Jurnal
Teknologi

Full Paper

PUNCHING SHEAR RESISTANCE OF STEEL FIBRE REINFORCED SELF-COMPACTING CONCRETE ONE-WAY RIBBED SLAB

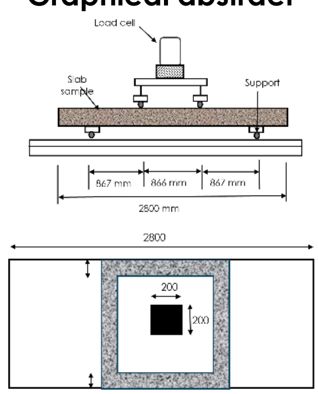
Muhammad Haziq Hizrami[a], Najwa Mohammad Fadzil[b], Mohd Hisbany Mohd Hashim[b]*, Hazrina Ahmad[b], Nurulain Hanida Mohd Fodzi[c], Mohd Fakri Muda[d], Marzuki Ab Rahman[d], Amin Al-Fakih[e,f], Abdul Rahman Mohd Sam[g]

[a]Industrial and Housing Estate, Lot 3, Jalan RP, Taman Rawang Perdana, Kawasan Industri Rawang Perdana, 48000 Rawang, Selangor, Malaysia
[b]Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[c]Department of Surveying, Lee Khong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, 43000 Cheras, Selangor, Malaysia
[d]Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM), Pahang Branch, Jengka Campus, Bandar Pusat Jengka, 26400 Jengka, Pahang, Malaysia
[e]Department of Civil and Environmental Engineering, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia
[f]Interdisciplinary Research Center for Construction and Building Materials, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia
[g]Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Article history
Received
22 August 2024
Received in revised form
26 November 2024
Accepted
27 November 2024
Published Online
26 June 2025

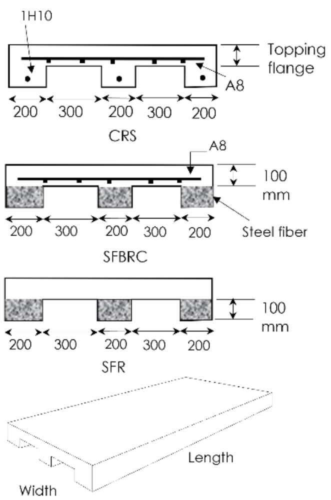
*Corresponding author
hisbany@uitm.edu.my

Graphical abstract



Abstract

In the field of modern construction engineering, the steel fiber reinforced self-compacting concrete (SFRSCC) represents a significant advancement over conventional reinforcement methodologies, presenting a promising avenue for achieving economic and temporal efficiencies without sacrificing structural robustness. This study focuses on the use of SFRSCC in the context of one-way ribbed slabs, which are strategically chosen for optimal performance in scenarios requiring an appropriate compromise of architectural aesthetics and mechanical strength, particularly in structures with medium spans, strict height, and overall mass constraints. The study investigates the advantages of the inherent stiffness of ribbed slabs and the outstanding compaction capabilities of self-compacting concrete (SCC) using an in-depth method that involves material selection, mix design, sample preparation, and comprehensive testing. The empirical results of this work show a considerable increase in the load-bearing capacity and ductility of SFSCC slabs, which is an immediate consequence of the steel fibers' characteristic high tensile strength and crack mitigation capabilities. This investigation highlights the improved structural performance and durability of SFRSCC in one-way ribbed slab applications and provides substantial evidence for its broader utilization in a variety of structural engineering projects, signalling a paradigm change in the direction of more sustainable and effective construction techniques.



Testing set-up and ribbed slab design

Keywords: Self-compacting concrete, Ribbed slab, Steel fibers, Flexural behavior, Cracking, Full replacement

Abstrak

Dalam bidang kejuruteraan pembinaan moden, konkrit mampatan diri bertetulang serat keluli (SFRSCC) mewakili kemajuan yang signifikan berbanding dengan metodologi tetulang konvensional, menawarkan jalan yang menjanjikan untuk mencapai kecekapan ekonomi dan masa tanpa mengorbankan kekuatan struktur. Kajian ini memfokuskan penggunaan SFRSCC dalam konteks slab berpenampang satu hala, yang dipilih secara strategik untuk prestasi optimum dalam senario yang memerlukan kompromi yang sesuai antara estetika seni bina dan kekuatan mekanikal, terutamanya dalam struktur dengan rentang sederhana, ketinggian yang ketat, dan kekangan jisim keseluruhan. Kajian ini menyiasat kelebihan kekakuan semula jadi slab berpenampang dan keupayaan mampatan cemerlang konkrit mampatan diri (SCC) menggunakan kaedah mendalam yang melibatkan pemilihan bahan, reka bentuk campuran, penyediaan sampel, dan ujian menyeluruh. Hasil empirikal kerja ini menunjukkan peningkatan yang ketara dalam kapasiti daya tampung dan keteguhan slab SFSCC, yang merupakan akibat langsung daripada kekuatan tegangan tinggi serat keluli dan keupayaan mitigasi retakan. Penyiasatan ini menyerlahkan prestasi struktur yang dipertingkatkan dan ketahanan SFRSCC dalam aplikasi slab berpenampang satu hala dan menyediakan bukti yang substansial untuk penggunaannya yang lebih luas dalam pelbagai projek kejuruteraan struktur, menandakan perubahan paradigma ke arah teknik pembinaan yang lebih mampan dan berkesan.

Kata kunci: Konkrit mampatan diri, Slab berpenampang, Serat keluli, Kekuatan lentur, Retakan, Penggantian sepenuhnya

1.0 INTRODUCTION

Ribbed slabs, characterized by evenly spaced ribs often topped with concrete, resemble T-beams or waffle systems and offer significant structural and economic benefits. By strategically removing concrete below the neutral axis, ribbed slabs reduce structural weight, minimize material usage, and decrease reinforcement requirements, resulting in more cost-effective and efficient designs for various applications [1], [2], [3]. However, these advantages come with challenges, particularly regarding load-bearing capacity, as the reduced cross-sectional areas can lead to high stress concentrations under concentrated loads [4], [5], [6].

Historical structural failures, such as the collapses of the Sampoong Department Store in Korea [7], Champlain Towers South Condominium in the United States [8], and Skyline Plaza in Virginia, USA [9], underscore the critical need for robust reinforcement strategies to improve punching shear resistance and prevent catastrophic failures. These events highlight the necessity of innovative approaches to enhance the structural performance and safety of ribbed slabs under various loading conditions.

One promising advancement in this field is the integration of steel fibers into concrete, which significantly enhances mechanical properties, including tensile strength, flexural rigidity, and crack resistance [10], [11], [12], [13]. Steel fibers with high aspect ratios improve ductility and load redistribution, mitigating concrete's inherent brittleness and providing superior stress distribution within the slab matrix [14], [15], [16]. Recent research has further demonstrated that incorporating steel fibers enhances the toughness and energy dissipation capacity of concrete under dynamic and concentrated loading conditions [19], [20], [21].

Self-compacting concrete (SCC) has revolutionized construction with its ability to flow under its own weight, eliminating the need for vibration during placement and reducing labor costs and construction time [17]. When combined with steel fibers, SCC meets advanced structural demands that conventional concrete cannot fulfill. Studies show that steel-fiber-reinforced self-compacting concrete (SFRSCC) improves residual flexural strength and toughness through enhanced pullout mechanisms and stronger bonding between the fibers and the composite matrix [22], [23]. Optimal fiber volume fractions, typically between 0.5% and 1.5%, ensure a balance between structural integrity and workability [24], [25], [26].

In recent advancements, research by Shubber *et al*. [27] explored the use of eco-friendly materials in producing economical reinforced concrete slabs, indicating potential sustainability benefits in modern construction. Similarly, Balamuralikrishnan *et al*. [28] demonstrated the efficacy of seismic strengthening of

RC beams using externally bonded fiberglass laminates, emphasizing structural resilience. Afifi *et al.* [29] investigated the punching capacity of ultra-high-performance concrete (UHPC) post-tensioned flat slabs, presenting new insights into enhanced shear resistance in slab systems. These studies illustrate the need for innovative approaches to enhance both performance and sustainability in concrete structures.

Despite these advancements, gaps remain in understanding the specific impacts of steel fibers on punching shear resistance in ribbed slabs, especially in one-way systems. While studies have addressed general mechanical improvements, the application of SFRSCC in ribbed slabs under practical loading conditions remains underexplored. This research aims to address this gap by systematically analyzing the punching shear resistance and overall structural performance of ribbed slabs reinforced with SFRSCC. By comparing plain self-compacting concrete (PSCC), SFRSCC, steel-fiber bar-reinforced concrete (SFBRC), and steel-fiber-reinforced (SFR) configurations, this study seeks to identify optimal reinforcement strategies for enhancing the load-bearing capacity and durability of ribbed slabs. The objectives of this study are:

1. To evaluate the impact of steel fibers on the mechanical properties and workability of self-compacting concrete.
2. To assess the punching shear resistance of ribbed slabs reinforced with different configurations of SFRSCC.
3. To provide comparative insights into the performance of these slabs against conventional reinforcement strategies, highlighting their suitability for sustainable and efficient construction.

This work aligns with the European Guidelines for Self-Compacting Concrete [17] and contributes to advancing the understanding and application of SFRSCC in ribbed slab systems. The findings are expected to provide a foundation for adopting innovative, cost-effective, and sustainable reinforcement strategies in structural engineering.

2.0 METHODS AND MATERIALS

The methodology of this research is divided into three primary phases: 1) preliminary study and sample preparation; 2) experimental testing and data collection; and 3) result analysis and conclusion. The following subsections elaborate on each phase with more comprehensive details.

2.1 Design Mix

Two SCC mixtures were studied, a standard mix and another with 60-mm hooked-end steel fibers, comprising 1% of the total volume. The concrete was mixed using a truck mixer to ensure uniform distribution of fibers and cementitious materials. To homogenize the mix, the steel fibers were added gradually over five minutes while the concrete was in the mixer to prevent clumping. After mixing, the concrete was cast into molds of different dimensions. The mix proportions are detailed in Table 1.

Table 1 SCC mix

No	Material	Value (kg/m^3)
1	Ordinary Portland Cement	315
2	Water (w/c:0.44)	185
3	Fine Aggregate	865
4	Coarse Aggregate	831
5	Steel Fiber Concrete Reinforcement HE 0.55/35-1%	80

2.2 Compressive Test

Compressive strength testing for the SFRSCC followed BS EN 12390-3:2009 standards using both cube (150 mm^3) and cylindrical (300 mm × 150 mm) specimens. Specimens (as tabulated in Table 2) were precisely centered on a testing platform using a base plate to ensure even load application by an ELE 3000 kN capacity machine, which recorded the load at failure. This process was repeated for all specimens, with compressive strength calculated per the standard in Equation 1.

Table 2 Specimen distribution

Specimens Dimension(mm)	Steel Fibers	Labelling	No of sample
Cube 150 × 150 × 150	Plain (P)-0%	CU-PSCC	12
	Steel fiber (SF)-1%	CU-SFRSCC	12
Cylinder (Y) 300 × 150Ø	Plain (P)-0%	CY-PSCC	3
	Steel fiber (SF)-1%	CY-SFRSCC	3

f_{cu} and $f_{ck} = \frac{P}{[illegible]}$ Equation 1

Specimen preparation involved cleaning molds and applying oil to prevent adhesion, followed by a 24-hour room-temperature cure under wet gunny sacks and further immersion in a curing tank for up to 42 days. Post-curing, specimens were brought to room temperature before testing.

2.3 Slump Test

Slump flow tests were conducted according to BS EN 12350-8:2010 to evaluate the workability of the concrete. The concrete mix was poured into a standard slump cone placed on a flat, supported base plate. The cone was gradually lifted, allowing the concrete to spread freely. The time to reach a spread of 500 mm was recorded (T500 flow time), as well as the final spread diameter. This test was particularly important to assess the effects of steel fibers on the flow properties of SCC.

2.4 J-Ring Test

The J-ring test, as per BS EN 12350-12:2010, was used to evaluate the passing ability of SCC through dense reinforcement. The slump cone was placed within the J-ring, and the fresh SCC was poured inside. The flow spread, flow time, and blocking were recorded to examine the effect of steel fibers in restricting flow. The J-ring test demonstrated the concrete's ability to pass through the reinforcement without segregation, with steel fibers posing a particular challenge due to potential blockage.

2.5 Ribbed Slab Design and Casting

The study's ribs, designed for real-life applications, explored slab performance under punching shear. Different reinforcement types were used as indicated in Figure 1, including CRS slab with Y10 steel bars in the ribs and BRC A8 wire mesh in the topping, SFBRC with steel fibers in the ribs and wire mesh in the topping, and SFR with only steel fibers in the ribs. All slabs had the same dimensions (2800 mm by 1200 mm) with rib widths of 200 mm and 300 mm spacing.

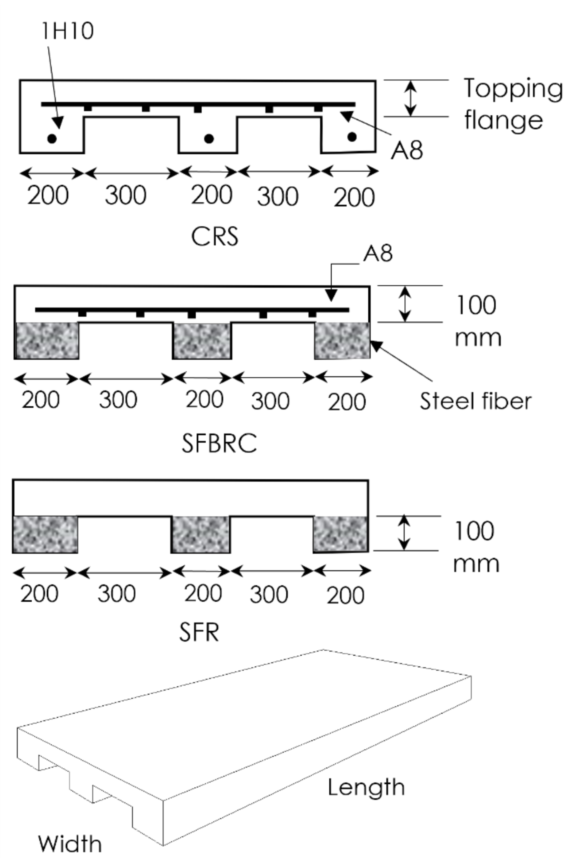


Figure 1 The cross-section front view in mm

The structural matrix uses Grade 30 concrete, consistent with Public Work Department standards, and incorporates hooked-end steel fibers with a tensile strength of 1100 MPa, a diameter of 0.55 mm, and a length of 35 mm. A fiber volume fraction of 1% (80 kg/m3) enhances the composite's properties without affecting workability.

Lightweight aluminum formwork lined with polystyrene wrapped in zinc sheath was used to create ribbed voids for the slabs. Before casting, the formwork was cleaned and coated with non-adhesive grease to ensure easy de-molding. The SCC mixture was poured into the formwork and wet-cured under gunnysacks. The slabs were painted white after curing to enhance crack visibility. Strain gauges were applied at critical points on the slabs to measure the deformation during testing.

2.6 Testing Set-Up

Eighteen 500-mm and 16-mm-diameter ribbed bars were placed in the lower portion of the slab, as shown in Figure 2. Linear Variable Displacement Transducers (LVDTs) were used to measure deflection at specific points on the slab during the test. Additionally, strain gauges were used to monitor the distribution of stress at key locations. A 200 mm by 200 mm square press was utilized to apply a simulated columnar load at the slab's center.

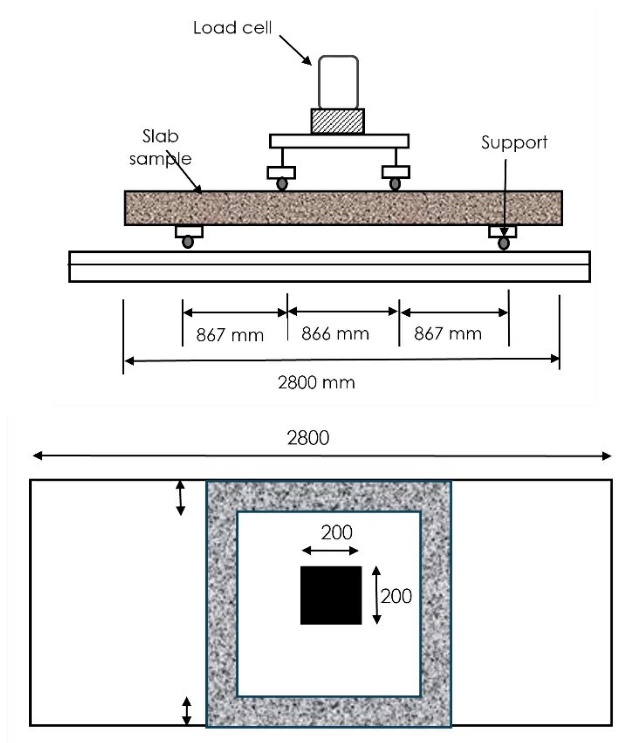


Figure 2 Schematic diagram of test set-up and from top view

The load gradually increased at a rate of 0.01 mm/s until failure. The setup aimed to simulate realistic conditions, allowing for an accurate evaluation of the punching shear resistance and performance of steel fiber-reinforced ribbed slabs under concentrated load conditions. The LVDTs provided detailed deflection profiles, while the strain gauges offered insights into the stress distribution throughout the slabs.

3.0 RESULTS AND DISCUSSION

3.1 Slump Flow

The slump flow test results Table 3 demonstrated that SFRSCC exhibited a reduced flow diameter compared to PSCC. The average spread for SFRSCC was 610 mm, marginally smaller than the 620 mm of PSCC, highlighting the influence of steel fibers on workability. The inclusion of steel fibers increased the internal friction within the mix, leading to slight reductions in flowability. Despite this reduction, both concrete types met the European Federation for Specialist Construction Chemicals and Concrete Systems (EFNARC) standards for self-compacting concrete, ensuring adequate workability for practical applications.

Table 3 Slump flow test results

Criteria	PSCC	SFRSCC	EFNARC Requirement
Slump flow Ø mm	620	610	550-650
T_{500} flow time (sec)	4.5	5	2-5

3.2 J-Ring Test

The J-ring test results in Table 4 showed a similar trend, with SFRSCC exhibiting a smaller spread diameter (505 mm) and increased flow time compared to PSCC (625 mm). This behavior can be attributed to the steel fibers' interference with the flow, particularly around the reinforcement bars simulated by the J-ring setup. The blockage effect caused by the hooked-end steel fibers is consistent with observations in other studies, which reported reduced passing ability with higher fiber volumes.

Table 4 J-Ring test results

Criteria	PSCC	SFRSCC	EFNARC requirement
T_{500j} flow time (sec)	7	6.7	2-5
Flow spread, SF_j	625	505	550-650
Passing ability, PJ (mm)	5	43	0-10

3.3 Compressive Strength

A subtle reduction in strength for SFRSCC in relation to PSCC is seen in the compressive strength assessment in Table 5. Other researchers have indicated that steel fibers have a negligible effect on compressive strength [18]. However, this study suggests that fibers enhance tensile characteristics and, thus, may lower compressive strength.

Table 5 Compressive strength of PSCC and SFRSCC for day three to day forty-two

Days	Specimen type	Weight	Maximum load (kN)	Stress (N/mm²)
3	PSCC	7.308	422	18.76
	SFRSCC	7.313	395	17.55
7	PSCC	7.377	505	22.44
	SFRSCC	7.415	462	20.55
28	PSCC	7.403	714	31.74
	SFRSCC	7.390	579	25.72
42	PSCC	7.457	749	33.27
	SFRSCC	7.383	654	30.43

Furthermore, it may be observed from Figure 3 that PSCC carries strength development at a faster rate with higher values compared to SFRSCC. The reason is that due to the incorporation of fibers, the workability and compaction are reduced as the fiber content rises, leading to poor compaction of the mix.

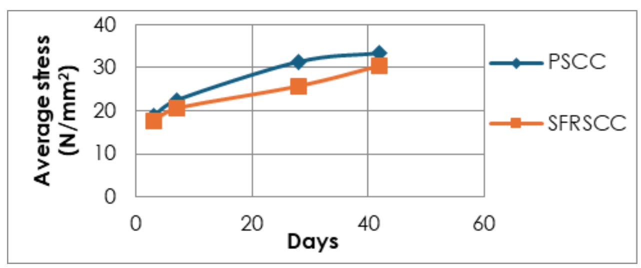


Figure 3 The progression of compressive strength from day three to day forty-two

Moreover, the fiber orientation also plays a role in strength. The fibers aligned in the direction of the load may leave voids that can lead to less compressive strength [30]. On day 42,

Figure 4 showed the average compressive strengths indicated superior performance for PSCC over that of SFRSCC, inferring that increased fiber content would potentially jeopardize compressive ability because of the adverse influence on workability and the internal structure.

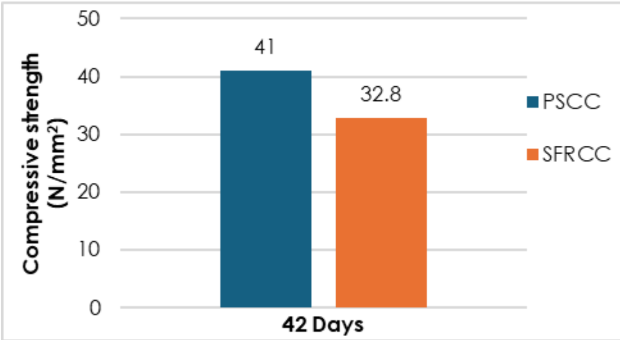


Figure 4 Average compressive strength of PSCC and SFRSCC after 42 days

3.4 Punching Shear Resistance

The punching shear resistance of the ribbed slabs was evaluated for three configurations (CRS, SFBRC, and SFR) as shown in Figure 5. The ultimate load capacities are summarized as follows:

- **CRS**: Exhibited the highest load capacity (187.13 kN) but failed catastrophically, with brittle fracture occurring around the column connection.
- **SFBRC**: Demonstrated a 4.3% reduction in ultimate load capacity compared to CRS but exhibited significantly improved ductility, as evidenced by the reduced deflection and delayed crack propagation.
- **SFR**: Achieved the lowest load capacity, failing prematurely due to the absence of wire mesh in the topping. Despite the reduced capacity, the steel fibers enhanced post-failure load resistance and delayed the onset of cracks.

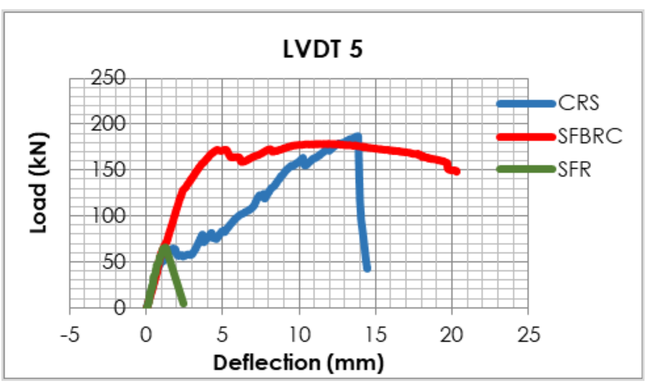


Figure 5 Comparison between deflection graph pattern of three slab samples

3.5 Deflection Analysis

Deflection profiles for all slab types are shown in Figure 6 and Figure 7. SFBRC demonstrated the lowest deflections under similar loading conditions, indicating superior stiffness provided by the combined effects of steel fibers and wire mesh reinforcement. In contrast, CRS exhibited higher deflections, emphasizing the role of additional reinforcements in enhancing structural stiffness. SFR slabs, while lacking topping mesh, showed moderate deflections, showcasing the ductility introduced by the steel fibers.

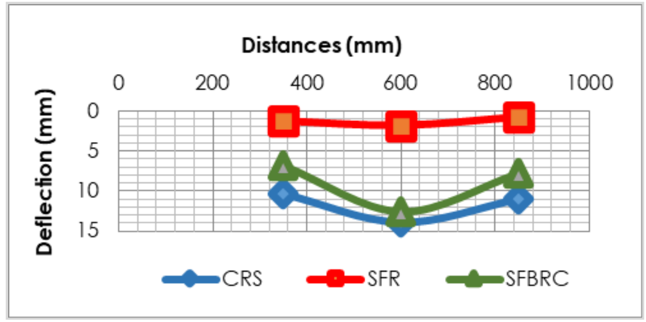


Figure 6 Deflection graph for the three slabs short span direction

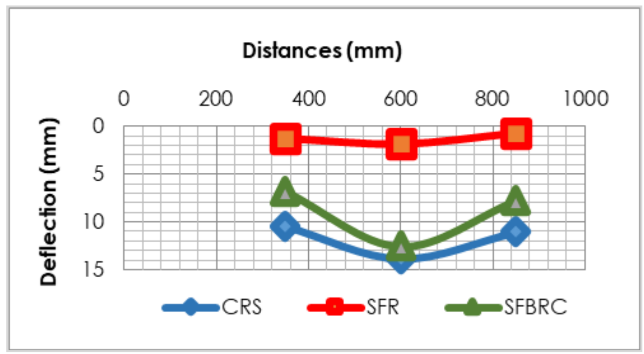


Figure 7 Deflection graph for the three slabs long span direction

3.6 Strain Analysis

The reinforcement methods of the three slab types produced different strain responses, as shown in Figure 8. The SFBRC slab had less strain than the CRS slab due to steel fibers in the ribs, which bridged and delayed cracking, enhancing energy absorption and load dispersal. CRS sustained higher loads, showing more strain under the same loading conditions. Strain gauge 3 provided a broader comparison, highlighting how reinforcement types influenced strain behavior across the varied slabs.

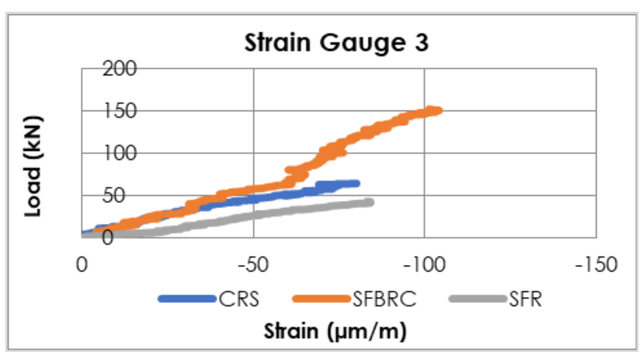


Figure 8 Load vs strain comparison of different slabs

3.7 Crack Propagation and Failure Modes

Crack detection during experiments involved meticulous manual monitoring from beneath the slabs, using light sources to identify hairline fractures. The initial crack in the CRS slab appeared at 57.06 kN directly below the column line, spreading laterally towards the external rib and remaining within the punching shear zone. Surface cracking was confined to the column's perimeter, while the mid-rib region displayed a punching shear cone detailed in Figure 9

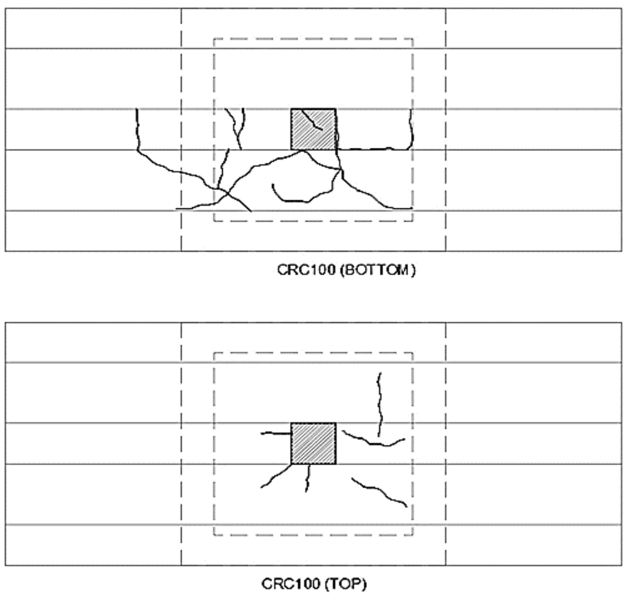


Figure 9 Cracks occurring at the bottom of slab

The SFBRC sample's first crack occurred at 81.54 kN, located at the mid-rib beneath the column, extending to the slab's edge and forming a punching cone along the external rib's sides as depicted in Figure 10.

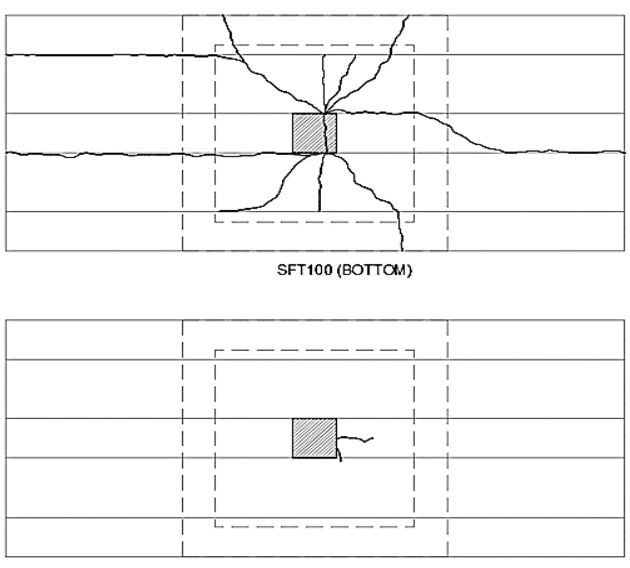


Figure 10 Sample SFBRC cracks only at bottom

The SFR sample exhibited no initial cracks but failed suddenly along the rib line due to the absence of wire mesh in the topping and reliance on rib-embedded steel fibers, as illustrated in Figure 11. SFBRC was most effective in resisting punching shear, demonstrating delayed crack onset and comparable load capacity to the CRS slab, while offering a more economical use of steel by leveraging rib-contained fibers for structural integrity.

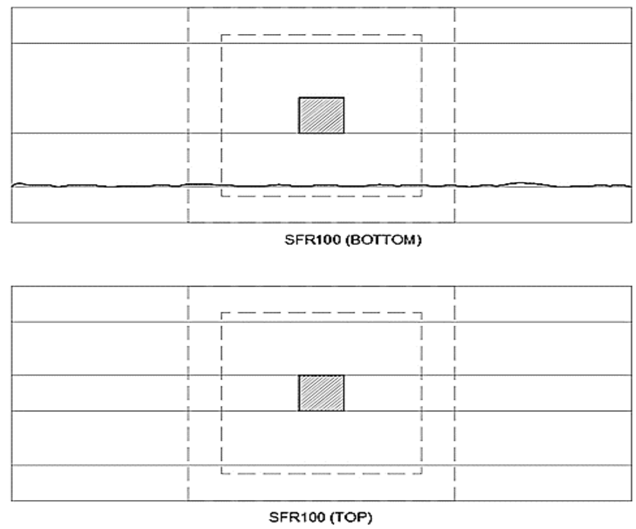


Figure 11 Sample SFR crack propagation

3.8 Comparative Studies

The findings are consistent with recent studies by Shubber *et al*. (2023) [27] and Afifi *et al*. (2023) [29], which emphasize the role of steel fibers in enhancing ductility and crack resistance in concrete slabs. While CRS offers higher load capacity, its brittle failure mode limits its application in scenarios requiring ductility. SFBRC presents a balanced solution, aligning with the work by Balamuralikrishnan *et al*. (2023) [28] on the effectiveness of hybrid reinforcement strategies in improving structural resilience.

4.0 CONCLUSION

This study investigated the structural performance of steel-fiber-reinforced self-compacting concrete (SFRSCC) one-way ribbed slabs under punching shear loading. By comparing control rib slabs (CRS), steel-fiber-reinforced slabs with wire mesh (SFBRC), and steel-fiber-reinforced slabs without topping mesh (SFR), the research has provided valuable insights into the advantages and limitations of SFRSCC as an innovative reinforcement material for ribbed slabs.

The findings indicate that SFRSCC is a viable alternative to traditional reinforcement for ribbed slabs, particularly in applications requiring enhanced ductility, energy absorption, and crack resistance. The

SFBRC configuration presents a balanced solution, combining high load-bearing capacity with superior post-failure performance, making it suitable for cost-efficient and sustainable construction practices.

4.1 Recommendations

The incorporation of steel fibers and wire mesh in ribbed slabs demonstrates significant potential for improving structural performance, particularly in applications demanding enhanced ductility and crack resistance. Future studies should explore the following research:

1. Investigate the long-term durability and behavior of SFRSCC under cyclic loading to evaluate its performance in real-world applications.
2. Optimize fiber volume fractions and aspect ratios to achieve a balance between workability, strength, and ductility.
3. Develop alternative reinforcement combinations, such as hybrid fiber systems, to enhance the performance of SFRSCC ribbed slabs.

Acknowledgement

The research is supported by the E-Science Fund (06-01-01-SF0835) under the Ministry of Science and Technology Malaysia and the School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

References

[1] F. A. Rahman, A. A. Bakar, M. H. M. Hashim, and H. Ahmad. 2017. Flexural Performance of Steel Fiber Reinforced Concrete (SFRC) Ribbed Slab with Various Topping Thicknesses. *AIP Conference Proceedings.* American Institute of Physics Inc. https://doi.org/10.1063/1.5011493.

[2] A. Baharin, H. Ahmad, M. H. Hizdrami, M. H. M. Hashim. 2023. Flexural Behaviour of Two Ribbed SFRC Slab Reinforced with GFRP Bars. *Journal of Sustainable Civil Engineering & Technology (JSCET).* 2(1): 22–35. https://joscetech.uitm.edu.my

[3] W. U. Nyong, O. O. Desmond, and O. S. Olalekan. 2023. Comparative Analysis and Design of Solid Ribbed and Waffle Slabs for Residential Buildings: A Review. *Indian Journal of Engineering.* 20(53). https://doi.org/10.54905/disssi/v20i53/e14ije1014.

[4] A. Gholamhoseini, A. Khanloo, G. Macrae, A. Scott, S. Hicks, and R. Leon. 2015. Ultimate Strength of Reinforced and Steel Fibre Reinforced Concrete (SFRC) Continuous Composite Slabs (An Experimental Study). *Steel Innovations Conference 2015*, Auckland, New Zealand.

[5] R. P. Manfredi, F. de Andrade Silva, and D. C. T. Cardoso. 2022. Punching Shear Strength of Steel Fiber-Reinforced Concrete Slabs-on-Ground. *ACI Struct J.* 119(4): 185–196. https://doi.org/10.14359/51734520.

[6] A. Marí, N. Spinella, and M. F. Rodríguez. 2023. Mechanical Model for The Shear-Punching Strength of Steel Fiber Reinforced Concrete Slabs Under Concentric Loading. *Structures.* 52: 854–867. https://doi.org/10.1016/j.istruc.2023.04.035.

[7] N. J. Gardner, J. Huh, and L. Chung. 2002. Lessons from the Sampoong Department Store Collapse. *Cem Concr Compos.* 24(6): 523–529. https://doi.org/10.1016/S0958-9465(01)00068-3.

[8] X. Lu *et al.* 2021. A Preliminary Analysis and Discussion of The Condominium Building Collapse in Surfside. *Frontiers of Structural and Civil Engineering.* 15(5): 1097–1110. https://doi.org/10.1007/s11709-021-0766-0.

[9] J. Schellhammer, N. J. Delatte, and P. A. Bosela. 2013. Another Look at the Collapse of Skyline Plaza at Bailey's Crossroads, Virginia. *Journal of Performance of Constructed Facilities.* 27(3): 354–361. https://doi.org/10.1061/(asce)cf.1943-5509.0000333.

[10] J. Ahmad, Z. Zhou, and A. F. Deifalla. 2023. Steel Fiber Reinforced Self-Compacting Concrete: A Comprehensive Review. *Int J Concr Struct Mater.* 17: 51. https://doi.org/10.1186/s40069-023-00602-7.

[11] C.-H. Huang. 2014. Effects of Rust and Scale of Reinforcing Bars on the Bond Performance of Reinforcement Concrete. *Journal of Materials in Civil Engineering*. 26(4): 576–581. https://doi.org/10.1061/(asce)mt.1943-5533.0000711.

[12] A. H. Mohammad, N. M. Abdulrazzaq, and B. O. Mawlood. 2019. Bond between Steel Bar Embedded in High Strength Self Compacting Concrete with and without Fibers. *Proceedings of the 5th International Engineering Conference, IEC 2019*. Institute of Electrical and Electronics Engineers Inc. 227–232. https://doi.org/10.1109/IEC47844.2019.8950515.

[13] S. A. O. Nair and R. G. Pillai. 2020. Microstructural and Corrosion Characteristics of Quenched and Self-Tempered (QST) Steel Reinforcing Bars. *Constr Build Mater.* 231. https://doi.org/10.1016/j.conbuildmat.2019.117109.

[14] Ş. Yazici and H. Ş. Arel, *The Effect of Steel Fiber on The Bond Between Concrete and Deformed Steel Bar in SFRCs*, 2013. https://doi.org/10.1016/j.conbuildmat.2012.09.098.

[15] S. S. Weli, I. S. Abbood, K. F. Hasan, and M. A. Jasim. 2020. Effect of Steel Fibers on the Concrete Strength Grade: A Review. *IOP Conference Series: Materials Science and Engineering.* Institute of Physics Publishing. https://doi.org/10.1088/1757-899X/888/1/012043.

[16] M. Pająk and T. Ponikiewski. 2017. Investigation on Concrete Reinforced with Two Types of Hooked Fibers under Flexure. *Procedia Engineering.* 128–135. https://doi.org/10.1016/j.proeng.2017.06.195.

[17] The European Guidelines for Self-Compacting Concrete Specification. 2005. Production and Use the European Guidelines for Self-Compacting Concrete. www.efnarc.org

[18] M. Karatas and A. Gunes. 2015. Engineering Properties of Self-Compacting Concrete Produced by Polypropylene and Steel Fiber. *Periodica Polytechnica Civil Engineering.* 59(2): 95–102. https://doi.org/10.3311/PPci.7348.

[19] A. Khaloo, E. M. Raisi, P. Hosseini, and H. Tahsiri. 2014. Mechanical Performance of Self-Compacting Concrete Reinforced with Steel Fibers. *Constr Build Mater*. 51: 179–186. https://doi.org/10.1016/j.conbuildmat.2013.10.054.

[20] V. V. Turlapati and Ch. Vineel. 2020. A Comparative Study on Performance of Synthetic and Natural Fibers on Compressive and Flexural Strength of Concrete. *Advanced Engineering Forum.* 36: 97–113. https://doi.org/10.4028/www.scientific.net/aef.36.97.

[21] N. H. M. Fodzi, M. H. M. Hashim, and M. S. M. Radzi. 2019. Testing Setup to Examine Punching Shear Strength in Self Compacting Fibre Reinforced Concrete (SCFRC) Ribbed Slabs. *IOP Conference Series: Materials Science and Engineering.* 615(1): 012095, https://doi.org/10.1088/1757-899X/615/1/012095.

[22] V. M. de Alencar Monteiro, L. R. Lima, and F. de Andrade Silva. 2018. Mechanical Behavior of Polypropylene, Steel and Hybrid Fiber Reinforced Self-Consolidating Concrete.

Constr Build Mater. 188: 280–291. https://doi.org/10.1016/j.conbuildmat.2018.08.103.

[23] H. Ahmad, M. H. M. Hashim, and N. H. M. Fodzi. 2022. A Brief Review of Steel Fiber Self-Compacting Concrete in Ribbed Slab. *ASEAN Engineering Journal*. 12(3): 39–47. https://doi.org/10.11113/aej.v12.17630.

[24] V. Prabhu and J. Rooby. 2018. Behavior of Steel Fiber Reinforced Concrete Beam Using Fly Ash. International Journal of Civil Engineering and Technology (IJCIET). 9(1): 79–89. http://iaeme.com.

[25] T. Liu, Y. Yang, Z. Chen, Y. Li, and R. Bai. 2020. Optimization of Fiber Volume Fraction to Enhance Reinforcing Efficiency in Hybrid Fiber Reinforced Strain Hardening Cementitious Composite. *Cem Concr Compos*. 113. https://doi.org/10.1016/j.cemconcomp.2020.103704.

[26] C. H. Jai Chandu and J. Supriya. 2015. Mechanical Properties of Steel Fiber Reinforced Concrete Composites. *International Journal of Computer Engineering in Research*. 2: 941–946. Available: www.ijcert.org.

[27] M. S. Shubber, T. J. Mohammed and K. M. Breesem. 2023. Production Economical Reinforced Concrete Slabs using Eco-Friendly Material. *Civil Engineering Journal*. 9(6): 1427–1436. https://doi.org/10.28991/CEJ-2023-09-06-010.

[28] R. Balamuralikrishnan, A. S. H. Al-Mawaali, M. Y. Y. Al-Yaarubi, B. B. Al-Mukhaini, and A. Kaleem. 2023. Seismic Upgradation of RC Beams Strengthened with Externally Bonded Spent Catalyst Based Ferrocement Laminates. *HighTech and Innovation Journal*. 4(1): 189–209. https://doi.org/10.28991/HIJ-2023-04-01-013.

[29] A. Afifi, M. Ramadan, A. M. F. Maree, A. M. Ebid, A. H. Zaher, D. M. Ors. 2023. Punching Capacity of UHPC Post Tensioned Flat Slabs with and Without Shear Reinforcement: An Experimental Study. *Civil Engineering Journal*. 9(3): 567–582. https://doi.org/10.28991/CEJ-2023-09-03-06.

[30] R. Madandoust, M. Ranjbar, R. Ghavidel, and S. Shahabi. 2015. Assessment of Factors Influencing Mechanical Properties of Steel Fiber Reinforced Self-Compacting Concrete. *Mater Des*. 83: 284–294. https://doi.org/10.1016/j.matdes.2015.06.024.