IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified ※ Impact Factor 8.066 ※ Peer-reviewed / Refereed journal ※ Vol. 10, Issue 9, September 2023

DOI: 10.17148/IARJSET.2023.10916

Study of Slope Stability During Road Construction Under Water Table Variations using PLAXIS Software.

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Abstract: This research investigates the behaviour of slopes during road construction on sloping terrains with a focus on the influence of water table variations and the effectiveness of soil nailing as a slope stabilization technique. The PLAXIS software is utilized to simulate the geotechnical aspects of the slope and analyse its stability and deformation under different water table conditions, both with and without the implementation of soil nailing. The study includes site investigation and data collection, conceptualization of the slope model, construction sequence simulation, and analysis of results.

The simulation results demonstrate that elevated water tables lead to reduced slope stability, increased settlements, and horizontal displacements. However, the implementation of soil nailing shows promising results in improving slope stability and reducing deformations. The findings provide essential insights for the design and construction of road infrastructure in hilly areas with varying water table conditions. The research highlights the significance of considering soil nailing as a viable slope stabilization technique in mitigating the impact of water table fluctuations. It contributes to the development of design guidelines and recommendations that incorporate soil nailing for ensuring the safety and longevity of road projects in such terrains. However, the practical application of these guidelines requires consideration of site-specific factors and engineering expertise.

I. INTRODUCTION

Stability of slope analysis is crucial in geotechnical engineering to assess stability of natural slopes, embankments, or man-made cuts. It is important to understand that slope stability analysis must be performed by qualified geotechnical engineers or professionals with expertise in this field, as it involves complex geotechnical principles and assumptions. Selection of the appropriate method depends on many factors which will be very crucial. There are numerous theoretical approaches commonly used to analyse slope stability.

Road construction projects often encounter challenges when working by sloping terrains, as the character of slopes and their response to various factors, such as water table conditions, can significantly affect the stability and long-term serving of the roadway. Understanding these behaviors and their interactions is crucial for ensuring the safe and efficient construction of roads on slopes.

The advantage of advanced geotechnical software, such as PLAXIS, has revolutionized the field of geotechnical engineering by providing powerful simulation capabilities for analyzing and predicting the character of soil and rock structures. PLAXIS enables engineers to create accurate numerical models that simulate real-world scenarios, allowing for a better understanding of the multifaceted relations between soil, water, and construction processes.

This study aims to leverage the capabilities of PLAXIS software to simulate the character of slopes during road construction and investigate the impact of varying water table conditions on slope deformation. The water table, defined as the level at which the ground is saturated with water, plays a critical role in the stability and performance of slopes, as it affects soil properties, pore-water pressures and ultimately the resistance to deformation. By employing PLAXIS software, this research will contribute to improving the knowledge and understanding of slope behavior during road construction on sloping terrains.

The ability to simulate and analyze slope deformations under dissimilar water table circumstances provides valuable insights for potential hazards and failure mechanisms that can arise during the construction process and throughout the service life of the road. The conclusions of this work will have applied inferences for engineers and project stakeholders

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involved in road construction projects on slopes. By seeing the effects of water table fluctuations, engineers can make well-versed decisions regarding slope stability, construction techniques, and the implementation of appropriate mitigation measures. Ultimately, this will result in safer, more cost-effective, and sustainable road construction practices.

Furthermore, the research outcomes might contribute to the development of design guidelines and recommendations specific to road construction on sloping terrains. These guidelines will be based on a comprehensive considerate of slope behavior and the impact of water table conditions, enabling engineers to optimize their designs, reduce risks, and ensure the long-term stability and performance of road infrastructure.

The utilization of PLAXIS software for simulating slope behavior during road construction and investigating the effects of water table variations provides a valuable platform for enhancing the consideration of slope stability on sloping terrains. The research outcomes will aid in making informed decisions, improving design practices, and ultimately, leading to safer and more resilient road infrastructure.

II. SIMULATION WORK

A. Soil Data Collection.

The first step in the methodology is to conduct a comprehensive site investigation of the road construction area on sloping terrain. This involves collecting geological and geotechnical data, including soil properties, groundwater levels, slope geometry, and other relevant site-specific information. The data composed during this phase will serve as the basis for the subsequent modeling and analysis. I have collected this soil profile data for the Slope Stability For A Road Construction Project form the PLAXIS tutorial, the link to the pdf is below.

https://communities.bentley.com/cfs-file/__key/communityserver-wikis-componentsfiles/00-00-000558/2068.Stability_5F00_of_5F00_a_5F00_road_5F00_along_5F00_a_5F00_hill_5F00_side_5F00_using_5F00_FEM_5F00_and_5F00_LEM_5F005B00_PLAXIS_5F00_2D_5F00_2021_5D00_.pdf

Parameter	Symbol	Intact siltstone	Weathered siltstone	Reinforced fill	Deep sand	Units
General						
Material model	Model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	
Type of behaviour	Type	Drained	Drained	Drained	Drained	
Dry weight	γ_{unsat}	16	16	19	17	kN/m^3
Wet weight	γ_{sat}	17	17	21	21	kN/m^3
Parameters						
Youngs's modulus	E'	12000	12000	20000	120000	kN/m^2
Poisson's ratio	υ'	0.3	0.3	0.3	0.3	-
Cohesion	C'	12	10	8	1	kN/m^2
Friction angle	ϕ	35	19	30	33	-
Dilatency angle	ψ	0	0	0	3	-
Tension cut-off	Tension cut-off	Disabled	Enabled	Enabled	Enabled	
Groundwater						
Permeabilities	K	0.0001	0.01	0.1	0.1	m/d

Table 1: Soil profile data.

B. Material Data Collection.

The next step involves selecting appropriate constitutive models within the PLAXIS software to represent the character of the soil and water in the slope. PLAXIS offers various soil models, such as Mohr-Coulomb, Hardening Soil, or Soft Soil models, which can be chosen, from the soil properties found from the site investigation. The material properties of the soil layers, such as shear strength, stiffness, and hydraulic conductivity, are assigned to the corresponding elements in the PLAXIS model. Boundary conditions are established to represent the constraints and loading conditions acting on the slope. These may include fixed boundaries, applied loads, and water table variations.

Parameter	Symbol	Slope liner	Road surface	Anchor rod	Grout body	Units
Material type		Elastic	Elastic	Elastic	Elastic	
Isotropic		Yes	Yes	Yes	Yes	
Axial stiffness	EA	14000000	250000	200000	10000	kN/m
Spacing	L			2.5		m
Flexural stiffness	EI	143000	500			kNm^2/m
Depth	d		0.155			m
Weight	w	8.4	3			kN/m/m
Poisson's ratio	υ'	0.15				

Table 2: Parameters Used in Simulation.

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C. Construction on Slope

Road construction projects often encounter challenges when working by sloping terrains, as the character of slopes and their response to various factors, such as water table conditions, can significantly affect the stability and long-term serving of the roadway. Understanding these behaviors and their interactions is crucial for ensuring the safe and efficient construction of roads on slopes. This study aims to leverage the capabilities of PLAXIS software to simulate the character of slopes during road construction and investigate the impact of varying water table conditions on slope deformation. The water table, defined as the level at which the ground is saturated with water, plays a critical role in the stability and performance of slopes, as it affects soil properties, pore-water pressures and ultimately the resistance to deformation. By employing PLAXIS software, this research will contribute to improving the knowledge and understanding of slope behavior during road construction on sloping terrains.

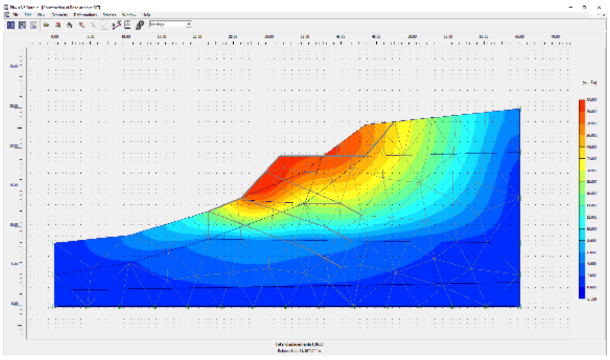

Fig. 1: Natural Prone Area.

D. Conceptualization of Slope Model:

Based on site investigation data, a conceptual model of slope is developed. This model defines slope geometry, including its dimensions, slope angles, and layers of different soil types or materials. The model should accurately represent the actual conditions at the site. Typical figure shown below which helps us to understand the project worked on here.

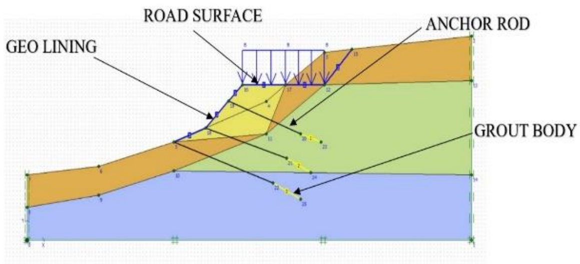

Fig. 2: Simulation of Model.

E. Load Consideration.

Using PLAXIS, engineers can simulate the submission of traffic loads on the road surface and analyze how the road and the primary soil respond to these loads. This analysis is crucial for verifying that the road can handle the anticipated traffic safely.

In hilly areas of India, road design and load calculations are typically carried out in accordance with the guidelines provided by the Indian Road Congress (IRC). The specific load calculations depend on factors such as road category, terrain, and traffic conditions.

As of my knowledge cutoff in September 2021, the IRC provides guidelines for different road categories and terrain conditions. For example, for flexible pavements in mountainous terrain (Category D as per IRC), the recommended axle load is 60 kN (approximately 13.5 kips) for rigid vehicles and 45 kN (approximately 10.1 kips) for semi-rigid vehicles.
To convert these axle loads to a Uniformly Distributed Load (UDL) that can be applied in PLAXIS 2D, you'll need to consider the load distribution area. If you assume a typical road width of 3.75 meters, you can calculate the UDL as follows:

DOI: 10.17148/IARJSET.2023.10916

the recommended UDL (Uniformly Distributed Load) in kN/m based on the Indian Road Congress (IRC) guidelines for flexible pavements in mountainous terrain (Category D) in hilly areas. As mentioned earlier, the recommended axle loads are 60 kN for rigid vehicles and 45 kN for semi-rigid vehicles. We'll consider the higher value of 60 kN for our calculation. Given:

Recommended Axle Load for rigid vehicles: 60 kN
Assumption: Road width: 3.75 meters

Conversion to UDL in kN/m:

1. Convert the axle load to kN:

Axle Load in kN = Recommended Axle Load in kN

2. Convert the width of the road to meters:

Width in meters = 3.75 meters

3. Calculate the UDL in kN/m:

UDL in kN/m = Axle Load in kN / Width in meters

Now, plug in the values:

UDL in kN/m = 60 kN / 3.75 meters

UDL in kN/m ≈ 16 kN/m.

So, based on the IRC guidelines for Category D (mountainous terrain) in hilly areas, the calculated UDL for road design is approximately 16 kN/m. You can use this UDL value as a load input in PLAXIS 2D for your analysis of road construction in hilly areas, specifically for flexible pavements. Please note that this is a simplified calculation and actual design considerations should involve a comprehensive analysis of site-specific conditions and factors.

III. PARAMETRIC STUDY

A. Water Table Variation Simulation:

To examine the impacts of water table variations on slope deformation, different water table levels are applied in the PLAXIS model. This could be achieved by adjusting the boundary conditions or using groundwater flow modules available in the software. The simulation analyzes the responses of the slope, including settlement, pore water pressure changes, and potential failure mechanisms, under different water table scenarios. Water table fluctuations can significantly influence slope stability by altering pore water pressures and shear strength parameters. Rising water tables can increase pore water pressures, reduce effective stress, and decrease soil shear strength, leading to potential slope instability. In contrast, lower water tables can improve slope stability by increasing effective stress and shear strength.

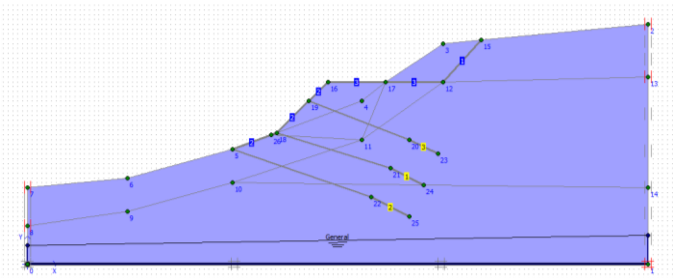

Fig. 3: Ground Water Table at Lower Level Condition.

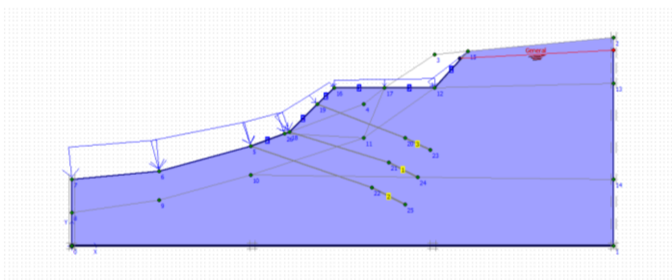

Fig. 4: Ground Water Table at Higher Level Condition.

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

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B. Simulated Slope Behavior:

The PLAXIS software enables the accurate simulation of slope behavior during road construction. The results may include deformations, settlements, and changes in pore water pressures at different stages of construction. The simulation can provide visions into the transient behavior of the slope, allowing engineers to identify critical construction phases and potential areas of concern and the overall deformation of the slope is shown below.

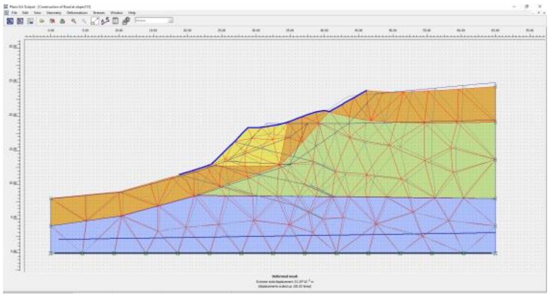

Fig. 5: Deformed Result without Soil Nailing and Loading.

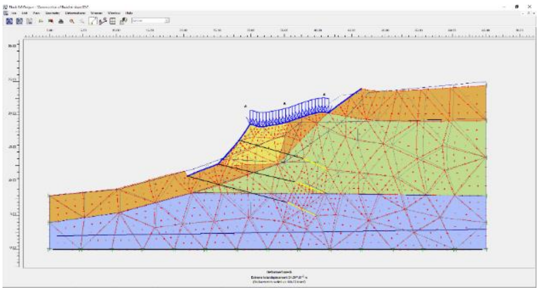

Fig. 6: Deformed Result with Soil Nailing and Loading.

Influence of Water Table Variations:

Vertical Displacements:

The simulation results can demonstrate the influence of varying water table conditions on slope deformation. The analysis may reveal that an elevated water table leads to increased pore water pressures, which in turn may induce higher settlements and reduced slope stability. Conversely, a lower water table may result in reduced pore water pressures and improved slope stability. These findings highlight the importance of considering water table fluctuations in slope design and construction.

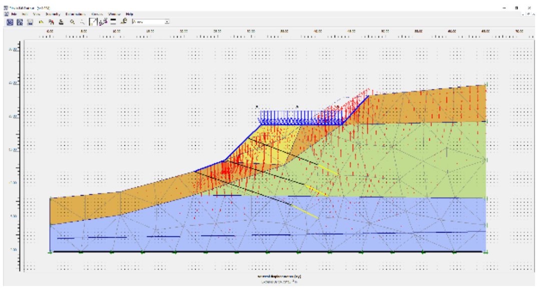

Fig. 7: Vertical Displacements due Low GWL

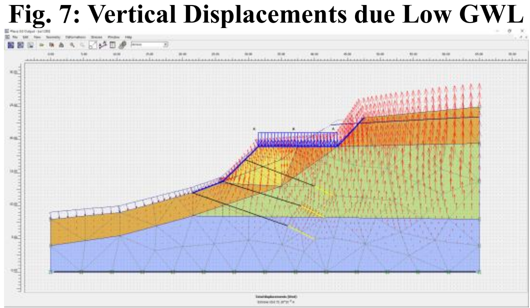

Fig. 8: Vertical Displacements due High GWL

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Horizontal Displacements:

This results may indicate that a higher water table level leads to increased settlement and horizontal displacements due to reduced effective stress and decreased shear strength of the soil. This data can help engineers assess the potential impact on road surface smoothness, pavement performance, and overall stability.

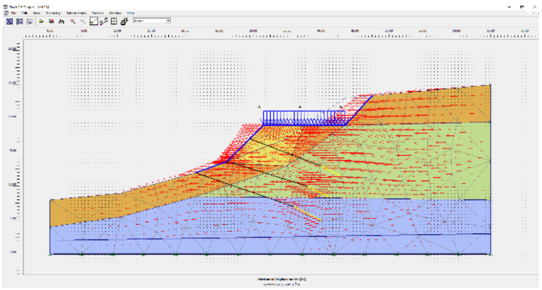

Fig. 9: Horizontal Displacements due Low GWL

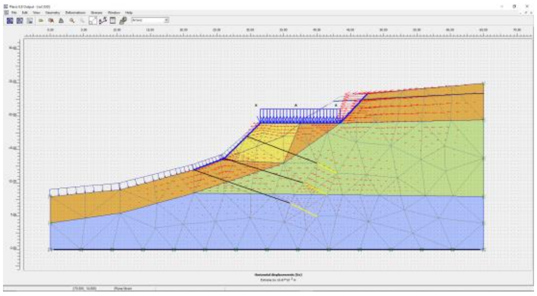

Fig. 10: Horizontal Displacements due High GWL

4.3 Failure Modes:

The analysis of the simulation results can identify potential failure modes and mechanisms associated with water table variations. For example, a rising water table might increase the potential for slope instability through mechanisms such as slope creep, slope failure, or soil liquefaction. These findings can guide the implementation of appropriate mitigation measures, such as slope reinforcement or drainage systems, to ensure slope stability during and after road construction.

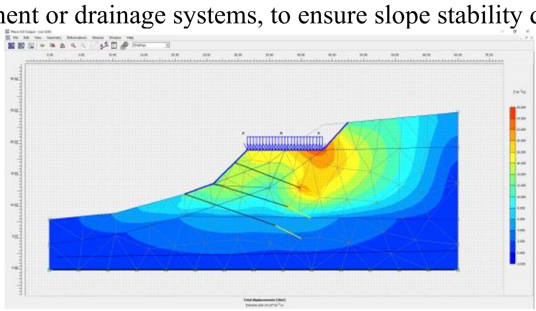

Fig. 11: Maximum Displacements due Low GWL

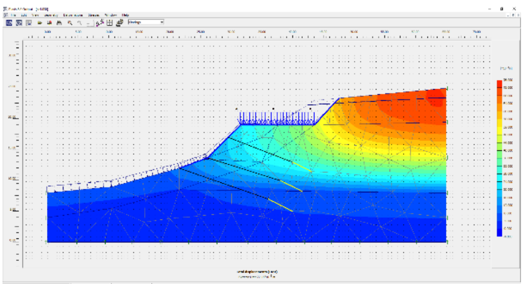

Fig. 12: Maximum Displacements due High GWL

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IV. RESULTS AND DISCUSSIONS

Interactions between Water Table and Slope Stability:

By studying the simulation results, engineers can gain a deeper understanding of the complex interactions between water table fluctuations and slope stability. The findings may reveal that water table variations affect pore water pressures, shear strength, and effective stress distribution within the slope. This understanding allows for the optimization of slope design and construction techniques, minimizing the risks related with water table changes. Here is the graph which helps us to understand the stress and strain of the designated points (A,B).

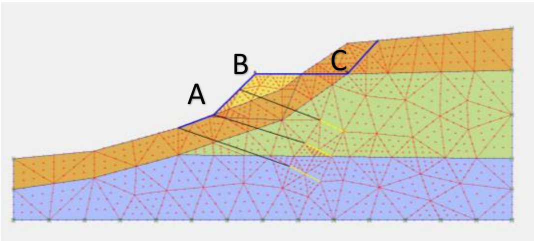

Fig13: Point A,B and C for Data Representation.

Stress and Strain Along Horizontal Direction.

Stress in the horizontal direction refers to the forces acting similar to slope's surface. In a slope stability analysis, the primary horizontal stresses include the weight of the slope materials, self-weight of any added structures or embankments, and external loads (e.g., traffic loads) applied to the slope surface. These forces contribute to the overall stability of the slope by resisting the tendency of the slope materials to slide or deform horizontally.

Strain in the horizontal direction refers to the deformation of the slope materials similar to slope surface. When subjected to external forces, the slope materials experience horizontal displacements and deformations. The quantity of strain depends on the slope's material properties, slope geometry, and applied loads.

Understanding the stress and strain alongside the horizontal direction is vital in slope stability analysis, as it provides appreciated insights into the slope's character under various water table fluctuations. Proper evaluation of these factors is crucial for designing safe and stable road constructions on sloping terrains.

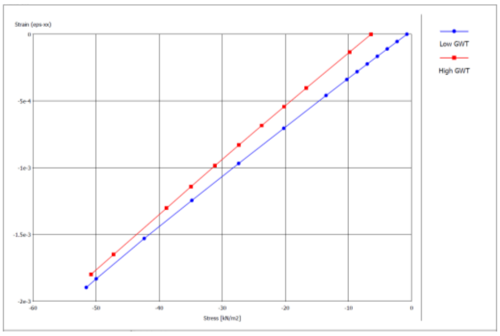

Fig. 14: Behaviour of Stress and strain in Horizontal Direction at Point A.

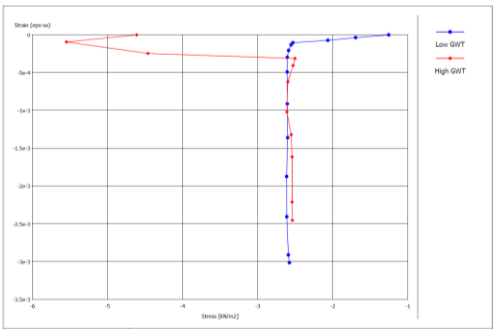

Fig. 15: Behaviour of Stress and strain in Horizontal Direction at Point B.

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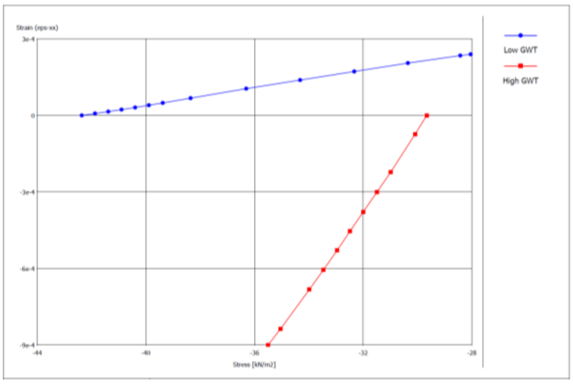

Fig. 16: Behaviour of Stress and strain in Horizontal Direction at Point C.

4.4.2 Stress and Strain Along Vertical Direction.

Stress in the vertical direction refers to the forces acting perpendicular to the slope's surface. The primary vertical stresses include the weight of the overlying materials, self-weight of the slope materials, and any additional vertical loads applied to the slope, such as structures or embankments. These forces contribute to the overall stability of the slope by resisting vertical deformation and potential collapse.

Strain in the vertical direction refers to the vertical deformation or displacement of the slope materials. When subjected to external loads, the slope materials experience vertical compression or extension, leading to changes in their original height and position.

Understanding the stress and strain along the vertical direction is critical for assessing the slope's overall stability and deformation behavior. Proper evaluation of these factors helps ensure the safe and resilient design and construction of road infrastructure on sloping terrains.

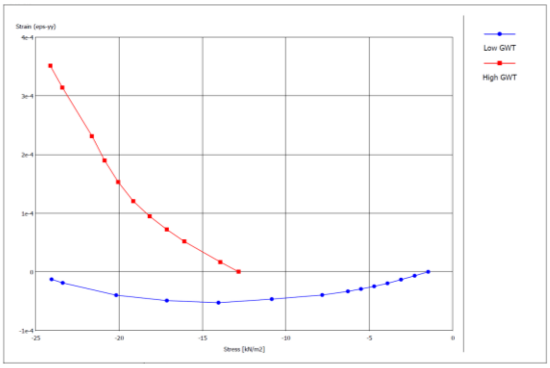

Fig. 17: Behaviour of Stress and strain in Vertical Direction at Point A.

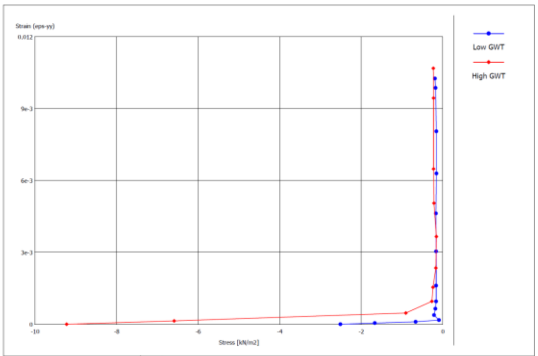

Fig. 18: Behaviour of Stress and strain in Vertical Direction at Point B.

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588
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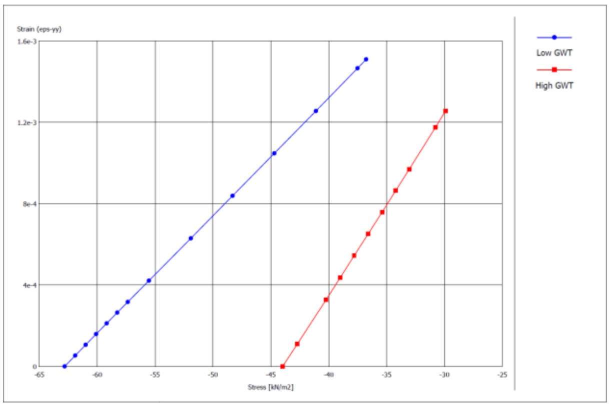

Fig. 19: Behaviour of Stress and strain in Vertical Direction at Point C.

V. CONCLUSION

- The study focused on simulating slope behavior during road construction using PLAXIS software and investigating the influence of varying water table conditions on slope deformation. The objectives were successfully addressed, and several significant findings appeared from the analysis.

- The utilization of PLAXIS software allowed for accurate numerical modeling of the slope, capturing its complex behavior during the construction process. The simulation results revealed that water table variations significantly impact slope stability, settlement, and horizontal displacements. Elevated water tables led to increased pore water pressures, reduced shear strength, and heightened potential for slope instability, while lower water tables exhibited improved slope stability.

- The interactions between water table fluctuations and slope behavior were thoroughly investigated, providing valuable insights for engineers and stakeholders involved in road construction on sloping terrains. By considering the effects of changing water table levels, engineers could make informed decisions to optimize slope design, construction techniques, and the implementation of appropriate mitigation measures. This approach enhances the safety, efficiency, and resilience of road infrastructure on slopes.

- The results and discussions contributed to the development of design guidelines and recommendations for road construction on sloping terrains. These guidelines emphasize the position of water table control, proper drainage systems, and slope reinforcement measures to prevent potential hazards linked with water table fluctuations.

- Overall, the study underscores the worth of incorporating water table variations into slope stability analysis during road construction. Use of PLAXIS software as a powerful numerical tool enabled a deeper understanding of slope behavior under different conditions, leading to more accurate design practices and improved decision-making for safer and more reliable road infrastructure.

- In conclusion, the study findings provided valued insights into the behavior of slopes during road construction and their response to varying water table conditions. The study's outcomes contribute to advancing geotechnical engineering knowledge and offer practical implications for optimizing road construction practices on sloping terrains, ultimately resulting in safer and more resilient road infrastructure. As road construction projects continue to face challenges on sloping terrains, the integration of these findings into engineering practices would lead to improved infrastructure development and safer transportation networks.

- The combination of Limit Equilibrium analysis and Finite Element analysis offers an effective solution for handling diverse safety factor requirements. By employing Finite Element analysis, the most critical slip surface could be identified, against which the outcomes from Limit Equilibrium analysis can be validated for the same failure mechanisms. Meanwhile, Limit Equilibrium analysis excels at determining factors of safety for non-critical regions more efficiently than Finite Element analysis. This integrated approach ensures a comprehensive assessment of safety factors, addressing various scenarios and optimizing the overall stability analysis.

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