EXPERIMENTAL ANALYSIS OF COLD FORMED LIGHT GAUGE STEEL STRUCTURAL COMPRESSION MEMBER BY IMPROVING DISTORTIONAL STRENGTH UNDER COMPRESSION

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Abstract - Steel is the most versatile commonly used structural material. Structural steel is used in load – bearing frames in buildings and as members in trusses, bridges and space frames. Cold-Formed Steel sections are defined as structural members cold formed to shapes in a rolling mill or press – brakes from carbon or low – alloy steel sheets or strips or flats. Cold formed steel sections are made from light gauge steel strips generally not thicker than 12.5 mm. Open cross sections are subjected to multiple modes of buckling as distortional, flexural and flexural – torsion buckling since the shear center does not coincide with the center of gravity such sections. From the available literature, it is observed that the studies on the behavior of thin-walled open cross section are very minimum. The present paper work aims at the study of buckling behavior of open web open cross section under compression. Introduction deals with the general idea about cold formed steel members, problems on investigation need for this research, objective of the investigation, geometrical cross section of the specimen, methodology and scope of the thesis. Literature review details with the review of the literature on torsional – flexural buckling, Distortional buckling, Rack Columns and cold formed members and Open web sections. Expressions for distortional buckling stress & flexural torsion buckling stress will be obtained for mono symmetric open cross section compression members. Four test specimens will be fabricated with geometry of Rack Section Column with various thicknesses and will be experimented. Buckling stresses which will be obtained from experiments will be compared with theoretical buckling stress. The theoretical results are compared with the experimental results. Design for maximum Limit strength of columns using Limit State Design (LSD) by British Standard (BS 5950 Part V) will also be presented. Results and discussion presents the results of work done, Comparison with theoretical &experimental results will be given the final conclusion of this research. Design method using BS method and also will be concluded from the investigation.

Keywords - Local & distortional buckling, Ultimate Stress, Design Stress, Deflect meter, LVDT

I. INTRODUCTION

1.1 General

In steel construction, there are two main families of structural members. One is the familiar group of hot-rolled shapes and members built up of plates. The other, less familiar but of growing importance, is composed of sections cold formed from steel sheet, strip, plates, or flat bars in roll-forming machines or by press brake or bending brake operations. These are cold-formed steel structural members [1], [2], [3], [4]. The use of cold-formed steel members in building construction began in about the 1850s in both the United States and Great Britain and widely spread throughout the world till date. As compared with thicker hot-rolled shapes, cold-formed light members can be manufactured for relatively light loads and or short spans and to any shapes. Cold-formed sections are manufacture by three methods namely Cold roll forming, Press brake operation and Bending brake operation. The various forms of cold form sections are shown below [5], [6], [7].
1.2 Cold–formed Steel Section

Cold-formed steel sections are defined as structural members cold formed to shapes in a rolling mill or press–brakes from carbon or low–alloy steel sheets or strips or flats. Cold formed steel sections are made from light gauge steel strips generally not thicker than 12.5 mm. The minimum yield strength for the steel conforming to IS 1079-1973 is 232 N/mm² and the ultimate strength is 390 N/mm².

Applications of CFSS: Cold-formed steel has widely used in buildings, automobile equipment, Ship building, Railway, Aircraft building, Agricultural, Mining, Petroleum, Nuclear industries, Space industries, home and office furniture, utility poles, storage racks, grain bins, highway products, drainage facilities and bridges [8], [9], [10].

II. RESEARCH METHODOLOGY

2.1 Tension Test on Steel Sheet

IS 1608-2005 prescribes the method of conducting tensile test on steel sheet strip less than 3 mm and not less than 0.5 mm thick.

Test Specimens
- The test piece has a width ‘b’ of 20 mm and a gauge length Lo of 80 mm. However, if the nominal thickness ‘a’ is not greater than 2 mm, the test piece may have a width of 12.5 mm and a gauge length ‘Lo’ of 50 mm.
- The test piece generally has enlarged ends, in which case there is a transition radius of not less than 20 mm between the gripped ends and the parallel lengths. The width of the enlarged ends is not less than 20 mm and not more than 40 mm. Alternatively, the test piece may consist of a strip with parallel sides.
Where,
\[ a = \text{Thickness of the test piece} \]
\[ b = \text{Width of the test piece} \]
\[ Lo = \text{Original gauge length} \]
\[ Le = \text{Parallel Length} \]
\[ Lt = \text{Total length} \]
- The ends of the test piece metal held in suitable grips in the testing machine in such a way that the center line of pull coincides with the longitudinal axis of the test piece.
- The parallel length is kept between \( Lo + b/2 \) & \( Lo + 2b \).

2.2 Rate of Loading

If the yield stress is to be determined, the speed of the machine should be so regulated that the rate of increase of stress on the test piece is not more than one kilogram force per square millimeter per second from a stress vs. approximately 5 kg/mm\(^2\) until the yield point is reached. The graphs were plotted and the young’s modulus and the yield stress were calculated.

| Thickness (mm) | Young’s Modulus (N/mm\(^2\)) | Yield Stress (N/mm\(^2\)) |
|---------------|-------------------------------|---------------------------|
| 1.6           | \(2 \times 10^3\)             | 250                       |

Test Section: The programmer involved fabrication of four specimens of Rack – section with lips column of open cross – section with various thicknesses from 0.8, 1.0, 1.2 & 1.6 mm. Test section geometry and dimensions are listed in Table 2.

2.3 Fabrications of sections

The first specimen is of Rack – section with lip column of open cross section with 0.8 mm thickness is shown in figure 3. It is open web cross section. The fourth side of the Rack column is kept open and other three sides are plain closed sides. The height of the specimen is 500 mm. Like this, the Second, third & fourth specimen are of Rack – section with lip column of open cross section with 1.0mm, 1.2 mm & 1.6 mm thickness are shown in figure 3. The heights of the specimen are also 500 mm.
2.4 Test setup and instrumentation

The experimental arrangement is shown in the figure 4 & figure 5 and also in the photograph. A 20 T capacity universal testing machine (UTM) is used to test all the specimens. The load is applied axially in the centroid of the column. The deflections in the X and Z directions and the axial deformations in the Y direction are measured by using Deflection meter and LVDT. Three deflectometers are placed at different heights at the specimen to measure the deflections in X and Z directions. One deflectometer is placed at the bottom of the specimen to measure axial deformation. Three numbers of LVDT are placed at various positions on the specimen to measure the deflections in X and Z directions. The load is applied axially at the centroid of the column.
2.5 TESTING PROCEDURE
Initially a seating load is applied to the specimen to held in position so as there is no eccentricity. All deflect meter reading are set to zero. Then, the load was applied gradually through UTM. The deflections were recorded as number of divisions at the every increment of load till the failure of the specimen takes place by Deflect meter and LVDT. Deflect meter readings are converted to mm by multiplying the divisions of the deflect meter by 0.01.

The load deflection curve and the result values for various specimens are presented in the following pages. The experimental results (say the critical load, ultimate stress) are tabulated below:

| Specimen | Area in mm² | Ultimate Load in kN | Exp.Ultimate Stress in N/mm² |
|----------|-------------|---------------------|-----------------------------|
| $S_p$ 01 | 284.16      | 40.00               | 140.765                     |
| $S_p$ 02 | 354.00      | 54.50               | 153.95                      |
| $S_p$ 03 | 423.36      | 62.00               | 146.44                      |
| $S_p$ 04 | 560.64      | 78.50               | 140.02                      |

![Figure-6 Failure mode shapes of specimens](image)

Figure-7 Load vs. Deflection Curve at axial deformation Figure 8 Load vs. Deflection Curve at 19 cm from Top flange
III. EXPERIMENTAL RESULTS AND DISCUSSION

The values derived from the experimental results, ANSYS results, Theoretical values and other design values like BS method are tabulated below. The table also gives the mode of failure of each specimen. The comparisons of experimental values are tabulated below.

Table 4- Comparison of Results

| Specimen No | Exp. Ultimate Stress N/mm$^2$ | Theoretical Ultimate Stress N/mm$^2$ | ANSYS Ultimate Stress N/mm$^2$ | Exp./The. | ANSYS/The | BS Design Stress N/mm$^2$ | Failure Mode         |
|-------------|-------------------------------|-------------------------------------|-------------------------------|-----------|-----------|----------------------------|----------------------|
| S_p 01      | 140.76                        | 123.17                              | 147.80                        | 1.14      | 1.19      | 163.64                     | Local & Distortional |
| S_p 02      | 153.95                        | 138.02                              | 163.84                        | 1.11      | 1.18      | 178.45                     | Local & Distortional |
| S_p 03      | 146.44                        | 125.63                              | 193.68                        | 1.15      | 1.54      | 201.58                     | Local & Distortional |
| S_p 04      | 140.02                        | 132.42                              | 196.20                        | 1.05      | 1.48      | 210.27                     | Local & Distortional |

The failure mode for the first specimen (Fig 5-SP 01) is mixed Local and Distortional buckling. The experimental ultimate stress in the specimen is 140.76 N/mm$^2$, it is only around 56.304% of the yield stress ($Y_s = 250$ N/mm$^2$). The ultimate stress derived from the ANSYS result is 147.80 N/mm$^2$. The ratio of Experimental & ANSYS result with Theoretical result is 1.14 & 1.19 respectively. The result stress from the BS design method is 163.64 N/mm$^2$.BS method gives slightly higher value than the other results.

The failure mode for the second specimen (Fig 6 -SP 02) is mixed Local and Distortional buckling. The experimental ultimate stress in the specimen is 153.95N/mm$^2$, it is only around 61.58% of the yield stress ($Y_s = 250$ N/mm$^2$). The ultimate stress derived from the ANSYS result is
163.84 N/mm². The ratio of Experimental & ANSYS result with Theoretical result is 1.11 & 1.18 respectively. The result stress from the BS design method is 178.45 N/mm². BS method gives slightly higher value than the other results.

The failure mode for the Third specimen is mixed Local and Distortional buckling. The experimental ultimate stress in the specimen is 146.44N/mm², it is only around 58.576 % of the yield stress (Yₛ =250 N/mm²). The ultimate stress derived from the ANSYS result is 193.68 N/mm². The ratio of Experimental & ANSYS result with Theoretical result is 1.15 & 1.54 respectively. The result stress from the BS design method is 201.58N/mm². BS method gives slightly higher value than the other results.

The failure mode for the Fourth specimen is mixed Local and Distortional buckling. The experimental ultimate stress in the specimen is 140.02N/mm², it is only around 56.00 % of the yield stress (Yₛ =250 N/mm²). The ultimate stress derived from the ANSYS result is 196.20 N/mm². The ratio of Experimental & ANSYS result with Theoretical result is 1.05 & 1.48 respectively. The result stress from the BS design method is 204.51 N/mm². BS method gives slightly higher value than the other results.

IV. Conclusion and Future Work

- Behavior of thin walled cold-formed steel columns requires consideration of local, distortional and Euler (i.e., flexural or flexural-torsional) buckling.
- Compression test on thin walled open web section has been carried out under hinged condition and investigated for flexural, flexural-torsional and mixed with local-distortional mode of buckling.
- Theoretical results are compared with ANSYS 11 and BS design. Theoretical results agree well with FEM results.
- Experimental failure modes of buckling shape are in good agreement with ANSYS output results.
- BS Design results are higher than theoretical and experimental result.
- Distortional buckling mode has lower post-buckling capacity than local buckling & has higher imperfection sensitivity than local buckling.
- If the failure is known to occur in the distortional mode, then the elastic distortional buckling stress (local) is used to predict the ultimate strength.
- Load carrying capacity should decreases with increase in w/t ratio.

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