Đề xuất quy trình tính toán độ bền dầm bê tông cốt thép chịu tác dụng của lực cắt theo TCVN 5574:2018

TÓM TẮT

Bài báo này phân tích lý thuyết tính toán độ bền cấu kiện bê tông cốt thép chịu tác dụng của lực cắt theo Tiêu chuẩn TCVN 5574:2018. Từ đó đề xuất một quy trình tính toán độ bền của dầm bê tông cốt thép chịu lực cắt theo tiêu chuẩn hiện hành của Việt Nam và sơ đồ hóa quy trình này, 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 tác dụng của lực cắt, dầm bê tông cốt thép chịu lực cắt, tính toán cường độ trên tiết diện nghiêng.*

Proposing a strength design process of reinforced concrete beams under shear force based on TCVN 5574:2018 standard

ABSTRACT

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

Keywords: *reinforced concrete beams ; strength design process for membes under shear force ; reinforced concrete beams under shear force ; Strength calculation of inclined sections.*

1. INTRODUCTION

The rapid growth of our country's economy has strongly driven the development pace of the construction industry in terms of both quantity and diversity of structural types. High-rise buildings, large-span structures, etc. are increasingly prevalent in Vietnam and other countries around the world. Reinforced concrete structures are widely and effectively utilized nowadays.

Evaluating the flexural - shear capacity of reinforced concrete members is an important task in the design. Among them, the assessment of the shear capacity of bending members, especially beams, has received significant research attention.

Section 8.1.3 of the TCVN 5574:2018 standard presents the principles of strength design of reinforced concrete members for shear forces. This article will rely on these principles to develop a process that can be applied to calculating the strength of inclined sections of bending members.

2. STRENGTH DESIGN OF REINFORCED CONCRETE MEMBERS FOR SHEAR FORCES BASED ON TCVN 5574:2018 STANDARD

2.1 Basic provisions[1]

Strength design of reinforced concrete members for shear forces is based on model of inclined sections.

In the design based on model of inclined sections, one should provide member strength of a strip between inclined sections and inclined section for shear forces, and strength of inclined section for moment.

The strength of inclined strip is characterized by maximum value of shear force, which may be sustained by inclined strip subjected to compressive forces along the strip and tensile forces due to transverse reinforcement crossing the inclined strip. While concrete strength is determined equal to axial compressive resistance of concrete taking account of combined stress state in the inclined strip.

Inclined section analysis for shear forces is performed based on the equilibrium expression of internal and external shear forces acting in the inclined section with projection length *C* on the longitudinal axis of a member. Internal shear forces include shear force sustained by concrete in the inclined section and shear force, sustained by transverse reinforcement crossing the inclined section. While shear forces sustained by concrete and transverse reinforcement are determined according to tensile resistance of concrete and reinforcement taking account of projection length *C* of the inclined section.

Inclined section analysis for moment is performed based on the equilibrium expression of internal and external forces acting in the inclined section with projection length *C* on the longitudinal axis of a member. Moments due to internal forces include a moment sustained by longitudinal tensile reinforcement crossing the inclined section, and moment sustained by transverse reinforcement crossing the inclined section. While moments sustained by longitudinal and transverse reinforcement are determined according to tensile resistance of longitudinal and transverse reinforcement taking account of projection length *C* of the inclined section.

2.2 Reinforced concrete member analysis of a strip between inclined sections

Analysis of bending reinforced concrete members of a concrete strip between inclined sections is performed considering the following condition (1)[1, 2] :

$$Q \le Q_{bt} = \varphi_{b1} R_b b h_0 \qquad (1)$$

Where:

Q: shear force in a normal section of a member;

Q_{bt}: principal compressive stress capacity;

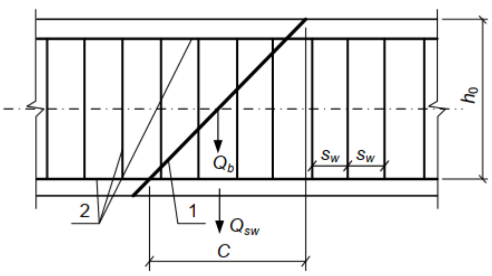
φ_{b1}: coefficient considering the influence of stress state characteristics of inclined strips, assumed equal to 0,3;

b: width of a cross-section;

h_0: effective depth of a cross-section.

2.3 Verification of inclined sections for shear forces

Verification of inclined sections of bending members (figure 1)[1] is performed according to the condition (2)[1,2]:



1 – inclined section; 2 – reinforcements.

Figure 1. Scheme of forces at the design of reinforced concrete members of an inclined section for shear forces.

$$Q \le Q_u = Q_b + Q_{sw} \qquad (2)$$

Where:

Q: shear force in an inclined section with projection length *C* on the longitudinal axis of a member determined due to all external loads located at the same side of the referred inclined section; while the most critical loading within the inclined section should be considered;

Q_u: shear capacity in an inclined section with projection length *C*;

Q_b: shear force sustained by concrete in an inclined section;

Q_{sw}: shear force sustained by transverse reinforcement in an inclined section.

+ Shear force Q_{sw} for transverse reinforcement normal to the longitudinal axis of a member is determined by the formula

$$Q_{sw} = \varphi_{sw} q_{sw} C \qquad (3)$$

Where:

φ_{sw}: coefficient assumed equal to 0,75;

q_{sw}: force in transverse reinforcement per unit length of a member, determined by the formula:

$$q_{sw} = \frac{R_{sw} A_{sw}}{s_w} \qquad (4)$$

Projection length *C* in formula (3) should comply with the condition: $h_0 \le C \le 2h_0$.

+ Shear force Q_b is determined as follows:

If $q_{sw} \ge 0,25 R_{bt} b$, Q_b is determined by the formula:

$$Q_b = \frac{\varphi_{b2} R_{bt} b h_0^2}{C} \qquad (5)$$

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

$$Q_b = \frac{4\varphi_{b2} h_0^2 q_{sw}}{C} \qquad (6)$$

Where Q_b should comply with the condition:

$$Q_{bmin} = 0,5 R_{bt} b h_0 \le Q_b \le Q_{bmax} = 2,5 R_{bt} b h_0 \qquad (7)$$

φ_{b2}: coefficient assumed equal to 1,5.

From (5) and (7), we have:

$$0,5 R_{bt} b h_0 \le Q_b = \frac{1,5 R_{bt} b h_0^2}{C} \le 2,5 R_{bt} b h_0$$

$$\Rightarrow \frac{1,5 R_{bt} b h_0^2}{2,5 R_{bt} b h_0} \le C \le \frac{1,5 R_{bt} b h_0^2}{0,5 R_{bt} b h_0}$$

$$\Rightarrow 0,6 h_0 \le C \le 3 h_0$$

Therefore, projection length *C* in formula (5) should comply with the condition $0,6h_0 \le C \le 3h_0$

From (6) and (7), we have:

$$0,5R_{bt}bh_0 \le Q_b = \frac{4\times1,5h_0^2q_{sw}}{C} \le 2,5R_{bt}bh_0$$

$$\Rightarrow \frac{6h_0^2q_{sw}}{2,5R_{bt}bh_0} \le C \le \frac{6h_0^2q_{sw}}{0,5R_{bt}bh_0}$$

$$\Rightarrow \frac{2,4h_0q_{sw}}{R_{bt}b} \le C \le \frac{12h_0q_{sw}}{R_{bt}b}$$

Therefore, projection length C in formula (6) should comply with the condition $\frac{2,4h_0q_{sw}}{R_{bt}b} \le C \le \frac{12h_0q_{sw}}{R_{bt}b}$.

According to TCVN 5574:2018, the verification of condition (2) is performed for inclined sections placed along the length of a member at the most critical projection length of the inclined section C.

In this paper, the authors will analyze reinforced concrete flexural members according to condition (2). In this condition, the shear force Q is taken as Q_{max} (the maximum shear force on the analyzed section), and Q_u is determined on the most critical projection length of the inclined section C_0. The most critical projection length of the inclined section C_0 is the inclined section where the shear capacity of the member $Q_u = Q_b + Q_{sw}$ reaches the minimum value.

+ When Q_b is determined according to formula (5):

$$Q_u = (Q_b + Q_{sw}) \to \min$$

$$\Rightarrow \left(\frac{1,5R_{bt}bh_0^2}{C} + 0,75q_{sw}C\right)_{\min}$$

$$\Rightarrow \left(\frac{1,5R_{bt}bh_0^2}{C} + 0,75q_{sw}C\right)' = 0$$

$$\Leftrightarrow -\frac{1,5R_{bt}bh_0^2}{C^2} + 0,75q_{sw} = 0$$

$$\Rightarrow C_0 = \sqrt{\frac{1,5R_{bt}bh_0^2}{0,75q_{sw}}} = \sqrt{\frac{2R_{bt}bh_0^2}{q_{sw}}} \qquad (8)$$

+ When Q_b is determined according to formula (6):

$$Q_u = (Q_b + Q_{sw}) \to \min$$

$$\Rightarrow \left(\frac{4\times1,5h_0^2q_{sw}}{C} + 0,75q_{sw}C\right)_{\min}$$

$$\Rightarrow \left(\frac{6h_0^2q_{sw}}{C} + 0,75q_{sw}C\right)' = 0$$

$$\Leftrightarrow -\frac{6h_0^2q_{sw}}{C^2} + 0,75q_{sw} = 0$$

$$\Rightarrow C_0 = \sqrt{\frac{6h_0^2q_{sw}}{0,75q_{sw}}} = \sqrt{8}\times h_0 \qquad (9)$$

Transverse reinforcement should meet structural requirements listed in 2.4.

2.4 Structural requirements for transverse reinforcement in beams and slabs[1,2]

- The diameter of transverse reinforcement (stirrups) in tied assemblies of bending elements is not less than 6 mm (8mm when using concrete with compressive strength class from B70 to B100).

- In reinforced concrete members where design shear force cannot be sustained only by concrete, the transverse reinforcement is to be placed with spacing not more than $0,5h_0$ and not more than 300mm (250mm when using concrete with compressive strength class from B70 to B100).

In solid and multiribbed slabs with height less than 300 mm and in beams (ribs) with height less than 150 mm in fragments where design shear force is sustained only by concrete, the transverse reinforcement may not be placed.

In beams and ribs with height of 150 mm and more, as well as in multiribbed slabs with height over 300 mm in fragments where design shear force is sustained only by concrete, the transverse reinforcement is to be placed with spacing not more than 0,75h0 and not more than 500 mm (400mm when using concrete with compressive strength class from B70 to B100).

In addition, the spacing of transverse reinforcement s_w should comply with the condition: $s_w \le s_{max} = \frac{R_{bt}\,b\,h_0^2}{Q}$

2.5 Establishing a process of strength design of reinforced concrete members for shear forces based on tcvn 5574:2018 standard

Problem in words: known: a beam with rectangular cross-section (bxh), Q, R_b, R_{bt}, R_s, R_{sc}, R_{sw}, ξ_R. Requirement: calculate and arrange the stirrups.

Perform the following steps:

Step 1: Verification of a strip between inclined sections according to (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 move to step 2.

Step 2: Check the condition for calculating the stirrups

Calculate minimum shear force sustained by concrete Q_{bmin}:

$$Q_{b\min} = 0,5R_{bt}bh_0 \quad (10)$$

On the considered beam span, take $Q = Q_{max}$

+ *Case 1*: if $Q \le Q_{bmin}$, the concrete alone has sufficient strength to resist shear forces, and the beam only needs structural stirrups. Select and arrange the stirrups as follows:

Diameter: $\phi_d \ge 6$ (11)

Spacing: $s_2 \le (0{,}75h_0\ ;\ 500\ ;\ s_{max})$ (12)

$$\text{Where } s_{\max} = \frac{R_{bt}\, b\, h_0^2}{Q_{\max}} \quad (13)$$

+ *Case 2*: if $Q > Q_{bmin}$ $\rightarrow$ calculate the transverse reinforcement to support shear force, move to step 3.

Step 3: For beams, the shear force near the supports is usually greater than in the middle of the span. Therefore, to save the stirrups, we divide the beam into three different regions: two near-support regions with a length of x, which are the regions with high shear force and will be arranged with a smaller spacing of transverse reinforcement; the remaining region in the middle of the span is the region with lower shear force and will be arranged with a larger spacing of transverse reinforcement (Figure 2).

Note: The selection of the length x based on the shear force envelope diagram to ensure economic efficiency. We can select: $x = l/4$, $x = a$, ...

Where: l – beam span ; a - distance from the support to the nearest concentrated load.

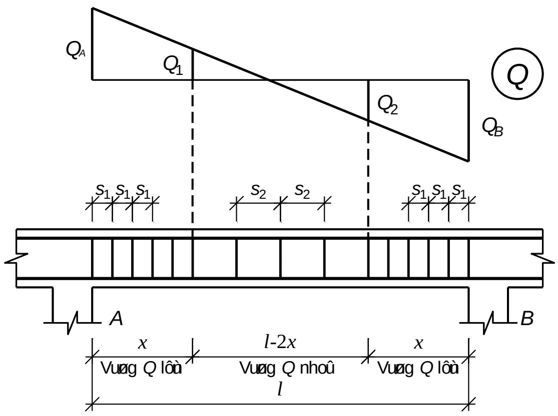


Figure 2. Stirrup arrangement on the beam.

Step 4: Check the shear capacity on the beam segment near the support

+ Select the stirrups as follows:

Diameter : $\phi_d \ge 6$ (14)

Spacing: $s_1 \le (0{,}5h_0\ ;\ 300\ ;\ s_{max})$ (15)

Where s_{max} is determined according to (13)

Take $s_w = s_1$ and calculate:

+ Calculate q_{sw} by (4)

a) Case 1: if $q_{sw} \ge 0,25R_{bt}b$:

+ Calculate C_0 by (8)

+ Calculate Q_{sw} by (3), where $h_0 \le C = C_0 \le 2h_0$ (if $C_0 < h_0$, take $C = h_0$; if $C_0 > 2h_0$, take $C = 2h_0$)

+ Calculate Q_b by (5), where $0{,}6h_0 \le C = C_0 \le 3h_0$ (if $C_0 < 0{,}6h_0$, take $C = 0{,}6h_0$; if $C_0 > 3h_0$, take $C = 3h_0$)

b) Case 2: if $q_{sw} < 0,25R_{bt}b$:

+ Calculate C_0 by (9)

+ Calculate Q_{sw} by (3), where $h_0 \le C = C_0 \le 2h_0$ (if $C_0 < h_0$, take $C = h_0$; if $C_0 > 2h_0$, take $C = 2h_0$)

+ Calculate Q_b by (6), where $\frac{2,4h_0 q_{sw}}{R_{bt}b} \le C = C_0 \le \frac{12h_0 q_{sw}}{R_{bt}b}$ (if $C_0 < \frac{2,4h_0 q_{sw}}{R_{bt}b}$, take $C = \frac{2,4h_0 q_{sw}}{R_{bt}b}$; if $C_0 > \frac{12h_0 q_{sw}}{R_{bt}b}$, take $C_0 = \frac{12h_0 q_{sw}}{R_{bt}b}$)

+ Check strength condition according to (2): $Q_{max} \le Q_b + Q_{sw}$

If condition (2) is satisfied, we conclude that the beam segment near the support has sufficient shear capacity. If condition (2) is not satisfied, we need to reselect the stirrups (we can increase R_{sw} or increase ϕ_d or reduce the spacing s_1) and repeat

Step 4 until condition (2) is satisfied.

Step 5: Check the shear capacity on the beam segment in the middle of the span

On the considered beam segment, take $Q = Q_{max} = \text{Max}(Q_1 ; Q_2)$

Consider the following two cases:

a) Case 1: if $Q \leq Q_{bmin}$, the beam segment in the middle of the span only needs structural stirrups. Select and arrange the stirrups according to (11) and (12).

b) Case 2: if $Q > Q_{bmin}$ $\rightarrow$ calculate the transverse reinforcement to support shear force. Select the stirrups and calculate similar to Step 4.

Note: To save stirrups, we should choose $s_2 > s_1$.

Step 6: Arrange the stirrups $\rightarrow$ **Finish**.

2.6 Flowchart for designing stirrups for beams

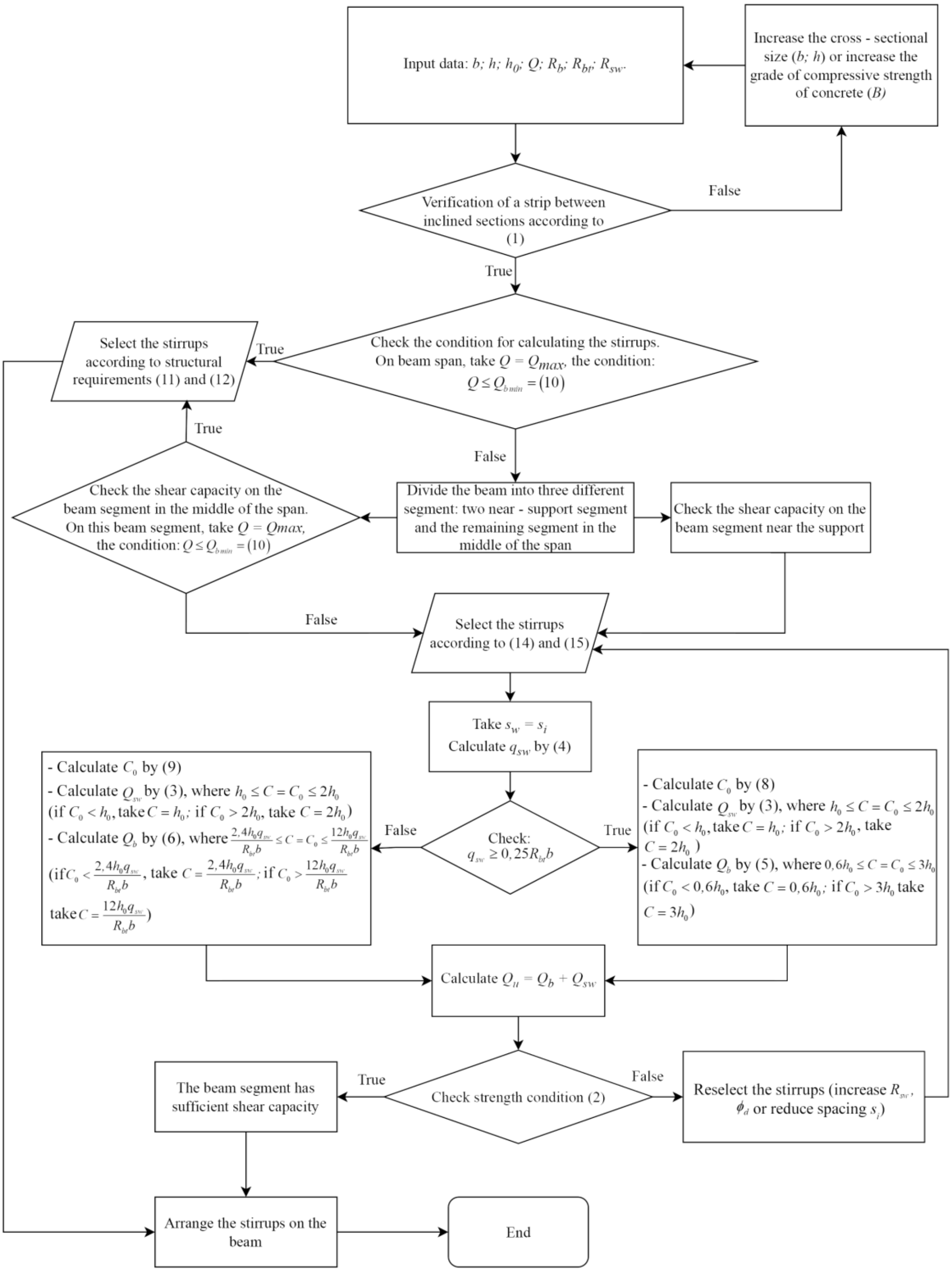


Figure 3. Flowchart for designing stirrups for beams.

2.7 Example

2.7.1 *Example 1*

A beam with point loads *P* (Figure 4a), shear force diagram (Figure 4b), rectangular cross-section: b = 220; h = 500; h_0 = 450 . Grade of compressive strength of concrete: B20. Stirrups: CB240-T. Requirement: calculate and arrange the stirrups.

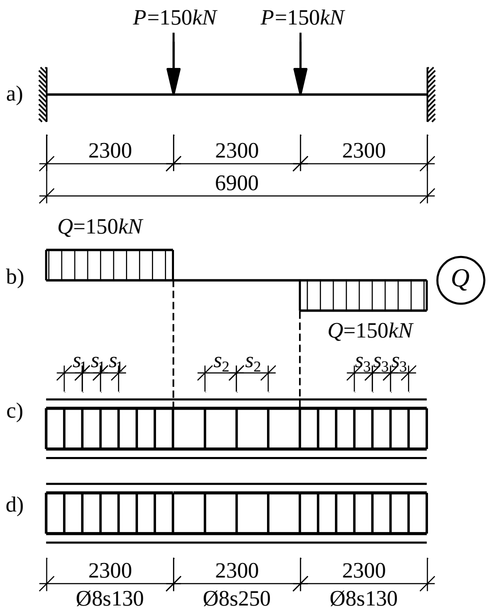


Figure 4. Beam scheme of example 1

Data: Concrete: $R_b = 11{,}5MPa$, $R_{bt} = 0{,}9MPa$; transverse reinforcement: $R_{sw} = 170MPa$.[1]

Perform the following steps:

Step 1: Verification of a strip between inclined sections

On the shear force envelope diagram (Figure 4b), take $Q = Q_{max} = 150kN$

Principal compressive stress capacity:

$$Q_{bt} = \varphi_{b1} R_b b h_0 = 0{,}3.11{,}5.220.450$$

$$= 341{,}550.10^3 N = 341{,}55kN$$

$\Rightarrow Q = Q_{max} = 150kN \le Q_{bt} = 341{,}55kN$ $\rightarrow$ concrete has sufficient capacity to resist the principal compressive stress.

Step 2: Check the condition for calculating the stirrups

Minimum shear force sustained by concrete:

$$Q_{b\,min} = 0{,}5R_{bt}bh_0 = 0{,}5.0{,}9.220.450 = 44{,}550.10^3 N$$

$$= 44{,}550kN$$

$\Rightarrow Q_{max} = 150kN > Q_{b\,min} = 44{,}550kN \rightarrow$ calculate the stirrups to support shear force.

Step 3: From the shear force envelope diagram (Figure 4b), to save the stirrups, we divide the beam into three different segments: two near-support segments with a length of x= 2,3*m*, which are the segments with high shear force and will be arranged with a smaller spacing of transverse reinforcement s_1; the remaining segment in the middle of the span with a length of 2,3*m*, which is the segment with lower shear force and will be arranged with a larger spacing of transverse reinforcement s_2 (Figure 4c).

Step 4: Check the shear capacity on the beam segment near the support

+ Select the stirrups with: diameter : ϕ8, two-legged stirrups, $A_{sw} = na_{sw} = 2.50{,}3 = 100{,}6mm^2$

Spacing:

$$s_1 \le (0{,}5h_0; 300; s_{max}) = (225; 300; 267{,}3)$$

$$s_{max} = \frac{R_{bt}bh_0^2}{Q_{max}} = \frac{0{,}9.220.450^2}{150000} = 267{,}3mm$$

Select $s_1 = 130mm$

Take $s_w = s_1$ =130*mm* and calculate :

$$+\ q_{sw} = \frac{R_{sw}A_{sw}}{s_w} = \frac{170.100{,}6}{130} = 131{,}6N/mm$$

$\Rightarrow\ q_{sw} = 131{,}6N/mm > 0{,}25R_{bt}b = 0{,}25.0{,}9.220$ = 49,5*N/mm*, The most critical projection length of the inclined section C_0 is determined by (8):

$$+\, C_0 = \sqrt{\frac{2R_{bt}bh_0^2}{q_{sw}}} = \sqrt{\frac{2.0{,}9.220.450^2}{131{,}6}} = 780{,}7mm$$

$\Rightarrow h_0 = 450mm < C_0 = 780{,}7mm < 2h_0 = 2.450 = 900mm$, take $C = C_0$ = 780,7*mm* to determine shear force sustained by stirrups :

$$+\ Q_{sw} = 0{,}75q_{sw}C = 0{,}75.131{,}6.780{,}7$$

$$= 77{,}028.10^3 N = 77{,}028kN$$

+ Determine Q_b according to (5). Because $0{,}6h_0 = 270mm < C_0 = 780{,}7mm < 3h_0 = 1350mm$, take $C = C_0$ = 780,7*mm* to calculate :

$$Q_b = \frac{1{,}5R_{bt}bh_0^2}{C} = \frac{1{,}5.0{,}9.220.450^2}{780{,}7} = 77{,}036.10^3 N$$

$$= 77{,}036kN$$

+ Shear capacity on the beam segment near the support:

$Q_u = Q_b + Q_{sw} = 77,036 + 77,028 = 154,064kN$

+ Check strength condition (2):

$Q_{max} = 150kN < Q_u = 154,064kN \Rightarrow$ the beam segment near the support has sufficient shear capacity. Select ϕ8s130 to arrange for two near-support regions.

Step 5: Check the shear capacity on the beam segment in the middle of the span

On the shear force envelope diagram (Figure 4b), shear force $Q = 0kN < Q_{bmin} \rightarrow$ arrange the stirrups according to structural requirements (11) and (12):

Diameter : ϕ8, Two-Legged Stirrups;

Spacing:

$s_2 \le (0,75h_0; 500; s_{max}) = (337,5; 500; 267,3)$

Select s_2 = 250*mm*

Step 6: Arrange the stirrups: arrange ϕ8, two-legged stirrups, *s* = 130*mm* for the 2,3*m* segment near the support; and ϕ8, two-legged stirrups *s* = 250*mm* for the segment in the middle of the span (Figure 4d) → **Finish**.

2.7.2 *Example 2*

A beam with uniformly distributed line load *q* (Figure 5a), shear force diagram (Figure 5b), rectangular cross-section: *b* = 220; *h* = 500; h_0 = 450 . Grade of compressive strength of concrete: B20. Stirrups: CB240-T. Requirement: calculate and arrange the stirrups.

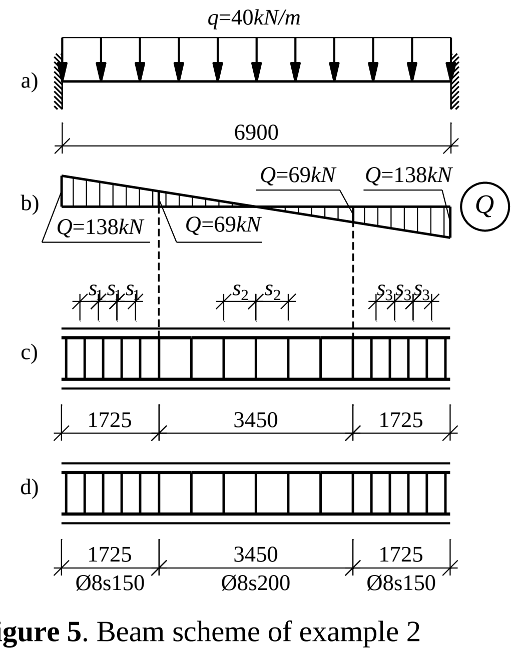


Figure 5. Beam scheme of example 2

Data: Concrete: R_b = 11,5*MPa*, R_{bt} = 0,9*MPa*; transverse reinforcement: R_{sw} = 170*MPa*.[1]

Perform the following steps:

Step 1: Verification of a strip between inclined sections

On the shear force envelope diagram (Figure 5b), take $Q = Q_{max} = 138kN$

Principal compressive stress capacity:

$$Q_{bt} = \varphi_{b1} R_b b h_0 = 0,3.11,5.220.450$$

$$= 341,550.10^3 N = 341,55kN$$

$\Rightarrow Q = Q_{max} = 138kN \le Q_{bt} = 341,55kN$ → concrete has sufficient capacity to resist the principal compressive stress.

Step 2: Check the condition for calculating the stirrups

Minimum shear force sustained by concrete:

$$Q_{bmin} = 0,5R_{bt}bh_0 = 0,5.0,9.220.450 = 44,550.10^3 N$$

$$= 44,550kN$$

$\Rightarrow$ $Q_{max} = 138kN > Q_{bmin} = 44,550kN$ → calculate the stirrups to support shear force.

Step 3: From the shear force envelope diagram (Figure 5b), to save the stirrups, we divide the beam into three different segments: two near-support segments with a length of *l*/4 = 1,725*m*, which are the regions with high shear force and will be arranged with a smaller spacing of transverse reinforcement s_1; the remaining segment in the middle of the span with a length of 3,45*m*, which is the segment with lower shear force and will be arranged with a larger spacing of transverse reinforcement s_2 (Figure 5c).

Step 4: Check the shear capacity on the beam segment near the support

+ Select the stirrups with: diameter : ϕ8, two-legged stirrups, $A_{sw} = na_{sw} = 2.50,3 = 100,6mm^2$

Spacing:

$s_1 \le (0,5h_0; 300; s_{max}) = (225; 300; 290,5)$

$$s_{max} = \frac{R_{bt}bh_0^2}{Q_{max}} = \frac{0,9.220.450^2}{138000} = 290,5mm$$

Select $s_1 = 150mm$

Take s_w = s_1 =150*mm* and calculate :

$$+ \; q_{sw} = \frac{R_{sw}A_{sw}}{s_w} = \frac{170.100,6}{150} = 114N / mm$$

$\Rightarrow$ $q_{sw} = 114N / mm > 0,25R_{bt}b = 0,25.0,9.220 =$ 49,5*N/mm*, The most critical projection length of the inclined section C_0 is determined by (8):

$$+C_0=\sqrt{\frac{2R_{bt}bh_0^2}{q_{sw}}}=\sqrt{\frac{2.0,9.220.450^2}{114}}=838,7mm$$

$\Rightarrow h_0$ = 450*mm* < C_0=*838,7mm* < $2h_0$ = 2.450 = 900*mm*, take $C = C_0$ = 838,7*mm* to determine shear force sustained by stirrups:

$$+\ Q_{sw}=0,75q_{sw}C=0,75.114.838,7$$

$$=71,709.10^3N=71,709kN$$

+ Determine Q_b according to (5). Because $0,6h_0$ = 270*mm* < C_0 = 838,7*mm* < $3h_0$ = 1350*mm*, take $C = C_0$ = 838,7*mm* to calculate:

$$Q_b=\frac{1,5R_{bt}bh_0^2}{C}=\frac{1,5.0,9.220.450^2}{838,7}=71,709.10^3N$$

$$=71,709kN$$

+ Shear capacity on the beam segment near the support:

$$Q_u=Q_b+Q_{sw}=71,709+71,709=143,418kN$$

+ Check strength condition (2):

$Q_{max}=138kN<Q_u=143,418kN\Rightarrow$ the beam segment near the support has sufficient shear capacity. Select ϕ8s150 to arrange for two near-support regions.

Step 5: Check the shear capacity on the beam segment in the middle of the span

On the shear force envelope diagram (Figure 5b), shear force $Q=69kN>Q_{bmin}$ $\rightarrow$ calculate the stirrups to support shear force:

+ Select the stirrups with: diameter : ϕ8, two-legged stirrups, $A_{sw}=na_{sw}=2.50,3=100,6mm^2$

Spacing:

$$s_1\le(0,5h_0;300;s_{max})=(225;300;290,5)$$

Select $s_1=200mm$

Take $s_w = s_1$ = 200*mm* and calculate :

$$+\ q_{sw}=\frac{R_{sw}A_{sw}}{s_w}=\frac{170.100,6}{200}=85,5N/mm$$

$\Rightarrow\ q_{sw}=85,5N/mm>0,25R_{bt}b=0,25.0,9.220$ = 49,5*N/mm*, The most critical projection length of the inclined section C_0 is determined by (8):

$$+C_0=\sqrt{\frac{2R_{bt}bh_0^2}{q_{sw}}}=\sqrt{\frac{2.0,9.220.450^2}{85,5}}=968,4mm$$

$\Rightarrow C_0$=*968,4mm* > $2h_0$ = 900*mm*, take $C = 2h_0$ = 900*mm* to determine shear force sustained by stirrups:

$$+\ Q_{sw}=0,75q_{sw}C=0,75.85,5.900$$

$$=57,713.10^3N=57,713kN$$

+ Determine Q_b according to (5). Because $0,6h_0$ = 270*mm* < C_0 = 968,4*mm* < $3h_0$ = 1350*mm*, take $C = C_0$ = 968,4*mm* to calculate:

$$Q_b=\frac{1,5R_{bt}bh_0^2}{C}=\frac{1,5.0,9.220.450^2}{968,4}=62,105.10^3N$$

$$=62,105kN$$

+ Shear capacity on the beam segment in the middle of the span:

$$Q_u=Q_b+Q_{sw}=62,105+57,713=119,818kN$$

+ Check strength condition (2):

$Q_{max}=69kN<Q_u=119,818kN\Rightarrow$ the beam segment has sufficient shear capacity. Select ϕ8s200 to arrange for the beam segment in the middle of the span.

Step 6: Arrange the stirrups: arrange ϕ8, two-legged stirrups, *s* = 150*mm* for the 1,725*m* segment near the support; and ϕ8, two-legged stirrups *s* = 200*mm* for the segment in the middle of the span (Figure 5d) $\rightarrow$ **Finish**.

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 subjected to shear forces. However 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 and diagramming this process is highly practical and can be applied more easily in the design of structures.

The calculation of the shear strength of reinforced concrete members in [1] and [5] is almost similar in terms of formulas. However, the formulas provided in [1] are simpler because they have significantly reduced the number of empirical coefficients.

From Section 2.4 and the examples, we can see that the tructural requirements for load-bearing stirrups and structural stirrups in beams are different. Therefore, the selection of the length (*x*) of the beam segment near the support affects the amount of stirrups placed on the beam segment in the middle of the span. In design, depending on each specific member and its shear force envelope diagram *Q*, choosing a reasonable length *x* will help save the amount of stirrups.

The assessment of the strength design process of reinforced concrete beams under shear forces is based on [1] compared to [5] and some advanced standards in the world will be presented in the next issue.

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