

# Chapter 17

## Behavior of Pile in Sloped Grounds Under the Influence of Surcharge Loads



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### Introduction

The pile is an important substructural element to transfer the superstructure loads to the soil. The pile can able to transfer both axial and transverse loads from the superstructures or different situations. Wind, earthquake, soil movements, surcharge load nearer to structures, etc., influence lateral force to pile. Many research works are going on in the field of study on lateral responses of the pile [1]. The effect of vertical load on lateral response of the long pile in sandy soil is significant, and it is not valid in clayey soil if the pile length is beyond 15 times its width. Muthukkumaran et al. [2] modify the API method to construct the P-Y curves for the lateral responses of a piles in a sloped ground [3]. Until a spacing of a pile is 8d, the spacing between [4]. In the case of long piles, the soil's subgrade reactions can increase by reducing the thickness of the weaker soil layer. In short pile, the pile subgrade reaction increases by increasing the compactness of the soil and slenderness ratio of the pile [5]. The effects of embankment slopes are invalid if the pile has been placed 15 times the pile diameter from the slope crest [6]. Reduction of the adhesiveness between soil and the pile will significantly reduce the P-Y curve's ultimate load. Chandrasekaran et al. [7] the lateral capacity of pile in  $3 \times 3$  pile group with 3d times spacing is 40% less than a single pile with [8, 9] developed a finite element model and determined the influences of slope and relative density of soil [10]. The combined loads increase the

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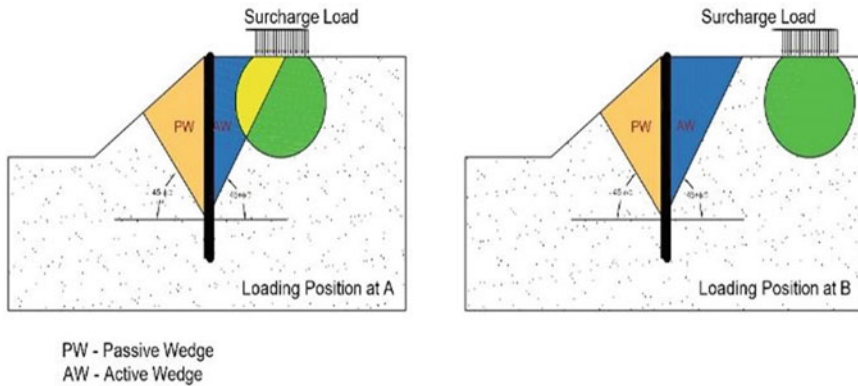
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**Fig. 17.1** Schematic diagram of surcharge loads at loading positions A and B

lateral load-carrying capacity of a pile in homogenous sandy soil, and it is not valid in the pile with combined loading in clayey soil. Rathod et al. [11] study influences of ground sloping on P-Y curves for lateral piles. Jayasree et al. [12] compare the comparative study between Indian standard and theoretical (using Vesic's equation) approaches [13]. Three-dimensional study on the pile group at sloped surfaces. The influences of the slope angle on the pile and pile spacing are discussed. The literature shows the importance of the studies on the lateral responses of the pile under the effects of lateral soil movements. This present study is about the lateral responses of a free head pile in homogenous sandy soil medium at slope crest, under the influences of varying surcharge loads, ground slopes and relative densities of soil. For the effects of different surcharge loads (50–200 kN/m) with a 5 m span, consider it at two locations (A and B). The loading position A starts immediately from the end of the active wedge, and the loading position B starts from 10 m away from the end of the active wedge. Both the surcharge loading positions will ensure with and without interactions between the pressure bulb of surcharge loads and active wedge. This study considers the varying ground slope as (1V:1.5H, 1V:2H and 1V:2.5H) and relative densities of soil as 70%. Develop the two-dimensional finite element models with standard fixities boundary conditions in PLAXIS 2D and calculating the lateral responses of the pile at slope crest (lateral deflections) by considering various lateral forces (surcharges load and ground slopes) on it. The schematic diagram of the surcharge loading positions in the model is shown in Fig. 17.1.

## Model Features and Validation

The lateral responses of a free-headed single pile at slope crest loads in homogenous sandy soil profiles under the influences of varying surcharges loads are determining

**Table 17.1** Input parameters

Soil details		Pile details	
$C_u$ (kN/m <sup>2</sup> )	0.1	E.A. (kN)	$2.83 \times 10^7$
$\varphi$	38°	E.I. (kNm <sup>2</sup> )	$2.54 \times 10^6$
$\psi$	8°	Diameter	1.2 m
$E_s$ (MPa)	78	Length	18 m
$\mu_s$	0.3	Material	Concrete
$\gamma_s$ (kN/m <sup>3</sup> )	17.6	Grade of concrete	M25
R.D (%)	70%	$\mu_c$	0.15

**Table 17.2** Active wedge calculation as per IS 2911

S. No.	Soil type	Relative density (R.D.) (%)	Width of active wedge (m)
1	Loose sand	30	1.89
2	Medium sand	45	1.46
3	dense sand	70	1.05

by developing two-dimensional finite element models under the plane-strain condition with standard fixities boundary conditions in PLAXIS 2D. Generate a pile model using five-nodded plate elements (Beam element), and a soil model uses 15 nodded triangular Mohr–Coulomb model for soil.

Considering 15 nodes triangular elements for soil medium generate five pairs of nodes with zero thickness interface. The standard fixities boundary condition confirms the fixed condition at the bottom and roller at the vertical direction of the model. Table 17.1 shows the input parameters of the model. Calculate the active wedge width from IS2911, and Table 17.2 shows it. Figure 17.2 shows the surcharge loading positions at A and B in the present finite element models in PLAXIS 2D. The dimensions of the finite element models are dimensions from Karthigeyan et al. [1].

Two different published studies [1, 14] are using for the validation of this present finite element model in PLAXIS 2D. Figure 17.3 shows that the current two-dimensional finite element PLAXIS models match the lateral responses of pile in homogenous and multilayered soil models.

## Results and Discussion

This present study evaluates the lateral responses of a pile at slope crest by considering varying ground slopes (1V:1.5H, 1V:2H and 1V:2.5H) surcharge loads (50–200 kN/m) at two different loading positions A and B. The soil profile is entirely homogenous sandy soil with a relative density of 70%. The results and discussions of this paper are based on the developed two-dimensional finite element model in

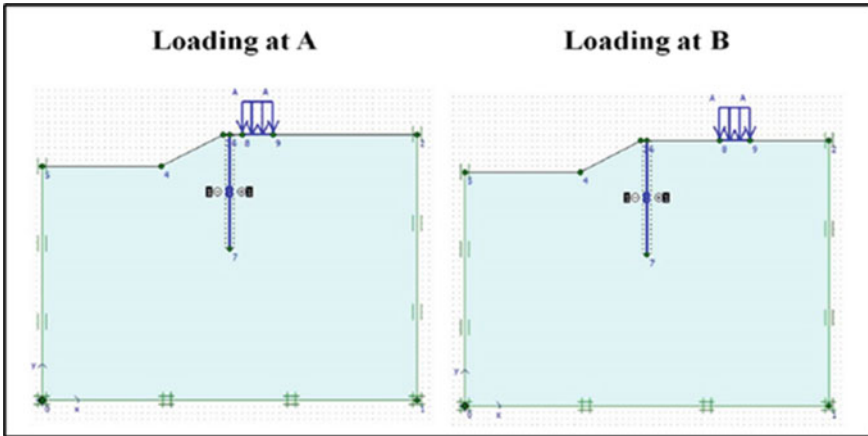


Fig. 17.2 Present finite element model

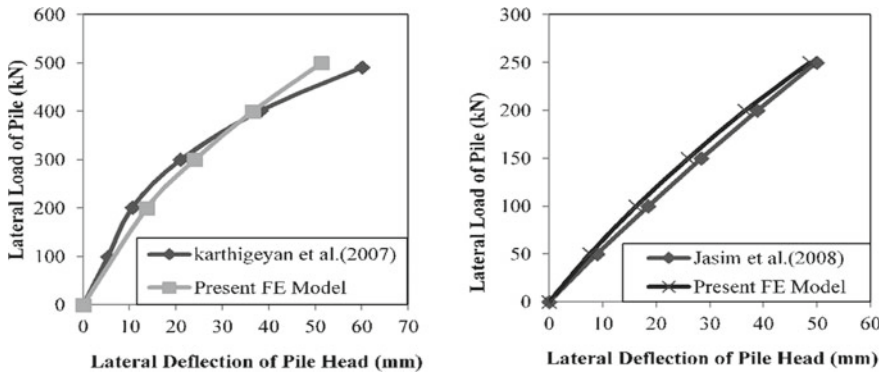
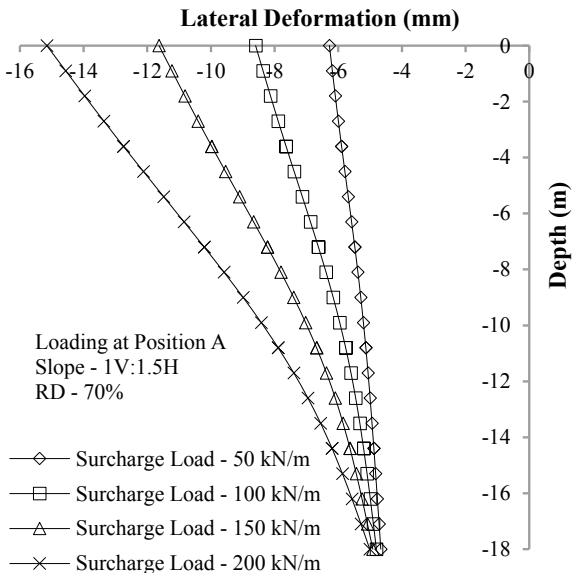


Fig. 17.3 Validation of the present finite element model

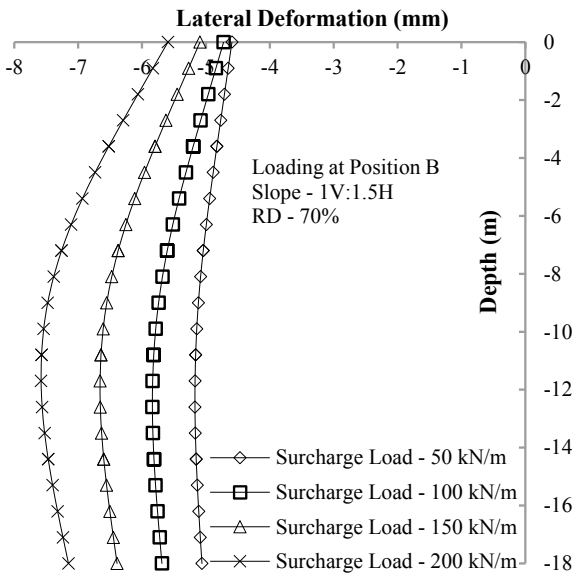
PLAXIS 2D. The varying surcharge loads and ground slopes are the significant factors for the magnitude of passive loads on a pile at slope crest. When the surcharge load is at loading position A, the passive loads (surcharge loads and soil movements due to sloping effect) dominate at the pile head zone. Due to soil confinement, the overburdened pressure is dominant at the pile base portion. It will work against the pile displacements. The pressure distribution of the surcharge load at loading position B will affect the pile base. It will create the base displacement of the pile in the direction of the passive loads, and the pile head will displace the opposite to the pile base displacement. Both the opposite directions of displacements will create rotation in the pile. Nearer to the pile head, the overburden pressure is very minimum. So, the pile head displacement in the opposite direction is possible. The magnitude of the surcharge load at the loading position at B is directly proportional to the magnitude of bottom displacement of a pile (along with the direction of passive load).

Figures 17.4, 17.5, 17.6, 17.7, 17.8, 17.9, 17.10 and 17.11 represent the lateral displacements of a pile at slope crest due to the varying surcharge loads (50–200 kN/m) at loading positions A and B with different ground slopes (1V:1.5H, 1V:2H and 1V:2.5H).

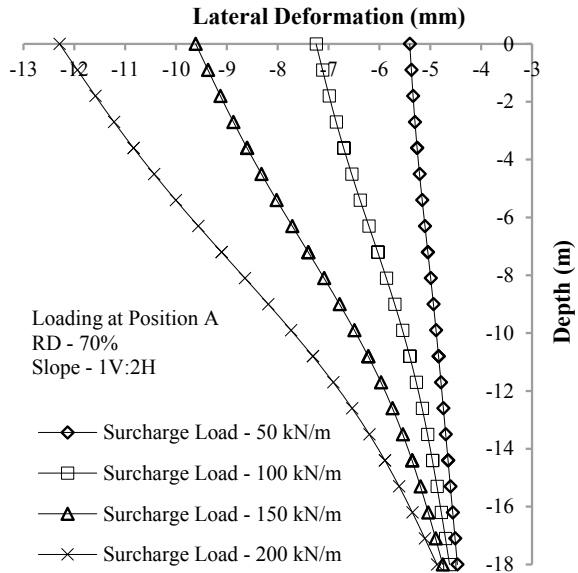
**Fig. 17.4** Lateral displacement of pile at sloped ground 1V:1.5H, surcharge load at A



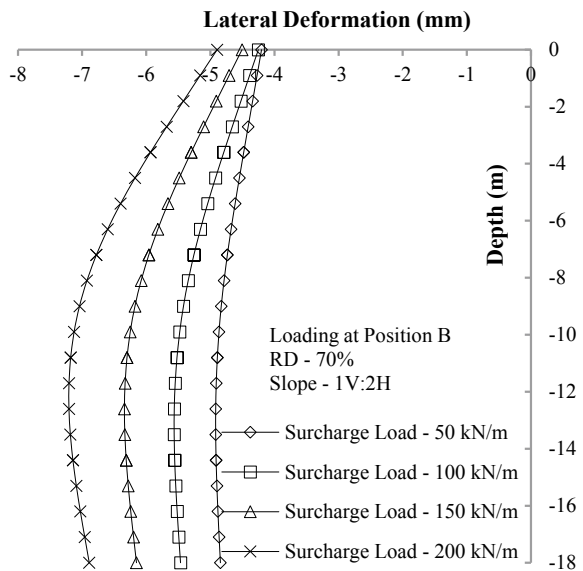
**Fig. 17.5** Lateral displacement of pile at sloped ground 1V:1.5H, surcharge load at B



**Fig. 17.6** Lateral displacement of pile at sloped ground 1V:2H, surcharge load at A

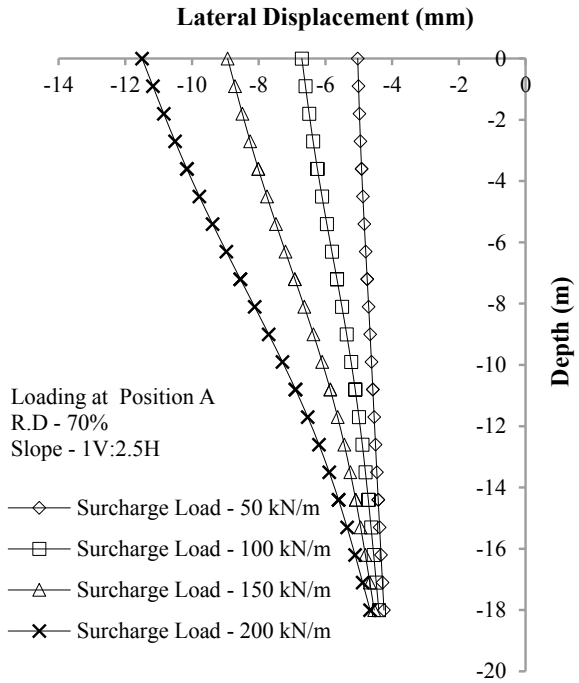


**Fig. 17.7** Lateral displacement of pile at sloped ground 1V:2H, surcharge load at B

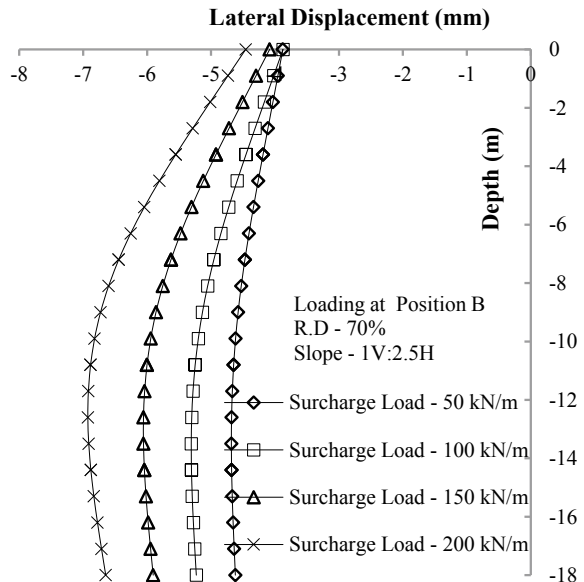


Figures 17.4 and 17.5 show the varying surcharge loading at positions A and B in the homogenous sandy soil of 70% relative density at sloping ground 1V:1.5H. The varying surcharge load at loading position A will create both pile head and bottom displacements in a pile at slope crest. Comparing the pile head displacements with pile base for the corresponding surcharge loads 50, 100, 150 and 200 kN/m, the pile

**Fig. 17.8** Lateral displacement of pile at sloped ground 1V:2.5H, surcharge load at A



**Fig. 17.9** Lateral displacement of pile at sloped ground 1V:2.5H, surcharge load at B



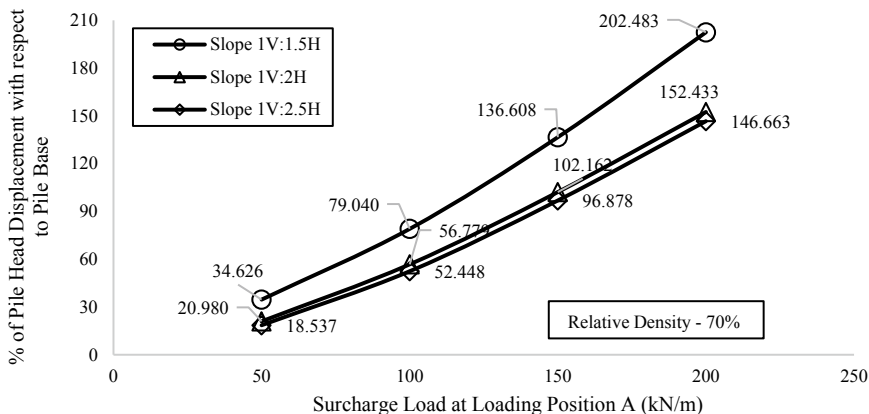


Fig. 17.10 Percentage of pile head displacement, surcharge load at position A

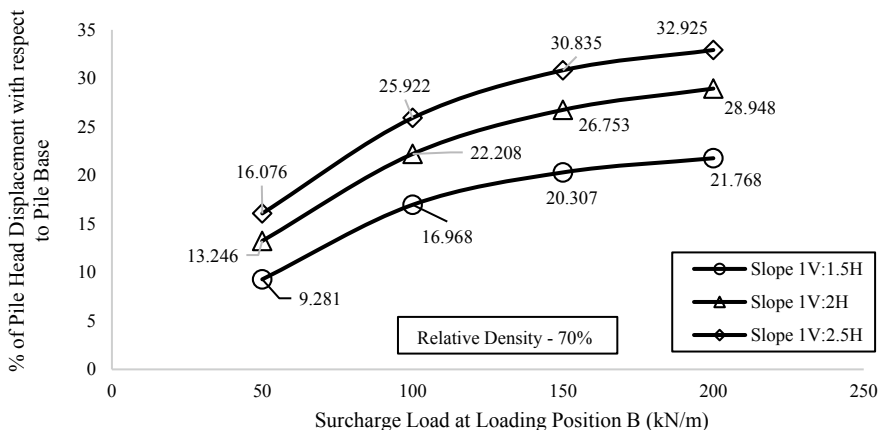


Fig. 17.11 Percentage of pile head displacement, surcharge load at position B

head displacements are 34.626, 79.040, 136.608 and 202.483% high. The varying surcharge loading at position B in the sandy soil of 70% relative density at sloping ground 1V:1.5H will create both pile head and bottom displacements in a pile at slope crest. Comparing pile head displacements with pile base for the corresponding surcharge loads 50, 100, 150 and 200 kN/m, the pile head displacements are 9.281, 16.968, 20.307 and 21.768% low.

Figures 17.6 and 17.7 show the varying surcharge loading at positions A and B in the homogenous sandy soil of 70% relative density at sloping ground 1V:2H. Comparing pile head displacements with pile base displacements when the varying surcharge loads at loading positions A, for the corresponding surcharge loads 50, 100, 150 and 200 kN/m, the pile head displacements are 20.980, 56.779, 102.162



and 152.433% high. Comparing pile head displacements with pile base when the varying surcharge loads at loading positions B for the corresponding surcharge loads 50, 100, 150 and 200 kN/m, the pile head displacements are 13.246, 22.208, 26.753 and 28.948% low.

Figures 17.8 and 17.9 show the varying surcharge loading at positions A and B in the sandy soil of 70% relative density at sloping ground 1V:2.5H. Comparing pile head displacements with pile base displacements for the corresponding surcharge loads 50, 100, 150 and 200 kN/m, the pile head displacements are 18.537, 52.448, 96.878 and 146.663% high. Comparing pile head displacements with pile base displacements for the corresponding surcharge loads 50, 100, 150 and 200 kN/m, the pile head displacements are 16.076, 25.922, 30.835 and 32.925% low. Figures 17.10 and 17.11 show the percentages of the pile head displacements with pile base displacements in both surcharge loading positions A and B.

Figure 17.10 shows that the percentage of pile head displacement increases with increasing surcharge loads (50–200 kN/m) at loading position A and rising ground slopes (1V:1.5H, 1V:2H and 1V:2.5H). The percentage of pile head displacement is high in steeper ground slope 1V:1.5H and low in flatter ground slope 1V:2.5H. The surcharging loading at position A highly dominates the pile head displacements. Under this loading condition, with the effects of ground slope, both pile head and base are displacing toward the same direction (direction of passive load). The pile head displacement is higher than its base displacement, and the difference between pile head and base displacement is more significant. It will make higher bending curvature in the pile.

Figure 17.11 shows that the percentage of pile head displacement increases with increasing surcharge loads (50–200 kN/m) at loading position B and rising ground slopes (1V:1.5H, 1V:2H and 1V:2.5H). Figure 17.11 shows that increasing surcharge load at loading position B will increase the pile head displacements, and it is valid for surcharge load at both loading positions.

In the surcharge loading position A, increasing ground slope angle increases the pile head displacements. Still, it is invalid in the surcharge load at location B. Because the surcharging loading at position B highly dominates the pile base displacements. Due to this, the pile base will move along the direction of passive load, and the pile head will move in the opposite direction of passive load. But in the sloping ground, the lateral soil movement is very high at surface level and acts as a passive load on the pile. The lateral soil movement in the sloping ground will work against the pile head displacement. As a result, in the case of surcharge loads at loading position B, the slope steepness of the grounds reduces the bending curvature of the pile by decreasing the difference between pile head and base displacements. So in the case of surcharge loads at loading position B, the pile bending moment is high in flat slope (1V:2.5H). But it is not valid for the surcharge load at loading position A. The maximum bending curvature due to the surcharge loading at position A is directly proportional to the ground steepness. It is inversely proportional to the surcharge loading at position B.

## Conclusion

This present study is discussing the behavior of a single pile due to the passive loading conditions. By considering the varying surcharge load at different locations and ground slopes, we can derive the passive load conditions to the pile at the slope crest. Under these conditions, developed a finite element two-dimensional model in PLAXIS 2D. Based on the finite element model, the following results are made.

1. Due to the varying surcharge load at loading position A, both the pile head and pile base move along the same directions (direction of passive load).
2. Due to the varying surcharge load at loading position B, both the pile head and pile base will move along in the opposite directions (pile base will move along the direction of passive load, and pile head will move opposite to it.).
3. Surcharge loading at position A, comparing the pile head displacements with pile base for the corresponding surcharge loads 50, 100, 150 and 200 kN/m. The pile head displacements are 34.626, 79.040, 136.608 and 202.483% high in a sloped ground 1V:1.5H.
4. Surcharge loading at position B, comparing pile head displacements with pile base for the corresponding surcharge loads 50, 100, 150 and 200 kN/m. The pile head displacements are 9.281, 16.968, 20.307 and 21.768% low in a sloped ground 1V:1.5H.
5. Surcharge loading at position A, comparing pile head displacements with pile base displacements when the varying surcharge loads at loading positions A, for the corresponding surcharge loads 50, 100, 150 and 200 kN/m, the pile head displacements are 20.980, 56.779, 102.162 and 152.433% high in a sloped ground 1V:2H.
6. Surcharge loading at position B, comparing pile head displacements with pile base when the varying surcharge loads at loading positions B for the corresponding surcharge loads 50, 100, 150 and 200 kN/m, the pile head displacements are 13.246, 22.208, 26.753 and 28.948% low in a sloped ground 1V:1.5H.
7. Surcharge loading at position A, comparing pile head displacements with pile base displacements for the corresponding surcharge loads 50, 100, 150 and 200 kN/m. The pile head displacements are 18.537, 52.448, 96.878 and 146.663% high in a sloped ground 1V:2.5H.
8. Surcharge loading at position B, comparing pile head displacements with pile base displacements for the corresponding surcharge loads 50, 100, 150 and 200 kN/m. The pile head displacements are 16.076, 25.922, 30.835 and 32.925% low in a sloped ground 1V:2.5H.
9. In the case of surcharge loading at position A, by comparing pile head displacements with pile base displacements, the pile head displacements are higher than the pile base displacements and directly proportional to the magnitude of surcharge load and ground slope steepness.

10. In the case of surcharge loading at position B, by comparing pile head displacements with pile base displacements, the pile head displacements are lower than the pile base displacements and directly proportional to the magnitude of surcharge load and indirectly proportional to the ground slope steepness.

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