \times 600 = 16.047 \times 10^6 \text{ Nmm}$$

$$17. T_0 = T_{sw} + T_s = 16.041 \times 10^6 + 16.047 \times 10^6 = 32.088 \times 10^6 \text{ Nmm} = 32.088 \text{ kNm}$$

$$18. \xi = \frac{R_s A_s}{R_b Z_1 (Z_2 - a)} = \frac{350 \times 1018}{11.5 \times 300 \times 566} = 0.182$$

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

$$20. M_0 = \alpha_m R_b Z_1 (Z_2 - a)^2 = 0.166 \times 11.5 \times 300 \times 566^2 = 183.468 \times 10^6 \text{ Nmm} = 183.468 \text{ kNm}$$

21. We see that:

$$T = 40 \text{ kNm} > T_0 \sqrt{1 - \left(\frac{M}{M_0} \right)^2} = 32.088 \sqrt{1 - \left(\frac{160}{183.468} \right)^2} = 15.702 \text{ kNm}$$

⇒ The member does not have enough load bearing capacity.

Re-select the longitudinal reinforcement:
 $A_s = 4\phi 25 = 1963 \text{ mm}^2$; $A'_s = 2\phi 25 = 982 \text{ mm}^2$;
 structural reinforcement in the middle of edge
 $h: 2\phi 25 = 982 \text{ mm}^2$

Concrete cover: 25 mm

$$a = 25 + 25/2 = 37.5 \text{ mm}; h_0 = 562.5 \text{ mm}; a' = 25 + 25/2 = 37.5 \text{ mm}$$

Transverse reinforcement: $\phi 10$ with $A_{sw} = 2 \times 78.5 = 157 \text{ mm}^2$.

Distance: $s = 70 \text{ mm}$.

⇒ Repeat from step 9 to 21:

$$9. \text{ Take } A_{s,1} = 4\phi 25 = 1963 \text{ mm}^2; A_{sw,1} = \phi 10 = 78.5 \text{ mm}^2$$

$$q_{sw,1} = R_{sw} A_{sw,1} / s = 210 \times 78.5 / 70 = 235.5 \text{ N/mm}$$

$$\text{We see: } \frac{q_{sw,1} Z_1}{R_s A_{s,1}} = \frac{235.5 \times 300}{350 \times 1963} = 0.103 < 0.5$$

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

Take $A_{s,1} = 400 \text{ mm}^2$

$$0.5 < \frac{q_{sw,1} Z_1}{R_s A_{s,1}} = \frac{235.5 \times 300}{350 \times 400} = 0.505 < 1.5$$

10.

$$C = \sqrt{\frac{R_s A_{s,1} (2Z_2 + Z_1)}{q_{sw,1}}} = \sqrt{\frac{350 \times 400 (2 \times 600 + 300)}{235.5}} = 944 \text{ mm}$$

We see that:

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

$$11. \delta = 0.2$$

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

$$13. N_{sw} = q_{sw,1} C_{sw} = 235.5 \times 188.8 = 44462.4 \text{ N}$$

$$14. T_{sw} = 0.9 N_{sw} Z_2 = 0.9 \times 44462.4 \times 600 = 24.010 \times 10^6 \text{ Nmm}$$

$$15. N_s = R_s A_{s,1} = 350 \times 400 = 140000 \text{ N}$$

16.

$$T_s = 0.9 N_s \frac{Z_1}{C} Z_2 = 0.9 \times 140000 \times \frac{300}{944} \times 600 = 24.025 \times 10^6 \text{ Nmm}$$

$$17. T_0 = T_{sw} + T_s = 24.010 \times 10^6 + 24.025 \times 10^6 = 48.035 \times 10^6 \text{ Nmm} = 48.035 \text{ kNm}$$

$$18. \xi = \frac{R_s A_s}{R_b Z_1 (Z_2 - a)} = \frac{350 \times 1963}{11.5 \times 300 \times 562.5} = 0.354$$

$$19. \alpha_m = \xi(1-0.5\xi) = 0.354(1-0.5 \times 0.354) = 0.291$$

$$20. M_0 = \alpha_m R_b Z_1 (Z_2 - a)^2 = 0.291 \times 11.5 \times 300 \times 562.5^2 = 318.029 \times 10^6 \text{ Nmm} = 318.029 \text{ kNm}$$

21. We see that:

$$T = 40 \text{ kNm} < T_0 \sqrt{1 - \left(\frac{M}{M_0} \right)^2} = 48.035 \sqrt{1 - \left(\frac{160}{318.029} \right)^2} = 41.513 \text{ kNm}$$

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 $A_s = 4\phi 25$, CB400-V and stirrup $\phi 10$, CB300-T, $s = 70 \text{ mm}$.

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

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

$$22. T_0 = 0.1 R_b h b^2 = 62.1 \text{ kNm}.$$

$$23. Q_0 = 0.3R_b b h_0 = 0.3 \times 11.5 \times 300 \times 562.5 = 582187.5 \text{ N} = 582.188 \text{ kN}$$

24. Check the condition (17):

$$T = 40 \text{ kN} \leq T_0 \left(1 - \frac{Q}{Q_0} \right) = 62.1 \left(1 - \frac{120}{582.188} \right) = 49.3 \text{ kN} \Rightarrow \text{Satisfied}$$

25. Condition on the strength of spatial sections:

From Figure 2c, we have:

$$Z_1 = h = 600 \text{ mm}; Z_2 = b = 300 \text{ mm}$$

$$A_{s,1} = 3\phi 25 = 1473 \text{ mm}^2; A_{sw,1} = \phi 10 = 78.5 \text{ mm}^2$$

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

$$\text{We see: } \frac{q_{sw,1} Z_1}{R_s A_{s,1}} = \frac{235.5 \times 600}{350 \times 1473} = 0.274 < 0.5$$

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

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

$$\Rightarrow 0.5 < \frac{q_{sw,1} Z_1}{R_s A_{s,1}} = \frac{235.5 \times 600}{350 \times 800} = 0.505 < 1.5$$

26. Perform steps from 10 to 17.

$$C = \sqrt{\frac{R_s A_{s,1} (2Z_2 + Z_1)}{q_{sw,1}}} = \sqrt{\frac{350 \times 800 (2 \times 300 + 600)}{235.5}} = 1194 \text{ mm}$$

We see:

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

$$\delta = \frac{Z_1}{2Z_2 + Z_1} = \frac{600}{2 \times 300 + 600} = 0.5$$

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

$$N_{sw} = q_{sw,1} C_{sw} = 235.5 \times 597 = 140593.5 \text{ N}$$

$$\Rightarrow T_{sw} = 0.9 N_{sw} Z_2 = 0.9 \times 140593.5 \times 300 = 37.960 \times 10^6 \text{ Nmm}$$

$$N_s = R_s A_{s,1} = 350 \times 800 = 280000 \text{ N}$$

$$T_s = 0.9 N_s \frac{Z_1}{C} Z_2 = 0.9 \times 280000 \times \frac{600}{1194} \times 300 = 37.990 \times 10^6 \text{ Nmm}$$

$$\Rightarrow T_0 = T_{sw} + T_s = 37.960 \times 10^6 + 37.990 \times 10^6 = 75.95 \times 10^6 \text{ Nmm} = 75.95 \text{ kNm}$$

27. Calculate $Q_0 = (20)$:

$$C' = \sqrt{\frac{2R_{bt} b h_0^2}{q_{sw}}} = \sqrt{\frac{2 \times 0.9 \times 300 \times 562.5^2}{2 \times 235.5}} = 602 \text{ mm}$$

$$\text{We see that } 0.6h_0 = 337.5 \text{ mm} < C' = 602 \text{ mm} < 3h_0 = 1687.5 \text{ mm}$$

$$\Rightarrow Q_b = \frac{1.5 R_{bt} b h_0^2}{C'} = \frac{1.5 \times 0.9 \times 300 \times 562.5^2}{602} = 212.865 \times 10^3 \text{ N} = 212.865 \text{ kN}$$

$$\text{We see that } h_0 = 562.5 \text{ mm} < C' = 602 \text{ mm} < 2h_0 = 1125 \text{ mm}$$

$$\Rightarrow Q_{sw} = 0.75 q_{sw} C' = 0.75 \times 2 \times 235.5 \times 602 = 212.657 \times 10^3 \text{ N} = 212.657 \text{ kN}$$

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

28. We see that:

$$T = 40 \text{ kNm} < T_0 \left(1 - \frac{Q}{Q_0} \right) = 75.95 \left(1 - \frac{120}{425.552} \right) = 54.533 \text{ kNm}$$

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.

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 ($A_{s,l}$ and $A_{sw,l}$) 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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