Behaviour of Reinforced High Performance Concrete Filled UPVC Columns

Saraswati Setia
Department of Civil Engineering
National Institute of Technology
Kurukshetra-136119
ss_ts97@rediffmail.com

Abstract: *Steel is used for high rise buildings, but it is expensive proposition for low cost housing. Products like Unplasticised Poly Vinyl Chloride (UPVC) tubes can be used for low cost housing because of there low self weight and economy they affect. PVC pipes are readily available for piping work; its use is intended to be studied for its effectiveness in being used as columns. This type of columns is generally referred to as Concrete Filled UPVC Tube (CFUT).Local pipes which are 40% cheaper as compared to ISI pipes are also tested for their behaviour in this study. Fly ash is used as replacement material to cement (OPC grade 43) in order to reduce the cost of concrete. A total of 24 samples of Concrete Filled UPVC Tubes (CFUTs) were cast using M30 and M40 grade of concrete with 20% and 30% replacement of fly ash. The UPVC tubes of 190mm in diameter and 750mm of length short columns with L/D 3.93 and 3.94 and D/t is between 28 and 31. Parameters studied were the effects of fly ash on the strength of concrete when filled in UPVC tubes of same diameter with a clear cover of 40mm..*

Keywords: *UPVC, flyash, short columns, L/D ratio*

1. INTRODUCTION

Experimental studies on concrete-filled steel tubes have been on-going for many decades. Concrete filled tubular (CFT) columns have been increasingly used in many modern structures, such as dwelling houses, tall buildings, and arch bridges. The composite tubular columns have better structural performance than that of bare steel or reinforced concrete structural members. Steel hollow sections act as reinforcement for the concrete. Steel concrete composite members have advantageous qualities such as enhanced strength, ductility and stiffness. Concrete filled steel tubes are an economical column type, as the majority of the axial load is resisted by the concrete, which is less expensive than steel. The steel tube serves as the formwork for casting the concrete, which reduces the construction cost. No other reinforcement is needed since the tube acts as longitudinal and lateral reinforcement for the concrete core. The confining effect causes the core concrete to behave in a triaxial stress state while the core concrete prevents the wall of the steel hollow section from buckling inward. A review of available experimental studies shows that the main parameters affecting the behavior and strength is the diameter/ thickness (d/t) ratio.

1.1 High Performance Concrete

High performance concrete is a concrete mixture, which possess high durability and high strength when compared to conventional concrete. This concrete contains one or more cementious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usually a super plasticizer. The term 'high performance 'is somewhat pretentious because the essential feature of this concrete is that it's ingredients and proportions are specifically chosen so as to have particularly appropriate properties for the expected use of the structure such as high strength and low permeability. Hence High performance concrete is not a special type of concrete. The fly ash utilization decreases the cost of the concrete; it will not hamper all the other parameters of normal concrete. Even the production of fly ash in the world is very high. So it is a best alternative and best use of a waste by-product too. It comprises of the same materials as that of the conventional cement concrete. The use of some mineral and chemical admixtures like fly ash and super plasticizer enhances the strength, durability and workability qualities to a very high extent. During last few decades requirement of high performance and highly durable concrete has been on rise.

.

2. LITERATURE REVIEW

Circular CFT with various grade of concrete with column diameter & length constant, d/t ratio varying from 22.9 to 30.5, were examined for the effects of steel tube thickness, bond strength between the concrete and the steel tube, and the confinement of concrete achieved. The obtained strengths are examined with the predicted values of Euro (code 4), Australian standard and American codes. The results found that the effect due to concrete shrinkage is critical for high strength concrete and negligible for normal strength concrete, and all the codes predicted lesser values than the obtained values, but Euro (code 4) gave the estimation for both CFT with normal and high strength concrete (Georgios, 2003).

When a concrete-filled FRP tube is under compression, the axially compressed concrete is also subjected to lateral confinement from the FRP tube, which is in tension in the circumferential (or hoop) direction. This lateral confinement from the FRP tube can increase both the strength and the ductility of the concrete significantly. As a result, a highly ductile compression member can be formed from the two brittle materials, namely, FRP and concrete, even when steel reinforcement is completely absent (Mirmiran, Shahawyet al, 1997). In addition to excellent ductility, the advantages of concrete filled FRP tubes include their excellent corrosion resistance and the lightweight nature of FRP tubes compared to steel tubes. With these advantages, concrete-filled FRP tubes are attractive for use as bridge columns and piles, both of which are commonly exposed to severe outdoor environments (e.g., seawater). Many studies (e.g. Fam et al 2001, 2002; Hong et al. 2002; Zhang et al. 2000; Mirmiran 2003) have conducted numerous studies on CFFTs over recent years. These studies were critically examined in the process of developing the Chinese Code, to establish reliable design provisions for CFFTs as compression members.

2.1 Unplasticised Poly Vinyl Chloride

The design of PVC-FRP confined concrete members requires accurate evaluation of the performance enhancement due to the confinement provided by PVC-FRP tube. Based on the study (Feng Yu and Di tao Niu, 2010) the static equilibrium condition and the yield criteria of concrete and PVC-FRP tube, presented a calculating model of the load-carrying capacity of PVC-FRP confined concrete column, the influences of the hoop spacing of FRP strips and equivalent confinement effect coefficient on load-carrying capacity were well considered. According to the ingression of experimental data, a calculating formula of the ultimate axial strain is also put forward. A bilinear stress-strain model of PVC-FRP confined concrete column in axial and lateral directions is established. The comparison between experimental and numerical results indicates that the model provides satisfactory predictions of the stress-strain response of the columns. For reinforced concrete column, the confining stress of steel spirals to concrete keeps constant after steel spirals yielding. But for PVC-FRP confined concrete column, the confining action of PVC-FRP tube to concrete is different. In the beginning load stage, the confining action of PVC-FRP tube to concrete is still not activated due to the small lateral deformation of core concrete. In the vicinity of ultimate compressive strength of unconfined concrete, the confinement of PVC-FRP tube is activated and starts to be obviously enhanced. In the final stage, the confining action continuously increase with the increment of axial load, and the load-carrying capacity and axial deformation has been greatly improved before the failure of PVC-FRP tube. The load carrying capacity and ductility of PVC-FRP confined concrete column can be obviously improved by the confinement of PVC-FRP tube to concrete. The proposed formula agreed well with test data. The model is not only simple, but also has higher calculating precision, the predicted stress-strain curves compare favorably with the results of this paper. A new type of concrete columns was developed at the University of Alabama in Huntsville for new construction to achieve more durable and economical structures by (Toutanji and Saafi, 2001). The columns are made of concrete cores encased in a PVC tube reinforced with fiber reinforced polymer (FRP).The PVC tubes are externally reinforced with continuous impregnated fibers in the form of hoops at different spacing. The PVC acts as formwork and a protective jacket, while the FRP hoops provide confinement to the concrete so that the ultimate compressive strength and ductility of concrete columns can be significantly increased. The volume of fibers used in this hybrid column system is very modest compared to other existing confinement methods such as FRP tubes and FRP jackets. This paper discussed the stress-strain behavior of these new composite concrete cylinders under axial compression loading. Test variables include the type of fiber, volume of fiber, and the spacing between the FRP hoops. A theoretical analysis was performed to predict the ultimate strength, failure strain and the entire stress-strain curve of concrete confined with PVC-FRP tubes. Test results show that the external confinement of concrete columns by PVC-FRP tubes results in enhancing compressive strength, ductility and energy absorption capacity. A comparison between experimental and analytical results indicated that the models provide satisfactory predictions of ultimate compressive strength, failure strain and stress-strain response. More tests are needed to investigate the applicability of the proposed models for different cross sections, shapes, high strength concrete and type of bond.

2.2 Concrete Filled UPVC Tubes

UPVC tubes were filled with concrete mix of M30 grade and M40 grade. The aim was to study the effect of confinement on concrete and enhancement of its strength. M30 and M40 grade of concrete were chosen to compare the strength values with varying amount of fly ash, as M30 and M40 grades are commonly used in multistory buildings as columns.

2.3 Selection of UPVC Tubes

UPVC pipes of 190mm external diameter and a length of 750mm are taken for this experiment for testing. These tubes were cut to their respective dimensions, sizes and their ends leveled and made smooth. Their lengths and external diameters were measured and accordingly their L/D ratio and D/t ratio were calculated and shown below in the table 1.

Table 1

S. No.	Nominal external diameter (mm)	Average Length (mm)	Average external diameter (mm)	Average thick- (mm)	L/D ratio	D/t ratio
1	190	750	190.45	6.1	3.938	31.221
2	190	750	190.30	6.3	3.941	30.206
3	190	750	190.65	6.6	3.933	28.886
4	190	750	190.10	6.2	3.945	30.661

Nomenclature of the samples

20FM30D190: 20F stands for 20 percent fly ash and M30 stands for compressive strength of concrete and D190 stands for the diameter of the UPVC tube.

The same naming is done for all the samples 6 bars of 12mm diameter was used as main reinforcement and 8mm diameter bars are used as ties at a spacing of 150mm center to center.

3.0 RESULTS & DISCUSSION

Results of the load carrying capacity of CFUT's are obtained from the corresponding load displacement curve of the specimen. The load carrying capacity due to the UPVC confinement effect was analyzed. The specimens were tested for combined loading i.e concrete loading and UPVC loading, so these two results were compared according to their grade of concrete and the amount of varying fly ash. The results of the compressive strength are given in tables 2 to 5. The load Vs displacement graphs were plotted from figs 1 to 4. The tables represent the peak load of all the four categories. The graphs were also plotted for all the four categories with load in KN on Y-axis and displacements in mm on X-axis respectively. These graphs have been plotted; by taking the average values of load and displacement for each category, so a total number of 4.

Table 2: Compressive Load of the Columns with 20% flyash replacement

S. No	Specimen	Max load (kn)
1	20FM40D190	999
2	20FM40D190	990
3	20FM40D190	942
4	20FM40D190	981
5	20FM40D190	985
6	20FM40D190	974

Table 3: Compressive Load of the Columns with 20% flyash replacement

S. No	Specimen	Max load (kn)
1	20FM30D190	878.3
2	20FM30D190	877
3	20FM30D190	852.4
4	20FM30D190	837.1
5	20FM30D190	825
6	20FM30D190	812.7

Table 4: Compressive Load of the Columns with 30% flyash replacement

S. No	Specimen	Max load (kn)
1	30FM40D190	779.4
2	30FM40D190	775.3
3	30FM40D190	773.7
4	30FM40D190	750
5	30FM40D190	739.4
6	30FM40D190	410

Table 5: Compressive Load of the Columns with 30% flyash replacement

S. No	Specimen	Max load (kn)
1	30FM30D190	440
2	30FM30D190	459.9
3	30FM30D190	457
4	30FM30D190	440.4
5	30FM30D190	432.4
6	30FM30D190	428.2

3.1 Load Vs Displacement for 20FM40D190 and 30FM30D190

In Fig 1 the load vs displacement is plotted for M40 grade of concrete with the variation in the amount of fly ash and the following points are observed:

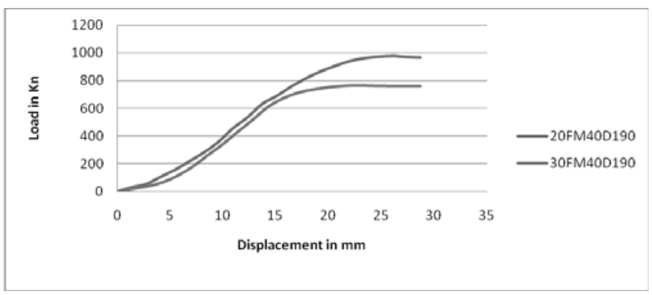

Fig 1: Load Vs Displacement of average of 20FM40D190& 30FM40D190

Both the graphs behave linearly until they reach peak load because the load is taken both by the concrete filled UPVC tube. 20FM40D190 does not show signs of major displacement after peak load because the maximum load capacity is reached by the concrete filled UPVC tube and initial cracking occurs when it reaches 97.80% of its total strength.30FM40D190 displays resistance at peak load so a straight line can be observed in the graph, so at this point resistance is offered by the UPVC tube which leads to displacement. Resistance is being offered only by the UPVC tube in this case because concrete fails at an early stage, due to the presence of extra fly ash. The initial cracking can be observed when it reaches 58.83% of its total strength. For 20FM40D190 the cube strength achieved in this design shows enhanced strength in a UPVC tube because of confinement pressure. For 30FM40D190 the cube strength achieved is lower than 20% fly ash replacement, but it show enhanced strength due to the presence of the UPVC tube which exerts a confinement pressure.

3.2 Load Vs Displacement for 20FM30D190 and 30FM30D190

In Fig 2 the load and displacement is plotted for M30 grade of concrete with the variation in the amount of fly ash and the following points are observed:

20FM30D190 and 30FM30D190 behaves linearly until peak load because of the composite of the concrete filled UPVC tube action. Initial cracking for 20FM30D190 is at 93.40% of its total strength, so at this point the concrete fails in the concrete filled UPVC tube, which causes lesser displacement after peak load. For 30 FM30D190 the initial cracking is at 67.84%, the concrete fails at an early stage because of the excess amount of fly ash. But it is hard to tell at what exact point the concrete fails, because of the early failure of concrete bulging is very high compared to due to this reason the displacement is very high compared to 20FM30D190.

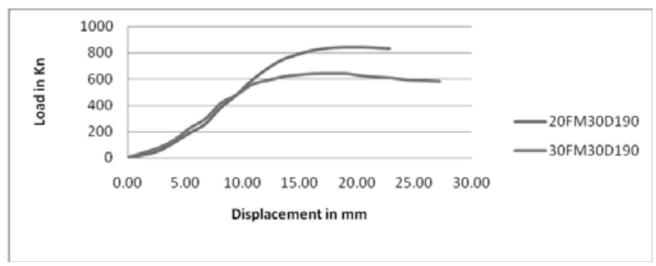

Fig 2: Load Vs Displacement of average of 20FM30D190 & 30FM30D190

3.3 Load Vs displacements for 20FM40D190 and 20FM30D190

In the graph (Fig 3) load and displacement is plotted while keeping fly ash constant and the following points are observed The displacement at peak load is a bit higher for 20FM30D190 because the concrete fails earlier than 20FM40D190. The failure of CFUT is almost sudden because the concrete fails at 93.40% of its total strength for 20FM30D190 and 97.80% for 20FM40D190. For lower grades of concrete, i.e is less than M30 the confinement effect is very significant, because concrete fails early before reaching the strength of the UPVC tube. Sudden failure of CFUTs is being observed in both the cases.

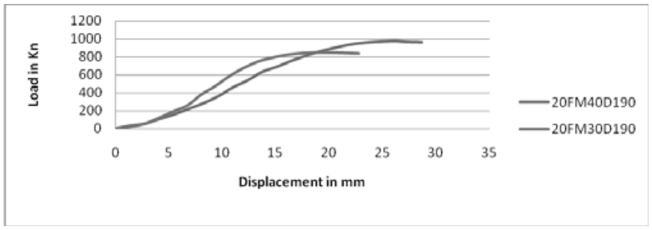

Fig. 3: Load Vs Displacement of average of 20FM40D190& 20FM30D190

3.4 Load Vs Displacement for 30FM30D190 and 30FM40D190

In the graph (Fig 4) load and displacement is plotted while keeping fly ash constant and the following points are observed:

The initial cracking for 30FM40D190 is at 58.83% of its total strength and 67.84% for 30FM30D190.For same amount of fly ash with different grades of concrete depicted in both the graph was similar but the displacements at the peak load are a bit higher by 20% for 30FM30D190 than 30FM40D190.30FM30D190 displays larger resistance to peak load when compared with 30FM40D190.The confinement effect is effectively utilized for 30FM30D190 than 30FM40D190. The higher displacement for 30FM30D190 justifies the statement. Higher fly ash content reduces the strength of concrete by 30%, so the UPVC will be subjected to load at a very earlier stage, so the displacements are higher. Even though the fly ash reduces the strength of concrete, the confinement effect increases the strength of the CFUT in both cases.

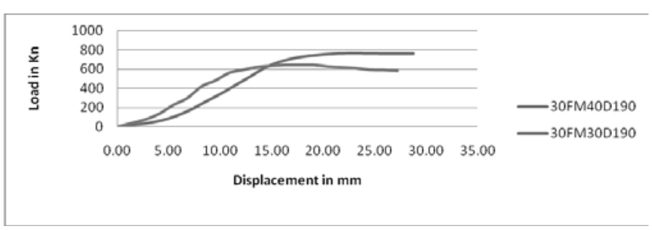

Fig. 4: Load Vs Displacement of average of 30FM40D190 & 30FM30D190

4. CONCLUSIONS

The longitudinal steel bars provide significant dowel action, which delays the dilation of concrete core inside CFUT, thereby improving the ductility of CFUT columns. It is found that most of the CFUT columns failed by local buckling and bulging of material radially in the out ward direction of the Fig. 5 and 6 Specimen before and after testing diameter of the column which causes the failure of UPVC tubes. The load-carrying capacities of the CFUT are considerably higher than the conventional RC columns. The strength enhancement will depend on percentage of the stiffness of the UPVC tube in radial direction. Local pipes fail by explosion and hence not preferred for low cost housing. The local pipes cannot be used for low cost housing; however the CFUT's can be used as piles, because the external pressure of the soil keeps the pipes intact preventing from an explosion. Most of the samples are failing in shear failure with diagonal crack, resulting to an explosion. Higher grade of concrete makes the CFUT's much brittle, because the breaking point of concrete is higher than the UPVC tubes. The mode of failure of the CFUT columns was by local buckling and bulging of material radial outer ward direction of the column. Higher fly ash content in concrete provides better strength in CFUT's than in RCC members.

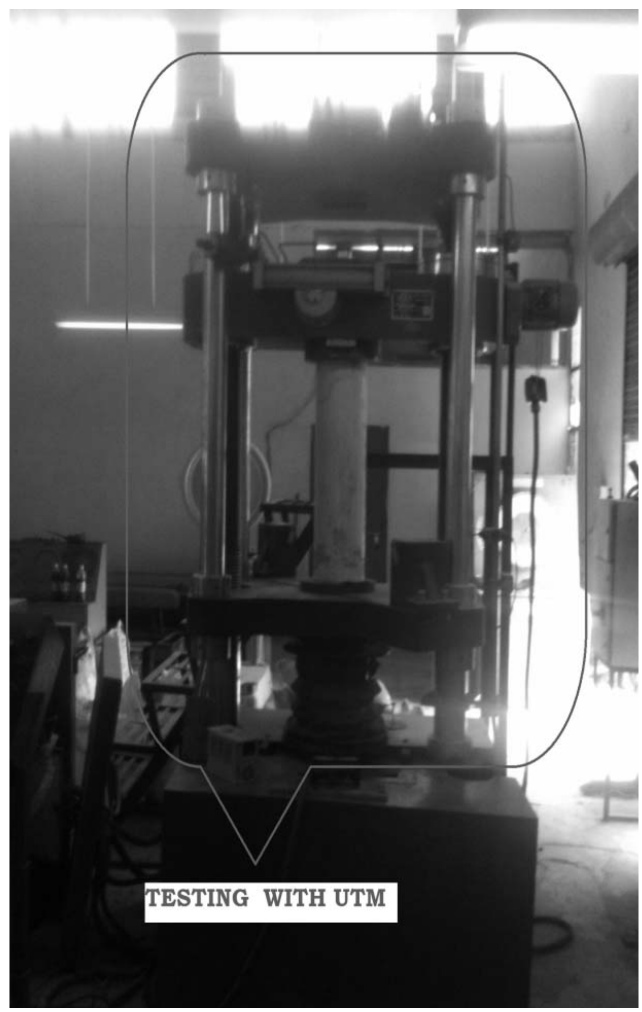

Fig. 5: Testing with UTM

Fig. 6: Failure of both Concrete and Steel

References

1. Artiomas Kuranovas,Douglas Goode, Audronis Kazimieras Kvedaras. Shantong Zhong: Load-Bearing Capacity of Concrete-filled Steel Columns: Journal of Civil Engineering and Management, 2009.

2. Chawla. Krishna.K, Composite Materials science and Engineering 2nd edition", Dept. of Materials & Mechanical Engineering, University of Alabama at Birmingham, U.S.A, 1988.

3. Department of Metallurgical and Materials Engineering, N.I.T, Karnataka (India) 2009.

4. F.W. Lu, S.P. Li, Guojun Sun, "A study on the behaviour of eccentrically compressed square concrete-filled Steel tube columns" Department of Engineering Mechanics, Shanghai Jiao Tong University, Shanghai, 200240, China, 2006.

5. Gian Piero Lignola, Andrea Prota, Gaetano Manfredi, Edoardo Cosenza: Unified theory for confinement of RC solid and hollow circular columns: Department of Structural Engineering, University of Naples "Federico II" Via Claudio 21, Naples I-80125, Italy.

6. Georgios Giakoumelis, Dennis Lam: "Axial capacity of circular CFT columns" Department of civil and environment engineering Imperial college, London, 2003.

7. Hui Lu, Lin-Hai Han, Xiao-Ling Zhao: Analytical behaviour of circular concrete-filled thin-walled steel tubes subjected to bending: Thin-Walled Structures 47 (2009) 346-358.

8. Houssam Toutanji and Mohamed saafi: Durability studies on concrete columns encased in PVC-FRP composite tubes; University of Alabama in Huntsville, USA, 2001.

9. IS: 383 Fine aggregate and Coarse Aggregate: UDC 691-322.

10. IS 456. 2000, Plain And Reinforced Concrete -Code of Practice (Fourth Revision).

11. Materials", Dept. of Mechanical and Aerospace Engineering University of Delaware, Dept, of civil engineering Ohio state university, USA 1986.

12. Manojkumar V. Chitawadagi, Mattur C. Narasimhan, S.M. Kulkarni "Axial strength of circular concrete-filled steel tube columns_DOE approach.

13. P.K. Gupta, S.M Sarda and M.S Kumar: Experimental and computational study of concrete filled steel tubular columns under axial loads: Journal of construction steel Research 63(2007) 182-193.

14. R. Eid, A.N. Dancygier: Confinement effectiveness in circular concrete columns: Engineering Structures 2S (2006) 1885-1896.

15. Srinivasan. K,"Composite Materials Production, Properties, testing and Applications".

16. Vinson, J.R and Sierakowski, R.L "The behavior of structures composed of composite".

17. Walter Luiz Andrade de Oliveira, Silvana De Nardin . Ana Lucia H. de Cresce El Debs, Mounir Khalil El Debs: Evaluation of passive confinement in CFT columns. Journal of (Constructional Steel Research 66 (2010)487_495.

18. Zhi-wu Yu. Fa-xing Ding, C.S. CAI, "Experimental behaviour of circular concrete-filled steel tube stub columns," College of Civil Architectural Engineering, Central South University, Changsha, Hunan Province 410075, PR China, Department of Civil and Environmental Engineering, Louisiana State University, Baton Rouge, USA, 2005.

❐