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Design and Development of Composite Columns in Seismic Zone

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Abstract: *The use of steel-fibres as reinforcement in plain concrete not only enhances the tensile strength of the composite system but also reduces cracking under serviceability conditions. Further, steel-fibres improve resistance to material deterioration as a result of fatigue, impact, shrinkage and thermal stresses. The improvements in material properties, which improve structural performance, have extended the use of fibre-reinforced concrete to applications in the area of fire. The presence of micro cracks in the mortar-aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by inclusion of fibers in the mixture. Different types of fibers, such as those used in traditional composite materials can be introduced into the concrete mixture to increase its toughness, or ability to resist crack growth. Since the present design methods and approaches are limited to the property, strength, stiffness and ductility of PCC in-filled columns and beams this study will provide the detailed investigation of the actual and local, post buckling and flexural behavior of SFRC in-filled light gauge steel box columns and beams subjected to various typical load conditions. The wider use of light gauge structural components in many areas of application has promoted considerable interest in the in-filled light gauge members. The main target of the examination is to investigate the conduct of hollow, Plain Cement Concrete (PCC) and Steel Fiber Reinforced Concrete (SFRC) in-filled stub, short and medium columns subjected to axial and eccentric loads and bars subjected to flexure. Trial, Theoretical and Numerical investigations have been completed. In the principal stage, trial investigations were completed to contemplate the conduct of hollow, PCC and SFRC in-filled light gauge steel stub, short and medium stature columns. 78 investigations were directed, out of which five tests were on stub columns, five tests were on short columns and 68 tests were on medium tallness columns.*

Keywords: SERC, Plain Cement Concrete, steel-fibres, Reinforced concrete

1. Introduction

The use of steel-fibres as reinforcement in plain concrete not only enhances the tensile strength of the composite system but also reduces cracking under serviceability conditions. Further, steel-fibres improve resistance to material deterioration as a result of fatigue, impact, shrinkage and thermal stresses. The improvements in material properties, which improve structural performance, have extended the use of fibre-reinforced concrete to applications in the area of fire. The addition of steel fibres to concrete is advantageous as the melting point of the steel fibres is relatively high in comparison to the other materials. It improves the mechanical properties of the concrete and its fire resistance in comparison to plain concrete, a number of experimental investigations has been conducted up to date with the aim to observe the fire response of concrete composites. Particularly, the studies have focused on the effect of a type, shape and content of fibres on the mechanical properties of concrete composites, mostly compressive and tensile strength including elastic modulus different kinds of fibres including steel fibres, synthetic fibres and a mixture of steel fibres & polypropylene fibres.

1.1 Composite Columns

The term 'composite column' implies a column constructed from two or more different materials in such a way that they work together in resisting stresses and strains induced by forces or conditions external to the column. (2) Strictly speaking, ordinary reinforced concrete columns fa1l within the scope of this definition. However, the term is normally used to indicate applications like either concrete-encased sections or concrete-filled tubes of square, rectangular or circular cross-section. Besides steel, newly emerging materials like Fiber Reinforced Plastics (FRPs) can be introduced as a tube material and they provide an interested field of study. In this way, concrete columns wrapped with FRP-sheets to provide confinement can also be attributed the name of 'composite column'.

➢ **Types of composite column**

a. **Stub column** - A stub column is a column whose length is sufficiently small to prevent failure as a column, but long enough to contain the same residual stress pattern that exists in the column itself. It is a type of column mainly adopted in construction of underground water tanks.

b. **Short Column** - The column, whose lateral dimension is very small when compared to its length (or height), is called as long column. The column, whose lateral dimension is very large when compared to its length (or height), is called as short column. It will generally fail in buckling

c. **Medium column** is a column which fails either due to direct stress or buckling stress. For medium columns, the slenderness ratio is more than 32 and less than 120. For medium columns, the length is more than 8 times but less than 30 times their least lateral dimension

➢ **Advantages and Disadvantages of Composite Columns** - Concrete filled tubes offer a number of advantages in both design and construction:

- The tube confines the concrete.
- The concrete prevents the tube from local buckling
- The tube provides well-distributed reinforcement
- The tube protects the surface of the concrete from physical damage and deterioration by environmental effects such as carbonation and chloride penetration.
- The tube provides a formwork for the casting of the concrete, which stays in place and does not need to be removed.
- The load-carrying capacity of a composite column is larger when compared to an ordinary reinforced concrete column of the same crosssectiona1 dimensions. In buildings therefore, more floor area is available for the occupants

The major disadvantage of a composite column is the exposure of the tube to environmental effects (heat, cold…). For steel tubes this raises concerns related to susceptibility to corrosion and fire safety. The fire resistance of a concrete-filled steel column is significantly less than that of ordinary reinforced column.

1.2 Steel-Fiber Reinforced Concrete

The presence of micro cracks in the mortar-aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by inclusion of fibers in the mixture. Different types of fibers, such as those used in traditional composite materials can be introduced into the concrete mixture to increase its toughness, or ability to resist crack growth. The fibers help to transfer loads at the internal micro cracks. Such a concrete is called fiber-reinforced concrete (FRC), the FRC in which Steel fibers are used is called Steel fiber-reinforced concrete (SFRC).

The one of the important properties of steel fiber reinforced concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fiber composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particular under flexural loading; and the fibers are able to hold the matrix together even after extensive cracking. The net result of all these is to impart to the fiber composite pronounced post – cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fiber composite and its ability to withstand repeatedly applied, shock or impact loading.

2. Review of Literature

Md Tanvir Hasan Fahim (2022) presented the comprehensive overview of the state of the art of evolution of composite columns in building structures based on experimental numerical and analytical studies is emphasized in the paper. Moreover, replacing concrete with various materials such as cement aggregates, limestones, fly ash, and industrial waste is suggested to deal with the high cost of the construction.

Georgios S. Papavasileiou, Dimos C. Charmpis (2020) investigates and compares the cost-effectiveness of seismically designed buildings having either pure steel or steel-concrete composite columns. In order to ensure an objective comparison of these two design approaches, the assessed building designs are obtained by a structural optimization procedure. Thus, any bias that would result from a particular designer's capabilities, experience, and subjectivity is avoided. Hence, a discrete Evolution Strategies optimization algorithm is employed to minimize the total cost of materials (steel and concrete) used in a structure subject to constraints associated with: (a) Eurocode 4 provisions for safety of composite column-members, (b) Eurocode 3 provisions for safety of structural steel members, and (c) seismic system behaviour and resistance. Extensive assessments and comparisons are performed for a variety of seismic intensities, for a number of building heights and plan configurations, etc. Results obtained by conducting 154 structural design optimization runs provide insight into potential advantages attained by partially substituting steel (as a main structural material) with concrete when designing the columns of earthquake-resistant buildings.

Sunita Dahal, Rajan Suwal (2018) present work, steel concrete composite (both full and half composite) with RCC options are considered for comparative study of seismic behavior of 10 multistoried commercial buildings (4-storied, 5-storied, 6-storied, 7-storied, 8-storied, 9-storied, 10-storied, 12-storied, 16-storied and 20-storied which is situated in earthquake zone V and for earthquake loading, the provisions of IS:1893(Part1)-2002 is considered. For modeling of composite and RCC structures, SAP2000 software is used. Steel-concrete composite construction system is an efficient, economical and innovative method for seismic resistance of multi storied buildings. Equivalent static method of seismic analysis is used in the analysis of models.

T. Arhaa et, al (2018) this study predicts the shear strength of steel fibre reinforced concrete (SFRC) members at elevated temperature using numerical modeling. The authors derived the stress-strain relation in the pure shear mode at ambient temperature based on a damage model calibrated at ambient and elevated temperatures. The model was validated on the special experimental arrangement for the pure shear mode of the SFRC in torsion. These results enable to determine the stress-strain diagram at elevated temperature. The shear strength of SFRC is compared with the compressive and tensile strength and used to observe reasons for experimentally observed failure model. The work is a part of comprehensive project focused on development of design models for the steel and SFRC composite columns with circular hollow section (CHS) at elevated temperature. Research includes two levels accuracy/complexity, allowing simplified or advanced approach to design following the coming changes in European standard for composite member design in fire, EN1994-1- 2:2021. Experimental studies of the project include mechanical material tests of heated fibre- concrete samples in tension and compression, thermal uniform and non-uniform tests of insulated fragments of CHS and tests of full scale SFRC CHS columns in steady-state and transient-state regimes.

E. Balaji (2017) Nano-technology is useful to study hydration and alkali silicate reactions of concrete which plays a major role to arrest segregation and micro cracks. In the present study Mechanical properties of M50 grade of Conventional concrete (CC) and Nanosilica concrete (NSC) were studied. Experimental results predict that NSC achieves superior properties than CC in strength criteria. This paper represents flexural behavior of CC and NSC in-filled in light gauge rectangular box cross sections under the criteria of pure bending. Here in this project used thickness of light gauge steel beams are 1.6 mm and 2.0 mm. Hence to arrest local buckling and to get internal support in cold formed steel members, these are infilled with concrete. It can increase the stiffness and flexural strength of the member by the moment of inertia of section. Hollow, conventional concrete in-filled and Nano silica concrete infilled beams in pure bending are to be tested until failure with respect to Zone of minor axis.

Ashraf Abdalkader et, al (2017) Steel fibers are added to concrete due to its ability to improve the tensile strength and control propagation of cracks in reinforced concrete members. Steel fiber reinforced concrete is made of cement, fine, water and coarse aggregate in addition to steel fibers. In this experimental work, flexural cracking behavior of reinforced concrete beams contains different percentage of hooked-end steel fibers with length of 50 mm and equivalent diameter of 0.5 mm was studied. The beams were tested under third-point loading test at 28 days. First cracking load, maximum crack width, cracks number, and load- deflection relations were investigated to evaluate the flexural cracking behavior of concrete beams with 34 MPa target mean strength. Workability, wet density, compressive and splitting tensile strength were also investigated. The results showed that the flexural crack width is significantly reduced with the addition of steel fibers.

Baarimah, A. O.; Syed Mohsin, S. M. (2017) This paper investigates the potential effect of steel fiber added into reinforced concrete slabs. Four-point bending test is conducted on six slabs to investigate the structural behaviour of the slabs by considering two different parameters; (i) thickness of slab (ii) volume fraction of steel fiber. The experimental work consists of six slabs, in which three slabs are designed in accordance to Eurocode 2 to fulfil shear capacity characteristic, whereas, the other three slabs are designed with 17% less thickness, intended to fail in shear. Both series of slabs are added with steel fiber with a volume fraction of $V_f = 0\%$, $V_f = 1\%$ and $V_f = 2\%$ in order to study the effect and potential of fiber to compensate the loss in shear capacity.

K. Perumal P, R. Srinivasan (2016) In modern construction, Concrete filled steel tubular (CFT) beam and column have better option in structural systems like buildings, bridges, caissons piers and deep foundations, because of its high compressive stiffness. These CFT members are applicable in curved bridge decks and where formwork is could not be provided. The CFT column has more stiffness and reduces local buckling failures. In present work study of torsional characteristics of steel beams, in-filled with plain cement concrete and fiber reinforced concrete Torsional moment and angle of twist has been studied of hollow steel tubular beam, tubular beam in-filled with Plain Cement Concrete (PCC) and

Steel Fiber Reinforced Concrete (SFRC) beams under torsion. The volume fraction of fiber added to concrete mix as 1.5%. The aspect ratio of steel fiber is kept as 50, crimped shaped steel fiber are used and its length 50mm. The M20 grade concrete used to infill material of steel tube all beam specimens has been tested under two points loading on self-straining loading frame (40-ton capacity) under pure torsion. Finally, to compare the torsional behavior of hollow, PCC in-filled and SFRC in-filled steel beams.

3. Proposed Methodology

Stub and short columns

In the present investigation, a series of experiments will be carried out to study the behavior of hollow, PCC in-filled and three varieties of SFRC in-filled stub, short, medium columns and beams with emphasizes on the ultimate strength, ductility, axial deformations, lateral deflections and post failure strength reserve in elastic as well as in the plastic ranges with a focus on the bond between steel and concrete. An effort will also been made to compare the experimental and theoretical results with the results obtained using numerical models.

- **Material characteristics**

1. **Steel Section -** The hollow sections will be made from light gauge steel sheets, continuously welded at the middle along its length. The light gauge steel sections will be shown in Figure. The size of the steel sections will be 100 mm × 50 mm and 2 mm thick.
2. **Plain Cement Concrete** - The concrete mix will be designed for a cube compressive strength of 20 MPa at 28 days. The design mix of 1:2.09:2.25 with a w/c ratio of 0.49, using 12.5 mm size (max.) coarse aggregate and 2.36mm (max.) size fine aggregate will be used as per ACI committee 211.1.1991 recommendations. The PCC and SFRC for the composite columns will be mixed in two separate batches.

Figure 1 a: Test specimens i.) Specimens ii) Cleaning for oil, Grease and grit

3. **Steel Fiber Reinforced Concrete (SFRC)** - To prepare the SFRC in-filled steel composite columns, three different volume fractions of steel fibers will be chosen viz., 0.75%, 1.00% and 1.25%. Crimped steel fibers will have an aspect ratio of 70 (l_f = 30.80 mm and d_f = 0.44mm) will be used for this purpose. The material properties of SFRC will be listed in Table will have been shown that it will be possible to relate the mechanical properties of fiber reinforced concrete to the fundamental properties of the fibers, such as diameter, length, and percentage in the matrix material, shape, bond characteristics and tensile strength. The expression for the compressive strength of fiber-reinforced concrete f_{cf} proposed by Nataraja e_t a_l is presented in equation

$$f_{cf} = f_c + 2.1604 \, (W_f \, l_f / d_f) \quad (1)$$

Where W_f = weight percentage of fibers

In contrast to plain cement concrete for which most structural codes assume negligible resistance in tension, fiber reinforced concrete will be, at the ultimate stage, a residual tensile strength f_{tu} given by Soroushan and Lee is

$$f_{tu} = 2 \, \eta_1 \eta_0 \, \tau \, V_f \, l_f / d_f \quad (2)$$

Where η_1 an effectiveness factor of the form of fibers given by

$$\eta_1 = (\tau / \sigma_{fu}) \, (l_f / d_f) \quad (3)$$

η_0 = distribution factor of fibers (= 0.41 for random distribution of fibers in a three-dimensional space) τ = bond strength of fibers (2 ~ 6 MPa), V_f = volume percentage of fibers.

- **Test Specimens**

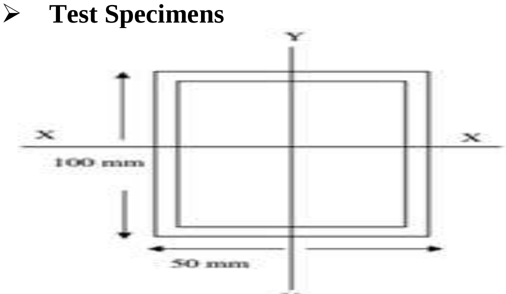

Figure 1.3: Cross section details of the test specimen

Push Out Tests - Push out tests will be carried out to study the bond strength between the steel sections and the in-fill. The test specimens for this test will be 550 mm in length and the concrete will be poured to 500 mm length leaving a 50 mm gap in which a groove of 7 mm in the form of an equilateral triangle will have been made at the end for relieving the air during testing. The load will be applied through a steel plate, which rests directly on concrete in small increments and the slip will be observed using a deflectometer as shown in the test set-up.

Table 1: Material properties of PCC and SFRC

Sl. No.	Type of in-fill	Cube Strength N/mm^2	Cylinder Strength N/mm^2	Cylinder Strength N/mm^2	Flexural Strength N/mm^2	Split Tensile Strength N/mm^2	Residual Tensile Strength N/mm^2	Young's Modulus (Ec) (by Test) (x104) N/mm^2
1	Plain Cement Concrete	32.44	26.65	--	4.24	4.1	--	2.968
2	0.75% Steel Fiber Reinforced Concrete	41.78	34.97	27.95	4.94	5.15	1.59	3.23
3	1.00% Steel Fiber Reinforced Concrete	57.78	47.19	28.34	5.86	6.55	2.13	3.8
4	1.25% Steel Fiber Reinforced Concrete	38.6	31.64	28.81	4.4	5.1	2.66	3.109

- **Stub Columns:**

Stub columns will have specimens whose height will not be less than three times the largest dimension of the section and not more than twenty times the least radius of gyration as prescribed in the IS: 801-1975. Tests on stub columns will be conducted on specimens to get their ultimate strength. In the present investigation five stub columns (with slenderness ratios of 17.50) will be tested.

- **Test Procedure** Rectangular hollow, PCC in-filled, 0.75%, 1.00% and 1.25% SFRC in-filled stub columns will be tested under axial load conditions. The test specimen will be placed centrally. The verticality of the stub column will be ensured. To make hinged end condition steel balls will be placed on the grooved plates. Deflectometer will be used to measure the axial shortening and strain gauges are fixed at the longer face of the specimen to measure strain.

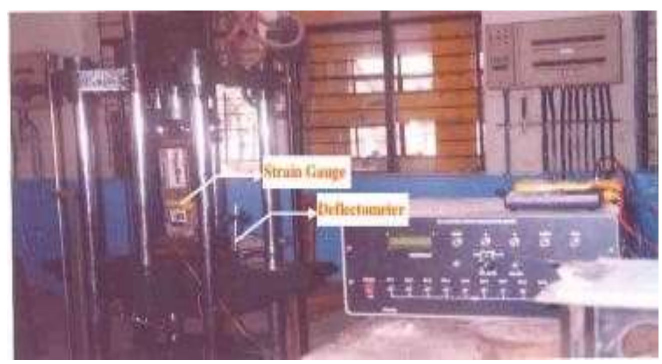

Figure 3: Test set up for stub column tests

- **Failure Mode and Ultimate Loads** - The failure mode will be characterized by crushing of concrete and outward bulging of the steel tubes at the bottom of the columns. Figure shows the tested specimens. It will also observed that the PCC in- filled columns are taking 53% more load than the hollow columns and SFRC in-filled columns will taking 85% more load than the hollow columns. Compared with PCC infilled columns the SFRC in-filled columns will be taking around 20% more load

- **Comparison of Test Results with the Design codes -** In this section, the experimental data will be compared with the values predicted by the design codes such as Eurocode4 and British code BS 5400. The EC4 will be applicable to CFT stub columns with concrete cylinder strength and steel yield stress will not be greater than 50 and 355MPa, respectively.

$$\text{Axial load capacity } N_u = A_s f_y + A_c f_c' \quad (4)$$

As per the British code BS5400, the strength of the stub column will be determined using the equation. A coefficient of 0.675 will be included in the concrete cube strength to account for long-term and size effects of concrete cube.

$$\text{Axial load capacity } N_c = A_s f_y + 0.675 A_c f_{cu} \quad (5)$$

- **Short Columns:**

These tests will be conducted to study the behavior of hinged short columns under axial load, which include rectangular hollow, PCC in-filled, 0.75%, 1.00% & 1.25% SFRC in- filled short columns whose slenderness ratio is 35. The test set up is shown

Figure 4: Test set up for short column

- **Test Procedure** The tests will be conducted on a column load frame. In order to apply truly axial load to the specimens, 22 mm thick plates will be directly welded to the ends of the specimen. To simulate simply supported end condition two plates 30 mm thick and size 300 × 200 mm with a spherical groove at the center to accommodate a ball of 40 mm diameter will be bolted to the end plates at either end by four 16 mm diameter bolts such that their centres coincide in plan. The load will be applied through a calibrated proving ring of 100 kN capacity. 10 mm electrical strain gauges will be used to measure the strains at 55 mid height of the columns.

Failure Modes and Ultimate Loads - It will be observed that all the in-filled columns will be crushed under the axial load and no buckling failures or shear failures will be observed. For the hollow columns alone, the failure will due to local buckling near the bottom support whereas, all the in-filled columns failed at their bottom due to crushing of in-fills at the verge of failure.

4. Results

Deformation Contours

The regular parallel deformation contours of medium columns under axial and eccentric loads are given in Figures 5 to 6.

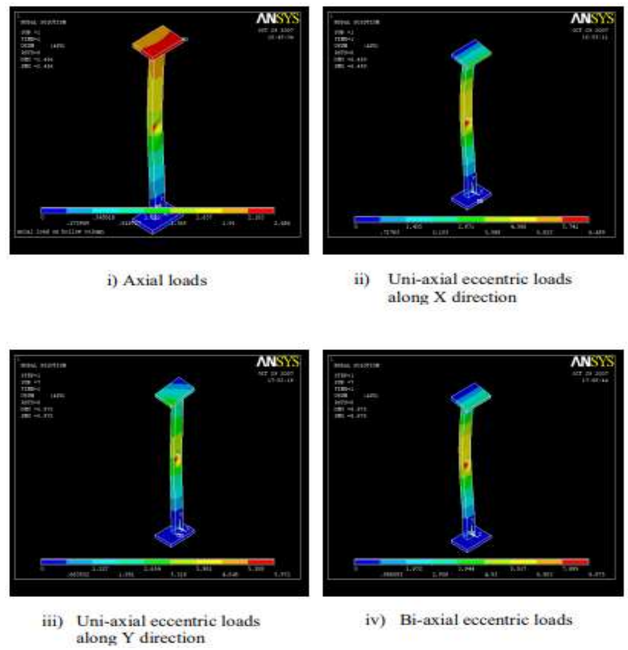

Figure 5: Typical deformation behavior of hollow columns

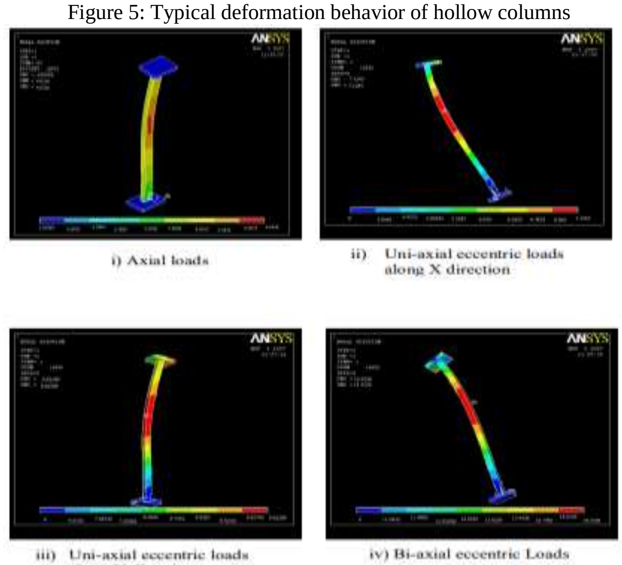

Figure 6: Typical deformation behavior of 0.75% SFRC in-filled columns

5. Conclusion

From the mathematical investigation using ANSYS software bundle, the nearby and in general buckling methods of the finite component model of the medium columns were found to intently coordinate the test buckling modes obtained tentatively. The buckling loads anticipated by finite component model concurred well with the exploratory loads with a margin of 1.50%. For the situation of axial loads, the horizontal avoidances from the mathematical examination were lesser than the exploratory qualities by a margin of 4.50%. For the columns subjected uni-axial eccentric loads, for example, 0.1ex, 0.3ex and 0.5ey, the horizontal redirections from the ANSYS results coordinated well with the trial results. The strains obtained from the mathematical methodology were marginally lesser. For the situation of axial loads, the strains obtained by ANSYS were lesser than the exploratory qualities by 0.20%. Since the loads, redirections and strains anticipated by the ANSYS model are nearest to their exploratory qualities, the FE model produced for the nonlinear buckling examination has addressed the genuine conduct of the columns as in the analysis's investigations.

6. Future Work

The future work of proposed work are:

- Similar trials can be directed on sections with various thinness proportions, with various kinds of fibers, different end conditions and section setup.
- Behavior of comparative columns with in-fills of various strengths can be examined.
- Finite Element Analysis can be reached out to include diverse end conditions and section setups.
- Behavior of these components in the gatherings of edges can be likewise examined.

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