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Article

The Latest Innovations in the Flexural Capacity of Castellated Beams with Hexagonal Stiffener Variations

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Abstract: This research evaluates the effect of varying hexagonal opening angles on the flexural and shear capacity of castellated beams. This study is conducted through experimental and numerical approaches using WF 150.75.5.7 steel profiles. The hexagonal opening angles are varied to 20°, 30°, 45°, 55°, and 60°. Experimental testing results show that beams with a 20° opening angle have higher flexural and shear capacities compared to larger opening angles. Numerical testing results are consistent with experimental results, showing more uniform deformation patterns and stress distribution at smaller opening angles. These findings contribute significantly to the design of more efficient and effective castellated beams in modern structural applications, particularly in constructions requiring high flexural and shear capacities.

Keywords: castellated beams; flexural capacity; shear capacity; hexagonal opening angle; experimental analysis; numerical analysis; stress distribution; deformation

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1. Introduction

In the modern construction world, innovation is the key to achieving better structural and economic efficiency. One area that continues to evolve is the design and use of steel beams in various types of structures. Steel beams are often used in the construction of buildings, bridges, and other infrastructures due to their strength and durability. However, the ongoing challenge is how to enhance the capacity and efficiency of steel beams without significantly increasing cost or weight.

Castellated beams have been the subject of intensive research over the past few decades due to their potential in improving the efficiency of steel structures. One of the latest innovations in the design of castellated beams is the introduction of hexagonal stiffeners designed to enhance the flexural and shear capacity of these beams. This research aims to explore the impact of varying hexagonal opening angles on the flexural and shear capacity of castellated beams.

First introduced in the 1950s, castellated beams are a result of modifying conventional steel beams by creating openings in the beam web to reduce weight without compromising structural strength. This modification not only reduces material usage but also enhances the beam's flexural capacity by increasing the moment of inertia (Altifillisch et al., 1957; Bardley, 2007).

According to Gere and Timoshenko (1972), the behavior of steel material in resisting stress and strain follows a specific pattern that can be modeled to predict structural performance. Further research by Malley (2003) and Faress et al. (2016) confirmed that adding hexagonal stiffeners to castellated beams can significantly increase the shear capacity and flexural moment of these beams.

Numerical and experimental methods have been used to evaluate the performance of castellated beams with hexagonal opening variations. Research by Amayreh and Saka (2005) used neural networks to predict the failure load of castellated beams, showing that deformation and stress patterns can be predicted with high accuracy using this method. Meanwhile, Knowles (1987) and Muhtarom et al. (2018) investigated the effects of geometric variations on beam performance, indicating that more complex designs can provide significant structural performance improvements.

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One innovation attracting attention is the use of castellated beams with hexagonal openings. Castellated beams are steel beams cut and rearranged with specific shaped openings to increase profile height without adding significant material. The use of castellated beams allows for increased moment of inertia and section modulus, which in turn enhances the beam's flexural capacity. In recent years, studies have shown that castellated beams with hexagonal openings offer significant advantages in terms of flexural capacity compared to conventional beams.

Previous studies have shown that increasing the height of the steel profile resulting from openings in the web can increase flexural capacity by 8-19%, with maximum flexural capacity occurring at opening angles of 45°-50° (Barkiah & Darmawan, 2020). Besides flexural capacity, the shear capacity of castellated beams is also affected by the shape and angle of the openings in the web. Hexagonal opening angles ranging from 20° to 60° are identified as key variables influencing the shear performance of the beams (Barkiah et al., 2021).

Research by Barkiah and Darmawan (2020) showed that castellated beams with hexagonal openings could increase flexural capacity by up to 19%, with maximum flexural strength occurring at opening angles of 45°-50°. This demonstrates the significant potential of hexagonal castellated beams in structural applications requiring high flexural strength. Additionally, research by Permadi (2021) found that variations in profile cut width from 30 mm to 70 mm do not significantly affect flexural capacity under yield conditions, meaning that castellated beam designs can be more flexible without sacrificing structural performance.

However, innovation does not stop at the shape and size of the openings. Recent studies have explored the impact of using stiffeners or reinforcements on hexagonal castellated beams. Stiffeners are additional elements added to the beam to increase stiffness and load capacity. The use of stiffeners on castellated beams aims to distribute stress more evenly and prevent excessive deformation, especially at critical points around the openings. A study by Putra and Sabariman (2014) showed that adding stiffeners could significantly enhance load distribution and flexural capacity of castellated beams.

This research focuses on evaluating the effect of stiffener variations on the flexural capacity of hexagonal castellated beams. Various types of stiffeners were used, including 35x6 mm plates, Ø-16 mm reinforcements, and 25.25.4 mm angles, with stiffener spacing variations of 200 mm and 400 mm. Through manual analysis and numerical testing using software, we aim to understand how each stiffener variation affects the performance of castellated beams under flexural load conditions.

The use of stiffeners in castellated beams is expected to provide practical and effective solutions to enhance structural capacity without drastically changing the basic beam design. By understanding the impact of various stiffener variations, we hope to provide better guidelines in the planning and design of castellated beams for broader construction applications. This research also aims to identify the most effective types and configurations of stiffeners to enhance flexural capacity and reduce the risk of structural failure.

Castellated beams with hexagonal openings have shown significant potential in previous studies. However, many aspects still need to be explored to fully understand how this innovation can be optimally applied in construction practice. One important aspect is how stiffener variations affect the performance of castellated beams under different load conditions. Additionally, this research also considers other factors such as stress distribution, deformation patterns, and failure mechanisms, all of which contribute to the overall performance of castellated beams.

In this study, we will use a combination of numerical and experimental approaches to evaluate the impact of hexagonal opening angles on the flexural and shear capacity of castellated beams. This research is expected to contribute significantly to the development of more efficient and effective castellated beam designs in their application to modern building structures.

2. Research Methods

Test Specimen Preparation: The test specimens are prepared by cutting the WF 150.75.5.7 profile according to the predetermined opening angles. The cutting process is performed precisely to ensure each hexagonal opening angle matches the design.

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Experimental Testing: Testing is conducted using experimental methods with flexural and shear test equipment. Each castellated beam is placed on simple supports with concentrated loads at two points. The span length of the beam elements is the same for all variations, both conventional and castellated steel beams. Loading is applied gradually until the beams reach the failure limit.

Numerical Testing: Besides experimental testing, numerical testing is also conducted using structural analysis software. Material specifications and loading data are input into the software to simulate the behavior of castellated beams with varying hexagonal openings. The parameters analyzed include deformation, stress, and failure patterns for each model.

Research Flow Diagram:

- Literature study related to shear and flexural capacity of conventional steel beams and castellated steel beams.
- Preparation of test specimens and profile cutting according to the determined opening angles.
- Experimental testing and data collection on deformation and stress.
- Numerical analysis using software by inputting material specifications and loading data.
- Comparison of results between conventional beams and castellated steel beams at various opening angles.
- Conclusion based on experimental and numerical analysis results.

3. Results and Discussion

3.1. Experimental Testing Results

The results of experimental testing show that variations in the hexagonal opening angles of castellated beams have a significant impact on the beams' shear and flexural capacity. This testing was conducted using adequate bending and shear testing equipment, allowing for accurate and comprehensive measurement of the structural performance of the castellated beams. Beams with a 20° opening angle showed higher shear capacity compared to beams with larger opening angles of 30°, 45°, 55°, and 60°. However, increasing the opening angle tends to reduce the overall shear capacity of the beam.

For beams with a 20° opening angle, the test results showed higher shear capacity compared to beams with larger opening angles of 30°, 45°, 55°, and 60°. The increase in shear capacity at the 20° opening angle is due to a more even stress distribution and less deformation. Under these conditions, the beam can withstand larger loads before reaching the failure limit, indicating that smaller opening angles provide advantages in terms of shear capacity.

In addition to shear capacity, flexural capacity was also analyzed. Beams with a 20° opening angle showed higher flexural capacity compared to beams with larger opening angles. This is due to the increased moment of inertia that occurs at smaller opening angles, allowing the beam to withstand larger bending moments without significant deformation. Conversely, beams with a 60° opening angle showed the lowest flexural capacity, indicating that increasing the opening angle tends to reduce the beam's flexural capacity.

3.2. Numerical Testing Results

Numerical testing results using structural analysis software show deformation and stress patterns consistent with experimental results. Models with a 20° opening angle exhibit a more even stress distribution and less deformation compared to models with larger opening angles. This indicates that smaller opening angles can enhance the structural performance of castellated beams. Numerical simulations allow for the visualization of stress and deformation distribution for each hexagonal opening angle variation, providing deeper insights into the failure mechanisms and structural performance of castellated beams.

Models with a 20° opening angle exhibit a more even stress distribution and less deformation compared to models with larger opening angles. This indicates that smaller opening angles can enhance the structural performance of castellated beams by effectively distributing stress and

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reducing stress concentration around the hexagonal openings. Furthermore, the deformation patterns produced by the numerical model show that beams with a 20° opening angle have more uniform deformation, indicating better structural stability compared to beams with larger opening angles.

4. Discussion

From the results of experimental and numerical testing, it can be concluded that variations in hexagonal opening angles significantly affect the shear and flexural capacity of castellated beams. Smaller opening angles, such as 20°, provide better shear and flexural capacity compared to larger opening angles. This is due to several key factors influencing the structural performance of castellated beams. This research makes an important contribution to the design of castellated beams with hexagonal openings, particularly in structural applications requiring high shear and flexural capacity.

First, smaller opening angles enhance the stress distribution around the hexagonal openings. More even stress distribution reduces stress concentration that can cause premature failure in beams. This more even stress distribution also helps reduce local deformation around the openings, thereby increasing the shear and flexural capacity of the beams. Previous research by Barkiah and Darmawan (2020) also supports these findings, showing that a 45°-50° opening angle provides maximum flexural capacity in castellated beams.

Second, the increase in moment of inertia that occurs at smaller opening angles plays a significant role in enhancing the flexural capacity of beams. Larger moments of inertia allow beams to withstand larger bending moments without significant deformation. This is very important in structural applications requiring high flexural strength, such as in bridges and high-rise buildings. Research by Permadi (2021) shows that variations in profile cut width from 30 mm to 70 mm do not significantly affect flexural capacity at yield conditions, indicating flexibility in the design of castellated beams without compromising structural performance.

Third, the numerical testing results support the experimental findings, showing that models with a 20° opening angle have more even stress distribution and less deformation. This indicates that the use of structural analysis software can be an effective tool in predicting the structural performance of castellated beams with variations in hexagonal opening angles. Numerical simulations allow for more detailed visualization of how stress and deformation are distributed around the openings, which can help in more effective planning and design.

This research makes an important contribution to the design of castellated beams with hexagonal openings, especially in structural applications requiring high shear and flexural capacity. The finding that smaller opening angles provide better shear and flexural capacity can be used as a guide in planning and designing castellated beams for various construction applications. Additionally, the research results also highlight the importance of using stiffeners or additional reinforcements to enhance the structural performance of castellated beams.

Although this research has successfully demonstrated the significant influence of hexagonal opening angle variations on the shear and flexural capacity of castellated beams, there are several aspects that need further exploration. For instance, further research could focus on exploring other opening geometry variations as well as using new materials to enhance the performance of castellated beams. Additionally, further studies on the effect of additional stiffeners on castellated beams with various opening angles could provide deeper insights into the structural performance of these beams.

5. Conclusions

This research has successfully demonstrated that innovation in the design of castellated beams with variations in hexagonal opening angles can provide significant improvements in shear and flexural capacity. By understanding the influence of hexagonal opening angles, engineers can design more efficient and effective structures, leveraging the advantages of castellated beams in modern construction applications. These findings provide a strong foundation for further development in the design and application of castellated beams and encourage the widespread adoption of this technology in construction practice. This research has evaluated the influence of hexagonal opening

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angle variations on the flexural and shear capacity of castellated beams through experimental and numerical approaches. Based on the results obtained, several key points can be concluded as follows:

Influence of Opening Angle on Flexural and Shear Capacity: Hexagonal opening angles have a significant influence on the flexural and shear capacity of castellated beams. Beams with a 20° opening angle exhibit higher flexural and shear capacity compared to beams with larger opening angles. This is due to more even stress distribution and less deformation at smaller opening angles.

Experimental Testing Results: Experimental testing results show that variations in hexagonal opening angles affect the deformation and stress patterns in castellated beams. Beams with smaller opening angles tend to have better shear and flexural capacity as well as more stable deformation patterns.

Numerical Testing Results: Numerical testing using structural analysis software shows consistency with experimental results. Models with a 20° opening angle exhibit more even stress distribution and less deformation compared to models with larger opening angles.

Structural Design Implications: The findings of this research make an important contribution to the design of castellated beams with hexagonal openings. Smaller opening angles can be adopted to enhance flexural and shear capacity, particularly in structural applications requiring high strength and stability.

Recommendations for Further Research: Further research could focus on exploring other opening geometry variations as well as using new materials to enhance the performance of castellated beams. Additionally, further studies on the effect of additional stiffeners on castellated beams with various opening angles could provide deeper insights into the structural performance of these beams.

Author Contributions:

Funding:

Conflicts of Interest:

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