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EXPERIMENTAL INVESTIGATION OF CORRUGATED STEEL SHEETING UNDER THE EFFECT OF WIND UPLIFT

S Ravikanth Reddy* and S Arul Jayachandran**

* Research Scholar, Indian Institute of Technology Madras
e-mail: ravikanthreddy039@gmail.com

** Professor, Indian Institute of Technology Madras
e-mail: aruls@civil.iitm.ac.in

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Abstract. *Industrial buildings and their components are prone to uplift failures during high wind events. The flexural performance of corrugated sheeting under wind usually depends on its moment of inertia and edge restraints from the supports. An effective technique is implemented to improve flexural performance by introducing discrete contact interaction using clips with guide channels. This paper presents the details of an experimental study on six configurations of corrugated steel sheeting subjected to wind uplift. A special vacuum chamber is fabricated per the specifications of ASTM-E-1592 for creating air pressure differences. The structural resistance of corrugated steel sheeting is investigated and the results are presented for the panels using wind lock clips and conventional panels.*

1 INTRODUCTION

Industrial buildings commonly use cold-formed steel as structural elements due to the advantages of having a high strength-to-weight ratio, faster erection, and ease of shape forming. Typically, the design of structural elements in the industrial buildings is governed by the wind actions. The corrugated sheeting with large unsupported areas attracts higher loads during wind uplift. The flexural deformation is relatively high, and also, with lower edge restraints, makes the corrugated sheeting fail at lower loads. Introducing contact interaction using wind lock clips an increased edge restraints are created with the guide channel.

Air pressure testing methods are widely used to assess the performance of roofing systems and other elements subjected to high winds. Schroter[1] carried out the air pressure testing of the sheet metal roofs and suggested that the static pressure tests are more reliable for negative pressures. Hancock[2] at the University of Sydney commissioned a large vacuum test rig to carry out pressure tests on sheet metal roofing systems. using the infrastructure of Hancock[2] Georgiou [2] performed uplift pressure testing on purlins supporting screw-fastened sheeting and validated the semi-analytical methods. Michael Celeban[3] conducted the downward loading air pressure testing on the continuous purlins and compared the test results with the Australian standards. Koshy [4] has conducted experiments on the standing seam metal roofing systems and suggested variable clip length based on reliable index. Song [5] conducted air pressure testing on standing seam metal roofing systems and showed that the interlocking methods may alter the failure mode during uplift loads. Reddy [6] conducted experiments on standing seam metal roofing systems and presented the interactions of purlin sheeting systems using standing seam clips.

The literature discussed above is the experimental work primarily on the structural elements in the roofing systems but with the standard reference of air pressure testing methods.

To normalize these air pressure testing, qualitative assessment of wind uplift capacity protocols is introduced in the various codes of practice and some of them are outlined below.

UL 580 [7] is the type of qualitative air pressure testing method to determine the uplift capacity of the roof assembly. The test results are assigned to three classes of ratings – 30,60, and 90 according to the performance of the systems at failure. FM4471[8] is the test method to determine the performance of the roofing systems with a minimum rating of class-60 to class-180. The ASTM E1592[9] is the test method that provides the quantitative measurement of the performance of the roofing systems subjected to the static air pressure difference.

This paper aims to study the performances of the corrugated sheeting under wind uplift. The primary intent was to guide the large lateral deformations which happens due to the large deflection at the midpoint. The test rig was fabricated as per the standard of ASTM E1592. The experiments are carried out on two configurations of the corrugated sheeting and also a conventional panel with normal simply supported boundary conditions.

2 TEST SETUP

The corrugated sheeting shown in figure 1 was subjected to uniform negative pressure to simulate uplift loads. The test specimen is 530 mm wide and seamed to form the required width. The corrugated sheeting is then inserted into the guide channel, and the entire test setup is placed in the test rig to apply wind loads. The geometric details and the strength parameters of the test specimens are considered as per test reports submitted by the manufacturer. The horizontal spreader beam is provided on either ends to support channel guides. The spreader beams are placed on top of the vacuum chamber, and a polythene cover is placed on top to create air pressure difference.

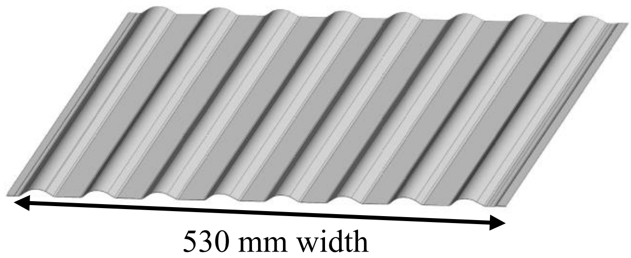

Figure 1: Corrugated sheeting.

The experiments were conducted in two sets, (i) the first set of experiments without wind lock clips, the (ii) second set of experiments with wind lock clips, as shown in figure 2, and an additional one test with a conventional panel. The details of the test specimens are provided in table 1.

2.1 TEST RIG

A special rectangular chamber is fabricated to create air pressure difference. The steel plate of 8 mm thickness is used as the bottom plate and ensured to withstand differential pressures during loading. The channel sections are 400 mm deep and are used as side walls. The bottom plate and side walls are combined to form a rectangular box for a length of 5.66 mm and 3.0 m wide. To withstand desired air pressure differences, 0.15 mm PVC polythene cover is placed over the test specimen with sufficient folds in order to be in contact during deformation. The schematic 3D model of the fabricated test rig is shown in figure 3, and the actual test setup is shown in figure 4. The test specimens used are shorter in width than the test rig. The remaining volume of the test rig is covered with plastic sphere balls to decrease the suction volume during the test. A vacuum pump of 2000 liters per minute creates a vacuum in the test rig. The digital vacuum pressure sensor is placed to record the suction pressures. Vertical displacement transducers are used to record the sheeting deformation at the mid-span.

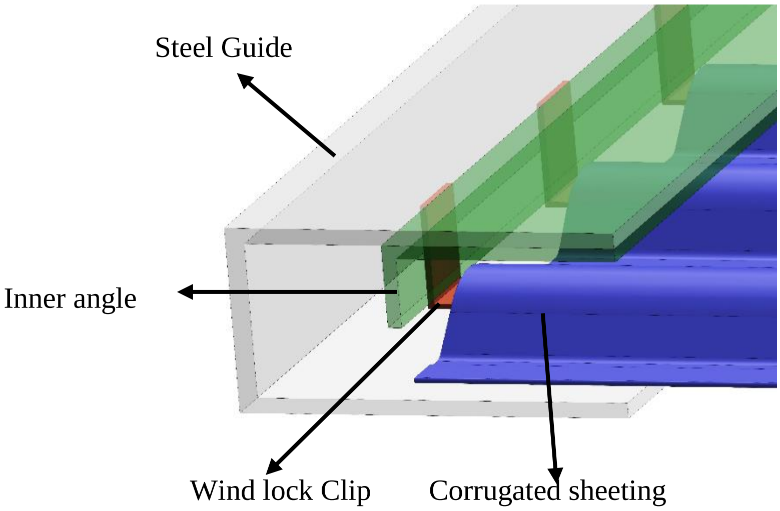

Figure 2: Wind lock guide and corrugated sheeting.

Table 1: Details of the test specimens.

S.no	Description	Specimen Length (mm)	Specimen width (mm)	Panel Thickness (mm)	Wind lock clips	Yield stress Fy (Mpa)
1	Test-1	4090	1500	0.45	×	300
2	Test-2	3000	1500	0.45	×	300
3	Test-3	2500	1500	0.45	×	300
4	Test-4	4064	1500	0.45	42	300
5	Test-5	4064	1500	0.45	24	300
6	Test-6	4090	1500	1.0	×	250

2.2 RESULTS OF THE EXPERIMENTAL PROGRAM

The pressure vs deformations graph is shown in figure 5. The initial deformation of corrugated sheeting follows the flexural behavior of a plate which possess weak flexural stiffness in the plane of loading. Further deformation is based on the edge restraints developed from the contact resistance of the sheeting with the guide. For the test without wind lock clips, the sheeting failed at lower pressures and pull out of sheeting is observed. There were not enough edge restraints. The graphs are not provided because the specimens failed at low pressures and also due to fluctuations in data.

Two tests were carried out with the presence of with 42 numbers of wind lock clips in Test-4 with 14 clips fixed to each panel and for Test-5 with 8 clips per panel. During the test, the specimens followed identical flexural behavior of plate with significant deformations at lower load levels. After considerable deformation, the wind lock clips provide larger lateral edge restraints in the form of contact resistance of clips with inner angle. The pull-out failure of the sheeting along with the bending of clips and inner angle is observed. The bending of clips is shown in figure 6, and the inner angle is shown in figure 7. Test-6 is conducted with the conventional corrugated sheeting to compare flexural performance of the sheeting with wind lock clips.

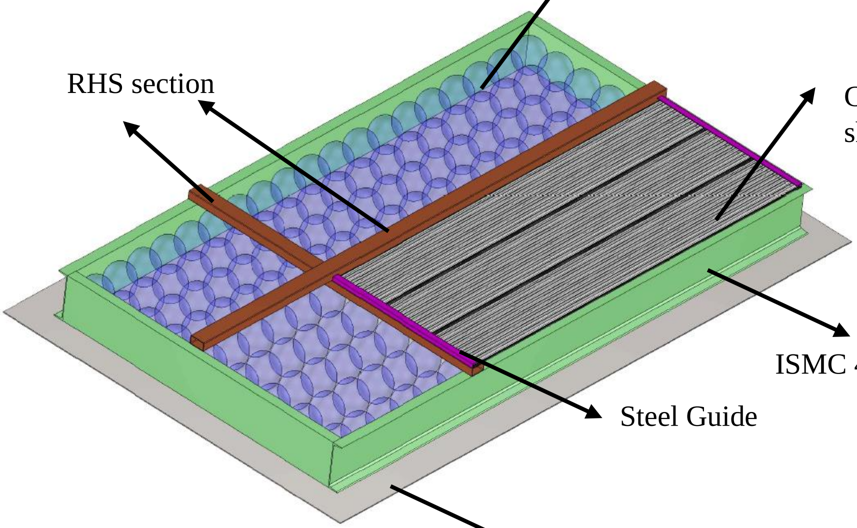

Figure 3: 3d model of Test rig

Figure 4: Actual setup of Test rig

Table 2: Details of the failure pressures.

S.no	Description	Wind lock clips	Failure pressure (kPa)
1	Test-1	×	0.085
2	Test-2	×	0.146
3	Test-3	×	0.327
4	Test-4	42	3.22
5	Test-5	24	3.20
6	Test-6	×	1.03

The deformation of the conventional sheeting is identical due to the weak flexural stiffness in the plane of loading and the effect of the sheeting is observed. At later stages, the deformation continues with the edge restraints provided by the guide channel in the form of contact resistance and a pull-out mode of failure is observed.

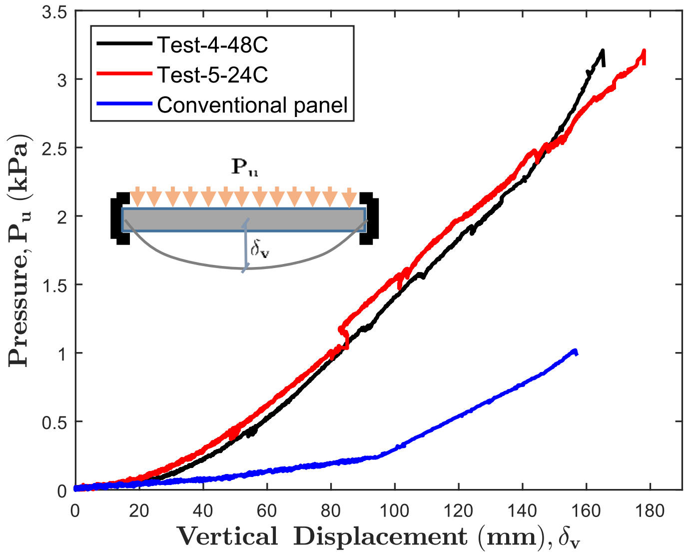

Figure 5: Pressure v/s deformation of corrugated sheeting.

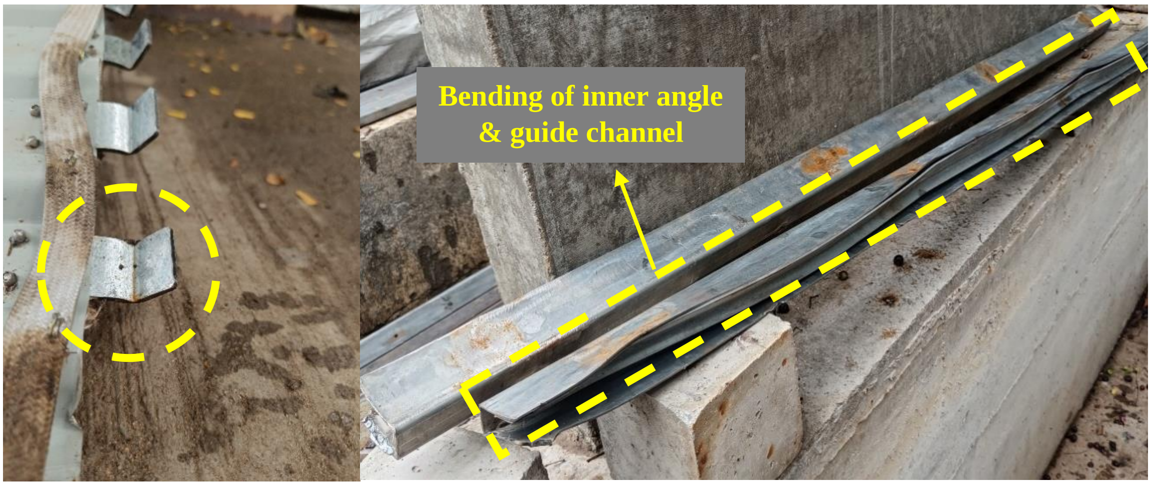

Figure 6: Bending of wind lock clips and followed by bending of inner angle with guide.

Table 3: Design recommendations and wind velocity

S.no	Description	Failure pressure (kPa)	Permissible wind velocity (m/s)
1	Test-1	0.085	9.72
2	Test-2	0.146	12.74
3	Test-3	0.327	19.06
4	Test-4	3.22	59.81
5	Test-5	3.20	59.63
6	Test-6	1.03	33.83

3 DESIGN RECOMMENDATIONS

The design recommendations are provided for corrugated sheeting with the presence of clips and no clips. There are significant differences in the failure pressures with the identical corrugated sheeting with the panel width of 530 mm and 65 mm pitch length. The wind velocities are calculated according to the Indian design code (IS:875 (Part-3)-1987) which may be useful in the design of the thin-walled corrugated sheeting.

The design wind pressure as per IS 875(part-3)-1987 [10]can be calculated as follows.

$$P_d = 0.6\ V_z^2 \quad (1)$$

Where, P_d is the design wind pressure (N/m^2) and V_z is the design wind velocity m/s .For the tests without clips i.e., Test-1, the design wind velocity is about $9.72\ \mathrm{m/s}$ which is very low due to less restraints provided by the sheet and guide channel contact interaction. For the test Test-4 and Test-5, larger edge restraints are received from the sheeting to the guide channel. However, for the Test -5 clips are reduced to half compared with the Test-4, the difference in failure pressure is very less and may be taken as the maximum number of clips for the maximum resistance. The design recommendations are provided in table:3.

5 CONCLUSIONS

The test results of the thin-walled corrugated sheeting with the vacuum test rig are presented in this paper. The test rig was fabricated as per the standard ASTM E1592. The failure modes and ultimate load-carrying capacity under wind uplift were shown, and the following conclusions were obtained.

The failure modes of the two corrugated sheeting configurations are similar. The test specimens without wind lock clips failed under the pull-out mode of failure. We have demonstrated in this paper that the presence of wind lock clips may alter the mode of failure and load-carrying capacity. Also, with wind lock clips, the failure pressures were higher comparatively due to the significant edge lateral restraints and contact interaction between wind lock clips and inner angle. The content of the paper is a useful information to the design engineers.

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