PUNCHING SHEAR BEHAVIOUR OF STEEL FIBRE REINFORCED SELF-COMPACTING CONCRETE FLAT SLABS

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DEDICATION

This thesis is dedicated to my parents, family, and friends,
who encouraged me to fly towards my dreams.

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ABSTRACT

Steel fibre reinforced self-compacting concrete (SFRSCC) consolidates under its own weight and has been shown to have the ability in providing efficient reinforcement mechanism. The research was carried out by leveraging the benefits of the SFRSCC to solve the punching shear problem caused by multiaxial forces in disturbed regions in reinforced concrete (RC) flat slabs. This thesis presents the results of three experimental testing phases to investigate the effectiveness of the SFRSCC, self-compacting concrete (SCC) and the normal concrete (NC) in resisting punching shear in RC flat slabs. Shear reinforcement in the forms of vertical links and welded inclined bars were also investigated in the slabs cast with SCC. The effect of the thickness of the slab, and the limiting area of SFRSCC around the column were also examined. The fresh and hardened properties of these concretes, as well as the optimum content of fibre in the SFRSCC used in the flat slab specimens were determined from the tests in Phase 1. Tests to study on the biaxial behaviour of the concrete to simulate the multi-axial force effects in the RC flat slabs were carried out in Phase 2. Phase 3 deals with the structural testing of slab specimens, tested under a single point load in the middle until failure. The results showed that SFRSCC slabs can withstand higher punching shear load than NC and SCC slabs, with and without shear reinforcement. The failure mode of all fibrous specimens were found to be more ductile as compared to others. The results also revealed that slabs with SFRSCC within a square area around the column can be as efficient in resisting the punching shear as the ones with the SFRSCC cast over the entire slab. These findings were corroborated from biaxial behaviour of concrete in Phase 2. The incorporation of steel fibres into the concrete matrix provides confining pressure, which contributes to an increase in concrete strength under biaxial loading whilst ensuring ductile failure. In term of verification, the numerical analysis with two semi-empirical expressions, namely the strut-and-tie model and the additive model is also presented. The analysis results for the appropriate specimens show good agreement with experimental results, with the additive model giving the closest estimate of the punching shear capacity of the slabs.

ABSTRAK

Konkrit bertetulang gentian keluli terpadat sendiri (SFRSCC) memadat oleh beratnya sendiri dan telah dibuktikan berkeupayaan menyediakan mekanisma tetulang yang cekap. Penyelidikan ini dijalankan dengan memanfaatkan kelebihan SFRSCC untuk menyelesaikan masalah ricih tebuk yang berpunca dari daya pelbagai paksi pada kawasan terganggu di papak rata konkrit bertetulang (RC). Tesis ini memaparkan keputusan ujikaji yang terdiri daripada tiga fasa untuk mengkaji keberkesanan SFRSCC, konkrit terpadat sendiri (SCC) dan konkrit biasa (NC) dalam menghalang ricih tebuk dalam RC papak rata. Tetulang ricih dalam bentuk perangkai pugak dan bar condong berkimpal turut dikaji di dalam papak dengan SCC. Pengaruh ketebalan papak dan keluasan terhad SFRSCC di keliling tiang turut juga diselidiki. Sifat-sifat konkrit tersebut pada peringkat segar dan keras dan kandungan optima SFRSCC yang digunakan dalam spesimen papak rata diperolehi dari Fasa 1 program ujikaji ini. Ujian-ujian ke atas kelakunan dwi-paksi konkrit untuk mewakili kesan-kesan daya pelbagai paksi dalam RC papak rata dijalankan dalam Fasa 2. Fasa 3 melibatkan ujikaji struktur untuk semua spesimen papak rata, diuji dengan satu beban tumpu di tengah papak sehingga berlaku kegagalan. Keputusan kajian menunjukkan papak dengan SFRSCC berupaya menanggung beban ricih tebuk yang lebih besar berbanding daripada papak-papak lain yang dengan NC dan SCC, bertetulang atau tidak mempunyai tetulang ricih. Mod kegagalan bagi papak-papak bergentian adalah bersifat lebih mulur berbanding dengan jenis papak yang lain. Keputusan kajian juga menunjukkan bahawa SFRSCC dalam keluasan empat segi sama di keliling tiang boleh memberikan kesan yang sama dalam merintangi ricih tebuk seperti papak dengan keseluruhan keluasannya daripada SFRSCC. Kelakunan dwi-paksi konkrit dalam Fasa 2 menyokong penemuan ini. Campuran gentian keluli dalam konkrit memberikan tekanan mengurung, yang mana menyumbang pada peningkatan kekuatan konkrit di bawah beban dwi-paksi, dan juga memastikan kegagalan yang mulur. Untuk pengesahan, analisis berangka dengan dua ekspresi separa-empirikal iaitu model tujah-dan-penambat dan model tambahan juga dipaparkan. Keputusan analisis ke atas spesimen-spesimen berkaitan memberikan keserasian yang baik dengan keputusan ujikaji, dengan model tambahan memberikan anggaran ricih tebuk yang terhampir.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
BS	-	British Standard
C-C	-	Compression - compression
CCT	-	Two struts (C) and one tie (T)
C-T	-	Compression - tension
EC2	-	Euro Code 2
EFNARC	-	European Federations of Producers and Contractor of Specialist Products for Structures
HSC	-	High strength concrete
LVDT	-	Linear variable displacement transducers
NC	-	Normal concrete
OPC	-	Ordinary Portland Cement
PL	-	Passing ability
SCC	-	Self - compacting concrete
SF	-	Slump flow
SFRC	-	Steel fibre reinforced concrete
SFRSCC	-	Steel fibre self-compacting concrete
SP	-	Superplasticizer
SR	-	Segregation resistance
SSD	-	Surface dry condition
STM	-	Strut and tie model
RC	-	Reinforced concrete
T-T	-	Tension - tension
VF	-	V-funnel

LIST OF SYMBOLS

ROMAN UPPERCASE LETTER

A	-	Ratio of applied force to the yield force of the flexural reinforcement
A_{bar}	-	Cross- sectional area of bar
A_f	-	Cross-sectional area of calculated steel fibre
A_{sw}	-	Cross-sectional area of shear reinforcement link
B	-	Diameter of column
C	-	Column side dimension
D_b	-	Diameter of the flexural reinforcement
F	-	Fibre factor
F_c	-	Total compression force
L	-	Axis to axis distance between columns
N_1	-	Number of fibre per cross-sectional area
N_f	-	Number of fibre counted on the fractured surface
P_{flex}	-	Flexural ultimate load capacity
S_r	-	Spacing of shear reinforcement in radial direction
V	-	Applied force
$V_{R,ACI}$	-	Predicted punching shear strength of RC flat slab according to ACI 318-11
V_a	-	Strength contribution from aggregate interlock at the crack interface
V_b	-	Strength contribution of fibre
V_c, V_{cd}	-	Strength contribution of concrete
V_{core}	-	Hydrostatic volume of core
V_d	-	Shear strength from dowel action of the flexural reinforcement
V_f	-	Fibre volume fraction
V_m	-	Matrix volume fraction
V_{pun}, V_u	-	Punching shear resistance of RC flat slab

V_s, V_{sd}	-	Shear strength of shear reinforcement
W_f	-	Weight fibre percentage
W_{sf}	-	Weight of fibre
X	-	Neutral axis depth

ROMAN LOWER CASE LETTER

a	-	Length between supports of a square slab
b, b_p	-	Critical perimeter
b_f	-	Modified critical perimeter
d	-	Effective depth
d_f	-	Diameter of fibre
$f_{Rk,4}$	-	Residual flexural tensile strength
f_{cf}	-	Flexural strength of concrete
f_{ck}	-	Compressive cylinder strength of concrete
f_{ct}	-	Tensile splitting strength of concrete
f_{cu}	-	Compressive cube strength of concrete
f_{cu}	-	Maximum strength of concrete in the strut
f_{fu}	-	Ultimate tensile strength of a single fibre.
f_{sw}	-	Link yield strength
f_{yk}	-	Steel yield strength
k	-	Size effect factor
l_{crit}	-	Critical fibre length
l_f	-	Fibre length
m	-	Moment capacity per unit length
r	-	Ratio of the fibre cross-sectional area to the fibre perimeter
s	-	Side dimension of a square slab
u	-	Control perimeter
$u_{out,ef}$	-	Control perimeter at which shear reinforcement is not required
$v_{Rd,c}$	-	Punching shear stress
v_{fd}	-	Shear stress contribution from fibre bridging action
w_c	-	Specific weight of the concrete

y	-	Height of the rectangular compressive stress field Depth of the compression zone
y_f	-	Depth of compression zone at flexure critical section
y_s	-	Depth of the compression zone of the shear critical section at punching

GREEK LETTER

$\emptyset_{bar}$	-	Diameter of the flexural reinforcement
β_c	-	Ratio of the long side to the short side of the column
γ_c	-	Partial safety of concrete
ε_{cu}	-	Ultimate concrete strain
ε_o	-	Concrete strain at the level of the end of the rectangular concrete stress block
η_1	-	Fibre length correction factor
η_θ	-	Fibre orientation factor
λ_f	-	Fibre aspect ratio
ρ_f	-	Bond factor of steel fibre
ρ_{sf}	-	Density of steel fibre
σ_c	-	Uniaxial compressive stress
σ_{cr}	-	Cracking stress of the composites in direct tension
σ_f	-	Ultimate stress in fibre at matrix cracking
σ_{fu}	-	Ultimate strength of the composite concrete is contributed by the fracture strength of the fibre
σ_{mu}	-	Cracking stress of matrix
σ_s	-	Axial tensile stress in the reinforcing bar
σ_{tu}	-	Ultimate post-cracking tensile stress
τ_c	-	Maximum shearing stress
τ_f	-	Fibre-matrix interfacial bond stress
τ_{fd}	-	Design value of increment in shear strength due to steel fibre
α	-	Inclination of the link with the plane of the slab
θ	-	Inclination of crack
λ	-	Size effect factor

ρ	-	Flexural reinforcement ratio
σ	-	Normal stress
τ	-	Shear stress

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Slab-column or flat plate frame system offers numerous construction and architectural advantages, which make them a popular choice in reinforced concrete (RC) construction. This constructive system is the most competitive for residential and commercial buildings with span length between columns varying from 7.0 to 9.0 m and a live load not exceeding 5 kN/m^2 (PCA–Portland Cement Association, 2005; Delahay and Christopher, 2007). The construction of the flat slab eliminates the use of beam, where the slab is supported directly by columns. It also offers a simpler formwork and greater clear story height as compared to beam-column frame construction, leading to substantial savings in construction costs.

Despite its simple appearance, this slab-column connection is susceptible to punching shear failures, which could lead to substantial floor damage and even the worst scenario of the structural collapse such as the collapse of the Skyline Plaza (Carino *et al.*, 1983), Sampoong department store (Gardner *et al.*, 2002) and 16-storey apartment building at 2000 Commonwealth Avenue (King and Delatte, 2004).

Punching shear failure is a main governing failure mode for a flat slab. It occurs when total shear forces act on the slab is greater than shear resistance of the slab, high bending moment and shear forces at the slab-column connection (Tuan Ngo, 2003), or when the flexural member is unable to develop yield mechanism to fail in a ductile manner (Harajli *et al.*, 1995). On top of that, the structure failed in punching shear failure showed a sudden drop in load-carrying capacity, and the structure collapsed instantaneously without giving people any time to escape (Menétrey, 2002).

Generally, the shear capacity of this connection can be enhanced by increasing the slab thickness or using drop panels or column capitals, which is not an economical or practical option as well as architectural disadvantages. This is because increasing the slab thickness will also increase the cost and the weight of the building. Furthermore, the presence of the drop panel or column head causes the changes in slab cross-section and formwork which result in the non-uniformity in-floor bottom surface and decreasing clear story height. Thus, modifying the geometrical of the slab is not the only method to increase the punching shear capacity.

Therefore, since the 1950s, punching shear has been the subject of an intense experimental effort. Although, several methods have been proposed to increase the punching shear capacity of flat slabs. However, its application is still restricted. For example, traditional shear strengthening using stirrups is only applicable to slabs with a depth greater than 150 mm (ACI Committee 318, 2002), reinforcement using steel section shear head systems (Anderson, 1963; Corley and Hawkins, 1968), stud type reinforcement (Elgabry and Ghali, 1987), shear band system (Pilakoutas and Li, 2003) and lattice shear reinforcement (Park *et al.*, 2007) prolong the duration and increase the cost of construction.

Due to these circumstances, steel fibre reinforced concrete (SFRC) is seen as an alternative in enhancing the punching shear capacity, performance and cracking control of the slab-column connection. Steel fibres in a minimum amount of 30 kg/m^3 were found highly useful as an alternative reinforcement (Nguyen-Minh *et al.*, 2012; Ragab, 2013). The addition of steel fibres turns the quasi-brittle concrete into a ductile material. As the maximum tensile strength is improved, the fibre-knitting through the crack enables the transfer of stress even at wide crack openings. Amplitudes of residual strength enhancements depend primarily on the geometry and dosage of the fibres.

Owing to the advantages of including steel fibres in the concrete mix, several studies have tried to increase the volume content of steel fibres (Harajli *et al.*, 1995; De Hanai and Holanda, 2008; Gouveia *et al.*, 2014). Even, Facconi *et al.*(2016) and K. H. Tan and Venkateshwaran (2017) tried to fully replace the conventional reinforcement with the fibre reinforcement. Unfortunately, the specimen failed due to flexural failure. It should be borne in mind that the efficiency of steel fibres does not only depend on the volume of steel fibres in the concrete mix. The effectiveness of steel fibre reinforcement also relies on the concrete mix proportion, fresh and hardened state of the concrete. Therefore, the study on the correlation of the concrete properties and the effectiveness of steel fibre reinforcement in reinforced concrete flat slab is has become an important issue.

1.2 Problem Statement

Before focusing on a method for enhancing the integrity of the slab-column connection, it should not be overlooked from the structural point of view that it is highly problematic to support a thin slab directly on the column. This static discontinuity is one of the most critical D-regions occurring in concrete structures. The very high moments occur in this D-region of the flat slab and the three-dimensional stress state in extremely complex. In an attempt to find a viable solution to the deficiencies, the issues are outlined in detail.

1.2.1 Disturbed Region of the Reinforced Concrete Flat Slab

In designing a reinforced concrete structure, the component is divided into two parts, which is Beam or Bernoulli region (B-region) and Discontinuity region (D-region). The B-Region is part of a structure in which Bernoulli's hypothesis of straight-line strain profiles applies. The D-Region, on the other hand, is part of a structure with a complex variation in strain. For reinforced concrete, the absence of any transition between column and slab is extremely disadvantageous and the thickness of the slab is often determined by the punching problem. Besides, flat slabs inevitably violate the principle that the safety level of a structure should be equal throughout because, as against any other part of the slab, the D-region with the punching zone is not sufficiently ductile to gain capacity from force redistribution.

Hence, a number of shear reinforcement, such as stirrup, steel section shear head systems (Anderson, 1963; Corley and Hawkins, 1968), stud type reinforcement (Elgabry and Ghali, 1987), shear band system (Pilakoutas and Li, 2003) or lattice shear reinforcement (Park *et al.*, 2007) are provided to improve the ductility in this region. Improper dimensioning and distribution of reinforcing steel in disturbed regions can lead an adverse cracking and failure of the structure. The serviceability limit state is equally important to ultimate strength due to large stress concentrations in the vicinity of bearing surfaces.

However, the installation of any shear reinforcement in a thin element such as flat slab causes the steel reinforcement congestion, particularly within the critical perimeter of slab-column connection. If a lot of hoops overlap within a small space in the joint (as shown in Figure 1.1), the bond between the concrete and the rebar could be weak due to the limited space between the bars to allow the concrete to flow through. Furthermore, the placement and compaction of normal concrete are difficult in the congested area. Consequently, the development of bond between concrete and the bar is interrupted, as well as degrading the quality of concrete due to the existence of voids and honeycombs in the reinforced concrete structure (Mohamed, 2009). It is also affect the strength and durability of concrete, particularly the tensile strength of concrete which is so important in transferring the shear mechanism. On the other hand, increasing the depth of the slab would not be too beneficial, it would only increase the dead load of the structure. Thus, while retaining the comparable strength of the RC flat slab, it is important to minimize the slab depth.

Figure 1.1 The overlap stirrup within a small space in the joint may disturb the flow of concrete

Furthermore, when a concentrated force acts on the surface of a member, the compressive stresses fan out from the loaded region. The punching shear problem for a slab–column connection has a three-dimensional nature due to the complex state of the stresses that dictate failure around the connection region (Hallgren, 1996). Figure 1.2 shows the compression zone in the D-region subjected to multiaxial stresses. At such locations, the concrete is loaded with a combination of more than one force action, which induces a field of tensile stresses normal to the line of compression. Diagonal cracking can develop along planes perpendicular to the plane of principal tensile stress due to the low tensile properties of concrete. Therefore, the knowledge of the behaviour of the concrete subject to a multiaxial stress situation is necessary for a better understanding of the process of failure of the concrete.

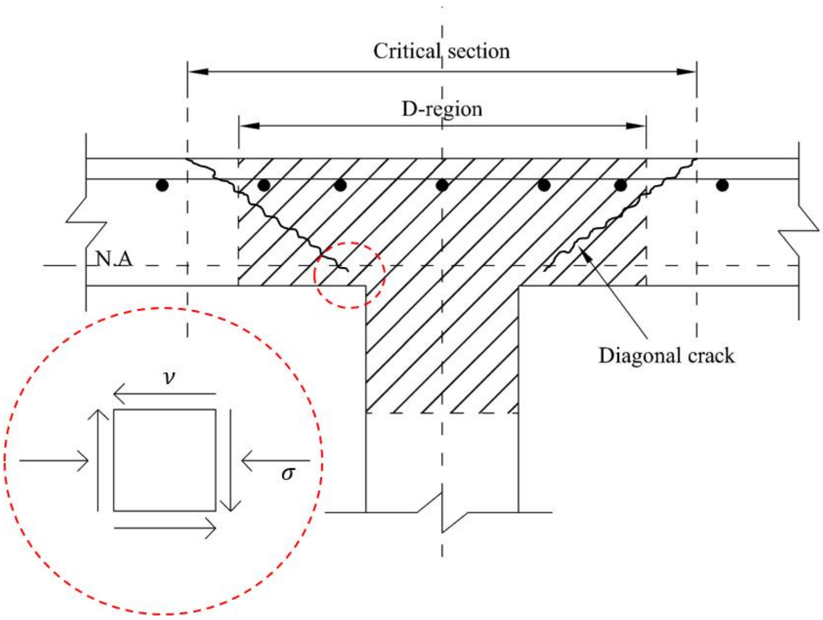

Figure 1.2 The disturbing region (D-region) at the slab-column connection of reinforced concrete flat slab

1.2.2 Application of Steel Fibre Reinforcement in Reinforced Concrete Slab

The steel fibres with an adequate amount has proven its ability to provide efficient reinforcement mechanism through its bridging action and consequently enhance the integrity of the slab-column connection (Nguyen-Minh *et al.*, 2011;

Facconi *et al.*, 2016). Apart from the fibre volume fraction and types of fibre, the efficiency of steel fibres also depends on other factors, such as the casting procedure, and the fresh and hardened state of the concrete. Due to its high specific weight, steel fibre has a higher tendency than other constituents to segregate towards the bottom surface, resulting in a lower fibre content near the top surface of the element (Barros and Antunes, 2003). This can be avoided by using high-flowing concrete matrices such as self-compacting concrete (SCC) as the medium to transport the fibre.

Despite the obvious advantages of SCC, relatively few works have been published related to the application of steel fibre reinforced self-compacting concrete (SFRSCC) to enhance the punching shear resistance of reinforced concrete flat slab (Facconi *et al.*, 2016; Nguyen *et al.*, 2017). Further research on this topic is therefore clearly desirable. On top of that, the use of shear reinforcement remains as a top choice to resist the punching shear issue, even though it is four times as labour-intensive as fibrous concrete in fabrication and casting of the slab (Narayanan and Darwish, 1987). This is because the use of fibrous concrete mix is costly as compared to the normal concrete.

Furthermore, the importance of this study is because, while many experimental researchers have studied various parameters in the punching capacity of fibre-reinforced slab-column connection, in most cases, concrete is only distinguished by its compression strength (Harajli *et al.*, 1995; Nguyen-Minh *et al.*, 2011; K H Tan and Venkateshwaran, 2017). The increment of the compressive strength of concrete due to the fibre addition is not significant (Olivito and Zuccarello, 2010; Iqbal *et al.*, 2015; Soulioti *et al.*, 2011). Therefore, the equations developed using compressive strength may not accurately represent the actual contribution of fibrous concrete to structural capacity enhancement. Only a few researchers addressed the concrete strength characteristic by its flexural tensile strength, which is the dominant strength of the fibrous concrete (Gouveia et al., 2014; Barros et al., 2015; Facconi et al., 2016). Furthermore, most of the researchers neglected the crucial information on the fibre dispersion and orientation in large-scale steel fibre concrete elements. Stähli and van Mier (2007) confirmed the result that the moulded smaller sized prism shows higher bending stresses than the geometrical specimens cut off from bigger cast specimens.

This so-called 'wall effect' has a significant effect when there is a huge difference in size or two different structural elements.

Meanwhile, the established design standard or codes such as ACI Building Code (ACI Committee 318, 2008), British standard (BS 8110-1, 1997), the Fib Model Code 2010 (Du Béton, 2010) and Euro code 2 (BS EN 1992-1-1, 2004) present various formulas to estimate the punching shear capacity of the reinforced concrete flat slabs. However, these formulas were developed for a normal reinforced concrete flat slab, thus, its applicability to predict the punching shear resistance of SFRC flat slab is debatable. Therefore, a solution for predicting the punching shear resistance is seen as a crucial issue.

1.3 Aim and Objectives of Research

The general aim of the investigation was to determine the possible benefits of using steel fibres in reinforced concrete flat slab. In more specific terms, the objectives of the study are as follows:

i. To develop an optimum mix design of SFRSCC by investigating the performance of the concrete in terms of fresh and hardened concrete properties.
ii. To study the behaviour of SCC and SFRSCC specimens subjected to the biaxial loads due to the multiple types of forces existed at a slab-column connection.
iii. To investigate the punching shear and deformation behaviour of RC flat slab made of SFRSCC.
iv. To relate the improvement in punching shear strength and ductility due to the inclusion of steel fibres into possible design equations for strength prediction of RC flat slab.

1.4 Scope of Research

The research would be experimental in nature, beginning with the development of SCC and SFRSCC with the addition of fibres at volume fractions of 0.5%, 0.75%, 1.0%, and 1.25%. In this study, hooked-end steel fibre with a length of 35 mm and an aspect ratio of 60 was used in SFRSCC mixes. To compare the properties of normal concrete (NC) and SCC, NC of the same grade as the SCC was also casted. Phase 1 focuses on the investigation of the properties of fresh and hardened concrete. The fresh properties included the filling ability, passing ability and the segregation resistance of concrete. Meanwhile, the hardened concrete properties included compressive, flexural tensile, splitting tensile and residual flexural tensile strengths, as well as the flexural toughness and modulus of elasticity.

The optimum fibre content determined in Phase 1 was investigated further in Phases 2 and 3. The second phase focuses on the investigation of concrete under biaxial loading in the compression–tension and tension – tension regions with variation in stress ratios. The last phase involved the use of fibre reinforcement in RC flat slabs. Eight RC flat slabs with a dimension of 1.65 m x 1.65 m were casted with an effective span of 1.4 m and simply supported on all edges. The RC flat slabs were provided with identical main reinforcement, which were designed to fail in punching shear. The variables considered were concrete types, shear reinforcement, slab thickness, and the effective area of SFRSCC. Lastly, new semi-empirical equations were proposed to predict the punching shear resistance of RC flat slabs with various parameters. The experimental results were used to validate the accuracy of the proposed equations.

1.5 Significance of Research

Punching shear is still a polemic topic and advancements in the state of the art are still required. This work intends to contribute with the additional results regarding the test of SFRSCC flat slabs, with a different approach from the previous works. As been mentioned earlier, the rheological properties of high-flowing concrete play an important role in determining the effectiveness of the steel fibre reinforcement, therefore, this study was focusing on understanding the material behaviour, by including the finding from the fresh and hardened concrete properties, hence an adequate mix composition of SFRSCC could be decided before structure testing. In addition, the behaviour of concrete under uniaxial and biaxial loading was further discussed in order to determine the actual behaviour of the SFRSCC specimens. This knowledge is scarce and is therefore of interest to the engineering and scientific community.

Apart from the investigation on the contribution of steel fibres as a secondary reinforcement, this study also investigated the boundary area of SFRSCC need to be provided to produce superior structural performance. This concept is similar to the concept of the use of high strength concrete in the column head area only. Thus, it was possible to minimize the economic impact of using SFRSCC and enhance its competitiveness. On top of that, the simple semi-empirical equation was proposed to predict structural performance. Thus, the experimental result and the proposed semi-empirical equation could contribute to future development and improve the phenomenological understanding of reinforced concrete flat slab using steel fibres as the secondary reinforcement.

1.6 Thesis layout

This thesis is made up of nine chapters. The outline of the thesis and the details of each chapter are as follows:

Chapter 1 describes the background, problem statements, the study objectives, the scope of the study and the significance of the study.

Chapter 2 and 3 present the compilation of literature data related to materials properties of SCC, SFRC, SFRSCC, and reinforced concrete flat slabs. Chapter 2 discusses the properties and behaviour of the steel fibres in the concrete matrix in order to broaden the perspective on the advantages of the steel fibres to be used in the structural system. In the continuation of Chapter 2, Chapter 3 is related to the previous studies and methods applied to enhance the punching shear capacity of a reinforced concrete flat slab, as well as considering the potential use of steel fibres as the replacement of conventional reinforcement.

Chapter 4 deals with the research methodology used to achieve the objectives of the study. The procedures and methods are described in detail in this chapter. Three phases of experimental work have been integrated into this study. Phase 1 and phase 2, which are mainly focused on the properties of concrete, explain the procedure in preparation of the NC, SCC, and SFRSCC. It also describes the testing procedures for the fresh and hardened concrete (e.g. test under uniaxial load and biaxial load). The last phase presented the experimental work related to the application of concrete in the structure system (namely: the reinforced concrete flat slab).

Chapter 5 reports the experimental findings from the fresh and hardened concrete tests. Objective 1 and 2 are discussed in this chapter. The results give the optimum fibre content evaluated based on its fresh and hardened concrete properties. It also produces the biaxial envelope, which is correlated to the concrete matrix behaviour in the structure system.

Chapter 6 presents the experimental findings retrieved from the punching shear test of a reinforced concrete flat slab. In this chapter, the related experimental parameters are discussed to determine the impact of the steel fibre reinforcement on the structural behaviour, such as punching shear capacity, steel and concrete strain, and mode of failure. The inter-connection of the results of concrete behaviour under biaxial loading to the behaviour of reinforced concrete flat slab is discussed.

Chapter 7 presents the development of the semi-empirical equation used to predict the punching shear capacity of reinforced concrete flat slab. The failure influencing factors, post cracking shear behaviour of SFRSCC flat slab and contribution from other factors such as the contribution of concrete, fibre bridging, compressive resistance and dowel action are considered in the development of the semi-empirical equation.

Chapter 8 presents the validation of the proposed semi-empirical equations, which are validated against experimental results and further compared to existing equations proposed by other researchers. In this chapter as well, the contribution of fibre in enhancing the shear strength is further analysed and discussed. The implication of the results of the tests on the use of steel fibres as a replacement for conventional reinforcement in the punching shear capacity of reinforced concrete flat slab is also presented.

Chapter 9 concludes the study by highlighting the significant outcome of the study and the achievement of the objectives mentioned in Chapter 1. Several recommendations for further research are suggested.

REFERENCES

Abdallah, S., Fan, M. and Rees, D. W. A. (2017) ‘Effect of Elevated Temperature on Pull-Out Behaviour of 4DH/5DH Hooked End Steel Fibres’, *Composite Structures*, 165, 180–191.

Abdallah, S., Fan, M. and Rees, D. W. A. (2018) ‘Bonding Mechanisms and Strength of Steel Fiber–Reinforced Cementitious Composites: Overview’, *Journal of Materials in Civil Engineering*, 30(3), 1-15.

Abdallah, S., Fan, M., Zhou, X. and Le Geyt, S. (2016) ‘Anchorage Effects of Various Steel Fibre Architectures for Concrete Reinforcement’, *International Journal of Concrete Structures and Materials*, 10(3), 325–335.

Abdull-Ahad, R. B. and Abbas, J. M. (1989) ‘Behaviour of Steel Fibre Reinforced Concrete Under Biaxial Stresses’, *International Conference on Recent Developments in Fibre Reinforced Cements and Concretes*, 126–135.

Akcay, B. and Tasdemir, M. A. (2012) ‘Mechanical Behaviour and Fibre Dispersion of Hybrid Steel Fibre Reinforced Self-Compacting Concrete’, *Construction and Building Materials*, 28(1), 287–293.

AL-Ameeri, A. (2013) ‘The Effect of Steel Fiber on Some Mechanical Properties of Self Compacting Concrete’, *American Journal of Civil Engineering*, 1(3), 102–110.

Alberti, M. G., Enfedaque, A., Gálvez, J. C., Cánovas, M. F. and Osorio, I. R. (2014) ‘Polyolefin Fiber-Reinforced Concrete Enhanced with Steel-Hooked Fibers in Low Proportions’, *Materials and Design*, 60, 57–65.

Alexander, S. D. B. and Simmonds, S. H. (1987) ‘Ultimate Strength of Slab-Column Connections’, *ACI Structural Journal*, 84(3), 255–261.

Alexander, S. D. B. and Simmonds, S. H. (1992) ‘Punching Shear Tests of Concrete Slab-Column Joints Containing Fiber Reinforcement’, *ACI Structural Journal*, 89(4), 425–432.

Alexandra, C., Bogdan, H., Camelia, N. and Zoltan, K. (2018) ‘Mix Design of Self-Compacting Concrete with Limestone Filler Versus Fly Ash Addition’, *Procedia Manufacturing*, 22, 301–308.

Al-Rousan, R. Z. (2016) 'Flexural Toughness Characteristics of Steel Synthetic Fibers-Lightweight Aggregate Concrete', I*nternational Journal of Engineering and Technology*, 8(3), 1536–1542.

American Concrete Institute (1991). *ACI 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*. Farmington Hills: American Concrete Institute.

American Concrete Institute (2007). *ACI 318-08 Building Code Requirements for Structural Concrete and Commentary*. Farmington Hills: American Concrete Institute.

American Concrete Institute (2011). *ACI 318-11 Building Code Requirements for Structural Concrete*. Farmington Hills: American Concrete Institute.

American Concrete Institute (2008). *ACI 544.3 R-08 Guide for Specifying Proportioning, and Production of Fiber-Reinforced Concrete*. Farmington Hills: ACI American Concrete Institute.

American Concrete Institute (1999). *ACI 544.4R-88: Design Considerations for Steel Fiber Reinforced Concrete*. Farmington Hills: ACI American Concrete Institute.

American Concrete Institute (2002). *ACI 318-02 Building Code Requirements for Structural Concrete*. Farmington Hills: ACI American Concrete Institute.

American Concrete Institute (2008). *ACI 318-08 Building Code Requirements for Structural Concrete*. Farmington Hills: ACI American Concrete Institute.

American Society for Testing and Materials (2011). *ASTM A820/A820M Standard Specification for Steel Fibers for Fiber-Reinforced Concrete*. United States: ASTM International.

American Society for Testing and Materials (2013). *ASTM C494/C494M: Standard Specification for Chemical Admixtures for Concrete*.

American Society for Testing and Materials (2012). *C 1609/C 1609M-12 (2012) Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)*. United States: ASTM International.

Anderson, J. L. (1963) *Punching of Concrete Slabs with Shear Reinforcement*. Royal Institute of Technology KTH Stockholm Switzerland.

ASCE-ACI (1998) 'Recent Approaches to Shear Design of Structural Concrete', *Journal of Structural Engineering*, 124(12), 1375–1417.

Baig, Z. I. (2019) ‘Influence of Flexural Reinforcement Ratios on Failure Modes of Slab-Column Connections: An Experimental Investigation’, *Science International (Lahore),* 31(3), 397–402.

Balaguru, P. N. and Shah, S. P. (1992) *Fiber-Reinforced Cement Composites*. New York: McGraw-Hill.

Bao, J., Wang, L., Zhang, Q., Liang, Y., Jiang, P. and Song, Y. (2018) ‘Combined Effects of Steel Fiber and Strain Rate on the Biaxial Compressive Behavior of Concrete’, *Construction and Building Materials*, 187, 394–405.

Barnett, S. J., Lataste, J. F., Parry, T., Millard, S. G. and Soutsos, M. N. (2010) ‘Assessment of Fibre Orientation in Ultra High Performance Fibre Reinforced Concrete and its Effect on Flexural Strength’, *Materials and Structures/Materiaux et Constructions*, 43(7), 1009–1023.

Barros, J. A. O. and Antunes, J. A. B. (2003) ‘Experimental Characterization of the Flexural Behaviour of Steel Fibre Reinforced Concrete According to RILEM TC 162-TDF Recommendations’, *RILEM TC*, 162, 77–89.

Barros, J. A. O., Cunha, V. M. C. F., Ribeiro, A. F. and Antunes, J. A. B. (2005) ‘Post-Cracking Behaviour of Steel Fibre Reinforced Concrete’, *Materials and Structures/Materiaux et Constructions*, 38(275), 47–56.

Barros, J. A. O., Moraes Neto, B. N., Melo, G. S. S. A. and Frazão, C. M. V. (2015) ‘Assessment of the Effectiveness of Steel Fibre Reinforcement for the Punching Resistance of Flat Slabs by Experimental Research and Design Approach’, *Composites Part B: Engineering*, 78, 8–25.

Bartos, P. J. M. (2000) Measurement of Key Properties of Fresh Self-Compacting Concrete. CEN*/PNR Workshop*. Paris.

Benedetty, C. A., Krahl, P. A., Almeida, L. C., Trautwein, L. M., Siqueira, G. H. and de Andrade Silva, F. (2021) ‘Interfacial Mechanics of Steel Fibers in a High-Strength Fiber-Reinforced Self Compacting Concrete’, *Construction and Building Materials*, 301(July).

Bentur, A. and Mindess, S. (2007) *Fibre Reinforced Cementitious Composites*. 2nd Edition. Oxon, UK: Taylor & Francis.

Du Béton, F. I. (2010) ‘Model Code 2010—First Complete Draft’, *fib Bulletin*, (55), 318.

Betterman, L. (1995) ‘Fiber-Matrix Interaction in Microfiber-Reinforced Mortar’, *Advanced Cement Based Materials*, 2(2), 53–61.

Beutel, R. and Hegger, J. (2002) 'The Effect of Anchorage on the Effectiveness of the Shear Reinforcement in the Punching Zone', *Cement and Concrete Composites*, 24(6), 539–549.

Binici, B. and Bayrak, O. (2003) 'Punching Shear Strengthening of Reinforced Concrete Flat Plates Using Carbon Fiber Reinforced Polymers', *Journal of Structural Engineering*, 129(September), 1173–1182.

Błaszczyński, T. and Przybylska-Fałek, M. (2015) 'Steel Fibre Reinforced Concrete as a Structural Material', *Procedia Engineering*, 122, 282–289.

Bompa, D. V and Oneţ, T. (2016) 'Punching Shear Strength of RC Flat Slabs at Interior Connections to Columns', *Magazine of Concrete Research*, 68, 24–42.

Breitenbücher, R., Meschke, G., Song, F. and Zhan, Y. (2014) 'Experimental, Analytical and Numerical Analysis of the Pull-out Behaviour of Steel Fibres Considering Different Fibre Types, Inclinations and Concrete Strengths', *Structural Concrete*, 15(2), 126–135.

Bresler, B. and Pister, K. S. (1958) 'Strength of Concrete Under Combined Stresses', *Journal Proceedings*, 55 (9), 321–345.

British Standard Institution (1983). *BS 1881: Part 121 Testing concrete: Method for Determination of Static Modulus of Elasticity in Compression*. London: British Standards Institution.

British Standard Institution (1997). *BS 8110-1: Structural Use of Concrete, Part 1– Code of Practice for Design and Construction*. London: British Standards Institution.

British Standard Institution (2001). *BS 8110-2: Structural Use of Concrete, Part 2- Code of Practice for Special Circumstanc*e. London: British Standards Institution.

British Standard Institution (2001). *BS EN 10002-1: Metallic Materials-Tensile Testing-Part 1: Method of Test at Ambient Temperature*. London: British Standards Institution.

British Standard Institution (2010). *BS EN 12350-10: Test Fresh Concrete - Part 10: Self- Compacting Concrete - L-Box Test.* London: British Standards Institution.

British Standard Institution (2010). *BS EN 12350-11: Testing Fresh Concrete- Part 11: Self- Compacting Concrete- Sieve Segregation Test*. London: British Standards Institution.

British Standard Institution (2009). *BS EN 12350-2: Testing Fresh Concrete. Part 2: Slump-Test*. London: British Standards Institution.

British Standard Institution (2010). *BS EN 12350-8: Testing Fresh Concrete-Part 8: Self-Compacting Concrete-Slump Flow Test*. London: British Standards Institution.

British Standard Institution (2010) *BS EN 12350-9: Testing Fresh Concrete-Part 9: Self-Compacting Concrete-V-Funnel Test.* London: British Standards Institution.

British Standard Institution (2009). *BS EN 12390-2: Testing Hardened Concrete- Part 2: Making and Curing Specimens for Strength Test*. London: British Standards Institution.

British Standard Institution (2009). *BS EN 12390-3: Testing Hardened Concrete- Part 3: Compressive Strength of Test Specimens*. London: British Standards Institution.

British Standard Institution (2009). *BS EN 12390-5: Testing Hardened Concrete. Part 5: Flexural Strength of Test Specimens.* London: British Standards Institution.

British Standard Institution (2009). *BS EN 12390-6: Testing Hardened Concrete- Part 6: Tensile Splitting Strength of Test Specimens*. London: British Standards Institution.

British Standard Institution (2013). *BS EN 12620: Aggregates for concrete*. London: British Standards Institution.

British Standard Institution (2005). *BS EN 14651: Test Method for Metallic Fibred Concrete — Measuring The Flexural Tensile Strength (Limit of Proportionality (LOP), Residual).* London: British Standards Institution.

British Standard Institution (2006). *BS EN 14889-1: Fibres for Concrete - Part 1: Steel Fibres - Definitions, Specifications and Conformity.* London: British Standards Institution.

British Standard Institution (2000). *BS EN 197-1: Cement-Part 1: Composition, Specifications and Conformity for Common Cements*. London: British Standards Institution.

British Standard Institution (2004). *BS EN 1992-1-1: Euro code 2: Design of Concrete Structures — Part 1-1: General Rules and Rules for Buildings*. London: British Standards Institution.

British Standard Institution (2013). *BS EN 206:2013: BSI Standards Publication Concrete — Specification, Performance, Production and Conformity*. London: British Standards Institution.

British Standard Institution (2001). *BS EN 934-2: Admixtures for Concrete, Mortar and Grout- Part 2: Concrete Admixtures- Definitions, Requirements, Conformity, Marking and Labelling*. London: British Standards Institution.

Carino, N. J., Woodward, K. A., Leyendecker, E. V. and Fattal, S. G. (1983) 'Review of the Skyline Plaza Collapse', *Concrete International*, 5(7), 35–42.

Chana, P. S. (1987) 'Investigation of The Mechanism of Shear Failure of Reinforced Concrete Beams', *Magazine of Concrete Research*, 39(141), 196–204.

Cheng, M. and Parra-Montesinos, G. J. (2010) 'Evaluation of Steel Fiber Reinforcement for Punching Shear Resistance in Slab-Column Connections — Part II: Lateral Displacement Reversals', *ACI Structural Journal,* 107(107), 110–118.

Cheng, M. and Parra-Montesinos, G. J. G. (2010) 'Evaluation of Steel Fiber Reinforcement for Punching Shear Resistance in Slab-Column Connections--Part I: Monotonically Increased Load.', *ACI Structural Journal*, 107(107), 101–109.

Chiew, S. M., Ibrahim, I. S., Jamaluddin, N., Sarbini, N. N., Ma, C. K. and Ahmad, Y. (2020) 'Behavior of Steel Fiber-Reinforced Concrete Under Biaxial Stresses', *ACI Structural Journal*, 117(4), 267–278.

Choi, K. K., Reda Taha, M. M., Park, H. G. and Maji, A. K. (2007) 'Punching Shear Strength of Interior Concrete Slab-Column Connections Reinforced with Steel Fibers', *Cement and Concrete Composites*, 29(5), 409–420.

Comité Euro-International Du Béton (1990). *CEB-FIP Model Code 1990. Design code*. Thomas Telford Publishing.

Cook, W. D. and Mitchell, D. (1988) 'Studies of Disturbed Regions Near Discontinuities in Reinforced Concrete Members', *ACI Structural Journal*, 85(2), 206–216.

Corley, W. G. and Hawkins, N. (1968) 'Shearhead Reinforcement for Slabs', *Journal Proceedings*, 65(10), 811–824.

Criswell, M. E. and Hawkins, N. W. (1974) 'Shear Strength of Slabs: Basic Principle and Their Relation to Current Methods of Analysis', *Special Publication*, 42, 641–676.

Cunha, V. M. C. F. (2010) *Steel Fibre Reinforced Self-Compacting Concrete (From Micromechanics to Composite Behavior*. PhD thesis, University of Minho, Portugal.

Daczko, J. A. (2012) *Self-consolidating concrete: Applying what we know, Self-Consolidating Concrete: Applying What We Know*. CRC Press.

De Schutter, G., Bartos, P. J. M., Domone, P. and Gibbs, J. (2008) *Self-compacting concrete*. Scotland: Whittles Publishing.

Delahay, P. E. J. and Christopher, P. E. B. (2007) 'Current Trends in Economical Concrete Construction, Part One: Floor Framing and Lateral Systems', *Structure Magazine*, 19–21.

Domone, P. L. (2006) 'Self-Compacting Concrete: An Analysis of 11 Years of Case Studies', *Cement and Concrete Composite*s, 28(2), 197–208.

Domski, J. and Katzer, J. (2013) 'Load-Deflection Characteristic of Fibre Concrete Based on Waste Ceramic Aggregate', *Rocznik Ochrona Srodowiska*, 15(1), 213–230.

Dupont, D. and Vandewalle, L. (2005) 'Distribution of Steel Fibres in Rectangular Sections', *Cement and Concrete Composites*, 27(3), 391–398.

EFNARC (2002) *Specification and Guidelines for Self-Compacting Concrete*. United Kingdom.

Elgabry, A. and Ghali, A. (1987) 'Tests on Concrete Slab-Column Connections with Stud-Shear Reinforcement Subjected to Shear-Moment Transfer', *ACI Materials Journal*, 84(5), pp. 433–442.

Elliott, K. S., Peaston, C. H. and Paine, K. A. (2002) 'Experimental and Theoretical Investigation of the Shear Resistance of Steel Fibre Reinforced Pre stressed Concrete X-Beams - Part II: Theoretical Analysis and Comparison with Experiments', *Materials and Structures*, 35, 528–535.

Elsanadedy, H. M., Al-Salloum, Y. A. and Alsayed, S. H. (2013) 'Prediction of Punching Shear Strength of HSC Interior Slab-Column Connections', *KSCE Journal of Civil Engineering*, 17(2), 473–485.

Elstner, R. C. and Hognestad, E. (1956) 'Shearing Strength of Reinforced Concrete Slabs', *Journal Proceedings*, 53(7), 29–58.

Facconi, L., Minelli, F. and Plizzari, G. (2016) 'Steel Fiber Reinforced Self-Compacting Concrete Thin Slabs-Experimental Study and Verification Against Model Code 2010 Provisions', *Engineering Structures*, 122, 226–237.

Farhey, D. N., Adin, M. A. and Yankelevsky, D. Z. (1993) ‘RC Flat Slab–Column Subassemblages Under Lateral Loading’, *Journal of Structural Engineering*, 119(6), 1903–1916.

Fernández Ruiz, M., Mirzaei, Y. and Muttoni, A. (2013) ‘Post-Punching Behavior of Flat Slabs Supported by Columns’, *ACI Structural Journal*, 110, 801–812.

Ferrara, L. (2003) ‘The Use of Viscosity Enhancing Admixtures to Improve the Homogeneity of Fibre Distribution in Steel Fibre Reinforced Concretes’, *Brittle Matrix Composites* 7, 287–300.

Ferrara, L. and Meda, A. (2006) ‘Relationships Between Fibre Distribution, Workability and The Mechanical Properties of SFRC Applied to Precast Roof Elements’, *Materials and Structures/Materiaux et Constructions*, 39(288), 411–420.

Foltz, R. R., Lee, D. H. and LaFave, J. M. (2017) ‘Biaxial Behavior of High-Performance Fiber-Reinforced Cementitious Composite Plates’, *Construction and Building Materials*. E143, 501–514.

Foster, S. (2010) 12 Design of FRC beams for shear using the VEM and the draft Model Code approach in Shear and Punching Shear in RC and FRC Elements: Technical Report. *Proceedings of a Workshop*. 15-16 October 2010. Salò, Lake Garda, Italy.

Gaimster, R. and Gibbs, J. (2001) ‘Current Practice Sheet 123: Self-Compacting Concrete. Part 1: The Material and its Properties’, *Concrete (London)*, 35(7), 32.

Gardner, N. J. (1990) ‘Relationship of the Punching Shear Capacity of Reinforced Concrete Slabs with Concrete Strength’, *ACI Structural Journal*, 87(1), 66–71.

Gardner, N. J., Huh, J. and Chung, L. (2002) ‘Lessons from the Sampoong Department Store Collapse’, *Cement and Concrete Composites*, 24(6), 523–529.

Girish, S., Ranganath, R. V. and Vengala, J. (2010) ‘Influence of Powder and Paste on Flow Properties of SCC’, *Construction and Building Materials*. 24(12), 2481–2488.

González-Taboada, I., González-Fonteboa, B., Eiras-López, J. and Rojo-López, G. (2017) ‘Tools for the Study of Self-Compacting Recycled Concrete Fresh Behaviour: Workability And Rheology’, *Journal of Cleaner Production*, 156, 1–18.

Gouveia, N. D., Fernandes, N. A. G., Faria, D. M. V, Ramos, A. M. P. and Lucio, V. J. G. (2014) 'SFRC Flat Slabs Punching Behaviour - Experimental Research', *Composites Part B: Engineering*. 63, 161–171.

Gouveia, N. D., Lapi, M. and Orlando, M. (2017) 'Experimental and Theoretical Evaluation of Punching Strength of Steel Fiber Reinforced Concrete Slabs', *Structural Concrete*, (November), 1–13.

Groth, P. and Nemegeer, D. (1999) *The Use of Steel Bars in Self-Compacting Concrete. 1st International RILEM Symposium on Self-Compacting Concrete*. Stockholm, Sweden: RILEM Publication.

Grunewald, S. (2004) *Performance-Based Design of Self-Compacting Fibre Reinforced Concrete, Technology*. Ph.D. thesis, Delft University of Technology, Netherlands.

Grünewald, S., Laranjeira, F., Walraven, J., Aguado, A. and Molins, C. (2012) 'Improved Tensile Performance with Fiber Reinforced Self-Compacting Concrete', *RILEM Bookseries*, 2, 51–58.

Grünewald, S. and Walraven, J. C. (2001) 'Parameter-Study on the Influence of Steel Fibers and Coarse Aggregate Content on the Fresh Properties of Self-Compacting Concrete', *Cement and Concrete Research*, 31(12), 1793–1798.

Gupta, N., Siddique, R. and Belarbi, R. (2021) 'Sustainable and Greener Self – Compacting Concrete incorporating Industrial By-Products: A Review', *Journal of Cleaner Production*, 284.

Hallgren, M. (1996) *Punching Shear Capacity of Reinforced High-Strength Concrete Slabs*. Ph.D. Thesis, KTH Stockholm, Royal Institute of Technology, Sweden.

Hameed, A. A. and Al-Sherrawi, M. H. (2018) 'Influence of Steel Fiber on the Shear Strength of a Concrete Beam', *Civil Engineering Journal*, 4(7), 1501–1509.

Hameed, R., Turatsinze, A., Duprat, F. and Sellier, A. (2009) 'Metallic Fiber Reinforced Concrete: Effect of Fiber Aspect Ratio on The Flexural Properties', *ARPN Journal of Engineering and Applied Sciences*, 4(5), 67–72.

Hamoush, S., Abu-Lebdeh, T. and Cummins, T. (2010) 'Deflection Behavior of Concrete Beams Reinforced with PVA Micro-Fibers', *Construction and Building Materials*, 24(11), 2285–2293.

De Hanai, J. B. and Holanda, K. M. A. (2008) 'Similarities Between Punching and Shear Strength of Steel Fiber Reinforced Concrete (SFRC) slabs and beams', *Ibracon Structures and Material Journal*, 1(1), 1–16.

Harajli, M. H., Maalouf, D. and Khatib, H. (1995) ‘Effect of Fibers on The Punching Shear Strength of Slab-Column Connections’, *Cement and Concrete Composites*, 17(2), 161–170.

Hawkins, N. M. (1974) ‘Shear Strength of Slabs with Shear Reinforcement’, *Special Publication*, 42, 785–816.

Hawkins, N. M. and Mitchell, D. (1979) ‘Progressive Collapse of Flat Plate Structures’, *J Am Concr Inst*, 76(7), 775–808.

Higashiyama, H., Ota, A. and Mizukoshi, M. (2011) ‘Design Equation for Punching Shear Capacity of SFRC Slabs’, *International Journal of Concrete Structures and Materials*, 5(1), 35–42.

Hughes, B. P. and Xiao, Y. (1995) ‘Flat slabs with Fibre or Link Reinforcement at Slab-Column Connections’, *Proceedings of the Institution of Civil Engineers: Structures and Buildings*, 110(3), 308–321.

Hwang, S. J. and Lee, H. J. (2002) ‘Strength Prediction for Discontinuity Regions by Softened Strut and Tie Model’, *Journal of Structural Engineering*, 128, 1519–1526.

Inácio, M. M. G., Almeida, A. F. O., Faria, D. M. V, Lúcio, V. J. G. and Ramos, A. P. (2015) ‘Punching of High Strength Concrete Flat Slabs without Shear Reinforcement’, *Engineering Structures*, 103, 275–284.

Ince, R., Yalcin, E. and Arslan, A. (2007) ‘Size-Dependent Response of Dowel Action in R.C. Members’, *Engineering Structures*, 29(6), 955–961.

Iqbal, S., Ali, A., Holschemacher, K. and Bier, T. A. (2015) ‘Mechanical Properties of Steel Fiber Reinforced High Strength Lightweight Self-Compacting Concrete (SHLSCC)’, *Construction and Building Materials*, 98, 325–333.

Islam, M. S. and Alam, S. (2013) ‘Principal Component and Multiple Regression Analysis for Steel Fiber Reinforced Concrete (SFRC) Beams’, *International Journal of Concrete Structures and Materials*, 7(4), 303–317.

Jatale, V. B. and Kalurkar, L. G. (2013) ‘Punching Shear High Strength Steel Fiber Reinforced Concrete Slabs’, *International Journal of Engineering Research and Applications*, 3(6), 269–275.

Jelić, I., Pavlović, M. N. and Kotsovos, M. D. (1999) ‘Study of Dowel Action in Reinforced Concrete Beams’, *Magazine of Concrete Research*, 51(2), 131–141.

Ju, H., Cheon, N.-R., Lee, D. H., Oh, J.-Y., Hwang, J.-H. and Kim, K. S. (2015) ‘Consideration On Punching Shear Strength of Steel-Fiber-Reinforced Concrete Slabs’, *Advances in Mechanical Engineering*, 7(5), 1-12.

Khaloo, A. R. and Afshari, M. (2005) ‘Flexural Behaviour of Small Steel Fibre Reinforced Concrete Slabs’, *Cement and Concrete Composites*, 27(1), 141–149.

Khaloo, A., Raisi, E. M., Hosseini, P. and Tahsiri, H. (2014) ‘Mechanical Performance of Self-Compacting Concrete Reinforced with Steel Fibers’, *Construction and Building Materials*, 51, 179–186.

Khayat, K. H., Ghezal, A. and Hadriche, M. S. (1999) ‘Factorial Design Models for Proportioning Self-Consolidating Concrete’, *Materials and Structures/Materiaux et Constructions*, 32(223), 679–686.

Khayat, K. H. and Roussel, Y. (2000) ‘Testing and Performance of Fiber-Reinforced, Self- Consolidating Concrete’, *ACI Materials Journal*, 33(July), 391–397.

Kheder, G. F. and Al Jadiri, R. S. (2010) ‘New Method for Proportioning Self-Consolidating Concrete Based on Compressive Strength Requirements’, *ACI Materials Journal*, 107(5), 490–497.

King, S. and Delatte, N. J. (2004) ‘Collapse of 2000 Commonwealth Avenue: Punching Shear Case Study’, *Journal of Performance of Constructed Facilities*, 18(1), 54–61.

Klug, Y. and Holschemacher, K. (2003) ‘Comparison of the Hardened Properties of Self-Compacting and Normal Vibrated Concrete’, *3rd International Symposium on Self-Compacting Concrete*, 596–605.

Kosaka, Y., Tanigawa, Y. and Hatanaka, S. (1985) ‘Lateral Confining Stresses Due to Steel Fibres in Concrete Under Compression’, *International Journal of Cement Composites and Lightweight Concrete*, 7(2), 81–92.

Kotsovos, M. D. and Pavlovic, M. N. (1998) *Ultimate Limit-State Design of Concrete Structures: A new approach*. Thomas Telford.

Kupfer, H., Hilsdorf, H. K. and Rusch, H. (1969) ‘Behaviour of Concrete Under Biaxial Stresses’, *ACI Journal*, 66(8), 656–666.

Lamide, J. A. (2017) *Shear Strength of Steel Fibre Self-Compacting Concrete in Precast Concrete Corbels.* Ph.D. Thesis, Universiti Teknologi Malaysia, Skudai.

Lamide, J. A., Mohamed, R. N. and Abd Rahman, A. B. (2016) 'Experimental Results on the Shear Behaviour of Steel Fibre Self-Compacting Concrete (SFSCC) Beams', *Jurnal Teknologi*, 78(11), 103–111.

Lee, S. J., Eom, A. H., Ryu, S. J. and Won, J. P. (2016) 'Optimal Dimension of Arch-Type Steel Fibre-Reinforced Cementitious Composite for Shotcrete', *Composite Structures*, 152, 600–606.

Leng, Y. B. and Song, X. B. (2017) 'Flexural and Shear Performance of Steel-Concrete-Steel Sandwich Slabs Under Concentrate Loads', *Journal of Constructional Steel Research*, 134, 38–52.

Li, V. C., Stang, H. and Krenchel, H. (1993) 'Micromechanics of Crack Bridging in Fibre-Reinforced Concrete', *Materials and Structures*, 26(8), 486–494.

Li, Z. (2011) *Advanced Concrete Technology*. Hoboken, New Jersey: John Wiley and Sons, Inc.

Lim, B. T. (1997) *Punching Shear Capacity of Flat Slab-Column Junctions (A Study by 3-D Non-Linear Finite Element Analysis)*. Doctoral Dissertation, University of Glasgow, Glasgow.

Lim, D. H. and Nawy, E. G. (2005) 'Behaviour of Plain Concrete and Steel-Fibre-Reinforced High-Strength Concrete under Uniaxial and Biaxial Compression', *Magazine of Concrete Research*, 57(10), 603–610.

Lim, D. H. and Oh, B. H. (1999) 'Experimental and Theoretical Investigation on the Shear of Steel Fibre Reinforced Concrete Beams', *Engineering Structures*, 21(10), 937–944.

Lim, T. Y., Paramasivam, P. and Lee, S. L. (1987) 'Analytical Model for Tensile Behaviour of Steel-Fiber Concrete', *ACI Materials Journal*, 84(4), 286–298.

Löfgren, I. (2005) *Fibre-reinforced Concrete for Industrial Construction- A Fracture Mechanics Approach to Material Testing and Structural Analysis*. Ph.D. Thesis, Chalmers University of Technology, Sweden.

Madandoust, R., Ranjbar, M. M., Ghavidel, R. and Fatemeh Shahabi, S. (2015) 'Assessment of Factors Influencing Mechanical Properties of Steel Fiber Reinforced Self-Compacting Concrete', *Materials and Design*, 83, 284–294.

Mangat, P. S. (1976) 'Tensile Strength of Steel Fiber Reinforced Concrete', *Cement and Concrete Research*, 6(2), 245–252.

Mansur, M. A., Chin, M. S. and Wee, T. H. (1999) ‘Stress-Strain Relationship of High-Strength Fiber Concrete in Compression’, *Journal of Materials in Civil Engineering*, 11(1), 21–29.

Marzouk, H. and Hussein, A. (1991) ‘Experimental Investigation on the Behavior of High-Strength Concrete Slabs’, *ACI Structural Journal*, 88(6), 701–713.

Marzouk, H. and Jiang, D. (1997) ‘Experimental Investigation on Shear Enhancement Types for High-Strength Concrete Plates’, *ACI Structural Journal*, 94(1), 49–58.

Maya, L. F., Fernández Ruiz, M., Muttoni, A. and Foster, S. J. (2012) ‘Punching Shear Strength of Steel Fibre Reinforced Concrete Slabs’, *Engineering Structures*, 40, 83–94.

Menétrey, P. (1996) ‘Analytical Computation of the Punching Strength of Reinforced Concrete’, *ACI Structural Journal*, September-October, 503–511.

Menétrey, P. (2002) ‘Synthesis of Punching Failure in Reinforced Concrete’, *Cement and Concrete Composites*, 24(6), 497–507.

Menetrey Ph. (1998) ‘Relationship between Flexural and Punching Failure’, *ACI Materials Journal*, 95(4), 412–419.

Michels, J., Waldmann, D., Maas, S. and Zürbes, A. (2012) ‘Steel Fibers as Only Reinforcement for Flat Slab Construction - Experimental Investigation and Design’, *Construction and Building Materials*, 26(1), 145–155.

Millard, S. G. and Johnson, R. P. (1984) ‘Shear Transfer Across Cracks in Reinforced Concrete Due to Aggregate Interlock and to Dowel Action’, *Magazine of concrete research*, 36(126), 9–21.

Moe, J. (1961) *Shearing Strength of Reinforced Concrete Slabs and Footings under Concentrated Loads.* Portland Cement Association, Research and Development Laboratories.

Mohamed, R. N. (2009) *Shear Strength of Precast Beam-Half Joints Using Steel Fibre Self-Compacting Concrete*, Ph.D. thesis, University of Nottingham, Nottingham.

Mohamed, R. N., Zamri, N. F., Elliott, K. S., Rahman, A. B. A. and Bakhary, N. (2019) ‘Steel Fibre Self-Compacting Concrete under Biaxial Loading’, *Construction and Building Materials*, 224, 255–265.

Mohsin, S. M. S., Manaf, M. F., Sarbini, N. N. and Muthusamy, K. (2016) 'Behaviour of Reinforced Concrete Beams with Kenaf and Steel Hybrid Fibre', *ARPN Journal of Engineering and Applied Sciences*, 11(8), 5385–5390.

Moraes Neto, B. N., Barros, J. A. O. and Melo, G. S. S. A. (2013) 'A Model for the Prediction of the Punching Resistance of Steel Fibre Reinforced Concrete Slabs Centrically Loaded', *Construction and Building Materials*, 46, 211–223.

Murugappan, B. K., Paramasivam, P. and Tan, K. H. (1994) 'Composite Strain', *Journal of Materials*, 5(4), 436–446.

Musa, M. Y., Yaacob, M. N. A. and Hamzah, S. H. (2012) 'Effect of Steel Fibres in Inhibiting Flexural Cracks in Beam', *Malaysian Construction Research Journal*, 10(1), 17–31.

Muttoni, A. (2008) 'Punching Shear Strength of Reinforced Concrete Slabs without Transverse Reinforcement', *ACI Structural Journal*, 105(4), 440–450.

Naaman, A. E. and Reinhardt, H. W. (1996) Characterization of High Performance Fiber Reinforced Cement Composites—HPFRCC. *Proceeding on the Second International Workshop 'High Performance Fiber Reinforced Cement Composites'*. 11-14 June 1995. Ann Arbor, USA, 1-24.

Narayanan, R. and Darwish, I. Y. S. (1987) 'Punching Shear Tests on Steel-Fibre-Reinforced Micro-Concrete Slabs', *Magazine of Concrete Research*, 39(138), 42–50.

Narayanan, R. and Darwish, I. Y. S. (1987b) 'Use of Steel Fibers as Shear Reinforcement', *ACI Structural Journal*, 84(3), 216–227.

Nguyen, T. N., Nguyen, T. T. and Pansuk, W. (2017) 'Experimental Study of the Punching Shear Behavior of High Performance Steel Fiber Reinforced Concrete Slabs Considering Casting Directions', *Engineering Structures*, 131, 564–573.

Nguyen-Minh, L., Rovňák, M. and Tran-Quoc, T. (2012) 'Punching Shear Capacity of Interior SFRC Slab-Column Connections', *Journal of Structural Engineering*, 138(5), 613–624.

Nguyen-Minh, L., RovňÁk, M., Tran-Quoc, T. and Nguyen-Kim, K. (2011) 'Punching Shear Resistance of Steel Fiber Reinforced Concrete Flat Slabs', *Procedia Engineering*, 14, 1830–1837.

Okamura, H. and Ouchi, M. (2003) 'Self-Compacting Concrete', *Journal of Advanced Concrete Technology*, 1(1), 5–15.

Okamura, H. and Ozawa, K. (1995) ‘Mix Design for Self-Compacting Concrete’, *Concrete library of JSCE*, 25(6), 107–120.

Olivito, R. S. and Zuccarello, F. A. (2010) ‘An Experimental Study on the Tensile Strength of Steel Fiber Reinforced Concrete’, *Composites Part B: Engineering*, 41(3), 246–255.

Owens, P. L. (1999) ‘Pulverised-Fuel Ash. Part I: Origin and Properties’, *Concrete (London)*, 33(4), 27–28.

Ozawa, K., Maekawa, K., Kunishima, M. and Okamura, H. (1989) ‘Development of High Performance Concrete Based on the Durability Design of Concrete Structures’, *Proceeding of the Second East - Asia and Pacific Conference on Structural Engineering and Construction (EASEC - 2)*, 445–450.

Ozden, S., Ersoy, U. and Ozturan, T. (2006) ‘Punching Shear Tests of Normal and High Strength Concrete Flat Plates’, *Canadian Journal of Civil Engineering*, 33(11), 1389–1400.

Ozyurt, N., Mason, T. O. and Shah, S. P. (2007) ‘Correlation of Fiber Dispersion, Rheology and Mechanical Performance of FRCs’, *Cement and Concrete Composites*, 29(2), 70–79.

Paine, K. A. (1998) *Steel Fibre Reinforced Concrete for Pre stressed Hollow Core Slabs*. Ph.D. Thesis. University of Nottingham, Nottingham.

Pająk, M. and Ponikiewski, T. (2013) ‘Flexural Behavior of Self-Compacting Concrete Reinforced with Different Types of Steel Fibers’, *Construction and Building Materials*, 47, 397–408.

Park, H. G., Ahn, K. S., Choi, K. K. and Chung, L. (2007) ‘Lattice Shear Reinforcement for Slab-Column Connections’, *ACI Structural Journal*, 104(3), 294–303.

Park, H. G. and Choi, K. K. (2007) ‘Strength of Exterior Slab-Column Connections Subjected to Unbalanced Moments’, *Engineering Structures*, 29(6), 1096–1114.

Park, H. G., Choi, K. K. and Chung, L. (2011) ‘Strain-Based Strength Model for Direct Punching Shear of Interior Slab-Column Connections’, *Engineering Structures*, 33(3), 1062–1073.

PCA–Portland Cement Association (2005). Economical Concrete Floor System. Illinois: Portland Cement Association.

Persson, B. (2001) ‘A Comparison between Mechanical Properties of Self-Compacting Concrete and the Corresponding Properties of Normal Concrete’, *Cement and Concrete Research*, 31(2), 193–198.

Pierre, P., Pleau, R. and Pigeon, M. (1999) ‘Mechanical Properties of Steel Microfiber Reinforced Cement Pastes and Mortars’, *Journal of Materials in Civil Engineering*, 11(4), 317–324.

Pilakoutas, K. and Li, X. (2003) ‘Alternative Shear Reinforcement for Reinforced Concrete Flat Slabs’, *Journal of Structural Engineering*, 129(9), 1164–1172.

Ponikiewski, T. (2011) ‘The Rheology of Fresh Steel Fibre Reinforced Self-Compacting Mixtures’, *Architecture Civil Engineering Environment*, 4(2), 65–72.

Ponikiewski, T. and Katzer, J. (2017) ‘Fresh Mix Characteristics of Self-Compacting Concrete Reinforced by Fibre’, *Periodica Polytechnica Civil Engineering*, 61(2), 226–231.

Prudencio, L., Austin, S., Jones, P., Armelin, H. and Robins, P. (2006) ‘Prediction of Steel Fibre Reinforced Concrete under Flexure from an Inferred Fibre Pull-Out Response’, *Materials and Structures/Materiaux et Constructions*, 39(6), 601–610.

Pruijssers, A. F. (1988) *Aggregate Interlock and Dowel Action under Monotonic and Cyclic* Loading. Ph.D. Thesis, Delft University of Technology: Delft, The Netherlands.

Ragab, K. S. (2013) ‘Study Punching Shear of Steel Fiber Reinforced Self Compacting Concrete Slabs by Nonlinear Analysis’, *International Journal of Civil and Environmental Engineering*, 7(9), 123–134.

Rankin, G. I. B. and Long, A. E. (1987) ‘Predicting the Punching Strength of Conventional Slab-Column Specimens.’, *Proceedings of the Institution of Civil Engineers (London)*, 82, 327–346.

Regan, P. (1981) *Behaviour of Reinforced Concrete Flat Slabs*. Construction Industry Research and Information Association.

Regan, P. E. (1983) *Punching shear in prestressed concrete slab bridges*. Polytechnic of Central London Engineering Structures Research Group.

Regan, P. E. and Braestrup, M. W. (1985) *Punching shear in reinforced concrete—a state-of-art report by CEB Bull.* Comité euro-international du béton.

Reinhardt, H. W. and Walraven, J. C. (1982) ‘Crack in Concrete Subject to Shear’, *ASCE J Struct Div*, 108(ST1), 207–224.

RILEM-TC-162-TDF (2003) ‘Test and Design Methods for Steel Fibre Reinforced Concrete’, *Materials and Structures/Materiaux et Constructions*, 36(262), 560–567.

Rizk, E., Marzouk, H. and Tiller, R. (2012) ‘Design of Thick Concrete Plates using Strut-and-Tie Model’, *ACI Structural Journal*, 109(5), 677–686.

Romualdi, J. P. and Mandel, J. A. (1964) ‘Tensile Strength of Concrete Affected by Uniformly Distributed and Closely Spaced Short Lengths of Wire Reinforcement’, *Journal Proceedings*, 61, 657–672.

Ruiz, M. F. and Muttoni, A. (2009) ‘Applications of Critical Shear Crack Theory to Punching of Reinforced Concrete Slabs with Transverse Reinforcement’, *ACI Structural Journal*, 106(4), 485–494.

Sanjeev, J. and Sai Nitesh, K. J. N. (2020) ‘Study on the Effect of Steel and Glass Fibers on Fresh and Hardened Properties of Vibrated Concrete and Self-Compacting Concrete’, *Materials Today: Proceedings*, 27, 1559–1568.

Schlaich, J. and Schiifer, K. (1991) ‘Design and Detailing of Structural Concrete using Strut and Tie Models’, *The structural Engineer*, 69(6), 113–125.

Schlaich, J. and Weischede, D. (1982) *Detailing of Concrete Structures: First Draft of a Design Manual*. Comité Euro-International du Beton.

Schumacher, P. (2006) *Rotation Capacity of Self-Compacting Steel Fiber Reinforced Concrete*. Ph.D. Thesis, Delft University of Technology.

Sermet, F. and Ozdemir, A. (2016) ‘Investigation of Punching Behaviour of Steel and Polypropylene Fibre Reinforced Concrete Slabs Under Normal Load’, *Procedia Engineering*. 161, 458–465.

Shaaban, A. M. and Gesund, H. (1994) ‘Punching Shear Strength of Steel Fiber Reinforced Concrete Flat Plates’, *ACI Structural Journal*, 91(4), 406–414.

Sharma, A. K. (1986) ‘Shear Strength of Steel Fiber Reinforced Concrete Beams.’, *Journal of the American Concrete Institute*, 83(4), 624–628.

Shiming, S. and Yupu, S. (2013) ‘Dynamic Biaxial Tensile-Compressive Strength and Failure Criterion of Plain Concrete’, *Construction and Building Materials*, 40, 322–329.

Shindoh, T. and Matsuoka, Y. (2003) 'Development of Combination-Type Self-Compacting Concrete and Evaluation Test Methods', *Journal of Advanced Concrete Technology,* 1(1)*,* 26–36.

Siddique, R., Aggarwal, P. and Aggarwal, Y. (2012) 'Influence of Water / Powder Ratio on Strength Properties of Self-Compacting Concrete Containing Coal Fly Ash and Bottom Ash'*, Construction and Building Materials,* 29*,* 73–81.

Siddique, R., Kaur, G. and Kunal (2016) 'Strength and Permeation Properties of Self-Compacting Concrete Containing Fly Ash and Hooked Steel Fibres', *Construction and Building Materials,* 103*,* 15–22.

Singh, S. P., Singh, A. P. and Bajaj, V. (2010) 'Strength and Flexural Toughness of Concrete Reinforced with Steel - Polypropylene Hybrid Fibres', *Asian Journal of Civil Engineering,* 11(4)*,* 495–507.

Skadins, U. and Brauns, J. (2008) 'Influence of Fibre Amount on SFRC Pre- and Post-Crack Behaviour', *4th International Conference Civil Engineering 13 Proceeding Part 1 Structural Engineering*, 91–98.

Skarendahl, A. (2003) 'The Present-The Future', *Proceedings of the 3rd International RILEM Symposium*, 6–14.

Skarendahl, A. and Petersson, Ö. (2000) 'State-of-The-Art Report of RILEM Technical Committee 174-SCC, Self-Compacting Concrete.', *RILEM Publication*, 17–22.

Smarzewski, P. (2018) 'Flexural Toughness of High-Performance Concrete with Basalt and Polypropylene Short Fibres', *Advances in Civil Engineering*, 2018.

Soetens, T. and Matthys, S. (2014) 'Different Methods to Model the Post-Cracking Behaviour of Hooked-End Steel Fibre Reinforced Concrete', *Construction and Building Materials,*73, 458–471.

Sonebi, M. (2004) 'Medium Strength Self-Compacting Concrete Containing Fly Ash: Modelling using Factorial Experimental Plans', *Cement and Concrete Research,* 34(7), 1199–1208.

Sonebi, M., Bartos, P. J., Zhu, W., Gibbs, J. and Tamimi, A. (2000) Task 4 Properties of Hardened Concrete*, Brite Euram Proposal No. BE96-3801*.

Song, P. S. and Hwang, S. (2004) 'Mechanical Properties of High-Strength Steel Fiber-Reinforced Concrete', *Construction and Building Materials,* 18(9), 669–673.

Soulioti, D. V., Barkoula, N. M., Paipetis, A. and Matikas, T. E. (2011) ‘Effects of Fibre Geometry and Volume Fraction on the Flexural Behaviour of Steel-Fibre Reinforced Concrete’, *Strain*, 47, 535–541.

Srikar, G., Anand, G. and Suriya Prakash, S. (2016) ‘A Study on Residual Compression Behavior of Structural Fiber Reinforced Concrete Exposed to Moderate Temperature Using Digital Image Correlation’, *International Journal of Concrete Structures and Materials*, 10(1), 75–85.

Stähli, P. and van Mier, J. G. M. (2007) ‘Manufacturing, Fibre Anisotropy and Fracture of Hybrid Fibre Concrete’, *Engineering Fracture Mechanics*, 74(1–2), 223–242.

Stevenson, A. M. (1994) *Post-tensioned Concrete Floors in Multi-Storey Buildings: An Introduction to the Development, Benefits, Design and Construction of In-Situ Pre-Stressed Suspended Floors*. British Cement Association.

Su, N., Hsu, K. C. and Chai, H. W. (2001) ‘A Simple Mix Design Method for Self-Compacting Concrete’, *Cement and Concrete Research*, 31(12), 1799–1807.

Su, N. and Miao, B. (2003) ‘A New Method for the Mix Design of Medium Strength Flowing Concrete with Low Cement Content’, *Cement and Concrete Composites*, 25(2), 215–222.

Sukumar, B., Nagamani, K. and Srinivasa Raghavan, R. (2008) ‘Evaluation of Strength at Early Ages of Self-Compacting Concrete with High Volume Fly Ash’, *Construction and Building Materials*, 22(7), 1394–1401.

Sunarmasto and Adi Kristiawan, S. (2015) ‘Effect of Fly Ash on Compressive Strength and Porosity of Self-Compacting Concrete’, *Applied Mechanics and Materials*, 754–755, 447–451.

Swamy, R. N. and Al-Ta’an, S. A. (1981) ‘Deformation and Ultimate Strength in Flexure of Reinforced Concrete Beams Made with Steel Fiber Concrete.’, *Journal of the American Concrete Institute*, 78(5), 395–405.

Swamy, R. N. and Bahia, H. M. (1985) ‘The Effectiveness of Steel Fibers as Shear Reinforcement’, *Concrete International*, 7(3), 35–40.

Tadepalli, P. R., Dhonde, H. B., Mo, Y. L. and Hsu, T. T. C. (2015) ‘Shear Strength of Prestressed Steel Fiber Concrete I-Beams’, *International Journal of Concrete Structures and Materials*, 9(3), 267–281.

Tan, K. H., Murugappan, K. and Paramasivam, P. (1994) 'Constitutive Relation for Steel Fibre Concrete under Biaxial Compression', *Cement and Concrete Composites*, 16, 9–14.

Tan, K. H. and Venkateshwaran, A. (2017) 'Punching Shear in Steel Fibre Reinforced Concrete Slabs Without Traditional Reinforcement', *IOP Conference Series: Materials Science and Engineering*, 246(1).

Tassinari, L., Lips, S., Muttoni, A. and Fern, M. (2011) 'Applications of Bent-Up Bars as Shear and Integrity Reinforcement in R / C Slabs', *fib Symposium Prague 2011* ,631–634.

Tasuji, M. E., Slate, F. O. and Nilson, A. H. (1978) 'Stress-Strain Response and Fracture of a Concrete Model in Biaxial Loading', *ACI Journal*, 75(7), 306–312.

The European Project Group (2005) *The European Guidelines for Self-Compacting Concrete Specification, Production and Use*. United Kingdom: The European Project Group.

Theodorakopoulos, D. D. (1981) *Punching Shear Strength of Steel Fibre Reinforced Lightweight Concrete Slabs*. Ph.D. Thesis, University of Sheffield, Sheffield.

Theodorakopoulos, D. D. and Swamy, R. N. (2002) 'Ultimate Punching Shear Strength Analysis of Slab-Column Connections', *Cement and Concrete Composites*, 24(6), 509–521.

Thomas, J. and Ananth, R. (2007) 'Mechanical Properties of Steel Fiber-Reinforced Concrete', *Journal of Materials in Civil Engineering*, 19(5), 385–392.

Tiller, R. W. (1995) *Strut-and-tie model for punching shear of concrete slabs*. Master Thesis, Memorial University of Newfoundland.

Tjhin, T. N. and Kuchma, D. A. (2002) 'Computer-Based Tools for Design by Strut-and-Tie Method: Advances and Challenges', *ACI Structural Journal*, 99(5), 586–594.

Torrenti, J. M. and Djebri, B. (1995) 'Behaviour of Steel-Fibre-Reinforced Concretes under Biaxial Compression Loads', *Cement and Concrete Composites*, 17(4), 261–266.

Traina, L. A. and Mansour, S. A. (1991) 'Biaxial Strength and Deformational Behavior of Plain and Steel Fiber Concrete', *ACI Materials Journal*, 88(4), 354–362.

Tran, V. L. and Kim, S. E. (2020) 'A Practical ANN Model for Predicting the PSS of Two-Way Reinforced Concrete Slabs', *Engineering with Computers*.

Tuan Ngo, D. (2003) ‘Punching Shear Resistance of High-Strength Concrete Slabs’, *Electronic Journal of Structural Engineering,* 1(1), 2–14.

Turk, K., Karatas, M. and Gonen, T. (2013) ‘Effect of Fly Ash and Silica Fume On Compressive Strength, Sorptivity and Carbonation of SCC’, *KSCE Journal of Civil Engineering*, 17, 202–209.

Vecchio, F. J. and Collins, M. P. (1986) ‘Modified Compression-Field Theory for Reinforced Concrete Elements Subjected to Shear.’, *Journal of the American Concrete Institute*, 83(2), 219–231.

Walraven, J. (2003) ‘Structural Aspects of Self-Compacting Concrete’, *International RILEM Symposium on Self-Compacting Concrete,* 15-22

Walraven, J. C. (1981) ‘Fundamental Analysis of Aggregate Interlock’, *ASCE J Struct Div*, 107(11), 2245–2270.

Wille, K. and Naaman, A. E. (2012) ‘Pullout Behavior of High-Strength Steel Fibers Embedded in Ultra-High-Performance Concrete’, *ACI Materials Journal*, 109(4), 479–488.

Wood, J. G. M. (2003) *Pipers Row Car Park Wolverhampton: Quantitative Study of the Causes of the Partial Collapse on 20th March 1997, Structural Studies & Design Ltd*. Chiddingfold, UK.

Wu, Z., Shi, C., He, W. and Wu, L. (2016) ‘Effects of Steel Fiber Content and Shape on Mechanical Properties of Ultra High Performance Concrete’, *Construction and Building Materials*. 103, 8–14.

Yankelevsky, D. Z. and Leibowitz, O. (1999) ‘Punching Shear in Concrete Slabs’, *International Journal of Mechanical Sciences*, 41(1), 1–15.

Yap, S. P., Bu, C. H., Alengaram, U. J., Mo, K. H. and Jumaat, M. Z. (2014) ‘Flexural Toughness Characteristics of Steel-Polypropylene Hybrid Fibre-Reinforced Oil Palm Shell Concrete’, *Materials and Design*, 57, 652–659.

Yazici, Ş., Inan, G. and Tabak, V. (2007) ‘Effect of Aspect Ratio and Volume Fraction of Steel Fiber on the Mechanical Properties of SFRC’, *Construction and Building Materials*, 21(6), 1250–1253.

Yehia, S., Douba, A. E., Abdullahi, O. and Farrag, S. (2016) ‘Mechanical and Durability Evaluation of Fiber-Reinforced Self-Compacting Concrete’, *Construction and Building Materials*, 121, 120–133.

Yin, W. S., Su, E. C. M., Mansur, M. A. and Hsu, T. T. C. (1989) ‘Biaxial Tests of Plain and Fiber Concrete’, *ACI Materials Journal*, 86(3), 236–243.

Yusof, M. A., Nor, N. M., Fauzi, M., Zain, M., Peng, N. C., Ismail, A., Sohaimi, R. M., Mujahid, A. and Zaidi, A. (2011) 'Mechanical Properties of Hybrid Steel Fibre Reinforced Concrete with Different Aspect Ratio', *Australian Journal of Basic and Applied Sciences*, 5(7), 159–166.

Zamri, N. F., Mohamed, R. N., Ab Kadir, M. A., Awalluddin, M. D. K., Mansor, S., Ahmad Shukri, N. and Mahmoor, M. S. N. (2019) 'The Flexural Strength Properties of Steel Fibre Reinforced Self-Compacting Concrete (SFRSCC)', *Malaysian Construction Research Journal*, 6(1), 193–203.

Zollo, R. F. (1997) 'Fiber-Reinforced Concrete: An Overview After 30 Years of Development', *Cement and Concrete Composites*, 107–122.

LIST OF PUBLICATIONS

Indexed Journal

a) **Zamri, N. F.**, Mohamed, R. N., Ab Kadir, M. A., Awalluddin, M. D. K., Mansor, S., Ahmad Shukri, N. and Mahmoor, M. S. N. (2019) 'The flexural strength properties of steel fibre reinforced self-compacting concrete (SFRSCC)', *Malaysian Construction Research Journal*, 6(1), 24-35. **(Indexed by SCOPUS)**

Indexed Conference Proceeding

a) **Zamri, N. F.**, Mohamed, R. N., Khalid, N. H. A., Mansor, S., Shukri, N. A., Mahmoor, M. S. N. and Awalluddin, M. D. K. (2018) 'Performance of medium strength of steel fibre reinforced self-compacting concrete (SFRSCC)', *IOP Conference Series: Materials Science and Engineering*, 431, 1-8. **(Indexed by SCOPUS)**

b) **Zamri, N. F.**, Mohamed, R. N. and Awalluddin, D. (2020) 'The experimental studies of punching shear behaviour of reinforced concrete flat slab with the inclusion of steel fibre: Overview', *IOP Conference Series: Materials Science and Engineering*, 849, 1–10. **(Indexed by SCOPUS)**