Discussion Session D2 (Embankments)
Contribution of the Discussion Leader

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Geotechnical Engineering Challenges to Meet Current and Emerging Needs of Society

Les Défis de la Géotechnique pour Répondre aux Besoins Actuels et Émergents de la Société

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Discussion Session D2 (Embankments) Contribution of the Discussion Leader

Session de discussion D2 (Remblais) Contribution de l'Animateur de la Discussion

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1 INTRODUCTION

Embankments are special structures that play a crucial role in various civil engineering projects, namely in the construction of roads, railways, dams, dikes, airports, and more. These types of earthworks provide vital support, stability, and protection in diverse infrastructure developments, making them a key subject in the field of geotechnical engineering. The design and construction of embankments require careful consideration of soil properties, foundation conditions, loading requirements, and environmental factors to ensure their long-term performance and structural integrity.

Embankments are not only fundamental for creating elevated platforms for transportation networks but also serve as barriers for flood protection, reservoir containment, and land reclamation. The success of embankment projects relies on effective engineering solutions that address challenges such as settlement control, slope stability, and material selection. Innovations in geotechnical practices, including the use of geosynthetics, reinforcement techniques, and sustainable construction methods, have significantly advanced the design and construction of embankments, enhancing their durability and performance.

This session about embankments focuses on the latest developments, research findings, and practical applications related to embankments in geotechnical engineering. By exploring topics such as cost-effective solutions, sustainable construction practices, innovative reinforcement systems, and performance evaluation methods, this session aims to provide valuable insights and knowledge exchange opportunities for professionals, researchers, and practitioners in the field.

2 SYNTHETIC DESCRIPTION OF THE PAPERS

Paper 1: Management of the dynamic performance of earthworks for high-speed rail [1]

- **Problem:** The HS2 high-speed rail project, particularly the stretch between Wendover and Southam (Contract C23), faced challenges in managing the dynamic performance of embankments for high-speed trains. The interaction between high-speed trains, rail systems, and supporting soil can amplify the quasi-static deflections of the tracks, especially when train speed approaches a "critical velocity."

- **Major Findings:** The study highlights that the critical site velocity is determined by the minimum phase velocity of Rayleigh waves for the embankment and foundation. It found that the track slab's bending stiffness does not affect this critical velocity, allowing the embankment's stiffness to be designed independently of the rail system. A 1D modeling approach was effective in estimating Rayleigh wave dispersion in layered systems, enabling quick assessment of the embankment structure. Replacing low-speed

layers with high-speed materials at the embankment base was shown to improve dynamic performance.

- **Open Problems:** The paper highlights that while attenuation dissipates wave energy, it doesn't change the Rayleigh wave velocity or its amplification potential, which could impact embankment stability and nearby structures. Further research is needed on mitigation strategies and the role of frequency and wavelength in affecting particle excitation depth. The practical effects of this interaction, especially in high-speed rail projects, remain an open question for future study.

Paper 2: Cost-effective & Sustainable Solutions for Embankments on Soft Soils - performance review of geocells in embankment [6]

- **Problem:** The paper focused on evaluating the effectiveness of geocells in enhancing embankment stability on soft soils, aiming to provide cost-effective and sustainable solutions for geotechnical challenges.
- **Major Findings:** The study demonstrated that geocells are effective in improving embankment performance on soft soils, offering a promising solution for sustainable construction practices.
- **Open Problems:** Further investigations are needed to explore the optimal design parameters and installation techniques for geocells in different soil types and environmental conditions.

Paper 3: Consideration of the variable contact geometry between the drum and the soil surface in vibratory roller compaction [4]

- **Problem:** The research addressed the impact of variable contact geometry between the drum and soil surface during vibratory roller compaction on the quality of soil compaction.
- **Major Findings:** By considering variable contact geometry, the study highlighted the potential to optimize compaction processes and improve the overall quality of soil compaction.
- **Open Problems:** Future studies should focus on developing practical guidelines for incorporating variable contact geometry considerations into compaction equipment design and operation.

Paper 4: Groundwater in geosynthetics-reinforced pile-supported embankments, 3D Experiments [10]

- **Problem:** The paper investigated the behavior of groundwater in geosynthetics-reinforced pile-supported embankments to understand its influence on embankment stability and performance.
- **Major Findings:** The study shows that an increase in the groundwater table reduces the load on piles mainly due to uplift forces (Archimedes' principle), with a minor impact on soil arching effect but the arching effect quickly recovers when the groundwater table decreases. The Concentric Arches (CA) model, combined with Archimedes' principle, provides the most accurate match with experimental results compared to the other two calculation models considered (EBGEO and Hewlett & Randolph 1988).
- **Open Problems:** Further research is needed to explain the discrepancy between this study's findings and reports of deformation and load distribution changes after heavy rainfall. More investigation is also required to determine if the differences in measured responses are due to fill material characteristics. Additionally, long-term performance of GRPS embankments under varying groundwater conditions needs to be evaluated.

Paper 5: 3D Small-Scale Tests on Steel-Reinforced Piled Embankments [11]

- **Problem:** The study focused on evaluating the behavior of steel-reinforced piled embankments through small-scale tests to understand the performance of reinforcement systems.
- **Major Findings:** The study found that steel reinforcement stiffness does not significantly affect soil arching above piles, and the load transferred to piles is similar for both steel and geosynthetic reinforcements. The fill material's friction angle has a greater impact on soil arching. DFOS sensors provided valuable 3D insights into deformations.
- **Open Problems:** The paper highlights that small-scale test results may not directly apply to real-scale scenarios, emphasizing the need for larger-scale investigations. It also acknowledges the necessity of different load-deflection models for steel mesh and geosynthetics due to steel's distinct bending behavior, which must be accurately captured in design models.

Paper 6: Staged Construction of Surcharged Embankments over Peat for a national road in Co. Donegal, Ireland [8]

- **Problem:** The paper addressed the challenges of implementing staged construction of surcharged embankments on soft blanket peat soils, focusing on optimizing construction methods for improved stability.
- **Major Findings:** The study introduced innovative geotechnical methods utilizing shear wave velocities and consolidation benefits to optimize filling schedules and enhance embankment performance.
- **Open Problems:** Future research should concentrate on assessing the long-term stability and settlement characteristics of surcharged embankments over peat soils to develop comprehensive design guidelines for sustainable construction practices.

Paper 7: Large-scale test on basal steel-reinforced piled embankments [7]

- **Problem:** The paper investigates the behavior of pile-supported embankments reinforced with a base layer of welded steel mesh. The authors study the influence of this technique on soil arching, deformation patterns, and stress distribution within the embankment. The study also examines the critical height of the embankment, comparing it to predictions from previous studies.
- **Major Findings:** The study concludes that the stiffness of the steel reinforcement has a minimal impact on soil arching in pile-supported embankments. It also indicates that the stiffness of the reinforcement does not significantly affect the load distribution pattern. However, the deformation distribution in the steel differs from that in geosynthetics. The measured critical height of the embankment aligns with predictions from previous studies.
- **Open Problems:** It remains to be clarified whether the stiffness of the reinforcement influences the load distribution. Additionally, it is still uncertain if the existing design methods for pile-supported embankments using geosynthetic reinforcement can be adapted for steel reinforcement or if modifications are necessary. Furthermore, the differences in deformation distributions between steel and geosynthetic reinforcement warrant further investigation.

Paper 8: Acceleration of embankment construction on soft soils of Salamanga using wick drains and counterweight fills [3]

- **Problem:** The article addresses challenges in constructing embankments over soft soils, focusing on excessive settlement and low shear strength. It explores the use of prefabricated vertical drains (wick drains) combined with counterweight embankments to accelerate construction and enhance stability.
- **Major Findings:** The main conclusions of the presented case study are: the installation of prefabricated vertical drains (wick drains) significantly accelerates the consolidation process of soft soil, and the use of counterweight embankments ensures the stability of the embankment during staged construction. Additionally, the article emphasizes that the success of the solution relies on thorough geotechnical investigation and continuous monitoring of settlements during construction.
- **Open Problems:** The paper highlights the need for maintenance measures, such as refilling pavement in critical sections, indicating that residual settlement, although minimized, still requires attention throughout the road's lifespan.

Paper 9: The use of foam glass for a lightweight fill and highway foundation on soft soil conditions [5]

- **Problem:** The article discusses the construction of a new road in the Netherlands over soft soil using foam glass as lightweight fill and stabilized foundation. The aim is to accelerate the construction process, reduce the carbon footprint, and minimize settlement by avoiding traditional preloading methods.
- **Major Findings:** The foam glass not only reduces remaining settlements, it also accelerates the construction process and allows the asphalt layer to be less thick, thereby reducing the carbon footprint.
- **Open Problems:** The sustainability of the foam glass on the long term remains an issue for further investigation.

Paper 10: Effect of the variable discharge capacity of prefabricated vertical drains on the behaviour of an embankment built on soft soils [9]

- **Problem:** The drainage capacity of Prefabricated Vertical Drains (PVDs) decays over time, which is generally not taken into account in design calculations. The paper proposes a formulation to take the reducing drainage capacity over time into account.

- **Major Findings:** A formula is proposed to account for the time-dependent reducing drainage capacity of PVDs. A numerical analysis on an embankment case study demonstrates the effects on vertical and horizontal deformations.
- **Open Problems:** Further validation of the formulation in other case studies may be required.

Paper 11: Execution and quality control applied on the construction of soil-cement embankments [2]

- **Problem:** The article discusses the challenges of constructing large embankments in road projects, focusing on optimizing local resource use and minimizing environmental impact. It presents a case study of the A4 motorway in Portugal, where locally excavated materials were used for embankments up to 70 meters high. The key issue is ensuring the stability and sustainability of these embankments while integrating large volumes of excavated material and solutions that blend with the natural landscape.
- **Major Findings:** According to the article, the main advantages of soil-cement technology in embankments are the optimization of local resources through the incorporation of excavated materials, the reduction of land occupancy by constructing steeper slopes, and the sustainability resulting from the combination of these factors. The technique enables the construction of high and long embankments, as demonstrated in the A4 motorway in Portugal.
- **Open Problems:** The application of soil-cement technology in embankments requires attention to the variability of materials, especially grain size, with laboratory tests needed to determine the ideal cement dosage. The bearing capacity of the foundation soil is crucial, necessitating excavation until adequate conditions are reached. The execution and compaction of the mixture, with moisture control, are essential to ensure the strength of the embankment. Continuous monitoring of the structure during and after construction is vital for detecting anomalies.

3 OVERALL CONCLUSIONS

The papers presented at the XVIII ECSMGE 2024 conference collectively address a diverse range of geotechnical engineering challenges in construction, ranging from material performance evaluation to reinforcement behavior analysis and construction method optimization. Sustainable solutions such as geocells and innovative construction techniques show promise in enhancing embankment stability and improving construction practices. However, further research is needed to validate the findings, explore the long-term performance and durability of solutions, and optimize construction methods for different soil conditions and project requirements.

The most common issue discussed in the provided source material is the use of innovative and sustainable methods to improve the construction of embankments on soft soil. Traditional methods, such as preloading, which can be time-consuming, costly, and consequently have a significant carbon footprint

To overcome this issues, some of the innovative methods discussed include using lightweight fill materials like foam glass to reduce load and accelerate construction, stabilizing foundation layers with a foam glass-cement-clay mix to create stronger bases and reduce asphalt thickness, employing wick drains with surcharge loading to accelerate consolidation, utilizing soil-cement embankments for cost-effective resource use, and implementing geosynthetic solutions like cellular foundation mattresses to reduce time, costs, and environmental impact.

4 SUBJECTS ADDRESSED IN THE DISCUSSION

The session discussed several papers on embankment design and geotechnical engineering, focusing on three main areas: construction methods and reinforcement, material performance, and sustainable solutions. There was a notable emphasis on the challenges of working with soft soils, where monitoring—particularly using fiber optics—plays a key role in assessing innovative construction techniques. Sustainability and cost efficiency were also addressed, though the exact cost improvements remained unclear. The long-term behavior of materials was a point of concern.

Questions were raised about the durability of certain materials, especially foam glass, and its cost-effectiveness compared to traditional materials like sand. A key insight was that while fabricated materials might initially cost more, the reduction in necessary preloading can make them cost-effective in the long run. Another topic was the manufacturing capacity for these materials, as some countries face limitations in production. A question was asked about the performance of demolition waste material, particularly the difference in deformation values compared to geosynthetics.

Further discussions explored the technical challenges of using fiber optic sensing for settlement measurements, addressing the friction between the soil and cables. The importance of pile spacing in geosynthetic designs was also highlighted, with research showing that closer pile spacing, around 2.5 meters, offers more effective load distribution. Stretching this distance can compromise performance.

Overall, the session covered a range of practical and theoretical concerns, including long-term material performance, cost efficiency, production capacity, and the technical specifics of fiber optic monitoring and pile reinforcement.

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