Proceedings of the Sixth Academic Sessions, University of Ruhuna 2009
Vol. 6 pg s 269 - 274

Comparison of sturctural behaviour of exsisting cold-formed steel purlin sections used in Sri Lanka

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Abstract
Until recently, the hot-rolled steel members have been recognized as the most popular and widely used steel group, but in recent times, the use of cold-formed high strength steel members has rapidly increased. The cold formed steel sections which made out of thin-gauge high strength steel have been found as an ideal solution to replace the stocky hot-rolled steel sections used in simple light steel structures. The application of such cold formed steel sections in the light steel structures give many advantages over the conventional hot-rolled steel sections such as; cost effectiveness, easy handling, easy forming of various section shapes and light weight. Structural behavior of these light gauge high strength cold-formed steel members characterized by various buckling modes has not been fully understood yet. The existing cold-formed steel sections such as C- and Z-sections are commonly used because of their simple forming procedures and easy connections, but they suffer from certain buckling modes. It is therefore important that these buckling modes are either delayed or eliminated to increase the ultimate capacity of these members. Therefore this research was undertaken to study the flexural behavior of existing cold-formed steel purlin sections and thereby suggest most economical and structurally viable cold-formed steel section to be used as purlins. The structural analysis software SAP 2000 was used to model the different shape of purlin sections. The accuracy of computer model was tested using a set of laboratory experiments conducted at the building engineering laboratory with results reaching an 11% deviation in the yielding capacity to what predicted in the SAP model indicating the models can be accepted, with the consideration of practical difficulties in building a physical model which is close to the computer model. Out of the common sections modeled C section showed the highest capacity.

Keywords: Cold-Formed Steel, Purlin

Introduction

In Sri Lanka most of the steel structures are made out of hot rolled steel and only about 5% have used cold-formed steel. However previous research has shown that the, cold-formed steel is very efficient structurally and economically. According to Chinthani etal., the previous research group which investigated on cold formed steel applications in Sri Lanka,(2006) even the small amount of cold-formed steel applications in Sri Lanka are not to a proper design.

Further Chinthanie et.al (2006) stated that cold-formed steel sections are mostly used as purlins on commercial and industrial buildings in Sri Lanka. They further said that these purlins are used without proper design and so that they had observed failure in many places. The main reasons behind these failures are improper structural design of cold- formed steel elements, and lack of awareness. This project is aimed at finding an optimal cold-formed steel section to use as a purlin. There are several important issues in cold-formed steel design which are neglected in conventional hot rolled steel design. These include the tendency of local and distortional buckling modes to control the design and the work hardening of the corners of the section. Furthermore Cold formed steel violates many of the assumptions used in matrix structural analysis. For an instance, in matrix structural analysis assumes stress and deformation follow beam theory stiffness matrix and in contrast cold formed steel behavior is such that the stress and deformation follow plate or shell theory. The Objective of the research was to find the most economical and appropriate shape for a purlin through a finite element modal analysis backed by an experimental investigation to verify the FEM analysis with the available resources.

Methodology

With the exploration of design aspects of cold-formed steel, analytical methods, experimental methods, and failure modes of purlin sections it was understood that elimination of flexural torsional buckling would be important, as the possibility of failing due to flexural torsional buckling will vary among the sections with the variation of eccentricity of shear center in different sections. In order to eliminate this problem, the models of various sections, are built to enable loading at shear center giving consistence in comparison of various sections. Finite element models were developed to analyze various cold-formed steel purlin sections using SAP 2000 structural analysis software. Based on the results obtained finite element analysis, a suitable and convenient purlin section was selected to carry out experimental investigations and hence validate the finite element model. The test specimens were fabricated and one point bending tests were carried out in building material laboratory at the department of Civil and Environmental Engineering department. Based on the results obtained at modeling and experimental phases, conclusions were drawn at the final phase.

Resultes and Discussion

Computer Modeling

A computer model was developed using SAP 2000 to analyze variety of sections. The model was developed in such a way that, the beam is subjected to pure bending. A single spanned beam with simply supported end conditions was used as the model with shell elements. Quarter point loading system was used to get pure bending in the mid portion of the beam.

SAP 2000 Shell Analysis of a Section Prone to Local Buckling

The finite element model was developed considering the ideal support and loading conditions. Common characteristics of model will be discussed further in the next section. Figure 1 shows a model developed for lipped C section.

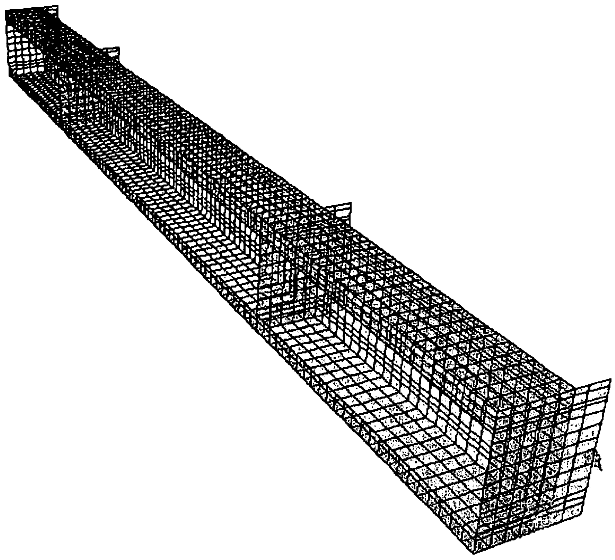


Figure 1 Lipped C section modeled in SAP 2000

The purlins were modeled using thin shear flexible shell elements. Since most of the cold form steel sections come in thickness ranges 2.5mm or less, shell elements is the most suitable type for this modeling.

The supports were modeled to simulate pin end condition so that all the end nodes were connected to its shear center by a rigid plate and then the shear center was restrained against horizontal and vertical movements.

Geometry and Loading

The modeling was performed C, Z, and L sections with and without lipped. All the sections were modeled as unbraced simply supported beams with quarter point loadings. The loads were applied at the shear centers by using rigid plates at L/4 sections. The geometry of the test setup is shown in Figure 2.

Cross-Section Geometry

The geometry of cross sections is chosen giving priority for market available sections, such as C, Z and Ls. The criterion used to get equivalent section was the equal weight per unit length (3.44 kg/m) for all the sections.

Material Properties

According BS 5950- Part 5, the properties for cold formed steel are as follows.

Modulus of Elasticity	=	205 MPa
Poisson's Ratio	=	0.3
Maximum Yield Stress	=	0.35 KN/mm^2 (For Grade 350 Steel)
Maximum Tensile Stress	=	0.43 KN/mm^2

Supports and Loading

The supports restrain the displacement and twisting, but the flexural rotations are not restrained. (See Figure 3.a and 3.b) The loading arrangement is such that the loads produce no rotations. Since the shear center is coinciding with the point of application of the vertical load, the load does not cause any torque. Hence the beams are expected to fail by yielding due to large transverse displacements.

Cross-Section Geometry

In defining cross section geometry, initially, some cold form steel sections which are already available (in *) to be used as purlins were modeled which were having equal weight per unit length of 3.44kg/m. The other sections (in **) were dimensioned to have the same weight per unit length and were then modeled at SAP. The modeled Section geometries are shown in the Table 1 below.

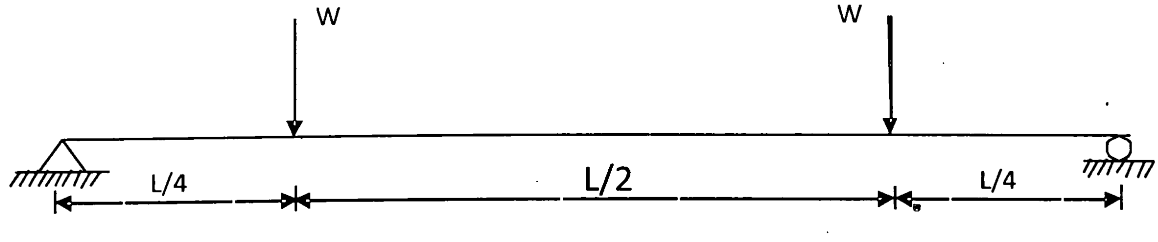


Figure: 2 Schematic Diagram of SAP Model

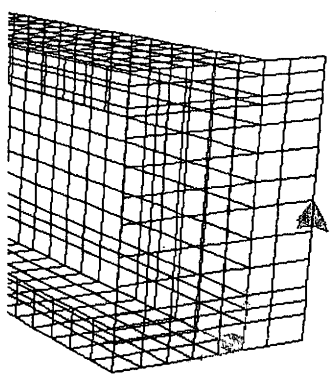
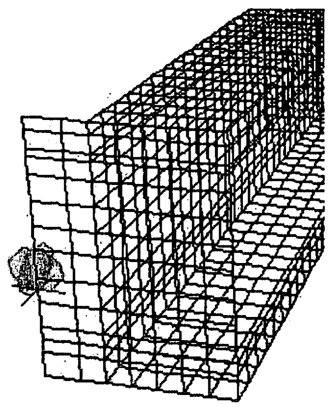


Figure 3. a Pinned Support provided at one end



b. Roller Support provided at one end

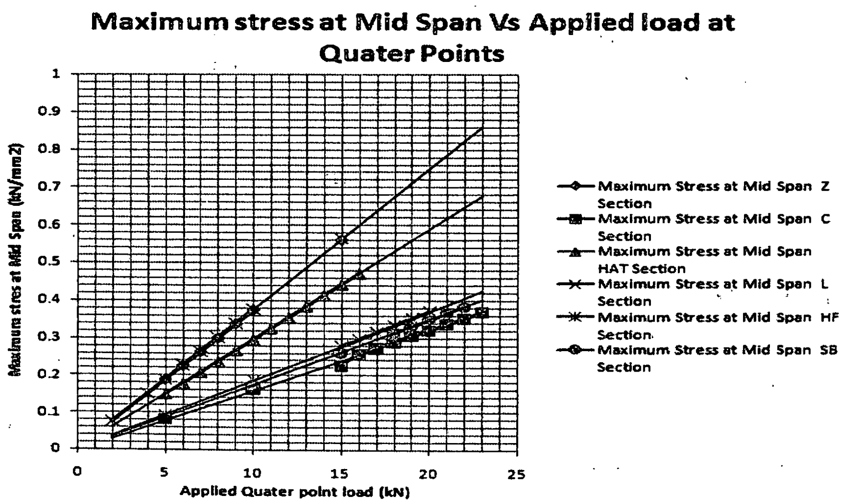
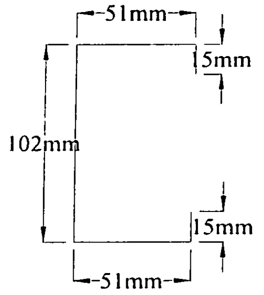
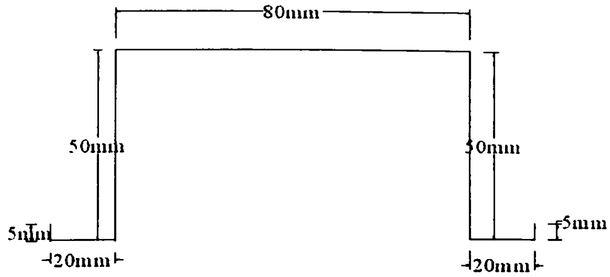


Figure 4: Graphical representation of relationship between stress and quarter point loading

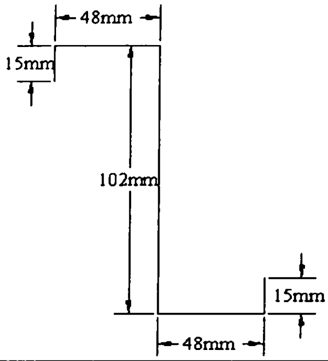
Table 1: Sections modeled in the Research



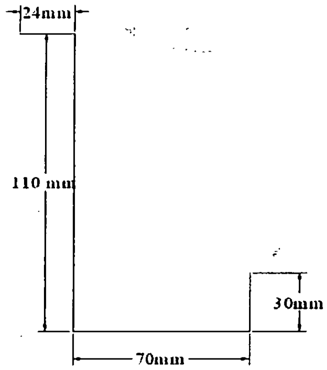
01. Lip Channel*



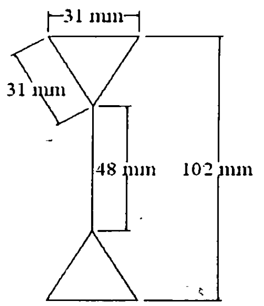
02. Hat Section**



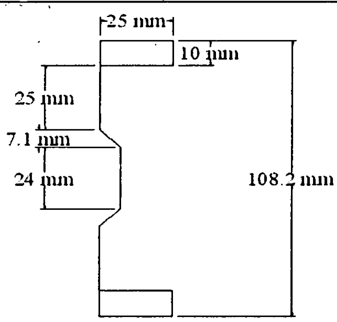
03. Zed Section*



04. L Section**



05. Hollow Flange Section**



06. Steel Beam Section**

Observations & Output

A total of 6 sections were analyzed of different cross sections and maximum capacity and Figure 4. shows the maximum stress at mid span Vs. load curves for the 6 sections, obtained using finite element models. Out of the models, C section holds highest capacity where to reach a particular yield stress takes the largest loading.

Experimental Investigation

Using the test apparatus Monsanto Tensometer Tensile Strength of the Test Specimen Material was determined using standard test pieces complying with Cl. 6.3 of AS 1391-1991- Methods for tensile testing of Metals (Ref. 5) for rectangular test specimens as shown in Figure 5.

Figure 5. Gripped Specimen between chucks after fracture

Interpretation of Results Stress Strain Relationship

Figure 6 shows stress Vs Strain graphs obtained from tensile test of 3 specimens. The actual material properties were required to include in the FE model, for experimental validation. It is a typical stress strain relationship for high strength steel.

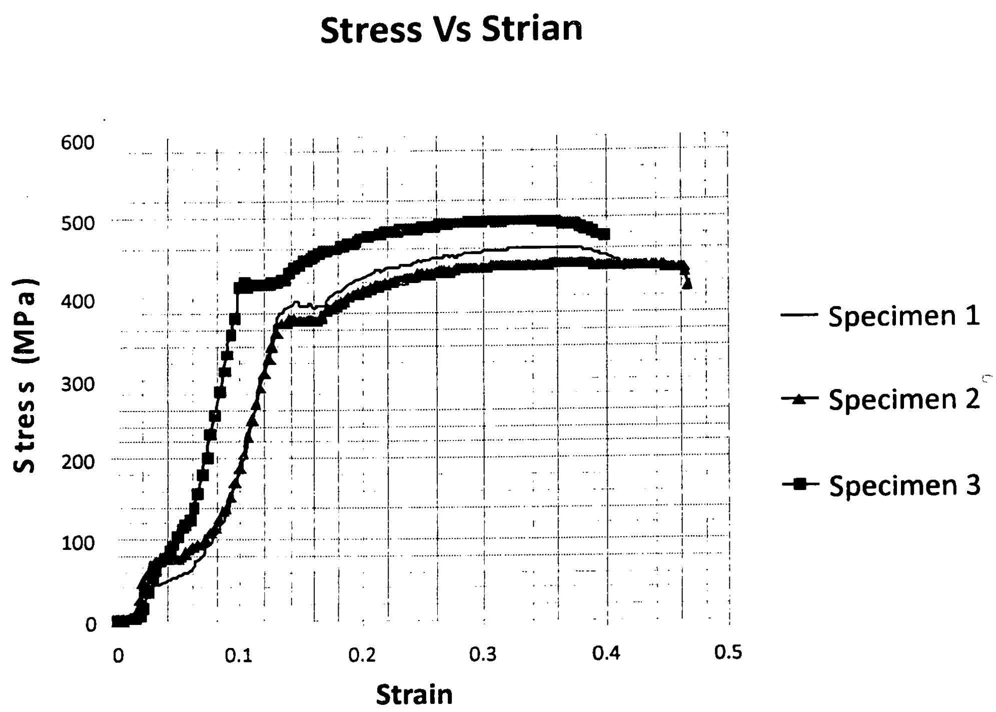


Figure 6: Graphical representation of Stress Strain Relationship of the 3 Specimens

Experimental Verification

The C section was fabricated with different spans and sectional dimensions to test them in bending by one point load at mid span. The failure loads obtained for 4 specimens are given in Table 2.

Table 2: Experimental value of critical loads at Failure

Specimen No	Span (m)	Thickness (mm)	Failure Load at Section Yielding (kN)
1	1	2	17.652
2	1	2	15.691
3	2	2	6.865
4	2	2	7.845

Table 3: Maximum deflection at Failure

Specimen No	Span (m)	Thickness (mm)	Maximum Deflection at Failure load (mm)
1	1	2	8.55
2	1	2	5.15
3	2	2	51.98
4	2	2	27.05

Table 3 shows the maximum deflection values at mid span of the beam which was measured using deflection measuring gauges.

Comparison of experimental data with analytical data

A SAP model with same mid span loading was drawn to be compared with the experimental results. This was done with the intention of verifying the SAP models done in the modeling part.

Experimental Investigations

Tensile Test

Mean Yield Stress obtained by Tensile Test = 390.03 MPa

Experimental and SAP Model Data Comparison

Failure Load

Table 4: Comparison of Failure Loads - experimental and SAP modal values

Specimen No	Span (m)	Thickness (mm)	Failure Load at Section Yielding (kN) Experimental	Failure Load at Section Yielding (kN) SAP Model	Percentage Error
100X50 C Section	1	2	16.67	18.74	11%
100X50 C Section	2	2	8.45	10.55	20%

Deflection

In considering the maximum stress values obtained at Finite element model and the experimental analysis the deviation varies from 11- 20 % while as for the deflection the variation is much larger as the span increases. With the available resources and funds there were restrictions to conduct highly accurate experimental modals which closely represent the ideal conditions which were modeled in the Finite Element analysis.

Table 5: Comparison of Mid span Deflection - experimental and SAP modal values

Specimen No	Span (m)	Thickness (mm)	Maximum Deflection at Mid Span (mm) Experimental	Maximum Deflection at Mid Span (mm) SAP Model
100X50 C Section	1	2	6.7	1.9
100X50 C Section	2	2	39.52	9.49

However it can inferred that finite element modals can be used to modal cold formed steel sections, with the close maximum stresses obtained at the experimental modeling and finite element modeling and also the case backed with other literature available on studies done on cold formed steel behavior.

Conclusions

This study was conducted to compare the flexural behavior of exiting cold formed steel sections such as C, Z, hat, etc. and hence suggest the most suitable section to be used as purlin section. The analytical study conducted by using a Finite Element model was validated by using experimental results, indicate that the ∈ section, the most suitable section to be used as a purlin section.

In considering the section properties the chosen C section dimension gives the highest section capacity. In further, optimization of section, dimensions can be changed to get the maximum section capacity while the equal weight per unit length is maintained. The case of optimization of section capacity will involve writing down computer algorithms which will have to be the next step of this research project.

When considering the design procedure of cold form steel sections it is necessary to pay more attention for the buckling effect (specially local buckling) since there is a high possibility to have buckling for thin sections. Because of that the local buckling criterion is one of major design parameter in here.

Further it is important to test locally fabricated sections and specimens to have insight of locally available strengths and workmanship, when complying with standards for cold formed steel in an actual design case in determining with safety factors.

Referances

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