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Failure modes of Cold formed steel beam- A Review

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Abstract- **Cold-formed steel members have many advantages over hot-rolled steel members. However, they are susceptible to various buckling modes at stresses below the yield stress of the member because of their relatively high width-to-thickness ratio. Cold formed steel beam members have various buckling modes. In this paper various literatures is studied about cold formed steel beams. Web crippling, web buckling are the major failure modes that occurs in the beam element. Numerical analysis, experimental analysis and theoretical analysis were compared to each other. North American specifications, direct strength method were used mostly.**
Keywords: cold formed steel beam, web crippling, web crushing, DSM, I-section.

I. INTRODUCTION

In steel structures, two primary structural steel member types are used: Hot rolled steel members and Cold- forming steel members. The Hot rolled steel members are formed at elevated temperature whereas Cold formed steel are formed at room temperature. The Hot rolled section are heavy weight instead of this; Cold formed steel are less weight. Cross sectional shapes are formed to close tolerances and these can be consistently repeated for as long as required. Cold rolling can be employed to produce almost any desired shape to any desired length. It is possible to displace the material far away from the neutral axis in order to enhance the load carrying capacity.

Cold-formed steel sections are widely used in construction and building industries. The popularity of these products has dramatically increased in recent years due to their wide range of application, ease of fabrication and high strength-to-weight ratios. Cold-formed steel structural members may lead to a more economic design than hot-rolled steel members. Cold-formed steel members are either cold-rolled or brake-pressed into structural shapes.

II. ADVANTAGES OF COLD FORMED SECTIONS

Some of the main advantages of cold rolled sections, as compared with their hot-rolled are as follows:

A. Cross sectional shapes are formed to close tolerances.
B. Cold rolling can be employed to produce almost any desired shape to any desired length.
C. Pre-galvanised or pre-coated metals can be formed, so that high resistance to corrosion, besides an attractive surface finish, can be achieved.
D. All jointing methods, (i.e. riveting, bolting, welding and adhesives) can be employed easily.
E. High strength to weight ratio.
F. Easy to transport and erect.

III. LITERATURE REVIEW

Abbas et al (2006) theoretically presented the Behavior of Corrugated Web I-Girders under In-Plane loading condition. The equilibrium of a length of a corrugated web I-girder was studied, and the cross-sectional stresses and stress resultants due to primary bending moment and shear were deduced. The analysis showed that a corrugated web I-girder will twist out-of-plane simultaneously and deflected in-plane under the action of in-plane loads. In this paper, the in-plane bending behavior was analyzed using conventional beam theory method and the out-of-plane torsional behavior was analyzed as a flange transverse bending problem. Finally, finite element analysis results were presented and compared to the theoretical results for validation.

Abbas et al (2007) investigated theoretically, experimentally, and numerically the results for the linear elastic behavior of corrugated web steel I-girders under in-plane loads. In his previous research it was concluded that a corrugated web I-girder under primary moment and shear cannot be analyzed using conventional beam theory alone, and a flange transverse bending analysis was required.

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Therefore a theoretical method, i.e., the fictitious load method, was presented for quantifying flange transverse bending in corrugated web I-girders. The measured flange transverse displacements and flange stresses agreed good with the theoretical results especially in the regions of constant shear. Finite element analysis results for the test girder were also presented, and compared to both the experimental and theoretical results

Santaputra et al (2015) studied the web crippling behaviour of high-strength cold-formed steel beams. The author investigated analytically and experimentally both the hat sections and I-beams that were formed from five different types of high-strength sheet steels. These were investigated under various loading conditions. The evaluation indicates that the present available design criteria were not suitable for high strength materials with yield strengths exceeding 552 MPa. Therefore, new design formulas had been derived for different types of loading conditions with varying yield strengths ranging from 207 to 1,138 MPa. These equations distinguished between web crippling failure caused by overstressing and web buckling failure. The .newly proposed design equations had been verified by test results.

Cheng Yu and Benjamin W. Schafer (2006) studied the distortional Buckling Tests on Cold-Formed Steel Beams. For cold-formed steel joists, purlins, or girts, when the compression flange has not been restrained in attachment to sheathing or paneling, then distortional buckling be the important failure mode. Therefore a series of distortional buckling tests on cold-formed steel C and Z sections in bending was conducted. They were selected so as to allow distortional buckling mode but restrict lateral-torsional buckling. It was observed that large strength reductions are in the tested specimens when distortional buckling initiated the failure instead of local buckling. Hence, the Australian/New Zealand Standard and the direct strength method provided explicit methods for calculating the capacity in the distortional buckling mode.

Ibrahim et al (2006) experimentally studied the fatigue behaviour of corrugated web plate girders. Due to stress concentration during welding transverse stiffeners in flat-web plate girders reduces their fatigue life. Therefore this study had been focused to investigate the behavior of trapezoidal corrugated-web plate girders under fatigue loading by means of evaluating their fatigue life under different stress ranges. The girders failed by fatigue cracks, which started at the weld between the web and the tension flange near the web fold line. A relationship between the stress range and the number of cycles to failure were developed. Fatigue lives of the test were compared to other girder types and the test results were related to the current AASHTO specifications. Hence, trapezoidal web corrugation is an efficient way of web stiffening that provides longer fatigue life than conventionally stiffened plate girders.

Sudha.K and Sukumar (2014) an experimental and numerical investigation on the bending strength and behaviour of cold-formed (CF) steel built-up flexural members was studied. Eight specimens with equal flanges and with unequal flanges had been fabricated and experimented. The experimental results showed the modes of buckling and their influence on the bending strength and behaviour of cold formed built-up I sections. Then the experimental results were verified by simulating finite element models analyzed using FEM software ANSYS. The results obtained are in good agreement with the experimental results.

Arunkumar et al (2013) studied the effect of web corrugation and hw/tw ratio on the flexural strength of cold formed steel lipped I section. Totally five specimens were experimented one with flat web and the remaining with trapezoidal corrugations in the web. The length of the specimen is kept constant for 3600 mm and hw/tw ratio was varied by keeping all the other parameters constant. All specimens were experimented under two point loading with simply supported condition. The experimental results were then verified with finite element analysis using ANSYS software. Experimental and numerical results were then compared with the predicted resistance by North American Specifications (AISI S100-2007) and Australian/New zealand Standards (AS/NZS: 4600-2005). The experimental result showed that the flexural capacity of the corrugated web was larger than flat web.

Divahar and Joanna (2014) investigated the results of the experimental study on the lateral buckling behaviour of cold-formed steel section with trapezoid web. A total of six cold-formed steel beams with plain webs and corrugated webs were tested. The moment carrying capacity of cold-formed steel beam with plain web was studied and compared with the moment carrying capacity of beam with trapezoidal corrugated web having 300 and 450 corrugations. The specimens were tested under two point loading for its pure flexural behaviour. It was found that the cold-formed steel beam with trapezoidal corrugated web section have higher resistance to lateral buckling compared to that of section with plain web. As a result it was concluded that the average load carrying capacity of cold-formed steel beams with 300 corrugated webs increased by 25% than the beam with plain web. But there was an only marginal increase in load carrying of beam with 300 corrugated webs than that of beam with 450 corrugated webs.

Divahar and Joanna (2014) investigated the use of corrugated steel plate buckling behaviour of cold-formed steel section with trapezoid web. In order to increase the shear capacity of web of large steel plate girders, the web with different patterns such as tapered web, haunches, and corrugations of different shapes were used. A total of six cold-formed steel beams with plain webs and corrugated webs were tested. The load carrying capacity of cold-formed steel beam with plain web was studied and compared with the load carrying capacity of beam with trapezoidal corrugated web having 300 and 450 corrugations. The specimens were tested under two point loading for its pure flexural behaviour. From the study, it was found that the cold-formed steel beam with trapezoidal corrugated web having 30 corrugations has higher load carrying capacity compared to the beams having plain web and 45 corrugated web.

Soliman et al (2013) studied the interaction between bending and web crippling and reduced the load carrying capacity. Numerical study on web crippling and interaction between bending and web crippling were performed considering the material and geometric nonlinearities. The study was performed on channel sections subjected to web crippling under interior one flange loading conditions. Finite element models were verified against experimental tests, and then extended to predict the web crippling strength of the studied channel sections. FE was used to investigate the interaction between bending and web crippling in C-sections. It was found that, the strengths predicted by design codes were generally inadequate for channels with a practical web slenderness range. Therefore, modifications were proposed to improve the strength predicted by codes.

Cheng et al (2014) presented a numerical investigation on the buckling behaviour of plasterboard protected CFS channel section beams subjected to uniformly distributed loads which was exposed to fire on its one side. The work involved three phases, namely heat transfer analysis, pre-buckling analysis and buckling analysis. The heat transfer analysis was used two-dimensional finite element analysis methods, from which the temperature fields of the channel-section beams were obtained. The pre-buckling analysis was completed with the Bernoulli bending theory of beams. The results showed that there were significant temperature variations in web, fire exposed flange and lip. Also, it was found that the buckling behaviour of the beam with temperature variation in its section was quite different from that of the beam with a constant uniform temperature in its section.

Prema et al. (2015) investigated on the behavior of cold form steel built up I - section with triangular web corrugation at varying depth. The experimental results are verified with finite element analysis using ANSYS software. The results obtained from test experiments and ANSYS software were compared with the predicted Indian Specifications (IS 801- 1975). The experimental result showed that the flexural capacity of the triangular web was larger than flat web. Also the effect of hw/tw ratio on the flexural strength capacity was studied and discussed. Due to the provision of triangular web corrugation, there was no failure in shear zone or in web portion.

Jayaraman et al. (2014) studied the behaviour and economical of cold formed steel (CFS) built up channel section and channel section by same cross sectional area. Overall two specimens were designed and comparison of all the internal force, and hence, to evaluate the co-existing moments and shear forces at the critical cross-section with same configuration area by keeping all other parameters constant. The main aim of the study provides which section is economical, high bending strength, more load carrying capacity and high flexural strength by analysis of theoretical and numerical investigation. Therefore channel section is most suitable and economical compare than the built up channel section.

Cilmar Basaglia1 and Dinar Camotim (2013) reported the buckling, post buckling strength, and collapse behavior of cold-formed steel continuous beams and simple frames and also developed direct strength method to design this structural systems. The results available at this stage concern two- and three-span lipped channel beams subjected to non-uniform bending, and they include the assessment of how accurately the beam ultimate strengths can be predicted by the current DSM design curves. The numerical results presented and discussed are obtained through analyses based on generalized beam theory and shell finite-element models. Ultimate strength values yielded by geometrically and materially nonlinear shell finite-element analyses were compared with estimates provided by the DSM equations, and on the basis of this comparison, it was possible to identify some features that must be included in a DSM approach applicable to continuous cold-formed steel beams.

Vinod (2015) studied about the plate girder. The corrugated steel plates were widely used structural elements in many fields of application because of its numerous favorable properties. To increase the shear capacity of web for large steel plate girders, the web with different types such as tapered web, haunches, corrugations of different shapes are used. Corrugated steel panels have been recognized as excellent load carrying members. The addition of stiffness to plate girders was made with different corrugations. Then parameters were compared and it was established that corrugated web plate girders were better than plane web plate girder.

Cheng et al (2013) presented an analytical study of the flexural buckling and lateral–torsional buckling of cold-formed steel channel section beams subjected to combined compression and bending. In considering channel section beams a bending about the minor axis creates a non-symmetric pre-buckling stress distribution. The interaction between the compression load and the bending moments about the major and minor axes was studied. It had been found that for a section subject to combined compression and the major-axis bending the bending moment will decrease the critical compression load, although the critical value of the largest compressive stress in the section actually increases with the applied bending moment. However, for a section subject to combined

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compression and the minor-axis bending the effect of the bending moment on the critical compression load depends on the direction of bending applied. For bending that creates a compressive stress in the lips the bending moment will reduce the critical compression load.

Limaye et al (2013) used the corrugated steel plate to increase the shear capacity of web of large steel plate girders. The web with different patterns such as tapered web, haunches, and corrugations of different shapes were used. Present paper deals with the determination of buckling strength of a plate girder considering rectangular corrugated web plate. The finite element analysis of a plate girder is carried out using ANSYS. The results obtained from analysis were then compared with the plate girder with plane web of uniform depth. Some parameters like buckling strength and weight were compared together. It was concluded that the corrugated web plate has high buckling strength and sufficient reduction in weight with light gauge elements, than plate girder with plane web.

Yu and Schafer (2003) studied the design provisions for stiffened elements under a stress gradient - the web of *C* or *Z* sections. New methods had been proposed for design, and an interim method has been adopted in the North American Specification. Existing tests on *C* and *Z* sections do not provide a definitive evaluation of the design expressions. In this paper a series of flexural tests with details selected specifically to insure that local buckling is free to form, but distortional buckling and lateral-torsional buckling are restricted was studied. The authors intend to test additionally and analysis the distortional buckling capacity of *C*'s and *Z*'s as well as more closely define the role of fasteners and other details.

Driver et al (2006) studied the shear behaviour of corrugated web bridge girders. A systematic analysis of these data has revealed that previously proposed equations based on plate buckling theories can overestimate the shear strength of corrugated webs by a considerable margin. The results of finite element analyses conducted as part of this investigation suggest that the strength is overestimated, because of the sensitivity of the shear behavior to the presence of initial imperfections in the web. Therefore, two full-scale corrugated web girders made of HPS 485W steel were tested. The shear strength and failure mode of the girders are reported and the effect of web initial geometric imperfections is assessed through measurements of the out-of-plane displacements of the web.

Elgaaly et al (1996) investigated beams with corrugated webs to fail under shear. The failure was due to buckling of the web. The test specimens were modeled using finite elements and the computer program *ABAQUS* was used to perform nonlinear analysis. The load increments as well as the mesh size were selected based on studies to examine their effects. Then comparison between the results from the finite-element analysis and the tests was satisfactory. It was noted from the experimental as well as the analytical results that buckling of the web is local and global for the coarse and dense corrugations, respectively. Buckling formulas are suggested, which are based on local buckling of the corrugation folds as isotropic flat plates or global buckling of the entire web panel as an orthotropic plate. Comparisons between the results from the formulas, the finite-element analysis, and the tests are given and shown to be satisfactory.

IV. CONCLUSION

Cold formed steel members are widely used due to its various advantages over hot rolled members. From this study, it is concluded that the beam members exhibit web crushing, web buckling behaviour. North American specification and direct strength method was mostly used for the theoretical investigation. Finally the experimental test is performed and compared with numerical and theoretical values.

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