Future Engineering Journal

Volume 2 | Issue 1 Article 5

January 2021

Exploring the Effect of In-plane Tensile Forces on the Two-way Shear Strength: review, comparative study and future works

Ahmed F. Deifalla
Future University In egypt, ahmed.deifalla@fue.edu.eg

eslam mousa
eslam.mousa@yahoo.com

dina yehia
dina.yehya@fue.edu.eg

amr abdelrahman
amr@aace-eg.com

FUTURE ENGINEERING JOURNAL 2 (2021) 2314-7237

HOSTED BY
ELSEVIER

Future Engineering Journal

Journal homepage: https://digitalcommons.aaru.edu.jo/fej/

Exploring the Effect of In-plane Tensile Forces on the Two-way Shear Strength: review, comparative study, and future works

***A. Deifalla*[a,*], *D. Zakaria*[b], *Eslam Mousa*[c], *Amr Abdelrahman*[d]**

a Associate Professor, Department of Structural Engineering and Construction Management, Future University in Egypt, New Cairo City.
b PhD candadiates, Department of Structural Engineering, Faculty of Engineering, Ain Shams University, Cairo, Egypt.
c Assistant Professor, National Research and Housing Institute, Cairo, Egypt.
d Professor of Concrete Structures, Chairman of Structural Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

A R T I C L E I N F O

Article history:
Received **October 2020**
Accepted **January 2021**

Keywords:
Two-way shear
Axial tension
Biaxial tension
Design codes

A B S T R A C T

Two-way shear failure of slabs is a sudden one, which has catastrophic outcome. Slabs with large dimensions, may be subjected to in plane tensile forces due to restraint or earthquake loading. There is a lack of agreement between various design codes regarding the significance of in-plane tensile forces on the two-way shear strength. The purpose of this study is to explore, propose a simplified two-way shear strength model, which include the effect of in-plane tensile forces on the strength. A review for the experimental investigations, existing models, design codes for two-way shear of slabs is presented, with emphasis on in-plane tensile forces. The loading method used in the current experimental testing are misleading, where the two-way shear and the in-plane forces are independent. A comparative study was conducted between existing formula and design codes for this case. The comparison between different codes with the experimental results show that the new proposed Eurocode design code was found to be the most accurate one. However, it did not include the effect of the in-plane tensile forces in a physically sound manner. In addition, more full testing of concrete slabs under combined two-way shear and tensile forces are required to refine this existing two-way shear design code provisions or develop new formulas or mechanical model.

1. Introduction

Two-way shear failure in reinforced concrete (RC) without shear reinforcement is brittle and should be carefully considered. Two-way shear failure while subjected to in-plane tension occurs in walls of nuclear containment vessels or slabs of large restrained dimensions due to thermal loading (Jau et al. 1982).

**Corresponding author, diffalaf@mcmaster.ca; ahmed.deifalla@fue.edu.eg.*

Nomenclature

v_c the nominal two-way shear strength in MPa, calculated as the ratio between the punching shear failure load and the $b_o d$.
v_{cE} the nominal applied two-way shear strength in MPa, calculated as the ratio between the applied punching shear load and the $b_o d$.
λ_s the size effect factor, which is calculated differently for each design code.
α_s factor for unbalanced moment, which varies depending on the design code used.
β_c aspect ratio between loaded area dimensions.
$\beta =$. 1.15, 1.4 and 1,5 for inner, edge, corner column, respectively.
ρ_l flexure reinforcement ratio taken as $\sqrt{\rho_{ly}\rho_{lz}} \leq 0.02$
ψ the slab rotation.
A the larger dimension of the tested slab.
A_{vmin}. the minimum shear reinforcements taken as $\frac{b_w s}{f_{yt}}\begin{cases}0.062\sqrt{f_c'}\\ 0.35\end{cases}$
B the smaller dimension of the tested slab.
D_{max} maximum nominal aggregate size, taken as zero for lightweight concrete.
E_s young's modulus of Flexure reinforcements.
a the larger dimension of the loading area.
b the smaller dimension of the loading area.
b_o the control perimeter taken at distance d/2 from the edge of the loaded area.
b_1 total length of that portion of perimeter b_o for which Vc_1 is computed.
b_2 total length of that portion of perimeter b_o for which Vc_2 is computed.
b_w the width of element.
d the effective depth of the slab.
d_{dg} the aggregate factor.
e the eccentricity of the applied load, taken as the unbalanced moment to the shear ratio.
f_{ct} the concrete tensile strength.
f_c' the concrete compressive strength.
f_y the tensile yield stress of reinforcements.
f_s the applied tensile stress in reinforcements due to in-plane tension loads.
k_b failure criteria, which varies depending on the design code used.
m_{Ed} the unbalanced moment on the slab.
m_{Rd} $the\ r$esisting slab flexure strength.
r_s distance between the centerline of loading area and the inflection point.
s spacing between shear reinforcements.
μ factor for eccentric loading taken as 8, 5, and 3 for inner, edge, corner column, respectively.

One of the extreme loading conditions imposed on nuclear containment vessels is the simultaneous internal pressurization of the vessel and the application of in-plane tensile forces, which may be caused by missile impacts, pipe momentum, and jets of fluid or steam, on the wall. They produce two-way shearing stresses combined by biaxial tension. Most design codes include the effect of axial tension on one-way shear strength, however, that effect on the two-way shear is rarely considered. For the last five decades, extensive research has been done on two-way shear strength of reinforced concrete slabs with compression loading, only a few of experimental studies have included tensile loading. Design codes and mechanical models focused on compression loading, which is common in the case of prestressed slabs. On the other hand, it kept a blind eye on tensile loading. Several mechanical models exist for two-way shear of slabs with and without reinforcements, however, none of them deals with tensile forces (Kueres et al., 2019). The most commonly implemented is the critical shear crack theory (CSCT) model (Muttoni, 2008; Muttoni et al., 2018). In recent design codes, significant development in the shear design provisions of both the American and European design codes, The ACI-318-19 (2019) proposed modifications for the two-way shear design of slabs, in order to include the size effect. in April 2018, a third and final draft of the next generation of Eurocode 2 (prEC2) was developed (2018), which was based on a the CSCT developed by Muttoni (2008). Both the American and European design codes lack the agreement for the case of combined two-way shear and in-plane loading, where the ACI-318 did not include the effect of in-plane tension in the two-way shear design, while the Eurocode included that effect. A detailed review of the few studies available in the literature showed that design codes and researchers have been inconsistent when it comes to the effect of membrane tensile stresses on the two-way shear strength of RC. Most of the previous studies (Abrams, 1979; Johnson and Arnouti, 1980;

*Corresponding author, diffalaf@mcmaster.ca; ahmed.deifalla@fue.edu.eg.
Peer review under responsibility of Faculty of Engineering and Technology, Future University in Egypt.

https://digitalcommons.aaru.edu.jo/fej/

Jau et al., 1982; Ramos et al., 2011; Hoang, 2011). The effect of in plane tensile forces on the two-way shear resistance is contradictory. Some design codes include it and others do not. Even those design codes that include it based on extensive databases of two-way shear testing of prestressed concrete slabs.Thus, the present study investigates the two-way shear behavior of RC, while subjected to in-plane tension. The existing experimental testing conducted were gathered, compiled and analyzed. In addition, the current formulas for combined tension and two-way shear and selected design codes for RC were compared. Moreover, identify the need for and direction of future work in this area.

2. Literature review

In a study by Abrams (1979), 26 two-way shear tests were conducted on 150 mm thickness slab. Slabs were independently pre-cracked using biaxial tension forces before concentrically loaded in order to investigate the effect of biaxial tensile forces on the two-way shear strength. Based on the results of the experimental study, a proposed formula was presented. In addition, a bilinear relationship between two-way shear load and the vertical deflection was observed. Moreover, a reduction in the stiffness due to the increase in the biaxial tension was found. Last but not least, the two-way shear failure surface did not coincide with that of the biaxial tensile pre-cracking. In a study by Johnson and Arnouti (1980), RC slabs, 100 mm thickness were tested under combined two-way shear and different levels of biaxial tension 0.43fy and 0.86fy. The measured failure two-way shear strength of the tested slabs showed little reduction due to biaxial tension, thus no formula was proposed. The investigation by Jau et al. (1982) tested seven specimens, 1200 X 1200 mm by 150 mm thick. They investigated the effect of the shear span, size of loaded area, and reinforcing steel ratio on the two-way shear strength. The biaxial tension forces were applied at two levels (0 or 0.8fy), independently from the two-way shear load application. The following was observed: 1) two-way shear strength increases as the shear span to depth ratio is increased from 1 to 3; 2) two-way shear strength decreases with larger loading area; 3) increasing the flexure reinforcements, increases the two-way shear strength, and 4) the effect of biaxial tension on the two-way shear strength depends on the level of tension, while being more significant at a level of a least 0.8fy.
A study by Ramos et al. (2011), the experimental testing of thirteen reduced scaled RC slabs under two-way shear, subject to in-plane forces was conducted. The effect of the in-plane forces on the two-way shear resistance was investigated. It was found that the existing design codes predict the two-way shear resistances with in-plane tension well. However, the strengths predicted using ACI318 are underestimated. On the other hand, the EC2 can be non-conservative in some cases. A study by Hoang (2011) investigates the effect of tensile cracking on the two-way shear behavior of RC slabs. For this purpose, two-way shear tests have been conducted for 1050 mm X 1050 mm by 150 mm thick slabs. The initial crack patterns were created by mechanical tension, uniaxial as well as biaxial. The slabs were pre-cracked with crack thickness from 0.20 mm to 0.55 mm. Two-way shear testing was conducted independently from the axial loads, which were removed. The results indicate that diminishing the concrete tensile strength in the cross-sectional directions does not have any impact on the two-way shear strength of reinforced concrete slabs. In conclusion, different researchers are in disagreement regarding the significance of the effect of in-plane tension forces on the two-way shear behavior. Many investigations have found it insignificant (Hoang, 2011; Ramos et al., 2011), where others found it significant and developed formulas for quantifying that effect (Jau et al., 1982; Abrams, 1979). That inconsistency can be attributed to the method used in applying and the level of the tension forces, where many researchers have simply cracked the slab before loading it to fail in two-way shear. Where the two-way shear cracks are different than those of the tension forces, leading to misleading conclusions, regarding the significance of that parameter. In addition, the level of tension forces to the tensile yield value ranged between 20% to 80%.

2.1. Experimental Database Profile

Table (1) shows the 34 concrete elements tested under combined two-way shear and in-plane tension forces (Abrams, 1979; Johnson and Arnouti, 1980; Jau et al., 1982; Ramos et al., 2011; Hoang, 2011). A detailed review indicated that the testing method and the geometry have significant effect on the findings of each study. Specimen dimensions varied between 950 mm to 4000 mm. The dimension of the loading area varied between 60 mm to 600 mm. The depth varied between 65 mm to 267 mm. The longitudinal reinforcements ratio varied between 0.52% to 3.14%. The concrete strength varied between 24 MPa to 49 MPa. The level of tension forces with respect to the yield forces of flexure reinforcement is between 20% to 80%.

2.2. Selected formula and design codes for combined two-way shear and in-plane tension

A handful of models, which consider the effect of in-plane tensile forces on the two-way shear, were found in the literature. Internationally recognized design codes were selected. The model by Jau et al. (1982) as well as the design codes including ACI-349 (2006), ACI-318 (2019), EC2 (2004), MC (2010), and prEC2 (2018) were selected. Figure 2(a-h) show scattered point for the measured strength on the vertical axis versus calculated strength on the horizontal axis, while two dotted lines, the first is the exact match line and the second is the best fit line for the data. The closer the best fit line to the exact match shows the better data scattering and model performance.

- Jau et al. (1982)

The analysis of experimental testing of seven slabs under combined two-way shear and in-plane tension, updated the formula by Abrams (1979). Thus, they proposed the two-way shear strength calculated (J-formula), such that:

$$\mathbf{V} = \boldsymbol{b_o d} \begin{cases} \left(0.33 - \frac{f_s}{12 f_y}\right)(43\rho_l)^{0.25}\sqrt{f_c'} & \rho \leq 0.023 \\ \left(0.33 - \frac{f_s}{12 f_y}\right)\sqrt{f_c'} & \rho > 0.023 \end{cases} \quad (1)$$

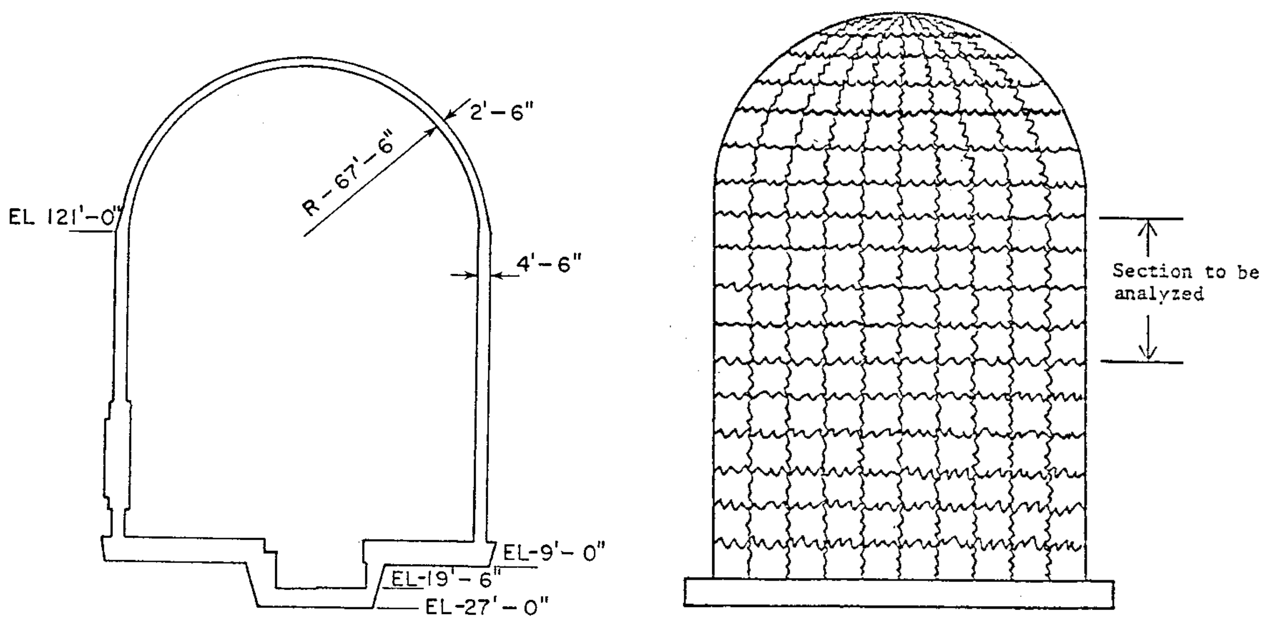
From figure 2h, it is clear that Jau formula is inaccurate, however conservative.

- EC2 (2004)

According to EC2, the two-way shear strength is calculated, such that:

$$\mathbf{V} = \boldsymbol{b_o d}\frac{1}{\beta}\left[0.18k(100\rho_l f_c')^{1/3} - 0.1\rho_l f_s\right] \geq \frac{1}{\beta}\left(0.028k^{\frac{3}{2}}\sqrt{f_c'} - 0.1\rho_l f_s\right) \quad (2)$$

Where $k = \left(1 + \sqrt{\frac{200}{d}}\right) \leq 2.0$, from Figure 2a, it is clear that EC2 is inaccurate, however conservative.



a) b)

Fig.1. Nuclear contaminant vessel, a) schematic, and b) cracking pattern (Jau et al. 1982).

Table 1. Profile of experimental database

Reference	n	A (mm)	B (mm)	a (mm)	b (mm)	d (mm)	ρ_l (%)	f_c' (MPa)	f_{s1}/f_y	f_{s2}/f_y
Abrams (1979)	22	1220	1220	100	100	117	0.52-3.17	22-31	0.2-0.8	0.2-0.8
Johnson and Arnaouti (1980)	2	1200	950	60	60	65	0.9	28	0.43	0.43
Jau et al. (1982)	3	1220	1220	100-200	100-200	117-122	0.76-3.14	24	0.8	0.8
Ramos et al. (2011)	3	1500	1500	100	100	100	1.28	41-44	0.30	0
Hoang (2011)	4	1200	1200	150	150	125	1.18	49	0.24-0.53	0-0.53

- ACI-349 (2006)

The two-way shear strength of concrete slabs of the ACI-349 design code is such that:

$$\mathbf{V} = \boldsymbol{V_1} + \boldsymbol{V_2} \quad (3)$$

$$\mathbf{V_1} = \boldsymbol{b_o d}\begin{cases} 0.\mathbf{083}\left(\mathbf{2} + \frac{\mathbf{4}}{\boldsymbol{\beta_c}}\right)\sqrt{f_c'}\frac{b_1'}{b_o}\left(\mathbf{1} - \frac{f_{s1}}{4f_y}\right) & \frac{f_{s1}}{f_y} \leq \mathbf{0.9} \\ 0.\mathbf{41}\sqrt{f_c'}\frac{b_1'}{b_o} & \frac{f_{s1}}{f_y} > \mathbf{0.9} \end{cases} \quad (4)$$

$$\mathbf{V_2} = \boldsymbol{b_o d}\begin{cases} 0.\mathbf{083}\left(\mathbf{2} + \frac{\mathbf{4}}{\boldsymbol{\beta_c}}\right)\sqrt{f_c'}\frac{b_2'}{b_o}\boldsymbol{h}\left(\mathbf{1} - \frac{f_{s2}}{4f_y}\right) & \frac{f_{s2}}{f_y} \leq \mathbf{0.9} \\ 0.\mathbf{41}\sqrt{f_c'}\frac{b_2'}{b_o}\boldsymbol{h} & \frac{f_{s2}}{f_y} > \mathbf{0.9} \end{cases} \quad (5)$$

From Figure 2b, it is clear that ACI-349 is consistent, however overly conservative.

- MC (2010)

The MC (2010) is based on a mechanical model, namely, the critical shear crack theory model (CSCT). The design provisions have two levels of approximation Level I, II and III for flat slabs without redistribution of internal forces, with significant redistribution of internal forces and with irregular slabs or for flat slabs, respectively.

$$\mathbf{V} = k_b\sqrt{f_c'}\boldsymbol{b_o d} \quad (6)$$

Where $k_b = \frac{1}{1.5+0.9\left(\frac{32}{d_{dg}}\right)\psi d} \leq 0.6$ and $d_{dg} = 16 + D_{max} \leq 42.67$, while $\psi = 1.5\frac{r_s}{d}\frac{f_y}{E_s}$, $1.5\frac{r_s}{d}\frac{f_y}{E_s}\left(\frac{m_{Ed}}{m_{Rd}}\right)^{1.5}$ and $1.2\frac{r_s}{d}\frac{f_y}{E_s}\left(\frac{m_{Ed}}{m_{Rd}}\right)^{1.5}$ for Level I, II and III approximation, respectively. Both m_{Ed} *and* m_{Rd} are the applied moment and resisting moment, respectively. Since most of the tested slabs are regular slabs with aspect ratio around one, thus, the MC (I) is the most appropriate one. However, all three levels were used to calculate the strength. Form Figures 2(c-e), it is clear that MC (III) is more accurate that MC (II), which is more accurate than MC (I), however all of them are inconsistent with data widely scattered.

- ACI-318 (2019)

The new ACI-318 design for two-way shear without shear reinforcements is, such that:

$$\mathbf{V} = \textbf{smallest of} \begin{cases} \mathbf{0.33}\boldsymbol{\lambda_s b_o d}\sqrt{\boldsymbol{f_c'}} \\ \mathbf{0.17}\left(\mathbf{1}+\frac{2}{\beta_c}\right)\boldsymbol{b_o d \lambda_s}\sqrt{\boldsymbol{f_c'}} \\ \mathbf{0.083}\left(\mathbf{2}+\frac{\alpha_s d}{b_o}\right)\boldsymbol{b_o d \lambda_s}\sqrt{\boldsymbol{f_c'}} \end{cases} \quad (7)$$

The 2019 code has implemented a new factor $\lambda_s = \sqrt{\frac{2}{1+0.004d}} \leq 1$, Which is limited to cases without shear reinforcement. $\lambda_s$is based on the principles of linear fracture mechanics and calibrated using test results (Hawkins and Ospina 2017; Dönmez and Bazant, 2017). From Figure 2f, it is clear that ACI-318 is inaccurate, however conservative.

- prEC2 (2018)

In this section, the two-way shear design provisions for flat slabs according to the third draft of the next generation of Eurocode 2 (2018) are shortly summarized focusing on the determination of concrete slab shear resistance. Over the last years, a new design concept for two-way shear based on MC2010 has been adapted for the next generation of prEC2 (2018). Closed-form design expressions were derived from the combination of simplified load-rotation relationships and a slightly modified failure criterion of the CSCT (Muttoni, 2008; Muttoni et al., 2018). The two-way shear resistance using prEC2 (2018), respectively, is such that:

$$\mathbf{V} = \frac{1}{\beta}\left[k_b\boldsymbol{b_o d}\left(100\rho_l\boldsymbol{f_c'}\frac{d_{dg}}{a_v}\right)^{1/3}\right] \leq \frac{1}{\beta}\left(0.6\boldsymbol{b_o d}\sqrt{\boldsymbol{f_c'}}\right) \quad (8)$$

Where $d_{dg} = 16 + D_{lower} \leq 40$, k_b failure criteria taken as $\sqrt{8\mu\frac{d}{b_o}} \geq 1$, from Figure 2g, it is clear that prEC2 is accurate, yet, reasonably conservative. it is clear that ACI-318 is inaccurate, however conservative.

3. Comparison between selected formula and current design codes

The strength was calculated using the selected formula and various design codes, then the ratio between the measured and calculated strength (Safety ratio) was calculated. Table 2 shows the statistical measures for the safety ratio using the various methods. From Figures 2(a-h) and Table 2, it is clear that prEC2 is the most accurate and consistent with significant improvement over the EC2. In addition, although the ACI-349 and Jau include the effect of the in-plane tensile forces, however, the ACI-318 is more accurate, yet the ACI-349 is still consistent.

Table 2. Statistical measures for the ratio between measured strength and calculated

Statistical measure	Jau	EC2	ACI-349	MC 2010			ACI-318	prEC2
				I	II	III		
Average	1.88	1.42	3.20	1.80	1.15	1.12	1.64	1.03
Standard deviation	0.70	0.49	0.83	0.48	0.56	0.49	0.45	0.28
Coefficient of variation	37%	34%	26%	27%	48%	44%	27%	27%
Maximum	4.65	2.98	6.33	3.31	3.31	3.02	3.29	2.07
Minimum	1.34	0.95	2.50	1.24	0.78	0.76	1.20	0.76
Median	1.70	1.19	2.99	1.70	1.04	1.04	1.52	0.95
95% C.L.	1.76	1.25	3.06	1.71	1.06	1.04	1.56	0.98

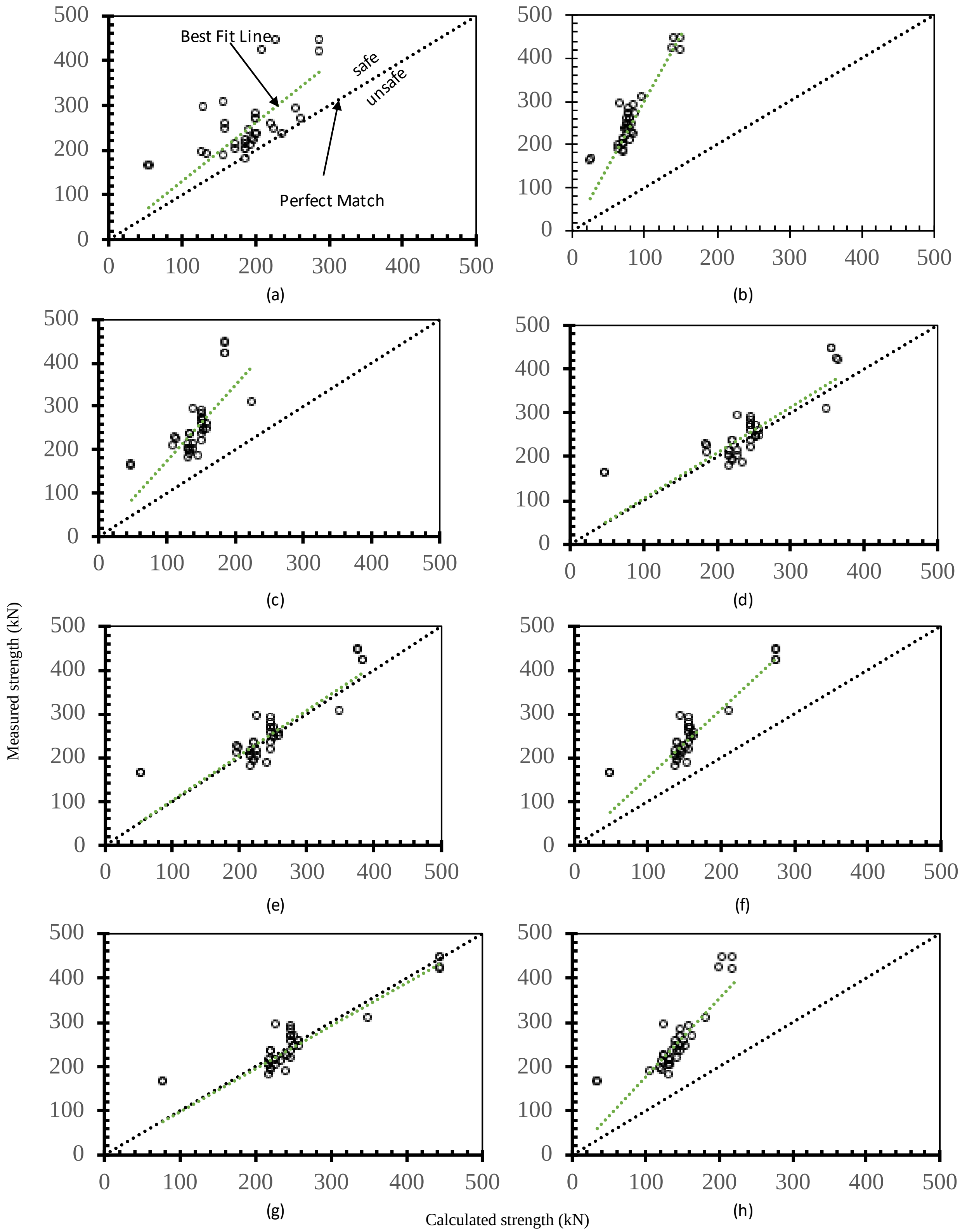


Fig. 2. The measured versus calculated strength using a) EC2, b) ACI-349, c) MC(I), d) MC(II), e) MC(III), f) ACI-318, g) prEC2, and h) Jau.

3.1. Effect of in-plane tensile forces

Figure 3(a-h) show the safety ratio of selected codes and model versus the level of the applied in-plane tensile forces. Away from the EC2 and ACI-349 design codes being overly conservative, all other codes are fairly consistent with respect to tension level. Although the prEC2 do not consider the effect of in-plane tensile forces, yet it is more accurate and consistent compared to all other selected codes. Which raises the question on whether to neglect the in plane tensile forces or consider it. Thus, it fair to conclude that further testing of full-scale slabs under combined two-way shear and in plane loading is essential for further validation of design codes. It is worth noting that prEC2 was found to be less conservative compare to other design codes for the case of normal weight and lightweight concrete (Deifalla, 2020a; Halvonik et al., 2019).

4. Summary and Conclusions

4.1. A comprehensive review of the existing experimental investigations was conducted, and the following conclusions were reached at:

- Although the experimental studies showed only a slight correlation between two-way shear stress and axial tension, a comprehensive understanding of the true behavior and mechanism of the slab under two-way shear force is still not fully developed.

- One of the main reasons for the contradictory conclusions regarding the effect of the in-plane tension forces on the two-way shear is the method of applying the tension forces. Most of the testing done, where the two-way shear loading was independent from the axial tension showed insignificant effect. On the other hand, applying the tension simultaneously with the two-way shear force showed a significant effect.

4.2. An experimental data base from seven different studies were gathered and used to calculate the strength using various formulas. The calculated strength was compared, and the following conclusions were found, which are limited to the available database, such that:

- Although the new draft of the Eurocode for two-way shear did not account for the in plane tensile forces, it provided the most accurate and consistent strength predictions compared to the experimentally observed strength.

- Although the ACI-318 do not account for the effect of in-plane tensile forces, however, it is more accurate compared to the ACI-349, yet the ACI-349 is still consistent.

- The MC (III) is more accurate that MC (II), which is more accurate than MC (I), however all of them are inconsistent with data widely scattered.

- Jau formula is inconsistent and overly conservative.

5. Recommendations for Future Study

- Testing of full-scale slabs, while subjected to two-way shear and in-plane tensile forces simultaneously is needed.

- Numerical models are needed for understanding and predicting the effect of in-plane forces on the two-way shear problem, especially with the higher tensile stresses.

- The development of a mechanical model that give this effect the physical sense is required.

- Newly developed design code provisions for two-way shear should be examined for the case of combined two-way shear and in plane tension in order to continue to provide accurate and consistent predictions.

References

Abrams, J.H., "The Punching Shear Strength of Precracked Reinforced Concrete in Biaxial Tension", M.S. Thesis Cornel University, May 1979.

ACI Committee 318. Building Code Requirements for Structural Concrete (ACI 318- 19) and Commentary on Building Code Requirements (ACI 318-19). Farmington Hills (MI): American Concrete Institute; 2019.

ACI-349 (2006), "Code Requirements for Nuclear Safety Related Concrete Structures", Detroit.

Bui T.T., Nana W.S.A., Abouri S., Limam A., Tedoldi B., Roure T. (2017). "Influence of uniaxial tension and compression on shear strength of concrete slabs without shear reinforcement under concentrated loads." Construction and Building Materials 146 (2017) 86–101. http://dx.doi.org/10.1016/j.conbuildmat.2017.04.068.

Deifalla A (2020a). Design of lightweight concrete slabs under two-way shear without shear reinforcements: a comparative study and a new model. Engineering Structures, Elsevier, 222 (2020) 111076.10.1016/j.engstruct.2020.111076.

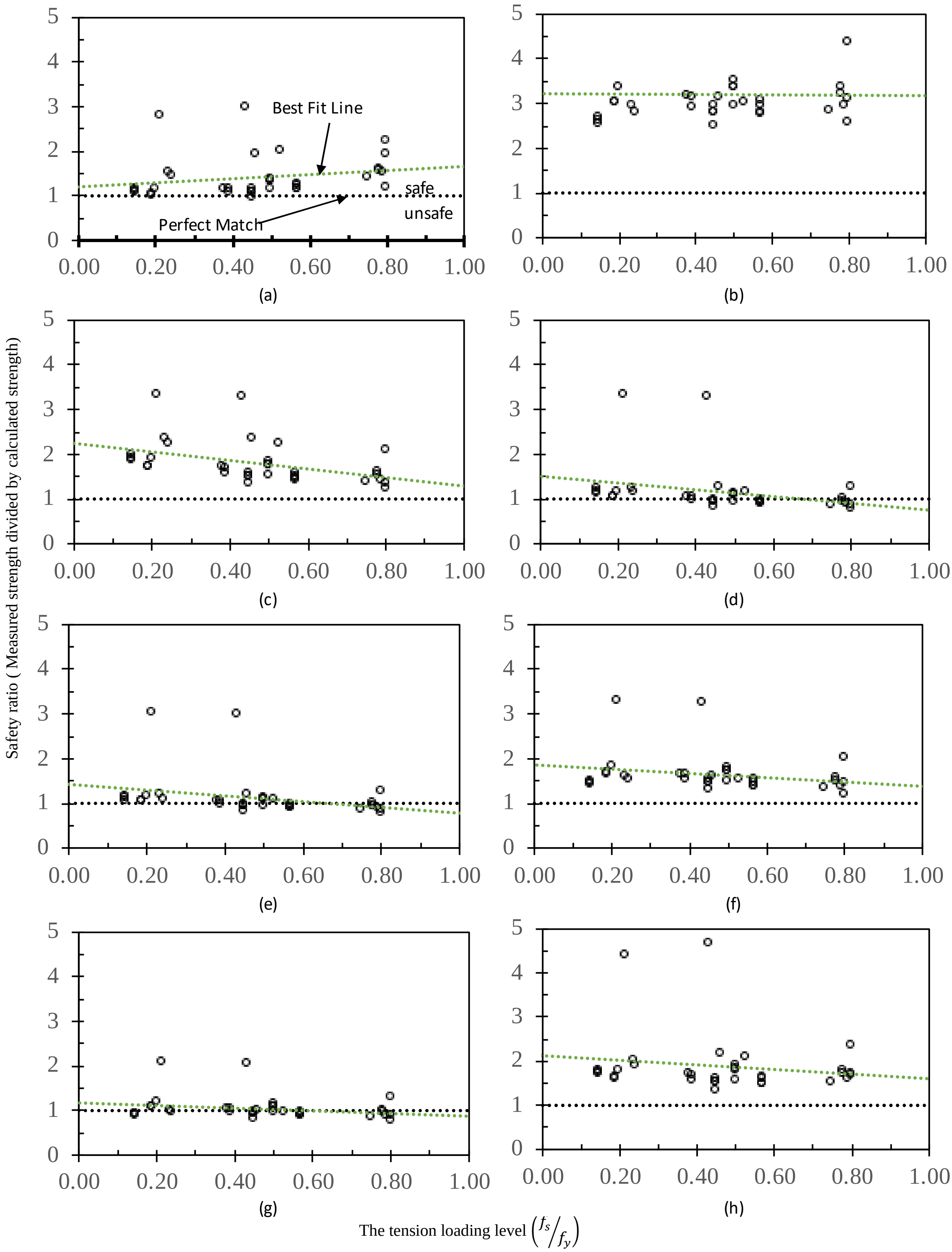


Fig. 3. The effect of the tension level on the safety ratio using a) EC2, b) ACI-349, c) MC(I), d) MC(II), e) MC(III), f) ACI-318, g) prEC2, and h) Jau.

Dönmez A and Bazant Z P, 2017. Size effect on Two-way shear Strength of Reinforced Concrete Slabs Without and With Shear Reinforcement," ACI Structural Journal, V. 114, No. 4, July-Aug., pp. 876-886. doi: 10.14359/51689719.

EC2 (EN 1992-1-1:2004): Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings. Incl. Corrigendum 1: EN 1992-1-1:2004/AC:2008, incl. Corrigendum 2: EN 1992-1-1:2004/AC:2010, incl. Amendment 1: EN 1992-1- 1:2004/A1:2014.

Halvonik J, Kalicka J, Majtanove L, Minarova M. Reliability of models aimed at evaluating the punching resistance of flat slabs without transverse reinforcement. Eng Struct 2019; 188:627–36.

Hawkinns, N M and Ospina C E (2017). Flexural Reinforcement and Depth on Punching Strength," Shear of Structural Concrete Slabs, SP-315, American Concrete Institute, Farmington Hills, MI, pp. 117-140. doi: 10.14359/51700935.

Hoang LC (2011). Punching Shear Tests on RC Slabs with Different Initial Crack Patterns. Procedia Engineering 14 (2011) 1183–1189.

Jau, W.C.; White, R.N. & Gergely, P. Behavior of reinforced concrete slabs subjected to combined punching shear and biaxial tension, report, September 1, 1982; University of North Texas Libraries, UNT Digital Library.

Johnson, R.P. and Arnouti, C., "Punching Shear Strength of Concrete Slabs Subjected to In-Plane Biaxial Tension", Magazine of Concrete Research, Vol. 32, No. 110, March 1980.

Kueres D, Schmidt P, Hegger J. (2019). "Two-parameter kinematic theory for punching shear in reinforced concrete slabs with shear reinforcement.'' Eng Struct; 181: 216–32.

Mattock, A.H., Johal, L., and Chow, H.C., "Shear Transfer in Reinforced Concrete with Moment or Tension Acting across the Shear Plane", PCI Journal, Vol. 20, No. 4, July/August 1975.

MC (2010). "Fib model code for concrete structures 2010." Ernst & Sohn; 2013.

Muttoni A, Fernández Ruiz M, Simões JT. The theoretical principles of the critical shear crack theory for punching shear failures and derivation of consistent closed-form design expressions. Struct Concrete 2018;19(1):174–90.

Muttoni, A., 2008, "Punching Shear Strength of Reinforced Concrete Slabs without Shear Reinforcement," ACI Structural Journal, V. 105, No. 4, July-Aug., pp. 440-450. doi: 10.14359/19858.

prEC2 (prEN 1992-1-1/2018-04): Eurocode 2: Design of Concrete Structures - Part 1-1: General rules for buildings, bridges and civil engineering structures. Third and final Draft by the Project Team SC2.T1; 2018.

Ramos A P, Lucio V J G, Regan P E (2011). "Punching of flat slabs with in-plane forces." Engineering Structures, 33(2011); 894-902, doi: 10.1016/j.engstruct.2010.12.010.