Behaviour of Concrete Filled Fiber Reinforced Polymer Tube under Blast Loading

SruthySagaran V,SruthiK Chandran

Abstract: In recent years, the public concern about safety has increased dramatically because of the tremendous increase in the number of explosive industrial accidents and terrorist attacks all over the world. Due to the threat from such extreme loading conditions, efforts have been made to develop methods of structural analysis and design to resist blast loads. Studies were conducted on the behavior of structural concrete subjected to blast loads. Improvement to existing construction methods that enhance blast resilience can ultimately save lives and property. Concrete filled FRP tubes (CFFTs) are known to improve a conventional reinforced concrete member's resistance to traditional loads by strengthening, protecting, and confining the reinforced concrete core. This paper outlines a numerical model built using commercially available software AnsysAutodyn to predict the response of concrete filled fiber reinforced polymer (FRP) tubes (CFFT) and determine the factors influencing their response. The comparison of dynamic behaviour CFFT and reinforced concrete (RC) column under blast loading has done. From the study it is clear that CFFT is more blast resilient than RC column. The parametric study was done on the effect of standoff distance and charge weight.

Index Terms— CONCRETE-FILLED FRP TUBE (CFFT); FIBER REINFORCED POLYMER (FRP) TUBE; REINFORCED CONCRETE (RC) COLUMN; HYDROCODE AUTODYN.

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1 INTRODUCTION

Blasts loading on columns are of great importance because columns tend to be critical load bearing members whose collapse may initiate a progressive collapse of the structure. Thus, any improvement in the blast resistance of columns can potentially save lives and property.

CFFT member is an innovative idea, in which a FRP element acts together with a concrete element. CFFT structures are carrying loads far in excess of their design loads because of their conservative design by modern standards. Glass fiber reinforced polymer (GFRP) tubes used as confinement. Hence it is necessary to restore or enhance the load carrying capacity and increase the life span of the structures.

Numerical and experimental investigation of concrete-filled FRP tube has been investigated extensively as in the study of Wonseok Chung et al. (2010), Amir Fam et al. (2010) has been investigated Behavior of Concrete-Filled FRP Tubes under Bending, Axial Loads, and Combined Loading, Aaron W. Malone (2010) has been investigated concrete filled steel tubular columns, a finite element study. This study focuses on the behavior of concrete-filled tubular (CFT) columns under combined axial load and bending moment, Hamdy M. Mohamed et al. (2011) has been investigated Deflection Prediction of Steel and FRP-Reinforced Concrete-Filled FRP Tube Beams. This paper presents the results of experimentaland theoretical investigations that study the flexural behavior of reinforced concretefilled fiber-reinforced polymer (FRP) tubes (RCFFTs) beams.

TogayOzbakkaloglu et al. (2012) has been investigated Behavior of FRP-Confined Normal- and High-Strength Concrete under Cyclic Axial Compression, Yilei Shi et al.(2013) has been investigated Assessment of Cyclic Behavior of Hybrid FRP Concrete Columns. Previous.

experimental studies have shown superior performance of concrete-filled fiber-reinforced polymer (FRP) tubes (CFFTs) under static or pseudostatic loading, TogayOzbakkaloglu (2013) has been investigated Concrete-Filled FRP Tubes Manufacture and Testing of New Forms Designed for Improved Performance.

Chun-yang ZHU et al. (2013) has been investigated Mechanical behavior of concrete filled glass fiber reinforced polymer-steel tube under cyclic loading, Thomas Vincent et al. (2014) has been investigated Influence of Slenderness on Stress-Strain Behaviour of Concrete-Filled FRP Tubes: Experimental Study, Alicia Echevarria et al. (2015) has been investigated Residual Axial Capacity Comparison of CFFT and RC Bridge Columns after Fire.

D.Asproneet al. (2015) has been investigated Behavior of Full-Scale Porous GFRP Barrier under Blast Load, Eric Jacques et al. (2015) has been investigated GFRP-Retrofitted Reinforced Concrete Columns Subjected to Simulated Blast Loading., Alicia Echevarria et al. (2015) has been developed Experimental Comparison of the Performance and Residual Capacity of CFFT and RC Bridge Columns Subjected to Blasts.

YazanQasrawi et al.(2014) has been investigated Performance of Concrete-Filled FRP Tubes under Field Close-in Blast Loading .They concluded that CFFT specimens performed significantly better than the conventional reinforced specimens, showing greater robustness with decreased localized damage and reduced residual displacements.

The objectives of the thesis are:

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1. To develop a model that captures the dynamic behaviour of CFFTs under blast loads.
2. To conduct a comparison study of RC column and CFFT
3. To conduct a parametric study (ie, effect of standoff distance and charge weight) to further investigates the dynamic behaviour of CFFTs under blast loading.

2 NUMERICAL MODELLING OF CFFT

The dynamic response of CFFT subjected to blast loading is investigated by employing the hydrocode - Autodyn. Autodyn is an explicit analysis tool for modelling nonlinear dynamics of solids, fluids, gas, and their interaction. It is an integral part of the Ansys Workbench environment.

2.1 Model Description

A CFFT of 4m long and outer diameter of 220mm including 5.5 mm thick GFRP, fixed support on two sides. The column is reinforced at a steel reinforcement ratio of 1.2% corresponding to four 11.65 mm diameter longitudinal bars. These steel reinforcement ratios approximated the 1 and 2.5% minimum and maximum recommended blast design reinforcement ratios to ensure strength and ductility. It contained 6-mm continuous steel spiral atspacing of the 0.1 m over the entire length with a reduced spacing of 0.05 m for 0.2 m from the ends over the supports. An equivalent charge weight of 50kg of C4 is used as explosive at a stand-off distance of 2 m from the surface of the column.

2.2 Material Models

1) C4 and TNT Explosives: The AnsysAutodynmaterial library's Jones-Wilkins-Lee (JWL) equation of state, which is predefined and already calibrated inAnsysAutodyn by fitting to TNT explosives.

2) Air: AnsysAutodyn's ideal gas equation of state, included in the standard material was used to model the air in the blast. The air's internal energy was set to 2.068 × 10^5 J to correspond to standard atmospheric pressure and temperature.

3) Reinforcing Steel: The Johnson and Cook constitutive model, built into AnsysAutodyn, was used to capture the plastic flow of the reinforcing bars. The JC model represents the strength behaviour of materials subjected to large strains, high strain rates and high temperatures .The erosion strain was set to 0.1 to correspond to observations made during the tensile tests.

4) Concrete: RHT concrete constitutive model developed by Riedel, Hiermaier and Thoma, which is an advanced plasticity model for brittle materials, is used in the present numerical formulation. The RHT model is a combined plasticity and shear damage model and in this, the deviatoric stress is limited by a generalised failure surface. The RHT model is setup in ANSYS Autodynsuch that changing the concrete's compressive strength would automatically scale the remaining terms proportionately.

5) GFRP Tube: ANSYS Autodyn allowed the entry of the GFRP tube's material properties in terms of the engineering constants. As the shell elements used to model the GFRP tube were two-dimensional elements, the through-thickness properties were omitted to achieve a plane stress situation. The Von Mises constitutive modelwas used to capture the GFRP tube's nonlinearity.

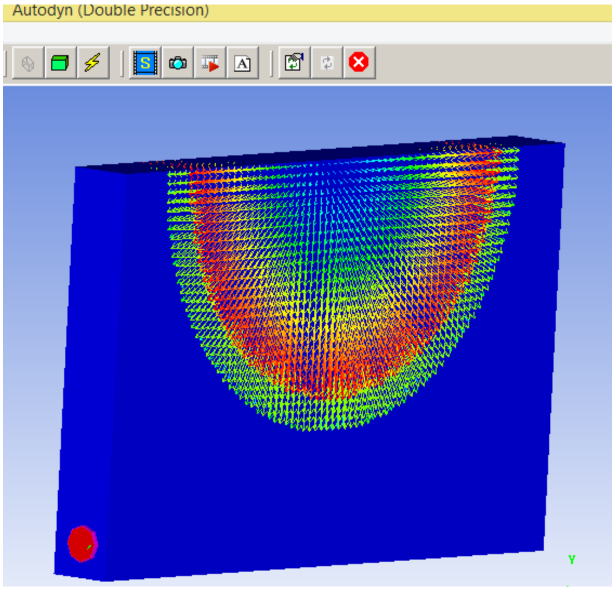

Fig.1 AnsysAutodyn's model of CFFT

TABLE 1

MATERIAL PARAMETERS

Concrete Parameters	
EOS	P- α
Reference density	2.4 g/cm^3
Strength	RHT concrete
Shear modulus	1.67 ×10^7kPa
Compressive strength	3.4×10^4kPa
Failure	RHT concrete
Tensile failure	Principal stress
Principal tensile failure stress	3.4×10^3kPa
Fracture energy	104.7 J/m^2
Erosion	Geometric strain
Erosion Strain	.0035
GFRP Tube	
EOS	Ortho
Reference density	1.938 g/cm^3
Young's modulus11	1.01×10^7kPa
Young's modulus22	2.16×10^7kPa
Poisson's ratio12	0.35
Shear modulus12	6.4 ×10^5kPa
Strength	Von Mises Strength
Shear modulus12	6.4 ×10^5kPa

Yield stress 11	4.83×10^4kPa
Failure	Material strain
Tensile failure strain11	0.0184
Tensile failure strain22	0.0184
Erosion	Geometric strain
Erosion	Geometric strain
Erosion Strain	0.02
Steel Parameters	
EOS	Linear
Reference density	7.85 g/cm^3
Strength	Johnson Cook
Shear modulus	7.69×10^7kPa
Yield stress	4.3×10^5kPa
Hardening constant	2.57×10^5kPa
Hardening exponent	0.26
Failure	Plastic strain
Plastic strain	0.1
Erosion	Plastic strain
Erosion Strain	0.1
Air and C4 Parameters	
Reference density of air	0.001225 g/cm^3
EOS for air	Ideal gas
Gamma	1.40
Reference density of C4	1.59 g/cm^3
EOS for C4	JWL

2.3 Validation

Validation of the model that we developed is done according to YazanQasrawi et al. [12].AnsysAutodyn's sophisticated remapping capabilities were used to speed up the modeling time. The blast wave was initially modeled using a two-dimensional (2D) axisymmetrical model from the explosion out to 1.975 m.When the blast shockwave was within 25 mm from the column, the results of the 2D analysis was remapped into a sphere in the three-dimensional (3D) model.

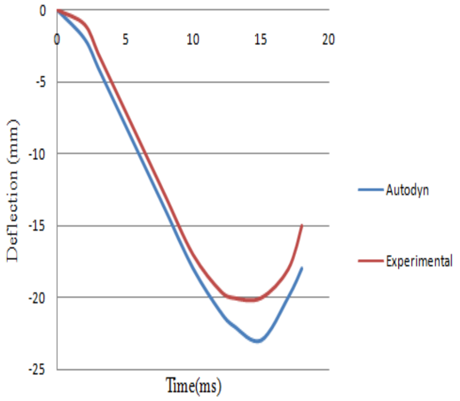

Fig.2 Comparison of results in previous and current studies

TABLE 2

VALIDATION RESULT

Study	Maximum deflection at midspan(mm)
Experimental study [12]	20
AUTODYN 3D model (present)	23

The radius of the central C4 spheres was calculated using the experimental tests' charge masses of 50 and the density of C4 of 1,590 kg/m^3. The calculated radii for the charges were 0.196 m for the 50 kg of C4 charge.25mm mesh for concrete was used to develop a model. The maximum deflection observed in the present study is also compared with those documented in the literature and is found to be in good concordance (Table2). Therefore, the present numerical model can effectively model the behaviour of CFFT under blast loading.

3 RESULT AND DISCUSSIONS

The results of this study can be mainly included under 3 part such as the result of validation, the result of comparison of CFFT and reinforced concrete column under blast loading and finally the result of parametric study of CFFT under different charge weight and standoff distance. Result of validation is already discussed above.

3.1 Comparison of CFFT and Reinforced Concrete Column

Base model description of CFFT used for comparison and parametric study was different from validation. In this case 10 mm diameter longitudinal bars and spacing of stirrups at 100mm throughout the length was used .The remaining details were same as validation model. The outer diameter of RC column is 209 mm. 80 mm mesh for concrete was used for the analysis. Because 25 mm mesh size was too difficult to analyse and its simulation time is also too large.50kg C4 explosive and 2m standoff distance is used for the analysis.

The obtained results is given below in table 3, it can easily understand that the CFFT was more blast resilient than the RC column. There was about 67% variation in the displacement of RC column compared to CFFT. CFFT shows 33 mm deflection under 50 kg C4 explosive but at the same time RC Column shows 100mm deflection and damage to concrete was seen at the column after 25 ms.

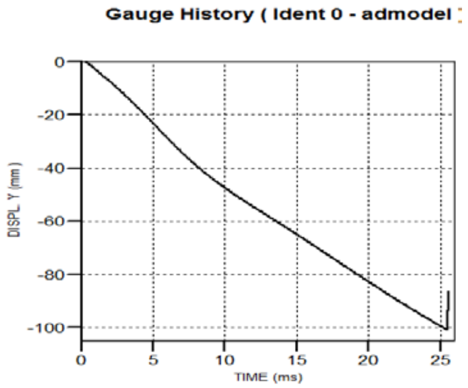

Fig.3 Autodyn's displacement versus time graph of RC column

TABLE 3

COMPARISON OF CFFT AND RC COLUMN

Item	Time(ms)	Maximum deflection at midspan(mm)
RC Column	25	100
CFFT	15	33

The failure of RC column under blast loading is clear from the graph given below (fig.3). In the case of CFFT there was no damage to concrete and there is only partial tear of the FRP material shows up to simulation time 60 ms. The addition of lateral confinement such as GFRP tube can reduce the concrete damage during blast loading. In both case there were no breakage of longitudinal and shear reinforcement.

3.2 Parametric Study –Effect of Standoff Distance

Parametric study of CFFT under 50 kg C4explosive and the standoff distance varying from 0.5 m to 2 m was done. It can be observed from table 4 that there is considerable effect of the variation of stand-off distance on the dynamic response of the CFFT and the midspan deflection reduced with the distance of explosive away from the CFFT. The simulation time was set as 60 ms.

TABLE 4

EFFECT OF STAND OFF DISTANCE

Standoff distance(m)	Deflection at midspan (mm)	Time(ms)
0.5	450*	-
1.0	99.09	31
1.5	43.00	17
2.00	31.85	15

*maximum deflection at midspan not attained within simulation time of 60 ms.

3.3 Parametric Study –Effect of Charge Weight

TABLE 5

EFFECT OF CHARGE WEIGHT

Charge weight(kg)	Midspan deflection(mm)	Time(ms)
10	7.00	10
25	13.36	10.50
50	31.85	15
75	49.8	18
100	88.14	25

Parametric study of CFFT under 2 m standoff distance and the charge weight (C4) varying from 10 kg to 100 kg was done. It can be observed from the table 5 that there is considerable effect of the variation of charge weight on the dynamic response of the CFFT and the midspan deflection increased with the charge weight increment. The simulation time was set as 60 ms.

4 CONCLUSIONS

In this study the dynamic behaviour of CFFT under 50 kg C4 explosive at a standoff distance of 2m has been investigated. The following conclusions are obtained from numerical investigations.

1. A model of CFFT developed using AnsysAutodyn to know the dynamic behaviour under blast loading.
2. Reinforced concrete specimen experienced concrete damage under blast loading.
3. The addition of lateral confinement such as GFRP tube can reduce the concrete damage during blast loading.
4. The 50 kg C4explosion at 2m standoff didn't break any lateral and shear reinforcement.
5. The midspan deflection reduced with the distance of explosive away from the CFFT.
6. The midspan deflection of CFFT is increased with the increment of charge weight.

5 RECOMMENDATIONS FOR FUTURE RESEARCH

Recommendations for future research are as follows:

1. Study the influence of different parameters such as diameter and reinforcement percentage, etc.on blast loading by conducting the parametric study.
2. Formulation of design guide lines for blast loading on CFFT.

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