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Structural Behavior and Fire Resistance of Shallow Steel-Concrete Composite Decks

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REVIEW ARTICLE

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Abstract

This study investigates the structural behavior and fire resistance of Shallow Steel-Beam-Concrete Composite (SSCC) decks, focusing on the influence of various Steel-Concrete (SC) bonding techniques. SSCC decks combine steel beams with concrete slabs, offering structural efficiency and durability under significant loads. The effectiveness of SC bonding methods is evaluated by comparing experimental results to Full Composite Action (FCA) simulations. Fire resistance in shallow floors, particularly SlimFlor systems, is analyzed using numerical simulations and parametric studies, highlighting their enhanced performance due to concrete's thermal shielding of steel. Additionally, the paper explores innovative deck profiles, particularly a top-hat section with transverse corrugations, improving buckling and shear resistance. Experimental tests of various loading scenarios validate the performance of these profiles, which may prove effective in composite slim-floor systems. Design recommendations are based on Australian Standards, with a call for adjustments to accommodate these novel profiles.

Keywords

Shallow Steel-Concrete Composite Decks, SC Bonding Techniques, Full Composite Action, Fire Resistance, Top-Hat Deck Profiles, Buckling Resistance

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Introduction

SSCC decks have gained popularity due to their structural efficiency and fire resistance, particularly in high-rise constructions. These systems are designed to address challenges of limited height and high load-bearing capacity. However, despite their widespread use, existing design standards like AISC360, Eurocode 4, and JGJ138-2016 do not fully account for the SC composite action, necessitating further research.

1. **Exploring the Influence of Shallow Deck-Type Steel Composites in Modern Construction**

   The behavior of shallow steel-beam-concrete composite (SSCC) decks—which are made of steel beams attached to concrete—will be investigated in this study. The impact of various Steel-beam-Concrete (SC) bonding methods and procedures on the composite action is emphasized. A thorough analysis of numerous experimental tests revealed that the SC bonding force is made up of two parts: one that depends on the chosen SC bonding technique and the other that is derived from the direct adhesion of steel to concrete in the compression zone. By contrasting the results of experimental tests with numerical simulations that exhibit Full Composite Action (FCA), one can evaluate the efficacy of such SC bonding techniques, which range from negligible to FCA. The more closely the test result matches the FCA result, the more successful the SC bonding technique that was used. Analytical formulas for the bending capacity of SSCC decks with FCA at yield and ultimate have been developed for use in design. [1]

The structurally efficient flooring system for designing floors with two opposing requirements—limited available height and substantial live loads—is a SSCC deck. Using a thorough analysis of SSCC decks, the most widely distributed typologies were categorized. Strong resistance to corrosion and fire, with a 60-minute burn time for the latter. All of these benefits result from the Steel-Beam-Concrete (SC) composite action, which regulates bearing capacity. Many long-term experimental studies have been carried out over the years to elucidate the impact of various SC bonding measures on enhancing the composite action.

Experimental investigations were conducted concurrently with a number of theoretical studies on SSCC decks. Descriptive released a structural model for a multi-layer laminated composite. Suggestive has presented an analytical approach for the analysis of generic multi-layered composite beams with n layers connected by flexible interfaces. Even though these methods are accurate, their application in real-world situations is hindered by their intricate mathematical foundation. Scheme that uses useful equations to determine the bnding capacity of deep-deck floors. Nevertheless, none of these methods can be applied with any degree of reliability to the calculation of all SSCC deck types. This is primarily because the effects of various SC bonding

techniques and measures on the SC bonding are not fully understood. Because of this, SSCC decks are not covered by AISC360, Eurocode 4, or the Chinese code JGJ138-2016. Therefore, more research is required to better understand the variables influencing the SC composite action in SSCC decks and to evaluate the efficacy of various SC bonding strategies.
Comparing experimental tests with the corresponding FCA model allows one to estimate the impact of various SC bonding measures and techniques on composite action. The present study's methodology is explicated in more detail below. Initially, studies on SSCC decks with varying SC bonding methods and measures have been gathered from the literature. Those experimental tests were compared in the second step to the outcomes of numerical models that used SC FCA implementation. The theory behind calculating each SC bonding approach's effectiveness is that the more closely the experimental response resembles the numerical one obtained using FCA, the more successful the SC bonding technique. A straightforward and efficient criterion for evaluation is to compare the experimental curve's yield moment with the FCA curve's. If the experimental curve's yield moment is less than 95% of the FCA curve's yield moment, then there is no FCA present. Following the identification of the most successful methods, i.e., those exhibiting a response near FCA, analytical mechanics-based design equations have been created to assess the associated moment–curvature response. Figure 1

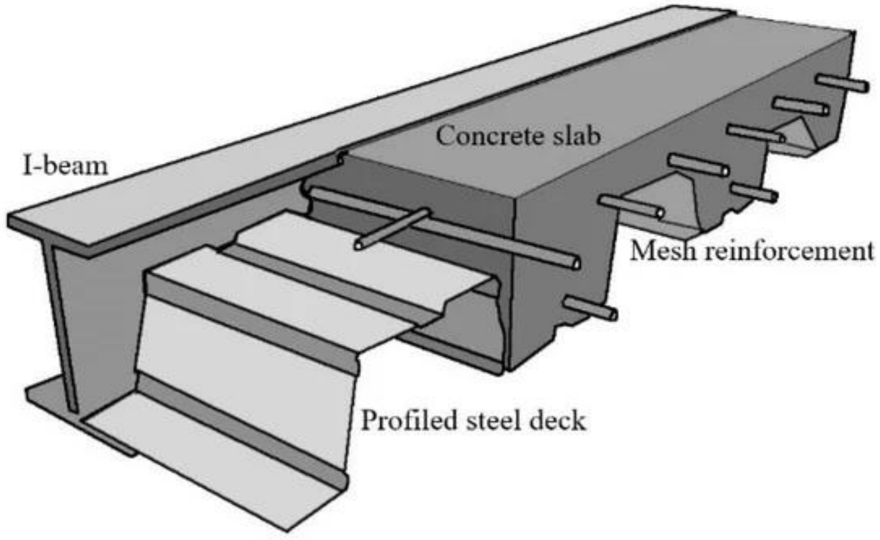

Figure 1 : Composite Floor System with I-Beam, Concrete Slab, Steel Deck, and Reinforcement

2. Deep

An international research project was released by Descriptive to investigate the fire behavior of a specific, economically attractive variety of composite steel concrete beams: shallow floor beams with composite slabs that use deep deckings. A brief summary of the outcomes of three full-scale fire tests is provided. Advanced numerical models that enable precise simulation of the fire tests and a parametric study into pertinent factors affecting the overall fire behavior of this type of composite structures have been established based on these fire tests. The parametric study's output is converted into practical, affordable calculation rules for engineering practice. Traditionally, primary and secondary beams, columns, and a steel frame make up a steel frame structure. Particularly for high-rise buildings, an economical load-bearing construction can be achieved by combining a steel frame with a composite steel concrete slab. A different type of load-bearing structure that incorporates steel beams into the floor slab has been developed recently. The focus of this paper is the so-called SlimFlor design, which consists of a Hot-Rolled Steel (HRS) plate that has been welded to a plate that has a composite slab with deep steel decking installed on it. Descriptive given the shallow floor construction, there are multiple benefits: (i) a lower floor depth; (ii) a nearly level underside of the floor allowing for an unrestricted service layout; and (iii) an intrinsically improved fire resistance of the steel beams because of the surrounding concrete's thermal shielding. Regarding the latter, it should be noted that while the general guidelines outlined above are applicable, Eurocode does not provide any particular guidelines for assessing the fire resistance of these kinds of beams or slabs. [2]

3. Load

In composite floor construction, trapezoidal-shaped thin-walled metallic profiled sheets are used to facilitate quick construction and minimize the need for formwork and reinforcement during concrete casting. Nonetheless, pertinent research revealed that the shear and buckling of the decking profiles—which are currently in place and trapezoidal and re-entrant—caused the early failure of steel sections. Regarding design guidelines, there are restrictions for composite flooring systems as well. The goal of the current work is to create a novel composite top-hat section that may be applied to composite slim-floor construction Transverse corrugations were added along the corrugated profile's primary direction as part of a new bending process used to create deck components. In the construction of buildings, sinusoidal metallic corrugated sheets are frequently utilized. In this case, the structural response of these novel sections under varied loads and support circumstances was investigated using a pilot experimental approach. The developed top-hat sections demonstrated significant resistance to bending and buckling due to efficient stress re-distribution under evaluated construction stage loading for single and continuous span conditions. The design strength was predicted and compared to experimental results using design equations for corrugated decks that are currently on the market and advised by Australian Standards. The code's suggested expressions were found to be insufficient for single span loading scenarios and would need to be modified before being implemented for the new profile. [3]

The use of various materials in concert to provide improved resistance under a range of loading conditions is known as composite construction. Steel-concrete composite construction has been used extensively in major Australian structures since 1965 and has been in use for more than a century. Large column-free spans in buildings are often achieved with composite flooring systems, allowing for greater structural flexibility or open-plan occupancy. Because they don't require formwork during construction, cold-formed steel decking profiles are becoming more and more popular in steel-concrete composite flooring systems. This is because they can save a lot of money and time. During the building phase, steel decks serve as the formwork for concrete, and after the concrete hardens, they serve as tensile reinforcement. In particular, Slimflor and Slimdek construction, which were first used in Europe in the 1990s, have grown in popularity and efficiency. Because these slabs use integrated steel beams that are contained within composite floor systems, varying floor thickness can be accommodated by relatively shallow slabs. For this kind of composite flooring, trapezoidal sheets or re-entrant-shaped decks have been widely utilized. These panels are not only used for flooring but also for wall cladding, roofing, and bridge decks. Their performance and behavior under various loading conditions have so been thoroughly examined over time. [4]

According to certain theories, longitudinal and vertical shear between the concrete and the steel deck is the main reason why composite flooring systems fail. One of the most important considerations in determining the optimal deck/rib configuration is the shear connection at the interface between the concrete and the steel deck. The shear and buckling properties of decks with trapezoidal and re-entrant shapes have been thoroughly studied. However, there aren't many attempts in the literature to further create new forms to improve composite decks' resistance to buckling and shear. Descriptive introduced a novel composite flooring system that interlocked long-span decks in an inverted hat configuration using cold-formed steel decks. After that, concrete was poured on top of a transversely laid, very light gauge, shallow steel deck that covered the top of the inverted hat. The shear connection at the interface of the concrete and steel deck is one of the most significant factors to consider when establishing the appropriate deck/rib arrangement. A mechanical clamping action is created when the profiled steel sheets distort, holding the two materials together. However, longitudinal shear stresses will cause slippage between the two components. It has been observed that features like notches or embossments on steel sheet profiles and thicker steel sheets improve the strength of composite sections. In addition to modifications in rib geometry, the effect of high ribbed decks on strength and shear connection has been investigated. The European codes' rib height limitations were published in a descriptive manner. The addition of various stiffener shapes also enhanced the profile geometry and, consequently, the buckling strength; however, the majority of research pertaining to deck profile modification was concentrated on trapezoidal or re-entrant deck types. [5]

Composite flooring systems are usually designed in two phases: (i) during building, when the steel sheeting alone must sustain the weight of wet concrete, workers, tools, and other live loads; and (ii) during service, when the steel deck and hardened concrete collaborate to support the design dead and live loads. Nevertheless, prior research on steel decks was primarily restricted to composite stage testing, which involves the use of concrete. The performance of the individual steel decks under construction loading was evaluated in very few reports. This understanding is vital for dealing with buckling and shear failure issues, as well as designing steel decks for composite floor systems. Parametric measurements on a number of corrugated deck types show that the geometry and flexibility of steel sheet under construction loads have a significant impact on the overall behavior of slabsThis understanding is vital for dealing with buckling and shear failure issues, as well as designing steel decks for composite floor systems. Parametric measurements on a number of corrugated deck types show that the geometry and flexibility of steel sheet under construction loads have a significant impact on the overall behavior of slabs. This context presents a new profile designed to enhance the performance of thin-walled decks and to solve common problems with buckling and shear failure observed in deck types that are widely available. The suggested sections are produced utilizing a novel metal forming technique that incorporates transverse corrugations into the corrugated profile's primary direction. It was developed by a manufacturer in Australia. Existing standards already address the strength, manufacture, and application of conventional trapezoidal and re-entrant decks in a variety of engineering contexts. However, profiled boards' yield and tensile strengths, as well as buckling and limited shear capacity brought on by inefficient rib design, undermine these decks' strength. Therefore, it is necessary to include extra features like stiffeners and embossments. The current study aims to evaluate the structural performance of a proposed steel deck geometry under construction loads in light of the previously mentioned problems. When concrete is added, the test results under construction load will clarify how the bare steel sections contribute to the composite action. The innovative profile's applicability is evaluated by testing one top-hat section and many top-hat section decks under a range of construction loading scenarios determined by linguists. The new decks can be employed in a variety of structural applications, such as slim-floor systems, in which the supporting beam is incorporated into the floor deck's depth. Both in terms of cost-effectiveness and structural performance, this composite slim-floor system may prove effective. [6,7]

Australia's AS/NZ 2327-2017 and Europe's EN 1994-1-1 provide design codes for composite floor systems. The deck with the numerous hat section was evaluated in the current study for its deck type properties in single span, continuous span, and end span settings in accordance with the testing guidelines in AS/NZ 2327-2017. In the current study, the deck with the many hat portion was tested for its deck type properties in single span, continuous span, and end span settings using the AS/NZ 2327-2017 testing guidelines. It is important to note that the majority of guidelines were created for decks with trapezoidal shapes; as a result, appropriate adjustments were made to accommodate the testing of the suggested corrugated shape utilized in the current study. The test results that were obtained were compared with those that were established using the general design guidelines for steel structures found in AS 4100-1998 and AS/NZ 4600-2018 for cold-formed steel sections. It was determined that before being applied to the new profile, the design suggestions made by the code needed to be revised because they are insufficient for some loading scenarios. [8-10]

Discussion

This study highlights the critical role of SC bonding techniques in achieving FCA and improving load-bearing capacity. Experimental tests reveal that some SC bonding techniques exhibit a near-perfect composite action, leading to more efficient designs. The study also addresses fire resistance, with the SlimFlor design showing superior performance due to the thermal shielding provided by concrete. The development of a new top-hat deck profile offers solutions to challenges in buckling and shear failure, particularly during the construction stage.

Conclusion

The study demonstrates the need for refined SC bonding techniques and improved deck profiles to enhance the structural performance and fire resistance of SSCC decks. The novel top-hat profile shows promise in addressing issues related to buckling and shear resistance, suggesting potential for broader application in composite slim-floor systems. Future design codes must incorporate these innovations for optimized performance.

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