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ANALYSIS OF CFFT PILE FOUNDATION SUBJECTED TO BLAST LOADING USING ANSYS

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Abstract — *It has been observed from past incidents of terrorist explosive threats that performance of building and response of bridges are greatly affected .So it is important to examine the adverse effects of blast loading. This paper makes an attempt to make an analysis of bridge pile foundation subjected to surface explosion. Concrete filled FRP tubes(CFFTs) are known to improve the resistance of a conventional reinforced member by strengthening, protecting and confining the RC core .In this work blast effect on CFFT pile and RC pile to findout which pile configuration shows better performance under blast load. For this purpose finite element tool ANSYS AUTODYN hydrocode software is used.*

Keywords- *Blast loading, Concrete-filled FRP tube, ANSYS AUTODYN hydrocode*

I. INTRODUCTION

Bridges are considered to be highly sensitive to terrorist attack hazard mostly because all their parts are easily accessible. The performance of foundations of bridges subjected to blast loads is a critical research area, as this provide an important role in the overall structure response. Pile foundations are the most common foundation systems for civil engineering structures such as high-rise buildings and bridges. Pile foundations transfer the large loads from the superstructure above into deeper, competent soil layers which have adequate capacity to carry these loads. It follows that if these foundations are structurally damaged due to blast loading, the superstructure becomes vulnerable to failure. Therefore, it is important to examine adverse effects on foundation caused by ground shocks prior to any reconstruction or rehabilitation procedures.

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 are used as confinement. Hence it is necessary to restore or enhance the load carrying capacity and increase the life span of the structures

In this study analysis is done on bridge substructure to understand effect of blast on bridge foundation.The nonlinear numerical analysis of the bridge with pile foundation was conducted using the AnsysAutodynhydrocode software. Also performance of CFFT piles and RC piles under blast load is analysed.

II. LITERATURE REVIEW

Jayasingh,D.PThambiratnam,N.Perera,Jayasooriya.(2013)studied the dynamic response of the pile in saturated sand and effect of varying explosive shape on the pile response using software LS-DYNA

R. Zheng ,Liang Wu, Yi-Feng Zhang ,LZ Sun(2016) studied effectiveness of FRP retrofit measures for strengthening of RC bridge structures

Christopher Eamon, Ahmad Aslendi(2011) investigated capacity of typical reinforced concrete bridge columns to resist an assumed blast and effective method for column protection using SFRP

SruthySagaranV,SruthiKChandran (2016) studied the response of concrete filled fiber reinforced polymer (FRP) tubes (CFFT) and determine the factors influencing their response.

III. OBJECTIVES

The main objectives of the present study are

a) To model bridge substructure including components pier cap , pier ,pile cap, pile using ANSYS workbench.

b) To investigate the performance of bridge with RC pile and CFFT pile under blast effect using ANSYS AUTODYN hydrocode software.

IV. MODEL DETAILS

The details of bridge used for modeling substructure components are given below

- The selected type of overpass measures 37 m in span .
- Total width is 7.8 m
- No of span =5
- Length of each span=6.3m
- Thickness of Slab = 0.30m
- Thickness of Wearing Coat = 0.080m
- Footpath = 1.2m on both sides
- Loading = IRC Class AA tracked vehicles

The substructure modelled include hammer headed pier of total depth 10 m with 25mm diameter longitudinal bar 12 mm lateral ties at spacing of 150 mm. Eight piles are provided for structure with a spacing of 2m c/c . Each pile of length 18m ,diameter of 0.7 m.For CFFT piles GFRP tubes of 5 mm thickness. Pile is provided with 12mm longitudinal bar and 6 mm lateral ties at spacing of 150 mm .Concrete elements are modelled with volumetric finite elements while bar finite elements are used for modelling reinforcement. Bar elements are placed within volumetric elements and are connected with them via body interaction that ensures joint behaviour when subjected to load. An ideal bonded contact between the concrete and reinforcement is assumed. Bridge substructure modelled in ANSYS workbench is shown in figure 1 .

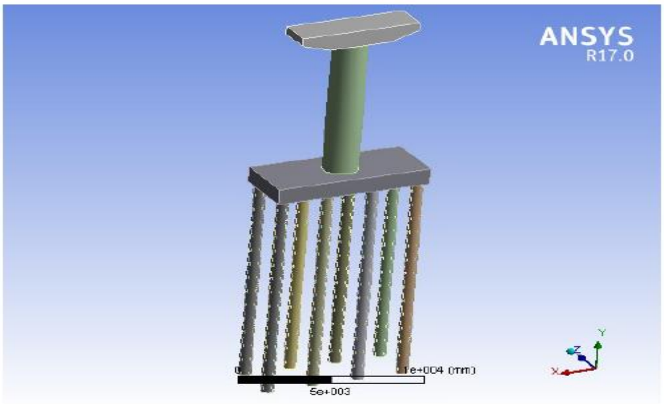

Figure 1 : Model of bridge substructure

The numerical model of the bridge substructure consists of a part that ismodelled as the Eulerian ideal gas and of a structured part representing the substructure. Soil is modelled by boundary condition that does not allow expansion of air particles in the explosion wave, nor expansion particles of eroded material of the structure (concrete and steel). The interaction between explosion wave and structure is calculated using the Euler-Lagrange interaction . Boundary conditions set for the remaining air zones enable free propagation of explosion wave pressure and eroded elements outside the modelled air volume.

TNT is modelled as a spherical burst in 1D wedge model. The radius of spherical charge of TNT is calculated using the default density of TNT (Density = 1.63 gm/cm3) and is obtained as per the following calculation:

Volume of TNT= mass of TNT/density of TNT
Density of TNT = 1.63 gm /cm3
Volume of TNT = $4/3\ \pi\ R^3$

where, R= Radius of spherical charge , m=Mass of TNT

The radius of the explosive was 195.437 mm. The 1D analysis was continued until the blast wave reached the boundary at 5000 mm. The termination time for the 1D analysis determined by trial and error was found to be 3.5 ms. Fig. 2 depicts the 1D wedge model used to simulate air for remapping.

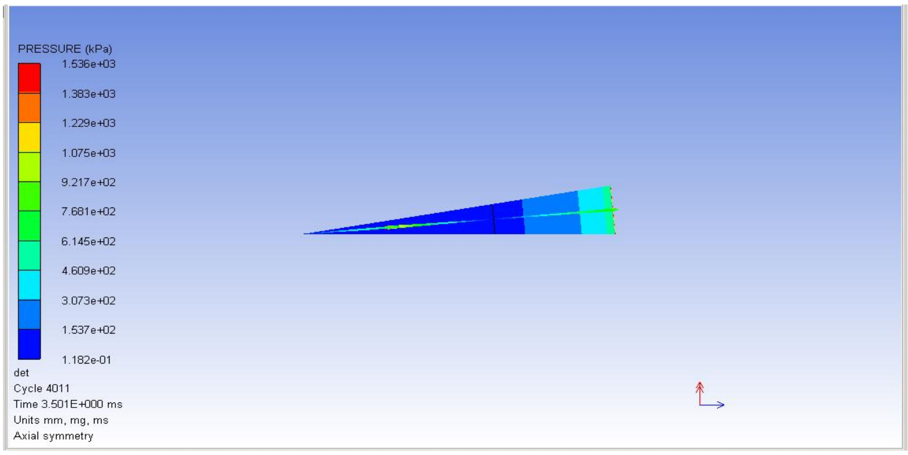

Figure 2: 1D wedge model used to simulate air for mapping

V. MATERIAL MODELS

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

Material model	*Adjusted parameters*	*Value*
TNT	Reference density of TNT	1.56 g/cm^3
	EOS of TNT	JWL

*2) Air :*Ideal gas equation of state ANSYS AUTODYN is included in the standard material was used to model the air in the blast. The internal energy of the air was set to 2.068 × 10^5 J to correspond to standard atmospheric pressure and temperature.

3)

Material model	*Adjusted parameters*	*Value*
AIR	Reference density of air	0.001225 g/cm^3
	EOS of air	Ideal gas

4) Reinforcing Steel: The Johnson and Cook constitutive model, built into Ansys Autodyn, 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.

Material model	*Adjusted parameters*	*Value*
REINFORCING STEEL	Reference density	Linear
	EOS of steel	7.85 g/cm^3
	Strength	Johnson Cook
	Shear modulus	7.69×10^7 kPa
	Yield stress	4.3×10^5 kPa
	Hardening component	2.57×10^5 kPa
	Hardening exponent	0.26
	Failure	Plastic strain
	Plastic strain	0.1
	Erosion	Plastic strain
	Erosion strain	0.1

5) 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 Autodyn such that changing the concrete's compressive strength would automatically scale the remaining terms proportionately.

Material model	*Adjusted parameters*	*Value*
CONCRETE	Equation of state	P-α
	Reference density	$2.4\ g/cm^3$
	Strength	RHT concrete
	Shear modulus	1.67×10^7 kPa
	Compressive strength	3.4×10^4 kPa
	Failure	RHT concrete
	Tensile failure	Principal stress
	Principal tensile failure stress	3.4×10^3 kPa
	Fracture energy	$104.7\ J/m^2$
	Erosion	Geometric strain
	Erosion Strain	.0035

6) 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 model was used to capture the GFRP tube's nonlinearity.

Material model	*Adjusted parameters*	*Value*
GFRP TUBE	Equation of state	Ortho
	Reference density	$1.938\ g/cm^3$
	Young's modulus11	1.01×10^7 kPa
	Young's modulus22	2.16×10^7 kPa
	Poisson's ratio12	0.35
	Shear modulus12	6.4×10^5 kPa
	Strength	Von Mises
	Shear modulus12	6.4×10^5 kPa
	Yield stress 11	4.83×10^4 kPa
	Failure	Material strain
	Tensile failure strain11	0.0184
	Tensile failure strain22	0.0184
	Erosion	Geometric strain
	Erosion Strain	0.02

V .COMPARISON OF RC PILE AND CFFT PILE IN BRIDGE SUBSTRUCTURE

For analysis two models of bridge substructure are modelled in Ansys. One with reinforced concrete pile as foundation as shown in figure 2 and other CFFT piles with GFRP tubes as shown in figure 3 . In this case 12 mm diameter longitudinal bars and 6mm lateral ties with 100mm spacing at two end regions and 150 mm spacing remaining regions .Length of each pile is 18m. The outer diameter of pile is 700 mm. In case of CFFT pile GFRP tube of thickness 5mm is provided . 50 mm mesh for concrete and GFRP was used for the analysis. Because 25 mm mesh size was too difficult to analyse and its simulation time is also too large, 500kg TNT explosive and 5m standoff distance is used for the analysis.

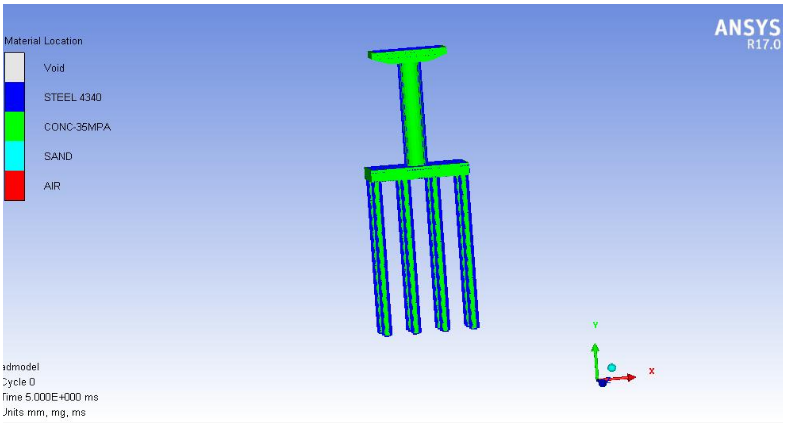

Figure 3:Bridge with RC pile

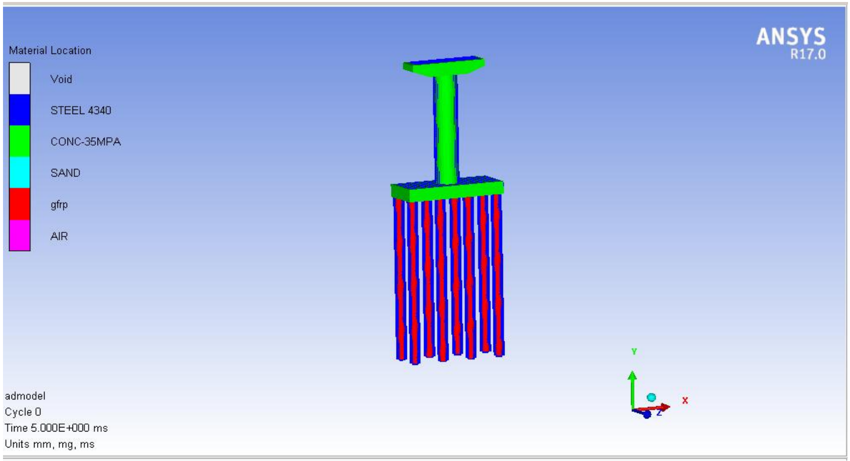

Figure 4: Bridge with CFFT pile

Gauges are provided in each pile at three regions at top of the pile , mid span of pile and bottom of the pile. Maximum displacement was observed in pile nearer to detonation point as shown in figure 5.

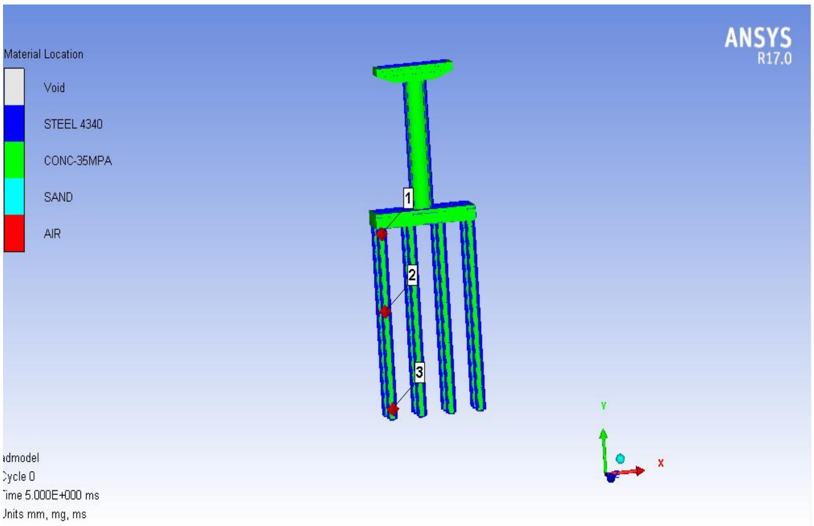

Figure 5: Gauges plotted on nearest pile

From the obtained results given below in table 3, one can easily understand that the CFFT was more blast resilient than the RC pile. CFFT shows 2.154 mm maximum displacement under 500 kg TNT explosive but at the same time RC Column shows 0.747 mm maximum displacement .

TABLE 3: RESULTS

ITEM	TIME(ms)	GAUGE	MAXIMUM DISPLACEMENT(mm)
RC PILE	25	1	2.154
		2	1.52
		3	0.230
CFFT PILE	25	1	0.747
		2	0.156
		3	0.126

VI. CONCLUSION

In this analysis the dynamic behaviour of RC pile and CFFTpile under 500 kg TNT at a standoff distance of 5m from the bridge surface has been investigated. The following conclusions are obtained from this analysis

1. Model of bridge substructure with RC pile and CFFT pile was developed using Ansys Autodyn hydrocode software to know the dynamic behaviour under blast loading
2. Reinforced concrete pile experienced more damage under blast loading
3. Maximum displacement was observed in pile nearer to detonation point that means displacement decreases with increase in standoff distance.
4. GFRP tubes as lateral confinement in pile reduce the damage to pile
5. RC pile shows more horizontal displacement than CFFT piles with GFRP tubes.

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