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Building for the Future: Durable, Sustainable, Resilient

Proceedings of the *fib* Symposium 2023 – Volume 1

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Editors
Alper Ilki
Civil Engineering Faculty
Istanbul Technical University
Sarıyer-Istanbul, Türkiye

Derya Çavunt
Civil Engineering Faculty
Istanbul Technical University
Sarıyer-Istanbul, Türkiye

Yavuz Selim Çavunt
Civil Engineering Faculty
Istanbul Technical University
Sarıyer-Istanbul, Türkiye

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Preface

Concrete is a widely used material in the construction industry due to its versatility, strength, and durability. However, the production of concrete has a significant impact on the environment, contributing to carbon emissions, resource depletion, and waste generation. This has led to an increasing need to address sustainability concerns in the construction industry.

As the world population grows and the impact of climate change becomes more severe, the demand for sustainable buildings has also increased. Sustainable buildings minimize their environmental impact by reducing resource consumption, minimizing waste generation, and improving energy efficiency. Moreover, durable and resilient structures are crucial aspects of sustainable construction. Structures that can withstand the test of time and natural disasters reduce the need for frequent repairs and replacements, thereby reducing the resources needed for ongoing maintenance.

Sustainable structures also provide long-term financial benefits by reducing operational costs. This is achieved through measures such as energy-efficient designs and the use of sustainable materials. In this aspect, it is essential for the construction industry to prioritize sustainability to ensure a better future for the world.

In order to address the next steps in the construction industry, the *fib* International Symposium 2023, "Building for the Future: Durable, Sustainable, Resilient," was held in Istanbul, Turkey on June 5–7, 2023, as an official symposium of the International Federation for Structural Concrete (*fib*), by the contribution of International Federation for Structural Concrete Turkey Branch (*fib* Turkey), Istanbul Technical University (ITU), and the Turkish Earthquake Foundation (TEF).

The primary goal of the symposium was to provide a platform for scientists, engineers, industrial partners, and practitioners to present and discuss recent advances, state of the practice, and future perspectives in terms of durability, sustainability, and resiliency in civil engineering. The symposium covered topics related to concrete and innovative materials, structural performance and design, construction methods and management, and outstanding structures.

We are pleased to present the proceedings book of the *fib* International Symposium 2023 published by Springer, which consists of two volumes and includes 372 papers from 55 countries worldwide. All papers submitted to the symposium underwent a rigorous review process by the members of the International Scientific Committee. We would like to thank all the authors for their valuable contributions, as well as the members of the International Scientific Committee for their hard work and dedication to ensuring the quality of the papers. In the symposium, a total of 412 presentations were made, including 6 keynote and 14 invited theme lecturer presentations. We would like to extend our sincere thanks and appreciation to all the speakers, with special thanks to the keynote and invited speakers for their invaluable contributions.

We would like to express our sincere thanks to the members of the organization committee of the symposium, as well as to Prof. Dr. Stephen J. Foster, the president of the *fib*, Dr. Akio Kasuga, previous president of the *fib*, Dr. David Fernández-Ordoñez, co-chair of the symposium, and secretary general of the *fib*, Ali Karahan, co-chair of the symposium, and Marie Reymond, communications and events specialist of the *fib*, for their support. Additionally, we are grateful for the support of ITU, TEF, the Scientific and Technological Research Council of Turkey (TUBITAK), *fib* Turkey, and the sponsors.

We would also like to extend our appreciation to the M.Sc./Ph.D. students who volunteered their time and efforts to ensure the success of the symposium.

We believe that the *fib* International Symposium 2023-Istanbul was a productive and unforgettable experience for all participants.

Sincerely,

June 2023

Alper Ilki
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Contents

Shear Capacity of Hollow Reinforced Concrete Members without Stirrups Strengthened with CFRP Sheets

Rendy Thamrin[1](✉), Zaidir[1], Sabril Haris[1], Sri Hartati Dewi[2], and Febi Putri Yastari[2]

[1] Lecturer in Civil Engineering Department, Universitas Andalas, Padang, Indonesia
rendythamrin@eng.unand.ac.id

[2] Graduate Student in Civil Engineering Department, Universitas Andalas, Padang, Indonesia

Abstract. This experimental study aims to determine the shear capacity of hollow reinforced concrete members without stirrups strengthened with CFRP sheets. The specimens tested consisted of three control specimens, three hollow specimens, and three hollow specimens strengthened with CFRP sheets. All specimens are designed without stirrups to see the contribution of CFRP sheets to strengthened specimens. The hollow area of the specimens with a hollow is 2.32% of the concrete cross-sectional area. Three diameters of steel reinforcement (13, 16, and 19 mm) were used in the specimens to obtain different flexural capacity variations. The test was carried out using a four-point bending test to achieve the expected internal force combination. The prediction of flexural capacity was also obtained with the help of a computer program based on the fiber element method. The test results showed that all specimens without CFRP sheets failed in shear failure mode, indicated by large diagonal cracks in the observed shear spans. Specimens strengthened with CFRP sheets failed in a flexural mode characterized by crushing of concrete in the compression zone. The prediction of flexural capacity using the fiber element method shows a pretty good comparison.

Keywords: Shear capacity · CFRP sheets · Four-point bending test · Hollow reinforced concrete member · Flexural capacity

1 Introduction

Structural members with circular cross-sections are widely used because of some advantages, such as symmetric cross-sections and a relatively high moment of inertia [1–4]. Pipes are often installed in columns, especially in columns with a circular cross-section [5]. The pipe installed in the column is intended for sanitation and aesthetics. Column cross sections with holes in the structure will also provide efficiency in material use [6–8].

The cross-sectional area is a significant variable in the contribution of concrete to shear resistance [9]. A hollow in the reinforced concrete section can reduce the contribution of concrete to shear resistance. Therefore, ACI 318M-11 requires the maximum permissible hole area to be 4% of the cross-sectional area [10].

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The updates made to the modern seismic code provision caused the buildings constructed before the new code to require an evaluation of their seismic performance. Following the change in the seismic code provision, weakening the structural elements due to hollows will provide a high possibility for the decision to strengthen the structure. This condition requires structural engineers to have good knowledge and experience in strengthening structures. One of the strengthening methods that is very popular today is to use CFRP sheets material [11]. Several CFRP sheet installation schemes include complete wrapping, U-Wrap, and side bonding [12]. CFRP sheets have become very popular due to many factors, one of which is easy installation and does not require heavy equipment.

Sudden failure due to shear forces must be avoided in reinforced concrete structures. This premature failure is usually caused by insufficient shear reinforcement, insufficient cross-sectional area to withstand shear, and other things that cause a decrease in shear capacity [13]. This paper studies the behavior and shear capacity of hollow reinforced concrete structural members strengthened with CFRP sheets.

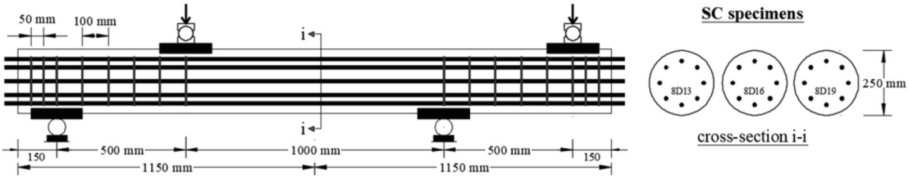
2 Experimental Study

Experimental studies were conducted to study the behavior and shear capacity of hollow reinforced concrete structural members strengthened with CFRP sheets. Nine specimens with circular cross-sections consisting of three control, three hollow, and three hollow specimens strengthened with CFRP sheets were tested. The hollow area of the specimens with a hollow is 2.32% of the concrete cross-sectional area. The specimen has a length of 2300 mm and a cross-sectional diameter of 250 mm (see Fig. 1). Each of the three specimens was varied with a different reinforcement ratio of 13, 16, and 19 mm with yield stress values of 427, 492, and 416 MPa, respectively. All specimens were not installed with transverse reinforcement to determine the contribution of CFRP sheets in resisting shear forces.

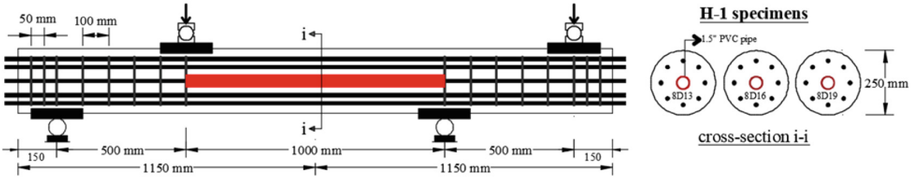
Fresh concrete was ordered from a ready-mix company with a concrete compressive strength of 40 MPa. Wrapping of CFRP strip with a thickness of 1 mm, a tensile strength of 986 MPa, and a modulus of elasticity of 230 GPa were installed in two wraps with a distance of 50 mm for each CFRP strip.

The specimens were tested horizontally with four-point bending, as shown in Fig. 2. This loading set-up provides a combination of internal forces as occurs in reinforced concrete columns in multi-story buildings. Three LVDTs and a load cell connected to a data logger were installed to measure deflection and load. The load is given monotonically until the specimen reaches the failure state.

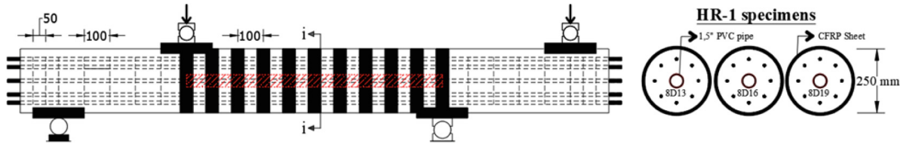
The nominal shear capacity of reinforced concrete sections in this study was calculated theoretically using the equation proposed in ACI 318–19 [8]. The contribution of the CFRP strip to shear is calculated theoretically using the equation available in ACI 440.2R-17 [12].



(a) Control spesimen [14]



(b) Specimen with hollow cross-section



(c) Specimen with hollow cross-section strengthened with CFRP sheets

Fig. 1. Dimensions, reinforcement, and strengthened details of the test specimens

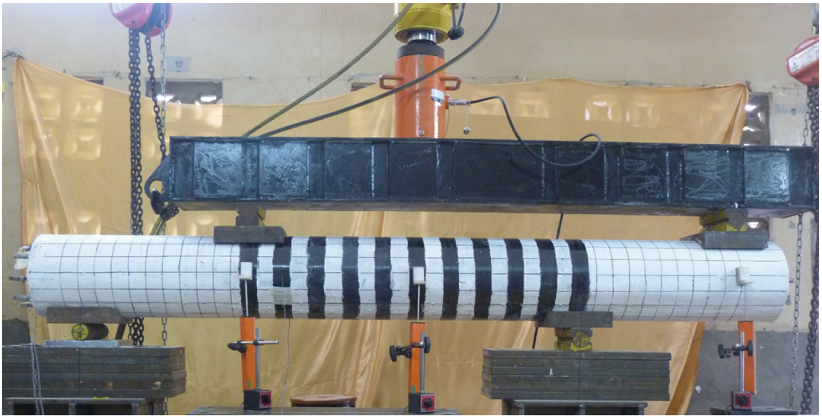


Fig. 2. Test set-up

3 Analytical Study

The flexural capacity of the specimens was obtained from cross-section analysis using the fiber element method. In this method, the cross-section of reinforced concrete elements is divided into layers of elements consisting of concrete elements and reinforcement. The strain distribution is obtained by assuming the curvature value. The stresses in each concrete and steel element are obtained by following the constitutive laws of each material. The forces acting on each layer of concrete and reinforcement elements are obtained by multiplying the area of each element by the corresponding stress. The equilibrium at the cross-section is then checked with the condition that the sum of the forces acting on the cross-section must be close to zero or meet certain tolerance criteria. If the total forces do not meet the tolerance value, the calculation is repeated by setting a new value for the strain at the neutral axis line. However, if the total forces meet the tolerance value, the calculation is continued by calculating the moment value at the cross-section. And the analysis is continued with the next incremental curvature value until the ultimate condition is reached. The load and deflection values are obtained from the moment-curvature curves from the previous calculation step. A complete description of the flexural analysis of reinforced concrete sections using the fiber element method can be found in the references [15, 16].

4 Test Results and Discussion

The test results show that the first crack in the specimen occurred simultaneously in the maximum bending moment zone (under load on the left side and above the support on the right side) with an average value of 23.23 kN. Then with increasing load, the crack propagated to the observed shear span zone (the zone between the load on the left side and above the support on the right side) and developed into diagonal cracks. Shear failure occurred in control specimens and specimens with hollow, which was indicated by the sudden occurrence of wide diagonal cracks. The difference in shear strength between control specimens and specimens with a hollow is not significant. It is because the area of the hole does not exceed the maximum permissible hollow area provided by the code, which is equal to 4% of the cross-sectional area.

Due to similar failure modes, the crack patterns of the control specimens and specimens with hollow are almost the same, as shown in Fig. 3, where the diagonal crack dominates the crack pattern. The difference is in the diagonal crack angle, which is the effect of the longitudinal reinforcement ratio. The higher the longitudinal reinforcement ratio, the smaller the diagonal crack angle.

Meanwhile, all specimens strengthened with CFRP sheets failed in flexural mode, indicated by crushing of concrete in the compression zone. Theoretical shear strength, first crack load, maximum shear load, diagonal crack angle, and identification of the type of failure of each test specimen are shown in Table 1 below. Failure modes with the letter S denote shear failure mode and F for flexural failure.

Flexural cracks dominate the crack patterns in specimens strengthened with CFRP sheets. Insignificant diagonal cracks were found in specimens with a higher reinforcement ratio. It is due to the higher bending capacity resulting in a higher shear force. Because these specimens do not use stirrups, it can be proven that CFRP sheets significantly contribute to resisting shear forces. In the ultimate condition, after the tensile reinforcement yielding, the concrete of these specimens in the compression zone suffers crushing, demonstrating flexural failure, as shown in Fig. 3.

Table 1. Theoretical shear strength, test results, and failure mode.

	Calculated Shear Capacity ACI 318M-19 and ACI.440.2R-17			Calculated Flexural Capacity	Experimental				
					Average load at first crack	Diagonal Crack Load	Max. Load	Angle of diagonal crack	Failure Mode
Specimens ID	V_c (kN)	Vf (kN)	V_n (kN)	V_a (kN)	(kN)	V_{ce} (kN)	V_m (kN)		
SC-1	41,7		41,7	117		57,83	72,3	45°	S
SC-2	47,9		47,9	189		67,50	87,1	22°	S
SC-3	53,7		53,7	227		82,63	84,1	21°	S
H-1-1	37,3		37,3	117		63,13	69,2	26°	S
H-1-2	42,9		42,9	189	26,2	60,97	82,3	24°	S
H-1-3	48,1		48,1	227		75,93	91,3	23°	S
HR-1-1	41,7	309,8	351,4	117		84,97	124,3	71°	F
HR-1-2	47,9	309,8	357,6	189		77,40	165,1	60°	F
HR-1-3	53,7	309,8	363,4	227		78,87	198,1	40°	F

Figure 4 shows the shear force vs. deflection of the test results throughout the specimen. The control specimens and specimens with hollow curves show sudden brittle failure due to shear. In contrast, all specimens strengthened with CFRP sheets show plastic deformation due to the longitudinal reinforcing steel reaching its yield stress value. The test curves clearly show the effect of the longitudinal reinforcement ratio on the stiffness and capacity. Specimens with a higher longitudinal reinforcement ratio exhibit higher stiffness and capacity.

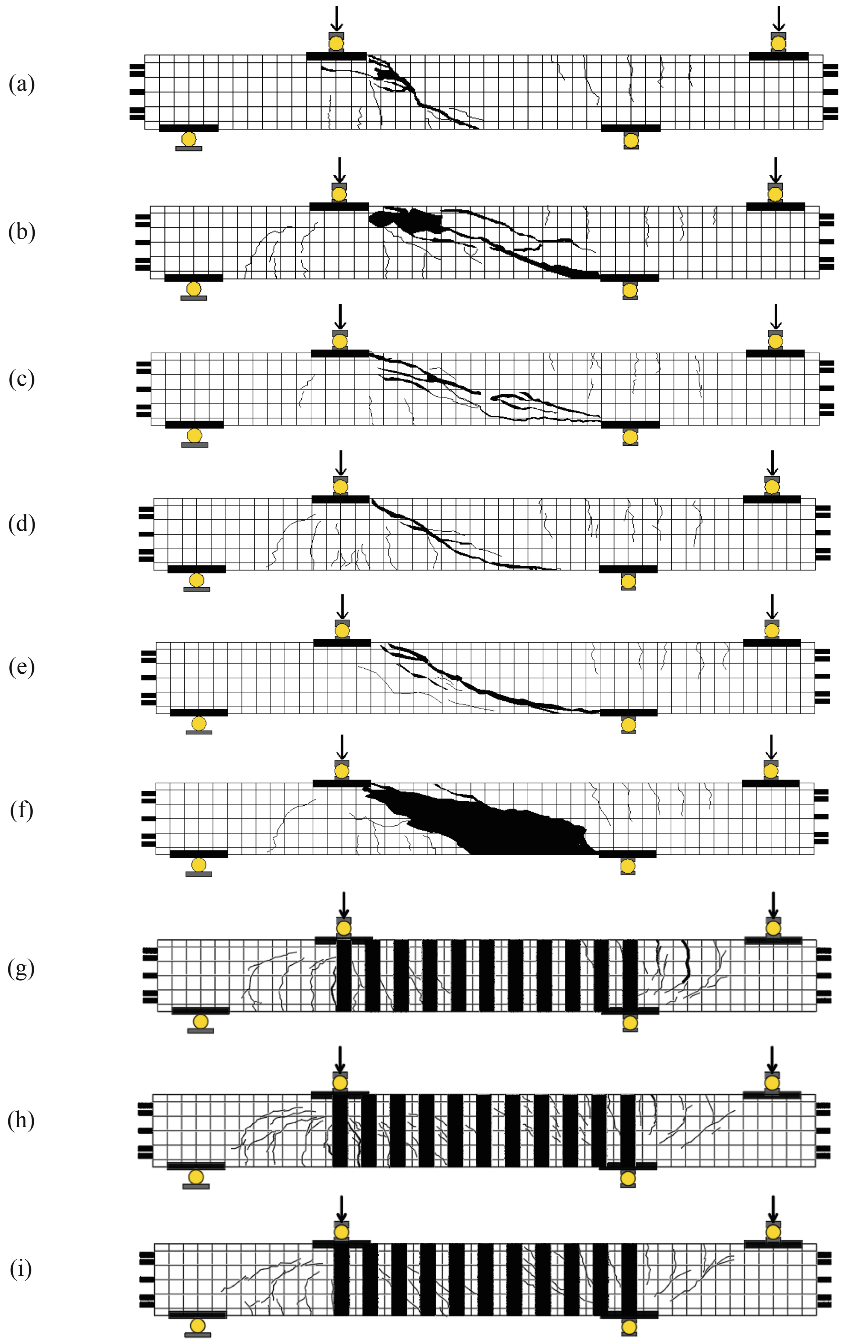
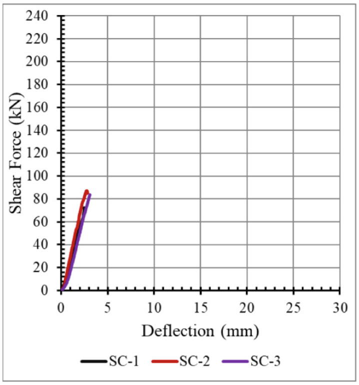
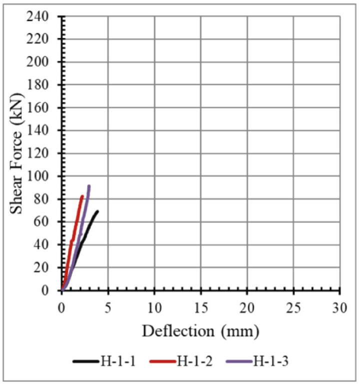


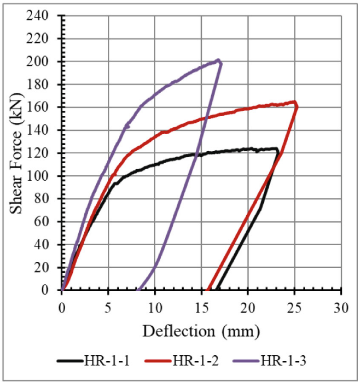
Fig. 3. Crack patterns of the members after the test (a) SC-1, (b) SC-2, (c) SC-3, (d) H-1–1, (e) H-1–2, (f) H-1–3, (g) HR-1–1, (h) HR-1–2, (i) HR-1–3



(a) Control spesimens



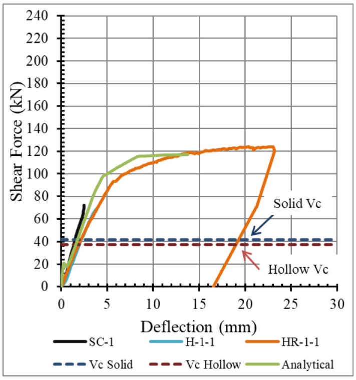
(b) Specimens with hollow



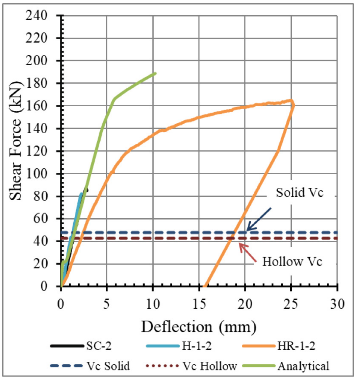
(d) Specimens with hollow strengthened with CFRP sheets

Fig. 4. Load-deflection curves of the tested specimens.

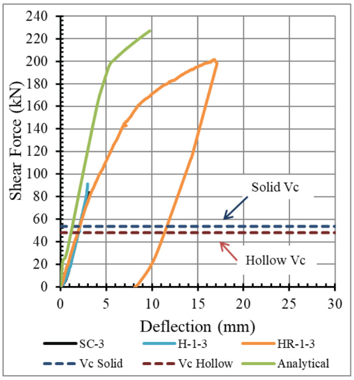
Figure 5 shows the load and deflection curves, the theoretical capacity (Vc), and the analytical predictions of the tested specimens. The dotted line show the theoretical contribution of concrete in resisting shear (Vc), calculated by ACI 318–19. It can be seen that the shear strength of the specimen that failed to shear was higher than that line. It proves that the Vc value of ACI 318–19 is conservative compared to the results obtained in this study. Comparison of the analytically obtained flexural capacities of the specimens with the test results shows good predictions for specimen with a low longitudinal reinforcement ratio. A slight difference occurs in the specimen with a higher reinforcement ratio due to higher shear force.



(a) Longitudinal reinforcement diameter of 13



(b) Longitudinal reinforcement diameter of 16



(c) Longitudinal reinforcement diameter of 19

Fig. 5. Load-deflection curves, theoretical capacities (Vc), and analytical prediction of the tested specimens.

5 Conclusions

Nine specimens were tested, and the results are presented in this paper. Some conclusions that can be written from the results of this study are as follows:

– Control specimens and specimens with hollow failed in brittle shear, which is indicated by the sudden occurrence of diagonal cracks.
– Specimens strengthened with CFRP sheets failed in ductile flexural type, which is indicated by the occurrence of yielding in the longitudinal reinforcement and crushing of concrete in the compression zone. It proves that CFRP sheets contribute significantly to resisting shear forces.
– Analytical predictions show a good approximation for specimens with low longitudinal reinforcement ratios. Still, there is a slight difference in specimens with higher reinforcement ratios due to higher shear forces, which cause shear behavior to be more dominant in the specimens.

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