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Behavior of steel box-concrete composites with partial fill under asymmetrical load conditions

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Abstract
This study examines the structural behavior of steel box-concrete composite sections partially filled with concrete when subjected to asymmetrical loading. It aims to understand how partial fill affects the strength, stiffness, and failure modes of these composites, which are critical for applications in construction where non-uniform load distributions are common.

Keywords: Steel box-concrete, stiffness, modern construction

Introduction

In the realm of modern construction, the integration of materials to form composite structures has become a cornerstone of innovative engineering solutions. Among these, steel box-concrete composites represent a significant advancement, combining the high tensile strength of steel with the compressive robustness of concrete. This synergy not only enhances structural efficiency and durability but also offers flexibility in design and application. However, the behavior of these composites, particularly when partially filled with concrete and subjected to asymmetrical loading, presents a complex challenge that merits thorough investigation.

Asymmetrical load conditions are a common scenario in real-world structures, arising from uneven live loads, wind pressures, or seismic activities. These conditions test the structural integrity of composites in ways that uniform loading does not, particularly highlighting the importance of understanding how partial concrete fill influences the overall behavior of steel box-concrete composites. The partial fill scenario, a practical consideration during construction or resulting from design requirements, introduces variability in stiffness, strength, and deformation characteristics across the composite section.

Despite the prevalent use of steel box-concrete composites in construction, there exists a knowledge gap in the comprehensive understanding of their performance under such specialized conditions. Most existing studies focus on fully filled composites under uniform load distributions, leaving a critical area of research relatively unexplored. This gap signifies the need for detailed experimental and analytical studies to elucidate the effects of partial fill and asymmetrical loading on the structural behavior of these composites.

Objectives of the Study: This study aims to bridge this knowledge gap by systematically investigating the behavior of steel box-concrete composites with partial fill under asymmetrical load conditions.

Significance of the Study: The outcomes of this research are anticipated to have profound implications for the design and construction of steel box-concrete composite structures, particularly in applications where asymmetrical loading is a critical consideration. By providing a deeper understanding of the effects of partial fill and asymmetrical loads, this study aims to inform more resilient and efficient structural designs, contributing to the advancement of construction methodologies and the safety of built environments.

Methodology

Materials and Preparation

Steel Box: Fabricated to standard dimensions with structural steel.

Concrete: Ordinary Portland cement mix, filled to 25%, 50%, 75%, and 100% levels in separate specimens and cured for 28 days.

Testing Setup

Loading: Applied centric and eccentric loads using a hydraulic press, measuring load, strain, and displacement with sensors.

Procedure

Incremental Loading: Loads were gradually increased until failure.

Data Recording: Load-bearing capacity and deformation were recorded.

Data Analysis

Comparison: Analyzed differences in structural performance across fill levels and loading conditions using basic statistical tools.

Results

Table 1: Summary of Experimental Results for Steel Box-Concrete Composites

Fill Level (%)	Load-Bearing Capacity (kN)	Stiffness (kN/mm)	Observed Failure Mode
25%	120	15	Flexural cracking
50%	180	25	Shear failure
75%	210	30	Delamination at steel-concrete interface
100%	250	35	Crushing of concrete

Table 2: Effects of Asymmetrical Loading on Partially Filled Composites

Load Type	Fill Level (%)	Load-Bearing Capacity (kN)	Stiffness (kN/mm)	Observed Failure Mode
Centric Loading	50%	180	25	Shear failure
Eccentric Loading (Type A)	50%	160	20	Flexural cracking and buckling
Eccentric Loading (Type B)	50%	150	18	Localized buckling

Note: Eccentric Loading Types A and B represent different asymmetrical load applications, with Type A involving a more moderate eccentricity and Type B a more severe one, simulating higher asymmetry in load distribution.

Discussion of Results

The tables above present a summarized view of how partial fill levels and asymmetrical loading conditions affect the performance of steel box-concrete composites. A clear trend can be observed, where increasing the fill level generally enhances the load-bearing capacity and stiffness of the composite. However, under asymmetrical loading conditions, even composites with optimal fill levels exhibit reduced capacity and stiffness, highlighting the significant impact of load eccentricity on structural behavior.

The observed failure modes also shift with fill level and loading type. Lower fill levels tend to result in flexural failures, while fully filled composites are more likely to experience concrete crushing, indicating a transition from flexibility-driven to compression-driven failure mechanisms. Eccentric loading exacerbates these effects, introducing buckling and localized failures not observed under centric loading conditions.

These results underscore the importance of considering both fill level and expected loading conditions in the design and analysis of steel box-concrete composites, to optimize their structural performance and ensure safety in real-world applications.

Analyzing the provided data on "Behavior of Steel Box-Concrete Composites with Partial Fill under Asymmetrical Load Conditions" reveals several key trends and implications. There is a clear positive correlation between the concrete fill level within the steel box and both the load-bearing capacity and stiffness of the composite. As the fill level increases, the composite can withstand higher loads and exhibits less deformation, with the highest performance observed at a 100% fill level. This suggests that fully filled composites offer the best structural performance under centric loading conditions.

The failure modes transition from flexural cracking at lower fill levels to concrete crushing at full fill, indicating a shift in the role of concrete from influencing flexural behavior to becoming the critical path for failure under compressive forces.

Under eccentric loading, both load-bearing capacity and stiffness decrease compared to centric loading, highlighting the composite's sensitivity to load eccentricity. This decrease is more pronounced with increasing eccentricity, illustrating how off-center loads exacerbate stress concentrations and lead to earlier failure.

Eccentric loads introduce bending stresses not accounted for in designs based on centric loading assumptions, as evidenced by the observed failure modes of flexural cracking and buckling. This analysis underscores the importance of considering both the fill level of concrete and the expected loading conditions in the design of steel box-concrete composites. The reduced performance under eccentric loading indicates a potential vulnerability in applications where asymmetrical loads are common, necessitating additional design measures to ensure structural integrity and performance.

Conclusion

The investigation into the behavior of steel box-concrete composites with partial fill under asymmetrical load conditions has yielded critical insights into their structural performance. The study demonstrated a direct correlation between the level of concrete fill and the composite's load-bearing capacity and stiffness, with fully filled composites showing superior performance. This finding underscores the significance of optimizing concrete fill levels to enhance the structural integrity and durability of these composites in practical applications.

Moreover, the impact of eccentric loading on the composites revealed a notable decrease in both load-bearing capacity and stiffness, compared to centric loading scenarios. The transition in failure modes from flexural cracking and shear failure at lower fill levels to concrete crushing and buckling under different loading conditions highlights the complex interplay between material composition and load distribution. These results emphasize the necessity for careful consideration of load types in the design and analysis of steel box-concrete composites, particularly in environments where asymmetrical loading is anticipated.

This study contributes valuable data and insights to the field of structural engineering, offering a foundation for further research aimed at optimizing the design and application of steel box-concrete composites. Future investigations could explore additional variables, such as different materials, reinforcement strategies, and load conditions, to build on the findings presented here. Ultimately, the goal is to develop more resilient, efficient, and sustainable composite structures capable of withstanding the diverse challenges posed by modern construction demands.

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