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Effect of Excavation on Adjacent Structure on Sandy Clayey Soil

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ABSTRACT: Many civil engineering projects in urban areas were constructed over existing underground structures, such as transit tunnels, utilities, etc. Urban area excavation design should include an estimation of the ground movement as well as stability check for support systems provided to excavation wall. In this paper, the results of analyses of effect of excavation adjacent to structure in sandy clay soil have been presented. For this purpose, model of building adjacent to excavation was developed in PLAXIS 2D, which is finite element method based software. This paper presents the analyses carried out for the effect of excavation adjacent to the structure subjected to working load on structure and excavation supported by support system. The parameters selected for analyses were the depth of excavation, height of structure, location of structure from excavation, and provision of sheet pile support systems and anchors to the support system. The analyses were carried out for structure with different heights and at various spacing from the excavation without support. The results of these analyses served as basis for the comparison with performance of structure near excavation with support to the excavation for similar conditions. From the analyses, the critical depth of excavation and deflection for different heights of structure was found out. Effect of anchoring on critical depth of excavation was also checked.

KEYWORDS: Sandy Clay, Sheet Pile, Anchors, PLAXIS 2D, Critical Depth of Excavation

I. INTRODUCTION

As urban areas are becoming increasingly developed with buildings, transportation structures, utilities, and other infrastructure, construction in these densely developed and confined areas can create several geotechnical challenges. Many civil engineering projects in urban areas were constructed over existing underground structures, such as transit tunnels, utilities, etc. Urban area excavation design should include an estimation of the ground movement as well as stability check of the braced and unbraced excavation wall. The common practice is to estimate both the settlement of the ground and that of the building, when the ground movement adjacent to an excavation site is estimated. However, since ground settlement occurs as a consequence of the ground's lateral movement, it is expected that heavy structure will undergo additional settlement due to its weight and the decrease in the stiffness of the foundation soil. The reduction of soil stiffness is a result of the lateral movement of the excavation side. The earlier studies were therefore extended to investigate the behaviour of structure due to excavation induced soil movement in soil.

II. LITERATURE REVIEW

Dinakar K N *et al.*⁵ (2014) conducted series of finite element analysis to study the performance of anchored sheet pile wall, stress analysis and deformation characteristics of ground and bending moment distributions in sheet pile wall were identified. It was concluded that Tie back sheet pile wall method acted as a stable supporting system to excavate for greater depths safely without considerable ground deformations.

Dr. A. I. Dhattrak and S. D. Kulkarni⁴ (2016) used finite element method to study the behaviour of pile adjacent to deep excavation in layered soil. From the results it was concluded that as the thickness of top layer of weak soil increases, deflection of pile also increases.

J. Jia, J. H. Wang, C. P. Liu, L. L. Zhang, and X. L. Xie (2008) studied a case history of a deep excavation in Shanghai, which was adjacent to a historical building founded on 27 m long wooden piles and operating Metro

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tunnels. The effects of the excavation on the nearby pile foundation and the existing tunnels were investigated using two-dimensional finite element modelling. The site was of the New Yi Bai Commercial Center. According to the numerical results, the maximum horizontal and vertical displacements of the wooden piles were 15.8 mm and 7.6 mm, respectively. The horizontal and vertical movements of the utility tunnel and Metro tunnel were all less than 10 mm, which satisfied the current design control criteria in Shanghai.

Karthigeyan S. and Sathiya G (2016) performed series of numerical analyses on the footing by incorporating varying parameters such as the footing location from an excavation, varying density of soil and depth of excavations. It was concluded that the effect of excavations to an adjacent circular footing had shown a significant influence on the settlement and bending moment of the footings.

Karthigeyan S. and Samanta M (2011) conducted finite element analysis to check the effect of indirect loading due to adjacent excavations on the lateral response of pile in sandy soil. It was concluded that The lateral response of pile was highly sensitive to indirect loading due to adjacent excavations with respect to the depth of excavation (H_e/B_e) and the pile location (X_p). The effect of indirect lateral loading on the pile was to increase the pile deflection and bending moments up to considerable distances away from the excavation.

Mostafa El Sawwaf , and Ashraf K. Nazir (2011) carried out laboratory investigations to study the effect of deep excavation induced lateral soil movements on the behaviour of strip footing supported on reinforced sand for parameters such as footing load, location of footing relative to excavation, relative density of sand, affected depth of soil excavation. Based on the experimental test results, it was concluded that the inclusion of soil reinforcement in granular soil under strip footing adjacent to deep excavation not only significantly decreased the footing settlement but had also provided greater stability to the footing.

III.SYSTEM DEVELOPEMENT

In this study, effect of excavation on adjacent structure in sandy clay and clayey soil bed has been studied. For this purpose, analyses were carried out on model developed in PLAXIS 2D.

A. Problem Definition

In the present research work, analysis of structure adjacent to excavation in sandy clay and clayey soil was carried out. The parametric study of excavation with different parameters such as height of building (H), depth of excavation (D), location of building from excavation (x), support to excavation face and anchored support was carried out. Figure 1 shows the typical problem with various parameters selected for analysis. The details of parameters are given in Table 1.

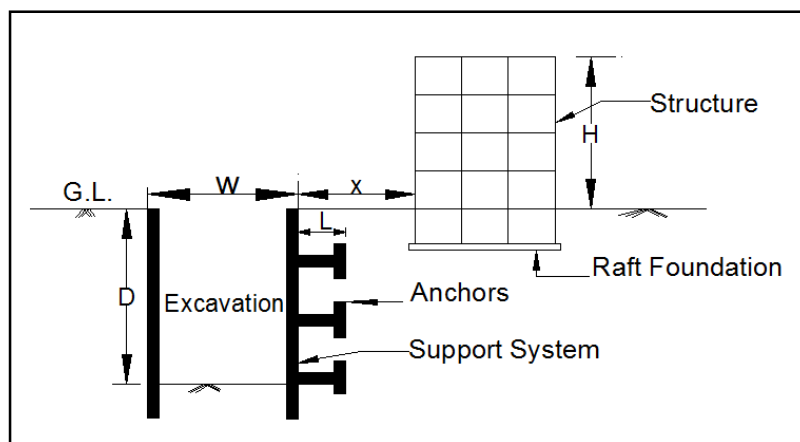


Fig.1: Problem Statement for Present Study

The FEM model was then generated in PLAXIS 2D Software for the setting already made as shown in Figure 2.

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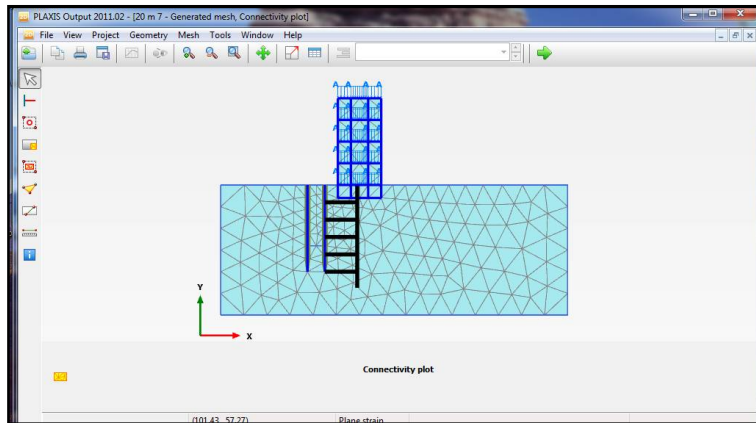


Fig.2: FEM Model in PLAXIS 2D for Present Study

Table 1: Details of Parameters Studied

Sr.No.	Parameters	Range of values	
1	Ratio of depth of excavation to the height of building (D_e/H),	0.1H,0.2H,0.3H,0.4H,0.5H,0.6H,0.7H, 0.8H, 0.9H, 1H	
2	Location of building from excavation (x) (m)	1 , 2 , 3 , 4 , 5 , 10	
3	Height of structure (H) (m)	5, 10, 15, 20, 25,30 , 35 , 40	
4	Type of support system	Sheet pile	
		Anchors	L = 3 m
			N = 1, 2, 3, 4, 5

B. Soil Bed

Soil bed adopted for the present study consisted of bed of sandy clay soil. The properties for soil bed were adopted from the literature [5] and, the soil model adopted was Mohr's Coloumb model. The properties assigned to these soil bed are shown in Table 2.

Table 2: Properties Assigned to the Sandy Clay Soil for Present Study

Properties	Symbols	Values
Unit weight	γ	18 kN/m ³
Friction angle	ϕ	30°
Dilatancy angle	ψ	2°
Poisson's ratio	μ	0.3
Young's Modulus	E	20000 kN/m ²
Cohesion	c	20 kN/m ²

C. Building Model

Building of width 10 m was modeled using plate elements and was considered to be very stiff and rough in the analysis. The building was considered to be made of various floors, each floor being 5.0 m in height. Building is

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considered with a raft foundation with foundation bed level at a depth of 3.0 m below ground level. The uniformly distributed load of 20kN/m^2 was considered at each floor level, as live load. The material type adopted for structural elements was Elasto-plastic model. The properties of building were selected from literature as shown in Table 3 and 4.

Table 3: Properties of Structural Element Selected for Present Study

PARAMETER	NAME	VALUE
Axial stiffness	EA	3.3×10^6 kN/m
Flexural rigidity	EI	6.19×10^3 kNm ² /m
Equivalent Thickness	D	0.15 m
Poisson's ratio	ν	0.20

Table 4: Properties of Foundation Selected for Present Study

PARAMETER	NAME	VALUE
Type of behaviour	Material type	Elasto-plastic
Axial stiffness	EA	1.1×10^7 kN/m
Flexural rigidity	EI	2.29×10^5 kNm ² /m
Equivalent Thickness	D	0.50 m
Poisson's ratio	ν	0.20

D. Support System

Type of support system used for excavation was sheet pile and anchors. The properties of sheet pile and anchors selected for present study are shown in Table 5 and 6. The model adopted for sheet pile was Elasto-plastic model.

Table 5: Properties of Sheet Pile Selected for Present Study

PARAMETER	NAME	VALUE
Axial stiffness	EA	3.12×10^6 kN/m
Flexural rigidity	EI	1.78×10^4 kNm ² /m
Equivalent Thickness	D	0.262 m
Poisson's ratio	ν	0.3

Table 6: Properties of Anchors Selected for Present Study

PARAMETER	NAME	VALUE
Anchor Modulus	E	200×10^6 kN
Anchor Thickness	t	25 mm
Anchor Spacing	L_s	4 m

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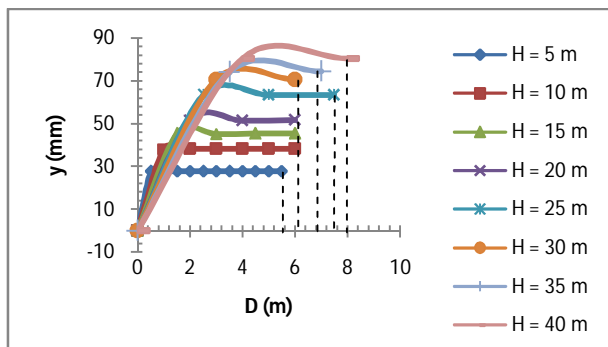
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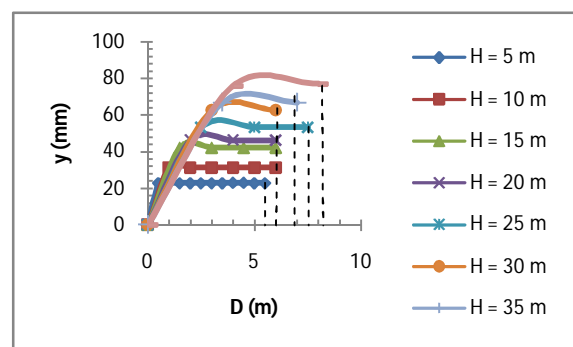
IV. ANALYTICAL RESULTS

E. Analysis of Structure Adjacent to Excavation Without Support to Sandy Clay Soil

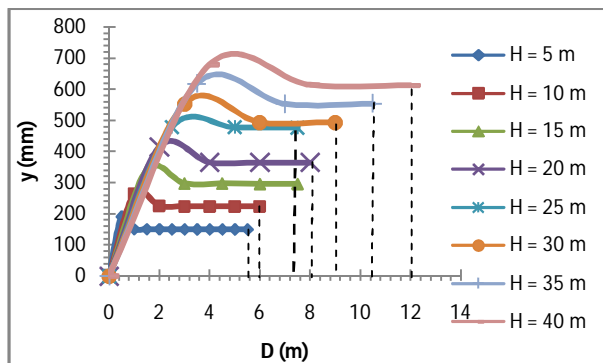
Initially, the analysis was carried out for structure with different heights and at various spacing from the excavation without support. The structure was subjected to uniformly distributed load of 20 kN/m² at each floor level. The results obtained for sandy clay soil from analyses are presented in Figure 3, which shows the variation of deflection of the corner of excavation near building (y) with respect to depth of excavation (D) for different values of x . From these curves, the critical depth of excavation (D_c) was determined in each case. The depth of excavation at which the building collapses has been termed as 'Critical depth of excavation' (D_c).



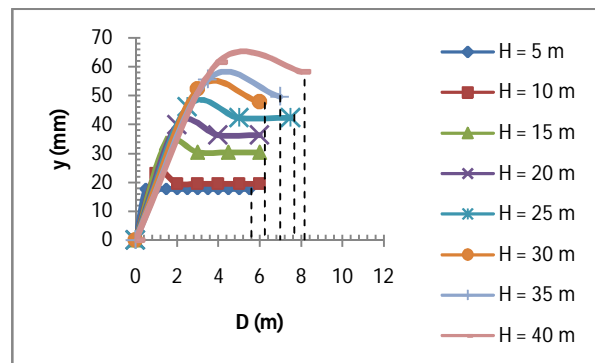
(a) $x = 1$ m



(b) $x = 2$ m



(c) $x = 3$ m



(d) $x = 4$ m

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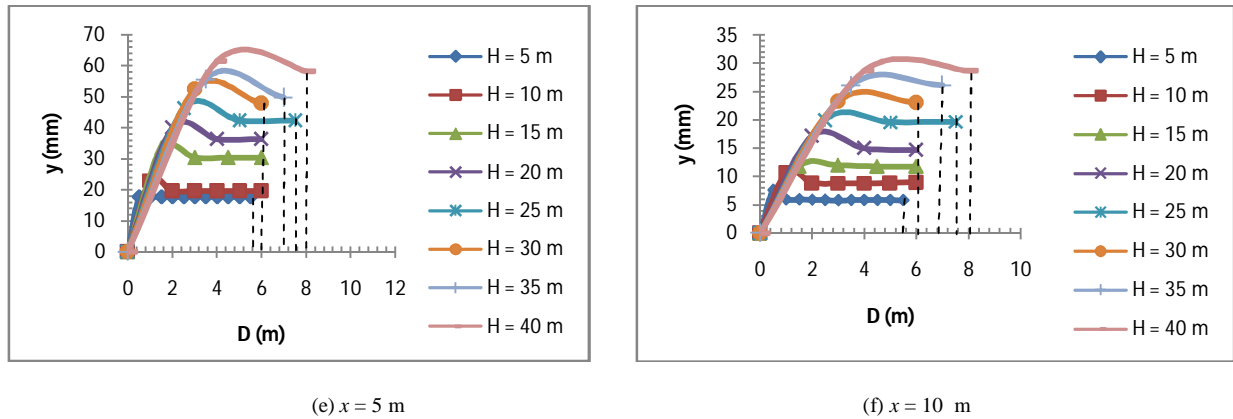
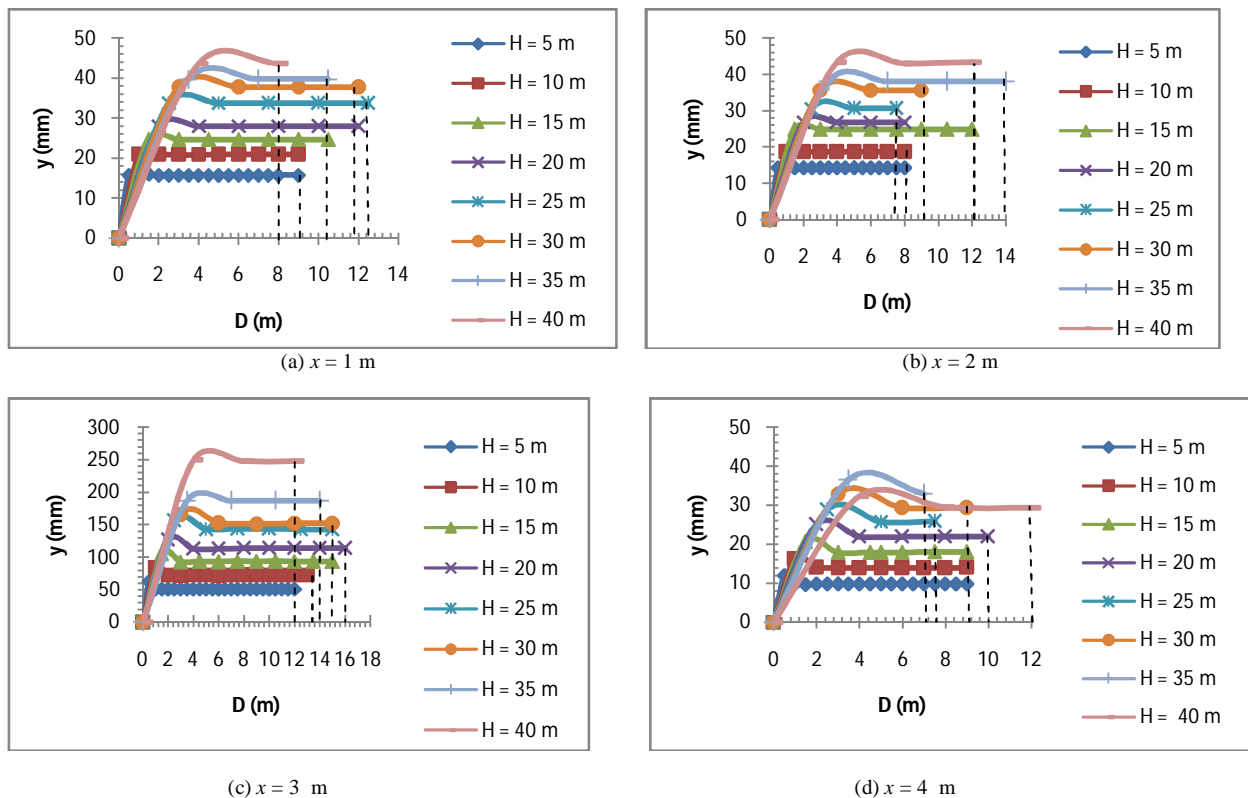


Fig. 3: Deflection of the Corner of Excavation near building (y) w. r. t Depth of Excavation (D) Without Support to Sandy Clay Soil Bed for (a) $x = 1$ m, (b) $x = 2$ m, (c) $x = 3$ m, (d) $x = 4$ m, (e) $x = 5$ m, (f) $x = 10$ m

F. Analysis of Structure Adjacent to Excavation With Support to Sandy Clay Soil

Further analyses were carried out for structure with different heights and at various spacing from the excavation with support. The structure was subjected to uniformly distributed load of 20 kN/m^2 at each floor level. The support system provided was sheet pile wall. The results obtained for sandy clay soil from analyses are presented in Figure 4 which shows the variation of deflection of the corner of excavation near building (y) with respect to depth of excavation (D) for different values of x . From these curves, the critical depth of excavation (D_c) was determined in each case.



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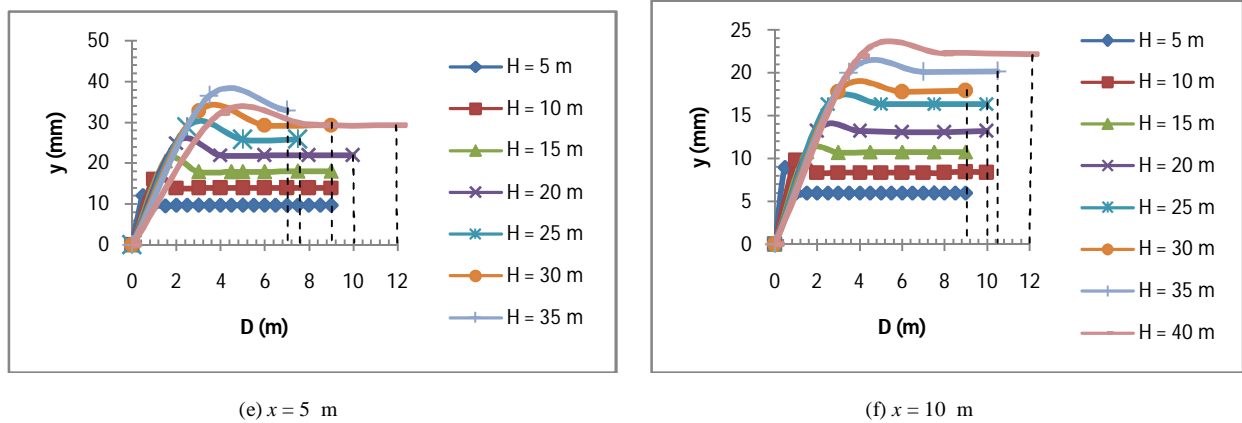


Fig. 4: Deflection of the Corner of Excavation near building (y) w. r. t Depth of Excavation (D) With Support to Sandy Clay Soil Bed for (a) x = 1 m, (b) x = 2 m, (c) x = 3 m, (d) x = 4 m, (e) x = 5 m, (f) x = 10 m

G. Analysis of Structure Adjacent to Excavation in Sandy Clay Soil With Anchored Support

The analyses was carried out for structure with different heights and at spacing of 3 m from the excavation with support. The structure was subjected to uniformly distributed load of 20 kN/m² at each floor level. The support system provided was sheet pile wall with anchors. Analyses were carried out by varying the numbers of anchors from 1 to 5 and anchors were placed at 4m.

The results obtained from analyses are presented in Table 7 which show the increase in critical depth of excavation due to provision of anchored.

Table 7: Increase in Critical Depth of Excavation in Sandy Clay Soil With Anchored Support for x = 3 m

Sr. No	Height of Building (H) (m)	Critical Depth of Excavation With Support (m)	Critical Depth of Excavation With Anchored Support				
			Number of Anchors				
			1	2	3	4	5
1	5	16	16	16	16	16	16
2	10	15	16	16	16	16	16
3	15	15	16.5	16.5	16.5	16.5	16.5
4	20	16	17	17	17	17	17
5	25	15	17.5	17.5	17.5	17.5	17.5
6	30	15	18	18	18	18	18
7	35	14	17.5	17.5	17.5	17.5	17.5
8	40	16	16	16	16	16	16

V. DISCUSSION OF RESULTS

H. Effect of Support System on Critical Depth of Excavation

The increase in critical depth of excavation due to provision of support to excavation are determined for sandy clay soil are presented in Table 8.

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Table 8. Critical Depth of Excavation for Without and With Support to Excavation

Sr. No	Height of building (m)	Critical Depth of Excavation Without Support (D_c) in (m)						Critical Depth of Excavation With Support (D_c) in (m)					
		x = 1 m	x = 2 m	x = 3 m	x = 4 m	x = 5 m	x = 10 m	x = 1 m	x = 2 m	x = 3 m	x = 4 m	x = 5 m	x = 10 m
1	5	5.5	5.5	5	5	5.5	5.5	9	9.5	16	9	9	9
2	10	6	6	6	6	6	6	9	10	15	9	10	10
3	15	6	6	7.5	6	6	6	10.5	10.5	15	9	9	9
4	20	6	6	8	6	6	6	12	12	16	10	10	10
5	25	7.5	7.5	10	7.5	7.5	7.5	12.5	12.5	15	10	10	10
6	30	6	6	12	6	6	6	12	15	15	9	9	9
7	35	7	7	10.5	7	7	7	10.5	14	14	7	10.5	10.5
8	40	8	8	8	8	8	8	8	12	12	8	12	12

From Table 9, it is observed that the maximum critical depth of excavation for structure adjacent to the excavation for with and without support system is at $x = 3$ m. Figure 5 shows the percentage increase in critical depth of excavation due to provision of support to excavation. Figure 6 shows the percentage decrease in deflection of structure due to provision of support to excavation.

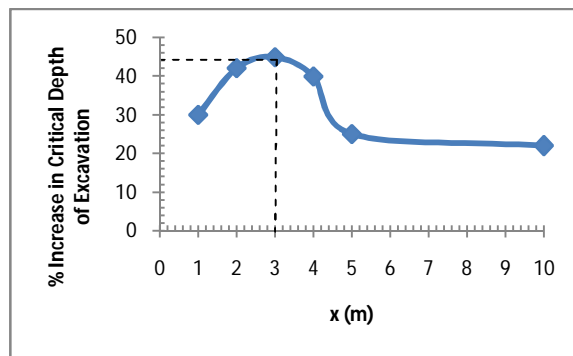


Fig. 5: Percentage Increase in Critical Depth of Excavation due to Provision of Support to Excavation w. r. t x ($H = 5$ m)

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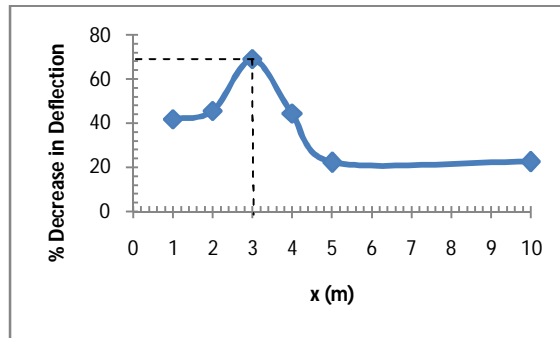


Fig. 6: Percentage Decrease in Deflection of Structure due to Provision of Support to Excavation w. r. t x ($H = 30$ m)

From Figure 5, it is observed that the % increase in critical depth of excavation increases as the distance between the excavation and structure increases and maximum increase occurs at $x = 3$ m which is @ 45% for 5 m height of building. From Figure 6, it is seen that the maximum decrease in deflection of structure also occurs at $x = 3$ m, which is @ 70 % for 30 m height of building. After $x = 5$ m, there is no considerable effect on % decrease in deflection due to support to the excavation.

I. Effect of Support System With Anchors to Excavation on Critical Depth of Excavation

The percentage increase in critical depth of excavation due to provision of support with anchors to excavation are determined are presented in Table 9.

Table 9: Percentage Increase in Critical Depth of Excavation With Anchored Support for Sandy Clay Soil for $x = 3$ m

Height of Structure (H) (m)	% Increase in Critical Depth of Excavation				
	Number of Anchors				
	1	2	3	4	5
5	0	0	0	0	0
10	7	7	7	7	7
15	9	9	9	9	9
20	10	10	10	10	10
25	15	15	15	15	15
30	17	17	17	17	17
35	20	20	20	20	20
40	0	0	0	0	0

Figure 7 shows the percentage increase in critical depth of excavation in sandy clay soils w. r. t height of building for $x = 3$ m. Figure 8 shows the percentage increase in critical depth of excavation in sandy clay soils w. r. t number of anchors for $x = 3$ m.

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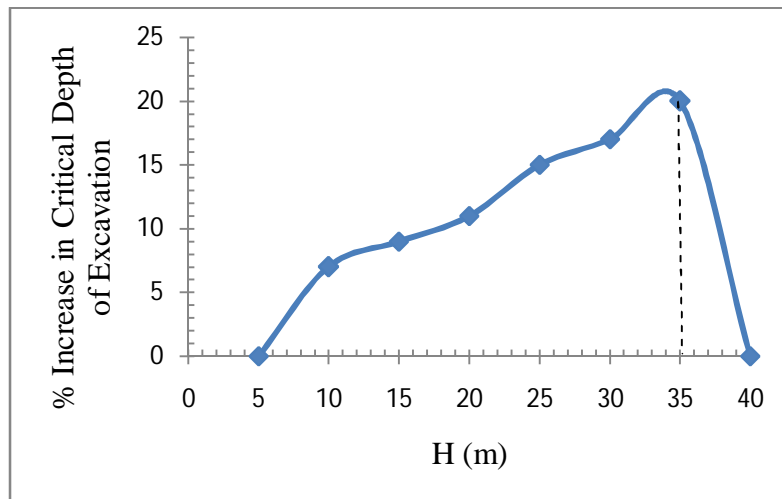


Fig. 7: Percentage Increase in Critical Depth of Excavation in sandy clay soil w. r. t Height of Building at $x = 3$ m

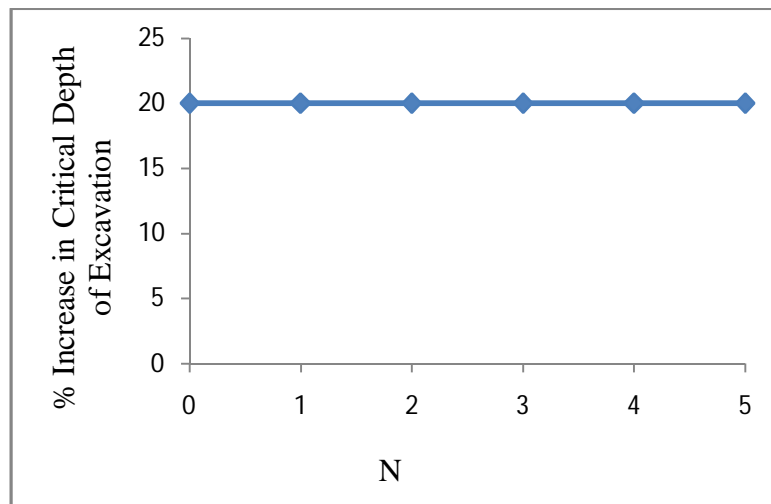


Fig. 8: Percentage Increase in Critical Depth of Excavation in sandy clay soil w. r. t Number of Anchors at $x = 3$ m

From Figure 7 and 8, it is observed that the percentage increase in critical depth of excavation increases with height of building due to provision of anchors to the support system up to height of building = 35 m. The percentage increase in critical depth of excavation remains constant with increase in number of anchors to the support system. Thus, number of anchors has no effect towards increasing the critical depth of excavation. Therefore, only one anchor at the center of support system is sufficient for improving the performance of support system to the excavation.

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VI. CONCLUSIONS

Based on the results of present study, following conclusions are drawn:

1. Deflection of structure near excavation increases with increase in height of structure in cases of without and with support to excavation.
2. By providing support to excavation faces, the deflection of structure is decreased and critical depth of excavation is increased.
3. Increase in the distance between the structure and excavation results in decrease in the deflection of structure and increase in critical depth of excavation.
4. By providing support to excavation faces, the deflection of structure is decreased. The maximum decrease in deflection of structure occurs when distance between structure and excavation is 3 m, which is @ 70 % in sandy clay soil. For distances greater than 5 m, there is no considerable effect on % decrease in deflection due to provision of support to the excavation in sandy clay soil.
5. By providing support to excavation faces, critical depth of excavation is increased. The maximum increase in critical depth of excavation of structure occurs when distance between structure and excavation is 3 m, which is @ 45 % in sandy clay soil. For distances greater than 5 m, there is no considerable effect on % increase in critical depth of excavation due to provision of support to the excavation in sandy clay soil.
6. Provision of anchors to the support system to the excavation results in increase in the critical depth of excavation. The percentage increase in critical depth of excavation increases with height of building due to provision of anchors to the support system in sandy clay soil.
7. Number of anchors to the support system has no effect towards increase in critical depth of excavation. Hence, only one anchor at the center of support system to the excavation is sufficient.

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