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Effect of Sustained Axial Load on Stub Columns Filled with Self Consolidated Concrete - Incorporating Waste Foundry Sand

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Abstract

In this research work, investigations have been carried out to find the effect of waste foundry sand in high strength self-consolidated Concrete Filled Steel Tubular (CFST) stub columns. A total of 14 stub columns were tested under monotonic compression load to identify the optimum percentage of waste foundry sand which is an industrial waste. Among 14 specimens, eight specimens with circular cross-section of diameter 100mm and length 300mm and another eight specimens with square cross-sections of sides 100mm and length 300mm.Each seven specimens can be classified into three categories: two hollow steel tubular sections, two plain SCC columns, and ten SCC filled steel tubular sections. The experimental investigations indicate that the utilization of waste foundry sand has a impact on the strength and ductility of the steel tubular sections. Also the steel tubular sections act as external reinforcement which reduces the local buckling and increases lateral stability. When compared with the circular columns, the square columns save 30% of steel.SCC mixes are prepared by varying the cement content with replacement of foundry waste sand. In this work CFST were prepared with 0%,5%,10%,15% and 20% of foundry waste sand replaced with the actual cement content .From the investigation it is noted that the ultimate load of steel tubular stub columns with foundry waste sand is higher when compared to conventional concrete and saves 10% of construction cost. The work proposes the solution for effective industrial waste management which reduces the environmental hazard and make an eco-friendly environment.

Keywords: Composite Columns, Concrete Filled Steel Tube, Foundry Waste Sand, Self Compacting Concrete, Stub column

I. INTRODUCTION

Recently many different types of composite material systems have been widely applied to concrete column design to provide better performance in terms of high strength, stiffness, ductility and seismic resistance. Some of these composite columns are fully encased steel sections, partially encased steel sections and concrete filled steel tube. Among them, the concrete-filled steel tube (CFST) column system has turned out to be one of the most successful composite concrete column systems. The CFST column is a composite material system which employs the various advantages of different materials and combines them together in a steel tube column which is filled-in with concrete. CFST columns have a number of distinct advantages over equivalent steel, reinforced concrete, or steel- reinforced concrete columns. Steel columns have the advantages of high tensile strength and ductility, while concrete columns have the advantages of high compressive strength and stiffness. Composite columns combine steel and concrete, resulting in a column that has the beneficial qualities of both materials. The steel tube serves as a form of casting the concrete, which reduces construction cost. No other reinforcement is needed since the tube acts as longitudinal and lateral reinforcement for the concrete core**.** In addition, the location of the steel and the concrete in the cross-section optimizes the strength and stiffness of the section. In the CFST the steel lies at the outer perimeter where it performs most effectively in tension and in resisting bending moment. Similarly, the stiffness of the concrete-filled column is greatly enhanced because the steel is situated farthest from the centroid, where it makes the greatest contribution to the moment of inertia. The continuous confinement provided to the concrete core by the steel tube enhances the core's strength and ductility**.** The concrete core delays the local buckling of the steel tube by preventing inward buckling, while steel tube prevents the concrete from spalling**.**

In the constructed structures of CFST, such as some multi-storey buildings and skyscrapers, hollow steel tubes are usually fixed first with steel beams, bracing structures and so on, and then the concrete is pumped into the hollow steel tubes after having established several or even dozens of stories. Consequently, in recent years, the use of self-compacting concrete, in such kinds of columns has been of interest to many structural engineers. Due to its rheological properties, the disadvantage of vibration can be eliminated while still obtaining good consolidation. Apart from reliability and constructability, advantages such as elimination of noise in processing plants, and the reduction of construction time and labour cost can be achieved. It is expected that SCC will be used in concrete-filled HSS columns in the future because of its good performance. However, the composite members are susceptible to the influence of concrete compaction.

Foundry sand is high quality silica sand used as a moulding material by ferrous and non-ferrous metal casting industries. It can be reused several times in foundries but, after a certain period, cannot be used further and becomes waste material, referred to as used or spent foundry sand (UFS or SFS). The majority of spent moulding sands are classified as nonhazardous waste (that is not corrosive, ignitable, reactive or toxic) Siddique and Noumowe, [2].Foundries use high quality size-specific silica sands for use in their moulding and casting operations.

The physical and chemical characteristics of foundry sand will depend in great part on the type of casting process and the industry sector from which it originates. In a recent study, Siddique et al. [3] reported that in the United States alone, up to 10 million tons of foundry sand are discarded annually and are available for recycling. Foundries purchase new, virgin sand to make casting moulds and the sand is reused numerous times within the foundry. However, heat and mechanical abrasion eventually render the sand unsuitable for use in casting moulds, and a portion of the sand is continuously removed and replaced with virgin sand.

There are about 35,000 foundries in the world with annual production of 90 million tones. In terms of number of foundries China has the highest score (9374), followed by India (6000), Bhimani et al. [4]. Singh and Siddique [5] reported that in India, approximately 2 million tons of waste foundry sand is produced yearly. WFS are major by-products of metal casting industry and successfully used as a land filling material for many years. But use of waste foundry sand (WFS) for land filling is becoming a problem due to rapid increase in disposal cost. In an effort to use the WFS in large volume, research has being carried out for its possible large scale utilization in making concrete as partial replacement of fine aggregate Sahmaran et al. [6] reported that no visible segregation or bleeding was observed in the fresh mixtures. The results for slump flow diameter, slump flow time, V-funnel flow time, and rheological parameters (yield stress and relative viscosity) of the SCC mixtures satisfy the "The European Guidelines for Self Compacting Concrete" [16]. Spread of 50FA-50SFS mixture which was a typical example of the uniform spread of SCC mixtures. Generally, for a given FA content, the super plasticizer requirement increases with SFS content for fresh properties like slump flow diameter. Guney et al. [7] observed that waste foundry sand decreased the fluidity and the slump value of the fresh concrete. In this study fine aggregates were partially replaced with 0, 5, 10 and 15% WFS. This may be probably due to the presence of clayey type fine materials in the waste foundry sand, which are effective in decreasing the fluidity of the fresh concrete. Naik et al. [8] studied the various tests on the use of foundry silica dust in self compacting concrete in which a control mixture was made in which ASTM C 618 Class C fly ash constituted 40% mass of the total cementitious materials. At 30% replacement of fly ash with foundry silica dust, the super plasticizer demand for SCC increased considerably. The VMA demand decreased as more fly ash was replaced with silica dust. This could be due to the increase in the amount of fines in SCC at higher replacements level. The slump flow of SCC containing the foundry silica dust was in range of 710-725mm, and H2/H1 in the U-flow test was 99%.SCC containing foundry silica dust did not show noticeably higher bleeding than the reference mixture. Guney et al. [7] examined the influence of inclusion of WFS as partial replacement of fine aggregates on the compressive strength of concrete up to the age of 56 days. Fine aggregates were partially replaced with 0, 5, 10 and 15% WFS. It was observed that the concrete with 10% waste foundry sand replacement exhibited highest compressive strength at the age of 56 days. Compressive strength decreased with an increasing amount of foundry sand. The concrete with 10% waste foundry replacement may indicate the optimum reallocation amount of waste foundry sand. This may indicate that the particle size distribution of the mixture with 10% waste foundry sand has sufficient adherence than the other mixtures with waste foundry sand. Siddique et al. [3] studied the properties of concrete mixtures in which fine aggregate (regular sand) was partially replaced with used-foundry sand (UFS).

In these fine aggregates was replaced with three percentages (10%, 20%, and 30%) of UFS by weight. The variation in the splitting tensile strength with UFS content was similar to that observed in the case of the compressive strength that is splitting tensile strength of concrete mixtures increased with the increase in UFS content. Guney et al. [7] determined the splitting tensile strength of concrete made with WFS as partial replacement of fine aggregates. The splitting tensile strength values of 5 and 15% waste foundry sand replaced specimens are lower than that of the control one; the specimens replaced with 10% waste foundry sand have slightly higher values than control mix (without foundry sand). Bakis et al. [9] explored the possible use of waste foundry sand (WFS) in asphalt concrete. In asphalt Concrete mixtures, fine aggregates were replaced with 0, 4, 7, 10, 14, 17 and 20% WFS. Indirect tensile strength tests were conducted as per AASTHO (1989). As the percentage of WFS was increased, the strength of the asphalt concrete mixtures linearly decreased, yielding values from 1.39 MPa with 0% WFS to 0.94 MPa with 20% WFS. Sahmaran et al. [6] investigated the permeability of self compacting concrete with fly ash and spent foundry sand. The Portland cement in the mixtures was replaced with Fly ash at 0, 30, 50 and 70% by mass. For each FA replacement level, about 0, 25, 50 and 100% of sand by volume was replaced with SFS. The results of RCP tests performed at 28 and 90 days. the use of FA significantly reduced the chloride permeability of the hardened SCC mixtures when compared to the control concretes with 0% FA. The results also showed that the rapid chloride permeability of most concretes containing FA and SFS was below 750 coulomb at 90 days, which indicate relatively high-quality SCC mixtures from rapid chloride permeability standpoint (ASTM C 1202 classifies the chloride ion penetrability of a concrete as ‘‘very low’’ as long as the charge passed is between 100 and 1,000 coulomb). Singh and Siddique [5] concluded that inclusion of WFS decreased the chloride ion penetration in concrete, which indicates that concrete has become denser and impermeable. At 28 days, charges passed were 1368, 1250, 1150, 1060 and 1190 coulombs at 0%, 5%, 10%, 15% and 20% of WFS. Coulomb value decreased with the increase in WFS content up to 15% WFS, which indicate that concrete became more dense. Coulombs charges passed at 91 days are less than those of 28 days, which indicate that concrete microstructure become denser.

The main objective of this study was to examine the effect of different types of infill used in CFST columns. An additional objective was to investigate the changes in behaviour if foundry waste sand is used for making the concrete. Fourteen different specimens were tested for columns with pinned end conditions and the results are analysed in detail in this paper.

II. EXPERIMENTAL PROGRAM

2.1 General

In this work, mild steel tubes used in the construction of the specimens were manufactured in Tamilnadu, the steel tube sections were cut from the original 6 m steel tube and the ends machined to meet required length have dimensions of cross section (100x100) mm and height of 300 mm with thickness of 2mm for square section as well as diameter of (100) mm and height of (300) mm with thickness of 2mm for circular sections. A total of 14 stub columns under monotonic compression load was tested in order to discover the best configuration of column system, seven specimens with circular cross-sections, while another seven specimens with square cross-sections, each of which can be classified into three categories: two hollow steel tube columns, two plain SCC columns, and ten SCC filled steel tube columns.

2.2 Material Properties

2.2.1 Steel

Mild steel tubes used in the construction of the specimens were manufactured in TamilNadu. The tensile tests were conducted on three steel coupons cut from the original steel tubes according to ASTM A 370-5.Each tensile specimen was cut at 90° a way from the weld seam of the virgin steel. The specimens are tested in a tensile machine of 50 kN in capacity. The measured properties of the steel tubes obtained from these tests are thickness 2mm, yield strength 355Mpa, ultimate strength 414Mpa, elastic modulus 200Gpa, and elongation percentage 18.

Ordinary Portland cement of 43 Grade having specifications as per IS 8112:1989 reaffirmed in 2005 was used in the experiments. No material will be added after burning other than gypsum in this grade of cement. The coarse aggregate percentage was fixed as 50 % by volume. The crushed stone aggregates which passing through 12.5 mm size and retained in 10mm sieve was selected to avoid blocking effect. Ordinary river sand with specific gravity 2.5 g/cm3 lying in Zone II was used. Figure 1 shows the grading of aggregates

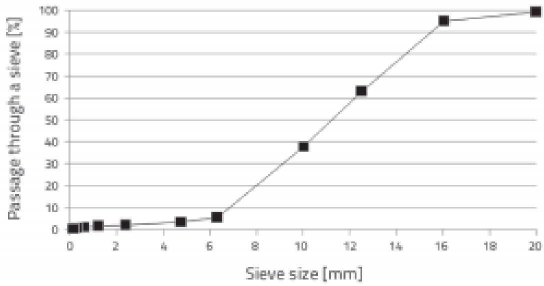

Fig 1. Grading of coarse aggregate used

Conplast SP430 was used as super plasticizer which is a chloride free, superplasticising admixture based on selected sulphonated naphthalene polymers. It is supplied as a brown solution which instantly disperses in water. Conplast SP430 disperses the fine particles in the concrete mix, enabling the water content of the concrete to perform more effectively. The very high levels of water reduction are possible which allow major increase in strength to be obtained. The FSW and FA were used as mineral admixtures. Class F fly ash was obtained from Mettur thermal power plant station near Mettur dam, India. The specific gravity of fly ash was found to be 2.1 g/cm3. The WFS from industries in Pudukkottai District, Tamilnadu, India was used. Since the WFS was fine, hydrometer analysis was carried to determine the particle size distribution. From hydrometer analysis it was found that the coefficient of curvature was 1.8 and coefficient of uniformity was 7.80. The specific gravity of the marble powder was found to be 2.56 g/cm3. The characteristic properties and mineralogical composition of these two mineral admixtures and the cement are given in Table 1.

TABLE 1. PROPERTIES OF ORDINARY PORTLAND CEMENT AND MINERAL ADMIXTURES

Component	Cement [%]	WFS [%]	Fly ash [%]
CaO	63.5	3.6	5.9
SiO_2	21.5	61.4	45
Al_2O_3	5.5	16.3	30
Fe_2O_3	0.55	3.6	11
MgO	1.5	1.7	2.25
SO_3	1.2	0.05	1.5
LOI	1.0	5.0	1.0
Alkali	0.12	6.2	2.1
Insoluble residue	0.8	0.9	0.2

From the XRD results shown in Figure 2, it is understood that the FSW used has more than 60 % of silica content which can give possible filling effect in SCC. Around 16.3 % of alumina in FSW and 30 % in FA assures some pozzolonic reaction in concrete which may contribute to the compressive strength. The remaining part of FSW consists of Cao (3.6 %), Fe2 O3 (3.6 %) and some residues presence of which has very less influence on strength. The BSW and FA are having specific amount of silica and alumina which suggested a potential pozzolonic reaction and a quasi cementitious nature. Fly ash as a additive to be used in concrete should contain at least 25 % reactive silica, which is satisfied in FSW also. Another limitation is that the sum of ferric oxide (Fe2 O3), alumina (Al2 O3) and silica (SiO2) must be at least 70 % in fly ash for possible use in concrete: the sum of these oxides is over 80 % in the chosen FSW, leading to the belief that it may be useful for concrete mixes. Although seemingly high, the FSW's alkali content (as Na2 O equivalent) was not available freely and therefore it is believed that it will be not able to contribute to any potential alkali-aggregate reaction. After evaluating the SEM graph (Scanning Electron Micrographs) shown in Figure 3, the particle's shape, texture and morphology showed that granite particles are highly irregular. Evaluation of the particles' shape, texture and morphology showed the FSW grains to be slightly larger, more angular, more porous and of greater specific surface and roughness than a typical fly ash sample which is spherical in nature.

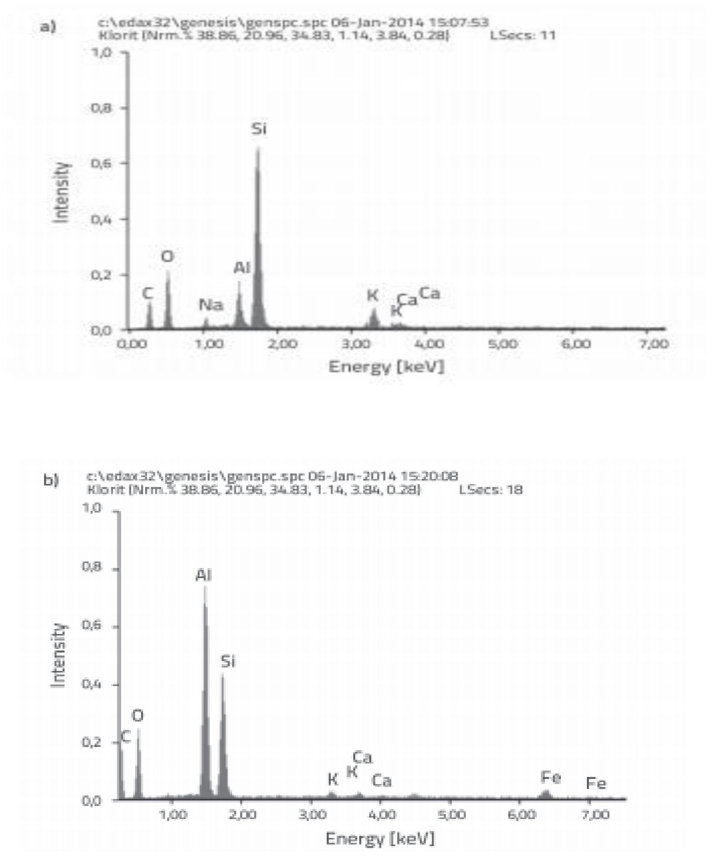

Fig 2. XRD results of foundry waste sand and fly ash

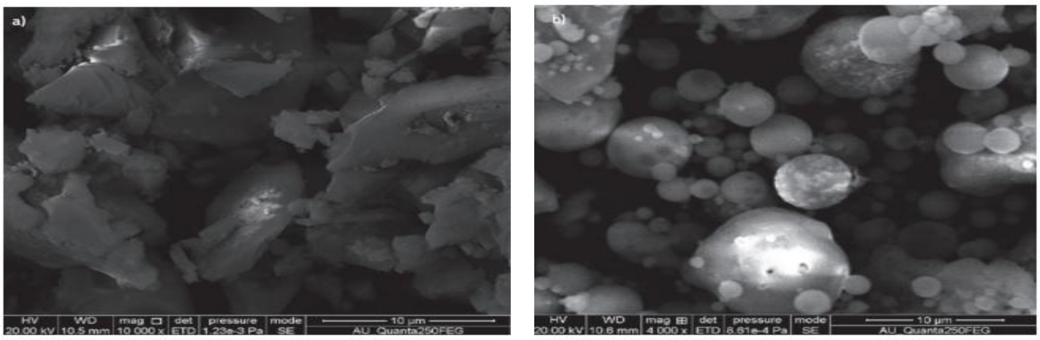

Fig 3. Comparison of scanning electron micrographs of foundry waste sand and fly ash

2.2.2 Mixture proportions

One of the best and popular methods for mix design of SCC was given by Okamura [1]. This method initially depends on the cement paste and mortar tests before considering the properties of the super plasticizer, cement, fine aggregate and other mineral admixtures. EFNARC specifications and guidelines based on Okamura was used to decide the mix proportions. One control and four mixtures with mineral admixtures were prepared and examined to quantify the properties of SCC. Table 2 presents the composition and labeling of the SCC mixtures.

TABLE 2. MIX PROPORTIONS

Composition	**Mixture**				
	SCC I	SCC II	SCC III	SCC IV	SCC V
Cement (kg/m^3)	431	409.5	388	366.5	345
Fly ash (kg/m^3)	97	97	97	97	97
Foundry sand waste(kg/m^3)	-	21.5	43	64.5	86
Fine Aggregate (kg/m^3)	913	913	913	913	913
Coarse Aggregate (kg/m^3)	755	755	755	755	755
Water (kg/m^3)	194	194	194	194	194
Super Plasticizer (by weight of powder)	1.25%	1.25%	1.25%	1.25%	1.25%

In the mixtures, cement was replaced with FSW at the contents of 0 %, 5 %, 10 %, 15 %, 20 % and Fly Ash 25 % by mass. After some preliminary experiments with varied powder content and super plasticizer dosage, the water–powder ratio by volume (w/p) was selected as 1.05 and the total powder content was fixed at 528 kg/m3. Super plasticizer dosage by trial and error was 1.3 % by weight of powder.

2.3 Fresh concrete tests

A separate batch was prepared for all mixtures. The sequence of mixing consisted of homogenizing the sand, the coarse aggregate, BSW, FA and cement in a lab mixer. After incorporation of water, superplasticizer was finally introduced to the wet mixture. The dispersion of super plasiticizers is a critical part in mixing. In order to sustain the equilibrium viscosity, longer mixing times are required. Optimum mixing time and order should be examined at pre-tests for each type of plant. The results of pre-tests showed that a total mixing time of 3-4 min is enough to stabilize the slump flow and V-funnel flow values. Thirty five percent of the batch was used for fresh concrete tests. The other part was used to prepare the specimens without any vibration in order to determine the mechanical properties. The specimens were membrane cured with water at 20o C right up until the testing day. For determining the self-compactability properties (slump flow, T50 time, V-flow time, L-box blocking ratio) tests were performed. All fresh test measurements were repeated and the average of measurements was given. In order to reduce the effect of workability loss on variability of test results, the fresh-state properties of mixtures were determined in a period of 20 min after mixing. Before testing, fresh SCC was remixed for 30 seconds. The order of testing was: a) Spread flow test and measurement of T50 time b) V-flow test c) L-box test d) U-box test e) J-ring. During slump flow test, the required time for SCC to reach 500 mm slump diameter and final diameter of concrete circle formed by SCC were measured. For the experiment of V funnel, required time for the self compacting concrete to flow thorough V funnel by virtue of its own weight was measured. In the L Box test, the control gate was suddenly opened and the SCC was allowed to flow thorough horizontal part of L box. After the flow was stopped, the heights of concrete at the end and at the beginning were measured and the blocking ratio is the ratio between height at end and height at beginning. The slump flow values of the different SCC mixes were measured to be the mean spread diameter of concrete between 650mm and 800mm. In order to achieve good balance between deformability and stability, a low water powder ratio was selected. The FSW and FA act as good filler material but they do not affect the cohesiveness of the mix. Therefore the T50 values were found to be around 5-6 sec. The slump flow values were found to be between 700 mm and 750 mm. The blocking ratio was observed to be within 0.8 to 0.9 which ensures adequate viscosity of the mix. The results of fresh concrete properties like flowability and passing ability are shown in Table 4. Since the preliminary tests were conducted to decide the mix proportions and super plasticizer dosage, all the SCC mixes satisfied the self compactability criteria. They showed a similar trend of flow properties. Initially it was felt that the angular nature of BSW may affect the flowability and self compacting nature. Since the fly ash contains spherical particles tending to improve the cohesiveness and the effect of angularity was minimized, improved the flow parameters.

TABLE 3. EFNARC SPECIFICATIONS FOR SCC

Property	**Test Methods**	**Typical Range**
Filling ability	Slump flow	650-800 mm
	T_{50} cm slump flow	2-8 s
	V- funnel	8-12 s
Passing ability	L- box (H_2-H_1)	0.8-1
	U-Box (R_1-R_2)	0-30 mm
Segregation Resistance	V-Funnel T_5 min	+3 sec

Fig 4. Fresh Properties of SCC: J Ring, V Funnel, L box, U box and Slump flow

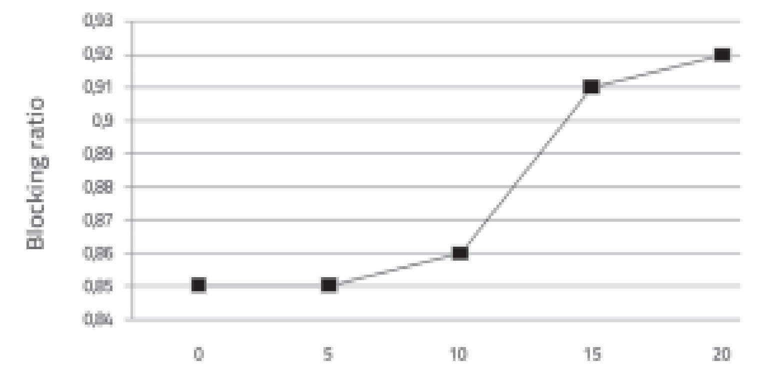

Fig 5. Influence of FSW on blocking ratio

TABLE 4. RESULTS OF FRESH PROPERTIES OF SCC

Foundry sand waste (FSW) (%)	Slump Flow (mm)	T_{50} cm Slump flow	V-funnel (s)	L-box H_2/H_1	U-box R_1-R_2	J-ring
SCC I (0%)	730	5	8.66	0.85	6	5.3
SCC II (5%)	740	5	8.75	0.85	6	5.3
SCCIII (10%)	735	4	8.48	0.86	4	5.8
SCCIV (15%)	735	4	8.24	0.91	5	7.5
SCC V (20%)	740	4	8.27	0.92	4	7.7

2.4 Test Set-Up And Procedure To Determine Hardened Property

All the tests were carried out in an electronic universal testing machine (UTM) of capacity 1 000 kN. The columns were hinged at both ends and axial compressive load was applied. The test set-up of columns is shown in Figure 1. A pre-load of about 5 kN was applied to hold the specimen upright. Dial gauges were used to measure the lateral and longitudinal deformations of the columns. The load was applied in small increments of 20 kN. At each load increment, the deformations were recorded. All specimens were loaded up to failure.

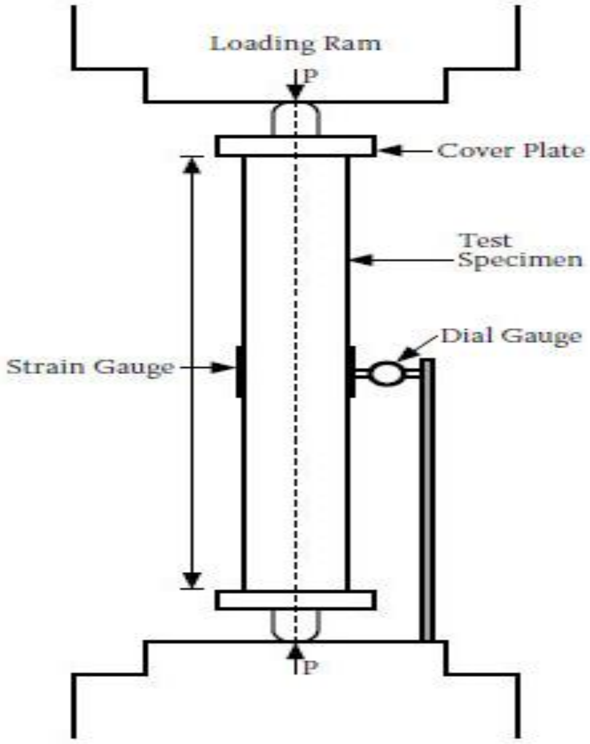

Fig 6. Test setup of stub columns in electronic UTM (1000 KN)

2.5 Failure Modes of Specimens

Figure 7 shows that the failure mode of 300 mm long columns is by local buckling close to the supports, as indicated in each column.

Fig 7. Testing of stub columns in electronic UTM (1000 KN)

III. TEST RESULTS AND DISCUSSIONS

Figure 7 shows the testing of stub columns in electronic UTM (1000 KN). From the results it can be noted that the load carrying capacity of square columns of all sizes, hollow as well as filled with plain concrete and foundry waste sand concrete, is more than that of the circular column with a comparable size. Figure 8 shows the load lateral deflection patterns for both hollow circular and square columns. From Figure 8 it can be observed that the hollow square column performs better than the hollow circular column. Hence about 30% of steel can be saved when square columns are used to obtain the same load capacity. Table 4 and 5 shows the load carrying capacity of square and circular columns

TABLE 4. LOAD CARRYING CAPACITY OF SQUARE COLUMNS

Model - Square	Maximum load (KN)	Mode of failure
Hollow	414	Local buckling
Plain SCC	208	Local buckling
Fill.Scc 0%	518	Local buckling
Fill.Scc 5%	526	Local buckling
Fill.Scc 10%	535	Local buckling
Fill.Scc 15%	540	Local buckling
Fill.Scc 20%	520	Local buckling

TABLE5. LOAD CARRYING CAPACITY OF CIRCULAR COLUMNS

Model - Circular	Maximum load (KN)	Mode of failure
Hollow	518	Local buckling
Plain SCC	468	Local buckling
Fill.Scc 0%	1528	Local buckling
Fill.Scc 5%	1545	Local buckling
Fill.Scc 10%	1580	Local buckling
Fill.Scc 15%	1610	Local buckling
Fill.Scc 20%	1526	Local buckling

Figure 8 shows the load lateral deflection patterns for both hollow circular and square columns. From Figure 8 it can be observed that the hollow square column performs better than the hollow circular column. Hence about 30% of steel can be saved when square columns are used to obtain the same load capacity

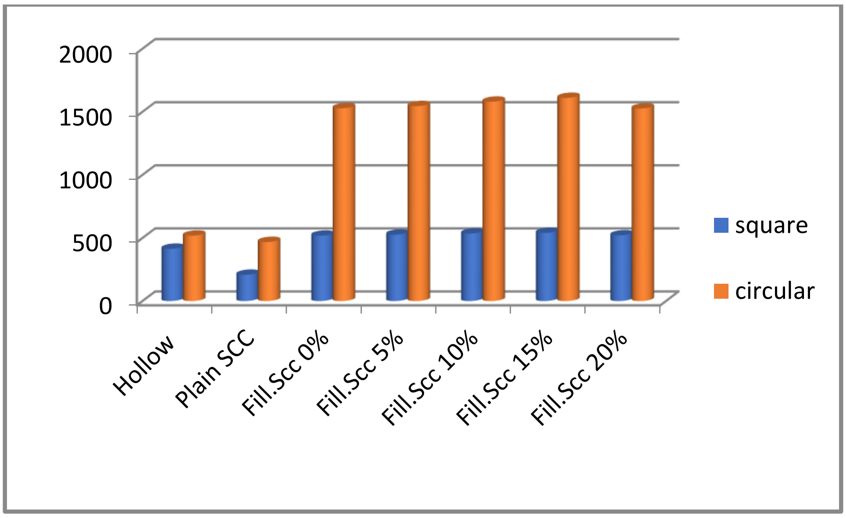

Fig 8: comparison of load carrying capacity of all stub columns

IV CONCLUSION

The aim of the study was to determine the optimum solution with reference to strength of the column, shape, size, material etc. This paper compared the failure of square, circular short, hollow steel columns, as well as concrete-filled columns, with conventional concrete and foundry sand waste concrete. From the experimental studies, the following conclusions were drawn:

Concrete-filled steel tubular columns can resist 60-112% more load than hollow steel tubular columns for sections with the same size and steel area.Foundry waste sand concrete-filled columns resist 66-121% more load than hollow columns, and 6-10% more than columns filled with plain concrete. Circular columns resist 34-41% more load than square columns for the same area of steel. Hence, size reduction for circular columns is possible.In the case of circular columns, a cost saving in the region of 30% can be achieved when compared to square columns of the same cross-sectional area.

The previously described results show that good deformability in a self compacting concrete mix can be obtained by reducing the water powder ratio. From the XRD results, it is found that the foundary sand waste particles are more angular with high specific surface. Hence they tend to increase the cohesiveness of the mix but they decrease the workability of mix. Since the fly ash particles are spherical in nature they improve the workability and enhance deformability, and a blend of the above two produces a more workable mix. Since the water powder ratio is constant the flowability is uniform for all mixes.The FSW (Foundry Sand Waste) is having greater than 25 % of reactive silica hence it can be partly used as a substitute material for cement. The main composition of FSW which are SiO_2 , Al_2O_3, CaO and Fe_2O_3 based components along with their tiny particle size ensure their use as a partial replacement material for cement in concrete. When the FSW is used as a replacement material for cement by15 % it increases the strength. FSW can be used without the loss of compressive strength because of their appropriate particle size distribution and potential pozzolanic activity. The continued hydration and void filling nature of FSW causes the increase in the density of concrete

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