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Structural behavior of lapped cold-formed steel Z sections with generic bolted configurations

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Abstract

In order to improve the buildability of cold-formed steel structures, a series of research and development projects have been undertaken by the authors to study the structural behavior of bolted moment connections between cold-formed steel sections. As one of the major applications of cold-formed steel sections in building construction is modern roof structures with multi-span purlin systems, an extensive experimental and theoretical investigation on the structural behavior of lapped moment connections between cold-formed steel Z sections was carried out. Both generic configurations with high structural efficiency were adopted, namely, *Config. W4* and *W6*, in which only the webs of the sections were bolted together for easy installation. Moreover, an analysis and design method was proposed to assess both the moment resistance and the effective flexural rigidity of the generic lapped connections. The research work aims to provide understanding on the structural behavior of cold-formed steel Z sections with lapped connections, and hence, to develop a set of rational design rules for multi-span purlin systems with overlaps.

In order to verify the applicability of the proposed analysis and design method for other commonly adopted connection configurations, namely, *Config. W2F2* and *W4F2* where bolts were installed to both section webs and flanges within the lapped connections, an experimental and theoretical investigation on a total of 12 one point load tests on lapped cold-formed steel Z sections were carried out. Among all tests, section failure under combined bending and shear at the ends of lap was found to be critical while twisting of the lapped Z sections was apparent throughout the entire deformation ranges. In general, the structural behavior of lapped connections with *Config. W2F2* and *W4F2* was found to be similar to those with *Config. W4* and *W6*.

Moreover, the formulation of the proposed analysis and design method was modified to accommodate the presence of the flange bolts, and back analysis of the lapped Z sections against combined bending and shear using the proposed method was performed. After careful calibration against test data, the method was shown to be structurally adequate and efficient for lapped connections with *Config. W2F2* and *W4F2*. Moreover, simple design expressions were also proposed for the evaluation of effective flexural rigidities of the lapped connections. Comparison on the structural behavior between the two sets of connection configurations was also presented.

Keywords: Cold-formed steel; Beam; Purlin; Connection; Design

1. Modern roof systems with cold-formed steel purlins

Cold-formed steel purlins are widely used in modern roof structures in many countries due to their high structural efficiency and buildability. The most common shapes of cold-formed steel purlins are C and Z sections, and the section depths typically range from 100 to 350 mm while the thicknesses range from 1.2 to 3.0 mm. Common yield strengths are 280 and 350 N/mm^2, but in the recent years, sections with yield strengths up to 450 N/mm^2 may be found in some propriety purlin systems giving improved load carrying capacities. In practice, multi-span purlin systems using cold-formed steel Z sections with overlaps are the most popular owing to their low transportation cost with effective stacking and high structural efficiency with high level of continuity between members. It should be noted that the structural performance of these purlin systems depend on many factors, such as steel grades, section shapes and sizes of purlin members, restraints

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provided by attached roof sheetings and intermediate bracing members, as well as connection configurations over purlin–rafter supports.

Up to the presence, there is only limited research [1–3] reported on the structural behavior of bolted connections between cold-formed steel sections, in particular, of bolted moment connections between lapped Z sections. Hence, little guidance is available for structural engineers to design multi-span purlin systems with overlaps. In fact, most modern roof structures with cold-formed steel purlin systems are developed through prolonged and expensive full-scale testing in order to acquire high market competitiveness.

2. Recent research studies

A large number of research projects have been carried out on the lateral instability of purlin members, and design rules were proposed to assess the load carrying capacities of partially restrained purlin members [4–7]. It was found that lateral restraints provided by attached roofs to purlin members should always be incorporated during the determination of the load carrying capacities of purlin members for efficient design. However, only limited research was reported on the structural behavior of lapped Z sections over internal supports, and it was commonly assumed that both the moment resistances and the flexural rigidities of the lapped connections were same as those connected sections. However, some designers took an optimistic view that both the moment resistances and the flexural rigidities of lapped Z sections might be taken as the sum of those connected sections [8]. This would not only affect the moment resistances and the flexural rigidities of the lapped connections but also the distribution of internal moments and shear forces among the purlin members.

A total of 28 tests were carried out to verify such enhancements in lapped Z sections [9,10], and it was shown that both the load carrying capacities and the flexural rigidities of these lapped sections were significantly increased for lapped sections with a lap length to test span ratio equal to 0.5. A number of empirical expressions on the load carrying capacities of these lapped sections were proposed, but no rational design method on lapped sections was provided. However, it was considered by the authors that lapped connections with shorter lap lengths should be investigated instead as they were more practical, and rational design methods should be provided for general design of multi-span purlin systems.

In order to improve the buildability of cold-formed steel structures, a series of research and development projects have been undertaken by the authors to study the structural behavior of bolted moment connections between cold-formed steel sections. As one of the major applications of cold-formed steel sections in building construction are modern roof structures with multi-span purlin systems, an extensive experimental and theoretical investigation on the structural behavior of lapped moment connections between cold-formed steel Z sections was carried out, and a summary of the research study is reported as follows.

2.1. Experimental investigation on structural behavior of lapped Z sections

A total of 26 one point load tests on lapped cold-formed steel Z sections were carried out to investigate the structural behavior of bolted moment connections between lapped Z sections [11,12]. Lapped connections with two generic Z sections of different section depths and thicknesses were tested while two generic connection configurations, namely, *Config. W4* and *W6* as shown in Fig. 1, were adopted after considering ease of installation. Both the moment resistances and the flexural rigidities of the lapped connections with various lap lengths and test spans were examined.

Among all tests, section failure at the end of lap under combined bending and shear was always found to be critical in the lapped Z sections. Moreover, the moment resistances of lapped connections with lap lengths equal to 1.2 times section depth were found to be only 80% of the moment capacities of connected sections. For lapped

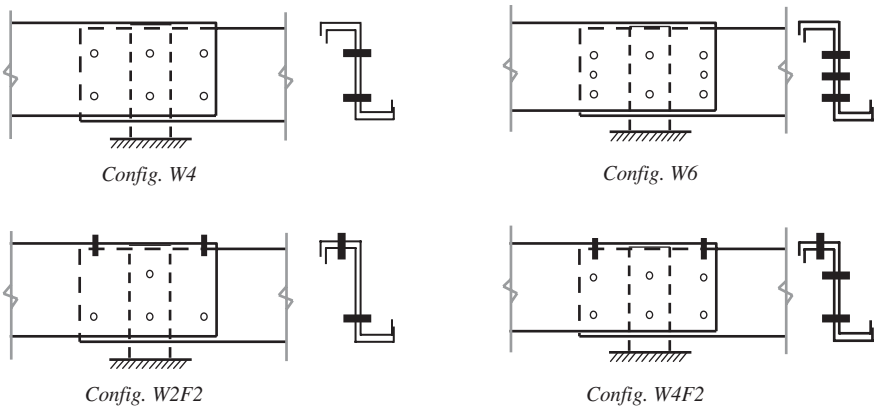

Fig. 1. Details of blot configurations in lapped Z sections.