Numerical Study of Fixed Ended Lean Duplex Stainless Steel (LDSS) Stub Column: A Review

[*]V Indumathy, [#]Dr. Anu James

[*]PG Student, [#]Assistant Professor, [*,#]Department of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam, Kerala, India, [*]indhuvijay.ctr@gmail.com, [#]anujames@mace.ac.in

Abstract - Although tremendous progress has been made in the creation of high-performance steel alloys like stainless steel, the steel construction sector has historically been overshadowed by the use of carbon steel structural elements. Generally speaking, stainless steel can be divided into three basic classifications: austenitic, ferrite, and duplex. Its nickel content plays a key role in cost. For instance, austenitic steel has a 3–5 times higher cost than carbon steel due to its high nickel content, which ranges from 8–10% by mass. However, it has recently been possible to reduce the cost, making Lean Duplex Stainless Steel (LDSS) a promising stainless steel type. LDSS has a nickel content of less than 1.5 percent. In this paper, we are going to discuss about behavior of using LDSS in stub column as a compression member.

Keywords- Lean duplex stainless steel, Stub column, Abaqus, FEA analysis

I. INTRODUCTION

Due to its inexpensive cost, extensive expertise, usable design guidelines, and wide range of strength classes, carbon steel often dominates the construction sector. Despite this, it suffers fundamentally from low corrosion resistance and higher material costs. Numerous stainless steel types can offer a very wide range of mechanical properties and material characteristics to meet the demands of numerous and diverse engineering applications as an improvement over carbon steel, with the added benefit of not requiring surface corrosion protection in moderate to highly aggressive environments. Its key benefits are high strength, smooth and uniform surface, high ductility, impact resistance, and ease of manufacture and maintenance. It is also very corrosion resistant. These advantages have led to a modest increase in the use of stainless steel in the building sector in recent years. Austenitic steel grades have historically been utilized extensively in the building sector. The demand for lean duplex stainless steel (LDSS) with low nickel content of 1.5 percent, such as grade EN1.4162, has increased, however, as a result of rising nickel costs (nickel content of 8 percent to 11 percent in austenitic stainless steel). With double the mechanical strength of typical austenitic and ferritic stainless steel, LDSS grade EN1.4162 in particular has the potential to be used in construction, and its utilisation has witnessed substantial expansion and development over the last 20 years. The primary forces behind this development have been rising raw material costs, such as nickel, together with rising demand for increased strength and corrosion resistance, allowing for a reduction in section sizes and resulting in higher strength to weight ratios.

II.DUPLEX STAINLESS STEEL

A group of stainless steels is called duplex stainless steels. Due to the fact that their metallurgical structure comprises of two phases, austenite (face-centered cubic lattice) and ferrite (body-centered cubic lattice) in about equal amounts, these grades are known as duplex (or austenitic-ferritic). They are made to be stronger than typical austenitic stainless steels and to offer improved corrosion resistance, notably against chloride stress corrosion and chloride pitting corrosion. **(Singh et al., 2021**)[1]. When compared to an austenitic stainless steel, the key changes in composition are that duplex steels have a greater chromium content (20–28%), higher molybdenum (up to 5%), lower nickel (up to 9%), and 0.05-0.50 percent nitrogen. Significant economic advantages are provided by the low nickel content as well as the high strength (which enables the use of thinner sections). **(Sachidananda et al., 2021)** Due to an alluring mix of superior mechanical qualities, strong corrosion resistance, and relatively inexpensive cost as compared to other high performance materials, duplex stainless steels have become widely used. Duplex stainless steels have higher toughness and strength (in particular, very high proof strength), thanks to smaller grain sizes and a two phase austenitic ferritic microstructure that inhibits grain growth. The super duplex grade, which was created approximately ten years ago, and other contemporary DSSs have been available on the market for many years. The great mechanical strength of DSSs is a result of their extremely fine-grained structure, nitrogen alloying, and ferrite and austenite combination. DSSs are suitable for use in a variety of corrosive conditions with temperatures between -50°C and less than 300°C. **(Sachidananda et al., 2021)** The weldability of contemporary duplex stainless steels is comparable to that of austenitic stainless steels. With the

DOI : 10.35291/2454-9150.2022.0349

exception of one-sided butt welding, where a slightly wider spacing and a bigger angle are desirable, the same type of joint preparations can be used for both. For the DSS, it is important to avoid both too low and too high heat inputs because both extremes can reduce the welded joint's ability to resist corrosion. The ideal outcomes can be obtained by adhering to the aforementioned suggestions because there is a large range between the extremes. When a higher level of corrosion resistance is sought in the weld than is often possible with pure argon, nitrogen additions to the shielding gas and the root gas can be used to advantage. **(Singh et al., 2021)**

III. LEAN DUPLEX STAINLESS STEEL

For less demanding uses, most commonly in the building and construction industry, grade EN 1.4362 has been created relatively recently. Their mechanical qualities are better, and their corrosion resistance is closer to the typical austenitic grade EN 1.4401 (with a bonus on resistance to stress corrosion cracking). When strength is crucial, this may be a huge benefit. **(Sachidananda et al., 2021)** Due to the decreases in Ni and Mo, lean duplex stainless steels (LDSS) are less expensive than 22 percent Cr duplex stainless steels. In general, the LDSS have comparable corrosion resistance to austenitic stainless steels and offer a strength advantage over other materials. In the current economic scenario, the LDSS are being used increasingly frequently, especially in structural applications. Uses include substituting austenitic stainless steels and carbon steels in structural work such as bridges rather than replacing traditional duplex alloys. **(Singh et al., 2021)[1].**

IV. LEAN DUPLEX STAINLESS STEEL (LDSS) FLAT OVAL HOLLOW STUB COLUMN WITH SQUARE PERFORATION

The thickness (t) and perforation size (ls) of a fixed ended square perforated flat oval stub hollow column have been varied using ABAQUS while maintaining constant the width between flat components (w), curvature radius (r), and flat length (l). Axial compression has been applied to the columns **(Sachidananda et al., 2021)**. To start, the FE modelling technique has been validated against the experimental findings of experiments carried out on square, flat oval, and elliptical cross sections under axial compression. Following validation, a parametric FE analysis employing the LDSS material characteristics of steel was conducted **(Singh et al., 2021).[1]** According to the results of the parametric investigation, a nearly linear decrease in ultimate load capacity (Pu) with perforation size (ls) has been noted. In comparison to the narrow cross-section, the decrease is shown to be larger for the stockier cross-section. When the section is thin and situated at the flat element, the percentage reduction in Pu or r for bigger perforation is mostly unaffected**(Singh et al., 2021).[1]** Finite element analysis has been used to present a parametric investigation on the structural behaviour (load capacity and deformation modes or shapes) of fixed ended single square perforation in relation to perforation size and location (i.e. along transverse and longitudinal directions, on both the flat and curve elements) **(Sachidananda et al., 2021)**. The reduction in Pu is, however, considerably more pronounced for slender sections when the perforation occurs at the curve element, demonstrating the effectiveness of the curve sections for both slender and stocky sections. It is clear that, overall, the rate of growth of Pu along with thickness is rather larger for the perforation placed in the flat area as opposed to the perforation positioned in the curve portion **(Singh et al., 2021).[1]** As the perforation is positioned near the corner junction from the midflat area, it can be noted that perforated stocky sections exhibit a moderate Pu decrease when compared to slender sections for transverse variation of perforation location **(Sachidananda et al., 2021)**. The loss in load capacity is often observed to be greatest when the perforation is positioned close to the mid-height when the perforation site is altered longitudinally.

V.MODELING OF LEAN DUPLEX STAINLESS STEEL HOLLOW COLUMNS OF DIFFERENT CROSS SECTION

The construction industry has shown growing interest in the use of non-rectangular columns (NRCs), such as those with L-, T-, and shaped cross-sections, especially for reinforced concrete columns, over the past 20 years in addition to the conventional cross-sectional shapes of columns that have already been mentioned **(Patton et al., 2011)[5]**. Columns with NRCs have the benefit of offering a flushing wall face, resulting in an increased useable indoor floor space area and also in making the interior space more regular, over columns with rectangular/square cross-sections. As a result, reinforced concrete, or NRCs, were used in residential high-rise structures, and architects approved **(Patton et al., 2011)[5]**. The particular advantages of having significant stiffness and strength in the direction of their longer sections are also shared by these NRCs with L- or T-sections. In the current study, several parametric investigations (such as the impact of material cross sectional shapes and thicknesses on load bearing capacity of LDSS NRHCs exposed to pure axial compression) have been carried out using the general-purpose commercial finite element software ABAQUS**(Patton et al., 2011)**. Although the increase for SHC was considerably slower in thinner sections for all the NRHCs (i.e., LHC and THC), a roughly linear change of Pu with section thickness has been found (to12.5 mm). For SHC, LHC, and THC, respectively, the percent increase in Pu with a 300 percent increase in t (from 5mm to 20mm) is 1273 percent, 1252 percent, 1041 percent, and 679 percent **(Patton et al., 2011)[5]**. As the sections are altered from square -L-T, a roughly linear increase in Pu has also been seen. 136 percent, 114 percent, 96 percent, 72 percent, 48 percent, 25 percent, and 30 percent, respectively, for changes in section from square to + shape for 5mm, 10mm,

DOI : 10.35291/2454-9150.2022.0349

12.5 mm, 15mm, 17.5mm, and 20mm, demonstrating that the increase in Pu is more effective at thinner sections (to12.5 mm), where the increase is more than 70 percent.

VI. EFFECT OF SINGLE CIRCULAR PERFORATION IN LDSS HOLLOW CIRCULAR STUB COLUMNS

This work used general-purpose commercial software ABAQUS to conduct FE studies to investigate the effects of various perforation parameters, such as perforation diameter (d) and eccentricity (e), on the critical buckling load of LDSS hollow circular columns subjected to pure axial compression **(Umbarkar et al., 2013)[4]**. When the perforation is placed at mid-height (or e/L140.5), the buckling load decreases by a maximum of 13.9 percent, 13.5 percent, 12.0 percent, 10.1 percent, and 8. percent, respectively, when the perforation size (d/D) is increased from 0.02 to 0.20. For lesser values of d/D (let's say 0.02), perforation has no discernible impact on the buckling load for any values of eccentricity taken into consideration **(Umbarkar et al., 2013)[4]**. According to research, the buckling load rises by 72 percent with increasing thickness, rising by 5, 4, 2, 1, 3, and 0 percent for d/D ratios of 0.20, 0.12, 0.10, 0.08, 0.04 and 0.02 accordingly. The rate of increase is larger for higher d/D ratios **(Umbarkar et al., 2013)[4]**. Although (percent)deformations (u(p)) at greater d/D are only slightly higher (0.65%), they are higher for extremely small perforations (0.9-0.95%). When d/D is increased from 0.02 to 0.12, there is a decrease (about 25%) in u(p), and beyond 0.12, it seems to have stabilized, with thinner columns having lower values of u. (p) **(Umbarkar et al., 2013)[4]**. For all d/D values, it can be shown that u(p) increases (48%) by (72%) from t 2.75 mm with increasing thickness, with higher u(p) values being correlated with lower d/D values.

VII. FEA ANALYSIS OF CONCRETE-FILLED LDSS TUBULAR STUB COLUMNS

Due to its high material costs, stainless steel is rarely used by itself in conventional construction. A composite construction, which combines the benefits of both steel and concrete and provides not only an increase in the load-carrying capacity but also quick construction, is a promising and creative solution to decrease the cost **(Longshithung et al., 2014)[2]**. Concrete is poured within the stainless steel hollow sections. Non-rectangular Sections, or NRSs, are reinforced concrete columns with L-, T-, and +-shaped sections that have gained popularity in the construction industry over the past 20 years. When compared to rectangular and square sections in reinforced concrete columns, NRSs have the distinct advantages of having a flushing wall face, large compressive stiffness, and strength in the direction of their longer sections **(Longshithung et al., 2014)[2]**. As a result, there is more consistent internal space and a huge amount of usable indoor floor area. As a result, architects are ecstatic to see reinforced concrete columns with NRSs employed in residential multi - storied projects. To comprehend the impact of cross-sectional shape on the final load and deformation characteristics, FE analyses of CFDSST stub columns with NRSs and the representative square section for different concrete compressive strengths ranging from 25 to 100 MPa are provided **(Longshithung et al., 2014)[2]**. Given that steel is more expensive than concrete, all specimens' steel cross sections are maintained the same, which results in a reduction of the concrete core area for the CFDSST stub columns with NRSs of roughly 37%.

VIII. STRUCTURAL BEHAVIOUR OF FIXED ENDED STOCKY LDSS FLAT OVAL HOLLOW COLUMN UNDER AXIAL COMPRESSION

Finite element analyses have been carried out to evaluate the structural behaviour of a fixed ended LDSS flat oval hollow column while taking into account variations in the column's r (curvature radius), l (flat length), t (thickness), w (width between flat plates maintaining semi-circle curve portion at the ends), and l (column height) geometric parameters. The FE analyses were carried out taking into account both the geometrical (local and global) defects and the material non-linearity **(Singh et al., 2021)**.[1] By comparing the experimental findings of LDSS square hollow section columns under axial compression, of various lengths, with the results of the study's first section, the FE modelling approach is validated. Yield to yield with local buckling (Mechanism ST1), Yield to yield with flexural buckling (Mechanism ST2), and Flexural to flexural buckling are the three failure or deformation processes that have been identified (Mechanism ST3) **(Singh et al., 2021)**[1]. ST1, ST2, and ST3 mechanisms are equivalent to, respectively, 0.32, 0.321.0, and >1.0. The yield began failure mechanism at Pu is represented by ST1 and ST2, while the flexure buckling initiated failure mechanism is represented by ST3.

IX. CONCLUSIONS

The following are the findings of study into the use of LDSS material as a stub column material.

- The rate of increase of *Pu* along with thickness is relatively higher for the perforation located in the flat portion as compared to perforation in the curve portion.
- As the sections are switched from square -L-T-+, an early linear increase in Pu has also been seen. 136 percent, 114 percent, 96 percent, 72 percent, 48 percent, 25 percent, and 30 percent, respectively, for changes in section from square to + shape for 5mm, 10mm, 12.5 mm, 15mm, 17.5mm, and 20mm, demonstrating that the increase in Pu is more effective at thinner sections (to12.5 mm), where the increase is more than 70 percent.

DOI : 10.35291/2454-9150.2022.0349

It has been observed by using LDSS material in flat oval column stub column it improves the strengthening behavior of stub column and also reduces corrosion. Therefore, LDSS material have more advantage when compared to other alloys of stainless steel and be used in construction industry.

X. REFERENCES

[1] Konjengbam Darunkumar Singh. (2021), "Numerical study of fixed ended Lean duplex stainless steel (LDSS) flat oval hollow stub column with square perforation under pure axial compression." Journal of Structures 33, ELSEVIER, 33, 3691-3712.

[2] M. Longshithung Patton, (2021) "Numerical modeling of lean duplex stainless steel hollow columns of square, L-, T-,and +-shaped cross sections under pure axial compression" Journal of Thin Walled Structures, ELSEVIER, 53, 1-8.

[3] Sonuj K, (2017) "Shear characteristics of Lean Duplex Stainless Steel (LDSS) rectangular hollow beams" Journal of Structures, ELSEVIER, 10, 13-29.

[4] Kunal R. Umbarkar, Longshithung M. Patton, Konjengbam Darunkumar Singh, (2013) "Effect of single circular perforation in lean duplex stainless steel (LDSS) hollow circular stub columns under pure axial compression" Journal of Thin Walled Structures, ELSEVIER, 68, 18-25

[5] M. Longshithung Patton1 and Konjengbam Darunkumar Singh,(2014). "Finite Element Modelling of Concrete-filled Lean Duplex Stainless Steel Tubular Stub Columns." International Journal of Steel Structures, Springer.

[6] Khwairakpam Sachidananda, Konjengbam Darunkumar Singh,(2017) "Structural behaviour of fixed ended stocky Lean Duplex Stainless Steel (LDSS) flat oval hollow column under axial compression" Journal of Thin Walled Structures, ELSEVIER, 113, 47-60.

[7] Mann AP.(1993) "The structural use of stainless steel." Struct Eng; 71:60–8.

[8] Theofanous M, Gardner L.(2013), "Testing and numerical modelling of lean duplex stainless steel hollow section columns." Eng Struct;31:3047–58.

[9] Saliba N, Gardner L.(2013),"Cross-section stability of lean duplex stainless steel welded I-sections." JCSR;80:1–14.

[10] Huang Y, Young B.(2013), "Tests of pin-ended cold-formed lean duplex stainless steel columns." J Constr Steel Res; 82:203–15.

DOI : 10.35291/2454-9150.2022.0349