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Use of angle cleats to restrain cold-formed channels against lateral torsional instability

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ABSTRACT

It is common practice in the steel construction industry to restrain members that largely in flexure and torsion using a combination of angle cleats, connected at the top flange, and fly-bracings. This system is complicated and expensive, especially when used to restrain channels in bending. This paper investigates experimentally the use of angle cleats, connected to the webs of both the purlin and the channels, as a restraining system. Pairs of channels were subjected to a two point loading system in order to simulate a distributed load. Variable in the tests include the unbraced length between the two-point loads and the size of the channels. Failure of the channels occurred by lateral torsional buckling and catastrophic distortional buckling of the intermediate unbraced length. Tests showed that the purlin-cleat restraining system is able to resist lateral torsional buckling of the channels, and that this system can be used without any fly bracing. Distortional buckling was the final failure mode, and it occurred at moments less than the predicted lateral-torsional buckling moment of resistance. Distortional buckling is more critical in frames with shorter unbraced lengths and thicker channels.

1. Introduction

Lipped cold-formed channels are among the most used thin sections in the steel construction industry. The demand for these structural elements has increased remarkably during the last decade, especially in residential, industrial and commercial buildings. In these structures, the smaller sections are normally used as purlins and diagonal bracing elements, and the larger sections are used as the main beam. When cold-formed steel lipped channels are used as the main beam members they are usually restrained against lateral buckling behaviour by purlins at the top flange. This restraining system works together with an additional restrain system, called fly-bracing, to prevent torsional instability. As shown in Fig. 1(a) the purlin can be connected directly to the main beam or through an angle cleat, of the same width as the beam section, as shown in Fig. 1(b) and (c). In a common angle-cleat connection, one leg of the angle is connected to the web of the purlin through bolts and to the top of the main beam through either a bolted or a welded connection (Fig. 1(b) and (c)). The disadvantage of these restraining systems is that when the purlin/angle cleat is bolted or welded to the main beam, the bolt-hole or the welding process weakens the bearing length of the channel, especially when the purlin is subjected to large downward loads. Conversely the bolted area can easily tear-out if the top flange is in tension. In addition, the combined cost of providing this restraining system is high.

Due to the above reasons, this study investigates the use of a restraining system that avoids bolt holes and welding in the top flange of the main beam, and the use of fly bracings. Restraint of the main beam is still provided by a purlin-angle cleat connection; however the angle is long enough to connect the webs of the purlin and the main beam. Details of the restraining system are shown in Fig. 2. The restraining system consists of a lipped cold-formed angle cleat, connected to the main beam using 2, M20 mm diameter bolts, and connected to a purlin using 2, M12 mm diameter bolts. This means that the angle cleat restrains both lateral and torsional movements of the member. Since the angle cleat connects both elements (purlin and main beam) in the web, the proposed restraint has the added advantage of preventing the main beam and purlin's web from crippling at loading points. Each hole is located at 35mm from the top and bottom flanges to take advantage of the increased stiffness close to the corners of the channels.

The proposed restraining system has been used in portal framed structural systems, in previous investigations [1,2,3], and was found to be efficient in restraining lateral-torsional instability. In this study, three possible modes of failure were observed in the portal frames tested, namely: local buckling of the compression zone of the flange and web of the channels, lateral-torsional buckling of the channels between points of lateral support, and bolts in bearing. However, the governing failure mode in all these frames was not the lateral-torsional buckling failure mode. This means that the restraining capacity of the angle cleats could not be sufficiently ascertained. After considerable relative rotation of the channel sections within the eaves connection, the ultimate failure mode in all structures was local buckling of the compression flange and

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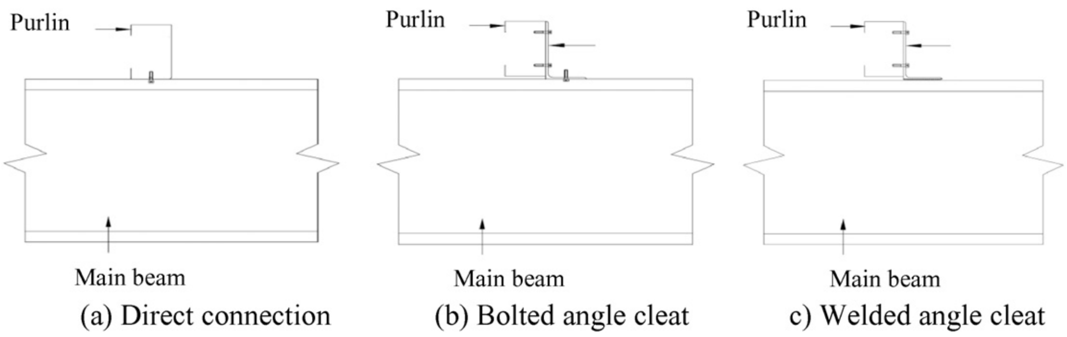

Fig. 1. Purlin-beam connections.

web. Local buckling was made more critical by stress concentrations, shear lag and bearing deformations caused by back-to-back bolted connections.

2. Selected literature review

Experimental research to determine the lateral-torsional buckling of cold-formed steel channel has been conducted by a number of researchers. These tests have been performed on single and pairs of plain and lipped channels with different cross section dimensions. Most of these tests used small cold-formed channels; typically the sizes that are normal used as purlins, and were restrained at various intervals within the length of the beam. The earliest tests to determine the lateral-torsional buckling strength of lipped channel beams were carried out by Winter et al. [4]. The purpose of these tests was to establish a brace spacing of channel beams that will achieve the same strengths as continuously braced channels. This study was the primary research work that led to the requirement of quarter-point bracing in the American Iron and Steel Institute Specification (AISI) for the Design of Cold-Formed Steel Structural members [5]. Quarter-point bracing system was specifically recommended for cold-formed steel channel and Z-flexural members to resist twisting and lateral buckling, when not attached to sheathing. In total Winter et al performed 18 tests on seven different cross-section dimensions, with web depths ranging from 102 to 203 mm, flange widths ranging from 63 to 102 mm, lip widths of 19 mm and the thicknesses ranging from 1.5 to 3.8 mm. Specific details of the dimensions of the sections were not given. For all tests, the span length of the beams was 3.5 m and the two concentrated loads were applied symmetrically about the mid-span, at a constant spacing of 0.66 m.

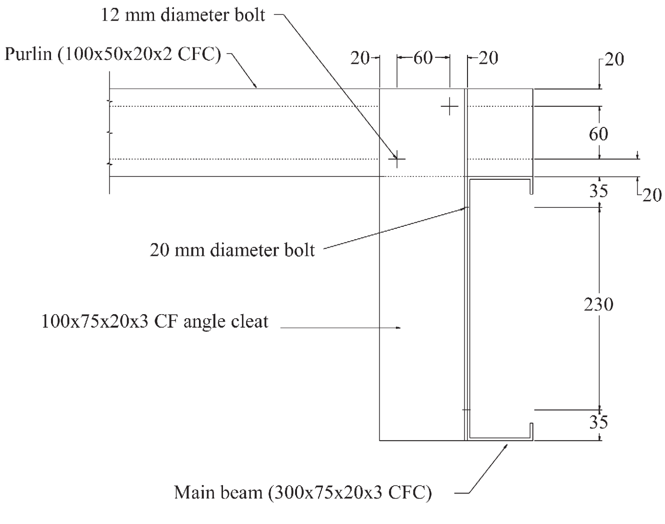

Fig. 2. Typical purlin-beam connection.

Lateral braces were located at each end supports and two other lateral bracings were located symmetrically about the mid-span. The two intermediate bracings were varied by increasing the distance between them and keeping the span constant. In total, four different ratios of the distance between the braces to the distance between end supports or span length were tested, namely; 0 m, 0,478 m, 0.652 m, and 1.0 m. The ratios represented a fully braced beam, a single mid-span brace, a bracing at a quarter and three quarter location and a completely unbraced span, respectively. The bracing configurations were varied so that each system could be compared with a fully braced and an unbraced beam. The beams were subjected to eccentric loads, applied through the top flange at the flange-web junction. These tests showed a decrease in strength as the brace spacing was increased, implying that the critical strength is a function of the braced length. The provision of quarter point bracing appeared in all succeeding American Iron and Steel Institute Specification up to the Addendum [6], when it was replaced by a more exact procedure for calculating lateral torsional buckling of doubly, singly, or point symmetrical sections.

Hill [7] conducted an experimental and analytical investigation to determine the lateral-torsional buckling behaviour of 84.5 × 31.6 × 3 mm equal-flanged cold-formed aluminium alloy channels. The aim of this study was to devise a rational procedure for designing such members. Four channels of unbraced lengths of 508, 762, 1143, and 1651 mm and corresponding flange-yield strength of 273.72, 309.58, 275.10 and 309.58 MPa were tested.

A total of four strain-gauges were attached close to mid-span of the channel; two at the top flange and two at the bottom flange. For each flange, one strain-gauge was placed at the toe and the other one at the heel. The purpose of the strain-gauges was to quantify the variations in stresses in each flange so that it could be established whether lateral-torsional buckling occurred or not. The beams were subjected to two point loads to simulate a distributed load and tested in pairs so as to provide a stable test setup. Lateral restraints were applied at both end supports to restrict warping and at points of applied load. In all cases these lateral restraints were connected to the webs of the tested beams. An analysis of these stresses showed that no significant changes in stresses occurred in each flange, implying that there was no horizontal deflection. The beams were short enough to discourage lateral-torsional buckling. The beams with a longer unsupported length of 1651mm failed in the elastic range whilst the beams of shorter length failed by local buckling or crumpling of the compression flange. A comparison of the results for all tested beams shows that the moments and stresses decrease with increase in the unbraced length.

A total of 160 lipped and unlipped cold-formed steel beams were tested by Lindner and Kurth [8]. The purpose of the tests was to compare the strength of the beams, with the load applied at mid-span, either through the top web-flange junction or centroid of the top flange. In both cases the beam tests were simply supported and the testing programme used a single beam for each test. The results from these tests showed that the strengths achieved in beams with the load applied through the centroid were significantly lower than those achieved in