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Tension field action for cold-formed sections in shear

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ABSTRACT

For shear, the design of sections for strength is usually governed by the web plate subjected to shear force and undergoing shear buckling, or yielding in shear or a combination of the two. For webs with relatively high depth-to-thickness ratios, the shear stress distribution in the web after buckling changes and significant post-buckling strength may occur as a result of the development of a diagonal tension which is called "Tension Field Action" (TFA). Recently, the full set of shear test results for the plain lipped C- and SupaCee® sections performed at the University of Sydney shows that the post-buckling strength was attributed to TFA which was provided by the increased transverse restraints created by bolted connections attached to loading stiffeners over the full depth of the web panel at the supports and loading point. This improved the post-buckling strengths of the web in shear. Firstly, the results of finite element nonlinear simulations are compared with tests where bolted connections not over the full depth of the web panel were used to validate the FE method. Then the range of test data described previously is extended using finite element models, by reducing the bolting at support and loading points in the test data to provide further guidance on the availability of TFA in particular. Design equations are provided for Tension Field Action.

Introduction

The Finite Element Method (FEM) can be used to undertake a second-order nonlinear inelastic analysis of cold-formed thin-walled structures. Numerical simulation using the FEM of thin-walled cold-formed steel sections undergoing buckling depends substantially on assumptions regarding boundary conditions, initial geometric imperfections, element mesh and type. For high strength sections in compression, Yang and Hancock [1] have achieved accurate simulations using ABAQUS [2]. For sections in bending, Yu [3] provided complete details of the finite element models consisting of shell elements to investigate the influence of the test setup on the buckling modes of cold-formed steel members in bending and additional nonlinear analysis is also included.

Recently, Pham and Hancock [4,5] presented the modeling and analysis of the experimental specimens of a shear and combined bending and shear test series on cold-formed C-sections [6,7] using the FEM program ABAQUS. In these investigations, the effects of such input parameters as initial geometric imperfection, element type and the size of element mesh on the convergence of the solution have been investigated. Experimental data from Pham and Hancock [6,7] was utilized to evaluate the performance of the FE model. The ABAQUS results were generally in good agreement with experimental values especially the ultimate loads and modes of failure.

In the above experimental programs [6,7] for which the test configuration is shown in Fig. 1, the bolts connecting the webs of the test channels to the loading channels (250*90*6 Cold-Formed Channel) spanned the full depth of the section for both 150 mm and 200 mm depth tests. The two vertical rows of bolts attached to the loading channels have increased the restraints to the web panel and act as web stiffeners. The increased restraints have improved the post-buckling strength of the web especially for the predominantly shear tests. This post-buckling strength may occur as a result of the development of diagonal tension which is called Tension Field Action (TFA). Experimental results obtained from the recent University of Sydney (UoS) tests [6,7] and the University of Missouri Rolla (UMR) tests in the 1970's [8] have been utilized to recommend new design rules for the Direct Strength Method (DSM) of design in shear, and combined bending and shear [9,10,11] including and excluding TFA. The Direct Strength Method [12] was formally adopted in the North American Design Specification in 2004 and in the Australian/New Zealand Standard AS/NZS 4600:2005 as an alternative to the traditional Effective Width Method (EWM) in 2005. In both Standards, the method presented (Chapter 7 of AS/NZS 4600:2005, Appendix 1 of NAS) is limited to pure compression and pure bending. The situations of pure shear, and combined bending and shear as occurs in a continuous purlin system are not considered.

This paper extends the modeling and analysis of the experimental lipped C- and SupaCee® [13] channel sections of predominantly shear tests by using the Finite Element Method (FEM) program ABAQUS to investigate reduced bolting. To validate the performance of the model for reduced bolting, 5 tests from [8], for which the available data

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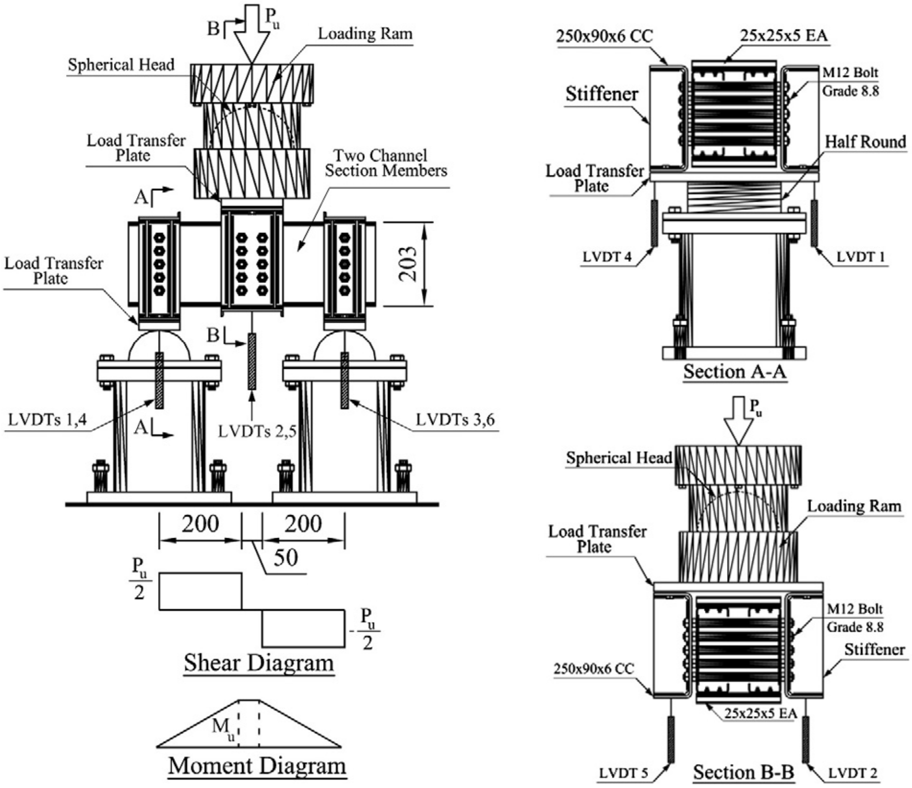

Fig. 1. Predominantly shear test configuration (200 mm depth).

allows a comparison, are used to check their accuracy. Studies of such effects as reducing the bolting at supports and loading points are then provided for further guidance on the availability of TFA in particular. Three different bolt connection configurations, which represent different Patterns A, B and C of reduced bolting at both supports and loading points, are studied.

1. Experimental programs, Direct Strength Method and finite-element validation

1.1. Test rig design

The experimental program comprised a total of thirty six tests conducted in the J. W. Roderick Laboratory for Materials and Structures at the University of Sydney. Two different commercially available plain C-lipped and SupaCee® sections of 150 and 200 mm depths as shown in Fig. 2 were chosen with three different thicknesses of 1.5, 1.9 and 2.4 mm (for plain C-lipped sections) and 1.2, 1.5 and 2.4 mm (for SupaCee® sections). The test set-up for the predominantly shear tests with the ratio of span to depth of 1:1 is shown in Fig. 1. The channel section members were tested in pairs with flanges facing inwards and with a gap between them to ensure inside assembly was possible. Some of the tests had a strap at the loading point as shown in Fig. 3(a) and the others did not as shown in Fig. 3(b).

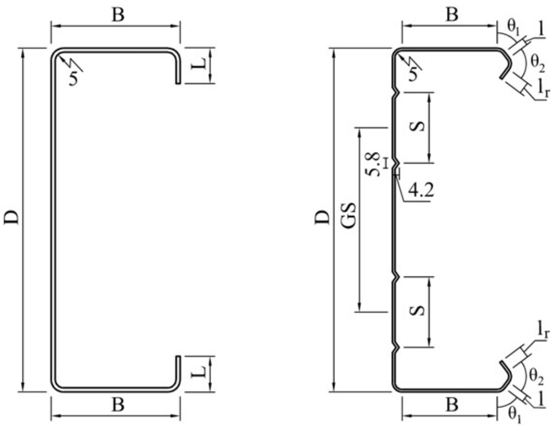

Fig. 2. Dimensions of plain and SupaCee® channel sections.

The test specimens were labeled in order to express the series, test number, channel section, depth and thickness. Typical test labels for plain C- “V1-C15015” and SupaCee® sections “V1-SC15015w” are defined as follows:

- V indicates the predominantly shear test series. “1” indicates the first test and a “w” expresses the test “without” straps adjacent to loading points.
- “C150” and “SC150” indicate plain C-section (C150) and SupaCee® section (SC150) respectively with the web depth of 150.
- “The final 15” is the actual thickness (1.5 in mm) times 10.

At the supports, the two test beam specimens were bolted through the webs by vertical rows of M12 high tensile bolts. These rows of bolts were connected to two channel sections 250 × 90 × 6 Cold-Formed Channel with stiffeners. A shim plate was used between the test channels and loading channels to prevent full contact of the sections with the loading rig. Steel plates of 20 mm thickness were used as load transfer plates which were also bolted through the flanges of the channel sections 250 × 90 × 6 Cold-Formed Channel with stiffeners. These load bearing plates rested on the half rounds of the DARTEC supports to simulate a set of simple supports as also shown in Fig. 1.

At the loading point at mid-span, the DARTEC loading ram has a spherical head to ensure that the load is applied uniformly on the bearing plate. The load was transferred to two channel sections 250 × 90 × 6 Cold-Formed Channel with stiffeners which were