

# ASSESSMENT OF SHEAR RESISTANCE OF RC MEMBERS WITHOUT SHEAR REINFORCEMENT OF VIETNAM STANDARD 5574-2012 AND OTHER BUILDING CODES

## ĐÁNH GIÁ KHẢ NĂNG CHỊU CẮT CỦA CẤU KIỆN BÊ TÔNG CỐT THÉP KHÔNG CÓ CỐT THÉP NGANG THEO TCVN 5574-2012 VÀ MỘT SỐ TIÊU CHUẨN KHÁC

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**Abstract** - Several structural reinforced concrete members are constructed without shear reinforcement such as slabs, footings, and lightly stressed members. The design of these members for shear has become an issue of debate as the shear capacity according to various building codes are very different. The paper investigates the design shear strength of reinforced concrete beams without transverse reinforcement using provisions from Vietnam Standard 5574-2012, ACI 318-14, EC2 EN 1992-1:2004, and BS 8110-1:1997. The results show that Vietnam Standard 5574-2012 does not account for the influence of longitudinal tension reinforcement ratio, shear span ratio, and size effect on the shear resistance provided by the concrete which are the important factors incorporated in the other codes. Comparisons of the design shear strength versus concrete strength and axial load level are also carried out among these four building codes.

**Key words** - reinforced concrete; concrete member; shear strength; shear reinforcement; building code.

### 1. Introduction

Reinforced concrete structures have been widely used in buildings, bridges, tunnels, and many other structures. Several structural reinforced concrete members are constructed without shear reinforcement such as slabs, footings, and lightly stressed members. The design of these members for shear has become an issue of debate as the shear capacity according to various building codes are very different due to the complex stress redistributions that occur after cracking. Shear transfer mechanisms have been proved to be influenced by various parameters.

Figure 1 [1] explains the basic mechanisms of shear transfer based on the findings of the reports by joint ASCE-ACI Committee 426 [2] and joint ASCE-ACI Committee 445 [3]. The five mechanisms of shear transfer are shear stresses in un-cracked concrete, that is, the flexural compression zone; interface shear transfer, which is also called aggregate interlock or crack friction; dowel action of the longitudinal reinforcing bars; arch action; and residual tensile stresses transmitted directly across cracks.

Several factors have an influence on the shear capacity of structural members without shear reinforcement. The most influenced parameters are known as the concrete strength, longitudinal tension reinforcement, axial force, shear span ratio, and size effect. This study investigates the design shear strength of reinforced concrete beams without transverse reinforcement using provisions from the four building codes: Vietnam Standard 5574-2012, ACI 318-14, EC2 EN 1992-1:2004, and BS 8110-1:1997.

**Tóm tắt** - Nhiều cấu kiện bê tông cốt thép được chế tạo và xây dựng mà không cần bố trí cốt thép ngang như các sàn, bản móng và các cấu kiện chịu lực cắt không lớn. Việc thiết kế chịu cắt cho các cấu kiện này đã trở thành một vấn đề tranh cãi vì khả năng chịu cắt của bê tông theo các tiêu chuẩn khác nhau là rất khác nhau. Bài báo trình bày nghiên cứu khả năng chịu cắt thiết kế của dầm bê tông cốt thép không có cốt thép ngang theo các tiêu chuẩn TCVN 5574-2012, ACI 318-14, EC2 EN 1992-1:2004, and BS 8110-1:1997. Kết quả nghiên cứu chỉ ra rằng tiêu chuẩn TCVN 5574-2012 không xét đến ảnh hưởng của hàm lượng cốt thép dọc dầm kéo, tỉ số giữa khoảng cách đặt lực với chiều cao dầm, và kích cỡ của cấu kiện đến khả năng chịu cắt của bê tông, trong khi đây là các yếu tố quan trọng đã được tích hợp vào các tiêu chuẩn khác. Bài báo cũng so sánh khả năng chịu cắt theo cường độ bê tông và tỉ số nền giữa bốn tiêu chuẩn này.

**Từ khóa** - bê tông cốt thép; cấu kiện bê tông; khả năng chịu cắt; cốt thép ngang; tiêu chuẩn thiết kế.

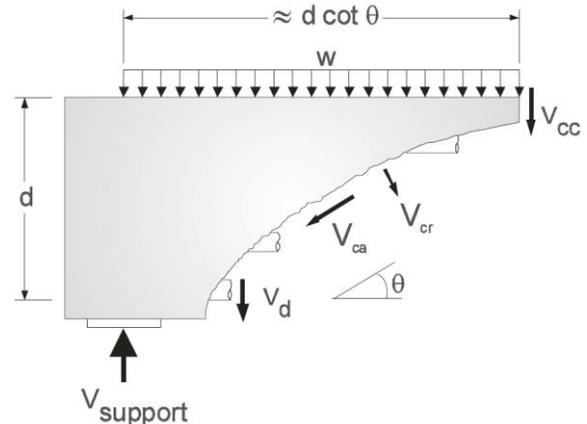


Figure 1. Shear transfer contributing to shear resistance

$V_{cc}$  = Shear in compression zone

$V_{cr}$  = Residual tensile stress in concrete

$V_{ca}$  = Interface shear transfer

$V_d$  = Dowel action

### 2. Shear provisions in various building codes

#### 2.1. TCVN 5574-2012

The design value for the shear resistance of members without shear reinforcement is given by:

$$V_c = \frac{\phi_{b4}(1 + \phi_n)R_{bt}bh_o^2}{C} \quad (1.1)$$

where  $R_{bt}$  is the design tensile strength of concrete;

$b$  is the width of beam;  $h_o$  is the effective depth of the beam;  $C$  is the projection of the inclined crack on the axis of the beam which should not be greater than  $2h_o$ :

$$C \leq 2h_o \quad (1.2)$$

$\varphi_{b4}$  is the modification factor to account for the type of concrete,  $\varphi_{b4}=1.5$  for normal concrete;  $\varphi_n$  is the factor to account for the influence of axial force on shear strength, to be determined as follows.

For compression force  $N$ ,  $\varphi_n$  is calculated as Eq (1.3) but is not greater than 0.5.

$$\varphi_n = \frac{0.1N}{R_{bt} bh_o} \leq 0.5 \quad (1.3)$$

For tension force  $N$ ,  $\varphi_n$  is calculated as Eq (1.4) but is not greater than 0.8.

$$\varphi_n = -\frac{0.2N}{R_{bt} bh_o} \leq 0.8 \quad (1.4)$$

The design value  $V_c$  also needs to satisfy the following conditions.

$$V_c \geq \varphi_{b3} (1 + \varphi_n) R_{bt} bh_o \quad (1.5)$$

$$V_c \leq 2.5R_{bt} bh_o \quad (1.6)$$

From (1.1), (1.2), (1.5) and (1.6),  $C$  must be in the range:

$$0.6h_o \leq C \leq 2h_o \quad (1.7)$$

## 2.2. ACI 318-14

For members without axial force, the nominal shear strength provided by concrete is calculated by:

$$V_c = 2\lambda\sqrt{f'_c}b_wd \quad (2.1)$$

For detailed analysis, the following equation can be used:

$$V_c = \left( 1.9\lambda\sqrt{f'_c} + 2500 \frac{\rho_w V_u d}{M_u} \right) b_w d \leq 3.5\lambda\sqrt{f'_c}b_wd \quad (2.2)$$

where  $\lambda$  is the modification factor to reflect the reduced mechanical properties of lightweight concrete relative to normal weight concrete of the same compressive strength,  $\lambda=1.0$  for normal concrete;  $f'_c$  (psi) is the specified compressive strength of concrete;  $b_w$  (in.) is the web width of the beam;  $d$  (in.) is the distance from the extreme compressive fiber to centroid of longitudinal tension reinforcement;  $\rho_w=A_s/(b_wd)$  is the ratio of longitudinal tension reinforcement;  $M_u$  and  $V_u$  are the factored moment and shear force at the critical section, respectively. The ratio  $(V_u d)/M_u$  must satisfy the following condition:

$$\frac{V_u d}{M_u} \leq 1.0 \quad (2.3)$$

For members with axial compression,  $V_c$  is calculated by:

$$V_c = 2 \left( 1 + \frac{N_u}{2000A_g} \right) \lambda\sqrt{f'_c}b_wd \quad (2.4)$$

For members with significant axial tension,  $V_c$  is calculated by:

$$V_c = 2 \left( 1 + \frac{N_u}{500A_g} \right) \lambda\sqrt{f'_c}b_wd \quad (2.5)$$

where  $N_u$  (lb) is the factored axial force to be taken as positive for compression and negative for tension;  $A_g$  (in<sup>2</sup>) is the gross area of the beam.

In SI units, the four equations (2.1), (2.2), (2.4), (2.5) are replaced with the four following equations (2.6), (2.7), (2.8), (2.9), respectively.

$$V_c = 0.17\lambda\sqrt{f'_c}b_wd \quad (2.6)$$

$$V_c = \left( 0.16\lambda\sqrt{f'_c} + 17\rho_w \frac{V_u d}{M_u} \right) b_w d \leq 0.29\lambda\sqrt{f'_c}b_wd \quad (2.7)$$

$$V_c = 0.17 \left( 1 + \frac{N_u}{14A_g} \right) \lambda\sqrt{f'_c}b_wd \quad (2.8)$$

$$V_c = 0.17 \left( 1 + \frac{0.29N_u}{A_g} \right) \lambda\sqrt{f'_c}b_wd \quad (2.9)$$

where there are  $f'_c$  (MPa),  $b_w$  (mm) and  $d$  (mm).

The design shear strength of concrete beams without shear reinforcement is  $\Phi V_n$ , where  $\Phi=0.75$  is the strength reduction factor for shear.

## 2.3. EN 1992-1:2004

The design value for the shear resistance of members without shear reinforcement is given by:

$$V_c = \left[ C_{Rd,c} k (100\rho_1 f_{ck})^{1/3} + k_1 \rho_{cp} \right] b_w d \geq V_{c,\min} \quad (3.1)$$

The shear resistance  $V_c$  is not less than:

$$V_{c,\min} = (v_{\min} + k_1 \rho_{cp}) b_w d \quad (3.2)$$

where  $f_{ck}$  (MPa) is the characteristic compressive cylinder strength of concrete at 28 days;

$$k = \left( 1 + \sqrt{\frac{200}{d}} \right) \leq 2.0 \quad (3.3)$$

with  $d$  (mm);  $\rho_1$  is the longitudinal tension reinforcement ratio:

$$\rho_1 = \frac{A_{s1}}{b_w d} \leq 0.02 \quad (3.4)$$

$A_{s1}$  is the area of longitudinal tension reinforcement, which extends  $\geq (l_{bd}+d)$  beyond the section considered;  $k_1$  is 0.15;  $\sigma_{cp}$  (MPa) is the compressive stress in the concrete from axial load,

$$\sigma_{cp} = \frac{N_{Ed}}{A_c} \leq 0.2f_{cd} \quad (3.5)$$

$N_{Ed}$  (N) is the axial force in the cross-section due to loading; to be taken as positive for compression and negative for tension;  $A_c$  (mm<sup>2</sup>) is the area of the concrete cross section;  $f_{cd}$  (MPa) is the design value of concrete

compressive strength;  $b_w$  (mm) is the smallest width of the cross-section in the tensile area;  $d$  (mm) is the distance from the extreme compressive fiber to centroid of longitudinal tension reinforcement,  $v_{min}$  is determined as :

$$v_{min} = 0.035k^{3/2} f_{ck}^{1/2} \quad (3.6)$$

**2.4. BS 8110-1:1997**

For members with axial force, the design value for the shear resistance of members without shear reinforcement is given by:

$$V_c = \frac{0.79}{\gamma_m} \left( \frac{100A_s}{b_v d} \right)^{1/3} \left( \frac{400}{d} \right)^{1/4} b_v d \quad (4.1)$$

where  $\gamma_m$  is the partial safety factor for strength of concrete,  $\gamma_m=1.25$  for shear strength without reinforcement;  $100A_s/(b_v d)$  is the longitudinal tension reinforcement ratio which should not be less than 0.15 but greater than 3.0;  $A_s$  is the area of longitudinal tension reinforcement;  $b_v$  (mm) is the breadth of section (for a flanged beam this should be taken as the average width of the rib below the flange);  $d$  (mm) is the effective depth of the longitudinal tension reinforcement;  $(400/d)^{1/4}$  takes into account the size effect and should be not less than 0.67 for members without web reinforcement.

For characteristic concrete strengths greater than 25MPa, equation (4.1) is multiplied by  $(f_{cu}/25)^{1/3}$  to account for the influence of higher compressive concrete strength on the shear strength.

For members without axial force, the design value for the shear resistance of members without shear reinforcement is given by:

$$V'_c = V_c + 0.6 \frac{NVh}{A_c M} b_v d \quad (4.2)$$

where  $M$  is the design ultimate moment;  $N$  is the design axial force;  $V$  is the design shear force at the section considered due to ultimate loads;  $A_c$  is area of the beam cross-section.

**3. Parametric study**

The shear resistance of a concrete beam without shear reinforcement is investigated based on the four building code provisions: TCVN 5574-2012, ACI 318-14, EC2 EN 1992-1:2004, and BS 8110-1:1997. The beam has the cross-section of 25×45cm.

**3.1. Shear resistance versus concrete compressive strength level**

Figure 2 shows the relation between the design shear resistance  $V_c$  and concrete compressive strength level  $B$  mentioned in TCVN 5574-2012. There is no axial load acting on the beam and the longitudinal tension reinforcement ratio is kept constant as 1.5% for the four building codes. As can be seen from the figure,  $V_c$  calculated based on ACI and EC2 codes are very closed together and are the lowest shear strength. TCVN code gives the highest  $V_c$  for concrete with compressive strength level greater than B25. At B60, the design shear capacity of Vietnam Standard is almost 50% greater than ACI and

EC2 codes.

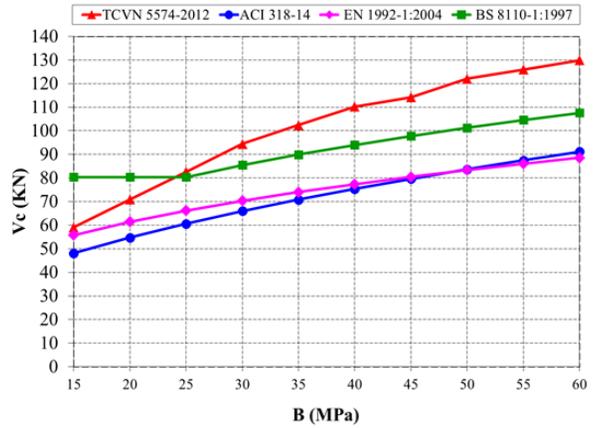


Figure 2. Comparison of  $V_c$  versus  $B$

**3.2. Shear resistance versus longitudinal tension reinforcement**

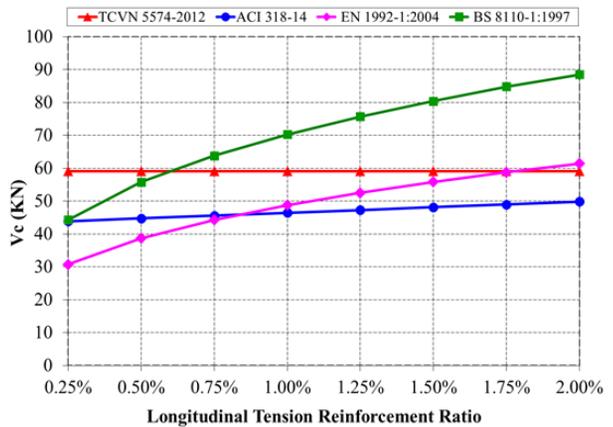


Figure 3. Comparison of  $V_c$  versus longitudinal tension reinforcement ratio for concrete B15

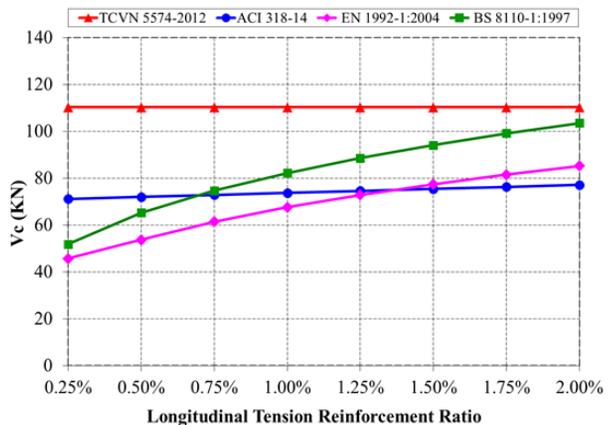


Figure 4. Comparison of  $V_c$  versus longitudinal tension reinforcement ratio for concrete B40

Figures 3 and 4 plot the comparison of  $V_c$  versus longitudinal tension reinforcement ratio  $\rho_l$  for concrete B15 and B40, respectively. Of the four building codes investigated, only the shear resistance in Vietnam Standard is not influenced by the amount of tension reinforcement.  $V_c$  in EC2 and BS codes depends significantly on  $\rho_l$  and it almost doubles when  $\rho_l$  increases from 0.25% to 2.0%. In ACI code,  $V_c$  increases only around 10% in the same range

of tension reinforcement ratio.

3.3. Shear resistance versus axial load ratio

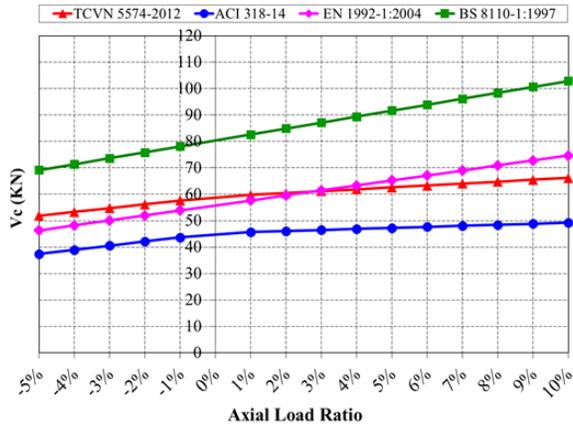


Figure 5. Comparison of  $V_c$  versus axial load ratio for concrete B15

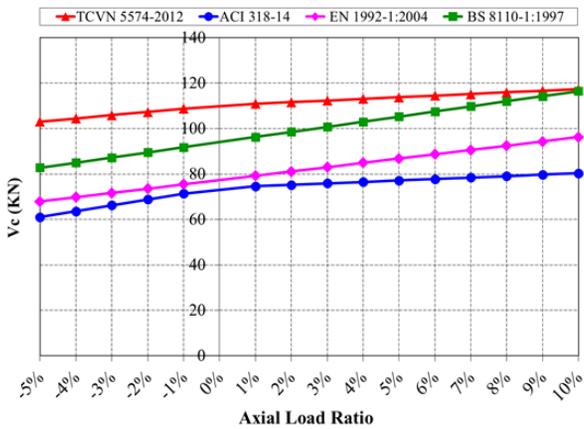


Figure 6. Comparison of  $V_c$  versus axial load ratio for concrete B40

Figures 5 and 6 describe the relation between  $V_c$  and axial load for concrete B15 and B40, respectively. The figures indicate that axial load affects the shear capacity in all building codes.  $V_c$  increases with compression force and decreases with tension force. The shear resistance in EC2 and BS codes depend more significantly on axial load than that in Vietnam Standard and ACI codes.

3.4. Shear resistance versus shear span ratio

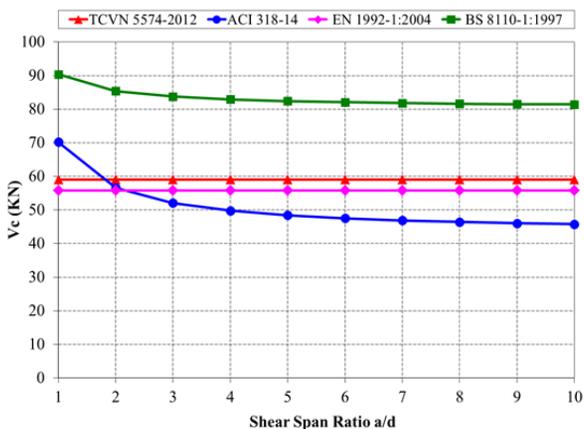


Figure 7. Comparison of  $V_c$  versus shear span ratio for concrete B15

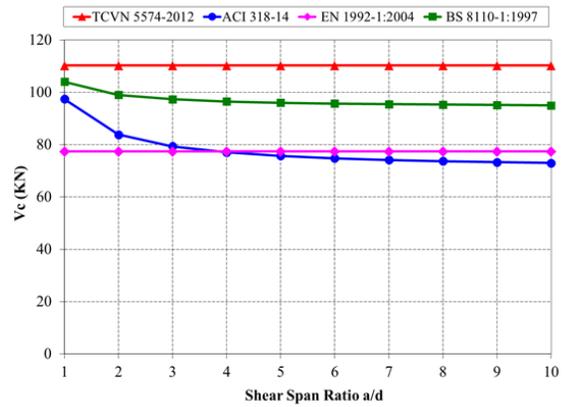


Figure 8. Comparison of  $V_c$  versus shear span ratio for concrete B40

In the case of short shear span ratio, the shear resistance in beams increases due to the arch action. Only ACI and BS codes include this effect in their provisions by incorporating the ratio  $\frac{V_u d}{M_u}$  and  $\frac{V_h}{M}$ , respectively (Figures 7 and 8). At low strength concrete such as B15 and high tension reinforcement ratio,  $V_c$  in ACI increases over 50% when the shear span ratio decreases down to 1.

3.5. Shear resistance versus effective depth

The concrete shear capacity decreases when  $d$  increases but this size effect is not incorporated in Vietnam Standard and ACI codes. The size effect has the most impact on the shear resistance in BS code which decreases almost 30% when  $d$  increases from 20cm to 100cm.

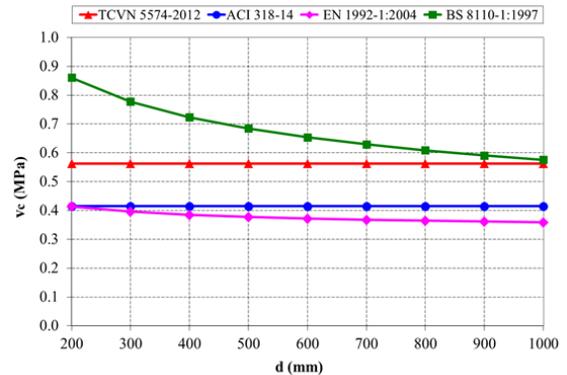


Figure 9. Comparison of  $V_c$  versus effective depth for concrete B15

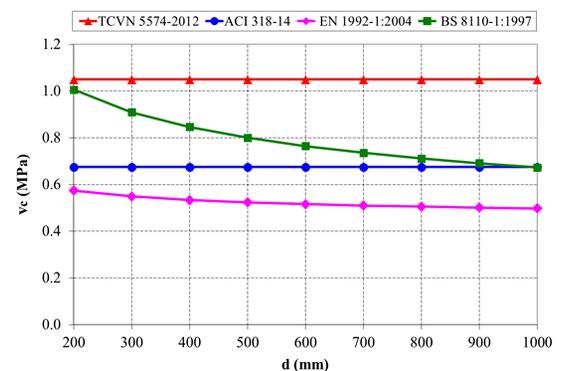


Figure 10. Comparison of  $V_c$  versus effective depth for concrete B40

#### 4. Conclusion

A parametric study is carried out to investigate the influence of various parameters on the concrete shear resistance in the four building codes: Vietnam Standard 5574-2012, ACI 318-14, EC2 EN 1992-1:2004, and BS 8110-1:1997. The concrete beam has no shear reinforcement and has the cross-section 25×45cm. From the study, the following conclusions can be drawn.

- Vietnam Standard 5574-2012 does not account for the impact of longitudinal tension reinforcement, shear span ratio, and size effect on the shear resistance provided by the concrete. These three parameters have significant influence on  $V_c$  as shown in the other codes. The design shear capacity in EC2 and BS codes may double when the tension reinforcement ratio varies from 0.25% to 2.0%. The shear capacity increases over 50% when the shear span ratio decreases down to 1 in ACI code whereas it decreases almost 30% when the effective depth  $d$  increases from 20cm to 100cm in BS code.

- The concrete shear capacity calculated from ACI and EC2 codes are quite closed together, especially when the longitudinal tension reinforcement ranges from 0.75% to 1.5%. These are also the most conservative codes on shear

strength of concrete members without shear reinforcement.

- In most of the cases, Vietnam Standard gives the highest shear resistance for beams with high strength concrete, i.e.  $B$  greater than 40. On the contrary, for concrete with compressive strength lower than B15, BS code usually gives the highest shear capacity.

#### REFERENCES

- [1] Jung S. and Kim K.S. (2008). Knowledge-based prediction of shear strength of concrete beams without shear reinforcement, *Engineering Structures*, V30, pp. 1515-1525.
- [2] ASCE-ACI Committee 426 (1973). The Shear Strength of Reinforced Concrete Members, *Journal of Structural Division*, ASCE, V. 99, No. 6, pp. 1091-11872.
- [3] ASCE-ACI Committee 445 (1999). ACI 445R-99 Recent Approaches to Shear Design of Structural Concrete.
- [4] TCVN 5574-2012 Concrete and reinforced concrete structures - Design standard.
- [5] ACI 318-14 Building code requirements for structural concrete and commentary. American Concrete Institute. Farmington Hills.
- [6] EC2 EN 1992-1:2004. Design of concrete structures - Part 1-1: General rules and rules for buildings.
- [7] BS 8110-1:1997 Structural use of concrete - Part 1: Code of practice for design and construction. British Standards Institute.

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