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Behaviour and design of composite beams subjected to negative bending and compression

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ABSTRACT

This paper investigates the behaviour of steel–concrete composite beams subjected to the combined effects of negative bending and axial compression. For this study, six full-scale tests were conducted on composite beams subjected to negative moment while compression was applied simultaneously. The level of the applied axial compression varied from low to high. Following the tests, a nonlinear finite element model was developed and calibrated against the experimental results. The model was found to be capable of predicting the nonlinear response and the ultimate failure modes of the tested beams. The developed finite element model was further used to carry out a series of parametric analyses on a range of composite sections commonly used in practice. It was found that, when a compressive load acts in the composite section, the negative moment capacity of a composite beam is significantly reduced and local buckling in the steel beam is more pronounced, compromising the ductility of the section. Rigid plastic analysis based on sectional equilibrium can reasonably predict the combined strength of a composite section and, thus, can be used conservatively in the design practice. Detailing with longitudinal stiffeners in the web of the steel beam in the regions of negative bending eliminate web buckling and increase the rotational capacity of the composite section. Based on the experimental outcomes and the finite element analyses a simplified design model is proposed for use in engineering practice.

1. Introduction

Composite construction of steel and concrete is a popular structural method due to its numerous advantages against conventional solutions. The optimal combination of the properties of the two most popular construction materials, i.e. steel and concrete, results in structures that are both safe and economic. Composite action between the steel beam and the reinforced concrete slab, which is commonly achieved through the welding of shear studs to the top flange of the beam, results in significant reduction of beam deflections, enabling the use of smaller steel sections compared with bare steel systems.

Continuous composite beams represent an efficient structural method in many structural systems, such as buildings and bridges, due to additional advantages associated with the favourable redistribution of internal forces across the member and the easier satisfaction of serviceability checks. However, the design and analysis of continuous composite beams is rather complicated due to their different behaviour in positive (or sagging) and negative (or hogging) moment regions. Moreover, in regions of hogging moments, e.g. at the internal support regions of continuous members, a large part of the steel beam section is subjected to compressive stresses, thus the bottom flange and the web are susceptible to local instabilities.

In engineering practice, there are situations where composite beams are subjected to combined actions, e.g. simultaneous action of positive or negative bending and axial tension or compression. Such examples include: a) in floor beams where the axial force can either be as part of a specific bracing system or where the beam acts as part of a diaphragm [1]; b) high-rise frames where the effects of wind loading become significant and can impose large axial forces on the beams of the building; c) structures where inclined members are used, e.g. stadia beams or inclined parking ramp approaches; and d) bridges, where inclination and traffic loads may introduce large axial forces on the supporting beams.

Current structural codes, e.g. [2–4], do not provide specific rules for the design of composite beams under combined axial forces and bending moments; they rather refer to rules established for bare steel sections. Since the behaviour of a composite beam differs substantially from that of a bare steel section, the moment–axial load interaction of composite beams still deserves further investigation. Despite the large amount of available experimental data on the flexural behaviour of composite beams [5–7], experimental data on the behaviour of composite beams under combined loading is rather limited. The effects of axial tension on the sagging and hogging moment regions of composite beams were studied in previous research by the authors [8,9]. In this work, the ultimate strength of composite beams subjected to combined actions was investigated by a large experimental programme, rigid plastic sectional analyses and extensive finite element simulations. Interaction curves were established and simple design rules were proposed for

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