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Explicit modelling of large deflection behaviour of restrained reinforced concrete beams in fire

Sherwan Albrifkani, Yong C. Wang *

School of Mechanical, Aerospace and Civil Engineering, University of Manchester, UK

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ABSTRACT

This paper presents a dynamic explicit finite element (FE) simulation method to predict the highly non-linear response of axially and rotationally restrained reinforced concrete (RC) beams at ambient temperature and in fire condition. Catenary action, developed during the large deflection behaviour of RC beams, is an important mechanism of resisting progressive collapse. This paper explains the numerical simulation challenges, including temporary instabilities, local failure of materials, non-convergence and long simulation time, and proposes methods to resolve these challenges. The effectiveness of the proposed simulation model is checked by comparison of the simulation results against relevant test results of restrained RC beams at ambient temperature and in fire. It has been found that using the explicit simulation method can follow the whole range behaviour of restrained RC beams until complete structural failure. Either load factoring or mass scaling may be used to speed up the simulation process. Damping can be applied to minimise significant dynamic effects following beam bending failure. This paper will give guidance on how to select the appropriate load factoring, mass scaling and damping values.

1. Introduction

The prescriptive-based approach to fire resistance design of reinforced concrete (RC) structures involves specifying the minimum concrete cover and the minimum size of member cross section depending on the load ratio, in codes such as EN 1992-1-2 [1], according to the required standard fire resistance rating. This is being progressively replaced by the performance-based approach in which the provisions for fire resistance are according to the performance requirements.

In performance-based evaluation of the fire resistance of structures, it is necessary to consider the interactions between different structural members. Furthermore, large deflections are involved in structural behaviour at the high temperatures experienced in fires. At large deflections, the structural members can develop alternative load carrying mechanisms that would not normally be considered in small deflection analysis. For axially restrained beams, the alternative load carrying mechanism of catenary action can develop after the conventional flexural bending mechanism. The development of catenary action can significantly enhance the beam survival time compared to the fire resistance estimated based on bending resistance. Whilst there have been extensive research studies on the behaviour of axially restrained steel beams in fire, for RC beams in fire [2–22], the effect of axial restraint is rarely considered and even when axial restraint is present [2–4,8,11], the research did not address the development of catenary action at very large beam deflections.

Using catenary action as an alternative load-carrying mechanism for beams is the basis of mitigating progressive collapse under the column removal scenario at ambient temperature and this mechanism has been investigated in recent years [23–33]. While the same philosophy is applicable to the fire situation, there has been little research to assess the feasibility. In order to exploit the potential of using catenary action as a means of controlling progressive collapse in RC structures in fire, it is necessary to be able to reliably quantify this behaviour. This is the aim of this research.

Since conducting physical fire tests on axially restrained RC beams to observe the development of catenary action is expensive and technically demanding, development of a robust numerical simulation model is needed and this is the specific objective of this paper.

Many numerical models have been developed to predict the structural behaviour of RC beams at elevated temperatures. Most of these models were proposed for unrestrained beams [5,6,9,13,16–22]. The few developed models that can be applicable

* Corresponding author.

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to restrained RC beams in fire [3,8,11,12] were specifically intended to assess the behaviour of members at small deflections under the combined effects of flexural bending and axial compressive forces generated by the restraint to thermal expansion.

Faithful numerical simulation of the large deflection structural behaviour of axially restrained RC beams presents serious challenges due to the material failures that can occur, including concrete cracking, crushing and reinforcement fracture (which may

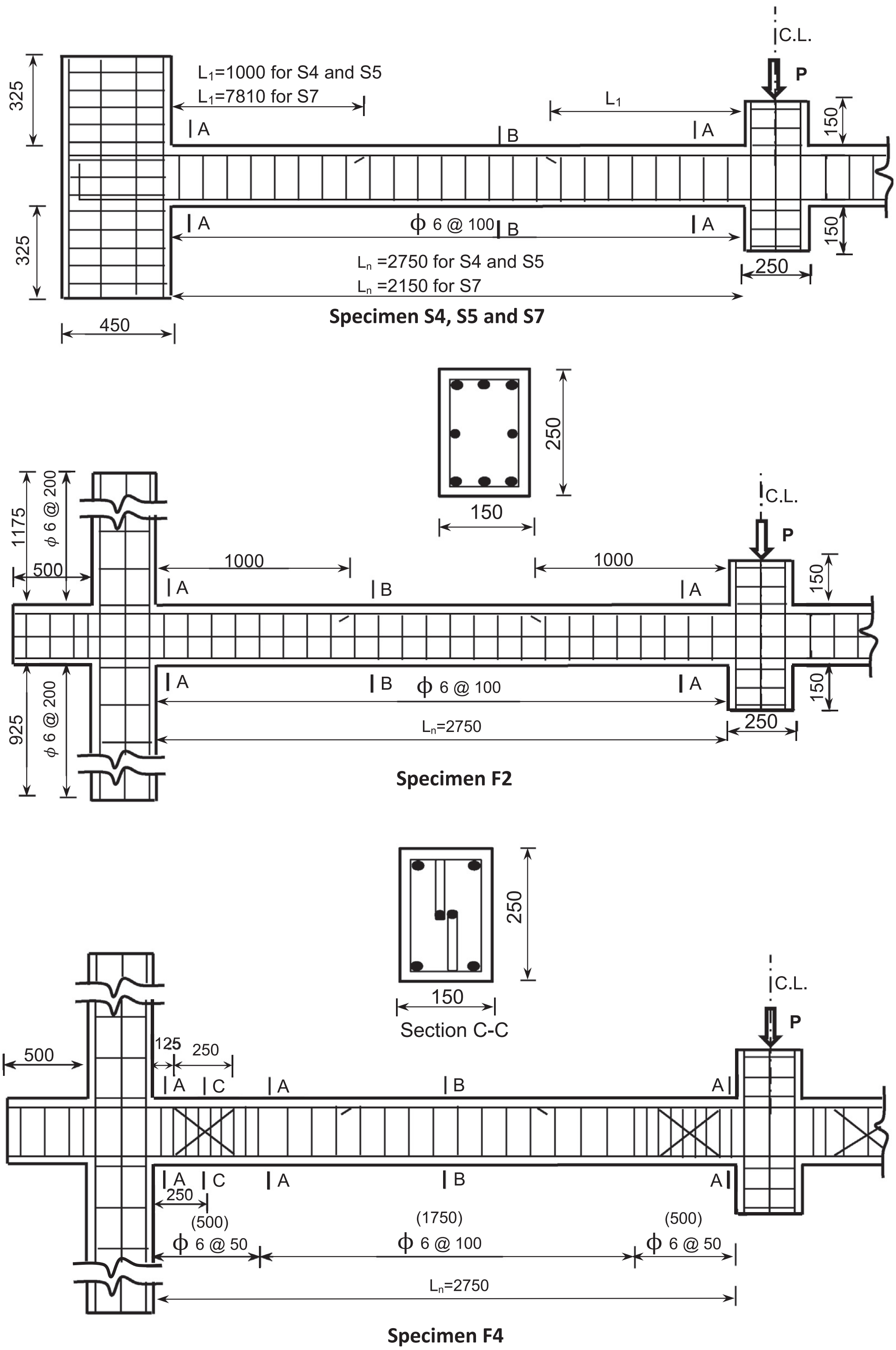

Fig. 1. Geometrical details of RC beam–column sub-assemblages and frames by Yu and Tan [28,32,39].