Behaviour of Hollow Sections with and without Infill under Compression and Flexure

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Abstract- Composite column are structural members, which are mainly subjected to forces and end moments. The steel tube serves as a formwork for casting the concrete, which reduces the construction cost. No other reinforcement is needed since the tube itself act as a longitudinal and lateral reinforcement for the concrete core. The Concrete filled steel tube member has many advantages compared with the conventional concrete structural member made of steel reinforcement. Concrete filled steel tubes are frequently used for columns, caissons, piers & deep foundations because of their large compressive stiffness. These composite sections have the rigidity and formability of reinforced concrete with the strength and speed of construction associated with structure, thereby making them economical. In the present study, an experiment is conducted on rectangular and square hollow structural steel with and without infill under compression and flexure. The infill material used in the hollow sections is conventional concrete and light weight concrete with chemical bond and mechanical bond. Compression and flexure tests are performed on the specimens and the behavior of the specimens are plotted. The behavior of hollow specimens with and without infill is observed from the experiment also effect of bonding between the concrete and steel is obtained. The results obtained from the experimental work are compared with numerical study by Finite Element Modeling using ANSYS.

Keywords- Hollow Sections, Finite Element Modeling, ANSYS, Compression and flexure tests.

1. INTRODUCTION

A steel-concrete composite structural member contains both structural steel and concrete elements which work together. There are many combinations between structural steel and concrete. For example, a concrete slab on a steel beam with mechanical shear connectors allows the slab and beam to resist bending moment together. A concrete-filled steel tubular (CFST) column is formed by filling a steel tube with concrete. It is well known that concrete-filled steel tubular (CFST) columns are currently being increasingly used in the construction of buildings, due to their excellent static and earthquake-resistant properties, such as high strength, high ductility, large energy absorption capacity, bending stiffness, fire performance along with favorable construction ability etc. Recently, the behavior of the CFST columns has become of great interest to design engineers, infrastructure owners and researchers. Steel-reinforced concrete column (SRCC), comprising a structural steel core surrounded by reinforced concrete, is used when an exposed concrete surface is required and when concrete is to protect the steel core from fire. Two types of composite columns, those with steel section encased in concrete and those with steel section in-filled with concrete are commonly used in buildings. Under severe flexural overload, concrete encasement cracks resulting in reduction of stiffness but the steel core provides shear capacity and ductile resistance to subsequent cycles of overload. Concrete-filled steel tubular columns have been used for bridge piers subject to impact from traffic, columns to support storage tanks, decks of railways, columns in high-rise buildings and as piles. In current international practice, CFSTs columns are used in the primary lateral resistance systems of both braced and unbraced building structures. There exist applications in Japan and Europe where CFST are also used as bridge piers. Recently in Australia, Singapore, and other developed nations, concrete-filled steel columns have experienced a renaissance in their use. The major reasons for this renewed interest are the savings in construction time, which can be achieved with this method. Concrete filled steel tubular columns have been utilized in dwelling houses, tall buildings and many types of arch bridges. Steel hollow sections used as reinforcement in this composite structure. CFST columns have established an appropriate loading capacity, ductility and energy absorption capacity. The steel tube functions as the formwork for casting the concrete and hence, construction cost is reduced. There is no other reinforcement and the tube acts as longitudinal and lateral reinforcement for the concrete core. An evaluation of available experimental studies shows that the main parameters influencing the behaviour and strength of concrete filled steel tubular columns are slenderness, the diameter to wall thickness (D/t) ratio and the initial geometry of the column. The mechanical parameters, such as the strength of the steel and concrete are also the main parameters.
The major benefits include:

- The steel column acts as permanent and integral formwork.
- The steel column provides external reinforcement.
- The steel column supports several levels of construction prior to concrete being pumped.

1.1 Motivation

A steel hollow section in-filled with concrete has higher strength and larger stiffness than the conventional structural steel section and reinforced concrete. Composite column are structural members, which are mainly subjected to forces and end moments. The steel tube serves as a formwork for casting the concrete, which reduces the construction cost. No other reinforcement is needed since the tube itself act as a longitudinal and lateral reinforcements for the concrete core. The continuous provided to the concrete core by the steel tube enhances the core's strength and ductility. The concrete core delays bending and buckling of the steel tube, while steel tube prevents the concrete from spalling. Also concrete filled tube (CFT) columns are suitable for tall buildings in high seismic regions since concrete delays the local buckling of steel hollow sections and increases the ductility of the section significantly. While there is a large number of studies on the behaviour of CFT columns and beam-columns. There is relatively little research reported on the flexural behaviour of concrete-filled hollow structural steel column. The structural behavior of a CFT is governed by the member strength, reflecting the fact that the load resistance is dependent not only on the material properties but also on the geometric properties of the entire member. Combining of these materials had a number of motivations; steel columns were often encased in concrete to protect them from fire, while concrete columns were combined with structural steel as reinforcement. Since past few decades, composite steel-concrete construction of column and girder is being used in the construction industry. These composite sections have the rigidity and formability of reinforced concrete with the strength and speed of construction associated with structure, thereby making them economical. The steel and the concrete element in a composite member complement each other ideally. Composite members consisting of rectangular steel tubes filled with concrete are extensively used in structures involving very large applied moments, particularly in zones of high seismic risk. Thus in present work the concrete filled steel tube columns and beams are cast and tested under compression and flexure respectively.

1.2 OBJECTIVES

1. To study the behavior of hollow and composite specimens under compression and flexure.
2. To study the effect of chemical and mechanical bond with composite section under compression and flexure.
3. To study the behavior of normal concrete and no-fines concrete under composite action.
4. To conduct finite element modeling and analyzing composite section under numerical method using ANSYS.
5.

2. LITERATURE REVIEW

2.1 Introduction

The first study of steel-concrete composite members began as early as 1908 at Columbia University. The combined material strength was not appreciated in the early days and the design concept considered two individual materials by either conservatively neglecting the contribution from one or another or by adding them separately. An early composite beam system that gained popularity was a concrete slab on steel beam with mechanical shear connectors. Later, other composite forms including concrete filled steel tube (CFSTS) construction where concrete is placed in a hollow steel member, reinforced-concrete steel (RCS) construction with RC columns and steel beams, and construction with steel-reinforced concrete (SRC) columns, became popular. SRC columns involves with steel members surrounded by concrete.

2.2 Experimentation

2.2.1 Compression test

Bhartesh and Sureshchandra have conducted tests in four series for each of the two tests. Each series consists of 9 specimens which are further subdivided as short column specimens, intermediate column specimens and long column specimens, consisting of 3 specimens respectively. Series 1 and 2 the specimens are cast with concrete and series 3 is cast with No-fines concrete. Each column has cross sectional dimension as 75 mm X 75 mm, and the length of specimens varies as 300 mm, 360 mm, and 400 mm for short, intermediate and long column specimens respectively. The thicknesses of hollow section used as 1.6 mm.

Chithira and Baskar experimentally investigated the thirty specimens subjected to eccentric load condition with and without shear connectors. Three different D/t ratios such as 21, 25 and 29, and L/D ratios varying from 5 to 20 here considered as parameters. Out of total 30 specimens, 6 specimens were based steel tubes as reference specimens and remaining 24 specimens were CFST columns-12 with shear connectors and 12 without shear connectors.

Patidar presented the advantages of concrete filled steel tube member with the conventional concrete structural member made of steel reinforcement. In this study experiment load verses axial deformation of composite columns were determined. The size of the column was 140 x 160 x 1500 mm and the grades of concrete infill are M20, M30 and M40. The thicknesses of the tube were taken as 2 mm, 3 mm, 4 mm, 5 mm and 6 mm and, the D/t ratio varies from 26.67 to 80.

Mohanraj and Kandasamy experimentally investigated ten slender steel tubular columns of circular and square sections filled with plain, fiber reinforced and partial replacement of coarse aggregate by rubber concrete. The specimens were tested under axial compression to investigate the effects of fiber reinforced and rubber concrete on the strength and behavior of slender composite columns.

Zhong and Lin-Haiet presented the results of axial compression test of fire-damaged concrete-filled steel tubes (CFST) repaired using unidirectional carbon fiber reinforced polymer (CFRP) composites. Both circular and square specimens were tested to investigate the repair effects of CFRP composites on them. The test results showed that the CFRP jackets enhanced the load-bearing capacity of the stub columns effectively. Enhancement of the columns' stiffness due to the CFRP jackets was also observed.

Sakino and Nakahara have done 5 year research on concrete-filled steel tubular CFT column system as a part of the fifth phase of the U.S.–Japan Cooperative Earthquake Research Program, and the tests of centrally loaded short columns were completed. The objectives of these tests were to see the synergistic interaction between steel tube and filled concrete and to derive methods to characterize the load–deformation relationship of CFT columns. A total of 114 specimens were fabricated and tested in the experimental phase of investigations of centrally loaded hollow and CFT short columns. Parameters for the tests were as follows, (1) tube shape (2) tube tensile strength, (3) tube diameter-to-thickness ratio, and (4) concrete strength. In determining the range of parameters, the emphasis was given on obtaining a wide range of test data for establishing a generally applicable design method of CFT column systems. Based on tests results for CFT columns with both circular and square cross sections design formulas were proposed to estimate the ultimate axial compressive load capacities.

Huang and Yeh experimentally investigated the behavior of axially loaded concrete-filled steel tubular CFT columns with the width-to-thickness ratios were in between 40 and 150, and proposes an effective stiffening scheme to improve the mechanical properties of square cross-sectional CFT columns. Seventeen specimens were tested experimentally to see the effects of cross-sectional shapes, width-to-thickness ratios, and stiffening arrangements on the ultimate strength, stiffness, and ductility of CFT columns.

Ghannam experimentally investigated twelve full scale column specimens of rectangular, circular steel filled with normal and lightweight concrete as Well as hollow sections to investigate the behavior of such columns under axial loadings and their buckling. The test results showed that both types of filled columns failed due to overall buckling, while hollow steel columns failed due to local buckling at the ends. The experimental results show that the steel tubes filled with lightweight aggregate concrete show acceptable strength under the applied load when compared to design calculations. Present work considered rectangular and square cross section steel filled with normal mix and light weight concrete also considered short columns for compression test. for special concrete no-fines concrete which is commonly termed as light weight concrete is used.

Shanmugam and Lakshmi have done extensive research on composite columns in which structural steel section are encased in concrete have been carried out. A review of the research carried out on composite columns is given with emphasis on experimental and analytical work. The review also includes research work that has been carried out accounting for the effects of local buckling, bond strength, seismic loading, confinement of concrete and secondary stresses on the behavior of steel– concrete composite columns. In this present work concrete filled steel tube columns are used.

2.2.2 Flexure test

Zhong and Lin-Haiet presented the results of bending test of fire-damaged concrete-filled steel tubes (CFST) repaired using unidirectional carbon fiber reinforced polymer (CFRP) composites. Both circular and square specimens were tested to investigate the repair effects of CFRP composites on them. Forbeams, the test results demonstrated that the repair effect was not as good when compared with that for stub columns. From the test results, it was recommended that other appropriate repair measures should be taken in repairing severely fire-damaged CFST beams, or those members subjected to comparatively large bending moments.

Lin-Hai mechanics model that can predict the behavior of concrete filled hollow structural section (HSS) beams. A series of concrete filled square and rectangular tube beam tests were carried out. The main parameters varied in the tests were the depth to-width ratio from 1 to 2, and tube depth to wall thickness ratio from 20 to 50. The load versus lateral deflection relationship was established for concrete filled HSS beams both experimentally and theoretically. It was conducted that because of the infill of concrete, the tested concrete-filled steel SHS and RHS beams behaved in a relatively ductile manner and testing proceeded in a smooth and controlled way. The enhanced structural
behavior of the columns can be explained in terms of composite action between the steel tube and the concrete core. The predicted load versus lateral deflection curves for the composite beams were found to be in good agreement with experimental values. The predicted maximum strength of beams agreed well with the tested values. Simplified methods for the calculations of the moment capacities of the composite beams were proposed based on the mechanics model in this paper. In this present study of aspect ratio for rectangular cross section of column in between 1-2 and for square cross section of column aspect ratio 1 was considered.

Famand Rizkalla experimentally investigated the results of large-scale concrete-filled glass fiber reinforced polymer (GFRP) circular tubes and control hollow GFRP and steel tubes tested under bending. The diameter of the beams was ranged from 89 to 942 mm and the spans ranged from 1.07 to 10.4 m. The study investigated the effects of concrete filling, cross-sectional configurations including tubes with a central hole, tube-in-tube with concrete filling in between, and different laminate structures of the GFRP tubes. The study demonstrated the benefits of concrete filling, and showed that a higher strength-to-weight ratio could be achieved by providing a central hole. The results indicated that the flexural behavior was highly dependent on the stiffness and diameter-to-thickness ratio of the tube, and, to a much less extent, on the concrete strength. Test results suggest that the contribution of concrete confinement to the flexural strength was insignificant; however, the ductility of the member was improved. A strain compatibility model was developed, verified by the experimental results, and used to provide a parametric study of the different parameters, significantly affecting the behavior. The parametric study covered a wide range of FRP sections filled with concrete, including under-reinforced, balanced, and over-reinforced sections.

Yue and Laurie investigated a series of four flexural rectangular and square cold-formed hollow structural steel sections and twelve concrete filled sections to assess the general behavior of these composite sections. The test specimens were selected to examine the effects of different ratios of depth to width and therefore of the proportions of steel and concrete in compression, and of different values of shear span to depth as related to the transfer of forces from one to the other when no direct means is provided for this transfer. The tests showed that the ultimate flexural strength of the concrete-filled sections is increased by about 10-30% over that of the bare steel sections, depending on the relative proportions of steel and concrete. The stiffness is also enhanced. In all cases, slip between the steel and concrete was not detrimental, even though shear-span-to-depth ratios as low as 1 were tested. Models are developed to predict the flexural strength of the composite section. Fully plastic stress blocks with the concrete at its maximum strength are used. The models are in excellent agreement with test results.

2.3 Numerical Analysis

2.3.1 Compression test

Mathankumar and Anbarasan analysed the behaviour of steel tubular section filled with concrete CFST using finite element software ANSYS. The present study was an attempt to understand the failure load of steel tubular section filled with concrete column under axial loading for different shapes such as circular and rectangular. In this project modelling of various cross section of column has been simulated nonlinearly by finite element method. Models were loaded in a concentric axial compression, and the failure loads are to be extracted. All models to be simulated have length to diameter ratio (L/D) not exceeding the value of 4.5 to act as short column and therefore no slenderness was be taken in to account. Failure loads calculated by ANSYS are compared with the results obtained using AISC code of practices and EURO CODE 4.The numericalresults obtained from ANSYS indicate good agreement with the theoretical resultcalculated by using AISC code of practice and Euro code 4.

Kurian and Pauloseet numerically investigated the deformationcharacteristics of composite columns by using software ANSYS workbench. This paper focuses on modeling of concrete filled steel tube (CFST) column under axial loading. In this study, three dimensional finite element models have been developed to investigate the force transfer by natural bond and the interaction between the steel tube and the concrete core of concrete filled steel tubes under loading. Both material and geometric nonlinearities are considered in the analysis. Concrete filled steel tubular columns axial capacity significantly affected with the cross section of the column, concrete's compressive strength and yield strength of the steel tubes.

2.3.2 Flexure test

Laxmi and Chitawadag presented the ANSYS model to predict the behaviour of concrete filled steel tubeto determine moment carrying capacity at ultimate point for beam. Concrete filled steel tube beams are studied and verified by the finite element program ANSYS against experimental data. The Main parameters affecting the behaviour and strength of concrete filled beams are geometrical parameters, material nonlinearities, loading, boundary conditions and degree of concrete confinement. The main parameters varied in analysis study are D/t ratio, characteristic strength of in filled concrete. The developed model predicts ultimate moment capacity for CFTbeams.In the numerical analysis, circularand rectangularCFT cross sections were consideredusing different grades of concrete. The predicted values were compared with experimental results. Numericalanalysis has shown that forrectangular CFT'sa good confining effect can be provided. Moment capacity results obtained from the ANSYS model are compared with the values predicted by Lin Han (2004)and different codes such as AISC-LRFD (1999) and EC4 (1994). It is found that finite element model predicts moment capacity at ultimate point for circular, rectangular CFT's quite agree with those determined from actual experiments.

Arivalagan and Kandasamy experimented the concretefilled steel tube (CFST) beams and verified by the Finite Element program ANSYS against experimental data. In the numerical analysis, the cross sections of the CFST are square steel sections, and sections strengthened by being filled with normal mix concrete and quarry waste concrete. Numerical analyses have shown that for square CFST a good confining effect can be provided. This effect was enhanced especially by the filling. Results of FE analysis and EC4 standard code show that the experimental investigation yields conservative prediction for the behaviour of CFST beams.

Das and Vimalanandanet experimentally investigated the flexural behaviour of GGBS concrete infilled steel tubular sections. A series of tests on concrete filled square beams and hollow tube were carried out. The experimental results showed that the load carrying capacity of concrete filled steel tubes (CFST) were much higher than that of hollow tubes. The deflection was higher for concrete filled steel tubular beam. The strain was less in concrete filledsteel tube. Analytical study was carried out for all types of specimen using ANSYS software. FEA results agrees well with experimental results.

3. METHODOLOGY

3.1 Introduction

To determine the Behaviour of Hollow sections with or without filling of concrete will be carried in such a way that we will get a clear idea about the advantages of Composite Section Over the conventional sections, the casting of composite columns and beams and tests are conducted on composite columns and beams in accordance with Indian standards. The results for hollow sections filled with normal concrete will be compared with that of no fines concrete. We will use 3 series of the sections having following details to achieve the desired results.

3.2 Composite Columns and Beams

The tests will be performed in four series. Table 3.1 indicates the first two series of specimens on which compression test will be performed. First and second series consists of 12 specimens each of rectangular and square cross sections respectively. Table 3.2 indicates the next two series of specimens on which flexure test will be performed. Third and fourth series consists of 12 specimens each of rectangular and square cross sections respectively. Each series consist of 12 specimens out of which 3 specimens will cast with normal concrete chemical bond, 3 specimens with normal concrete mechanical bond, 3 specimens with No-fines concrete chemical bond and remaining 3 specimens will be kept hollow i.e. without any bond and infill. First and second series consist of rectangular and square cross sections specimens of dimensions 95 X 50 mm and 72 X 72 mm respectively and lengths are 300 mm and 432 mm respectively. Third and fourth series consist of rectangular and square cross sections beams of dimensions same as like first two series specimens but actual lengths and gauge lengths of all beam specimens will 500 mm and 400 mm respectively. Thicknesses of all sections will be 2.4 mm.

Table3.1: Specifications of composite columns

Series No.	Concrete type	Bond type	Cross section of column	Abbreviations used
Series 1	Normal concrete	Chemical bond	Square	NCS-C1 NCS-C2 NCS-C3
	Normal concrete	Mechanical bond	Square	NMS-C1
	No-fines concrete	Chemical bond	Square	NFCS-C1 NFCS-C2 NFCS-C3
	Hollow section		Square	HS-C1 HS-C2 HS-C3

Series No.	Concrete type	Bond type	Cross section of column	Abbreviations used
Series 2	Normal concrete	Chemical bond	Rectangular	NCR-C1 NCR-C2 NCR-C3
	Normal concrete	Mechanical bond	Rectangular	NMR-C1 NMR-C2
	No-fines concrete	Chemical bond	Rectangular	NFCR-C1 NFCR-C2 NFCR-C3

Table3.2: Specifications of composite beams

Series No.	Concrete type	Bond type	Cross section of column	Abbreviations used
Series 3	Normal concrete	Chemical bond	Square	NCS-F1 NCS-F2 NCS-F3
	Normal concrete	Mechanical bond	Square	NMS-F1
	No-fines concrete	Chemical bond	Square	NFCS-F1 NFCS-F2 NFCS-F3
	Hollow section		Square	HS-F1 HS-F2 HS-F3

Series No.	Concrete type	Bond type	Cross section of column	Abbreviations used
	Normal concrete	Chemical bond	Rectangular	NCR-F1 NCR-F2 NCR-F3
	Normal concrete	Mechanical bond	Rectangular	NMR-F1
	No-fines concrete	Chemical bond	Rectangular	NFCR-F1

				NFCR-F2 NFCR-F3
Series 4	Hollow section		Rectangular	HR-F1 HR-F2 HR-F3

3.3 Material Properties

3.3.1 Cement

The cement used was Ordinary Portland Cement for no-fines concrete of 53 Grade confining to IS 12269. Cement should be fresh and of uniform consistency. Where there is evidence of lumps or any foreign matter in the material, it should not be used. Cement should be stored under the dry condition and for as short duration as possible. For normal concrete Pozzolana Portland Cement was used.

3.3.2 Water

Water used in the mixing is to be fresh and free from any organic and harmful solution which will lead to deterioration in the properties of the mortar. Salty water is not to be used. Potable water is fit for mixing of materials as well as curing.

3.3.3 Aggregate

It's obtained from crushed and broken hard stones. It is hard, strong, dense and durable. It is clean and free from dirt and any other foreign matter. It is sound, hard, and clean suitably graded in size. The size of the aggregate shall be 20mm graded down and shall be retained in 4.75mm size.

3.3.4 Sand

It is also called as a fine aggregate. Aggregate most of which passes 4.75 mm is sieve is known as a fine aggregate. Sand as a fine aggregate is coarse, consisting of sharp, angular grains and be of standard specifications. It is clean and free from dirt and any other foreign matter. Crushed stone may also be used as fine aggregate.

3.3.5 Hollow structural steel section

A hollow section shall be designated by its outside dimensions and its thickness in millimeters and shall be further classified into CF or HF depending upon whether it is cold formed or hot formed. For compression test the hollow sections used in the tests are square and rectangular cross sections of dimensions 72 x 72 x 2.4 mm and 95 x 50 x 2.4 mm respectively where 2.4 mm is the thickness of the hollow sections. The square and rectangular sections are having lengths of 432 mm and 300 mm respectively. The square and rectangular cross sectional flexural members having same dimensions as like the compression members but actual span of all flexural members were 500 mm and gauge lengths were 400 mm. The properties of the hot rolled structural section are tabulated in the table 3.3.

3.3.6 Cross sectional size of hollow sections

As per American Institute of Steel Construction 2005 the cross sectional area of steel hollow section shall be comprise at least one percent of the total composite cross

Section. The maximum b/t ratio for a rectangular HSS used as a composite column shall be equal to $2.26\sqrt{E/Fy}$. Higher ratios are permitted when their use is justified by testing or analysis. The maximum D/t ratio for a round HSS filled with concrete shall be 0.15 E/fy. Higher ratios are permitted when their use is justified by testing or analysis.

Table3.3: Tensile properties of hot formed sections

Grade	Tensile strength, min MPa	Yield stress, min MPa	Elongation percent Min
YSt 210	330	210	20
YSt 240	410	240	15
YSt 310	450	310	10

3.3.7 Concrete

Material properties were tested before designing the mix proportion and are tabulated in Table 3.4. Normal concrete and No-fines concrete was used in composite columns. Twenty four specimens are casted using normal concrete and twelve specimens are cast using No-fines concrete.

Table3.4: Properties of materials

Cement	
Grade	53
Specific gravity	3.2
20 mm coarse aggregates	
Specific gravity	2.6
Water absorption	2.43 %
10 mm coarse aggregates	
Specific gravity	2.58
Water absorption	3.87 %
Fine aggregates	
Specific gravity	2.66
Moisture content	4.6 %

Table3.5: Normal concrete proportion for M-20 grade concrete

Particulars	Quantity per cubic meter volume
Cement	379.53 kg
20 mm coarse aggregates	799.99 kg
10 mm coarse aggregates	342.85 kg
Fine aggregates	66.35 kg
Water	196.07 kg
Admixtures	1518.12 ml

4. RESULT AND DISCUSSION

We will Keep the Experimentation work and obtaining their results, modeling of steel tubes and analysis of the same tubes with ANSYS is included in future Plans.
Experimentation included all the various test to be performed on steel tubes of 4 series as mentioned above and will obtain their results.

4.1 Experimentation
This section includes the Compression test, Flexural test And Casting of tubes with Concrete And their Graphs.

4.2 Finite Element Modeling

To analyze and get precise results, software required some inputs like material property, element type, boundary condition, proper meshing etc. In this step sketching of hollow section is possible for both hollow column and beams sections and in case of composite column and beam sections the geometry is imported which is prepared in CATIA. In this step composite beam sections slicing is also done at required distances.

4.2 Analysis with ANSYS

Structural analysis is the process to analyze a structural system to predict its responses and behaviors by using physical laws and mathematical equation.
The main objective of structural analysis is to determine internal forces, stresses and deformation of structures under various load effects.

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