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Fracture Analysis of Concrete Composite Steel Tube Subjected to Compressive Loading

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ABSTRACT

Concept of Concrete-filled steel tube is of recent origin where in the steel pipe is utilized to constraint its core concrete and make the core concrete under complex stress state so that concrete strength can be improved for its ductility and toughness . This structure possesses high bearing load capacity, good ductility, good anti-seismic performance, fire resistance property and low cost. It has been widely used in the civil engineering, such as bridge structures, high-rise buildings, and industrial plants and so on. Now a days , the concrete-filled steel tube has been studied a lot and have made great progress, However, for its Monotonic Loading, the concrete fill results in good bearing capacity, and compression loading is very difficult to realize. The concrete columns under compression is common form of engineering structures. Hence, it is necessary to study the failure and damage process of concrete-filled steel tube (CFST) column with M20,M25,M30,M40 grade of concrete under compression load. Experimental Results of Concrete filled steel tubes (CFST) column with M20,M25,M30, and M40MPa grade of concrete obtained by Previous Research (From VTU R& D project conducted at R & D Centre, Civil Engineering Department, Ghousia College of Engineering, Ramnagaram) will be modeled for Fracture Analysis and compared with actual fracture of Concrete filled steel tubes (CFST) columns using the ABAQUS /CAE 6.10-1. Proper Analytical modeling will be carried out taking in to account all fracture parameters and justified with ABAQUS. Ultimate load for all the above four infill's, after crack will be determined.

Introduction

As the use of concrete as a structural material continues to increase, it becomes even more important that general failure criteria be developed that can predict when and how the concrete will fail when subjected to various loading cases. The main objective of this study is to develop general failure criteria for Concrete filled steel tubes (CFST) Subjected to Monotonic loading Concrete filled steel tubes (CFST) are gaining increasing usage in modern construction practice throughout the world, particularly in Australia and the Far East. This increase in use is largely due to the structural and economical advantages offered by concrete filled tubes over open and empty sections, as well as their aesthetic appeal. From a structural viewpoint, hollow sections exhibit high torsional and compressive resistance about all axes when compared with the open sections[3].. Additionally, the exposed surface area of a closed section is approximately two-thirds that of a similar sized open section, thus demanding lower painting and fireproofing costs .Composite columns comprise a combination of concrete and steel and utilize the most favorable properties of the constituent materials. Use of composite columns can result in significant savings in column size, which ultimately can lead to considerable economic savings. This reduction in column size provides is particularly beneficial where floor space is at a premium, such as in car parks and office blocks. The use of stainless steel columns filled with concrete is relatively new and innovative, and not only provides the advantages outlined above but also brings the durability associated with stainless steel. The term 'composite column' refers to a compression member in which the steel and concrete elements act compositely. The role of the concrete core in a composite column is not only to resist compressive forces but also to reduce the potential for buckling of the steel member. The steel tube reinforces the concrete to resist any tensile forces, bending moments and shear forces, and offers confinement to the concrete. Composite columns can buckle in local or overall modes, but this investigation is focused on the cross-section resistance of short composite columns, where only local buckling effects were exhibited. Unlike carbon steel, stainless steel possesses natural corrosion resistance; significantly, this means that, appropriately specified, the surface can be exposed without the need for any protective coatings. The principal disincentive for the utilization of stainless steel for structural elements is the high initial material cost, but, considered on a whole-life basis, cost comparisons with other metallic materials become more favorable . Concrete infilling on stainless steel tubes maintains the durable and aesthetic exposed surface, but will lead to reduced column sizes and material thickness, both of which have clear economic incentives. The main objective of this research program is to investigate the compressive behavior of composite stainless steel concrete filled columns with concrete infill strengths of 20, 25 30 and 40MPa. Comparisons are made with existing design rules based on Euro code 4 [8] and ACI-318 [7].

The researches and applications of the concrete-filled circular and square steel tube have been getting more attention in World, but the studies about the fracture and failure mechanism of the concrete-filled steel tube are not profoundly enough, where the further investigations are still needed. Numerical simulation software- can be used simulating the damage process of brittle material (such as rock and concrete),

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and it has been successfully used in simulating the fracture process of rock and concrete. Therefore, the paper carries on the numerical simulation on the damage process of concrete filled circular steel tube by HYPERMESH and ABAQUS 6.10. First, in order to get correct parameters on simulation, the ABAQUS was used to simulating the real concrete-filled circular steel tube axial compression experiment, compare the ultimate bearing capacity and load-strain curve of concrete-filled steel tube with experiment data .simulation data can match with test data well, then the correct simulation parameters is obtained. And then use these parameters to simulate the compression of concrete-filled steel tube, through simulate calculation , it can be got the cracks growth process, reappeared the concrete-filled steel tube failure process which under compression, through the simulation results we can canvassed study the failure mechanism of concrete-filled circular steel tube column which under axial compression.

Finite Element Method

The finite element analysis is a numerical technique. In this method all the complexities of the problems, like varying shape, boundary conditions and loads are maintained as they are but the solutions obtained are approximate. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in engineering.

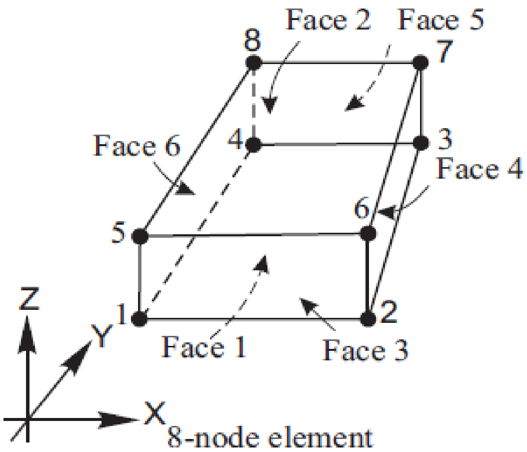

Fig 1. Eight- node solid element (C3D8)

Modling And Meshing Concrete Filled Circullar Tube

Solid elements in Hyper Mesh v11.0 used to be more efficient in modeling the steel tube as shown Fig 1 as well as it clearly defined boundaries of their elements. Three-dimensional eight-node solid element (C3D8I) is used in this study.

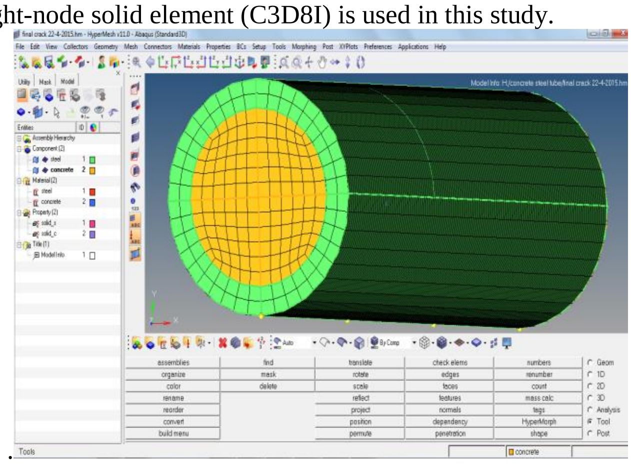

Fig 1. Finite Element Meshing Using Hyper mesh V11.0 (source shell is quads and element size is 2mm)

Materail Specfication

Material: Structural Steel Fe 250 MPa
Young's modules E=210000Mpa
Poison ratio v= 0.3
Density p=7850kg/m3

Concrete

Grade of concrete =M20,M30,M40
Young's modules E=22360(20), 25000Mpa(M25), 27386.12(M30), and 31622.78(M40).
Poison ratio v= 0.2
Density p=2400kg/m3

Boundary Condition

Bottom end of concrete filled steel tube is fixed as shown in Fig 2, displacement degrees freedom in 1,2,3 directions (U1,U2,U3,) as well as rotational degrees of freedom in 1,2,3 directions (UR1,UR2,UR3) were restrained to be zero. And the top surface of concrete filled steel tube is fixed with U1=U2=0 allowing displacement to take place in z direction.

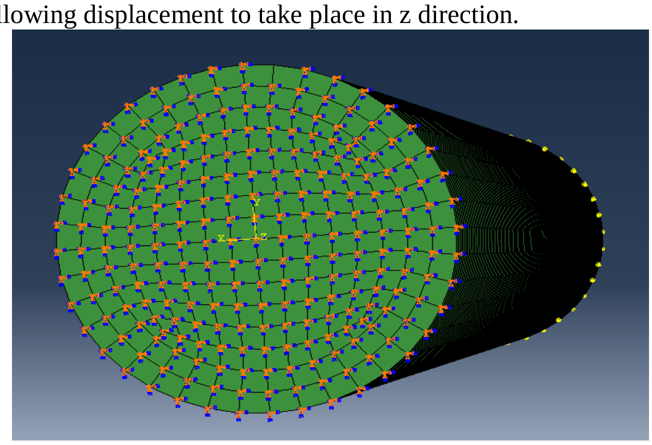

Fig 2. Boundary condition of concrete filled steel

Appling Load

Top surface of concrete steel tube selected first then Load is applied uniformly as shown below.

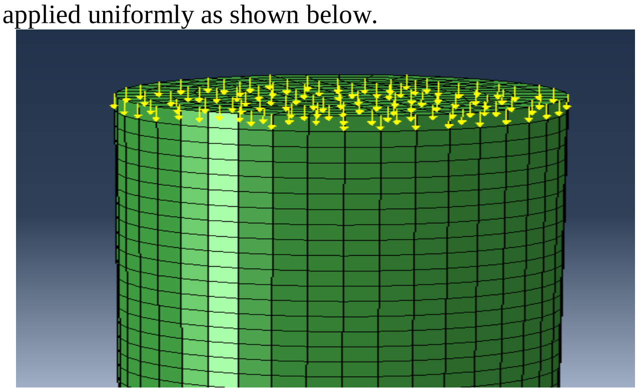

Fig 3. Load is applied uniformly on top concrete filled steel

Buckling Analysis

There are two major categories leading to the sudden failure of a mechanical component: material failure and structural instability, which is often called buckling. The load at which buckling occurs depends on the stiffness of a component, not upon the strength of its materials. Buckling refers to the loss of stability of a component and is usually independent of material strength. This loss of stability usually occurs within the elastic range of the material.

When the applied loading is increased, the buckling deformation also increases. Buckling occurs mainly in members subjected to compressive forces. If the member has high bending stiffness, its buckling resistance is high. Also, when the member length is increased, the buckling resistance is decreased. Thus the buckling resistance is high when the member length is short.

Procedure involved in modling concrete filled steel tube using hypermesh v11.0 and ABAQUS/CAE 6.10-1

The inner and outer diameter 12.5mm and 16.5mm along with length 300mm is entered using HYPER MESH and mechanical parameters of concrete and steel tube are entered.

The parameter for M20 concrete as follows :density of concrete is 2.400e-9MPa, Elastic modulus is 22360.70MPa and poisson ratio is 0.2 and for steel density is 7.860e-9, Elastic modulus is 210000 and poissons ratio is 0.3 and these parameters are assigned. And meshing is done with element size 2mm and boolen operation is done by selecting the entire model and element is ditched from model and model is exported as inp. File.

Model is imported to ABAQUS/CAE 6.10-1,buckling analysis is selected in step, number of Eigen values requested, Vectors used per iteration and maximum number of iterations are entered respectively. boundary conditions applied at top and bottom of concrete filled steel tube and load is applied at top surface concrete filled steel tube. And job is created and submit the model to analysis

Input File and Output Files

Abaqus 6.10-1 Date 04-May-2015 Time 12:47:0
*Heading
*Node
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*Elset, elset=ASSEMBLY_PART-1-1_STEEL
*Nset, nset=ASSEMBLY__PICKEDSET4
*Nset, nset=ASSEMBLY__PICKEDSET5
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*density
*elastic
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*Step, name=Step-1, perturbation
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*cload
*output, field
*nodeoutput
*endstep

E L E M E N T Q U A L I T Y C H E C K S

***NOTES: DISTORTED ISOPARAMETRIC ELEMENTS: ANGLE BETWEEN ISOPARAMETRIC LINES IS LESS THAN 45 DEGREES OR GREATER THAN 135 DEGREES.

TETRAHEDRAL QUALITY MEASURE: VOLUME OF TETRAHEDRON DIVIDED BY THE VOLUME OF EQUILATERAL TETRAHEDRON WITH SAME CIRCUMSPHERE RADIUS;

0 FOR DEGENERATE TETRAHEDRON AND 1 FOR EQUILATERIAL TETRAHEDRON. IT IS RECOMMENDED THAT THE TETRAHEDRAL QUALITY MEASURE BE GREATER THAN 0.02, THE MIN INTERIOR (DIHEDRAL) ANGLE BE GREATER THAN 10 DEGREES, AND THE MAX INTERIOR (DIHEDRAL) ANGLE BE LESS THAN 160 DEGREES.

TRIANGULAR QUALITY MEASURE: AREA OF TRIANGLE DIVIDED BY THE AREA OF EQUILATERAL TRIANGLE WITH SAME CIRCUMCIRCLE RADIUS; 0 FOR DEGENERATE TRIANGLE AND 1 FOR EQUILATERAL TRIANGLE. IT IS RECOMMENDED THAT THE TRIANGULAR QUALITY MEASURE BE GREATER THAN 0.01, THE MIN INTERIOR ANGLE BE GREATER THAN 10 DEGREES, AND THE MAX INTERIOR ANGLE BE LESS THAN 160 DEGREES.

NODAL ADJUSTMENTS ARISING FROM CONTACT INTERACTIONS AND/OR TIE CONSTRAINTS CAN CAUSE SEVERE ELEMENT DISTORTION. IT MAY BE NECESSARY TO REMESH IN ORDER TO REDUCE THE AMOUNT OF ADJUSTMENT.

Element	Min/max angle	Adjusted nodes
PART-1-1.3844	44.8639	NO
PART-1-1.3845	44.8639	NO
PART-1-1.3846	44.8639	NO
PART-1-1.3847	44.8639	NO
PART-1-1.3848	44.8639	NO
PART-1-1.3849	44.8639	NO
PART-1-1.3850	44.8639	NO
PART-1-1.3851	44.8639	NO
PART-1-1.3852	44.8639	NO
PART-1-1.3853	44.8639	NO
PART-1-1.3854	44.8639	NO
PART-1-1.3855	44.8639	NO
PART-1-1.3856	44.8639	NO
PART-1-1.3857	44.8639	NO
PART-1-1.3858	44.8639	NO
PART-1-1.3859	44.8639	NO
PART-1-1.3860	44.8639	NO
PART-1-1.3861	44.8639	NO

P R O B L E M S I Z E
NUMBER OF ELEMENTS IS 33000
NUMBER OF NODES IS 36520
NUMBER OF NODES DEFINED BY THE USER 36520
TOTAL NUMBER OF VARIABLES IN THE MODEL 109560
(DEGREES OF FREEDOM PLUS MAX NO. OF ANY LAGRANGE MULTIPLIER VARIABLES. INCLUDE *PRINT, SOLVE=YES TO GET THE ACTUAL NUMBER.)
END OF USER INPUT PROCESSING
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SYSTEM TIME (SEC) = 0.10000
TOTAL CPU TIME (SEC) = 3.6000
WALLCLOCK TIME (SEC) = 4
1
Abaqus 6.10-1 Date 04-May-2015 Time 12:47:10
For use by TEAM TBE under license from Dassault Systemes or its subsidiary.
STEP 1 INCREMENT 1
TIME COMPLETED IN THIS STEP 0.00
S T E P 1 C A L C U L A T I O N O F E I G E N V A L U E S F O R B U C K L I N G P R E D I C T I O N
THE SUBSPACE ITERATION METHOD IS USED FOR THIS ANALYSIS
NUMBER OF EIGENVALUES 5
MAXIMUM NUMBER OF ITERATIONS 300
NUMBER OF VECTORS IN ITERATION 10
THE BUCKLING MODE CONSTRAINTS
ARE DEFINED AS LOAD CASE 2
ONLY INITIAL STRESS EFFECTS ARE INCLUDED IN THE STIFFNESS MATRIX
THIS IS A LINEAR PERTURBATION STEP.
ALL LOADS ARE DEFINED AS CHANGE IN LOAD TO THE REFERENCE STATE
M E M O R Y E S T I M A T E
PROCESS FLOATING PT MINIMUM MEMORY MEMORY TO
OPERATIONS REQUIRED MINIMIZE I/O
PER ITERATION (MBYTES) (MBYTES)
1 6.67E+010 116 755
NOTE
(1) SINCE ABAQUS DOES NOT PRE-ALLOCATE MEMORY AND ONLY ALLOCATES MEMORY AS NEEDED DURING THE ANALYSIS,
THE MEMORY REQUIREMENT PRINTED HERE CAN ONLY BE VIEWED AS A GENERAL GUIDELINE BASED ON THE BEST
KNOWLEDGE AVAILABLE AT THE BEGINNING OF A STEP BEFORE THE SOLUTION PROCESS HAS BEGUN.
(2) THE ESTIMATE IS NORMALLY UPDATED AT THE BEGINNING OF EVERY STEP. IT IS THE MAXIMUM VALUE OF THE
ESTIMATE FROM THE CURRENT STEP TO THE LAST STEP OF THE ANALYSIS, WITH UNSYMMETRIC SOLUTION TAKEN INTO ACCOUNT IF APPLICABLE.
(3) SINCE THE ESTIMATE IS BASED ON THE ACTIVE DEGREES OF FREEDOM IN THE FIRST ITERATION OF THE
CURRENT STEP, THE MEMORY ESTIMATE MIGHT BE SIGNIFICANTLY DIFFERENT THAN ACTUAL USAGE FOR
PROBLEMS WITH SUBSTANTIAL CHANGES IN ACTIVE DEGREES OF FREEDOM BETWEEN STEPS (OR EVEN WITHIN
THE SAME STEP). EXAMPLES ARE: PROBLEMS WITH SIGNIFICANT CONTACT CHANGES, PROBLEMS WITH MODEL
4) FOR MULTI-PROCESS EXECUTION, THE ESTIMATED VALUE OF FLOATING POINT OPERATIONS FOR EACH PROCESS
IS BASED ON AN INITIAL SCHEDULING OF OPERATIONS AND MIGHT NOT REFLECT THE ACTUAL FLOATING
POINT OPERATIONS COMPLETED ON EACH PROCESS. OPERATIONS ARE DYNAMICALY BALANCED DURING EXECUTION,
SO THE ACTUAL BALANCE OF OPERATIONS BETWEEN PROCESSES IS EXPECTED TO BE BETTER THAN THE ESTIMATE
PRINTED HERE
CHECK POINT START OF SOLVER
CHECK POINT END OF SOLVER
ELAPSED USER TIME (SEC) = 1.4000
ELAPSED SYSTEM TIME (SEC) = 0.0000
ELAPSED TOTAL CPU TIME (SEC) = 1.4000
ELAPSED WALLCLOCK TIME (SEC) = 1
ITERATION 17 CURRENT ESTIMATES OF EIGENVALUES
1 7.42763E+05 2 8.22586E+05 3 3.63585E+06 4 6.44650E+06 5 1.19705E+07
6 1.22946E+07 7 1.53529E+07 8 1.62728E+07 9 1.80897E+07 10 4.18831E+07
THE FIRST 5 EIGENVALUES HAVE CONVERGED
THE ANALYSIS HAS BEEN COMPLETED

Process analysis of concrete filled steel tube failure

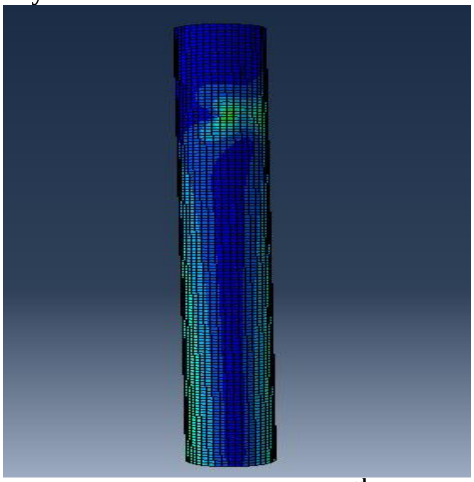

Fig 4(a) Formulation of crack @ 1/3rd of top circular concrete steel tube from ABAQUS

Fig 4(b) Formulation of crack @ 1/3rd from top circular concrete steel tube from experiment.

Formulation of crack @ 1/3rd from top circular concrete steel tube ,Then when load is applied at top surface ,Stress is developed, obviously concrete filled steel tube becomes shorter , concrete filled steel tube begins to lateral bending as shown in Fig 4(a) then load reaches maximum; Ultimate load carried by CFST is determined. These is compared with experimental results.

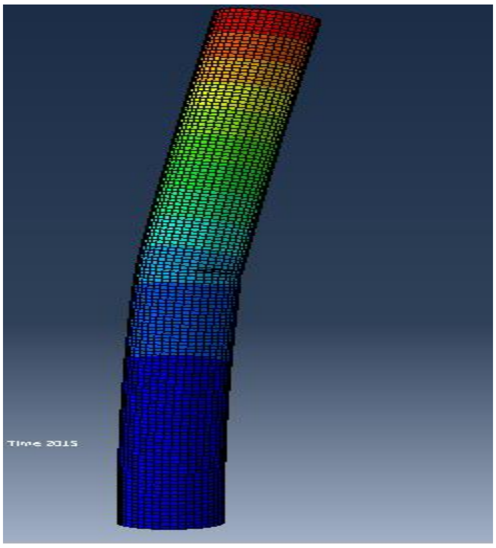

Fig 5.(a) Formulation of crack @ centre of circular concrete steel tube.

Formulation of crack @ Centre of circular concrete steel tube ,Then when load is applied at top surface ,Stress is developed, obviously concrete filled steel tube becomes shorter , concrete filled steel tube begins to lateral bending as shown in fig-5(a) then load reaches maximum; Ultimate load carried by CFST is determined. These is compared with experimental results.

Fig 5.(b) Formulation of crack @ centre of circular concrete steel tube.

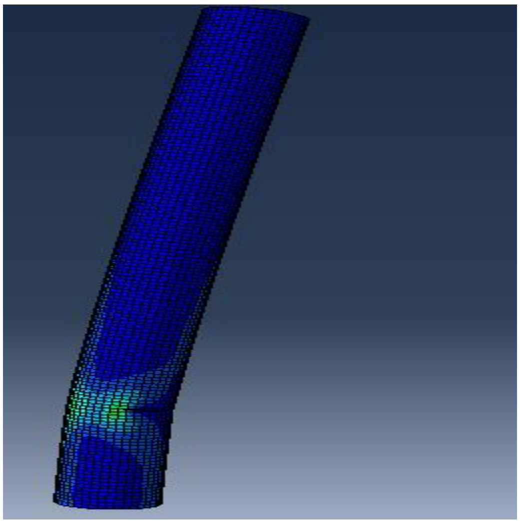

Fig 6(a) Formulation of crack @ centre of circular concrete steel tube

Fig 6.(b) Formulation of crack @ centre of circular concrete steel tube

Formulation of crack @ 1/3rd from bottom of circular concrete steel tube ,Then when load is applied at top surface ,Stress is developed, obviously concrete filled steel tube becomes shorter , concrete filled steel tube begins to lateral bending as shown in fig-5(a) then load reaches Maximum; Ultimate load carried by CFST is determined. These is compared with experimental results. It has been observed that ultimate load carried by crack @ 1/3rd of top concrete filled steel tube is more when compared with crack at centre and crack at 1/3rd from bottom CFST experiment as shown in Table 1, Table 2, and Table 3 and it can be seen that experiment results and numerically results are very close

Comparing Finite Element Model With Experimental Results

The Ultimate load ($Pu_{FE)}$ which is carried by finite element model and Ultimate load (Pu_{test})which was test from

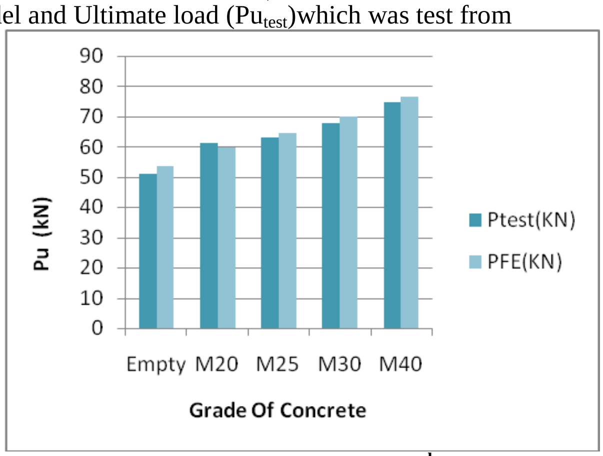

Chart 1. Formulation Of Crack @ 1/3rd Of Top Circular Concrete steel Tube

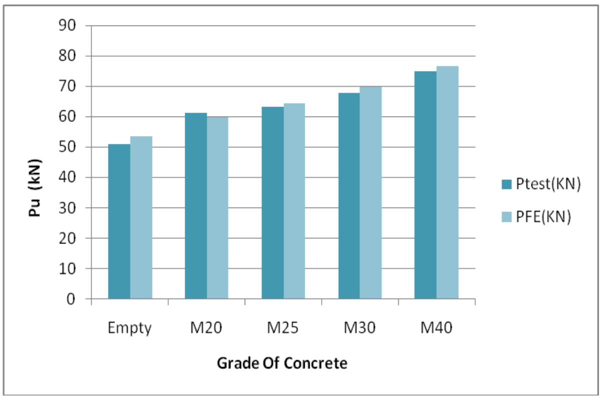

Chart 2. Formulation Of Crack @ Centre Of Circular Concrete steel Tube

Table 1. Formulation Of Crack @ 1/3rd from Top Circular Concrete steel Tube

Centre Sl, No	Diameter (MM)	Thickness (MM)	Length (MM)	Grade Of Concrete	Pu in KN (Uncracked Circular Tube in Abaqus)	Pu=As*fy+Ac*fc in KN(ACI METHOD)	Pu=As*fy+Ac*fc in KN (EUROCODE 4 method,)	Pu in KN (Experimental for Ccracked Circular tube)	Pu in KN (Cracked Circular Tube in Abaqus)
1	33.8	4	300	Empty	87.46	91.105	89.75	50.84	53.42
2	33	4	300	M20	94.86	100.922	99.449	61.10	59.87
3	33.8	4	300	M25	97.173	103.376	101.536	63.16	64.41
4	33	4	300	M30	102.656	105.831	103.622	67.72	69.85
5	33	4	300	M40	105.91	110.739	107.794	74.84	76.54

Table 2. Formulation Of Crack @ Centre Of Circular Concrete steel Tube

Bootom Sl, No	Diameter (MM)	Thickness (MM)	Length (MM)	Grade Of Concrete	Pu in KN (Uncracked Circular Tube in Abaqus)	Pu=As*fy+Ac*fc in KN(ACI METHOD)	Pu=As*fy+Ac*fc in KN (EUROCODE 4 method,)	Pu in KN (Experimental for Ccracked Circular tube)	Pu in KN (Cracked Circular Tube in Abaqus)
1	33	4	300	Empty	87.46	91.105	89.75	39.21	41.67
2	33	4	300	M20	94.86	100.922	99.449	47.38	48.09
3	33	4	300	M25	97.173	103.376	101.536	51.79	53.25
4	33	4	300	M30	102.656	105.831	103.622	55.48	57.33
5	33	4	300	M40	105.91	110.739	107.794	62.14	64.31

Table 3. Formulation Of Crack @ 1/3rd from Bottom Circular Concrete steel Tube

Top Sl, No	Diameter (MM)	Thickness (MM)	Length (MM)	Grade Of Concrete	Pu_{FE} in KN (Uncracked Circular Tube in Abaqus)	Pu=As*fy+Ac*fc in KN(ACI METHOD)	Pu=As*fy+Ac*fc in KN (EUROCODE 4 method,)	Pu in KN (Experimental for Ccracked Circular tube)	Pu in KN (Cracked Circular Tube in Abaqus)
1	33	4	300	Empty	87.46	91.105	89.75	71.32	74.42
2	33	4	300	M20	94.86	100.922	99.449	77.81	81.51
3	33	4	300	M25	97.173	103.376	101.536	83.05	87.37
4	33	4	300	M30	102.656	105.831	103.622	86.89	92.43
5	33	4	300	M40	105.91	110.739	107.794	93.54	98.49

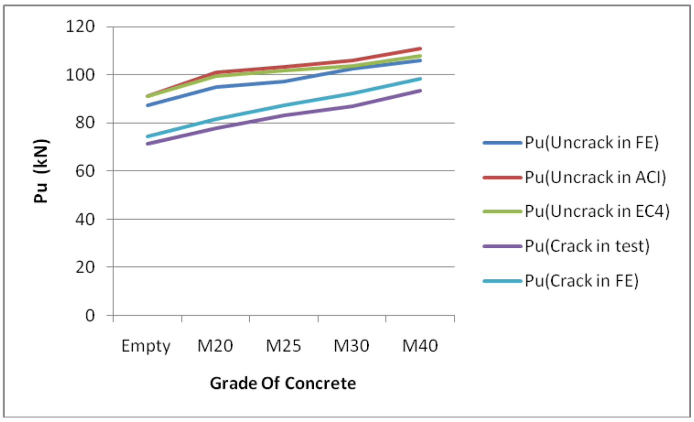

Chart 4. Variation of Uncrack and Formulation Of Crack @ 1/3rd from Top Circular Concrete steel Tube

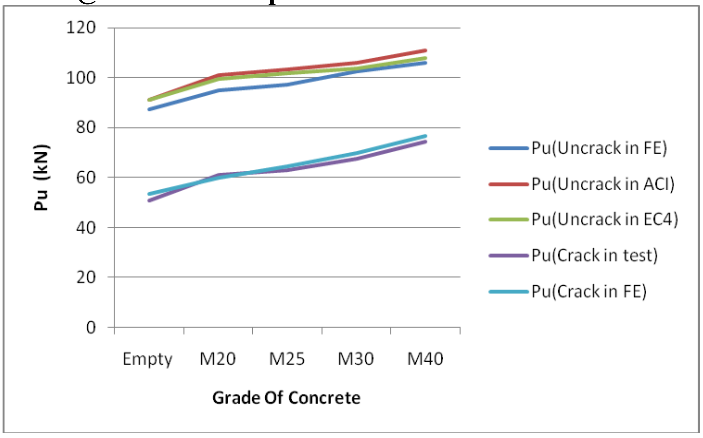

Chart 5. Variation of Uncrack model and Formulation Of Crack @ Centre Of Circular Concrete steel Tube

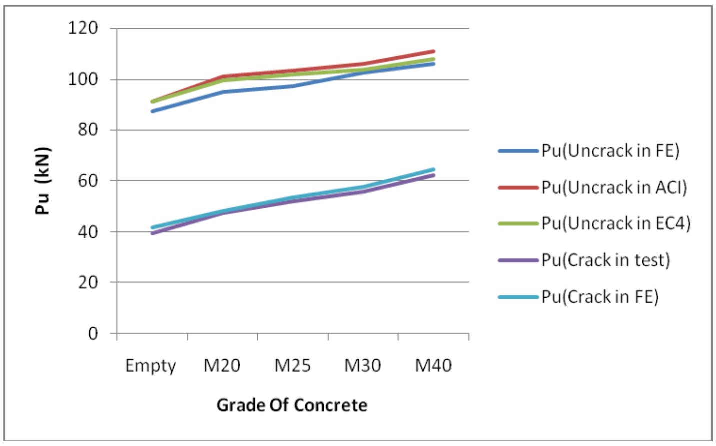

Chart 6. Variation of Uncrack model and Formulation Of Crack @ 1/3rdfrom Bottom Circular Concrete steel Tube

Conclusions

[1].Formulation of crack at 1/3rd from top of concrete filled circular steel tube carried more load when compared to the crack at centre and 1/3rd from bottom of tube.

[2].Position of cracks initiation obtained from ABAQUS package co-insided almost with cracks formed during experiments.

[3].Ultimate load carrying capacity decreased as crack formation increased.

[4].Ultimate load carrying capacity(Pu) decreased in range 10% to 15% when compared with uncracked and cracked numerical model(for empty steel tube) .

[5].As the Grade of concrete increase i.e M20 to M40, variations of ultimate load (Pu) between uncracked and cracked analytical models decreased from 18% to 8%.

[6].Variations of ultimate load of uncracked is found to be in range of 6% to 4% when the values obtained from American Concrete Institute (ACI) compared with results from ABAQUS package for empty and different grade of concrete.

[7].Variations of ultimate load of uncracked is found to be in range of 4% to 0.1% when the values obtained from Euro code -4 compared with results from ABAQUS package for empty and different grade of concrete.

[7].As the grade of concrete increases ultimate load carrying capacity of concrete filled circular steel tube is increased in the case of uncracked and cracked analytical section.

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Biographies

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