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Design of new cold rolled purlins by experimental testing and Direct Strength Method

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ABSTRACT

New cold roll formed channel and zed sections for purlins, namely UltraBEAM™2 and UltraZED™2, have been developed by Hadley Industries plc using a combined approach of experimental testing, finite element modelling and optimisation techniques. The new sections have improved strength to weight ratio by increasing the section's strength through the use of stiffeners in the section webs. The European standard, Eurocode 3 [1], uses the traditional Effective Width Method to determine the strength of a cold formed steel member. However, the design of the new sections UltraBEAM™2 and UltraZED™2 using this method is very complicated in calculating the effective section properties as these sections contain complex folded-in stiffeners. In addition, the incorporation of competing buckling modes such as distortional buckling of these sections can be difficult to analyse. To overcome difficulties of using Eurocode 3 or such a standard with the Effective Width Method for determining the strength of these sections, the Direct Strength Method is adopted in this paper. Four-point beam bending tests were carried out to determine the buckling and ultimate bending capacities of the UltraBEAM™2 and UltraZED™2 sections. Results from both experimental testing and Finite Element analysis were initially used as validation for the design using the Direct Strength Method. The Direct Strength Method's results were then compared with the experimental test results for a broader data in which the UltraBEAM™2 and UltraZED™2 sections had a range of different width-to-thickness ratios. It showed an excellent agreement between test and Direct Strength design values suggesting that the Direct Strength Method is a powerful tool for the design and optimisation of the new cold roll formed channel and zed purlins.

1. Introduction

Cold-formed purlin sections are usually manufactured into conventional channel and zed profiles. These sections consist of plate elements of the web and flanges which usually have a large width-to-thickness ratio. Therefore, they are prone to local or distortional buckling and these buckling phenomena govern the failure modes for cold-formed steel members. There have been extensive investigations on buckling and ultimate strengths of these conventional sections. Practical design methods for these sections are normally specified in codes of practice in different countries such as European Standard [1], North American Specification [2,3] and Australian/New Zealand Standard [4].

To improve the strength of cold-formed sections that are prone to local and distortional buckling, stiffeners have been placed at the web of the sections. These stiffeners subdivide the plate elements into smaller sub-elements and hence can considerably increase the local buckling of cold-formed sections subjected to compressive stresses due to the smaller width-to-thickness ratio of the sub-elements. In recent years, there has been a significant number of studies on the strength and design of cold-formed sections with web stiffeners [5–9]. However, the majority of these studies are for columns under compression or hat sections under bending and there have been limited investigations on channel and zed sections with web stiffeners subjected to bending.

A zed section with longitudinal stiffeners in the web, introduced during the cold roll forming, was designed and developed at the University of Strathclyde by Rhodes and Zaras [10] in conjunction with Hadley Industries plc, with the aim of improving the performance of a zed type section. The development using an analytical method suggested that when the stiffeners were placed about one fifth of the web width from each flange, the problem of local buckling in the web was eliminated. The channel section with longitudinal stiffeners in the web was later developed at Hadley Industries plc in an attempt to incorporate the innovative web stiffener configuration used in the new zed, into a channel shape [11]. Recent investigations using Finite

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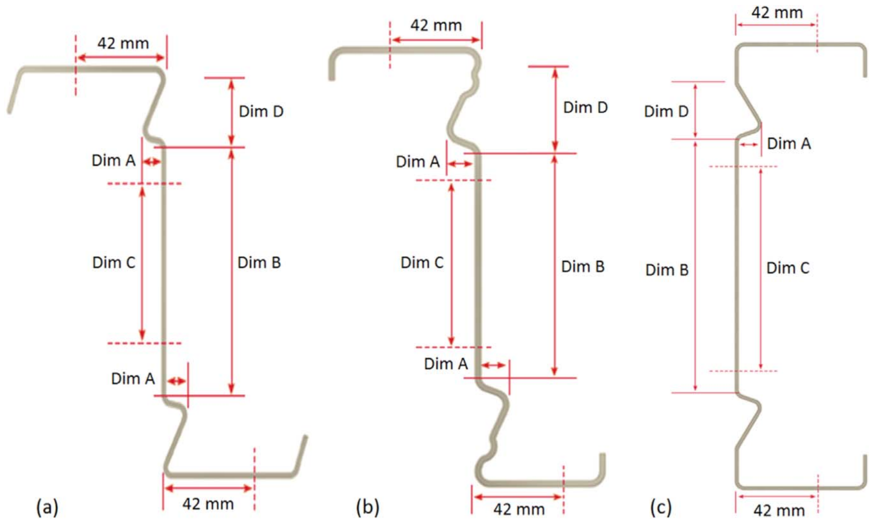

Fig. 1. Cross sections and geometries of beam specimens (a) UltraZED™2 145–170 mm deep sections, (b) UltraZED™2 200–305 mm deep sections, and (c) UltraBEAM™2 145–305 mm deep sections. The depth of the section is also called the web width; Dim C is the hole centre at the loading and end support positions.

Element analysis (FEA) and optimisation techniques have proved that when the two symmetrical stiffeners on the web were placed as much closely as possible to each flange, maximum buckling and ultimate strengths for the section were achieved [12,23]. Since the sections evolved had the basic zed shape, Z, and channel shape, C, with additional enhancements which proved improved performance, it was decided that these sections should be named the 'UltraZED™2′ and 'UltraBEAM™2′ as illustrated in Fig. 1, respectively from now on in this paper. The purlins developed are now registered designs, with patents applied for.

These new sections have a considerably improved strength to weight ratio considerably by using the web stiffener types as shown in Fig. 1. Additional small stiffeners in zed sections that have large width-to-thickness ratios were added to introduce a greater degree of work hardening, which raises the material yield strength in these regions, taking increased further advantage of eliminating the local and distortional buckling. All of the current design codes including the European standard Eurocode 3 (EC3) use the traditional Effective Width Method (EWM) to determine the strength of a cold formed steel member. However, the design of the new sections UltraBEAM™2 and UltraZED™2 using this method is very complicated and impractical in calculating the effective section properties as these sections contain complex folded-in stiffeners. In addition, the incorporation of competing buckling modes such as distortional buckling can be difficult for these sections.

An alternative to the EWM is the newly developed Direct Strength Method (DSM) [13] which was first formally adopted in the North American Specification in 2004 [3] and Australian/New Zealand standard [4]. In development of the DSM for beam bending, two series of flexural tests and finite element analyses on both plain channel and zed sections were conducted to isolate local buckling [14] and distortional buckling [15]. Additional tests on distortional buckling have also been conducted by Javaroni and Goncalves [16]. Recently, Pham and Hancock [17] provided additional experimental data on both plain C- and SupaCee channel sections in pure bending. In their study, the SupaCee purlin profile is a complex section with four small longitudinal web stiffeners and return lips which was developed by BlueScope Lysaght (BlueScope Steel Ltd., Melbourne, Australia) and the University of Sydney (Sydney, Australia). They found that the local and distortional buckling test results are better predicted by the DSM curves for slender sections.

The DSM uses the elastic buckling loads for the gross section considering local, distortional and global buckling to determine the strength of a cold-formed steel member. The DSM does not need to calculate the effective section properties; instead the elastic buckling analysis is calculated with computer aided numerical analysis so it can be used for design of cold-formed steel members with complex stiffeners [18]. On the other hand, the DSM in current specifications is a semi-empirical approach, which was calibrated to cover only the pre-qualified sections specified in NAS [2,3]. Unfortunately, sections with complex longitudinal stiffeners like the UltraBEAM™2 and UltraZED™2 shapes are not in lists of pre-qualified sections for using the DSM in any current design specifications. Therefore, the DSM was adopted in this paper for design of the UltraBEAM™2 and UltraZED™2 purlins and it was evaluated against experimental tests.

In this paper, four-point beam bending tests have been carried out to determine the ultimate bending capacity of the UltraBEAM™2 and UltraZED™2 sections which have a range of different geometries. Together with beam bending tests, tensile tests of the beam material were also conducted to determine the material properties. Finite Element (FE) simulations of the bending tests of the UltraBEAM™2 and UltraZED™2 sections were presented. The DSM in current specifications was evaluated for the strength of the UltraBEAM™2 and UltraZED™2 sections based on the experimental and FE results. The ultimate purpose of this study is to evaluate the applicability of the current Direct Strength Method for these new sections.

2. Experimental test programme

The beam specimens were cold roll formed along the rolling direction on steel coils with a nominal Young's modulus of 205 GPa. Typical cross sections of the test specimens are shown in Fig. 1. Measured test section geometries and dimensions are given in Table 1 for UltraBEAM™2 sections and Table 2 for UltraZED™2 sections. Dimensional measurements were carried out and recorded for all test specimens prior to testing. This allows the exact profile geometry to be evaluated within the DSM and FE simulations. Measurements taken include material thickness, web width (or depth), flange width, and lip length.

The beam specimens were labelled, an UltraBEAM™2 specimen label starts with C whilst an UltraZED™2 specimen starts with Z. For example, a specimen labelled as C-W145T1.2 is described as follows: C: Channel UltraBEAM™2 specimen; W: Web, 145: Nominal web height or beam depth (mm); T: Thickness, 1.2: Nominal plate thickness (mm). The forming process of each specimen is cold-rolled forming.

The material properties of the beam specimens were determined from tensile tests, adhering to Annex B of BS EN 10002–1:2001 [19]. Tensile test results in terms of yield stress, tensile strength and