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# INFLUENCE OF LONGITUDINAL REINFORCEMENT RATIO ON SHEAR CAPACITY OF NO COARSE-AGGREGATE CONCRETE

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**ABSTRACT:** The study investigated the effect of longitudinal reinforcement ratio on the shear capacity of concrete beams without transverse steel. The concrete mixture did not include coarse aggregate. The Joint ACI–ASCE Committee 426 (1973) has shown that the shear is transferred across the surface where there is slip and it is called the aggregate interlock. To study the effect of longitudinal reinforcement ratio on the shear capacity of concrete without coarse aggregate, six beam specimens with the size of 110 × 7 × 12.5 cm and a/d ratio of 45/10.5 were investigated. The longitudinal reinforcement ratios were set from the minimum to the maximum, i.e. 0.0077, 0.0137, 0.0214, 0.0308, 0.0547, and 0.0772. The ratios of the ultimate shear to the shear capacity of concrete (Vu/Vc) were found between 1.0705 and 2.8748. When the longitudinal reinforcement ratio increases particularly from the minimum ratio, the value of Vu/Vc also significantly increases. The values of Vu/Vc were found less than 2, thus Vs is required. When the longitudinal reinforcement ratio approaches maximum, Vu/Vc becomes relatively constant and was found more than 2. This concludes that the ratio of Vu/Vc of the concrete without coarse aggregate is lower than normal concrete. The existing ACI's formula for computing the shear capacity contributed by concrete, which has not been changed for decades, is only applicable for normal concrete (with coarse aggregate). This research proposes a theory to develop a new shear capacity formula specifically for concrete without coarse aggregate.

*Keywords: Coarse aggregate, Concrete beams, Longitudinal reinforcement ratio, Shear capacity*

## 1. INTRODUCTION

Concrete is one of the materials that has been widely used in various types of construction materials [1]. The increasing demand and widespread use of concrete show that more and more concrete is required in the future [2-5]. The design of a structure may be considered as the process of selecting the proper materials according to state-of-the-art engineering science and technology. In order to accomplish its purpose, the structure must meet the conditions of safety, serviceability, economy, and functionality. The development of concrete technology has encouraged researchers to enhance the quality of concrete, in particular of strength, ease of work, durability, and cost-efficiency in making concrete itself so that this leads to the ultra-high performance of the concrete era. Researches on ultra-high-performance concrete are progressing rapidly in recent years, such as [6-16]. Concrete is defined as "high strength" based solely on its compressive strength at a certain age. According to ACI 363.2R-11 "Guide to Quality Control and Assurance of High Strength Concrete," high-strength concrete is concrete which compressive strength surpasses the value of 55 MPa [17]. The column is the most important structural member which carries the gravity load and resists the earthquake load [18].

However, framing beams are also very essential in forming the overall structural frames and thus, they also need to be designed properly to satisfy the strength and ductility. In the design of reinforced concrete beams, flexural moment, shear and torsional capacities need to be provided higher or at least equal to the ultimate bending moment, shear force, and torsion, respectively [19].

Shear failure is very critical in beams due to its brittle manner. If the beams are designed properly to satisfy their strength requirements, they can experience flexural failure before shear failure. Shear crack causes the beam to split into two parts separated by a shear crack line, namely the top of the shear crack and the bottom of the shear crack. Shear cracks in the beam can be held with four elements, namely:

1. Surface roughness and aggregate form of concrete. The shape of the aggregate is angular and the surface is rough. This is very strong to resist shear because the aggregate will interlock, making it difficult to slip (not easily cracked) as shown in Fig.1 (a). However, if the aggregate is round and the surface is smooth, it cannot optimally resist the shear stress since it is easy to slip (easy to crack), as shown in Fig.1 (b).

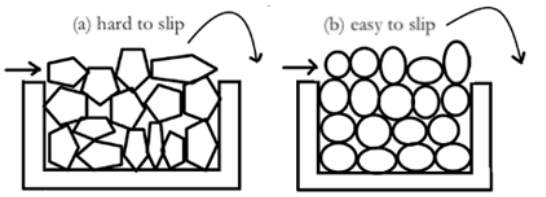


Fig.1 Comparison of the slip/crack strength of (a) angular coarse aggregate; (b) round coarse aggregate

2. Shear cracks are held by tensile and cutting forces (dowel action) of longitudinal reinforcement, as shown in Fig.2 and Fig.3 [20].

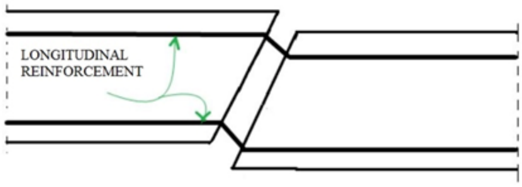


Fig.2 Shear cracks are held by longitudinal reinforcement

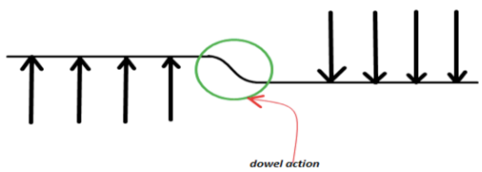


Fig.3 Dowel action on longitudinal reinforcement

3. Shear cracks are held by concrete compression. In Fig.4 Forces acting at inclined crack [21], $V_{cz}$ is shear carried by the compression zone.

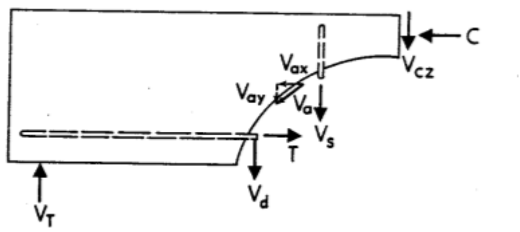


Fig.4 Forces acting at inclined crack [21]

4. Shear cracks are resisted by the tensile strength of the shear reinforcement in the form of both inclined and transverse reinforcements shown in Fig.5 and Fig.6, respectively.

According to the ASCE Committee 426 report, the shear strength of concrete does not only rely on the shear reinforcement, that is, the shear force values that cause the inclined cracks [21]. Therefore, the shear reinforcement is considered to resist the excess shear force only beyond which can be resisted by concrete. Shear crack on the beam will not occur if it is properly designed to withstand the shear force [22-24].

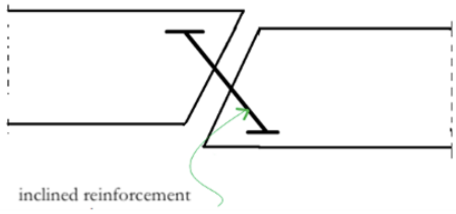


Fig.5 Shear cracks are held by an inclined reinforcement

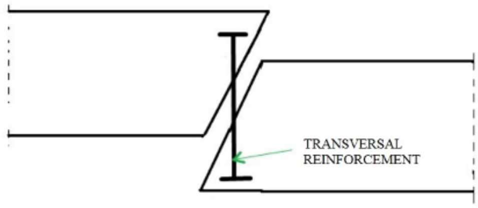


Fig.6 Shear cracks are held by transverse reinforcement (stirrup)

Possible types of cracks that might occur in a concrete beam are shown in Fig.7 and Fig.8 shows the cross-section of the corresponding beam in Fig.7.

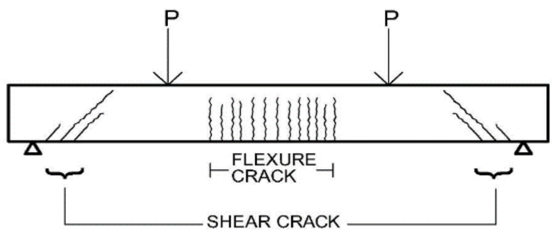


Fig.7 Cracks in concrete beam

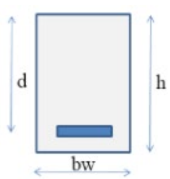


Fig.8 The beam's cross-section

Based on ACI 318-19M, one-way shear strength at a section, Vn, shall be calculated by [33]:

$$V_n = V_c + V_s \quad (1)$$

Furthermore, aims to determine the contribution of longitudinal reinforcement, then, the shear force ($V_n$) that can be resisted by concrete is the total of the concrete shear force ($V_c$), the shear force carried by the longitudinal reinforcement ($V_d$), and the shear force carried by stirrup ($V_s$) shown on Fig.4. It can be written as follows:

$$V_n = V_c + V_d + V_s \quad (2)$$

where $V_n$ = shear force, $V_c$ = shear force carried by concrete, $V_d$ = shear force carried by longitudinal reinforcement, $V_s$ = shear force carried by stirrups. In the study, no stirrup was used, thus $V_s = 0$. It can be rewritten as follows:

$$V_n = V_c + V_d \quad (3)$$

The forces that produce Vn based on equation 2, can be illustrated in Fig.4 Forces acting at inclined crack [21]

The study aims to investigate the influence of longitudinal reinforcement ratio on shear capacity of the beams without coarse aggregate.

The previous research also presents the influence of reinforcement ratio on the shear capacity of normal concrete, shown in Fig.9. The following research, shown in Fig.13, will display the influence of longitudinal reinforcement ratio on shear capacity in concrete without coarse aggregate.

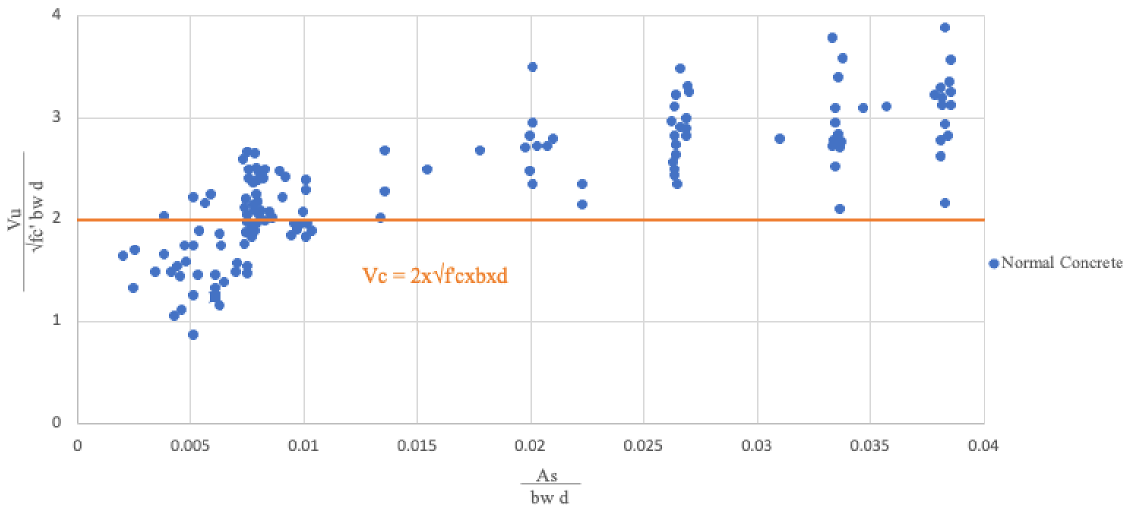


Fig.9 Influence of reinforcement ratio on the shear capacity of normal concrete [1].

## 2. RESEARCH SIGNIFICANCE

This research examines the effect of the ratio of longitudinal reinforcement on the shear capacity of concrete beams without transverse steel. The concrete mix does not include coarse aggregate. The ACI-ASCE Committee 426 (1973) has shown that shear is transferred across surfaces where there is slip and it is called aggregate interlock.

The ACI formula that has not changed for decades is used to calculate the shear capacity contributed by concrete only applies to normal concrete (with coarse aggregate), This study proposes a theory to develop a new shear capacity formula specifically for concrete without coarse aggregate, coarse aggregate which becomes the shortcoming of high-strength concrete is removed and concrete homogeneity is more assured.

## 3. REINFORCED CONCRETE WITHOUT COARSE AGGREGATE

Coarse aggregate is one of the elements that gives shear capacity contribution to concrete in bearing shear force. This research work reports on the shear capacity of normal concrete without any coarse-grained aggregate, and with various longitudinal reinforcement ratios from the minimum to the maximum value. To reach a concrete compressive strength of 100 MPa, innovative materials are used including silica fume, marble powder, superplasticizer, and also a curing process for 90 days. Silica fume was used as a filling and pozzolan material to fill the gap between mortar and aggregate [25].

## 4. NO-TRANSVERSE REINFORCEMENT BEAMS

Beam elements without stirrups can cause sudden failure.

Due to the load on a beam, sshear capacity can be contributed by the following aspects [1]:

1. Coarse Aggregate Size
   The increase of coarse aggregate diameter size largened the crack roughness, allowing higher shear stress to be transferred through the crack gap. In a high-strength concrete beam, cracks penetrate the aggregate rather

than surround it, resulting in a smoother cracked surface. Aggregate interlock along the cracks decreases shear transfer and reduces Vc, shown in Fig.4 Forces acting at inclined crack [21]

2. Aggregate Interlock
   Aggregate interlock transfers the majority of the total shear force to the supports. Fig.4, illustrates that $V_{ax}$ and $V_{ay}$ are the forces along the diagonal tension crack due to interface shear transfer and also called aggregate interlock.
3. Axial Tensile Force
   The raise of tensile stress in flexure reinforcement from direct axial tensile results in the increase of inclined crack width. Therefore, there is a decline in the number of maximum shear stress transferred through the crack gap. This mechanism decreases the load due to shear failure.
4. Beam Size
   The reduction in the maximum transferred shear stress across the crack by aggregate interlock is the result of the increase of crack width from the beam depth. An unstable condition forms by the time the shear stress transferred across the crack goes above the shear strength. When this happens, the crack surfaces slip, one relative to the other.
   In beams where the minimum required web reinforcement is applied, shear transfer across the crack from aggregate interlock is braced by the web reinforcement to keep the fracture surfaces intact. This leads to the decrease in shear strength due to the dimension displayed is not observed in beams with web reinforcement.
5. Concrete Tensile Strength
   If the first crack occurred is a flexural crack, it tends to interfere with the elastic stress field such that the crack tends to occur at the principal tensile stress. The crack of the concrete mainly depends on the tensile strength of the concrete.
6. Longitudinal Reinforcement Ratio (ρ)
   The smaller steel ratio will cause a higher extension of flexural crack occurred on beams. The crack opening also tends to be wider compared to beams with large values of steel ratio. The decrease in the maximum values of shear components, $V_d$, and $V_{ay}$, which are transferred across the inclined crack by dowel action or by shear tension on the crack surface, is caused by the increase in the crack width. By the time that the resistance along the crack falls under the requirement to support the load, sudden failure on beams may occur from shear.
7. Shear arm ratio, a/d
   The a/d ratio affects the type of shear failure. For a/d = 2.5 is the critical value. If a/d < 2.5 the mechanism shear resistance is arch action [22-29] and a/d > 2.5 the mechanism shear resistance is beam action [30-32].

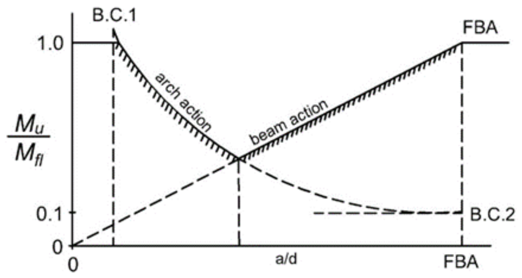


Fig.10 Shear when cracking and crushing [29]

## 5. CONCRETE SHEAR STRENGTH

Following Table 11.5.4.6 of ACI 318M-14 [21] for concrete members resisting shear and bending moment, the shear force capacity contributed by concrete only without transverse reinforcement can be calculated by

$$V_c=0.17\sqrt{f'c}\,.b_w\,.d \quad (5)$$

where f'c = concrete compressive strength (MPa), $b_w$ = beam width (mm), d = effective beam depth (mm). This formula remains the same until the latest edition of the ACI Building Code [33].

## 6. MATERIALS AND METHODS

The concrete-making materials used in this research with their specific gravities and proportions are given in Table 1. The tested curing days used in the research are 58, 70, 80, and 90 days.

**Table 1** Sample composition material

| Material | Specific Gravity ($kg/m^3$) | Ratio |
|---|---|---|
| Water | 1000 | 0.18 |
| Cement | 3150 | 1 |
| Silica Fume | 2200 | 0.2 |
| Sand* | 2617.8 | 1.1 |
| Marble powder | 2563 | 0.1 |
| Superplasticizer | 1150 | 0.025 |

**Using sieve analysis no. 30 (0.6 mm) and no. 50 (0.3 mm)*

To evaluate the compressive strength of the concrete used for the beam specimens, a set of two cylinders samples were taken from each batch of concrete for each beam specimen. The cylinder samples have a diameter and height of 100 mm and 200 mm, respectively.

All the beam specimens had an a/d ratio of 45/10.5 (beam action mechanism). A pair of identical beam specimens were made for each type of beam with various longitudinal bar ratios. Six types of beams comprise pairs each were experimentally tested to investigate the influence of different ratios of longitudinal reinforcement on their shear strength capacities. The variation of the longitudinal bars was set from the minimum to maximum reinforcement values.

The experimental setup as presented in Fig.11 was selected to ensure the shear failure occurred before the flexural failure at both ends of the beam. The load was increased by steps carefully and recorded until the beam reached its maximum capacity.

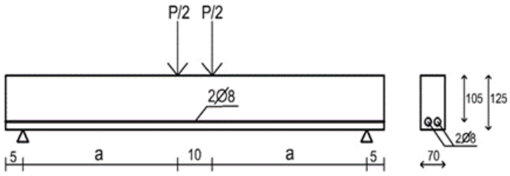


Fig.11 Beam details and experimental setup

## 7. RESULTS AND DISCUSSION

The test results of compressive loads and strengths of cylinder specimens are presented in Table 2. Fig.12 displays the representative beam A61 with a longitudinal bar diameter of 19 mm that undergoes shear failure.

**Table 2** Experimental test results of beams specimens and corresponding cylinder samples

| Beam ID | Longitudinal Bar Diameter (mm) | Cylinder 100×200 mm | | Beam 70×125×1100 mm | | Curing Time (day) |
|---|---|---|---|---|---|---|
| | | Load (kN) | f'c (MPa) | Load (kN) | Type of Failure | |
| A21 | 6 | 395.1 | 50.3 | 10.31 | Flexure | 58 |
| A22 | 6 | 516.7 | 65.79 | 10.13 | Flexure | 58 |
| A11 | 8 | 609.1 | 77.56 | 14.22 | Flexure & Shear | 58 |
| A12 | 8 | 583.3 | 74.56 | 18.55 | Flexure & Shear | 58 |
| A31 | 10 | 845.4 | 107.6 | 24.31 | Flexure & Shear | 58 |
| A32 | 10 | 867.3 | 110.4 | 25.52 | Flexure & Shear | 58 |
| A41 | 12 | 559.4 | 71.23 | 20.62 | Shear | 58 |
| A42 | 12 | 489.9 | 62.37 | 22.49 | Shear | 58 |
| A51 | 16 | 624.7 | 79.54 | 34.03 | Shear | 58 |
| A52 | 16 | 443.7 | 56.49 | 23.43 | Shear | 58 |
| A61 | 19 | 602.5 | 76.71 | 29.59 | Shear | 58 |
| A62 | 19 | 594.8 | 75.45 | 27.67 | Shear | 58 |


Fig.12 Beam A61 undergoes shear failure

The shear strength capacities of all beams specimens tested can be obtained following computational results. Table 3 and Table 4 present shear strength capacities of beam specimens and parametric data required for calculation respectively.

**Table 3** Summary of shear strength capacity of beam specimens

| Beam ID | Ø (DL) | Average f'c (MPa) | Average P (kN) | Vc (kN) | Mn (kNm) | Pm (kN) | Pv (kN) | Failure |
|---|---|---|---|---|---|---|---|---|
| A21 & A22 | 6 | 58.0 | 10.22 | 9.3329 | 2.0366 | 8.9360 | 18.4559 | Flexural |
| A11 & A12 | 8 | 75.9 | 16.39 | 10.6733 | 3.5838 | 15.8126 | 21.1367 | Flexural & Shear |
| A31 & A32 | 10 | 109.0 | 24.92 | 12.7894 | 5.5805 | 24.6869 | 25.3688 | Flexural & Shear |
| A41 & A42 | 12 | 66.8 | 22.06 | 10.0121 | 7.5761 | 33.5559 | 19.8142 | Shear |
| A51 & A52 | 16 | 68.0 | 28.73 | 10.1027 | 12.4067 | 55.0254 | 19.9955 | Shear |
| A61 & A62 | 19 | 76.1 | 28.63 | 10.6849 | 16.5818 | 73.5815 | 21.1598 | Shear |

Where P = Force from laboratory test results; $P_m$ = Theoretical force obtained from beam's bending moment diagram; $P_v$ = Theoretical force obtained from beam's shear force diagram

**Table 4** Parametric data requires for computing the values of $\frac{As}{b \times d}$ and $\frac{Vu}{\sqrt{f'c} \times b \times d}$

| Beam ID | Ø (DL) | Vu (kN) | Average f'c (MPa) | d (mm) | b (mm) | As ($mm^2$) |
|---|---|---|---|---|---|---|
| A21 & A22 | 6 | 5.2150 | 58.0450 | 105 | 70 | 56.5487 |
| A11 & A12 | 8 | 8.2975 | 75.9150 | 105 | 70 | 100.5310 |
| A31 & A32 | 10 | 12.5625 | 109.0000 | 105 | 70 | 157.0796 |
| A41 & A42 | 12 | 11.1325 | 66.8000 | 105 | 70 | 226.1947 |
| A51 & A52 | 16 | 14.4700 | 68.0150 | 105 | 70 | 402.1239 |
| A61 & A62 | 19 | 14.4200 | 76.0800 | 105 | 70 | 567.0575 |

The formula used to calculate Mn:

$$M_n = 0.85 \; f'c \times b_w \times a \times (d - 0.5a) \quad (4)$$

The values of both $\frac{As}{b \times d}$ and $\frac{Vu}{\sqrt{f'c} \times b \times d}$ obtained are then plotted in a graphical representation as can be seen in Fig.13. The computational results are also provided in Table 5.

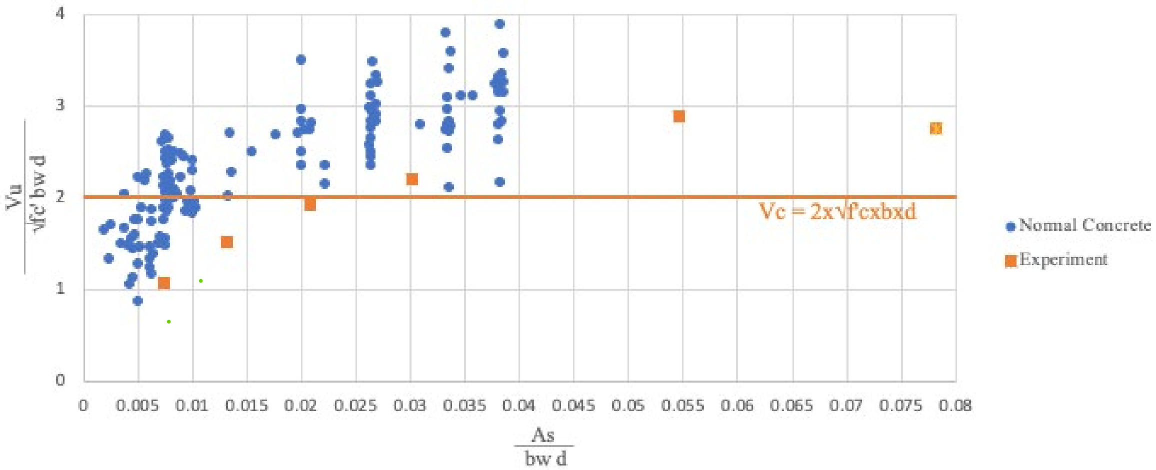


Fig.13 Effect of longitudinal reinforcement ratio, on shear capacity without stirrups

**Table 5** Correlation between Presult, f'c and ρ1

| Beam ID | $P_{result}$ (kN) | f'c (MPa) | ρ (%) |
|---|---|---|---|
| A21 & A22 | 10.22 | 58.045 | 0.77 |
| A11 & A12 | 16.385 | 75.915 | 1.37 |
| A31 & A32 | 24.915 | 109 | 2.14 |
| A41 & A42 | 22.055 | 66.8 | 3.08 |
| A51 & A52 | 28.73 | 68.015 | 5.47 |
| A61 & A62 | 28.63 | 76.08 | 7.72 |

The relation between the longitudinal steel ratio and the values of Vu/Vc are plotted graphically to illustrate the effect of longitudinal steel on the Vu/Vc as shown in Fig.13. Comparisons are also made with the Vc formula by Zsutty [34] and Cavagnis [35], also shown in Fig.14. The analysis has taken into account the variation in concrete strength. It can be concluded that the greater the reinforcement ratio, the higher the value of the Vu/Vc. It can also be seen that the trend is similar, which is Vu/Vc increases as reinforcement ratio increases when the ratio is smaller than 0.03 and almost constant when the ratio is larger than 0.03.

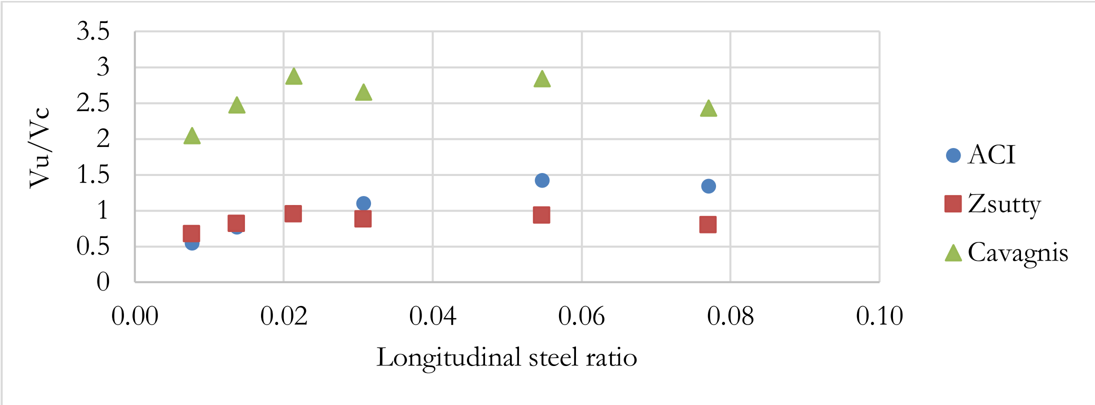


Fig.14 Relation between longitudinal steel ratio and Vu/Vc

## 8. CONCLUSIONS

Based on the study and discussion above, it can be concluded that:

1. There is a significant effect of longitudinal reinforcement ratio on the shear strength capacity ratio (Vu/Vc) of concrete beams without coarse aggregate and transverse steel. The greater the longitudinal reinforcement ratio, the higher the shear strength capacity of the concrete beam, and the increase of shear strength capacity of beam with maximum longitudinal reinforcement ratio against that with minimum longitudinal reinforcement ratio is about 82.82 percent.
2. The increase in shear strength capacity ratio (Vu/Vc) of concrete beams without coarse aggregate and transverse steel becomes insignificant as the flexure reinforcement ratio approaches the maximum value.
3. The shear strength capacity of the concrete beam does not meet the computational result according to the ACI Code formula. Therefore, transverse reinforcement is required as the longitudinal reinforcement ratio reaches its minimum value where the ratio of Vu/Vc is less than 2.
4. The formula provided by the ACI Code for calculating the shear strength capacity of concrete is applicable as the longitudinal reinforcement ratio approaches its maximum value, where the ratio of Vu/Vc is greater than 2.
5. The ratio between the ultimate shear force and the shear strength capacity (Vu/Vc) of concrete beams without coarse aggregate and transverse steel is lower than that of normal concrete.

## 9. ACKNOWLEDGMENTS

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