Journal of Constructional Steel Research 117 (2016) 227–242

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Shear connection modelling for column removal analysis

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ARTICLE INFO

Article history:
Received 26 May 2015
Received in revised form 2 October 2015
Accepted 17 October 2015
Available online 4 November 2015

Keywords:
Column removal
Component springs
Ductility
Mechanical model
Progressive collapse
Steel shear connection

ABSTRACT

Although methods for modelling steel shear connections under column removal scenarios are available in widely-used design guidelines, they tend to be based on earthquake engineering research rather than research examining scenarios relevant to progressive collapse. Even where these have been adapted explicitly for this new purpose, they take a form that does not account for the true connection behaviour under this unique loading regime. This paper describes an accurate mechanical model that has been developed based on observations from a comprehensive testing programme designed specifically to study the behaviour of steel shear connections under column removal scenarios. The model is used to assess the influences of key parameters and develop a simple single-spring model practical for use in full-building collapse analyses.

1. Introduction

Modern design guidelines that are commonly used for evaluating the progressive collapse resistance of building structures require analysis of the theoretical performance of a structure following instantaneous column removal scenarios [1,2]. These guidelines rely heavily on earthquake engineering research for the connection modelling provisions. It is widely recognized that this approach has significant shortcomings, but no simple and practical method is yet available for modelling connections that has been developed explicitly for this specialized purpose. As a step toward addressing this problem, a broad-based research programme was initiated at the University of Alberta to study steel shear connection behaviour and performance under column removal scenarios. This paper describes a new mechanical component model for simulating the behaviour of several common types of steel shear connections, as well as an overview of the model validation exercises based on the results of physical tests. Through observations from the parametric study and the results of the experimental programme, a simple bilinear single-spring connection model is developed that is both accurate and practical for use in full-building alternative load path analyses.

2. Experimental programme

In order to investigate the inherent robustness of commonly-used steel shear connections, an experimental programme consisting of 35 full-scale physical tests was completed. Specimens included shear tab, welded–bolted single angle, bolted–bolted single angle, bolted–bolted double angle, and seat and top angle connections combined with different types of shear connections at the beam web. A testing procedure was developed that imposes upon a connection the force and deformation demands that are expected following central column removal in a symmetric two-bay frame. Various geometric arrangements of each connection type were tested, with each subjected to a range of loading histories representing different column removal scenarios. The physical test results characterize the load development history, deformation mechanisms, and failure modes expected following column removal for each type of connection. Details of the experimental programme are reported by Oosterhof and Driver [3].

The behaviour of both shear tab and welded–bolted single angle connections was observed to be dominated by deformation mechanisms and failure modes related to bolt bearing and tear-out. Thus, for the sake of the discussion and analysis contained in this paper, they are categorized together, and descriptions referring to “shear tab connections” generally refer to both connection types. Similarly, single and double angle connections bolted to the beam web and to the column flange (“bolted–bolted”) are considered together, since they were both dominated by the unfolding of the angles under catenary tension through the formation of plastic hinges, and the eventual tearing along one of these plastic hinges.

3. Mechanical modelling

Fig. 1(a) shows the von Mises strains recorded by an optical strain imaging system during a shear tab connection test performed by Oosterhof and Driver [3]. (In all tests the beam was rotated upward.) Strains are clearly concentrated at bolt bearing locations and are relatively small elsewhere. The top bolt in the five-bolt shear tab specimen

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http://dx.doi.org/10.1016/j.jcsr.2015.10.015

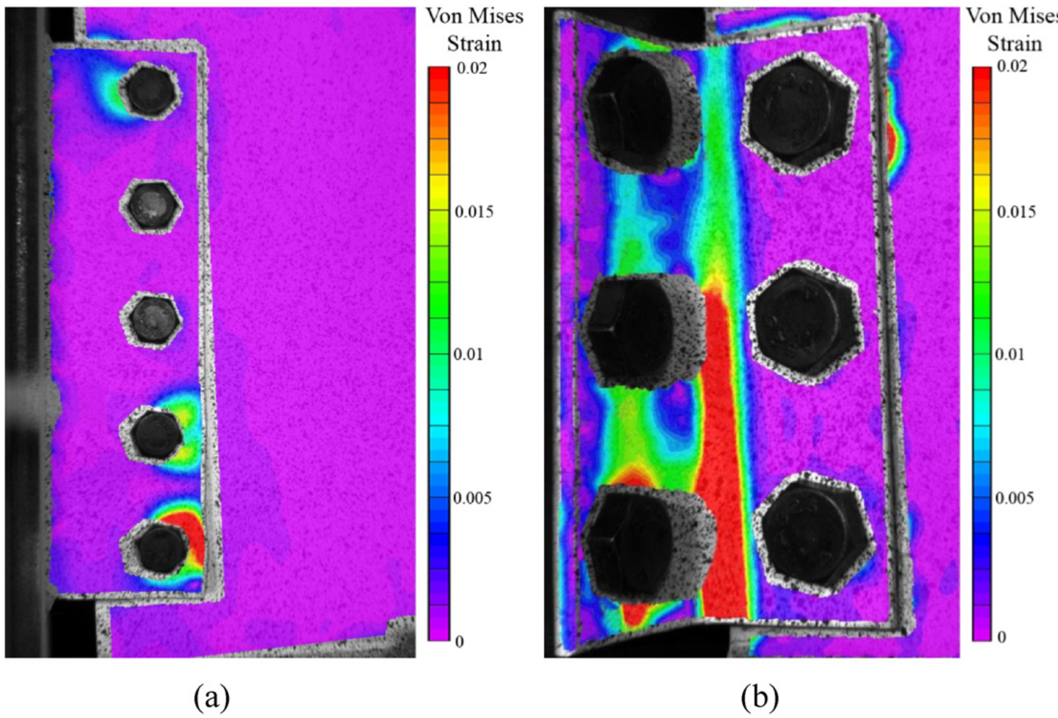

Fig. 1. Von Mises strain showing (a) localized bearing effects at bolt locations in shear tab connection, and (b) plastic hinge formation along angle heel and column bolt line (at left) in bolted–bolted angle connection.

shown is engaged in bearing in the compressive direction, and the development of shear tear-out planes in the tensile direction is evident ahead of each of the two bolts closest to the bottom of the connection. The dominance of localized stresses at bolt locations allows the behaviour of the entire connection to be accurately simulated by modelling a series of discrete spring elements at bolt locations. Fig. 1(b) shows the von Mises strains during a bolted–bolted single angle test, which are highest at plastic hinges that have formed along a partial depth of the angle heel and column bolt line. The partial-depth hinges shown in the figure correspond to a low beam rotation (and associated low tensile demands), at which time both the rotational and axial stiffnesses of the connection are relatively high. Connection stiffness then decreases when increasing rotational and axial demands cause the plastic hinges to develop along the full depth of the angle. Relatively high strains are also visible in Fig. 1(b) on the beam web near the top bolt, as a result of the top of the angle bearing against the column flange.

A mechanical model has been developed to predict the behaviour observed during the physical tests, consisting of identical zero-length springs at bolt locations, as shown schematically in Fig. 2. The rigid element on the column side is fixed, since deformations of the column did not actively contribute to the overall deformations that were measured during the tests. The rigid element on the beam side of the connection is

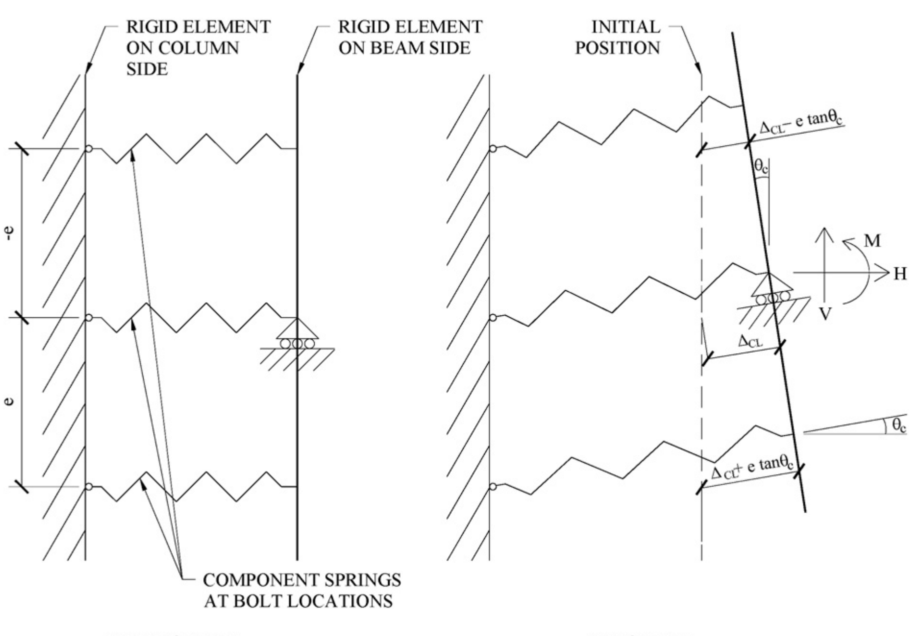

Fig. 2. Mechanical model of shear connections under column removal.