Transactions, SMiRT-23
Manchester, United Kingdom - August 10-14, 2015
Division V, Paper ID 088

Vibration Response in Pile Foundation Embedded In Soil due to Under Ground Explosion.

Mrigendra Nath Ray[1] Rohan Belhe[2] Shivam Srivastava[3]

1. **Nuclear Domain Expert , Larsen & Toubro Technology Services, Vadodara, India.**
2. **Executive Engineer , Larsen & Toubro Technology Services ,Vadodara ,India.**
3. **Assistant Manager, Larsen & Toubro Technology Services, Vadodara, India.**

ABSTRUCT

Underground explosion within a concrete chamber deep inside a soil mass generates instantaneous high pressure wave inside the chamber and flows into the concrete wall deforming it and finally passes into the soil and structures resting on concrete piles. Authors in this paper have attempted to analyse the dynamic effect on concrete wall, soil surrounding the concrete wall and embedded pile nearby. Total work is divided into first constructing a mathematical model in LaGrange domain for the concrete chamber and soil mass as a solid element C3D8R using Programme ABAQUS version 6.13 in Explicit Domain and thereafter analysing the model to get the desired result. The size of the external soil mass was 10mx6mx6m within which a 5mx3mx3m hollow box made of Concrete Grade 15 with a wall thickness 0.25m was conceived. Inside the chamber, the empty air space of size 4.5m x 2.5m x 2.5m was modelled as a solid element again and within the air space, explosive TNT of size 0.50metre cube was modelled in the centre location.The explosive was ignited at its centre. All the material data was taken from the literature [1&2].After completing the analysis in ABAQUS, similar model was conceived in ANSYS vers13 and results were compared.

INTRODUCTION

Evaluation of dynamic response on soil due to underground explosion remains always a subject of worry to the Mining and Tunnelling Engineers. In the present days of urbanisation, quite often metro Tunnels are required to be dug in a tunnelling operation much below city road level. Due to paucity of space and high compensation for damage to existing Structure, there remains a huge requirement to predict blast induced response in soil at a much higher location. In this paper, authors have tried to derive analytically the Dynamic Response in Pile Foundation embedded in soil nodes by Explicit Technique using Program ABAQUS 6.13.

A mathematical model using Lagrangian Tetrahedron Element is created in Explicit Domain modelling the air inside the Concrete Box of size 5metre by 3 metre by 3metre with a wall thickness 25cm.The explosive element is modelled as solid element of size 0.5mx1mx1m and placed at the centre within the air element. Thereafter, 3D soil elements are placed all around the Concrete box to represent an infinite soil mass with an outside dimension 10mx6mx6m. A vertical cylindrical concrete Pile section of diameter 0.5m was also modelled at a distance of 3.50m from centre of the Concrete Box within the same soil mass and this Arbitrary Lagrangian Eulerian (ALE) model was analysed for the Blast induced Response in soil at various Sections of the Composite Model to examine the possibility of Caving, Liquefaction of soil and Peak particle velocity of Soil below foundation level. The Physics of Interaction of Pile with Soil and Soil with concrete has been modelled as surface to surface contact as a contact option in ABAQUS.The contact of air to concrete and air to explosive is considered frictionless.

Fig-1 and 2 shows the Model feature, dimension and number of elements in each part. The programme got aborted due to excessive distortion in the explosive element at a time of 0.039sec from start but making available all the output during the run.

MATERIAL MODEL

The material model for air and TNT explosive Eulerian elements are shown in Table-1, the same for Lagrangian elements Soil is shown in Table-2 and data for Concrete Chamber, Concrete Pile in Table-3.The material data for Air and Explosive is very generic and taken from [1].The material data for Soil and Concrete was taken from [2] as experimental data done by Research Scientist. Equation of State has been considered for Explosive, Air and soil with the understanding that adiabatic transformation do take place under excessive heat and pressure generated in Soil medium also, in addition to much severe condition prevailing in Air and explosive.

Table-1 Material Data for Air and Explosive

Material	Type	Property	Value	Unit
Air	Density	Mass density (1)	1.293	kg/m^3
	Eos	Specific gas constant (2)	287	J/kgK
		Ambient pressure (3)	101325	N/m^2
	Specific heat	Specific heat	717.6	J/kgK
	Viscosity	Viscosity (4)	6.924e-06 at 100.0K	kg/s*m
	Initial state	Specific energy	193300	J/kg
		Ambient pressure	101325	N/m^2
TNT	Density	Mass density (1)	1630	kg/m^3
	JWL Eos	Detonation wave speed	6930	m/s
		A	373770000000	N/m^2
		B	3747100000	N/m^2
		ω	0.35	-
		R_1	4.15	-
		R_2	0.9	-
		Detonation energy density	0.0	J/kg
		Pre-detonation bulk modulus	0.0	N/m^2
	Initial state	Specific energy (5)	3680000	J/kg
		Ambient pressure	101325	N/m^2

Equation of state(EOS) for Air was taken it as ideal gas and the same for TNT has been considered as per Jones-Wilkens-Lee (JWL) with standard parameters considered from literature [1].

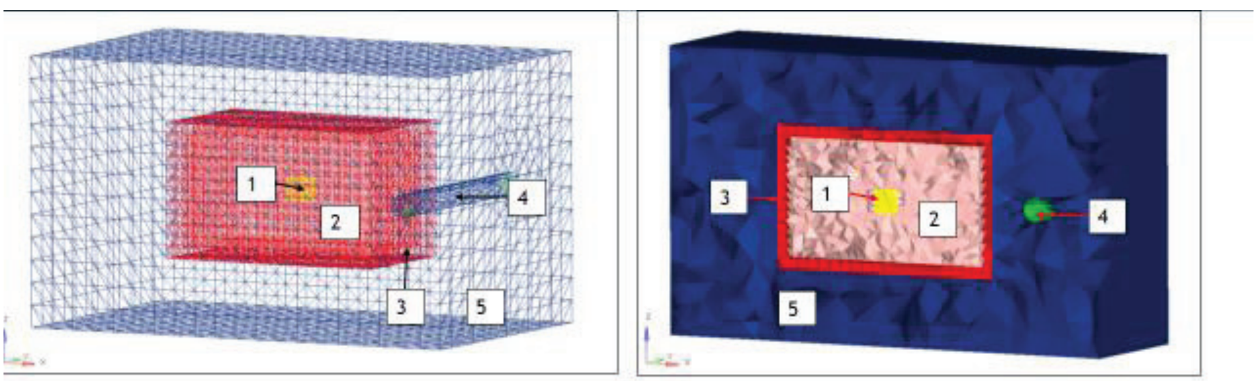
Table- 2 Material data for Soil

Parameters	Soil
Young's modulus (E)	51.7 MPa
Poisson's ratio (v)	0.45
Density (ρ)	1750 kg/m^3
Material cohesion (d)	0.036 MPa
Material angle of friction (β)	30°
Cap eccentricity parameter (R)	0.3
Initial cap yield surface position (ε_v)	0.02
Transition surface radius parameter (α)	0.05
Cap hardening behaviour (*Stress, plastic volumetric strain*)	2.75 MPa, 0.00 4.83 MPa, 0.02 5.15 MPa, 0.04 6.20 MPa, 0.08

The soil is considered as a very dry brown clay soil of classification CL [3] The soil behaviour is modelled by an elastic-plastic Drucker- Prager Cap model as described in [4].The modified Drucker-Prager/Cap plasticity/creep model is intended to model cohesive geological materials that exhibit pressure-dependent yield, such as soils and rocks and is based on the addition of a cap yield surface to the Drucker-Prager plasticity model ("Extended Drucker-Prager models," Section 23.3.1), which provides an inelastic hardening mechanism to account for plastic compaction and helps to control volume dilatancy when the material yields in shear. Similarly, concrete has been modelled as Concrete damaged Plasticity (CDP) as described in [4].

Table-3 Material Data for Concrete

The parameters of CDP model		Value	
Young's modulus E (GPa)		19.7	
Poisson's ratio ν		0.19	
β		38^0	
Flow potential eccentricity (ε)		1	
σ_{b0}/σ_{c0}		1.12	
K_c		0.666	
Concrete compression hardening		Concrete compression damage	
Stress [Pa]	Crushing strain	Damage	Crushing strain
15.0e6	0.0	0.0	0.0
20.197804e6	0.0000747307	0.0	0.0000747307
30.000609e6	0.0000988479	0.0	0.0000988479
40.303781e6	0.000154123	0.0	0.000154123
50.007692e6	0.000761538	0.0	0.000761538
40.236090e6	0.002557559	0.195402	0.002557559
20.236090e6	0.005675431	0.596382	0.005675431
5.257557e6	0.011733119	0.894865	0.011733119
Concrete tension stiffening		Concrete tension damage	
Stress [Pa]	Cracking strain	Damage	Cracking strain
1.99893e6	0.0	0.0	0.0
2.842e6	0.00003333	0.0	0.00003333
1.86981e6	0.000160427	0.406411	0.000160427
0.862723e6	0.000279763	0.69638	0.000279763
0.226254e6	0.000684593	0.920389	0.000684593
0.056576e6	0.00108673	0.980093	0.00108673



1. RDX - (0.5m x 0.5m x 0.5m)
2. Air - (4.5m x 2.5m x 2.5m)
3. Concrete - (5.0m x 3.0m x 3.0m , thickness 0.25 m)
4. Pile - (dia. = 0.5m , length = 5.0 m)
5. Soil - (10.0m x 6.0m x 6.0m)

Note:- Friction Contacts are simulated between the parts.

Part	Element Type	No. of Nodes	No. of Elements
RDX	C3D8R	1331	1000
Air	C3D4	5148	26071
Concrete	C3D4	3228	12818
Pile	C3D4	156	459
Soil	C3D4	3648	16807

Fig-1 :Mathematical model of the Infinte Soil Mass,Concrete Chambar and Embedded Pile.

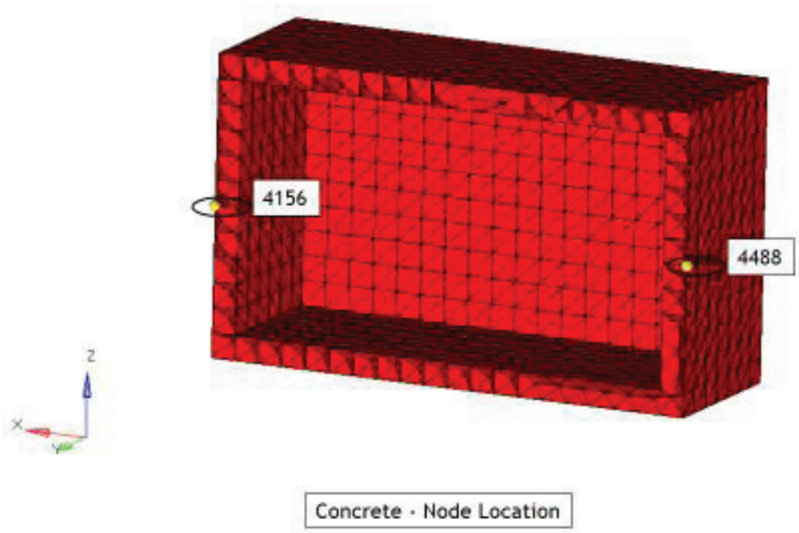


Fig-2 Concrete Chamber meshed in Tetrahedron Element Showing Nodes for mapping the Stress.

VIBRATION RESPONSE DUE TO UNDER GROUND EXPLOSION.

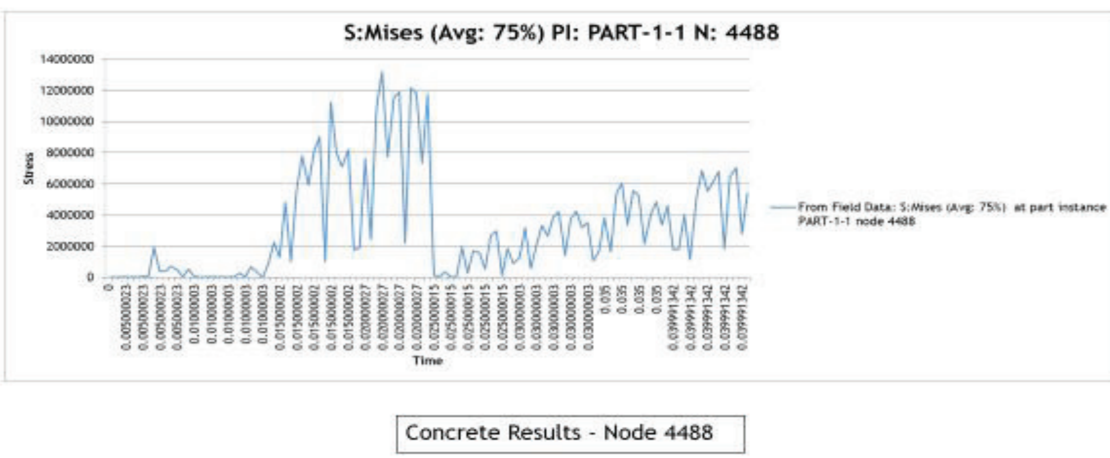


Fig-3 Stress Time History for Concrete Chamber

BLAST RESPONSE IN CONCRETE CHAMBER

The Concrete Chamber in the model is the first barrier where the blast wave will hit in the first instant ,the peak Tensile stress in concrete reaches to a value12 Mpa at a node 4458 at a period of 15-25 milisec after going through at least 4 to 5 Load reversal cycle .The second stage of Concrete Strain hardening at the same node starts at an instant 26 mili sec and continues to rise up to 0.040 sec with a peak stress 6 Mpa.These Details are illustrated in Fig-3.

Authors during the stage of modelling the concrete chamber observed that blast wave propagation inside a closed chamber depends on the size of the chamber also. The initial post blast pressure generated using JWL equation shoots up depending upon the size of chamber. Bigger the size, initial reflective pressure is more .Of course size should be such that hemispherical or cylindrical pressure pulse cannot be produced.

Since the CDP Model in ABAQUS does not include element erosion, at the end of 0.025 sec the entire concrete chamber elements goes into plastic stage but does not erode. In this context it can be mentioned that a 2nd model similar in dimension with minor variations in material data was analysed in ANSYS version 13 in explicit domain which also revealed the concrete degradation phenomenon experienced under similar blast load conditions.

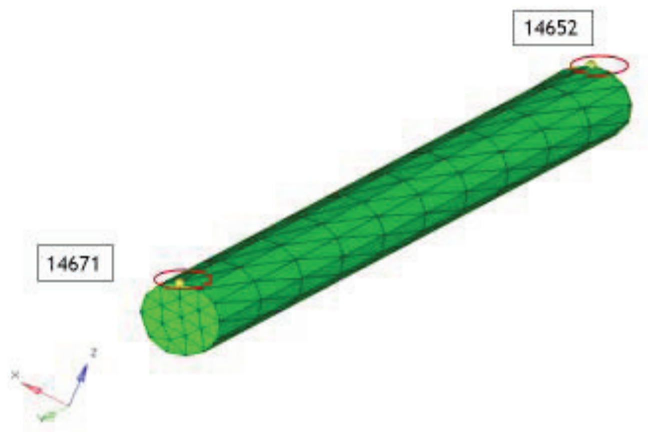


Fig-4 Concrete Pile with meshing showing Location of Nodes

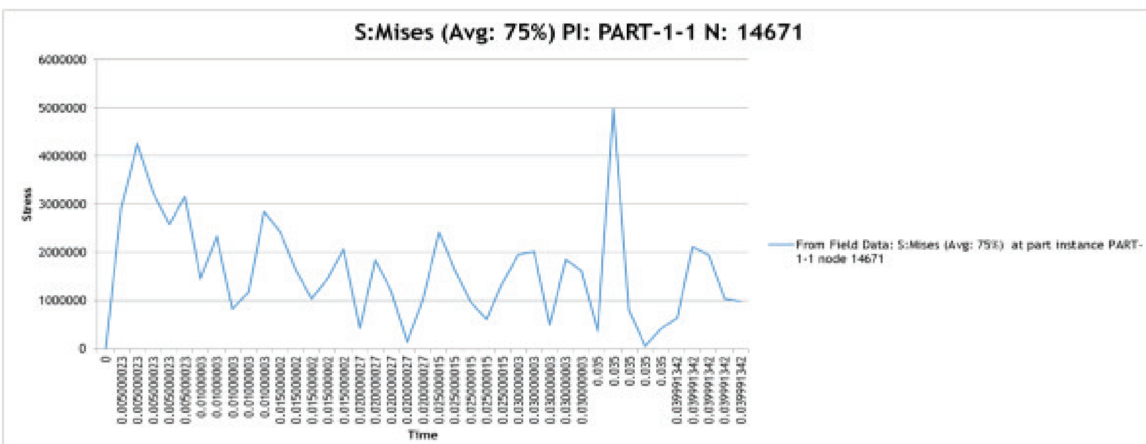


Fig-5 Pile Stress Mapping with time for Top Node 14671

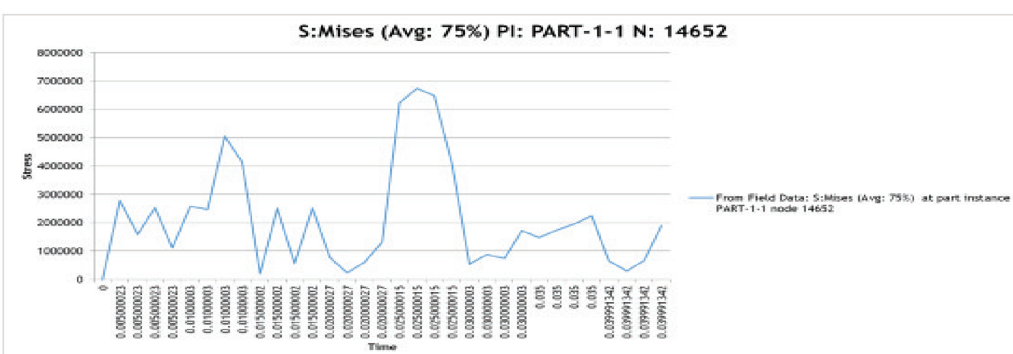


Fig-6 Pile Stress Mapping at end node 14652

BLAST RESPONSE IN PILE

This Pile is a representative pile section embedded in soil. To pick up the stress in Pile, two nodes are selected at end locations as shown in Fig-4. In foundation engineering, there are two most common types of piles are considered for design. These are friction pile and end bearing pile. In this paper authors have considered a case of friction pile which carries load by frictional resistance developed during driving the pile inside soil mass thereby developing adequate frictional resistance. Now in ABAQUS, Pile to soil contact is represented by surface to surface contact with a friction coefficient 0.45 and mechanical constraint as penalty. By reviewing the Misses Stress in Concrete Pile at top and bottom two peaks observed in both end nodes .In one end node 14671 Von Misses stresses shoots up to 4 and 5Mpa and in the other end 14652 the two peaks shoots up to 5 and 6.75Mpa thereafter the Stress level dips down to 2.5 Mpa to 3.0 Mpa which is just above the allowable Tensile stress in Concrete in tension 1.99Mpa. This means that the concrete pile has observed stresses beyond yield stress of concrete in tension and might have cracked.

BLAST RESPONSE IN SOIL

To understand the blast response on soil near pile, Authors have taken 2 nodes in soil adjacent to Concrete pile and taken average soil stress considered as that near the pile. The averaged stress in soil near pile node is 0.23 Mpa which is much more than the allowable Cohesive stress in soil 0.036Mpa indicating failure of soil mass in providing required adhesion or cohesion to Concrete Pile by the soil element. This Stress position also corroborated in the deformation of soil element adjacent to pile over the entire length of the pile which shows that the pile is disjointed from the soil mass and under this condition, limited sinking of pile is not eliminated though a total sinking is not expected as duration of blast load is very short and the pile will get frictional resistance after sinking a bit.

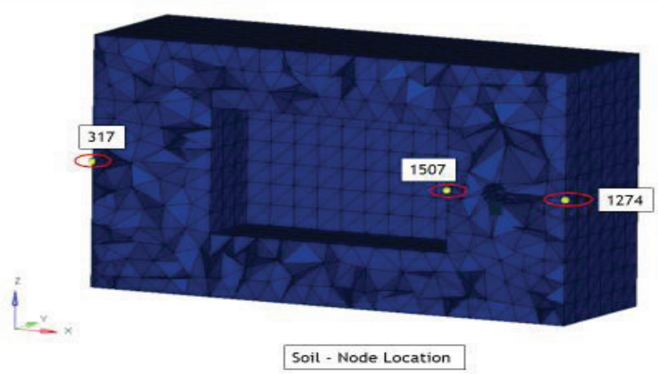
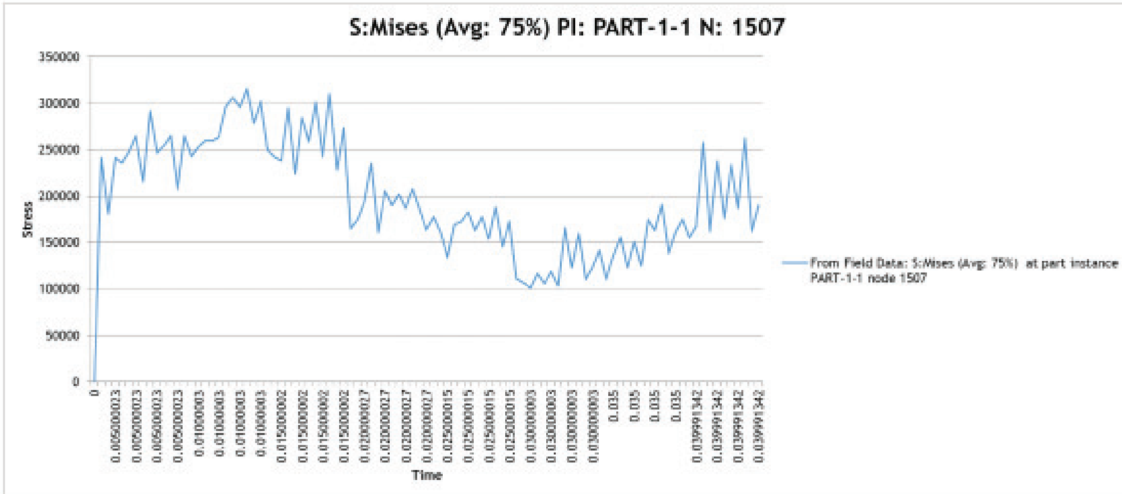
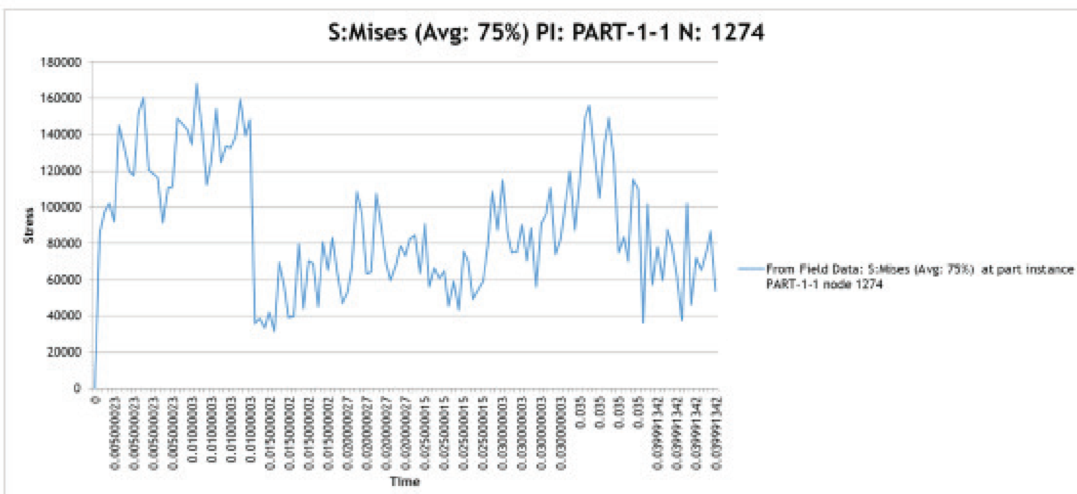


Fig-7 Soil Node Location around Concrete Chamber



Soil Results - Node 1507

Fig-8 State of Stressess in Soil



Soil Results - Node 1274

Fig-9 State of Stressess in Soil

THE 2ND MODEL ANALYSED IN ANSYS HAVING SIMILAR GEOMETRY OF VARIOUS PARTS

Ansys Mechanical FEM Solver vers 13.0 was used to model all the parts used in ABAQUS model in the same geometric dimension in explicit domain but with the exception that concrete was having Max Characteristic Strength 35 Mpa instead of 15 Mpa used in ABAQUS and Sand as soil in ANSYS was taken from Explicit Material library .The other data related to Air and Explosive remained as same.
The purpose of using different FEM Solver of ANSYS was to compare the results in both cases and justify the variations if any.Location of the Probing Point was at the center of each side of the Cube of Soil,Concrete Chamber to match the probing point in ABAQUS Model and the actual probing time was recorded.

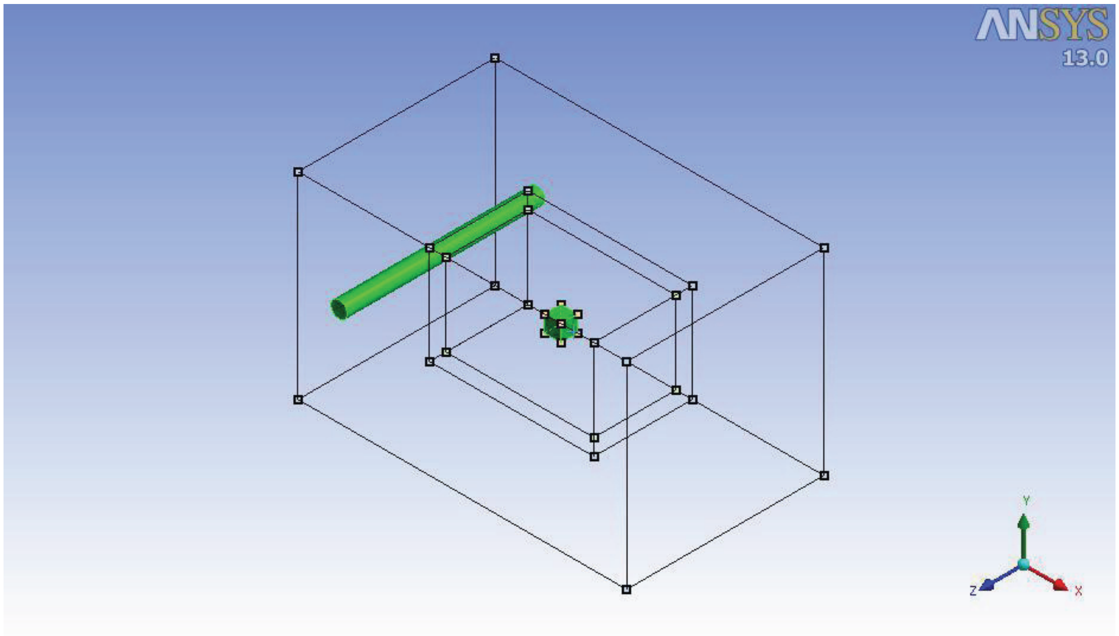


Fig-10 ANSYS Model Soil-Pile-Conc.Chamber-air-Explos

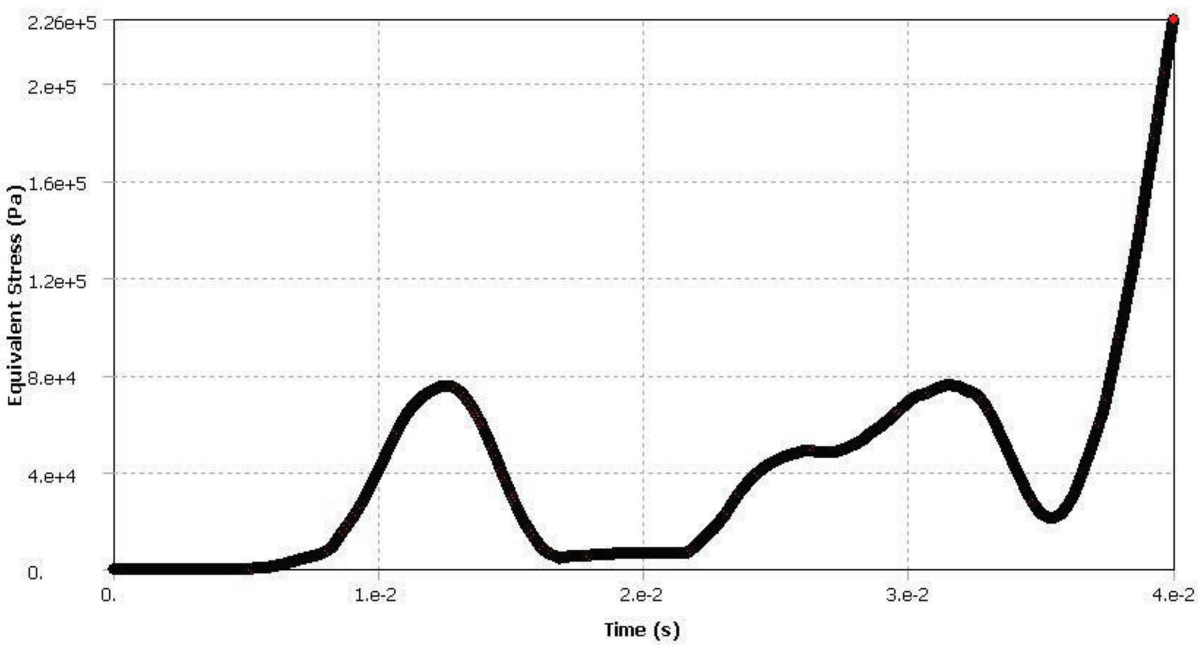


Fig-11 Soil Stress(Mises) at Time 0.04sec.

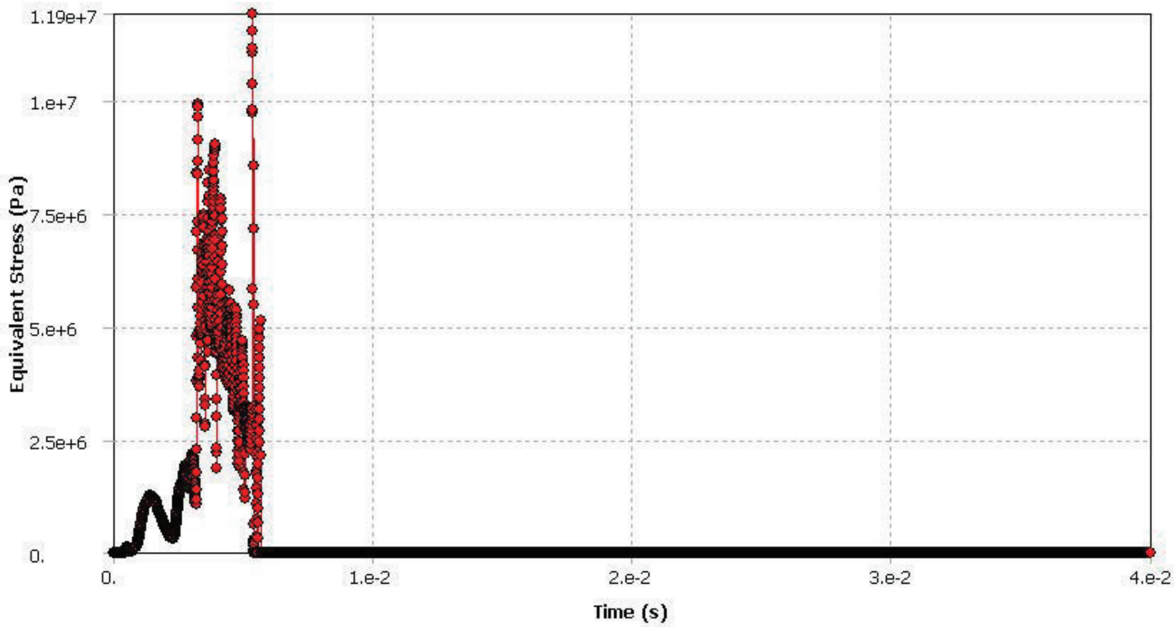


Fig-12 Von Mises Stress Plot at Conc.Chamber Mid Section.

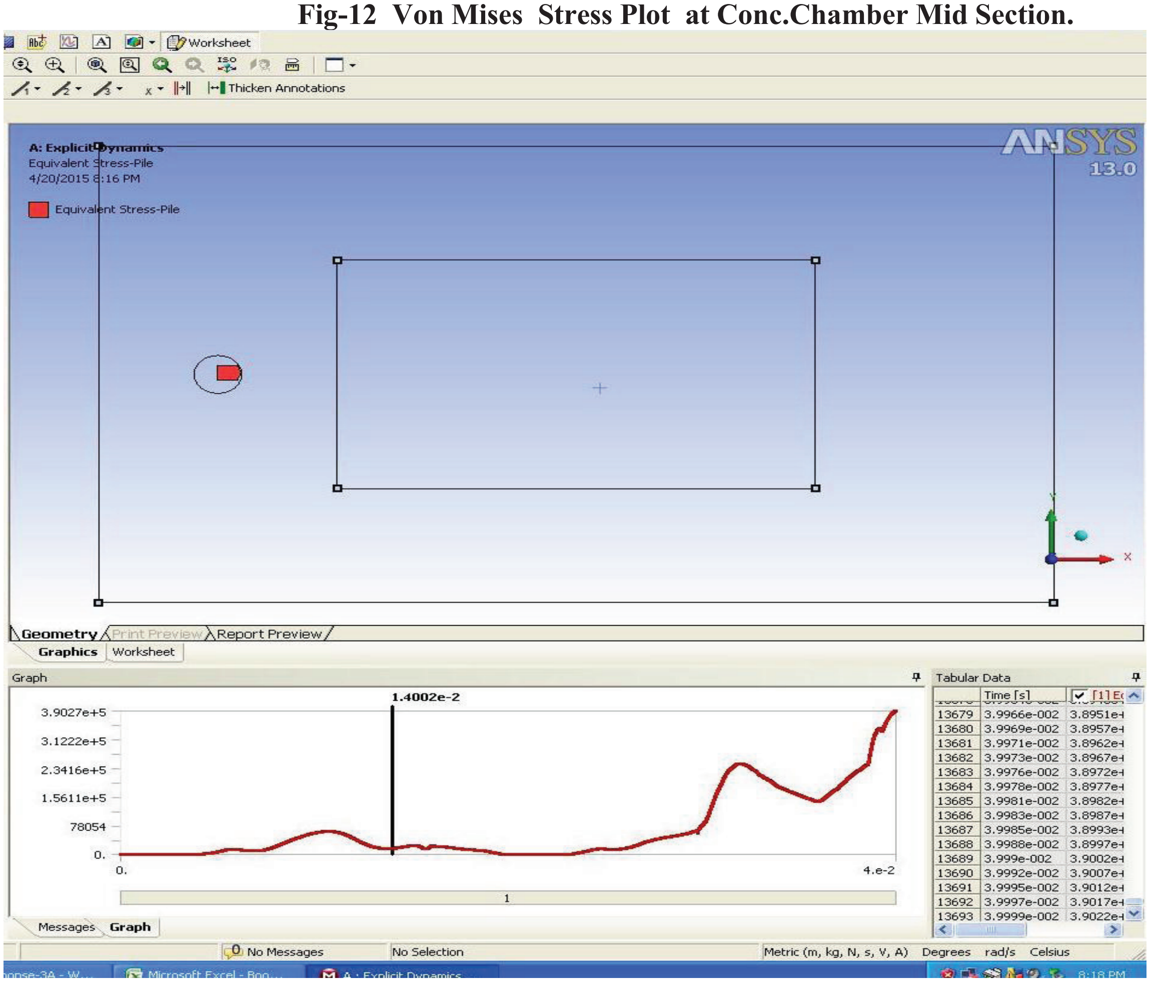


Fig-13 Location of Pile Stress Probe Point and Pile Stress(Mises)Graph.

RESULTS OF ANSYS & ABAQUS .

Table-4

Parts	Max.Mises ANSYS	Time	Time	MaxMises ABAQUS	TotalDeform ANSYS	Total Deform ABAQUS	Reasons for difference
Pile	**0.17Mpa**	**0.035 sec**	**0.035 sec**	**5.0Mpa**	**0.008 -- 0.015m**	**0.007-0.009m**	**Due to Concrete data difference**
Conc Cham ber	**12.0Mpa**	**0.005 sec**	**0.020 sec**	**13.0Mpa**	**0.040m at 0.04 sec**	**0.008m at 0.04sec**	**Due to Concrete data difference**
Soil	**0.226Mpa**	**0.04 sec**	**0.015 sec**	**0.3Mpa**	**0.012m**	**0.010**	**Due to Soil data difference**

CONCLUSION.

The Study of underground explosion inside a closed chamber has revealed that the blast wave pressure gets magnified once it get reflected on the wall and further hiked Blast wave penetrates the concrete wall and passes' into the soil mass in a damped state. Under the effect of the blast wave,the concrete chamber experiences high Mises stress and all most entire concrete chamber goes to a plastic stage.Further authors also verified the state of stress in soil which is adjacent to Concrete chamber. Here also it is seen that the cohesive stress in soil has been exceeded by nearly 8 to 10 times indicating failure of soil mass.Another interesting revealation was that Pile may partially sink due to loss of Friction with adjacent soil as checked from state of stress of soil around the pile.

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