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# EFFECT OF AXIAL TENSION ON THE SHEAR STRENGTH OF REINFORCED CONCRETE SLABS

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**الملخص العربى :**

**تتأثر مقاومة القص للبلاطات الخرسانية المسلحة بتأثير الأحمال المحورية الواقعة عليها حيث يمكن أن تتعرض البلاطات الخرسانية في نفس الوقت لأحمال رأسية وأحمال شد أو ضغط محورية. قد تحدث هذه الظاهرة في البلاطات المحملة على الأعمدة والمعرضة لحمل أفقي نتيجة لتغير درجة الحرارة وانكماش العناصر المقيدة والزلازل وما إلى ذلك. .تم رصد عدد قليل من التجارب التي تتناول تأثير الاحمال المحورية على مقاومة القص للبلاطات الخرسانية المسلحة. وقد أجريت معظم تلك التجارب على الكمرات فقط. يدرس هذا البحث تأثير حمل الشد المحورى على مقاومة القص للبلاطات الخرسانية المسلحة بدون تسليح للقص. تشمل الاختبارات المعملية من ست بلاطات خرسانية مسلحة فى اتجاه واحد بابعاد ( 2000 مم X 500 مم X 140 مم) ببحر 1600 مم و طول الكابولى 400 مم . تمت مقارنة النتائج المعملية بالقيم الناتجة من معادلات التصميم بكل من الكود المصرى والكود الامريكى والكود الأوروبى. وقد أظهرت النتائج المعملية أن مقاومة البلاطات للقص قلت بمقدار 20 % مع وجود شد محورى بنسبة 0.75 من مقاومة الخرسانة للشد.**

**الكلمات المفتاحية : مقاومة القص, حمل محورى,بلاطات, تجارب, خرسانة متوسطة المقاومة**

## ABSTRACT:

Shear strength of Reinforced Concrete (RC) slabs may be affected by the influence of axial loads. RC slabs can be simultaneously subjected to vertical loads and in-plane axial tensile or compressive stresses. This phenomenon may take place in floor slabs supported on columns and subjected to a horizontal load because of change in temperature, shrinkage in the restrained members, earthquakes and so on. Few experiments addressing the effect of axial stress on the shear strength of reinforced concrete slabs have been reported in the literature. Most of the experiments that have been found in the literature were conducted on beams. The purpose of this research is to investigate the effect of axial tension on the shear strength of RC one-way slabs without shear reinforcement experimentally. The experimental framework consists of six slabs specimens (one-way R.C slabs with one side cantilever) with dimensions (2000 mm X 500 mm X 140 mm) with a clear span 1600 mm and a cantilever 400 mm long. Comparison between the experimental results and the design codes ACI 318-14, ECP 203-

2018, Eurocode 2 has been carried out. The experimental results declared that the applying of axial tensile stress of 0.75 of the concrete tensile strength reduces the shear capacity by 20%.

**KEYWORDS:** Shear strength, Axial load, Slabs, Experiments, and Normal strength concrete

## 1. INTRODUCTION

Before cracking, reinforced concrete withstands ‘‘pure shear” by equal compressive and tensile stresses inclined at $45^{\circ}$. After diagonal cracking, reinforced concrete resists shear by complex mechanisms including increased compressive stresses and decreased tensile stresses in the concrete and correspondingly increased tensile stresses in the reinforcement. Shear failure of reinforced concrete slabs may be affected by the influence of axial loads. RC slabs can be simultaneously subjected to vertical loads and in-plane axial tensile or compressive forces. This phenomenon takes place in slabs supported on columns and subjected to a horizontal load because of change in temperature, shrinkage in the restrained members, earthquakes and so on. This phenomenon can also be found in continuous box girder bridges, at intermediate supports, where tensile stresses arise in top slab because of bending moments and may act together with a heavy vehicle load. It is well known that the compressive axial forces improve the shear capacity, while the tensile forces reduce the shear capacity of reinforced concrete structures without shear reinforcement. Compression forces delay the cracks formation giving the structure greater shear capacity. On the other hand, the axial tension reduces the compression area accelerates the cracks formation which reduce the shear strength of the members. Until now, it is not clear how much the shear strength of RC members affected due to the presence of compression or tensile axial forces. The number of researches conducted on the shear strength of reinforced concrete members with axial load is very limited compared with those without axial load. Also, the researches investigating shear strength of reinforced concrete members under tension forces are also very limited. Few experiments addressing the effect of axial stress on the shear strength of reinforced concrete slabs have been reported in the literature. The purpose of this research is to investigate the effect of axial tension on the shear strength of RC one-way slabs without shear reinforcement. Experimental tests were conducted on the slabs in order to investigate shear strength under axial tension and the accompanied failure modes.

## 2. LITERATURE REVIEW

Elstner and Hognestad (1957) [1] studied the partial failure of a warehouse (Wilkins Air Force Base). The beams were destroyed in shear at lower shear values than expected. Their test results showed that the shear strength of the reinforced concrete sections that was used in the warehouse have been reduced to 50 % of its value due to the application of 1.4 MPa axial tension force. It was recommended that the failure was happened by the dead load combined with axial tension due to change in temperature and shrinkage that caused tensile stress which led to a reduction in the shear capacity of the beams then collapsed. Walraven [2] reported that the shear strength is hardly reduced as long as the member is well designed for axial tension forces. Jørgensen et al. (2013) [3] made an experimental program, which studied the influence of high axial tension on the shear strength of RC beams without shear reinforcement. The experimental results were used to evaluate the applicability of the Eurocode 2 (EC2) design formula in cases with large normal forces. It was observed that, for low levels of tension, the shear strength of the beams was not significantly affected for less than 40 % of the tensile yield strength. Above this level of tension, a decrease in the shear strength was generally observed for increasing axial tension. David Fernández-Montes et al. (2015) [4] carried out tests on RC T-shaped beams without transverse reinforcement subjected to transverse and axial loads until shear failure. The investigation results stated that under levels of tension exceed 25 % of the concrete tensile strength, the shear strength reduced to more than 30 % of its value. T.T. Bui et al. [5] studied the shear strength of RC slabs without shear reinforcement subjected to a concentrated load near the support. The axial tension load decreased the shear strength capacity by 30 % when the axial stress was around 0.34 $F_{ctr}$. The shear capacity tended to drop sharply when high tension was applied. Duc Toan Pham et al. (2020) [6] presented the results of testing the shear capacity of 15 beams without stirrups under the effect of axial tension that differ from each other by the level of axial force. The test results showed that the shear strength slightly decreased under increasing axial force (N), as long as the beam sections are not totally cracked.

## 3. EXPERIMENTAL WORK

### 3.1 Test Specimens

The experimental framework consists of six one-way slabs specimens with dimensions (2000 mm X 500 mm X 140 mm) with a clear span 1600 mm and a cantilever 400 mm long as shown in **Fig. 1**. All slabs are without shear reinforcement with the same dimensions. The slabs were subjected to line load at the edge of the cantilever under the effect of different levels of axial tension. The shear span ratio (a/d) was taken sufficiently large equal 2.54 for all slabs to avoid the direct transmission of the load to the supports (where a is the horizontal distance from the center of the load to the center line of the support and d is the effective depth of the slab). **Table 1** illustrates the test matrix, the slabs were with the same dimensions and reinforcement ratio. The slabs were exposed to different levels of axial stress. The longitudinal and transverse reinforcement were designed to ensure that there is no flexural failure takes place before the shear failure is reached. All slabs were reinforced with 5 Φ 8 mm diameter steel bars in the compression side and 5 Φ 16 mm diameter steel bars in the tension side in the longitudinal direction perpendicular to the supports lines ($\rho_l$ = 1.43 %). The reinforcement in the transverse direction is 5 Φ 8 /m in both upper and lower side.

### 3.2 Material Properties

The slabs were cast using normal-strength concrete ($f_{cu}$ = 33.73 MPa, $f_c$ = 27.42 MPa). The tensile strength was experimentally obtained by splitting test ($f_t$ = 3.19 MPa). High-grade locally produced steel was used as the main and secondary reinforcement. The reinforcement bars were tested according to the specifications listed in the Egyptian Standard Specifications (ESS). The results of the experimental works have been compared with the limits given in (ESS). The materials (water, aggregates, cement) used in the tests met the Egyptian Standards Specifications.

**Table 1:** The Test Matrix of The Tested Slabs

| Slab code | Axial Load (KN) | Axial Stress (MPa) | Axial Stress/ $f_{ctr}$ |
|---|---|---|---|
| S1 | 0 | 0 | 0 |
| S2 | 56 | 0.8 | 0.23 |
| S3 | 112 | 1.6 | 0.46 |
| S4 | 168 | 2.4 | 0.69 |
| S5 | 224 | 3.2 | 0.92 |
| S6 | 280 | 4 | 1.15 |

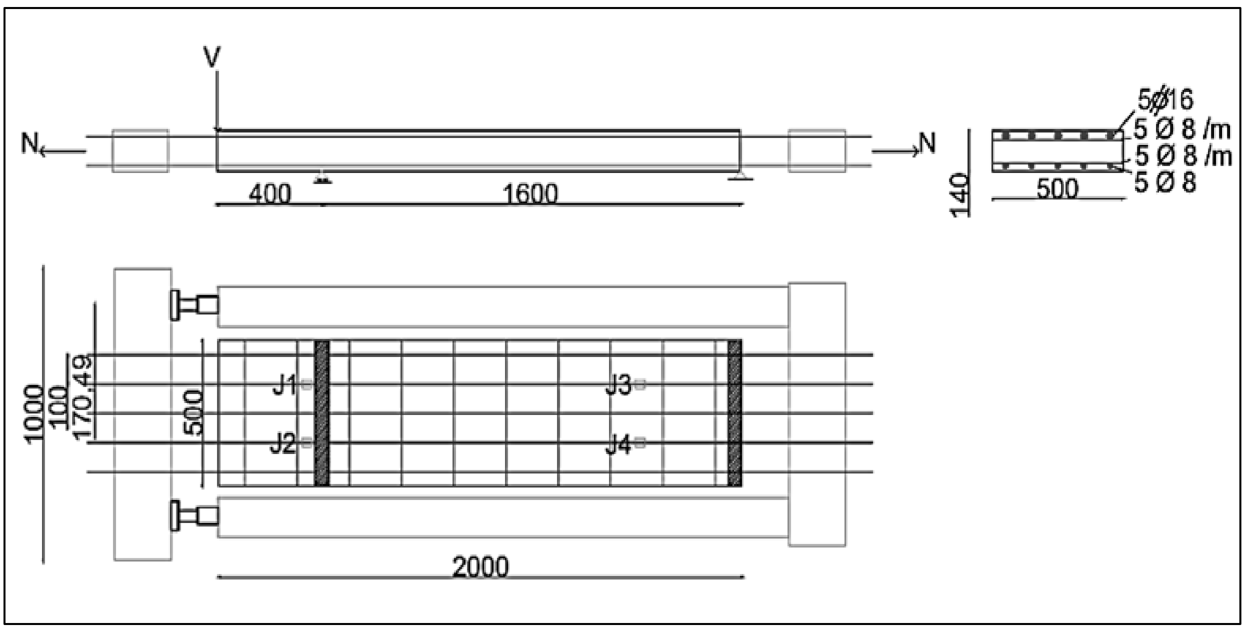


**Fig. 1**: Layout of The Specimens

### 3.3 Test Setup

The six slabs were tested as a cantilever part with a back span. The slabs were tested under a vertical line load at the edge of the cantilever by an out-of-plane hydraulic jack of 100-ton capacity through a loading plate with width 5 cm. The out-of-plane hydraulic jack was connected to a rigid steel frame and fixed to the strong reinforced concrete floor in the laboratory.

The vertical out-of-plane loading location was corresponding to a clear distance from the center line of the support equal to 30 cm. This location is corresponding to 2.54 d. where d is the effective depth of the longitudinal reinforcement. The axial tensile stress was applied by two in-plane hydraulic jacks at one side to ensure the uniform distribution of the stresses along the slabs cross-section. The axial force was transferred to the specimens using the ten reinforcement bars. The slabs were preloaded by the tensile stresses. The test setup is illustrated in **Fig. 2**. Two LVDTs were used to measure the vertical displacement of the slabs at the cantilever edge under the vertical load. During the test the force magnitude, deformation and displacement were recorded. The strain gauges were installed in the longitudinal reinforcement as illustrated in **Fig. 1** (J1, J2, J3 and J4). The gauges were in the longitudinal reinforcement near the line support in order to examine the distribution loading on the support. Two load cells of capacity 80 ton and 220 ton were installed to measure the reaction at the support as illustrated in **Fig. 2**. The slabs were tested at the ages of 28-days. The slab specimens were placed on the testing machine and adjusted so that the centerline, supports, line load and LVDTs were in their correct locations.

**Fig. 2:** The Test Setup

## 4 EXPERIMENTAL RESULTS

### 4.1 Crack Patterns and Failure Modes.

The failure crack pattern observed was similar for all the slabs specimens. Two types of cracks were observed. Firstly, flexural cracks with cracking line parallel to the support's lines (perpendicular to the specimen longitudinal axis). These cracks were well controlled by the longitudinal reinforcement. Secondly, cracks related to the final failure that was shear failure with a cracking line along the width close to the support. The failure mode of the slab specimens with axial tension forces was similar to the slab without axial force as shown in **Fig 3**.

By observing the failure mode of the slab specimens and the shear crack angle; it was found that as the axial tensile stress increases, the crack becomes steeper (the angle of inclination with the slab longitudinal axis increases). This observation confirms the effect of the axial tensile stresses on shear failure that was found in the beams tested by Adebar and Collins [8] and in the slabs tested by T.T. Bui et al. [5].

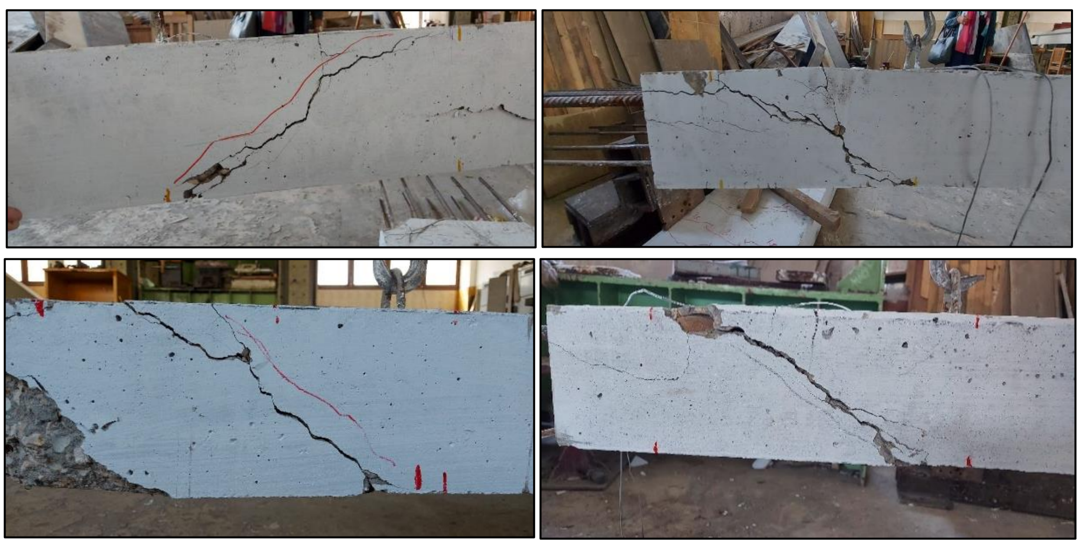

**Fig. 3:** Cracks at Failure of Slabs S1, S2, S5 & S6 respectively

### 4.2 Specimens Behavior

The results of the experimental investigation are listed in **Table 2**. As expected, the axial tensile stress reduced the shear capacity of the slab's specimens. $V_{exp}$ is the ultimate shear force. The influence of the axial tension on the shear strength tends to be a non-linear curve as shown in **Fig 4**. The shear strength dropped when a high tensile stress was applied. The effect of axial tension appears in:

- Decreasing the ultimate shear capacity by 20% when applying axial tensile stress about 0.7 $F_t$ (Concrete tensile strength).
- By applying high levels of axial tensile stresses about 1.25 $F_t$, the shear capacity drops to 50 % of its original capacity.
- From the force- displacement response curve shown in **Fig 5,** it is found that, after the peak load occurred, larger ductility was observed for specimens with axial tensions than the specimen without axial forces (it should be noted that displacement measured under the loading plate).
- The more the axial tension was applied, the more the stiffness was reduced (even in elastic phase).
- The displacement increases with a significant reduction in the applied force after the peak load.
- By noticing the number of flexural cracks (cracks perpendicular to the slab longitudinal axis) on the cantilever face of the slab specimens, it is found that as the level of axial tension increases the number of the generated flexural cracks due to the vertical load increases.
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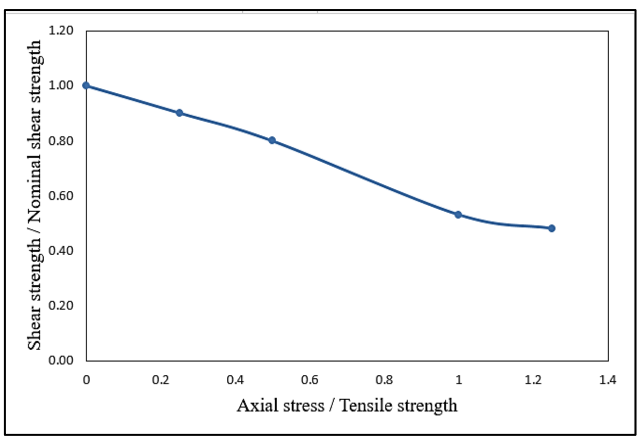


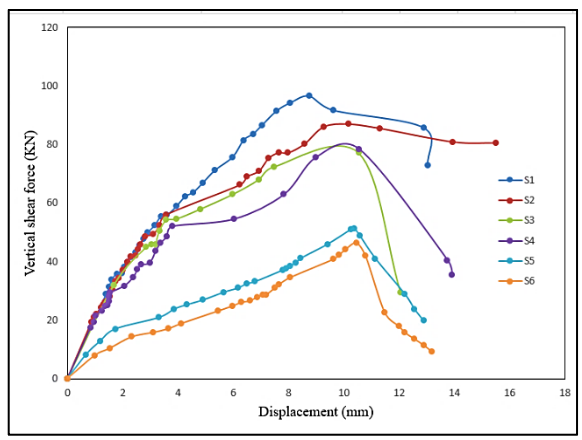


**Fig. 4:** The Effect of Axial Tension on The Shear Strength

**Fig. 5:** Load- Deflection Curve.

**Table 2:** Results of The Experimental Investigation

| Slab code | Axial Load (KN) | Axial Stress (MPa) | ($\sigma_{axial}$/ $f_t$) | $V_{exp}$ (KN) | Shear reduction (%) | $V_{exp}$/bd (MPa) |
|---|---|---|---|---|---|---|
| S1 | 0 | 0 | 0.00 | 96.45 | 0 | 1.63 |
| S2 | 56 | 0.8 | 0.25 | 86.91 | 9.89 | 1.47 |
| S3 | 112 | 1.6 | 0.50 | 77.05 | 20.11 | 1.31 |
| S4 | 168 | 2.4 | 0.75 | 78.37 | 18.75 | 1.33 |
| S5 | 224 | 3.2 | 1.00 | 51.13 | 46.99 | 0.87 |
| S6 | 280 | 4 | 1.25 | 46.36 | 51.93 | 0.79 |

# 5 COMPARISON BETWEEN THE SHEAR STRENGTH PREDICTED FROM THE DESIGN CODES AND THE EXPERIMENTAL RESULTS

The results of the experimental investigation were compared to the predicted shear strength based on the Eurocode 2 [9], ACI 318-14 [10] and the Egyptian code ECP 203-2018 [11].

## 5.1 According to the ACI 318-14:

ACI introduces different sets of equations according to the type of loading and different kinds of members. Formula for designing pre-stressed members differs from non-prestressed members. It depends also on the axial load applied. In section, 22.5.7 ACI introduces formula for the shear resistance ($Vc$) for non-prestressed members under axial load:

$$Vc = 0.17\left(1 + \frac{Nu}{3.5\ Ag}\right)\sqrt{fck}\ .bw.d \qquad (1)$$

For comparison, due to slabs tests, the web width ($b_w$) was taken as the slab width (b), the mean value of the material properties measured are used and all partial safety factors are equal to 1.

## 5.2 Eurocode 1992-1-1:2005 [9]

Section 6.2.2 explains the effect of axial stresses on shear strength by including the term ($K1.\sigma cp$) where $\sigma cp$ = $N_u/A_g$ (MPa), the shear strength for a structural element without shear reinforcement that is affected by axial forces can be calculated as:

$$VRd. = Max\begin{cases}\{CRd,c.K.\sqrt[3]{100}.\rho l.fck + K1.\sigma cp\}.bw.d = VRd,c1\\ \{Vmin + k1.\sigma cp\}.bw.d = Vrd,c2\end{cases} \qquad (2)$$

k = $1 + \sqrt{200/d}$

$C_{Rd,c}$: empirical factor for shear capacity , equal to $0.18/\gamma_c$
$\rho_l$: longitudinal tensile reinforcement ratio $\rho_l = A_{sl}/b_w.d$
$b_w$ : width of the cross-section in the tensile area (mm)
d: effective depth of the cross section ( mm)
$f_{ck}$ : compressive strength ( MPa), $f_{ck} \leq 90$ MPa $A_{sl}$: longitudinal reinforcement ($mm^2$)

### 5.3 According to the Egyptian code ECP 203-2018

There is not a certain section in the ECP (203-2018) [11] for the design limitations of the shear strength of RC slabs with axial stresses, The only design limitation for sections with axial tension load in the ECP (203-2018) [11] is for reinforced concrete beams which is in section (4-2-2-1-3). In case of tensile stresses, it neglects the concrete shear strength (zero) or to be more accurate the ECP (203-2018) decreased the shear strength by ($\delta_t$).

$$\delta t = 1 - 0.3(\frac{Pu}{Ac}) \quad (3)$$

Where: $P_u$ is the axial force, $A_c$ is the concrete cross-section area.
In order to obtain the results values from the previous design codes:

- The tensile axial stress was calculated for the gross area of the concrete section.
- There is no upper limit for the axial tensile stresses, so negative results from the formulas were considered as zero values, the section is regarded as having collapsed and its shear strength is therefore zero.

The comparison between the experimental results and the shear design code is shown in **Table 3**. The average (AVG) and standard deviation (STD) of the comparison between the test data and the calculation methods are also shown in the table. The table reveals that the experiments shear strength results seem to be more compatible with the Eurocode 2. The average value & standard deviation of the mean are 1.1 & 0.05 respectively. Both ACI & ECP have underestimated values for shear strength, which means that such codes give conservative values in case of shear strength prediction of slabs under axial load. The same trend was noticed from previous researches T.T. BUI results [5] which were compatible with Euro code with average values and standard deviation for EC 0.89 & 0.11.

The higher values of the average value & standard deviation for current research than BUI research is due to the application of higher levels of axial tensile stresses. Axial tensile stress for specimens S5 & S6 was 3.2 MPa & 4 MPa respectively which corresponding to $F_{ctr}$ & 1.25 $F_{ctr.}$ Design codes neglect the ability of the concrete to resist shear loads when the axial tensile stress exceeds the concrete tensile strength. The experimental results clarified that the slabs specimens S5 & S6 resisted shear load by a significant value.

The relatively variation between the experimental results and the codes predicted values is a result of the relatively high ratio of longitudinal reinforcement used in current research [2]. According to Walraven [2], the shear strength is hardly reduced if the member is well designed for axial tension forces.

**Table 3:** Shear Force Calculated with Predictions of the EC, ACI and ECP for all slabs specimens.

| Slab code | Axial Stress (MPa) | $V_{exp}$ (KN) | $V_{exp}/V_{EC}$ | $V_{exp}/V_{ACI}$ | $V_{exp}/V_{ECP}$ |
|---|---|---|---|---|---|
| S1 | 0 | 96.45 | 1.16 | 1.84 | 1.76 |
| S2 | 0.8 | 86.91 | 1.14 | 2.15 | 2.09 |
| S3 | 1.6 | 77.05 | 1.12 | 2.70 | 2.70 |
| S4 | 2.4 | 78.37 | 1.27 | 4.75 | 5.11 |
| S5 | 3.2 | 51.13 | 0.93 | 11.36 | 23.32 |
| S6 | 4 | 46.36 | 0.97 | 0.00 | 0.00 |
| AVG | | | 1.10 | 3.80 | 5.83 |
| STD of mean | | | 0.05 | 1.64 | 3.56 |

The results obtained from **Table 4** shows the calculations results from this research combined with the slabs results by T.T BUI and the results of 92 beams that have been tested with axial tension in the literature. **Table 4** shows the results of these beams with the three design codes mentioned before. In this table, $V_{exp}$ is the maximum shear load determined in the experimental tests.

**Fig 6** shows the comparison of the test results with the values from the design codes (EC 2, ACI and ECP). The shear capacity obtained from ACI 318-14 is conservative for most of the experiments in literature. For slab members affected by axial tension, ACI & ECP give very underestimating values for the shear capacity. It should be noted that the ACI 318-14 & ECP codes don't take into account the effect of the longitudinal reinforcement on the shear capacity of the slab members. Euro code gives more converging values for the shear capacity of RC slabs. Euro code gives unconservative values for beams and some slabs with high axial tension.

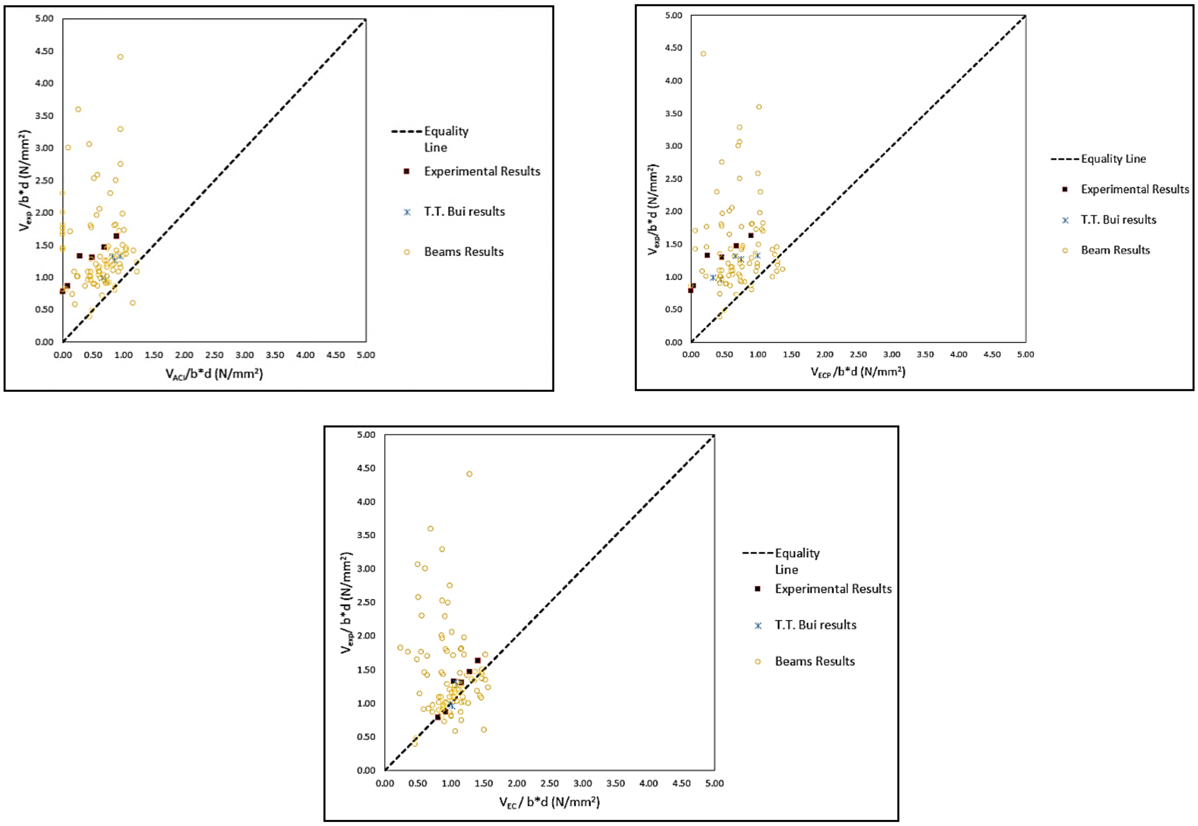


**Fig. 6:** Comparison of test results with ACI 318-14, ECP (203-2018) and EC2.

## 6. SUMMARY AND CONCLUSIONS

This research contributes a database of experimental results of six slabs specimens that were tested to determine the one-way shear strength under the effect of different levels of axial tension. The experimental results are compared with those calculated from three codes methods: EC2, ACI 318-14 and ECP (203-2018). A review of previous experimental studies is also presented and calculated with the three design codes. The following conclusions can be obtained from the results:

1) The axial tensile stress reduced the shear strength of reinforced concrete slabs. As the axial tension increases, the stiffness of the force-displacement response decreases.
2) The axial tension reduces the initial cracking force. The application of tensile stress of 75% of the concrete tensile strength reduces the shear capacity by 20%, while the application of tensile stress of 1.25 $_{Fctr}$ reduces the shear capacity by 50%.
3) Specimens with high axial tension values were found to have a significant shear resistance against shear load, Due to the relatively high longitudinal reinforcement ratio ($\rho_l$ =1.43 %).
4) It was found that as the axial tension increase, the angle of the shear crack becomes steeper (the angle with the slab's longitudinal axis increase).

5) The ACI (318-14) and ECP (203-2018) give conservative values for the shear strength of RC slabs under axial tension. These codes shear equations under axial tension don't take into account the longitudinal reinforcement ratio which has a significant effect on the ultimate load.
6) The EC2 is more compatible with the test results despite it gives overestimated values for slabs with high level of axial tension and some beams.
7) The codes expressions for combined shear and tension members need more revision to provide more accurate prediction.

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## REFERENCES :

1. R.C. Elstner, E. Hognestad, 1957, Laboratory investigation of rigid frame failure, J.Proc.53 (1) , 637–668.
2. Walraven J.C. Background document for EC-2. Chapter 6.2 Shear. Delft University of Dent Technology, 2002
3. Jørgensen, H. B., Hoang, L. C., Fabrin, L. S., & Malgaard, J. (2013). Influence of High Axial Tension on the Shear Strength of non-shear RC Beams. In Proceedings of the International IABSE conference: Assessment, Upgrading, Refurbishment of Infrastructures.
4. D. Fernández-Montes/E. G. Valle/E. Díaz Heredia • Influence of axial tension on the shear strength of floor joists without transverse reinforcement
5. T.T. Bui a,⇑, W.S.A. Nana a, S. Abouri b, A. Limam c, B. Tedoldi b, T. Roure
6. Pham DT, Fouré B, Pinoteau N, Abouri S, Mège R. Influence of axial tension on the shear strength of RC beams without stirrups. Structural Concrete. 2020;1–17.
7. G.N.J. Kani, The riddle of shear failure and its solution, J. Proc. 61 (4) (1964)441–468British Standard Institution. (2009). BS EN 12390-3: Testing hardened concrete Part 3: Compressive strength of test specimens, , UK. In British Standard (Issue August, pp. 1–16).
8. P. Adebar, M.P. Collins, Shear strength of members without transverse reinforcement, Can. J. Civ. Eng. 23 (1) (1996) 30–41
9. CEN, Eurocode 2: Design of Concrete Structures - Part 1-1: General Rules and Rules for Buildings EN 1992-1-1:2005, Comité Européen de Normalisation, Brussels, Belgium, 2005, p. 229.

10. ACI Committee 318, Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary, American Concrete Institute, 2014, p. 520.
11. ECP 203, (2018), "The Egyptian Building Code for Design and Construction of Reinforced Concrete Structures", Ministry of Housing.
12. A.H. Mattock, Diagonal tension cracking in concrete beams with axial forces, J. Struct. Div. ASCE 95 (ST 9) (1969) 1887–1990.
13. M.J. Haddadin, S.T. Hong, A.H. Mattock, Stirrup effectiveness in reinforced concrete beams with axial force, J. Struct. Div. (1971).
14. P.E. Regan, Beams Subjected to Axial Loads, Imperial College, London, 1971, pp.93–118.
15. M. Yamada, O. Kiyomiya, Shear Capacity of Reinforced Concrete Beams With Initial Cracks, Transactions of the Japan Concrete Institute, 1995, p. 17.
16. T. Tamura et al., A study of proposed design equation for the shear strength of R/C beams subjected to axial tension, Doboku Gakkai Ronbunshu 1995 (520) (1995) 225–234.

## Nomenclature

$f_{ctr}$ concrete tensile strength calculated from ECP at the age of testing the concrete

$f_t$ measured concrete tensile strength from splitting test at the age of testing the conceret.

$f_{cu}$ measured concrete compressive strength at the age of testing the concrete

$f_c$ measured cylinder compressive strength at the age of testing the concrete

$\sigma cp$ the average normal concrete stress over the cross section.

$V_{exp}$ the experimental shear load at failure

$\sigma_{axial}$ the axial stress over the cross section

b the slab width

d the slab effective depth

$V_{ACI}$ maximum shear load calculated according to ACI 318-14

$V_{ECP}$ maximum shear load calculated according to ECP (203-2018)

$V_{EC2}$ maximum shear load calculated according to Eurocode 2.