Concrete Encased Steel Composite Columns: A Review

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December 1, 2020

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Abstract—**Concrete Encased Steel composite columns are those columns in which structural steel is encased inside reinforced concrete. By combining both materials, columns can handle a large amount of load with a lesser cross sectional area. Moreover they improves the overall rigidity of the building and provide significant resistance to lateral loads. These columns are widely used in high rise building construction. Main disadvantage of these columns are the construction difficulties. Since reinforcement bars and steel sections are encased, the concrete pouring becomes more difficult. Solution for these problems are the use of welding couplers or providing holes in steel flanges and steel web. Both the methods will increase the cost of construction and also compromise the total bearing capacity and reliability of the structure. An innovative method proposed to overcome these difficulties is the use of steel fibres and replacing the reinforcement bars. This paper discuss various studies conducted on concrete encased steel composite members.**

Keywords—concrete encased steel, steel fibre, composite column

I. INTRODUCTION

Concrete encased steel construction is a typical type of composite construction in which both the concrete and steel are effectively used to maximise the advantages of each material. The CES composite column consists of structural steel encased in reinforced concrete. The composite columns bring economic advantages by carrying a large amount of load with a smaller cross sectional area. Nowadays, for the construction of high rise structures these composite columns are widely used. They can reduce the column sizes and maximise the usable space of the floor plan. Moreover, they enhance the overall rigidity of the building and provide excellent seismic behaviour compared to ordinary reinforced concrete structures. In addition, they provide better protection against fire. The cross section details of CES member is shown in fig 1.

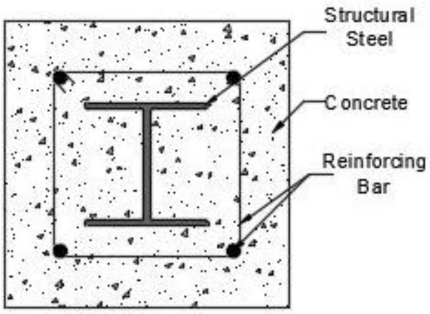

Fig 1. Cross Section details of CES section

Fibre reinforced concrete is a composite material made with Portland cement, aggregates and discrete fibres. Steel fibre reinforced concrete combines concrete and fibres together. Steel fibre is recommended as a better in-fill material due to its high flexural and tensile strength, lower shrinkage and better fire resistance. By adding steel fibres into the concrete matrix, mechanical performance can be improved under tensile load due to high strength of steel fibre and its interaction with matrix. Factors such as percentage of fibre, orientation and aspect ratio affects the workability of concrete. Workability decreases with increase in aspect ratio.

Concrete encased steel construction have some construction difficulties like the interference between structural steel and reinforcing bar or poor concrete pouring quality, steel fibre reinforced concrete encased steel construction was proposed by removing the steel reinforcing cage and incorporating steel fibres. Because the structural steel section and reinforcement cage both are encased within the member, the concrete placement is much more difficult than the reinforced concrete structures. When the steel ratio is high and the gap between steel and rebar is very small, the concrete may have low pouring quality. Also, the structural steel can cause difficulty in forming the rebar cage. The space conflicts may leads to unclosed stirrups and discontinuous rebars. Present solutions for these problems are to use welding couplers to attach rebar to reinforcing steel or make openings at the steel flange and web for stirrups to close up. Both these methods will increase the cost and difficulty of construction and affects the bearing capacity and reliability of the structure. Removing rebar cage from CES and adding steel fibres into concrete can avoid the construction difficulties and procedure of making rebar cages. Steel section can get closer to the section by removing the reinforcement cage. Moment of inertia and height of the structural steel increase and thus the shear and bending capacity of the member can be increased. Steel fibres delay the formation and elongation of the cracks and provide better ductility and improves the overall mechanical behaviour of the concrete.

II. LITERATURE REVIEW

A. *Concrete Encased Steel*

Concrete encased steel columns are a type of composite columns in which structural steel is placed inside concrete. External load in these columns are resisted by steel section and concrete by interacting with friction and contact [1]. These columns are gaining popularity in top-down construction [3]. In the construction of high rise buildings, composite columns are commonly used because of its advantages. They can reduce the size of column and can increase the usable space of the floor. Moreover, they provides excellent seismic performance than normal reinforced concrete (RC) structures.

Several studies were conducted on CES members both experimentally, numerically and analytically. Ultimate axial load carrying capacity of CES columns found to be increased when comparing with normal RC column [1]. Analytical model was proposed to predict the axial capacity and behaviour of CES composite stub columns [2]. The axial load carrying capacity is developed due to confinement effect of concrete which is due to the confining stress from structural steel and lateral reinforcement. A general method was presented to analyse the ultimate strength of CES columns in which structural steel section is asymmetrically placed based on nonlinear finite element (FE) modelling software ABAQUS [3]. Both numerical and analytical studies were conducted. A new method is proposed for predicting cross section resistance based on the modification of EC4 approach. The off-centered distance affects the compression and flexural resistance of the column. Behaviour of CES columns at elevated temperature was investigated using a nonlinear FE model [4]. The time–temperature relationships, deformed shapes at failure, time–axial displacement relationships, failure modes and fire resistances of the columns were evaluated. Fire resistance of the CES columns found to increase with decrease in column slenderness ratio and increase in structural steel ratio. Structural performance of CES with H shaped steel and fibre reinforced concrete were evaluated [5]. They found out that, by increasing the fibre content ratio, deformation capacity of CES can be improved. By considering the effects of axial load ratio, steel ratio, shear span ratio, fibre content ratio and flange width, a formula was proposed to evaluate the deformation capacity of CES column. Behaviour of fully encased steel-concrete composite columns under monotonic and cyclic loading were evaluated [6]. Sudden and violent failure was observed in high strength concrete (HSC) columns due to the development of cracks through the aggregates. In case of normal strength concrete (NSC) columns, slow failure was observed due to loss of bearing capacity with the growth of displacements. HSC columns have a higher energy absorption capacity. From the experimental tests conducted they found that fully encased composite columns have excellent seismic performance and they can be used as a competitive solution in seismic and non-seismic zones.

An experimental investigation was carried out on steel encased composite columns subjected to seismic loading conditions [6]. Results shows that encased composite members possess better cyclic strength and ductility when the buckling of longitudinal reinforcement is inhibited.

B. *Composite Column Behaviour*

Composite columns subjected to lateral loading and gravity loads develops axial force, shear and flexural forces. Columns at the ground floor experiences largest overturning moments and axial forces. As ductility is an important factor in earthquake resistant design, the analysis of CES columns need to perform to assess the moment-axial load and ductility interaction [7]. The axial load carrying capacity and axial load- deformation response of a short column can be found out based on strain compatibility on the composite section. For a uniform axial compressive strain assumed, the stress on each material on the composite member can be obtained from the constitutive model established for each material. Axial load on the composite member can be calculated by adding the axial force on each member and axial force can be calculated by multiplying stress on each material with corresponding cross sectional area [2]. It is well known that lateral reinforcement provides confining pressure to the concrete core. Depending upon the degree of confining pressure, the strength and ductility of the concrete is increased. The other factors which affects the confinement are distribution of longitudinal reinforcement, loading type and cross section configuration [2]. Mander et al proposed a unified stress-strain model of confined concrete for members with different cross sections and under various loading conditions [8]. The proposed model is shown in fig.2.

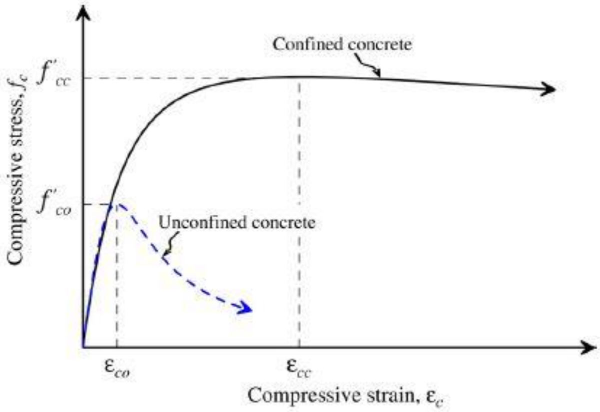

Fig.2 Stress-strain curve for unconfined and confined concrete [8]

C. *Steel Fibre Reinforced Concrete*

Concrete is one of the commonly used construction material. Since the early 1800’s it is evident that concrete is weak in tension. Thus, it requires some form of tensile reinforcement to improve its tensile strength and strain capacity to be used as a structural member [9]. Historically, steel is used for tensile reinforcement in concrete. Reinforcing bars are specially designed and placed in tensile zone of the concrete. Unlike that fibres are thin and short member randomly distributed throughout the concrete. Fibres are commercially available from steel, glass, plastic, asbestos and other natural materials. Each of them have their own advantages and disadvantages. Steel fibres are discrete, short length of steel having aspect ratio (ratio of length to diameter) of 20 to 100. They are sufficiently small and can be randomly distributed in fresh concrete using conventional mixing procedure. These steel fibres helps to improve tensile strength, flexural strength and improves abrasion, spalling and impact resistance. They also helps to delay or avoid bond failure. Moreover, they reduces the permeability and acts as a crack arrestor.

In 1910, the use of steel fibres in concrete is suggested by Porter [10]. However, the first scientific research on fibre reinforced concrete was done in 1963 [11]. Steel fibre reinforced concrete (SFRC) is produced using hydraulic cement, fine and coarse aggregates, water and steel fibres (SF). SFRC can be classified based on its fibre volume percentage. SF less than 1% per volume of concrete (very low volume fraction) is used to control plastic shrinkage and in pavement reinforcement. SFs with 1% to 2% per volume of concrete (moderate volume fraction) can improve flexural toughness, modulus of rupture, impact resistance and other mechanical properties of concrete. SFs with more than 2% per volume of concrete (high volume fraction) can be used for special applications like impact and blast resistance [9]. Due to the addition of SFs, workability of the concrete mix decreases and it accelerates the stiffening of fresh concrete. It will cause increase in construction labour and time due to excess vibration for making the concrete workable. This problem can be partially overcome by the use of high range superplasticizers.

Studies were carried out since 1985 to find out the effectiveness of steel fibres. An experimental investigation was conducted to evaluate the effectiveness of SF in shear strength and shear deformation [12]. They found that fibres helps to control dowel cracking. And also helps in controlling deflection, strains and rotation due to shear loads. Another study was conducted to evaluate the mechanical behaviour of SFRC [13]. Study shows that steel fibres contribute towards the shear strength of SFRC and reduces the crack width. Contribution of SFs towards the compressive strength of composite columns were evaluated by studying axially loaded normal reinforced concrete structure and SFRC [14]. Results shows that the use of SFs improves structural behaviour of composite columns. Slenderness ratio have remarkable effects on the strength and behaviour of SFRC infilled steel tube columns. Use of SFRC increases the ultimate load bearing capacity of the member. Structural application of SFRC with and without conventional reinforcement was studied [15]. They found out that steel fibres came into action as soon as micro-cracks are formed in the concrete. Fibres bridge across the cracks and transmits stress across it and it possess some resistance against widening and fracture of the cracks. Steel fibres reduces the requirement of conventional reinforcement. Studies also shows that the over dosage of SFs reduces the workability of SFRC and increases the risk of fibre balling. Therefore an optimum dosage of SFs are necessary. Beyond the optimum dosage, the addition does not improves the performance of SFRC. It makes the cementitious matrix weaker and cracks are likely to divert around fibre ends. Numerical simulation of SFRC was carried out by finite element analysis ABAQUS [16]. They found that mechanical behaviour of SFRC mainly depends on the orientation of SF. A slight change in the constitutive model of steel or distribution of steel fibres can affects the behaviour and numerical representation of the specimen. On the basis of observations from various tests, a simplified model was presented to estimate the shear strength of SFRC [17]. Three different types of SFs were evaluated in volume fractions of 0.75% and 1.5%. Shear stress in SFRC is assumed to be resisted by shear stress carried in compression zone and tension is transferred across the diagonal cracks by steel fibres. Experimental and numerical investigation have been carried out to investigate the behaviour of steel I beam embedded in normal RC and SFRC with or without high strength bolted connectors [18]. In controlling the splitting failure, the presence of steel fibres takes part an important role. Under the same surface condition and number of stirrups, specimens with larger number of bolts founds to provide better slip resistance. Behaviour of steel fibre reinforced self-stressing and self-compacting concrete filled steel tubes subjected to bending were studied [19]. Experimental results shows that the specimen behaves in a ductile manner and the steel fibres and self-stress failed to change the failure mode of concrete filled steel tube specimen. Steel fibres lengthens the elastic stage and improves the flexural capacity of the specimen. Self-stress slightly increases the flexural capacity and provides a higher flexural rigidity. Addition of SFs have no effects on flexural rigidity but improves the flexural capacity of the specimen. Experimental analysis on the behaviour of plain and SFRC filled tubular columns under biaxial bending and axial compression was carried out [20]. High strength stainless steel tube was found to be very effective in concrete filled steel tube behaviour. Use of high strength steel fibre concrete as in-filled material provides better ductility to the specimen. The ratio of column length to diameter and also the eccentricity significantly affects the strength capacity of the specimens. By the addition of steel fibres, the buckling failure has been reduced. Even though SFs improves the ductility and deformation capacity of the specimen, it has little effects on ultimate strength capacity of specimens. An experimental investigation have been conducted on the behaviour of steel concrete composite beams with different amount of steel fibres and conventional reinforcement [21]. An innovative method was proposed to replace steel reinforcement cage by adding different percentages of steel fibres. Results shows that the addition of SFs improves flexural and shear strength and ductility of the tested specimen. Stitching effects of SFs between cracks provides a stable bearing capacity to the specimen. SFs proved to be an alternative to the shear reinforcement.

D. Bond Behaviour of Reinforcing Bars in SFRC

Bond behaviour of reinforcing bars in different types of fibre reinforced concrete were experimentally studied [22]. Reinforcing bars embedded in cement composite and subjected to monotonic loading, unidirectional cyclic and reversed cyclic loading. They found out that bridging and confinement effects provided by fibres leads to enhanced bond resistance of reinforcement bars. Same reinforcement amount of fibres are more effective for enhancing bond strength and controlling cracks compared to conventional transverse reinforcement. Investigation was carried out on bond behaviour of steel fibres reinforced self-stressing and self-compacting concrete filled steel tube columns [23]. They found out that bond strength firstly decreases and the found to increase with increase in steel fibre volume percentage. And they proposed formulas for predicting the bond strength. Analysis of bond behaviour difference in steel and SFRC member with circular sections were carried out [24]. Results shows that displacement at free end was not in level with the loading end. Relative slip occurs at the free end well before the loading end. Interface damage firstly occurred at the free end and it develops gradually from free end to the loading end. After a relative slip, all the specimen shows a damage difference and steel fibres found to have a positive effect in controlling damage difference.

E. Steel Fibre Reinforced Concrete Encased Steel

Concrete encased steel also called steel reinforced concrete is formed by encasing structural steel inside reinforced concrete. CES columns have been popularly used because of its better performance in resisting seismic motions and fire accidents [21]. By providing structural steel in SRC structures, load carrying capacity, stiffness, deformation ability and ductility of the member is increased. But during the construction large number of steel reinforcement would be installed and often clash occurs between steel section and reinforcement bars. In order to overcome such construction difficulties, an innovative method is proposed by adding steel fibres and replacing the reinforcement cage. Analysis of the bearing and damage mechanism of steel-steel fibre reinforced concrete member have been conducted [25]. They found out that splitting cracks elongate from concrete surface to interface and the bonding cracks elongate from tip of the steel flange towards the concrete surface in a diagonal direction. For a steel fibre ratio of 3%, flexural strength of concrete is not significantly improved but the ultimate bond strength is improved.

Experimental study have been conducted on the seismic performance of composite column with ultra-high-strength concrete filled steel tube core [26]. On the basis of obtained load-lateral displacement hysteresis curve, the seismic behaviour such as ductility, energy dissipation, load bearing capacity and stiffness of the members were analysed. Energy dissipation and ductility of ultra-high-strength concrete encased concrete filled steel tube columns shows better performance compared with conventional reinforced concrete. By decreasing stirrup spacing and by using prestressed steel stirrups the specimen shows better seismic performance. Seismic performance of high strength fibre reinforced concrete frames were analysed [27]. The effectiveness of combined use of reinforcing fibres and transverse reinforcement were estimated by a nonlinear analysis of the framed structure under lateral displacement. By using very high percentage of transverse reinforcement or with less amount coupled with fibre reinforced concrete, comparable performance can be achieved. Seismic response of SFRC beam-column joints were studied [28]. Joints were subjected under reversed cyclic loading combined with constant axial force on the column. Steel fibres provided in optimum amount can substitute transverse reinforcement and helps in relaxation of stirrup congestion experienced in seismic detailing of beam-column joints. Behaviour of reinforced concrete flexural member with hybrid fibre under cyclic loading were investigated [29]. Addition of hybrid fibres increases the ductility characteristics by 80% and energy absorption characteristics by more than 160% by comparing with conventional reinforced concrete. Instead of using single fibre, hybrid fibres improves the energy absorption capacity. Seismic performance of composite reinforced concrete and steel moment frame structures were conducted [30]. The test and study of reinforced concrete structures are mainly on non-braced structures. It is practically difficult to conduct a lot of full-scale studies. Therefore FE analysis can be used as an effective method of research. An experimental investigation has been carried out on the seismic behaviour of composite SFRC shear walls [31]. Replacing traditional reinforcement with steel fibres changes the failure mode from flexural mode to shear mode. Maximum lateral force had almost same value but shows an improvement in cracking response and a decrease in ductility.

III. CRITICAL REVIEW

Steel fibre reinforced concrete encased steel composite columns are yet to be studied in detail. More convincing method to solve the construction difficulties in CES composite structures is to incorporate steel fibres and replacing the reinforcement cage. Experimental, numerical and analytical investigations have been conducted to investigate the performance of these composite structures. It is proved that the mechanical behaviour of the structure is significantly improved. By adding steel fibres into the CES section, the structural properties of the member is improved. Particularly the ultimate load carrying capacity, flexural and shear strength It is observed that no studies have been conducted to investigate the performance of the steel fibre reinforced concrete encased steel composite columns under cyclic loading condition. Addition of steel fibres improves the structural properties such as tensile strength, flexural strength and ductility. And also it helps to delay the formation and elongation of concrete cracks. Hence a study is to be conducted on the performance of steel fibre reinforced CES composite columns under seismic loading.

IV. CONCLUSIONS

Studies conducted on CES composite columns have been reviewed. Several experimental, numerical and analytical studies were conducted to investigate the behaviour of these composite columns. Disadvantages of these columns and proposed solutions were also discussed. Main conclusions obtained from literature study are as follows.

- CES columns shows improved structural performance compared to conventional RC columns.
- Because the rebar cage and structural steel both are encased within the member, concrete placement of CES structures are much more difficult than conventional reinforced concrete structures.
- An innovative method proposed to reduce the construction difficulties in CES construction is the addition of steel fibres and replacing the reinforcement cage.
- By adding steel fibres into CES columns increases the tensile, shear and flexural strength of the member. And also helps in delaying the formation and elongation of cracks.

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