International Conference on Earthquake Engineering and Disaster Mitigation

PROGRAM BOOK

September 28, 2022
Yogyakarta, Indonesia

5th ICEEDM Yogyakarta

International Conference on Earthquake Engineering and Disaster Mitigation

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International Conference on

Earthquake Engineering and Disaster Mitigation

September 28, 2022

Yogyakarta, Indonesia

The 5th International Conference on

Earthquake Engineering and Disaster Mitigation

September 28-30, 2022

Yogyakarta, Indonesia

PREFACE

Dear readers and participants,

It is our pleasure to welcome you to the 5th International Conference on Earthquake Engineering and Disaster Mitigation (5th ICEEDM). The 5th International Conference on Earthquake Engineering and Disaster Mitigation (5th ICEEDM), held on hybrid behalf in Conference Hall, SGLC Building, Faculty of Engineering UGM, Yogyakarta, Indonesia and also on Virtual by Zoom meeting. The series of event is Conference which was held on 28-29 September 2020 followed by a Short Course on 30 September. This biannual conference was initiated by Gadjah Mada University of Indonesia, Indonesia Earthquake Engineering Association, and has been recognized over the world since the 2nd International Conference was held. The initiators considered that more involvement of local and international universities will more enliven the conference and enable more knowledge to be shared. This rich program provides all attendees with the opportunities to meet and interact with one another. We hope your experience with 5th ICEEDM is a fruitful and long lasting one. With your support and participation, the conference will continue its success for a long time.

The organizing committee of the 5th International Conference received more than 112 abstracts. This great enthusiasm of researchers to join the conference was also shown by the inquiry to submit papers beyond the closing date of the submission. It is really hoped that 5th International Conference on Earthquake Engineering and Disaster Mitigation can provide an opportunity to share experiences, disseminate the latest research and development results related to earthquake engineering, which will be very useful for increasing knowledge and disaster mitigation policies. It is hoped that this conference will be beneficial for all parties in order to minimize the risk of earthquake hazards in Indonesia and throughout the world.

The 5th International Conference can be held thanks to the contribution of the supporting event, Bandung Institute of Technology, International Association for Earthquake Engineering, those are Atma Jaya University Yogyakarta, and Universitas Islam Indonesia (UII) and also from other countries which have been working hand in hand to make this conference successful. The conference is enlightened by the presence of students of the organizing institutions and is the announcement of the best student papers at the closing ceremony of the conference.

On behalf of the organizing committee and organizing institutions we would like to deliver our gratitude to participants and various parties who have contributed their financial support for the success of this conference, especially to PT. ADHI KARYA and PT. WIKA BETON appreciation is also conveyed to professional organizations; International Association for Earthquake Engineering. We also would like to express our gratitude to the organization staff, the members of the program committees and reviewers, and the authors for contributing their research result to the conference. Last but not least my deepest appreciation is also delivered to honorable reviewers who have worked hard to evaluate the papers for adequacy of substances and quality of research.

Thank you for the nice participations, we wish all attendees of 5th ICEEDM enjoy and may God be with you always. We look forward to seeing all of you next year at the conference.

Chairman of the Conferences

GENERAL INTRODUCTION

International Conference on Earthquake Engineering and Disaster Mitigation

Indonesia lies between the Pacific Ring of Fire and the Alpide belt that runs along the south and west from Sumatra, Java, Bali, Flores to Timor. Many strong earthquakes have occurred in Indonesia during the last decades and caused many casualties and damages on the infrastructures and lifeline facilities.

Among others, Yogyakarta Earthquake on 27 May 2006, magnitude of 6,2 Mw, depth 10 km, with 6234 deaths, more than 154,000 houses destroyed and 260,000 units experiencing damage, Aceh Earthquake & Tsunami on 26 December 2016, undersea megathrust earthquake, the third-largest ever recorded in the 21st century with magnitude of 9.1–9.3 Mw, depth 30 km below mean sea level, Lombok Earthquake on August 5 2018 with 563 dead and 1000 injured, magnitude of 6,9 Mw, depth 31 km, Palu Earthquake & Tsunami on 28 September 2018, a shallow, large earthquake with 4,340 dead and 10,679 injured, magnitude of 7.5 Mw, depth 20 km, and Mamuju Earthquake on 15 January 2021 with 108 dead and 3,369 injured, magnitude of 6,2 Mw, depth 18 km.

This conference is held to provide an opportunity to share experiences, disseminate the latest research and development results related to earthquake engineering, which will be very useful for increasing knowledge and disaster mitigation policies. It is hoped that this conference will be beneficial for all parties in order to minimize the risk of earthquake hazards in Indonesia and throughout the world.

About Yogyakarta, Indonesia

Yogyakarta is the capital city of the Special Region of Yogyakarta in Indonesia, in the south-central part of the island of Java. Yogyakarta city was the capital of economy and tourism. Yogyakarta was known with the slogan of “Jogja The Never ending Asia“ for its endless appeals. Today, it is also known as “ Jogja Istimewa “, a tagline that elaborates its special values. As the only Indonesian royal city still ruled by a monarchy, Yogyakarta is regarded as an important center for classical Javanese fine arts and culture such as ballet, batik textiles, drama, literature, music, poetry, silversmithing, visual arts, and wayang puppetry. Renowned as a center of Indonesian education, Yogyakarta is home to a large student population and dozens of schools and universities.

The area of the city of Yogyakarta is 32.5 square kilometers. While the city spreads in all directions from the Kraton, the Sultan's palace, the core of the modern city is to the north, centered around Dutch colonial-era buildings and the commercial district. Nearby to the city of Yogyakarta is Mount Merapi, with the northern outskirts of the city running up to the southern slopes of the mountain in Sleman Regency. Mount Merapi is an active stratovolcano located on the border between Central Java and Yogyakarta. It is the most active volcano in Indonesia.

This city is one of the foremost cultural centers of Indonesia. Yogyakarta was the seat of power that produced the magnificent temples of Borobudur and Prambanan in the 8th and 9th centuries and the new powerful Mataram kingdom of the 16th and 17th century. Malioboro is the most famous street in Yogyakarta. Located in the heart of the city, this is the main street and was once the ceremonial avenue for the Sultan to pass through on his way to and from the Keraton. Malioboro is packed with shops selling curiosities, and street vendors offering souvenirs at affordable prices, so you’re bound to find something of interest in this street.

Yogyakarta also has many beautiful beaches such as Parangtritis, Indrayanti, Pok Tunggal, Siung, Krakal, and Jogan are some of the famous beaches in town. Traditional food from Yogyakarta is gudeg. Gudeg is a special dish of traditional Javanese recipe that is iconic to this city. The Bakpia, is a traditional snack with many enticing flavors that are popular for souvenirs. Yogyakarta has a signature batik pattern that is usually made with a bright white base. Some of the motifs are namely The Parang Kusumo, Kawung, and Truntum, each was created with the special philosophy behind its every dot. Wayang is also an amazing art heritage known from Yogyakarta. There are Wayang Kulit or leather puppets, played on a shadow puppet show by the dalang or puppet master through a screen lit by lights.

CONFERENCE PROGRAM

Day 1 - Wednesday, September 28th 2022

Time	Program	Speaker
07.00 – 07.45	Registration	Committee
07.45 – 07.50	Safety Induction Team	MC
07.50 – 08.00	**Opening Ceremony: Singing Indonesia's National Anthem**	**MC**
08.00 – 08.10	Welcome Speech by the Chair of Organizing Committee	**Prof. Ir. Bambang Suhendro, M.Sc., Ph.D., IPU.**
08.15 – 08.25	Greeting Speech by The Secretary General of International Association of Earthquake Engineering / IAEE	**Prof. Koichi Kusunoki**
08.25 – 08.35	Greeting Speech by the Rector of Gadjah Mada University	**Prof. dr. Ova Emilia, M.Med., Ed., Sp.OG(K)., Ph.D.**
08.35 – 08.45	Opening Speech by the Minister of Public Works and Housing	**DR. Ir. Basuki Hadimulyono, M.Sc.***
08.45 – 08.50	Photo Session	MC
08.50 – 09.00	**Plenary Session 1: Introducing Keynote Speakers 1, 2, and 3**	**Moderator: Dr. Ali Awaludin**
09.00 – 09.35	Keynote Speech 1	**Prof. Jonathan D. Bray**** University of California, Berkeley, USA
09.35 – 10.10	Keynote Speech 2	**Prof. Koichi Kusunoki** University of Tokyo, Japan
10.10 – 10.45	Keynote Speech 3	**Prof. Chung-Che Chou**** National Taiwan Univ, NCREE, Taiwan
10.45 – 10.50	Certificate Award	
10.50 – 10.55	**Plenary Session 2: Introducing Keynote Speakers 4, 5, and 6**	**Moderator: Prof. Han Ay Lie**
10.55 – 11.20	Keynote Speech 4	**Ir. Diana Kusumastuti, M.T.* **** Director General of Human Settlements, MPWH, Indonesia
11.20 – 11.45	Keynote Speech 5	**Prof. Bambang Suhendro** Gadjah Mada University, Indonesia
11.45 – 12.10	Keynote Speech 6	**Prof. I Wayan Sengara** Bandung Institute of Technology, Indonesia
12.10 – 12.15	Certificate Award	
12.15 – 13.25	**Break & Lunch**	**-**

**) under confirmation   **) attends online*

13.25 – 13.30	**Parallel Session** **Moderator open the Parallel Session** and **introduce Invited Speakers**				
	Structures A	**Structures B**	**Geotechnics**	**Seismology**	**Disaster Mitigation**
MODERATOR	**Prof. Iman Satyarno**	**Prof. Fauzan**	**Dr. Didiek Djarwadi**	**Dr. Hendy Setiawan**	**Prof. H. Sarwidi**
13.30 – 13.50	**Prof. Iman Satyarno** P-INV-61-199	Yundha Syah Putra N-EB-61-187	**Dr. Didiek Djarwadi** P-INV-61-167	Dr. Rusnardi Rahmat P. ** P-INV-61-195	**Prof. H. Sarwidi** P-INV-61-179
13.50 – 14.10	Steven Hu ** E-NM-61-077	Fauziyah Iga Maura ** P-BE-61-159	Firman Hasiholan ** G-EE-61-012	Wahyu Dwiyantoro ** G-EE-61-126	**Dongjoo Kim** ** P-INV-61-170
14.10 – 14.30	Angga Arief Gumilang ** E-NM-61-132	Purwanto Purwanto ** E-NM-61-039	Benny Arianto ** E-NM-61-073	Det Komerdevi G-EE-61-194	Herlita Prawenti P-RR-61-028
14.30 – 14.50	Jonie Tanijaya ** S-EE-61-001	Ainil Mardhiyah ** S-DN-61-047	Takashi Kiyota G-EE-61-191	Takaaki Ikeda G-EE-61-131	**Dr. Sugeng Wijanto** P-INV-61-200
14.50 – 15.10	Discussion Q/A	Discussion Q/A	Discussion Q/A	Discussion Q/A	Discussion Q/A
15.10 – 15.30	**Break**				
MODERATOR	**Dr. Febrin Ismail**	**Prof. Widodo**	**Dr. A. Rifa'i**	**Dr. Hendy Setiawan**	**Dr. Dyah Kusumastuti**
15.30 – 15.50	**Dr. Febrin Ismail** P-INV-61-211	Lintang Enggartiasto ** S-AR-61-036	Kezia Ruus ** P-BE-61-031	Ren Hori G-EE-61-110	Puspita Rahmasari** S-HM-61-158
15.50 – 16.10	Geby Aryo Agista S-AR-61-206	Budi Santoso** S-DN-61-051	Daniar Rizky Septiadi** G-EE-61-011	Anisa Nurbaeti ** C-HE-61-111	Calvin Sandi E-NM-61-129
16.10 – 16.30	Ali Murtopo N-EB-61-060	Arvila Delitriana S-DA-61-168	Aziz Abdul Majid** E-NM-61-062	Bagus Adi Wibowo** S-MZ-61-116	Naurah Daffa Carol S-AR-61-186
16.30 – 16.50	Ariono Dhanisworo** S-DN-61-074	Suprapto Siswosukarto N-EB-61-188	Mahmoud Miari E-NM-61-208		Wiko Setyonegoro S-HM-61-108
16.50 – 17.10	Discussion Q/A	Discussion Q/A	Discussion Q/A	Discussion Q/A	Discussion Q/A
17.10 – 17.15	**Closing** **Moderator close the Parallel Session** and **announce the presentation schedule for 2nd day**				

***) attends online*

CONFERENCE PROGRAM

Day 2 - Thrusday, September 29th 2022

Time	Program	Speaker
07.00 – 08.30	Registration	Committee
08.30 – 08.40	Safety Induction Team	MC
08.40 – 08.50	**Opening Ceremony and Greeting Speech by the President of the Indonesian Earthquake Engineering Association (IEEA/AARGI)**	**Prof. I Wayan Sengara**
08.50 – 08.55	Photo Session	MC
08.50 – 09.00	**Plenary Session 1: Introducing Keynote Speakers 7, 8, and 9**	**Moderator: Prof. Yoyong Arfiadi**
09.00 – 09.35	Keynote Speech 7	**Prof. Tony Yang**** Univ. of British Columbia, Canada
09.35 – 10.10	Keynote Speech 8	**Prof. Hitoshi Tanaka**** Tohoku University, Japan
10.10 – 10.45	Keynote Speech 9	**Prof. Kazuo Konagai** University of Tokyo, Japan
10.45 – 10.50	Certificate Award	
10.50 – 10.55	**Plenary Session 2: Introducing Keynote Speakers 10, 11, and 12**	**Moderator: Prof. Mochamad Teguh**
10.55 – 11.20	Keynote Speech 10	**Prof. Junji Kiyono** Kyoto University, Japan
11.20 – 11.45	Keynote Speech 11	**Prof. Rajib Shaw**** Keio University, Japan
11.45 – 12.10	Keynote Speech 12	**Prof. Khrisna S. Pribadi** Bandung Institute of Technology, Indonesia
12.10 – 12.15	Certificate Award	
12.15 – 13.25	**Break and Lunch**	

***) attends online*

13.25 – 13.30	**Parallel Session** **Moderator open the Parallel Session** and **introduce Invited Speakers**				
	Structures A	**Structures B**	**Geotechnics**	**Seismology**	**Disaster Mitigation**
MODERATOR	**Prof. Priyo Suprobo**	**Prof. Made Sukrawa**	**Dr. Fikri Faris**	**Dr. Didiek Djarwadi**	**Dr. Rildova**
13.30 – 13.50	**Prof. Priyo Suprobo** P-INV-61-063	**Prof. Made Sukrawa** P-INV-61-171	Yulianisa** G-EE-61-010	**Dr. Didiek Djarwadi** P-INV-61-177	Dedy Wijarnoko ** S-SI-61-044
13.50–14.10	Dea Yunita Sari** P-BE-61-160	Siti Aisyah Nurjannah** P-BE-61-078	Askaviolita ** G-EE-61-014	Jaya Murjaya S-HM-61-080	Rahmat Setyo Yuliatmoko** S-HM-61-088
14.10 – 14.30	Edwin Edwin ** S-DN-61-087	Tobok Sihol Marito A. E-NM-61-172	Jodie Prayogo ** E-NM-61-046	Roi Milyardi S-HM-61-184	Febryan Nurdiansyah** G-EE-61-045
14.30 – 14.50	Muhammad Rizaldi Nuraulia** C-DG-61-072	Abadi Grafita Yans Sweiga** P-BE-61-198	Paulus Kevin ** G-EE-61-019	Takhul Bakhtiar ** S-MZ-61-035	
14.50 – 15.10	Discussion Q/A	Discussion Q/A	Discussion Q/A	Discussion Q/A	Discussion Q/A
15.10 – 15.30	**Break**				
MODERATOR	**Prof. Adang Surahman**	**Dr. Erwin Lim**	**Dr. Sito Ismanti**	**Dr. Andreas Triwiyono**	**Dr. Ashar Saputra**
15.30 – 15.50	Christophorus Alvin S. R. ** P-BE-61-056	Muslinang Moestopo E-NM-61-189	Ali Zakariya ** G-EE-61-024	Purwanto ** E-NM-61-183	I Putu Deny ** E-NM-61-204
15.50 – 16.10	Arita Asrianur ** E-NM-61-182	Mahmoud Miari E-NM-61-207	Clairino Galag** G-EE-61-025	Christian Johan ** E-NM-61-205	Tri Suryadi S-DA-61-061
16.10 – 16.30	Dr. Angga Fajar S S-SI-61-203	Seplika Yadi S-EE-61-155	Rensia Erlyana Majid** G-EE-61-032	Miftahul Iman S-DN-61-153	Sandy I. Yansiku** E-NM-61-209
16.30 – 16.50	Poltak Nababan S-DN-61-169	Discussion Q/A	Harasa Ramdhany P. ** G-EE-61-016	I Gede Adi Susila E-NM-61-201	
16.50 – 17.10	Discussion Q/A		Discussion Q/A	Discussion Q/A	Discussion Q/A
17.10 – 17.20	Plenary Session: Closing Speech by the Head of Civil and Environmental Engineering Department, Prof. Ir. Teuku Faisal Fathani, S.T., M.T., Ph.D., IPU., ASEAN Eng.				
	Closing **Moderator close the Parallel Session and announce the next ICEEDM Conference Program**				

***) attends online*

MEETING LINKS

PLENARY SESSION	
Auditorium	http://ugm.id/PlenaryICEEDM

PARALLEL SESSION		
Structures A	**Auditorium**	http://ugm.id/PlenaryICEEDM
Structures B	**Meeting Room 2, 3rd Floor**	http://ugm.id/ParalelICEEDMRoom1
Geotechnics	**Multifunction Room 1, 3rd Floor**	http://ugm.id/ParalelICEEDMRoom2
Seismology	**Multifunction Room 2, 3rd Floor**	http://ugm.id/ParalelICEEDMRoom3
Disaster Mitigation	**Room 5A1, 5th Floor**	http://ugm.id/ParalelICEEDMRoom4

LIST OF PAPER

Keynote Speakers

Invited Speakers

Case Histories in Recent Earthquake

Current Indonesian Design Codes & Guidelines

Experimental & Numerical Modeling

Geotechnical Earthquake Engineering

Non-engineered Buildings

Performance-Based Design and Evaluation

Post Disaster Recovery and Reconstruction

Seismic Devices and Applications

Seismic Hazard and Tsunami Disaster Mitigation

Seismic Micro-zonation

Soil Structure Interaction

S-SI-61-044	Mechanism and Formation of High Pore Water Pressure in Sidoarjo Mud Volcano (Lusi), The Impact Caused, and The Potential for Similar Events in Other Zones.
S-SI-61-203	Inelastic Behavior of An Extended Spun Pile Supporting Viaduct Structure Considering Soil Pile Interaction
S-SI-61-208	Effect of the soil type on the response of buildings experiencing floor-to-column pounding

Structural Assessment and Retrofit

S-AR-61-036	Assessment Of The Existing High-Rise Building Based On The Current Indonesian Codes
S-AR-61-186	Implementation of a Quick Assessment Application Called InaRISK for Damaged Houses after the 2022 West Pasaman Earthquake
S-AR-61-206	Rapid Assessment of The Public Buildings After Earthquake in West Pasaman, Indonesia

Structural Earthquake Engineering

S-EE-61-001	The Comparison of X-Braced Frame and Moment Frame on Structural Building (Case Study: Government Office of North Toraja, South Sulawesi)
S-EE-61-155	Experimental Study on the Effect of Different Ground Motion Characteristics on the Behavior of Cable-Stayed Bridge during Construction by Shaking-Table Test

Structural Dynamics

S-DN-61-047	Application Of Modal Analysis of Earthquake Force and Natural Frequency Tanjung Baru Bridge
S-DN-61-051	Dynamic Field Load Testing of A Horizontally Curved Longspan Lrt Kuningan Bridge Using Eccentric Mass Shaker And Experimental Modal Analysis
S-DN-61-074	High Speed Train Bridge Response to Dynamic Load Of Moving Train Calculating Train-Bridge Interaction During Earthquake

SHEAR CAPACITY OF HOLLOW REINFORCED CONCRETE MEMBERS WITHOUT STIRRUPS

Dewi, Sri Hartati[1]; Asrianur, Arita[2]; Thamrin, Rendy[3]; Zaidir, Zaidir[4]; and Haris, Sabril[5]

ABSTRACT

This paper presents experimental results on the shear capacity of hollow reinforced concrete members without stirrups. The area of the hole was 2.32% of the concrete cross-sectional area. The hole size used in this study is smaller than the maximum hole size required in the code, where the maximum hole area is 4% of the total cross-sectional area. The longitudinal reinforcement used in the specimen varies with the three types of reinforcement ratios. The test was carried out using the four-point shear test to achieve the expected shear failure mode. The loading was given monotonically until the specimen failed. Analytical flexural capacity was also calculated using the fiber element method. The test specimens failed in shear failure mode, indicated by large diagonal cracks in the observed shear span. The influence of the hole on the shear strength was also compared with the theoretical shear capacity proposed by the code. This comparison shows that the calculated theoretical shear capacity is conservative for hollow reinforced concrete structural elements. The results of the flexural analysis show that all the specimens did not reach the flexural capacity because they had experienced shear failure.

KEYWORDS: *analytical flexural capacity, four-point shear test, hollow reinforced concrete member, shear capacity, shear failure*

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GENERAL INFORMATION

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Pandawa Taxi

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Pataga Taxi

Telephone : (0274) 384384

Rajawali Taxi

Telephone : (0274) 487676

HOSPITAL

Public Hospital Dr. Sardjito

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Panti Rapih Hospital

Telephone : (0274) 514014

Bethesda Hospital

Telephone : (0274) 586708

Siloam Hospitals

Telephone : (0274) 4600900

DAILY EXPRESSION

Selamat Pagi

Good Morning.

Selamat Siang

Good Afternoon.

Selamat Malam

Good Evening

Apa Kabar?

How Are You?

Maaf menggangu, bisa minta bantuannya?

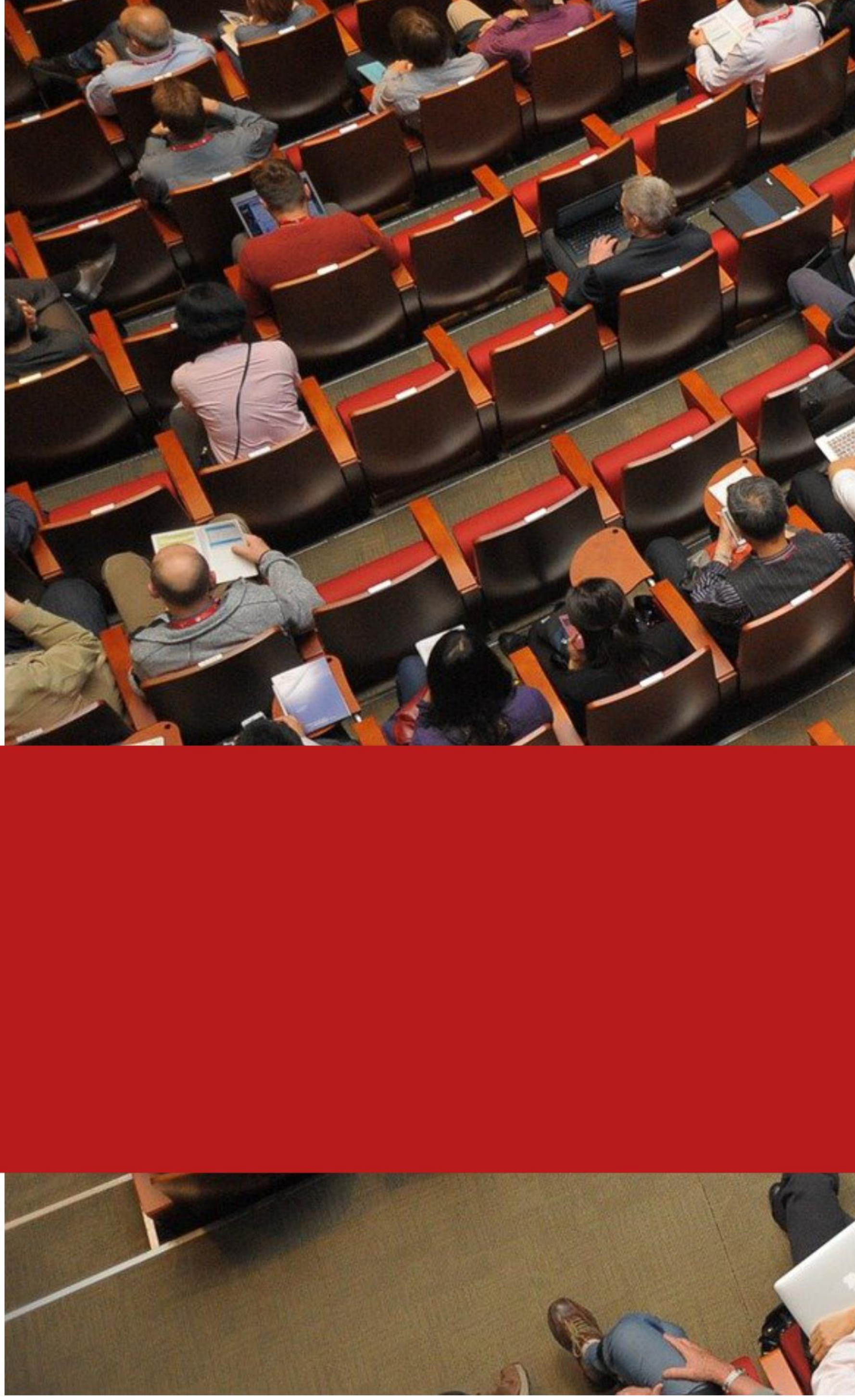
Excuse me, may I ask for your help?

Siapa nama anda?

What is your name?

Dimana....?

Where is....?



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PAPER • **OPEN ACCESS**

Shear Capacity of Hollow Reinforced Concrete Members without Stirrups

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Shear Capacity of Hollow Reinforced Concrete Members without Stirrups

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Abstract. This paper presents experimental results on the shear capacity of hollow reinforced concrete members without stirrups. The area of the hollow was 2.32% of the concrete cross-sectional area. The hollow size used in this study is smaller than the maximum percentage required in the code, where the maximum hollow area was 4% of the total cross-sectional area. The longitudinal reinforcement used in the specimen varies with the three types of reinforcement ratios. The test was carried out using the four-point shear test to achieve the expected shear failure mode. The loading was given monotonically until the specimen failed. Analytical flexural capacity was also calculated using the fiber element method. The specimens failed in shear failure mode, indicated by large diagonal cracks in the observed shear span. The influence of the hollow on the shear strength was also compared with the theoretical shear capacity proposed by the code. This comparison shows that the calculated theoretical shear capacity is conservative for hollow reinforced concrete structural elements with a hollow area smaller than 4%. The results of the flexural analysis show that all the specimens did not reach the flexural capacity due to premature shear failure.

Keywords: *four-point shear test, hollow reinforced concrete member, shear capacity, shear failure, analytical flexural capacity*

1. INTRODUCTION

Circular sections are widely used in reinforced concrete structural members because they have many advantages. The circular cross-section has advantages: easy work, high moment of inertia, and identical strength characteristics in all directions in carrying lateral and vertical loads [1,2].

Generally, circular sections are used for structural elements that carry axial compression loads, such as columns or piles. In addition to carrying axial loads, the structure also carries large lateral loads such as wind, earthquake, and other lateral loads that cause the columns to carry shear loads. Therefore the adequate shear capacity of the column must be calculated carefully [3].

Several variables that affect the shear capacity of a reinforced concrete section are the compressive strength of the concrete, the cross-sectional area, and the amount of longitudinal and transversal reinforcement [4,5]. Therefore, several studies used these variables to investigate their effect on the shear capacity of reinforced concrete structural elements.

However, in construction applications, other variables affect the shear capacity of reinforced concrete elements, such as the presence of a hollow in the middle of the cross-section. These hollows are mainly used for electrical installations, plumbing, or other purposes. In addition, the cross-section of the column with a hollow adds to the efficiency of using concrete materials [6].

The previous standard (SNI 03-2847-2002 Chapter 8) requires that the hollows for drains and pipes embedded in the column do not exceed 4% of the cross-sectional area [7]. Furthermore, the newer code (SNI-2847-2013 Chapter 6) states the same [8]. However, the latest standard (SNI-2847-2019) does not regulate the maximum requirement of the hollow area [9].

Although the shear capacity of reinforced concrete structural elements with a circular cross-section has been studied by several previous researchers [10,11]. This topic is still quite interesting to study with the additional variable, the effect of hollow area on the shear capacity of reinforced concrete columns. Therefore, this study focused on the effect of hollows in the circular cross-section on the shear capacity of reinforced concrete structural elements. The contribution of concrete in carrying shear loads with a hollow cross-section was investigated by setting the specimen without shear reinforcement. The work conducted in this study was laboratory-based to determine the shear capacity of reinforced concrete structures with circular cross-sections with three reinforcement ratios and two different concrete cross-sectional areas.

2. Experimental Setup

This research has six reinforced concrete column specimens with a circular cross-section and dimensions of 2300 mm long and 250 mm diameter. The test variable consisted of the ratio of longitudinal reinforcement and cross-section type (with and without a hollow).

The diameter of the longitudinal reinforcement used is 13, 16, and 19 mm, while the hollow diameter is 1.5 inches. The pipe hollow causes a reduction in the cross-sectional area of concrete by 2.32% of the cross-sectional area of concrete. Fresh concrete with a concrete compressive strength of 40 MPa was ordered from a ready-mix concrete company. The beam part observed in this study is located in the center of the column with a length of 1000 mm. As shown in Figure 1, the zone under consideration is not provided with shear reinforcement to realize shear failure.

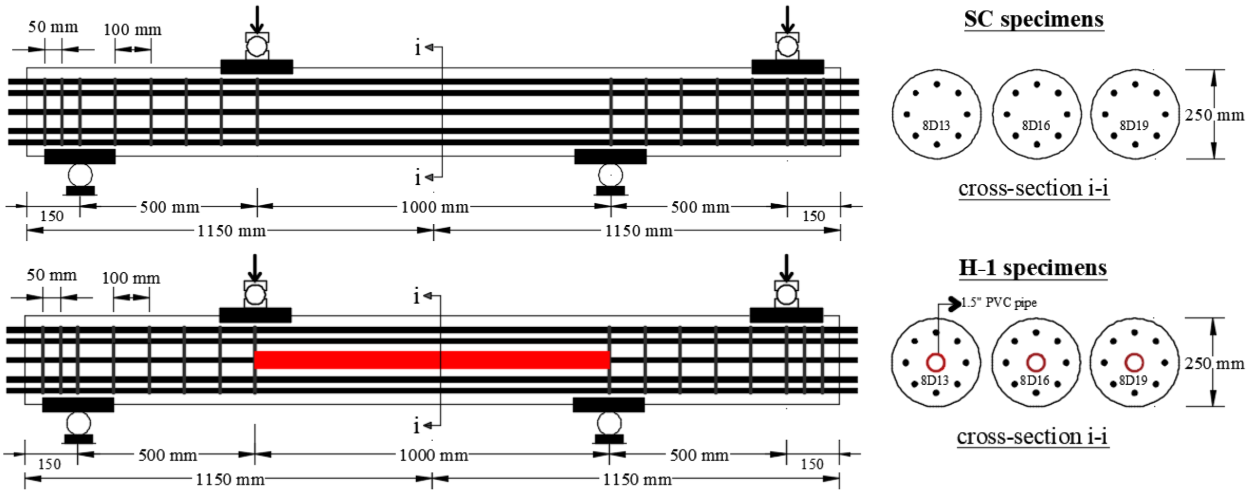

Figure 1 Specimens detail

In this paper, specimens without hollows use the SC code, and the hollow specimens are coded H. The hollow area in the H-1 specimen is below the maximum value required by the standard, which is 4%. Details of all specimens are shown in Table 1 below.

Table 1 Specimens data

Specimens data							Longitudinal reinforcement			
Specimens ID	*fc'* (MPa)	D_c (mm)	*Ac* (mm^2)	*d* (mm)	*a* (mm)	*a/d*	ϕ (mm)	*N*	f_y (MPa)	*As* (mm^2)
SC-01	40	250	50000	200	500	2.5	13	8	427	398
SC-02				200			16		492	603
SC-03				200			19		416	851
H-1-1			42380	200			13		427	398
H-1-2				200			16		492	603
H-1-3				200			19		416	851

The position of specimen, when the test was carried out, was placed horizontally with two concentrated loads and two supports, as shown in Figure 2. This loading position produces the desired combination of internal forces to cause shear failure. LVDTs and load cell were installed to measure deflection and load, which were connected to a data logger. Among the three different LVDT locations, the deflection data from LVDT 2 are plotted and reported in this paper.

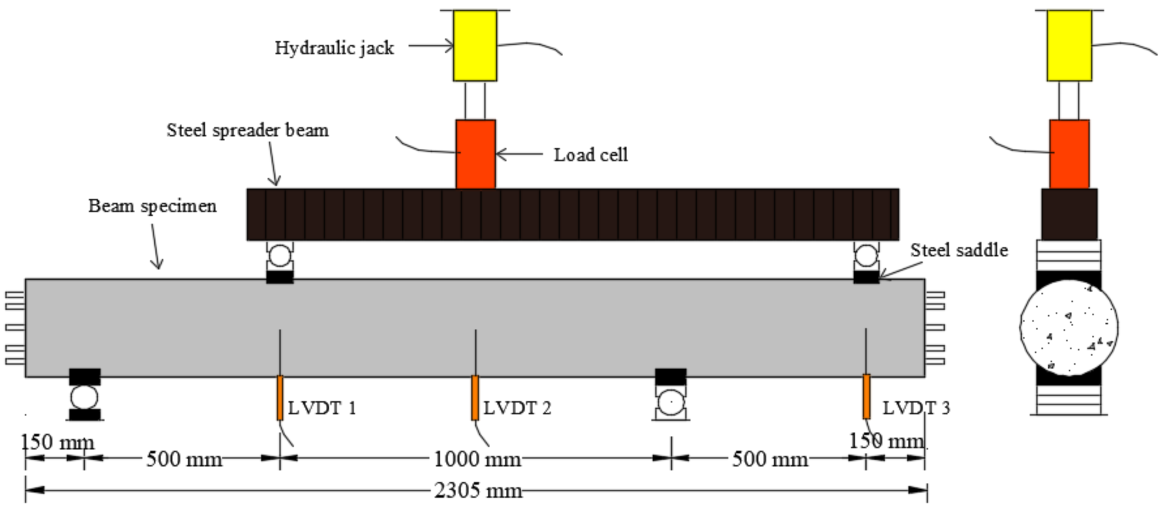

Figure 2 Schematic pictures of the tested specimen, dimension, and loading position

3. Analytical Study

The flexural analysis of reinforced concrete cross-sections performed numerically is used in analytical studies to obtain predictions of the flexural capacity of the specimens.

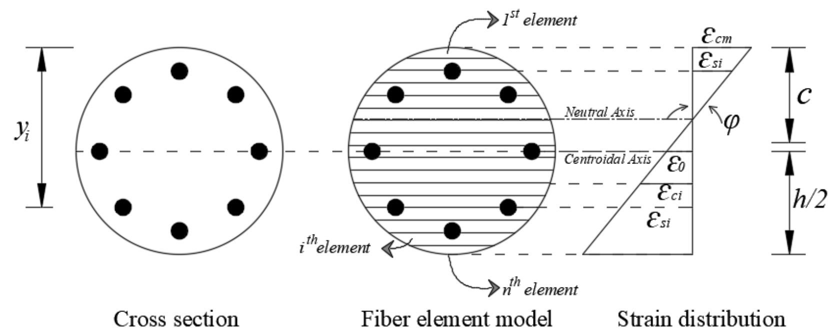

Figure 3 Solid circular cross-section with elements and strain distribution

The flexural analysis of the reinforced concrete cross-section is also assisted by a computer program developed by the author [12-14]. The layered element method divides the cross-section and reinforcement into elements, as shown in Figure 3.

4. Theoretical Shear Capacity

The nominal shear capacity of a reinforced concrete cross-section can be calculated theoretically using the equation proposed in the codes. The contribution of concrete to shear capacity is calculated based on ACI 318-19 [15], using Equation 1 below.

$$V_c = \left[0.66\lambda(\rho_w)^{\frac{1}{3}}\sqrt{f_c'} + \frac{N_u}{6A_g}\right] b_w d \qquad (1)$$

Where V_c is the shear capacity of the concrete cross-section, λ is a modification factor to reflect the reduced mechanical properties of normal-weight concrete of the same compressive strength, f_c' is the specified compressive strength of concrete, ρ_w is the ratio of the total area of longitudinal reinforcement to the cross-sectional area of concrete, D is the cross-sectional diameter of the concrete, N_u is the factored axial force normal to cross-section occurring, and A_g is the gross area of the concrete section.

In the circular cross-section, b_w in Equation 1 is converted to D and d to $0.8D$. Where D is the diameter of the circular cross-section, hence, Equation 1 can be written as Equation 2:

$$V_c = \left[0.66\lambda(\rho_w)^{\frac{1}{3}}\sqrt{f_c'}\right] 0.8\, D^2 \qquad (2)$$

Meanwhile, based on ACI 318-2019 for the shear capacity of the hollow circle cross-section, the code provided that the b_w value equals twice the wall thickness of the hollow circular section [15]. This study only reviews the shear capacity contributed by concrete. For this purpose, the specimens in this study did not use stirrups.

5. Test Result and Discussion

The failure mode in this study was observed visually, and the crack patterns in all specimens were almost the same, as shown in Figure 4. The failure that occurred in all specimens was a shear failure. It is shown by the direction and the wide diagonal shear crack propagating from the loading point. The shear failure occurs suddenly, followed by a wide shear crack in the observed zone. The failure location of all test specimens also appears in the same zone in the observed shear span.

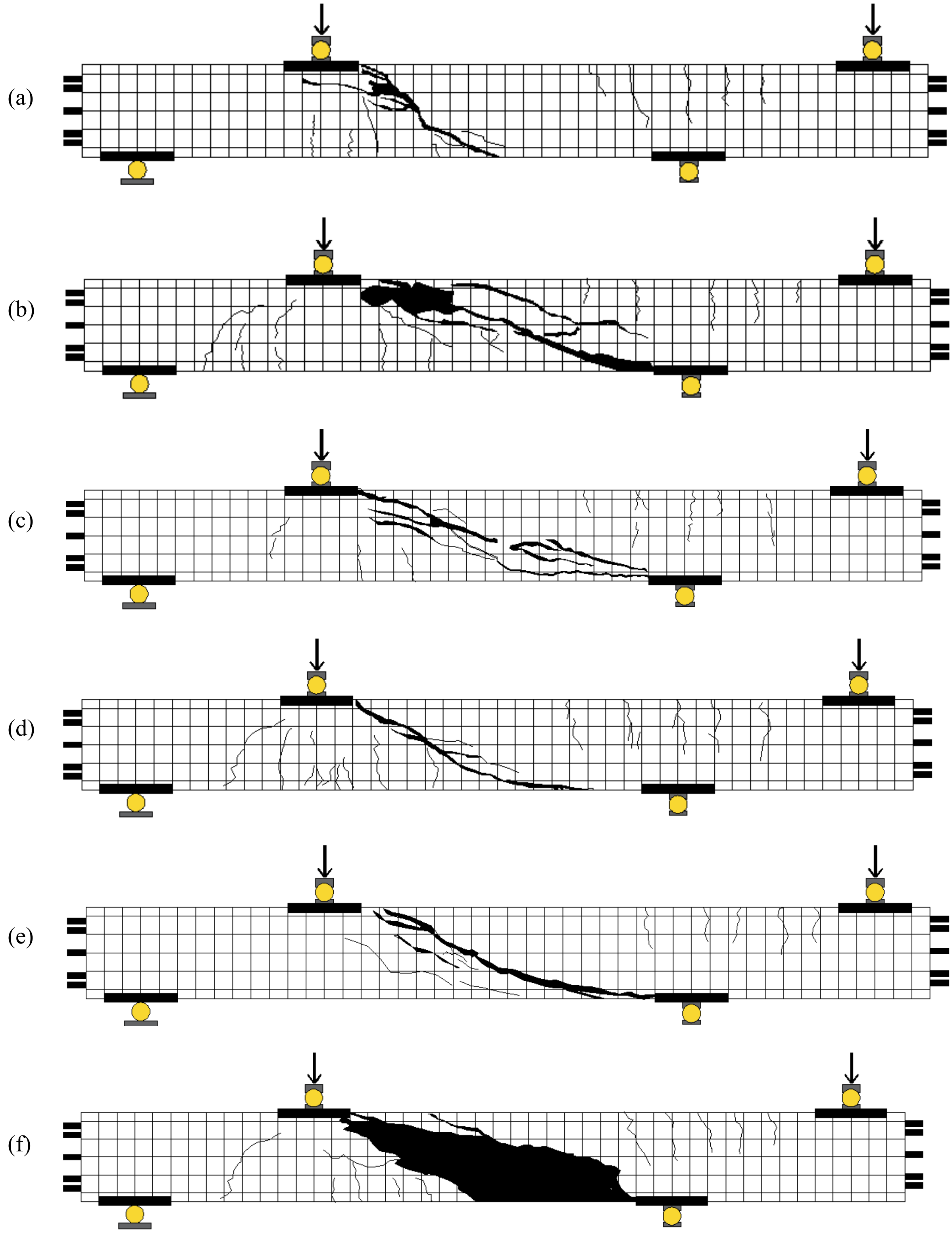

Figure 4 Crack patterns of the specimens after the test (a) SC-1, (b) SC-2, (c) SC-3, (d) H-1-1, (e) H-1-2, (f) H-1-3

From the observations, the first crack appears in the maximum bending moment zone with an average value of 23.23 kN. Then with increasing load, the flexural crack in the flexural zone extends to the shear span with a diagonal cracking mode. The test was stopped because the specimen had failed in shear mode.

Theoretical shear capacity and test results in terms of concrete shear capacity (V_c), first crack load, maximum shear load, diagonal crack angle, and identification of the type of failure of each specimen can be seen in Table 2 below. The failure mode with the letter S indicates the shear failure mode.

Table 2 Specimen theoretical capacities and experimental results

	Calculated Shear Capacity ACI 318M-19	Average load at first crack	Diagonal Crack Load	Max. Load	The major crack angle	Failure Mode
Specimens ID	V_c (kN)	(kN)	V_{ce} (kN)	V_{max} (kN)	θ^o	
SC-01	42.2	23.23	57.83	72.3	45°	S
SC-02	48.5		67.50	87.1	22°	S
SC-03	54.3s		82.63	83.7	21°	S
H-1-1	37.8		63.13	69.2	26	S
H-1-2	43.4		60.97	82.3	24	S
H-1-3	48.7		75.93	91.3	23	S

The results in Table 2 show that the shear strength of the hollow specimen is not too different from that of the solid specimen, as shown in Figure 5. It means that the hollow with an area of 2.32% (smaller than 4%) has no significant effect on the shear strength of the specimen. In addition, the test results show that the greater the reinforcement ratio, the higher the shear capacity obtained.

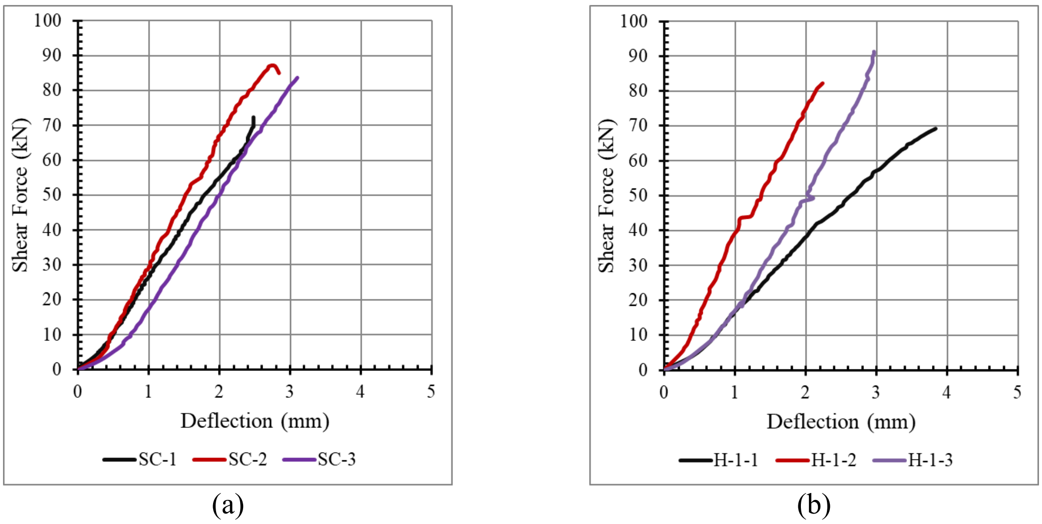

Figure 5 Load-deflection curve of the tested specimens (a) Control specimens (SC), (b) Hollow specimens (H-1)

Analytically, the flexural capacity of specimens with different reinforcement ratios is very different. Figure 6 shows that the greater the reinforcement ratio, the greater the flexural capacity. However, due to premature shear failure, all specimens were proven not to reach the flexural capacity obtained analytically.

The theoretical V_c value can be seen in Figure 6 as a straight solid line. As can be seen, this theoretical shear capacity value is below the maximum shear load value obtained from the test. It proves that hollows with an area below 4% of the cross-sectional area are still safe for use in reinforced concrete structural elements.

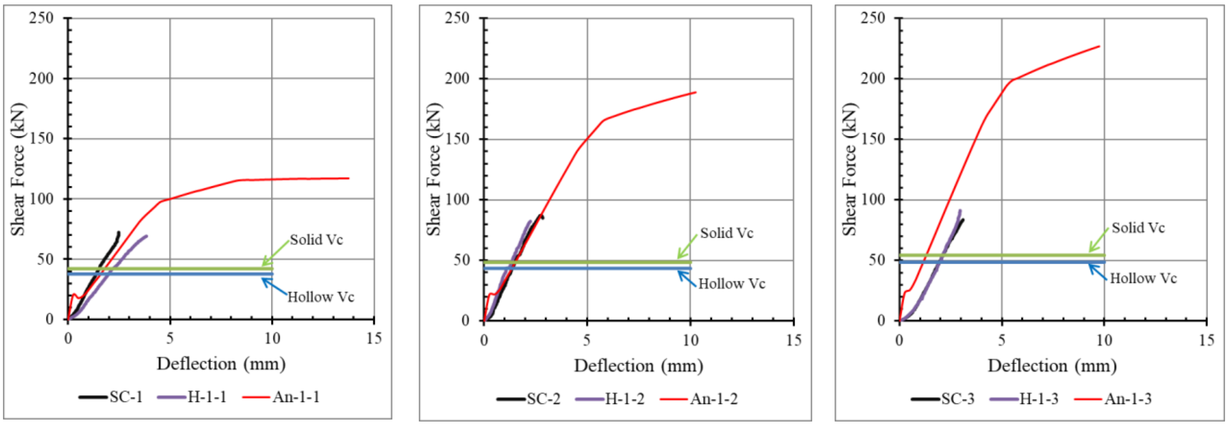

Figure 6 Load-deflection curves of specimens based on reinforcement ratio and analytical flexural capacities.

6. Conclusions

Based on the results of tests and analytical work carried out in this study, several points can be concluded as follows:

1. All specimens in this study failed in the shear mode, as indicated by a sudden wide diagonal crack.
2. Due to premature shear failure, the specimen does not reach its flexural capacity.
3. The maximum hollow area limitation provided in the code (4%) offers conservative results for the shear strength of hollow reinforced concrete structural elements.

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