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Safeguarding Railway Embankment Slope Stability and Seismic Resilience

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Abstract: Railway embankment stability is important for safe rail network operation. This study assesses slope stability of rail embankment using Slide V.6 software. The main aim is to study the software analysis outcomes so that potential variations in factors of safety become evident. The investigation uses real embankment data, considering factors like soil properties, embankment geometry and seismic forces. Furthermore, the research explores seismic impacts through secondary case studies for each section and evaluates the factor of safety with and without ground improvement for each case. This research enhances our understanding of software precision in geotechnical engineering.

Keywords: slope stability analysis, factor of safety, SLIDE V.6, seismic analysis, slope stability methods.

1. INTRODUCTION:

Railway embankments, forming the foundation of reliable rail systems, play a pivotal role in ensuring the safety and seamless functioning of rail operations. Railway embankments are the unsung heroes of our rail systems. They form the backbone that holds the tracks in place, ensuring that trains can run smoothly and safely across vast distances. Given their crucial role, maintaining the integrity and stability of these embankments is non-negotiable. That's why engineers put so much effort into evaluating them, focusing particularly on slope stability to make sure everything is solid. As rail networks grow, the need for detailed, reliable assessments has led to the rise of geotechnical engineering software designed specifically for this task The integrity and stability of these embankments are of paramount importance, necessitating meticulous evaluations to ascertain their reliability so the scrutiny of slope stability within these embankments gains prominence. In response to this demand, the field of geotechnical engineering offers a spectrum of specialized software tools designed to assess and predict slope stability with increasing precision. These specialized software tools are game-changers. They allow engineers to simulate and analyse a host of factors that affect embankment stability—soil composition, moisture levels, embankment design, train loads, and more. With these tools, engineers can create models that represent real-world conditions with remarkable accuracy. This enables them to predict where problems might occur and determine safety margins well before any actual issues arise. These tools are versatile enough to handle complex scenarios, allowing engineers to test different solutions and choose the best ones to ensure the safety and durability of railway embankments.

What's even more remarkable is that these tools aren't just limited to basic stability analysis. They can also simulate the impact of environmental factors like heavy rain or earthquakes, providing a more comprehensive view of the risks involved. This predictive capability is invaluable, especially when it comes to planning for future rail projects or fortifying existing ones. By anticipating potential issues, engineers can proactively implement measures that boost the resilience of railway infrastructure. As the climate becomes more unpredictable and rail networks continue to expand, these software tools are proving to be indispensable in keeping our trains running safely and efficiently.

Abha et al**.** [1] conducted study to examine the stability of riverbank slopes along the Padma River,. Using computer simulations, the researchers analyse how the slope's stability is affected by different conditions. The study looks at various slope shapes, soil properties and water levels, such as high water, dry conditions, and rapid drawdown. The findings reveal that soil properties like cohesion and friction angle significantly impact slope stability. The study shows that higher water levels enhance stability, while rapid drawdown reduces it. Slope angle and soil type also play crucial roles. Although the study doesn't cover deformation over time under rapid drawdown, it contributes important insights into riverbank slope stability.

The study "Numerical investigation on factors for deep-seated slope stability of stone column-supported embankments over soft clay"[2] focuses on using stone columns to improve the stability of embankments on soft soils [3]. Complex calculations are simplified into two-dimensional models to assess factors like stress concentration, area replacement, and soil conditions for short and long periods. Two column-wall approaches are

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compared and applied to stone column-supported embankments. The results show that the equivalent area method is better for continuous slip surfaces. The factor of safety is higher in the equivalent area model for short-term conditions, decreasing over time. The study concludes that both column-wall methods are suitable for analysis, stress concentration should be ignored, and the equivalent area model is effective for stability. Recommendations for reduction factors are also provided. Overall, the research aids in designing safer embankments on soft soils. The stability of Jamuna River embankments is crucial for safety and infrastructure protection, particularly in flood-prone areas like Bangladesh [4]. An embankment next to the Jamuna River is the subject of this investigation. The study examines embankment stability in a variety of settings, such as varying flood levels and slopes. Cohesion and friction angle are measured in lab testing, and the soil composition of the embankment is analysed. The research uses software to do stability analyses using these characteristics, taking into account different slopes and scenarios for rapid drawdown, flooding, and dry weather. According to the results, safety factors are increased on flatter slopes and decreased on higher ones. The study emphasizes how important soil strength is for maintaining embankment stability by outlining both potential failure scenarios and stable situations. In order to reinforce the embankment and provide protection in critical scenarios, a recommended revetment design utilizing layers of concrete block and geotextile is suggested. The study emphasizes the significance of soil strength and offers insights into aspects that contribute to embankment stability. The Revetment Design improves embankment safety and protection by providing a workable solution for areas like Bangladesh that are vulnerable to flooding and riverbank erosion.

Hoque et al. (2014) [5] conducted research on the hydro-meteorological hazards caused by short-term rainfall on Bangladesh's west bank of the Jamuna River [6]. The effect of brief rainfall on riverbank stability was examined in their research. By modelling seepage and stability using software, it finds that the Balighugri region's bank stability is greatly impacted by this kind of rainfall. Over time, and especially after 13 days of consistent rainfall or during a significant one-day downpour, the factor of safety values declines.

Slope Stability and Settlement Analysis for Dry Bulk Terminal at Mozambique [7] :This paper focuses on the importance of ensuring stability in man-made soil slopes for bulk terminal storage facilities, particularly when handling heavy materials like coal and iron ore. The study presents a detailed case study conducted in Beira, Mozambique, where ground improvement techniques were employed to enhance stability in challenging soil conditions.

The research begins by highlighting the necessity of ground improvement methods to stabilize soft soil sites for storage facilities. It looks into how iron ore and coal storage stacks should be designed while taking the site's geological features—such as soft clay layers covering sandy/silty sand layers—into account. In order to accelerate consolidation and boost strength, wick drain/strip drain techniques are used in the suggested ground improvement.

The study adopts staged construction methods to optimize cost and time, monitoring strength gain during each phase. Controlling settlement and evaluating lateral thrust on foundations are the primary objectives. At every level of construction, in-depth assessments are performed to assess the failure mechanisms of translation and rotational slide.

Significant settlement potential is revealed by the analysis, especially when iron ore stacking is taken into account. When evaluating the possibility of foundation failure, both translational and rotational failure modes are taken into account.

The study's thorough slope stability and settlement research informs its recommendations for a staged building plan and safe stacking heights at each step. It highlights the significance of accurate analysis and ground improvement in handling the difficulties presented by soft soil conditions for bulk storage facilities. Furthermore, the study emphasizes that all kinds of stacks—coal, iron ore, and railroad embankments—show favourable slope stability with a factor of safety greater than 1.

Grover et al. 2021 [8] examined the North-East Airport Runway's Slope Stability [9]. The study analyses the slope stability of a recently built airport runway in a mountainous area of India, highlighting the significance of retaining structure analysis along the runway's edges. The Morgenstern-Price approach is used in computer simulations to assess static and pseudo-static slope stability. To provide stability, a variety of reinforcing methods are used, such as an RCC cladding wall, cable anchors, rock bolts, and self-drilling anchors (SDAs). The main conclusions of the study are:

• Handling Weak Soil: The study suggests using reinforcement techniques that pierce weak top soil and attach into stronger layers below in order to combat local slope failures in weak soils.
• Shear Reinforcement for Steeper Slopes: Compared to cable anchors, SDAs' shear strength makes them appropriate for anchoring steeper slopes. In urgent situations, anchors and SDAs can be utilized in tandem.
•Long Fully Grouted Anchors: In hilly areas with poor top soil over fractured rock, the study recommends employing long fully grouted SDAs that are longer than the thickness of the top soil layer as the best option for slope stability. In summary, the study sheds light on the difficulties associated with slope stability in mountainous regions and identifies efficient reinforcing methods for

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retaining walls.

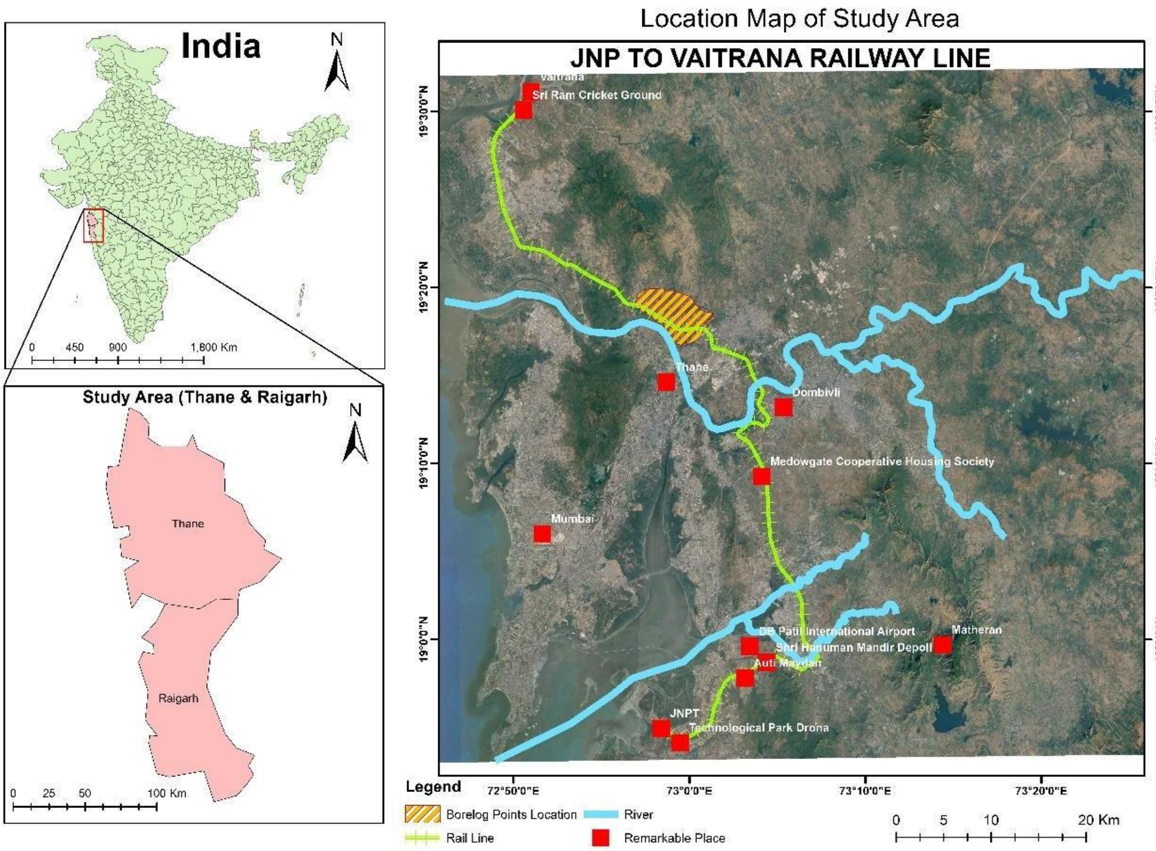
These results are useful for guaranteeing the security of vital infrastructure, such as airport runways, in difficult terrain. In this context, this research embarks on a unique trajectory by delving into a comprehensive analysis of slope stability outcomes for a critical railway embankment.

Through this endeavour, the research aims to shed light on the significance of software selection in slope stability analysis, particularly within the dynamic context of railway embankments. The ensuing exploration of software results underscores the necessity of informed decision-making in geotechnical engineering practices. As the railway industry endeavours to enhance the resilience and safety of its infrastructure, the insights gained from this analysis hold the potential to shape more accurate and dependable slope stability assessments.

2. PROJECT DESCRIPTION:

2.1 JNPT to VAITARANA

During the soil investigation soft ground encountered in proposed stretch of the alignment. The present document covers the detailed design of ground improvement between the stretches Ch 67+250 to Ch 69+100 based soil investigation report and the plan and profile of the alignment.



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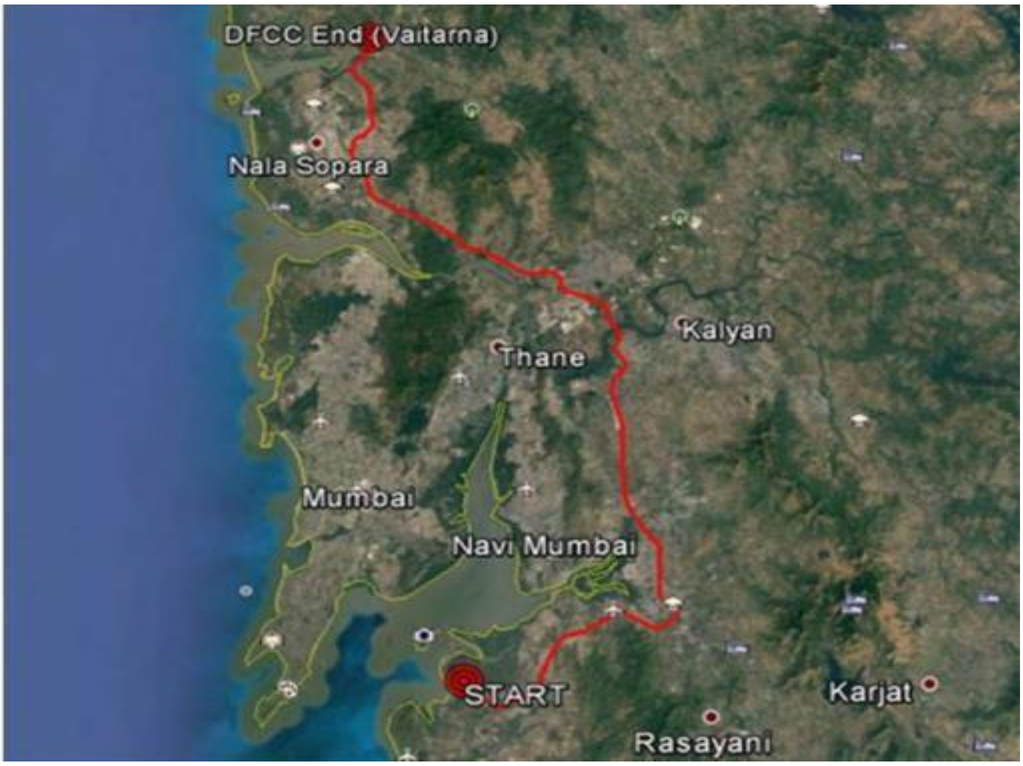

Fig. 1. Location map of survey area

To explore the soil condition geotechnical investigation carried at the proposed embankment stretch location. The geotechnical investigation consists of drilling and sampling, field test and collection of disturbed and undisturbed samples and carrying out laboratory tests. The details of the boreholes are listed below Table – 2.

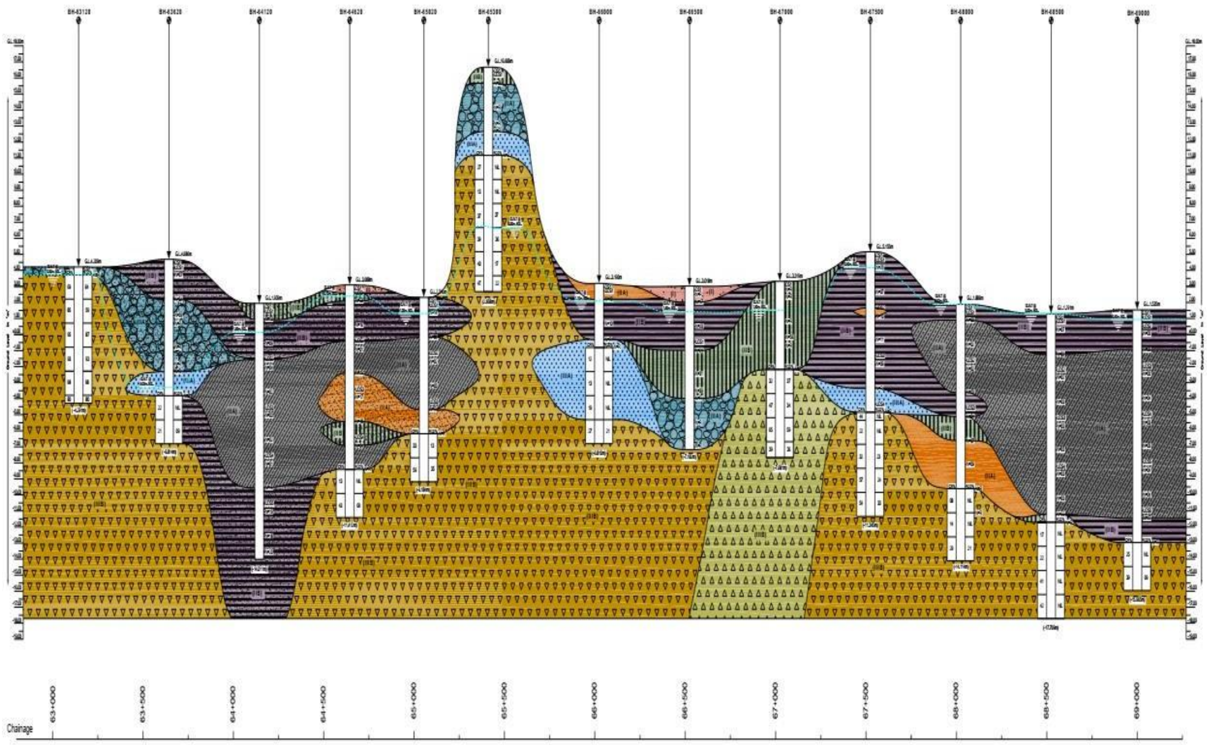

Fig. 2. Ground Profile along the alignment

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Fig. 3. Legend of ground profile along the alignment

Table 1. Soil Parameters

S.No	Soil Parameter	Values
1	Wet Density (gm/cc)	1.84-1.92
2	Dry Density (gm/cc)	1.42-1.52
3	Natural Moisture Content (%)	23.1-29.3
4	Liquid Limit	36-66
5	Plastic Limit	23-29
6	Plasticity Index	12-39
7	Compression Index C_c	0.44-0.62
8	Recompression Index C_r	
9	Initial void ratio, e_0	1.17-1.76
10	Coefficient of consolidation, C_v (m^2/year)	1-26.4
11	Undrained Shear Strength S_u (kg/cm^2)	0.10-0.58
12	Friction angle Φ (°)	2.29-28.8
13	Free Swell index (%)	30-36%
14	Specific Gravity G_s	2.63-2.65
15	Gravel (%)	3-22
16	Sand (%)	17-49
17	Silt (%)	17-28
18	Clay (%)	22-52

3. METHODOLOGY:

A practical railway embankment was pinpointed as the nucleus of the study.

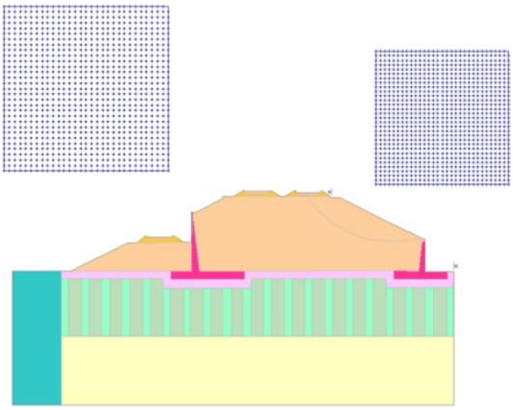

Fig. 4. Embankment model in SLIDE V.6 Software

Vital geotechnical information, encompassing soil characteristics, slope dimensions, groundwater attributes, and applied loads,

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were systematically gathered. No groundwater was considered in this study.

Table 2. Material Properties of chainage 67+250 to Ch 67+900.

Name	Model	Unit Weight (kN/m³)	Cohesion ' (kPa)	Phi ' (Â°)
Ballast	Mohr - Coulomb	20	0	40
Embankment	Mohr - Coulomb	18.72	16	23.27
Existing Soil	Mohr - Coulomb	17	27	0
Retaining Wall	Mohr - Coulomb	24	50	40
ROCK	Mohr - Coulomb	20	0	36
Sleeper	Mohr - Coulomb	24	50	40
Stone Aggregate	Mohr - Coulomb	20	0	40
Stone Columns	Mohr - Coulomb	22	0	40

Table 3. Material Properties of chainage 68+500 to Ch 69+100.

Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
Ballast	Mohr-Coulomb	20	0	40
Embankment	Mohr-Coulomb	18.72	16	23.27
Existing Soil	Mohr-Coulomb	17	27	0
Name	**Model**	**Unit Weight (kN/m³)**	**Cohesion' (kPa)**	**Phi' (°)**
Retaining Wall	Mohr-Coulomb	24	50	40
ROCK	Mohr-Coulomb	20	0	36
Sleeper	Mohr-Coulomb	24	50	40
Stone Aggregate	Mohr-Coulomb	20	0	40
Stone Columns	Mohr-Coulomb	22	0	40

3.1 Slope Stability Analysis: The analysis tool employed was Slide V.6 , a recognized software for slope stability analysis . Input parameters were taken from real embankment data .

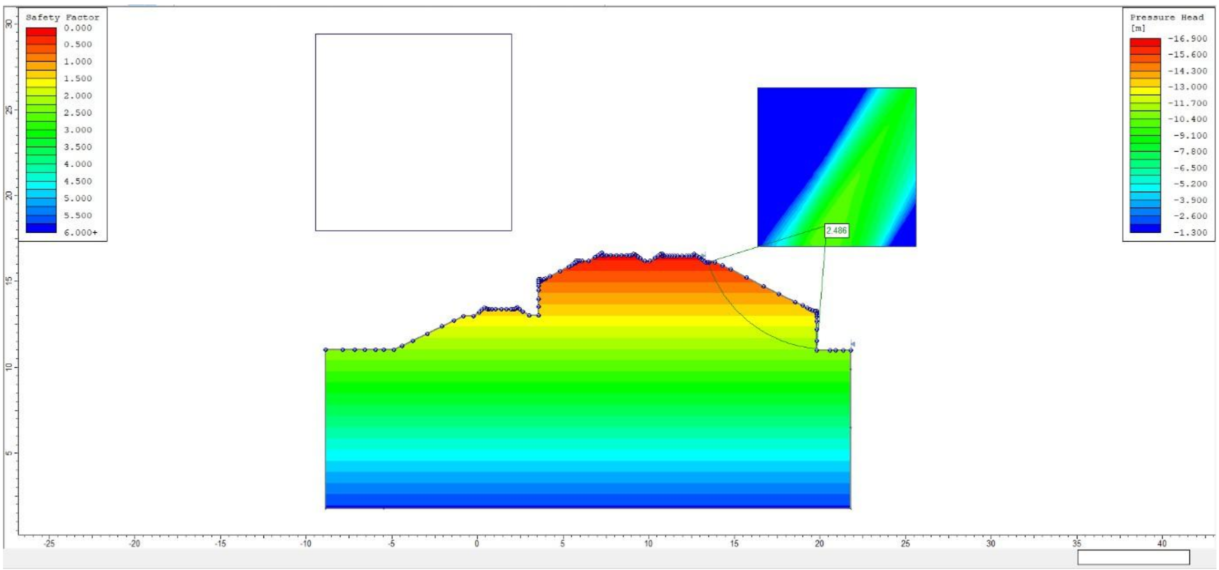

Fig. 5. Slope Stability Analysis Interpretation in SLIDE V.6 software

3.2 Seismic Loading Analysis: To enhance the analytical depth, dynamic seismic forces were introduced into the study. The embankment was divided into two segments, each subjected to seismic conditions using SLIDE V.6 software. This step demonstrated the software's adaptability to incorporate seismic considerations.

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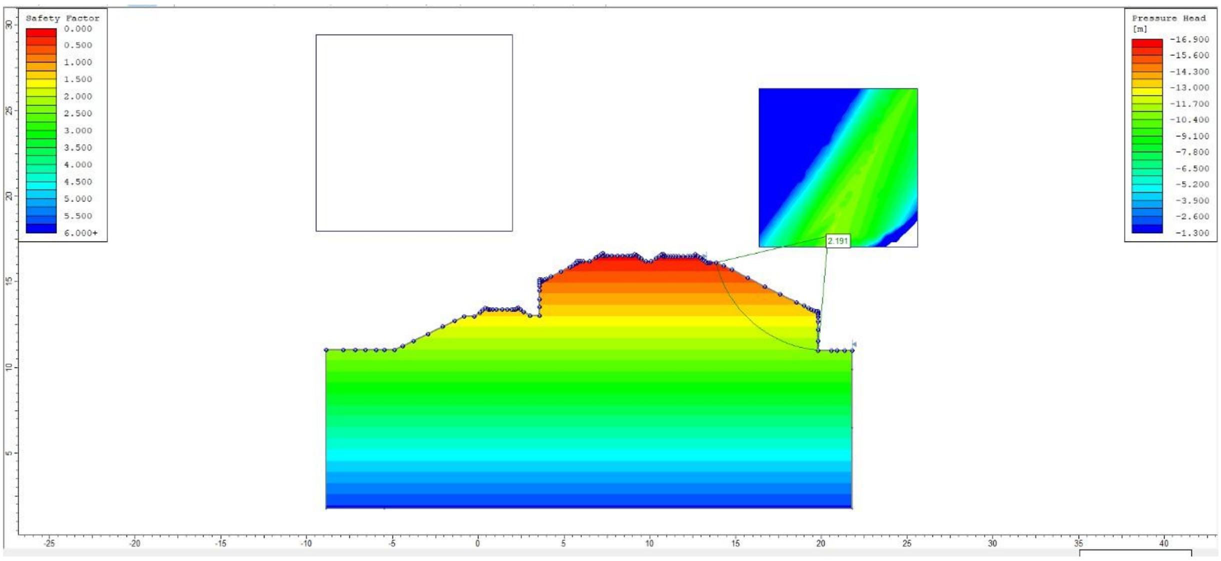

Fig. 6. Slope Stability Analysis Interpretation with seismic load Interpretation in SLIDE V.6 software

In conclusion, the methodology encompassed the selection of a practical railway embankment as the study focus. Geotechnical data collection formed the foundation of the analysis, covering soil characteristics, slope dimensions, groundwater attributes, and applied loads. A thorough slope stability investigation was made easier using Slide V.6. The program's versatility was demonstrated by the incorporation of seismic forces, which enhanced the analysis with dynamic factors.

4. RESULTS AND DISCUSSION:

4.1 Safety Factors: The study carefully examined the calculated safety factors that the software platforms generated. The evaluation of safety variables made it possible to fully comprehend how well the software performed while assessing slope stability.

4.2 Impact of Seismic Loading: Through the application of seismic forces to every section of the embankment, the research set out to unravel the complex interplay between dynamic forces and slope stability. The analysis's findings provide a thorough understanding of how seismic circumstances affected the embankment's stability. Understanding the embankment's resistance to changing stresses was made possible thanks in large part to this assessment.

All the calculated FOS have been depicted in Table 3.

Table 4. FOS Results from SLIDE V.6 Software

Case	Method	Chainage	FOS FOR STATIC CASE	FOS FOR SEISMIC CASE
A	Ordinary / Fellinus	CH 67+250 TO CH 67+900	2.464	2.135
A	Bishop	CH 67+250 TO CH 67+900	2.486	2.151
A	Janbu	CH 67+250 TO CH 67+900	2.48	2.113
A	Spencer	CH 67+250 TO CH 67+900	2.497	2.191
A	Morgensten-Price	CH 67+250 TO CH 67+900	2.487	2.158
B	Ordinary / Fellinus	CH 68+500 TO CH 69+100	2.024	1.645
B	Bishop	CH 68+500 TO CH 69+100	2.154	1.748
B	Janbu	CH 68+500 TO CH 69+100	1.956	1.572
B	Spencer	CH 68+500 TO CH 69+100	2.105	1.698
B	Morgensten-Price	CH 68+500 TO CH 69+100	2.154	1.696

Based on the Table 3., all the FOS values from both static and seismic condition shows > 1.1 (IRC 2015). These outcomes confirm the validity of the analysis.

Based on the data of the present investigation, stability analysis of some critical sections of the embankment has been carried out. The stability analysis has been conducted using Slide 6 [1]. The analysis depends on the soil parameters obtained during the construction of embankment. The analysis has been performed for soils at three conditions; high ground water table, seismic condition and stone column with three different slopes; 1:1, 1:1.5 and 1:2. The values of cohesion and angle of internal friction obtained from the shear test have been used in Slied 6. The minimum safety factor has been obtained 1.96 for static condition with a slope 1:2 while the minimum factor is 1.57 at seismic condition.

5. CONCLUSION:

The following conclusion can be drawn from the present study:

1. The subsoil is very soft and moderated compressible. Post construction settlement would be occurred which is not in allowable limit.
2. In slope stability analysis of the embankment, FOS with stone column satisfied the requirement in static and seismic cases.
3. The spacing and pattern of the stone column can be used.

6. FUTURE RESEARCH:

Peering deeper into the algorithms and presumptions underpinning distinct software solutions might uncover additional insights into the observed divergences. Enlarging the scope of the study to encompass diverse geotechnical scenarios would further reinforce the applicability of the findings.

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