High Strength Concrete Hollow Beam

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Abstract— Hollow section have been increasing applied in the construction of buildings, bridges, offshore structures, and towers for passing electrical and mechanical pipes or other utilities. Torsion caused by external force is a weakness of hollow sections that is rarely investigated. In particular, the behaviour of hollow sections with high-strength concrete (HSC) and ultra-high performance concrete (UHPC) remains poorly studied. This study aims to examine the behaviour of a reinforced concrete hollow beam with opening and compare it with a hollow beam without opening. The hollow beam with an opening is modeled using the finite element method and analysed under torsional, flexural, and cyclic loading with HSC and UHPC materials. The effect of the opening section size on the behaviour of hollow beam is also evaluated. The opening created in the web of hollow beams led to a decrease in beam capacity although the hollow beam with small opening can carry almost the same load as that of hollow beam without an opening. The results also shows that the capacity of UHPC beams for twisting is that of HSC beam.

Key words: High Strength Concrete (HSC), Hollow Beam

I. INTRODUCTION

A. Hollow Beams

A hollow structural section (HSS) is a type of metal profile with a hollow tubular cross section. The term is used predominantly in the United States, or other countries which follow US construction or engineering terminology. HSS members can be circular, square, or rectangular sections, although other shapes such as elliptical are also available. HSS is only composed of structural steel per code. HSS is sometimes mistakenly referenced as hollow structural steel. Rectangular and square HSS are also commonly called tube steel or structural tubing. Circular HSS are sometimes mistakenly called steel pipe, although true steel pipe is actually dimensioned and classed differently from HSS. (HSS dimensions are based on exterior dimensions of the profile; pipes are also manufactured to an exterior tolerance, albeit to a different standard.) The corners of HSS are heavily rounded, having a radius which is approximately twice the wall thickness. The wall thickness is uniform around the section. In the UK, or other countries which follow British construction or engineering terminology, the term HSS is not used. Rather, the three basic shapes are referenced as CHS, SHS, and RHS, being circular, square, and rectangular hollow sections. Typically, these designations will also relate to metric sizes, thus the dimensions and tolerances differ slightly from HSS.

B. Applications

- HSS, especially rectangular section, are commonly used in welded steel frames where members experience loading in multiple directions.
- Square and circular HSS have very efficient shape for this multiple-axis loading as they have uniform geometry along two or more cross-sectional axes, and thus uniform strength characteristics.
- This make 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 shape are in many cases a more efficient structural shape for this application.
- The HSS has superior resistance to lateral tensional buckling.

C. Advantages

- The hollow flange beam retains the advantages of light weight which has enabled the other cold-formed section take over this segment of the market, particularly for kit building, and has the added advantage of easier handling due to its torsional rigidly.
- Hollow beams, we might reduce the self-weight of the concrete, however this must be designed accordingly so that the capacity provided by the hollow section is adequate. Another practical purpose is that we could run utilities cable or pipes through the hollow part.
- Hollow shafts are much better to take torsional loads compared to solid shafts.
- Hollow shaft has a greater strength to weight ratio.

D. Disadvantages

- If we reduce the wall thickness, then there are chances of wrinkling or buckling of the shaft wall. So we have to be careful about these things
- Machining will take time.

II. LITERATURE REVIEW

Bernardo et al (2011) have to withstand high levels of torsion forces. As a consequence, box type obvious solution. It could be possible that the balance of transversal to longitudinal torsion reinforcement is not fully reached. The investigation presented here aimed to study such solution. The authors tested four hollow beams under pure solution. The level of the non-balanced ratio b/w internal longitudinal and transversal torsion reinforcement was one of the parameters that were considered in this investigation. The experimental results obtained from the tested beams, for torsion forces, the excess of longitudinal reinforcement in a beam is not effective when the amount of transversal reinforcement is low and deficit in relation with the longitudinal reinforcement. It has also been observed that the excess of longitudinal reinforcement can be somehow beneficial in the control of cracking. Design criteria before this technique can be safely used in practice.

Vivek Soni et al (2018) was most of the steel structures in India are made of conventional steel sections (such as angle, channel and beam sections). However, new hollow steel sections (such as square and rectangular hollow sections) are gaining popularity in recent steel constructions due to a number of advantages such as its higher strength to weight ratio, better fire resistance properties, higher radius of gyration, lesser surface area, etc. This type of hollow sections can save cost up to 30 to 50% over the conventional steel sections (Tata Steel brochure, 2012). Load carrying capacity of the joint and the maximum deformation capacity is highly sensitive to the type of connection used. Ultimate shear force capacity of the joint found to vary from 267 kN in basic model (welded) to 506 kN in Scheme 3 (using channel) with an increase of almost 90%. Similarly, the deformation at collapse is varying from 306 mm in basic model to 627 mm in Scheme 3 (an increase of about 105%). Performance of the joint with connection details of Scheme 3 (columns jacketed with two channel sections and connected with beam by welding) performs best among others with respect to the ultimate load, deformation at collapse and formation of plastic hinges.

Satheesh et al (2017) have analyzed to studies carried out on Flexural Behaviour of Hollow Square Beam Using Fibre Reinforced Concrete at various depths. As concrete is weak in tension, steel reinforcements are provided in this zone. The concrete below the neutral axis act as a stress transfer medium between the compression and tension zone. Behaviour of reinforced concrete beams with region below the neutral axis with voids created using PVC pipes. Presence of voids instead of concrete in the low stressed zone has not caused significant reduction in strength of reinforced concrete beams. It has been observed that the replacement of concrete by voids in reinforced concrete beams does not require any extra labour or time. The ultimate load carrying capacity of the beam is high in centroid zone of hollow core when compared to other zones of hollow core. The compressive strength and split tensile strength of M20 grades of glass fiber concrete mixes compared with 28 days is observed from 10 to 20%. The highest strain value is also occur in the centroid zone of the beam.

M. Ashour Al.Khuzaiea et al (2017) used silica fume in content of 25% as a filling material in pro-duct ion of RPC beam of hollow T-section leads to increase the compressive strength (*f'c*) by 12%, while splitting tensile strength, modulus of rupture and modulus of elasticity increased by 32%, 26% and 9%, respectively, in comparison with the concrete of zero content of silica fume. The addition of steel fibers in discrete forms into RPC changes its brittle mode of failure into a more ductile one and improves the concrete ductility, post-cracking load-carrying capacity, and energy absorption. Fibre addition results in more closely spaced cracks, reduces the crack width, bridges crack sand thus improves resistance to deformation. The length of the elastic portion of the torque vs. angle of twist relation was affected by the width of the flange and the reserve strength after first diagonal cracking was less for a beam with small flanges than with wider flanges. The increase in the flange thickness delayed the appearance of the first diagonal crack, but the specimens eventually failed with excessive diagonal cracks in the concrete.

Zhen-Feng Yang et al (2016) focus on the on-axis intensity evolutions of hollow beams in nonlinear media with a high non locality. It is found that, the evolutions of on-axis intensity with different beam powers are always periodic during propagation, whereas, depending on different beam powers, the evolution curves of on-axis intensity in each period may exhibit themselves as three different types, namely, a concave, a platform, or a convex shape. The critical power, the extreme values of on-axis intensity and their corresponding positions are all given analytically. The on-axis intensity evolutions of HBs in HNNM, and a set of analytical results are given. Three types of on-axis intensity evolution induced by different beam powers are illustrated in detail.

Mohsen Amraeia et al (2017) have presents a study on the residual stress, hardness and fatigue behaviour of butt-welded high strength square hollow section (SHS) steel tubes strengthened with carbon fibre reinforced polymer (CFRP). SHS tubes, with a nominal yield stress of 780 MPa and an ultimate tensile strength of 860 MPa, were butt-welded using the Gas Tungsten Arc Welding (GTAW) welding method. The strength in HAZ of the butt-welded SHS tubes is about 93% of that of the parent metal of the SHS tube. Average yield and ultimate tensile strength of the SHS tube are 780 MPa and 863 MPa, respectively, while the average tensile strength of the butt-welded SHS tube is about 800 MPa, showing a strength reduction of 7% in the HAZ. The increase in fatigue life varies from 100% to 7 times depending on the structure, loading, type of the CFRP and steel grade. Further studies are needed on bond between high/ultra-high strength steel and CFRP, as well as fatigue of welded high/ultra-high strength steel with and without CFRP strengthening.

Trahair et al (2018) have analyzed the shear distortion of the hollow flanges is analysed, and the strain energy stored in a distorted flange is compared with the strain energy stored during uniform torsion of the flange. This comparison allows the development of a suitable parameter for use in the evaluation of the effect of flange distortion on the torsional stiffness of a hollow flange beam. A simple approximation for uniform torsion is based on the assumption that the distortional and uniform torsional flexibilities contribute equally to the effective torsional flexibility. Torsion test results show that this approximation is conservative. More accurate simple approximations provide approximate lower bound and mean predictions of the test results. Approximations of high accuracy are made by using a reduced effective torsional rigidity in the classical equation for predicting the lateral buckling of simply supported beams in uniform bending.

Honrubia et al (2017) have evidenced that the proton fast ignition calculations carried out so far have been optimistic regarding the distribution function of protons assumed and, in particular, its angular divergence. Most of the analyses are based on perfectly collimated proton beams depositing their energy in a high density, isochoric DT core without surrounding plasmas. Those analyses have motivated the study presented here, which is a characterisation of the proton source in the FI scenario by means of 2D PIC simulations. Our study is still preliminary because we are still far from a full characterization of the proton source for FI. Nevertheless, we have obtained relevant conclusions. Two actions for reducing the beam divergence: (1) using high-Z elements at the cone tip in order to avoid important tip erosion by making it more rigid and (2) using laser intensities higher than the standard 1020 W$cm_2 proposed for proton FI.

Tiina Kraav et al (2017) determined from, the uniform and the hollow-sectional beams are considered. It is assumed that the beams are weakened by stable cracks. The influence of crack parameters on the critical buckling load is assessed making use of the method of massless rotational spring. According to this model the weakened beam can be considered as two sub-beams connected by the rotational spring at the cracked section. A method for determination of critical buckling loads for elastic non-uniform columns has been developed. The beam or column under consideration may have hollow sections. Moreover, the column is weakened with cracks located at the internal corners of re-entrant steps. The calculations carried out showed that the cracks or crack-like defects aggravate essentially the stability of the column. However, the critical buckling load is not sensitive with respect to small cracks.

Gajipara J M et al (2015) have present the experimental study total 12 RC hollow beams were casted with different amount of longitudinal and shear reinforcement and tested under pure cyclic torsion. The parameters studied were cracking torque, angle of twist, energy dissipation, and crack pattern and failure mode. It has been found that in pre cracking mode, reinforcement are ineffective for resisting the torsion moment but in post cracking mode all the torsional moment are resisted by the main reinforcement. It was overserved that longitudinal reinforcement increase the torsional flexibility of beam, for the same amount of transverse reinforcement. It was also found from the experiment that optimum spacing of transverse reinforcement is equally important parameter while designing for the torsional reinforcement. Main reinforcement is more influencing in torsional behaviour of RC hollow beam under pure cyclic torsion then shear reinforcement. Post-cracking behaviour of RC hollow beams under pure cyclic torsion is purely governed by longitudinal and shear reinforcement.

Prabhavathy et al (2012) observed from, the experimental study of five (5) double skinned concrete filled steel tubular (DSCFT) columns of concentrically placed circular sections filled with self-compacting concrete (SCC). Tests on the specimens were made by applying axial loads. The main experimental parameter varied for columns were slenderness ratio. The test results of DSCFT columns are compared with another five (5) concrete filled tube (CFT) columns of same area of steel (Ast) and outer diameter as in DSCFT columns. Both filled with self-compacting concrete of grade M50. Testing of specimens investigates the behavior on load deflection, confinement effect, and the strength of the columns. Various characteristics such as stiffness, ductility and failure mode are also discussed with the help of load deflection curves. The comparison with concrete filled tube (CFT) to the double skinned concrete filled tube (DSCFT) columns likely to be show that DSCFT columns are better than CFT columns in performance as well as in cost concern. The Double Skinned section (DSCFT) columns are hollow in the core part, it significantly reduces the self-weight of the member and also better in performance and Cost Efficiency than concrete filled tube CFT) columns. Because of the in-fill of concrete and a hollow core a relatively ductile behaviour of the Columns are observed. The load carrying capacity of the DSCFT is almost similar to the CFT columns but the overall weight of DSCFT is reduced when compared with the CFT columns.

Lopes et al (2009) have presented the Torsion plastic hinge is concentrated in a small length of the longitudinal axis of the beams. In this paper, the authors show that plastic models are possible for beams under torsion. A torsion plastic hinge at the failure cross section can be assumed. This paper also shows that torsional ductility becomes more difficult as the concrete strength increases. In future tests, it is also important to investigate the cases corresponding to break off of the concrete corners, since this type of behavior leads to premature failure, and the reinforcement ratios are not too different from those that correspond to ductile failures.

Soner Guler et al (2012) have presents an experimental investigation of the flexural behavior of square hollow steel section (HSS) beams subjected to pure bending. Totally six unfilled and nine ultra-high performance concrete (UHPC)-filled HSS beams were tested under four-point bending until failure. Results of experimental investigations of square hollow and UHPC-filled HSS beams have been presented in this paper. The following conclusions are highlighted. A significant increase in the moment capacity and the corresponding curvature of all the hollow sections used in this study are observed due to concrete filling. An increase in the wall thickness of the steel tube increases the ultimate moment capacity and the corresponding curvature both the hollow and UHPC-filled HSS beams. However, the increase in the moment capacity and the corresponding curvature is much greater for thinner HSS beams than thicker ones. The CIDECT design code and Han model are conservative for thicker HSS beams, they slightly overestimate the ultimate moment capacity of the UHPC-filled HSS beams with thinner ones.

Arivalagan et al (2008) have presents an experimental study of normal mix, fly ash, quarry waste and low strength concrete (brick-bat lime concrete) contribution to the ultimate moment capacity of square steel hollow sections. Fifteen simply supported beam specimens of 1200-mm long steel hollow sections filled with normal mix, fly ash, quarry waste and low strength concrete and identical dimensions of hollow sections were experimented. The tests conducted in this investigation confirm, that normal mix concrete, fly ash concrete and quarry waste concrete can be used as infill material in composite construction to increase the flexural capacity of steel sections.

GuoChang Li et al (2010) determined from, the specimens failed to work out of instability. Proper material constitutive models for HCFST columns are applied and verified by the nonlinear finite element software ABAQUS against experimental data. A comparison of experimental failure loads with the predicted failure loads in accordance with the method described in the reference showed good agreement. The main objective of this study is to investigate the behavior and strength of high strength concrete-filled square steel tube (HCFST) columns. For this purpose, several HCFST columns were constructed and tested subjected to bi-axial eccentric loading. The test results of HCFST column specimens have been compared with the analysis results and discuses. The HCFST columns subjected to bi-axial eccentric loading failed to work because of instability, and showed a certain degree of ductility. The deflection curves of test fit the ideal half-sine-wave curves well. The strain curves of specimen are consistent with plane-section assumption. The ultimate bearing capacity of HCFST subjected to bi-axial eccentric loading resulted from analyzing with finite element software ABAQUS shows good agreements with the test data the numerical method is verified to be reliable in predicting the load versus deformation relationships. The simplified formula was used to calculate bearing capacity of the test specimens, and the calculation results agree well with test data. The simplified formula can be referred to calculate the bearing capacity of HCFST within the parameters of this test.

Dong Yuan et al (2016) obtained from, by using the Collins formula and the Rytov method, the model used to descript the propagation properties of the conical hollow beams (CHBs) in the turbulent atmosphere is firstly constructed and the simulation is made by the numerical method. The results show that the initial transmission angle has important in fluency on the propagation properties. Beside these, the index structure constant and the order number also can in fluence the transverse intensity distribution. So according to the model, the intensity distribution of the conical hollow beams in the turbulent atmosphere can be controlled by adjusting these parameters. The initial state is conical hollow beam, the self-focusing effect doesn't appear again, that is the diffraction effect can be suppressed by the conical angle and the hollow area is turning bigger as the propagation distance increasing.

Varma et al (2002) observed from, the behavior of square CFT beam–columns made from high-strength materials was investigated experimentally. The initial and serviceability-level flexural section stiffness of a CFT beam–column can be predicted with reasonable accuracy using its untracked transformed and cracked transformed section properties, respectively. The moment capacity of high-strength square CFT columns can be predicted with reasonable accuracy using the current ACI code provisions for composite columns. The fiber-based models are recommended for conducting static and dynamic analyses of two-dimensional building frames with high-strength CFT columns. The method used to develop the FEM-based uniaxial stress–strain curves is recommended as a general approach for developing uniaxial stress–strain curves for the steel and concrete fibers of these fiber-based models.

Dajun Liu et al (2018) determined from, the propagation equations of no paraxial partially coherent flat-topped vortex hollow beam have been derived. And as a special case, the propagation equation of far field propagation can also be obtained. The intensity of non-paraxial partially coherent flat-topped vortex beam are investigated, it is found that the no paraxial partially coherent flat-topped vortex hollow beam will keep its dark hollow pattern better at the short propagation distance, and the beam will evolve into flat-topped beam as the propagation distance increases. And it is also found that the equations of far field propagation equation are special case of the no paraxial propagation at the long propagation distance.

Dalin Liu et al (2003) obtained from, 22 high-strength rectangular CFSHS stub columns are tested to failure under axial compression. The test results reveal that the columns could have similar failure behaviour as normal strength rectangular CFSHS columns. A high axial load capacity and a good ductility performance could be obtained. The comparison of results shows that the codes (EC4, AISC and ACI) have underestimated the ultimate capacity of test specimens. EC4 predicts closely with a difference of 6% while AISC and ACI underestimated the critical loads by 16 and 14%, respectively. The primary reason for the discrepancy of results is that the strength enhancement of CFSHS columns due to the confinement of core concrete by steel hollow section is considered in EC4 but not in AISC and ACI. In conclusion, the failure behaviour and the confining effect of core concrete of the high-strength rectangular CFSHS columns under various types of loading are still required to be extensively investigated so that guidelines and recommendations could be developed for design.

Haedir et al (2009) observed from, the huge potential of CFRP Sheets for enhanced strength, stiffness and ductility of reinforced steel circular hollow sections (CHS) beams has been realised .Different amount sand orientations of composite fibre sheets, and various fibre layouts were applied to CHS beam sin regions of pure bending, and they yielded not ably diverse characteristics. Because of the modest contribution of fibre strength in the compression zone, the efficiency factor used in the strength analysis to account for the effectiveness of fibre reinforcement in compression based on the hoop-to-long- itudinal fibre area ratio was suitably applied, and comparisons show that the predictions concur reasonably with the observed strength.

III. Conclusion

- The results discussed herein demonstrate that it is possible to utilise the composite action of the hoop fibre rings and the steel to induce restraining effect in the steel wall of a CHS, which combines with the longitudinally orientated fibre element to produce improved resistance to buckling, particularly in a section with higher class of cross-sectional geometry.
- The results have also shown that for a beam with deficit of transversal reinforcement, the solution of strengthening with external steel stirrups is very effective and compensates, in great extent, the lack of internal reinforcement.
- It is found that by the use of Glass fiber in the concrete mix increases the load carrying capacity of the beam against normal concrete.
- The ultimate load carrying capacity of the beam is high in centroid zone of hollow core when compared to other zones of hollow core.
- The highest strain value is also occur in the centroid zone of the beam.
- We have investigated the on-axis intensity evolutions of HBs in HNNM, and a set of analytical results are given. Three types of on-axis intensity evolution induced by different beam powers are illustrated in detail.
- Approximations of high accuracy are made by using a reduced effective torsional rigidity in the classical equation for predicting the lateral buckling of simply supported beams in uniform bending.
- The cubes were attained strength by replacing 15% of coarse aggregate weight with silica fume .The strength is also excepting in column.
- The Double Skinned section (DSCFT) columns are hollow in the core part, it significantly reduces the self-weight of the member and also better in performance and Cost Efficiency than concrete filled tube CFT) columns.

- The results clearly show that some codes are excessively permissive, and could lead to the acceptance of brittle beams or unsafe values of the predicted maximum torque.
- The experimental results of the current investigation, it can be concluded that the failure mechanism of the beam sections result in an excessive deflection with no lateral disturbances or any other form of instability.
- The propagation properties are total different: when the hollow beam is parallel at the initial position, the intensity of the hollow area in the near field is zero, but it changes into Gaussian beam at the far field, and as the turbulence intensity enhancing, the distance which used to evolve into the Gaussian beam turns shorter, this shows that is themselves - focusing effect can be strengthened by the turbulence.
- The propagation equations of non-paraxial partially coherent flat-topped vortex hollow beam have been derived. And as a special case, the propagation equation of far field propagation can also be obtained.

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