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ANALYSIS ON EFFECT OF BLAST LOAD ON SUB-STRUCTURES

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Abstract - *Explosions have been the preferred weapon of terrorist organizations, because they are truly destructive, easy for fabrication and transport friendly. Analysis of structures for blast loading is very important specially for critical civilian buildings since they are not designed for blast loads. Considering the fact that many studies have been made only for the super-structures and surface blasts, in this study we focus mainly on the effects on sub-structure (pile foundation in soft soil) when the blast loads are applied below the ground level at certain depth. Different intensities of blast loads are applied on pile foundation and their effects on piles as well as the stresses in the soil are analyzed. The analysis is done using computer aided softwares, SAP 2000 version 19.1.0 and ATBlast.*

***Key Words*: Standoff distance, blast below ground level, pile foundation, displacement, stresses, hinged support.**

1. INTRODUCTION

Recent past blast incidents in the country trigger the minds of developers, architects and engineers to find solutions to protect the occupants and structures from blast disasters. There has been lot of research carried out for the destruction caused on the super-structure due to the blast loading on surface of soil. Relatively, there are very less number of studies that are made on the destruction of sub-structures due to sub-surface blasts. There are different types of sub-structures, but, the sub-structure considered here is a pile foundation. The effects on the pile foundation and the stresses in the soil were considered in the study. Design consideration against explosions is very important in high-rise facilities such as public and commercial tall buildings and sub-structures, because there are many buildings that may be under threat of blast loads although not originally designed for the same.

Trinitrotoluene is usually known as TNT, which is highly explosive and does not occur naturally. It is a man-made solid compound which is yellow in color and odorless. It either absorbs water or dissolves which makes it reliable to use in wet environmental conditions. Amatol and composition B, can be the other constituents of this explosive. It is the most commonly used explosives in military and industrial applications. The use of this explosive for military purposes increased widely in World War 1 and became one of the dominant military explosives. It's melting temperature is around 810ºC, (the temperature below its detonation temperature) which makes it easy to be melted and easily be poured in to shells. The chemical formula for TNT is C_6H_2 $(NO2)_3CH_3$ and its chemical structure is as shown in Figure 1.

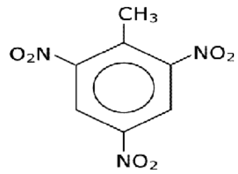

Fig-1. Chemical structure of TNT

2. OBJECTIVES

The main objectives of this study can be summarized as follows:

i. Understanding the fundamentals of blast hazards and the interaction of blast waves with sub-structure (pile foundation).
ii. Modeling and analysis of piles for explosions below ground level.
iii. To assess the results when the blast loads are applied on piles.
iv. To determine the lateral displacements of the piles and the stresses induced in the soil due to the blast loads.

3. METHODOLOGY

The study is concerned with the behavior of piles when subjected to blast loading and mainly focuses on the modeling of a pile structure and a super-structure consisting of nine storeys, using SAP2000 program and analyzing its behavior when subjected to blast loads. The blast loads are calculated using AT Blast Software. For the analysis of the sub-structure (i.e. pile foundation) three different charge weights are used to examine the effect of lateral displacement of the pile at a three different standoff distances and the variation of the stresses in the soil are analysed.

3.1 Modeling and analysis

Computer modelling of the building was performed using the finite element software SAP2000 version 19.1.0. Figure 2 shows the analysis flowchart. Soil blocks are modelled as solid elements. The parameters of the soft soil were considered for the analysis. Piles are modelled which are of

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three different lengths 10m, 16m and 20m within the soil. Figures 3 to 5 show the section of the soil and piles of different lengths. The loads from the super-structure are transferred on the group of piles as vertical loads through columns and then the load is divided and applied on individual piles. The analysis is carried out for different charge weights of 500kg, 1000kg and 1500kg TNT at three different standoff distances 3m, 5m and 7m and the results are tabulated. The reinforced concrete building is framed structure composed of columns and beams. The loads on the super-structure are considered as per IS 875 (part 2). Figure 6 shows the 3D view of the super-structure, soil and supports provided. The study reflects effects of blasts below the ground level, ground motion (i.e. stresses in the soil) and the lateral displacements of the piles. It is assumed that the soft soil behaves as a elastic medium, so the soil bottom and the piles are assigned hinged support.

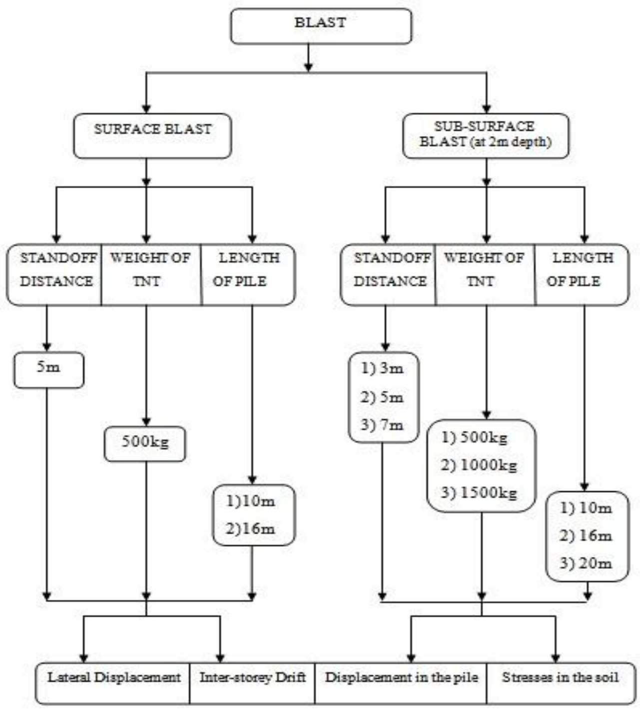

Fig-2. Analysis flowchart

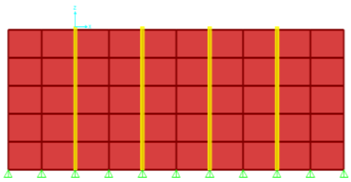

Fig-3. Section of soil and pile of 10m length

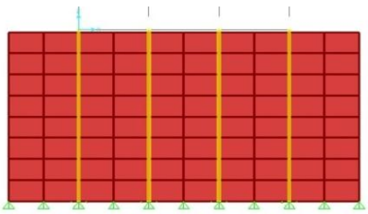

Fig-4. Section of soil and pile of 16m length

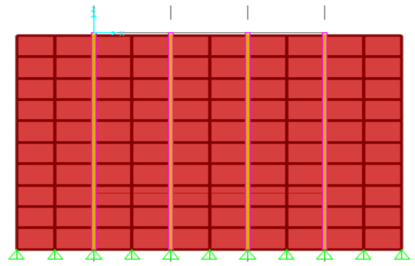

Fig-5. Section of soil and pile of 20m length

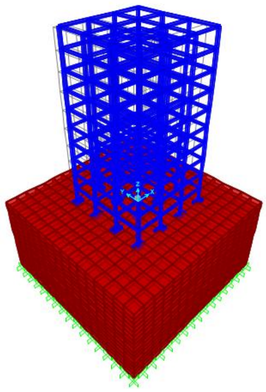

Fig-6. 3D view super-structure, soil and pile.

3.2 Analysis Results

The analysis results for different weights of TNT's, different standoff distances and different pile lengths are as follows,

A. For sub-structure (pile foundation)
   i. Stress versus depth of the soil.
   ii. Displacement versus length of the pile.
B. For super-structure (9 storey building)
   i. Lateral displacement versus storey height.
   ii. Inter-storey drift versus storey height.

Figures 7 to 9 show the stress versus depth of the soil graphs for different weights of TNT's when the blast load is applied at different standoff distances. Similarly, the graphs were plotted for16m and 20m pile lengths.

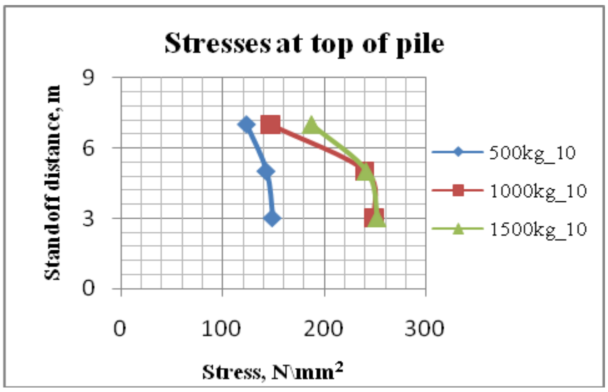

Fig-6. Stresses at top of pile for 10m pile length

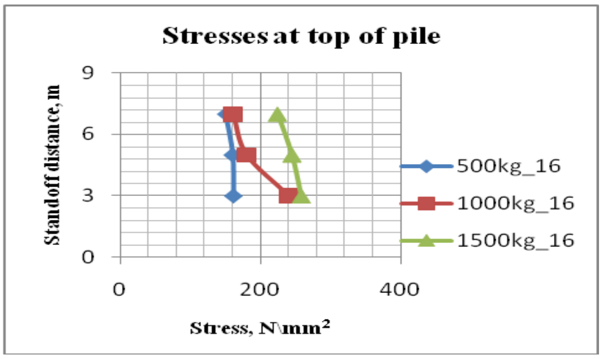

Fig-7. Stresses at top of pile for 16m pile length

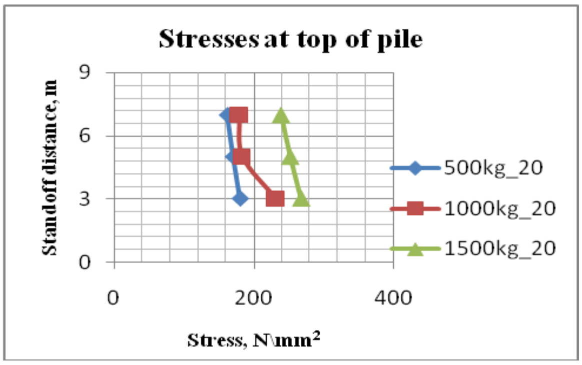

Fig-8. Stresses at top of pile for 20m pile length

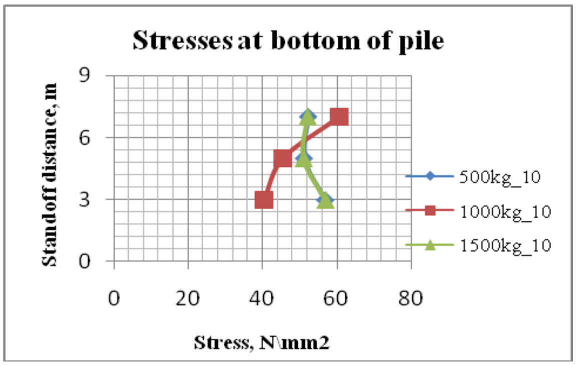

Fig-9. Stresses at bottom of pile for 10m pile length

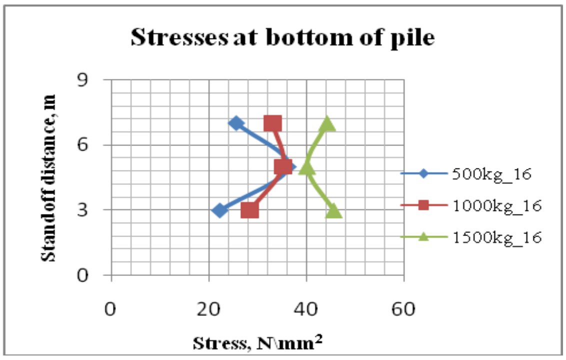

Fig-10. Stresses at bottom of pile for 16m pile length

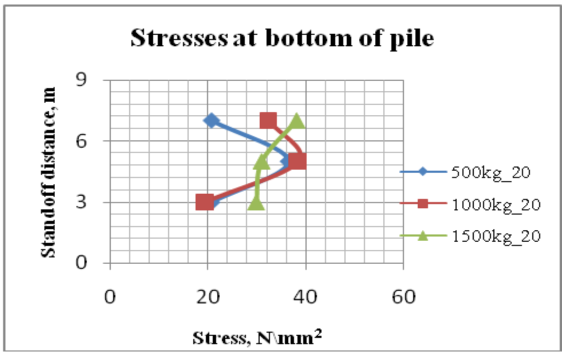

Fig-11. Stresses at bottom of pile for 20m pile length

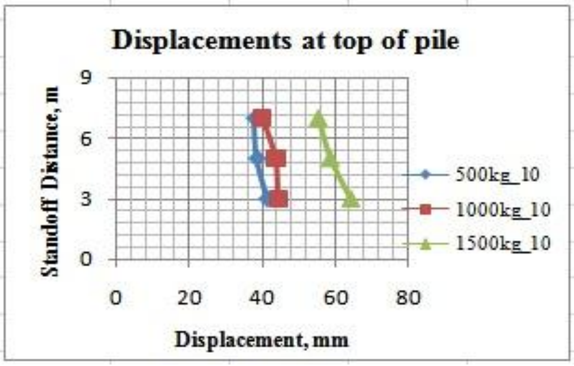

Fig-12. Displacements at top of pile for 10m pile length

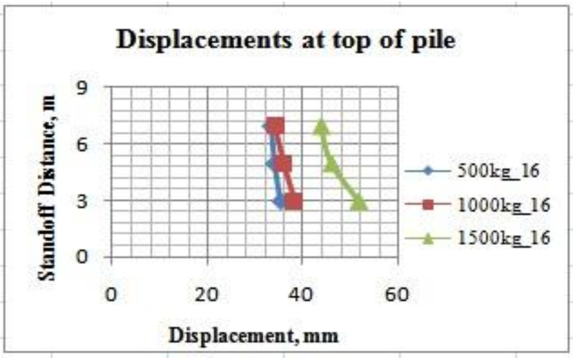

Fig-13. Displacements at top of pile for 16m pile length

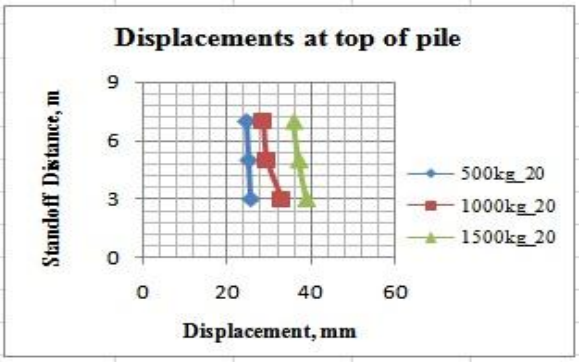

Fig-14. Displacements at top of pile for 20m pile length

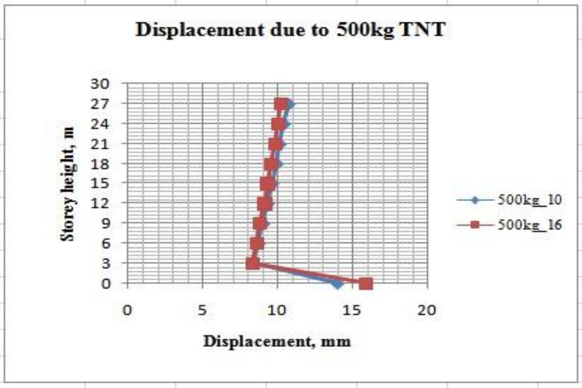

Fig-15. Displacements of super-structure for different pile lengths

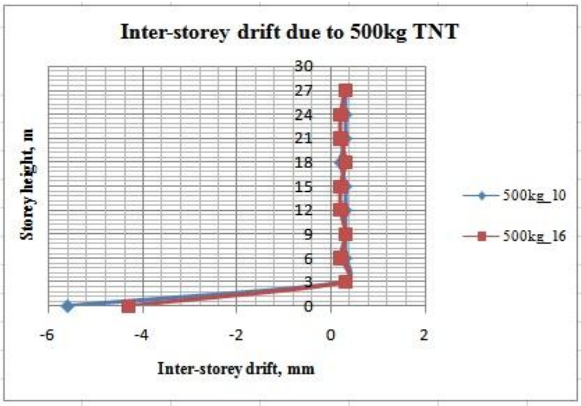

Fig-16. Inter-storey drifts of super-structure for different pile lengths

4. DISCUSSIONS

The following are the discussions made on the present study i.e., the blast is applied at a depth of 2m below the ground level and the lateral displacement of the pile and the stresses in the soil are analysed. It is found that the percentage change in the stress for 10m pile was higher with increasing standoff distances when compared to 16m and 20m piles (i.e. for 10m pile, percentage change in stress from 3m to 7m standoff distance is 70.1 - 49.35 = 20.75. For 16m pile, percentage change in stress from 3m to 7m standoff distance is 60.36 – 48.97 = 11.39. For 20m pile, percentage change in stress from 3m to 7m standoff distance is 48.1 – 46.74 = 1.36).

The following tables 1 to 3 show the percentage change in the stresses due to different weights of TNT applied at different standoff distances.

Standoff distance, m	Stress due to 500kg TNT, N/mm²	Stress due to 1000kg TNT, N/mm²	Stress due to 1500kg TNT, N/mm²	% change in stress
3	149.22	250.01	252.36	70.1
5	143.10	240.53	241.65	68.8
7	123.74	147.48	187.77	49.35

Table-1. Comparison of stress in soil for a 10m depth pile

Standoff distance, m	Stress due to 500kg TNT, N/mm²	Stress due to 1000kg TNT, N/mm²	Stress due to 1500kg TNT, N/mm²	% change in stress
3	161.23	240.37	258.56	60.36
5	160.22	179.83	245.32	53.11
7	150.92	160.38	224.84	48.97

Table-2. Comparison of stress in soil for a 16m depth pile

Standoff distance, m	Stress due to 500kg TNT, N/mm²	Stress due to 1000kg TNT, N/mm²	Stress due to 1500kg TNT, N/mm²	% change in stress
3	180.43	231.56	267.23	48.1
5	170.6	183.25	251.6	47.4
7	162.5	178.6	238.46	46.74

Table-3. Comparison of stress in soil for a 20m depth pile

The following tables 4 to 6 show the percentage change in displacement of the pile for different weights of TNT and standoff distances. It is found that, the percentage change in the displacement is higher from 10m to 16m pile but decreases for 20m pile (i.e. for 10m pile, percentage change in displacement from 3m to 7m standoff distance is 55.02 – 46.56 = 8.46. For 16m pile, the percentage change is 42.03 – 31.14 = 10.89. For 20m pile, the percentage change is 48.43 – 45.52 = 2.91).

Standoff distance, m	Disp. due to 500kg TNT, mm	Disp. due to 1000kg TNT, mm	Disp. due to 1500kg TNT, mm	% change in Disp.
3	41.3	44.4	64.1	55.02
5	38.5	43.7	58.6	52.2
7	37.8	40.1	55.4	46.56

Table-4. Comparison of displacement in soil for a 10m depth pile

Standoff distance, m	Disp. due to 500kg TNT, mm	Disp. due to 1000kg TNT, mm	Disp. due to 1500kg TNT, mm	% change in Disp.
3	35.4	38.2	51.7	42.03
5	34.1	36.0	46.0	34.89
7	33.4	34.3	43.8	31.14

Table-5. Comparison of displacement in soil for a 16m depth pile

Standoff distance, m	Disp. due to 500kg TNT, mm	Disp. due to 1000kg TNT, mm	Disp. due to 1500kg TNT, mm	% change in Disp.
3	25.6	32.9	38.8	48.43
5	25.10	29.5	37.01	47.4
7	24.6	28.6	35.80	45.52

Table-6. Comparison of displacement in soil for a 20m depth pile

5. CONCLUSIONS

The conclusions are:

1. As the standoff distance increases the stresses will be decreased at the top of the pile to the depth of 10m and further it remains constant with the variation of the pile length.
2. As the length of the pile increases, stresses in the soil are increased.
3. As the intensity of the blast load (weight of the TNT) increases, stresses in the soil also increases.
4. As the standoff distances of the blast load increases, the displacement in the pile decreases.
5. As the length of the pile increases, displacement values of the pile decreases.
6. As the intensity of the blast load (weight of the TNT) increases, lateral displacement of the pile increases.
7. For the super-structure, the displacement values gradually decreases when the length of the pile increases.
8. For the super-structure, the inter-storey drift values gradually decreases when the length of the pile increases.

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