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# An experimental study into flexural behaviour of sigma purlins attached with roof sheets

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ABSTRACT

Purlins made of cold-formed steel (CFS) sections are normally susceptible to failure caused by buckling due to their small wall thickness. Roof sheets, once attached to purlins with mechanical fasteners, will change the structural behaviours of purlin and produce beneficial effects by providing lateral or rotational restraints. In order to utilize these benefits, the interaction between purlins and roof sheeting needs to be considered in the purlin design. A number of research studies have been carried out on the behaviour of purlin-sheeting interaction. However, these investigations are mostly focused on purlins connected to sheeting with relatively small screw spacing, i.e. less than 300 mm. In engineering practice, screws are often applied at every other trough of roof sheeting to save installation time, which leads to the screw spacing usually exceeding 300 mm. Questions of whether and how the large screw spacing will affect the behaviour of purlins have not been specially addressed in any published literatures. This paper presents a detailed experimental study with the aim to answer these questions. A range of 27 CFS sigma purlins were connected to roof sheeting with screws applied at every other trough, as is adopted in installation practice, and were then subjected to both downward and uplift loading tests. From these tests, structural behaviours of purlin, i.e. the flexural stiffness, failure modes and the ultimate load, were examined, respectively. Test results are then used to develop design proposals for the sigma purlin that most codes or standards have not yet covered. This work is the first one that experimentally investigates sheeted sigma purlins subjected to both downward and uplift loads and considers screw spacing.



## 1. Introduction

The key structural components of modern light roof constructions for industrial or warehouse buildings normally consist of light-weight purlins attached with a roof sheeting system. The most popular type of purlin is made of cold formed steel (CFS) sections such as Z, C or sigma sections. These purlins are supported on raft beams through brackets and act as a secondary structural system. Due to their small wall thickness, they are notably susceptible to buckling failure [1,2]. One of the simplest sheeting systems is the single layer trapezoidal profiled steel sheet with weather coating. This type of sheet is fitted to purlins through self-drilling screws and rubber bonded washers to achieve water tightness. Wind load can be exerted on roof structures in both positive and negative directions, which will lead to different structural behaviours. Roof sheets, once installed, will provide beneficial effects on the structural performance of purlins by introducing a certain degree of restraining effect [3]. As a result, it is common and more economical to consider this type of interactive behaviour between purlin and sheeting in the modern roof design practice [4]. To facilitate this design consideration, a great deal of underlining research work has also emerged recently to provide fundamental understanding of this type of integrated system.

A series of full scale tests [5] were reported to investigate the loading resistance of sigma, Z, and Zeta purlin-sheeting systems under the gravity load. Experimental studies were carried out to examine the influences of the fastener location and the flange to lip width ratio on the resistance of C and Z purlin-sheeting systems under the gravity load [6]. Both a full [7] and a simplified FE models [8] have been developed to analyse purlin-sheeting systems under both gravity and uplift loads. A novel analytical model [9] was reported to perform the similar analysis. In that model, a translational spring was utilized to account for the effect of partial rotational restraint provided by sheeting, and a hypothetical lateral force was introduced to consider the effect of torsional moment caused by the applied load. This analytical model was later formally adopted by Eurocodes [4]. Tomà and Wittemann [10] compared the results of loading resistance predicted by Eurocodes [4] with their test data, and found that the design model in [4] can result to an uneconomical prediction for purlin-sheeting systems under either gravity or uplift load. An approach called as *R*-factor method is recommended by North American Specification [11]. The employment of the *R*-factor method is straightforward,

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namely, directly applying a reduction factor (*R* factor) to the cross-sectional resistance of the purlin alone to obtain the loading resistance of the purlin-sheeting system. To date, the reduction factors suggested in [11] are only available for C and Z sections. Johnston and Hancock [12] calibrated these reduction factors by using the test results of a series of C and Z purlin-sheeting system obtained in the University of Sydney. Later the calibrated reduction factors were adopted by Standards Australia [13]. Vrany [14] stated that the rotational stiffness provided by roof sheeting may vary with external loadings and proposed a design formula quantifying the effect of loading on the rotational stiffness. A non-linear finite element model was developed to estimate the rotational stiffness provided by a single layer sheeting [15]. A recent paper [16] reported an analytical method to calculate the rotational stiffness. The method has been demonstrated to be applicable for C and Z sections attached with single layer roof sheets by screw connections.

Literature survey reveals that most existing studies on the purlin-sheeting system concerns only low screw spacing, e.g. less than 300 mm or at every corrugation trough of the roof sheet. In engineering practice, however, in order to save installation time, the actual screw spacing will often be greater than these used in research studies. An example of a typical screw arrangement used in practice is illustrated in Fig. 1. It can be seen that except for those at the overlap joints of sheeting, most screws have a rather large spacing, e.g. over 400 mm. Questions of whether and how this large screw spacing will affect the behaviour of sigma purlins under both downward and uplift loadings are yet to answered. Furthermore, it is also noted that current codes of practice for structural design of sheeted purlins rarely cover the sigma section.

This paper reports an experimental research investigation into the flexural behaviour of a series of purlin-sheeting assemblies. Each assembly was composed of two single span cold formed steel (CFS) sigma purlins attached with trapezoidal profiled roof sheets. These sheets were fastened onto purlins by using self-drilling screws applied at predefined intervals, i.e. 200 mm for screws at the overlap joints of roof sheets and 400 mm for the rest. A total of 27 full scale assemblies were subjected to downward and uplift loadings, respectively. Test details and results are reported in this paper together with a discussion of test results and observations. Predicted results of moment resistance for the tested specimens by using the codified design specifications are also presented and compared with test results, from which suggestions of adaption are proposed for design models of sigma purlins attached with roof sheeting.

## 2. Test programme

In this test programme, purlin-sheeting assemblies, as shown schematically in Fig. 2a and b, were subjected to both downward and uplift loadings representing the actions of positive and negative wind pressure applied on a roof structure. They will be respectively referred to as downward and uplift loading tests hereafter. In each assembly, a pair of identical sigma purlins of 6 m length were placed in parallel with opposing faces. The purpose of such arrangement was to reduce the lateral movement of sheeting, through the opposing torsional movements experienced by the tested purlins. In doing so, the low in-plane shear stiffness problem due to the use of sheeting with a small width can be avoided or mitigated. Both purlin members were covered by single layer roof sheets overlapped in their end profiles throughout their span length. A six-point loading system was applied through four spreader beams placed on each test assembly.

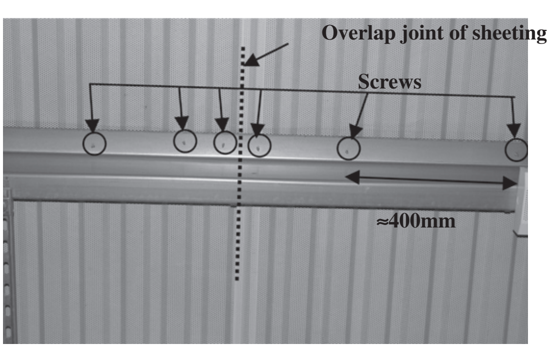


**Fig. 1.** Typical screw arrangement in sheeted roof construction.

Nine sigma purlin sections of different depth and thickness were chosen in this test programme. Two duplicated tests for each section were carried out for the downward loading test to demonstrate the repeatability of test results and only one test was for the uplift loading test. A three-part reference system is used to identify each test. For instance, if a test is referred as SD60-20012-1 or SU60-20012-1, the first part "SD60" or "SU60" indicates that the corresponding specimen is subjected to a single span downward or uplift loading test and has a 6 m specimen length; the second part "20012" refers to the section dimension, i.e., 200 mm of depth and 1.2 mm of thickness; and the last part "1" is the number of the duplicated test.

## 3. Test specimens

The sigma purlin sections chosen for tests include three depths, i.e. 200, 240 and 300 mm. The nominal cross-sectional dimensions of the sections are presented in Table 1a. The Young's Modulus, 0.2% proof stress, and the measured mean thickness of the sections are summarised in Table 1b. The material properties were obtained from material tensile coupon tests by following BS EN ISO 6892 [17], and the thickness was measured with a Digital Vernier Caliper at points located in the inner web, the top and bottom flanges, respectively. Table 1b also presents the second moment of area about the major axis of each section. A type of single layer trapezoidal steel roof sheeting system was used to cover these purlins. This type of sheeting is commonly used in industrial buildings that do not require thermal insulation. The sheets were measured 0.69 mm thick and were cut and delivered in a 1 m length. Other sheet dimensions are given in Fig. 3. Self drilling screws of 5.5 mm diameter, with EPDM bonded washers, were used to connect the sheeting to purlin sections at their middle flange point. In this study, #12–14 $\times$ 25 HEX washer head self drilling screws (Fig. 4) were used.

## 4. Set-up of test apparatuses and testing procedures

The purlin/roofing assembly was supported by two massive concrete blocks that have been crane-lifted onto pre-marked positions through stiffened angle cleats. The cleats were made of mild steel and pre-fixed onto the concrete blocks by using M16 expansion anchor bolts. The connections between cleats and purlins are through Grade 8.8 M12 bolts for section series 200 and 240 and M16 for section series 300. Standard clearance in bolt holes allowed a relative horizontal movement between two bolts and therefore did not provide any significant rotational fixity at supports. The horizontal distance between the outer webs of both purlins was 0.66 mm and the clear span length of all tested assemblies was 5.942 m. Six pieces of 1 $\times$ 1 m roof sheets were placed on the top purlin flanges, with the corrugation profiles perpendicular to the longitudinal span. Adjacent sheets were overlapped at one cap length of 71 mm (see Fig. 3) producing a total covered length of 5.66 m. For most specimens, the roof sheets were connected to