Comparison of Innovative Corrugated Hollow Steel Columns With Conventional Hollow Steel Column: Experimental And Numerical Study

Zakeer M. Mulani[1], Y. M. Ghugal[2]

Department of Applied Mechanics, Government College of Engineering, Karad, (India)

ABSTRACT

Steel structures can easily dismantle without loss to the integrity of the original structure. Most structural steel units were prefabricated in a workshop with a superior quality control compared to In-situ construction. Lighter steel structures are invariably prepared to the heavier alternatives such as reinforced concrete or prestress concrete. The main advantages of steel structure are its intrinsic strength, prefabrication and quicker transportability to the work site and faster erection. With the development of steel as a construction material, the varieties of steel sections were also increased. Among these sections, the Hollow structural sections (HSS) or Structural hollow sections were the most reliable one. Extensive research has been carried of corrugated web beam and girders, but fewer amounts of research for corrugated column and its utilization and advantages is available. In present project, three types of innovative corrugated hollow steel section (HSS) column are developed; fabricated and tested. The current work is separated in to two parts. first part is experimental work, the study of the behavior of the innovative corrugated hollow steel columns under axial loading using UTM was conducted, In the second part, the results of the experimental work are checked with numerical results which are obtained by analytical method by using computer software ANSYS. Results obtained from experimental testing and computer analysis are compared and validated. The comparison of innovative corrugated hollow steel columns with conventional hollow steel column is done to know the advantages of innovative corrugated HSS columns over conventional HSS column.

***Keywords*: ANSYS software, Corrugated Plates, conventional column, innovative column, thin walled structures.**

I. INTRODUCTION

A hollow structural section (HSS) is a type of metal profile with a hollow tubular cross section. HSS members can be circular, square, or rectangular sections, although other shapes are available, such as elliptical. HSS is only composed of structural steel per code. Rectangular and square HSS are also commonly called tube steel. Rather, the three basic shapes are referenced as CHS, SHS, and RHS, being circular, square, and rectangular hollow sections. HSS, especially rectangular sections, are commonly used in welded steel frames where members experience loading in multiple directions. Square and circular HSS have very efficient shapes for this multiple-axis loading as they have uniform geometry along two or more cross-sectional axes, and thus uniform strength characteristics. This makes them good choices for columns. They also have excellent resistance to torsion. HSS can also be used as beams, although wide flange or I-beam shapes are in many cases a more efficient structural shape for this application. However, the HSS has superior resistance to lateral torsional buckling. The flat square surfaces of rectangular HSS can ease construction, and they are sometimes preferred for architectural aesthetics in exposed structures, although elliptical HSS are becoming more popular in exposed structures for the same aesthetic reasons.

In the recent past, HSS was commonly available in mild steel, such as A500 grade B. Today, HSS is commonly available in mild steel, A500 grade C. Other steel grades available for HSS are A847 (weathering steel), A1065 (large sections up to 50 inch sq made with SAW process), and recently approved A1085 (higher strength, tighter tolerances than A500). Square HSS is made the same way as pipe.

During the manufacturing process flat steel plate is gradually changed in shape to become round where the edges are presented ready to weld. The edges are then welded together to form the mother tube. During the manufacturing process the mother tube goes through a series of shaping stands which form the round HSS (mother tube) into the final square or rectangular shape. Most American manufacturers adhere to the ASTM A500 or newly adopted ASTM A1085 standards, while Canadian manufacturers follow both ASTM A500 and CSA G40.21. European hollow sections are generally in accordance with the EN 10210 standard. HSS is often filled with concrete to improve fire rating, as well as robustness. When this is done, the product is referred to as a "Lally column" after its inventor John Lally of Waltham, Massachusetts. However, the pronunciation is often corrupted to "lolly column". For example, barriers around parking areas, bollards, made of HSS are often filled, to at least bumper height, with concrete. This is an inexpensive (when replacement costs are factored in) way of adding compressive strength to the bollard, which can help prevent unsightly local denting, though does not generally significantly increase the overall structural properties of the bollard.

Typically, these designations will also relate to metric sizes, thus the dimensions and tolerances differ slightly from HSS. The history of hollow structural section was very old and interesting because of their shape. The origin of Hollow structural section was connected with the origin and development of steel only. Basically, the concept of hollow structural section was developed by day to day lifestyle, first the concept of steel and then after the use of steel for different purposes. The concept of circle was firstly originated and then after square, rectangle etc. Initially, they were used for different purposes such as wheels of bullock carts, for different shapes of pot etc. First the conventional steels were used for different structures and then after, on identifying the benefits of different shapes such as circular, square, rectangular etc. The hollow sections were developed, experimented and used for construction purpose. The excellent properties of the tubular shape have been recognized for a long time i.e. .from ancient time. In 18th century, the first production methods for seamless and welded circular hollow sections were developed. In 1886, the “Mannesmann Brothers” developed the skew roll piercing process.

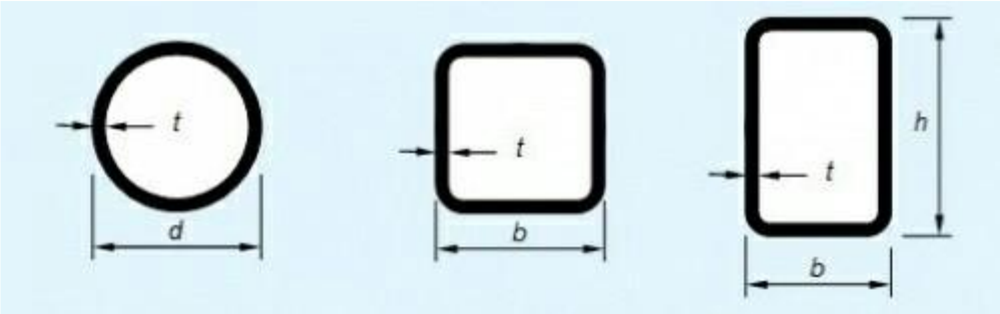

Fig 1.1 different types of hollow structural section

1.1 Corrugation

The extensive use of thin-walled steel structural systems in the building and construction industry is mostly indebted for their high strength to weight ratio attributes and remarkable fabrication versatility. Corrugated plates fallen in this category, also have a wide range of application in various engineering fields. They are lightweight, economical, and have much higher load carrying capacities than flat plates, which ensure their popularity and have attracted research interest since they were introduced. The corrugation shape provides continuous stiffening which permits the use of thinner plates. A corrugated plate can easily be bent in one direction, whereas it retains its rigidity in the other direction.

Corrugated steel is a building material composed of sheets of hot-dip galvanized mild steel, cold-rolled to produce a linear corrugated pattern in them. The corrugations increase the bending strength of the sheet in the direction perpendicular to the corrugations, but not parallel to them. Normally each sheet is manufactured longer in its strong direction. Corrugated steel is lightweight and easily transported. It was and still is widely used especially in rural and military buildings such as sheds and water tanks. Today the corrugation process is carried out using the process of roll forming. This modern process is highly automated to achieve high productivity and low costs associated with labour. In the corrugation process sheet metal is pulled off huge rolls and through rolling dies that form the corrugation. After the sheet metal passes through the rollers it is automatically sheared off at a desired length.

II. LITERATURE REVIEW

Somodi and Kövesdi [1] In this paper, the author studied that application range of the current EN 1993-1-1 for column buckling resistance whose determination is limited for the steel materials able to the steel grade of S460. The EN 1993-1-12 [1] these gives design rules for the materials up to the steel grade of S700. HSS steel structures is very essential in the design when stability failure, because due to the higher yield strength small cross sections can be used, which may be more sensitive for stability failure. According to the prior research paper results, the global buckling behavior of HSS as well as NSS columns can be significantly different, These differences are not considered in the design process of Euro-code. The purpose of present research is to study the column buckling behavior of HSS cold-formed hollow section columns on the basis of previous and current experimental investigations and based on numerical simulations. According to the numerical parametric conclusions made for the difference on the buckling resistance between NSS and HSS steel cold-formed hollow section columns were the buckling reduction factor of HSS columns can be higher due to the increased yield strength, the buckling reduction factor of HSS columns can be high due to magnitude of the bending residual stresses. The results of the numerical simulations give you an idea about two phenomena that increase and one phenomenon that decreases the buckling reduction factor of HSS columns compared to NSS material grades. The results of the current numerical simulations are in harmony with the results of the laboratory tests and the statistical evaluation of the measured column buckling resistances. Paper focused on the effect of the different material properties, imperfections and residual stresses on the global buckling behavior of HSS members. And give design proposals for the appropriate column buckling curves for the steel grades between (S420) S500 and S960.

Liao *et al*. [2] In this paper, the author has conducted axial compression bearing capacity tests and finite element analysis of nine multi-limbs built–up cold–formed steel stub columns with three different section forms. Multi-limbs built-up cold-formed steel stub columns are a main structural member consisting of a single C-shaped and U-shaped basic component attach by self-drilling screws. Results of FE analysis are close to the test results and verify the accuracy of the finite element analysis. To study the influence of width–thickness ratio and screw spacing on the bearing capacity of the build-up column, the parametric analysis were carried out on the maximum width–thickness ratio of the plates and the screw spacing. The results show that the failure modes of specimens are local buckling and distortional buckling. Multi-limbs built–up cold–formed steel stub columns consisting of a few basic components can work in agreement, the integral behavior is desirable. The failure modes of multi-limbs built-up cold-formed steel stub column specimens are local buckling and distortional buckling. According to results, it is obtained that multi-limbs built–up cold–formed steel stub columns consisting of a few basic components can work in harmony, the integral behavior is desirable. The screw spacing has not impact on the ultimate axial compression bearing capacity and the buckling bearing capacity, stiffness of the multi-limbs built-up cold-formed steel stub columns. The load-axial displacement curves, local buckling critical loads, ultimate loads, failure modes of the specimens analyzed by ANSYS were compared with the experimental test results and shows accuracy of ANSYS finite element analysis. The axial load bearing capacity of the multi-limbs built-up section stub column increases when the maximum width–thickness ratio of the plates decreases; the screw spacing has a little impact on the ultimate axial compressive capacity and the buckling capacity of the multi-limbs built-up cold-formed steel stub columns.

Yanga, *et al.* [3]In this paper, the author studied that interactive buckling behavior of welded steel box-section columns experimentally and numerically. A total of twelve steel medium-length columns, two with a welded square hollow section (SHS) and ten with a welded rectangular hollow section (RHS), were axially compressed. All specimens were designed to cover wide range of width-to-thickness ratios and slenderness. Material properties, geometric imperfections, buckling resistance, and load-displacement/strain curves were obtained. Test data were compared with current design codes Eurocode3 and ANSI/AISC 360-10, revealing overestimated design forecast. Further, the experimental results were supplemented by finite element imitation. Reliability of the modeling methodology was verified by comparisons with earlier test data. The design proposal was eventually carried out on both plain carbon steel as well as high-strength steel columns. All specimens failed in the form of local-overall interactive buckling. Local buckling was primarily presented in plates, after which the overall horizontal displacement increased until overall buckling occurred. Comparison of test data with current specifications illustrated that ANSI/AISC 360-10 overestimated while Eurocode 3 slightly overestimated the buckling resistance. Two possible causes lay in the overestimated effective width expression and preliminary loading eccentricities. Experimental results were supplemented by a parallel finite element investigation. The load-displacement curves and buckling strength obtained from experiments and FE simulations were compared. Finite Element results approached but were generally lower than the test results, illustrating the reliability of the FE model. The verified FE model was used to analyze a series of columns with varying materials and geometries, on which source a design proposal for steel column interactive buckling was determined.

Somodi and Kövesdi [4]In this paper, investigation of residual stress distribution in HSS member's residual stress in which measurements were carried out on cold-formed square hollow sections. According to the previous research results the effect of residual stresses on the high strength steel members (HSS) are less severe than for normal strength steel (NSS) structures. Residual stresses have a significant influence on the global stability behavior of steel structures; therefore the application of the existing buckling curves developed for NSS structures might lead to uneconomic design for HSS structures. The test specimens are delivered by three different manufacturers using five different steel grades (S420, S460, S500, S700, S960). Based on the test results the shape and the intensity of the measured longitudinal residual stresses are determined and evaluated. The measured values of the residual stress patterns are evaluated in the function of the yield strength and the geometric properties of the test specimens. The measured residual stresses are compared to the results of the previous experiments and an improved residual stress model is developed based on the previous and current test results and which model is usable for cold-formed square hollow sections having various steel grades.

Jiang et al. [5]In this paper, the author has discussed that high strength steel (HSS) box columns which are often fabricated by welding of steel plates together, welding process during fabrication inevitably introduces residual stresses in the columns and affects their strengths. Hence, a good understanding of the influence of the welding process on the residual stresses of HSS built-up box column is important for the design of such columns. In this study, an experimental investigation to investigate the effects of welding process on the residual stress distributions of HSS built-up box columns was carried out. Two groups of identical specimens fabricated by flux-cored arc welding and submerged arc welding were studied. The influence of different welding methods was investigated by employing the ASTM hole-drilling method to measure the residual stress distributions. In this paper, the results of a carefully design experimental study conducted to investigate the welding residual stress distributions of HSS built-up box column were presented. Two groups of specimens, corresponding to welding preformed with flux-cored arc welding (FCAW) and submerged arc welding (SAW), were fabricated. The effects of different welding methods on the residual stresses generated in the HSS built-up box columns were investigated by applying the standard ASTM hole-drilling method to measure the final residual stresses induced during the welding processes. Finally, for all specimens tested, greater reductions were observed for the longitudinal residual stresses Furthermore, a study was also conducted to evaluate the effects of different heat treatment procedures on the magnitude and distributions of the final residual stresses produced.

Javidan *et al*. [6] In this paper, the author has described that compressive and buckling behavior of an innovative long column. The proposed innovative fabricated columns consist of mild steel plates which are welded to mild steel tubes at corners. Experimental tests are conducted on one, two and three-meter columns whilst a robust finite element model is also developed which is validated against the results obtained from the experiments. Detailed focus is brought to the effect of fabrication imperfections, type of welding and residual stresses on the behavior of the proposed long hollow columns in test result analysis and the finite element modeling. The examined innovative column specimens are shown to exhibit superior compressive behavior since the interaction between section's plates and tubes leads to a significant increase in both strength and ductility. The comparison of failure mechanisms and strain behavior of innovative sections with the control specimens showed an effective interaction between tubes and plates of member justifying the high strength and ductility performance. Detailed finite element results conducted in this research work showed an acceptable match with the experimental behavior of the proposed sections in different heights which was used for modeling the results of 4 m column strength for the cost analysis. In an economical point of view, a primary cost estimation analysis was conducted which justifies the absolute benefit of IFCs in terms of overall weight and production compared to that for a conventional column with similar width, length and compressive strength. These sections are found to have beneficial application in structures in demand of very high strength compressive members such as bridges and high rise buildings with significant ductility and desirably

Nassirnia *et al*.[7] In this paper, the author studied that latest development in material and manufacturing technologies make it possible to increase the yield strength of steel to more than 1200MPa.These steel grades are suitable for structural and safety-related automotive components. The high-strength level gives potential for considerable weight reduction and a cost-effective way to produce energy efficient products. Following the recently introduced hollow corrugated columns, this paper presents an advanced innovative hollow corrugated column by incorporating ultrahigh-strength (UHS) steel tubes. Three different types of corrugated plates were introduced. The plates were welded to UHS tubes at the corners to form a square hollow section. For the comparison purposes, another hollow column similar to innovative column but with flat plates called control column was also considered. The superior performance of the proposed column under compressive loading is investigated in the present work. UHS tubes used at the corner shave yield stress of1250MPa.Three different corrugated plates are introduced and fabricated so that the effect of corrugation geometry parameters such as angle of inclination and height of corrugation get experimentally investigated. Along with experiments, an advanced finite element model is developed for predicting the behavior of proposed columns and validated by experimental results. The geometric imperfection, material and geometric non linearity, and heat affected zone generated due to welding are included in the FE analysis. The developed finite element model in this research showed a very good agreement with the experimental results of the proposed sections; so it can be used as a tool for further numerical investigation of innovative sections. However, a general formulation for estimating load carrying capacity of these novel sections is still a need which is currently under development by the authors. Thereafter, optimized geometric parameters for comprising corrugated plates can be provided. Apart from mechanical performance of innovative columns, the proposed columns were competitive in terms of cost and weight compared to the sections already available in the civil market. The results prove the high capacity and ductility of the proposed innovative columns under compression compared to the accumulated capacity of the individual components. Finally, the proposed high-strength columns are compared with the conventional columns in terms of weight and manufacturing costs.

Gardner and Nethercot [8] In this paper, has the author described numerical modeling of the structural response of stainless steel hollow sections. The aim of the investigation was to develop a consistent approach to the modeling of stainless steel structures. The developed finite element models are more sophisticated than any other reported attempts to model stainless steel structural behavior, with general expressions defined for material stress–strain behavior, enhanced strength corner properties, initial geometric imperfection modes, and amplitudes (local and global), and residual stresses. The general expressions define a consistent means of describing the key input parameters. A compound (two-stage) model is developed to describe stainless steel material stress–strain behavior in tension and compression. For the prediction of enhanced strength corner properties, a simple, though accurate model is proposed. Characterization of local plate imperfection amplitudes is described whereby a model originally devised for hot-rolled carbon steel cross sections was recalibrated and applied to stainless steel cross sections. Numerical prediction of the key performance measures from tests is achieved with a high degree of accuracy. This paper has described the FE modeling of stainless steel members subjected to a variety of loading arrangements. Key parameters and methods have been defined through examination of experimental data and through carefully conducted parametric studies to achieve a consistent approach to the modeling. Overall, it can be concluded that the ABAQUS-based FE models developed in this study represent a sound and cost effective alternative to physical testing as a means of predicting the full load–deformation response of stainless steel structural members whose behavior may involve a combination of local and overall buckling. On average, ultimate load was predicted to within 3% and with a low standard deviation; deformation at ultimate load was within 6%, but exhibited a higher standard deviation; and the general form of the load–deformation response and the failure modes were similar.

Aglaia *et al*. [9] In this paper, investigated the structural resistance of high-strength steel seamless tubular beam-columns of circular cross-section subjected to axial compression and bending loading, using experimental testing and numerical finite element simulations. Experiments on short and slender seamless tubular specimens are conducted, and simulated with rigorous finite element models. Prior to experimental testing, initial imperfections and residual stresses are measured, and the measurements are taken into account in the numerical models as initial conditions. A good comparison is achieved between numerical simulations and experimental results in terms of ultimate strength capacity. Using the finite element tools, parametric numerical analyses are conducted under combined axial bending loading conditions. First, the influence of initial imperfections (wrinkling) on the structural behavior of high-strength steel tubular members is examined, in terms of their cross-sectional strength. Subsequently, stability curves for axial compression, and thrust-bending interaction diagrams for the high-strength steel tubular members are obtained. The cross-sectional strength, the stability curves and the interaction diagrams obtained numerically are compared with existing relevant provisions of European and American specifications(EN 1993, API RP 2A and AISC) for the design of beam-column tubular members. The comparison shows that the provisions of those specifications, originally developed for mild steel CHS members, result in reasonable, yet conservative, predictions for the structural resistance of high-strength steel seamless CHS members. It is also suggested that significant improvement of EN 1993 predictions can be achieved revising the classification of high-strength steel CHS sections.

Wang *et al*. [10] In this paper represent the establishment of current design curves for predicting the maximum strengths of centrally loaded columns were mostly depending on the experimental and numerically studies of mild carbon steels. In order to study the overall buckling behavior of welded high strength steel (HSS) box-columns, an experimental study on the ultimate strength of welded box-columns with a nominal yield strength of 460 MPa under axial compression was conducted. This experiment program includes six welded box-columns with slenderness varying from 38 to 80. A nonlinear finite element model considering the actually measured geometric imperfections and residual stresses was developed and verified in order to perform an extensively parametric study. The effect of residual stresses on the ultimate bearing capacity and the sensitivity of yield strength to initial geometric imperfections were investigated and discussed. The purpose of the parametric study is to select an appropriate design curve for welded 460 MPa HSS box-columns. By comparing the theoretical curves with the design curves specified in Eurocode3 and GB 50017-2003, it is found that the currently adopted design curves underestimate the ultimate bearing capacity of the welded box-columns fabricated from 460 MPa HSS plates by 18.7% and 23.2% in average, respectively.

Wang *et al*. [11]In this paper, the author has discussed on the bending strength of hot-finished high strength steel (HSS) square and rectangular hollow sections; present the results of detailed experimental and numerical studies and structural design rules for HSS cross-sections are proposed. High strength steels, considered in the context of the structural Euro-codes, as steels with yield strength over460 MPa, are gaining increasing notice from structural engineers and researchers due to their potential to enable lighter and more economic structures. A total of 22 in-plane bending tests, in three-point bending and four-point bending configurations, on HSS sections in grades S460 and S690were conducted. The experimental results were replicated by means of non-linear finite element modeling. Upon validation of the finite element models, parametric studies were performed to assess the structural response of HSS sections over a wider range of cross-section slenderness, cross-section aspect ratio and moment gradient. Experimental results combined with the obtained numerical results were used to assess the suitability of the current European (EN 1993-1-1 and EN 1993-1-12) cross-section classification limits for HSS structural components.

Shi*et al*. [12] Paper focused on the steel sections made from normal strength steel (NSS), those fabricated from high strength steel(HSS) which are thinner and lighter because of the improvement of the steel yield strength. This results in higher width-to-thickness ratios of the component plates and makes local buckling more critical for members in compression. Axial compression experiments were performed on steel stub columns made from Q460 steel (with nominal yield strength greater than 460 MPa), including four box section members and nine I-section members. A finite element model was developed with accurate simulation of initial imperfections. The modeling results were verified by experiments and a parametric analysis was conducted based on the validated modeling. In comparing the ultimate stress calculated by design methods in different codes with the experimental and numerical results, it was found that for the component plates of box section members, the design methods overestimated the ultimate stress of local buckling, so that the result was not safe enough. For the flanges of I-section members, the design methods underestimated the ultimate stress, especially for cases with relatively higher width-to thickness ratio.

Yali *et al.*[13] In this paper, the author has discussed relationship between mechanical behaviors and shape of corrugated fiberboard by means of buckling analysis, it is done by FEM . Corrugated fiberboard, widely used in the packaging industry owing to its lightness, resistance to shock and low cost, is a sandwich plate composed of cores and facing plates agglutinated between paper strips or paperboard. Firstly, after analyze the structure of corrugated fiberboard a single-wall corrugated fiberboard model was built. The buckling load was measured in the idyllic condition by linear buckling analysis. Nonlinear buckling analysis of single wall corrugated fiberboard was performed using the results of the Eigen value buckling analysis. Finally, a finite element 3-D model of four-layer, five-layer corrugated fiberboard was established using ANSYS parametric design language (APDL) to improve mechanical properties of corrugated fiberboard based on comparing different Eigen value buckling loads. In this paper attempts to provide a study of corrugated fiberboard buckling analysis depends on FEM. The comparatively ideal buckling load can be obtained by exerting simple support constraints on corrugated fiberboard. Eigen value buckling analysis can forecast the buckling load of corrugated fiberboard.

Heidarpour *et al.* [14] In this paper, the author has discussed the behavior of square or triangular fabricated stub columns consisting of Grade 316L stainless steel tubes and Grade 350 mild steel plates at ambient and elevated temperatures. The nominal dimensions of steel tubes were 31.8 and 38.1 mm diameters with 2 and 1.6 mm thicknesses, respectively. The plates widths of 120 and 400 mm and a 3 mm thickness. Utilizing all combinations of geometries, a variety of the fabricated stub columns were experimentally tested and their behavior were compared with conventional square or triangular welded hollow sections utilizing mild steel plates as well as single tubes. The proposed fabricated sections defined above outperformed the conventional welded hollow columns under both room temperature and elevated temperature circumstances. The ductility of the sections was increased by utilizing stainless steel tubes.

III. CONCLUSION

1) Previous paper results shows that innovative columns can carry axial load at least two times greater than conventional columns.

2) Innovative fabricated column (IFC), comparison of failure mechanism and strain behaviour of innovative column with control column specimen shows effective interaction between tubes and plates of IFC member justify the ductility performance and high strength.

3) Load axial displacement curves, ultimate load, local buckling critical loads ,failure method of member analysed by ABAQUS were compared with test result. Which proves that accuracy of ABAQUS FEA.

4) Failure method of multi-limbs built-up cold formed steel stub column specimens are local and distortional buckling.

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