Employment of Earth Retaining System to Enhance Railway Infrastructure

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DECLARATION

I, Nwokata Evans C solemnly declare that this research titled "Employment of Earth Retaining Systems to Enhance Railway Infrastructure" has not been submitted to any other university or institution of learning for any academic purpose.

Furthermore, I affirm that the work included in this research is entirely my own, except where explicitly cited in the text. All sources used, whether quoted or paraphrased, have been duly acknowledged and referenced in accordance with the established academic standards.

I have thoroughly proofread, grammar checked, and spell checked this work to ensure its accuracy and integrity.

Signed:

…. ….
Nwokata Evans C

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ABSTRACT

This research delves into the utilization of earth retaining systems in the context of railway infrastructure, with a keen focus on their advantages and implications. The study objectives encompassed exploring the technical complexities and applications of earth retaining systems within railway infrastructure, covering various system types, design principles, and their suitability for diverse railway scenarios. Recent developments and advancements tailored for these systems in railway projects were reviewed, shedding light on the ever-evolving landscape of this field.

The research sought to assess the benefits and advantages associated with the incorporation of earth retaining systems in railway projects. It also meticulously identified the challenges and limitations inherent in implementing such systems in railway contexts. Finally, the study aimed to offer practical suggestions and advice for the effective utilization of earth retaining systems within railway infrastructure.

To achieve these objectives, both hand calculations and geotechnical software, such as GEO5 2023, The research's culmination revealed the profound significance of earth retaining systems in fortifying the durability, safety, and stability of railway infrastructure. The case study presented concrete advantages, including erosion mitigation, heightened track stability, and cost-effective construction methods. Furthermore, a rigorous analysis compared the results obtained through software and hand calculations, further reinforcing the research's findings.

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CHAPTER ONE
INTRODUCTION

Railway infrastructure plays a critical role in facilitating transportation and connecting communities. However, the construction and maintenance of railway systems often face significant challenges, particularly in relation to earth retaining systems (Abdallah, A. 2018). Earth Retaining Systems are structures used to retain earth materials on a slope. Typically, they are often designed for static loads, both for highway and railway infrastructures, vehicle-induced dynamic responses are also relevant (Qiang Luo, Tengfei Wang et al , 2023). Earth retaining systems are essential in providing structural stability and preventing slope failures along railway tracks (Indraratna, B., et al). These systems are often designed with a factor of safety that is higher than necessary, because it can be challenging to quantify the magnitude of expected dynamic stresses during the design stage. (Guishuai Feng, et al, 2023).

Earth retaining systems also play a vital role in controlling erosion. Railway infrastructure is susceptible to environmental elements like rainfall and water runoff, which can lead to soil erosion and compromise the stability of embankments. By implementing retaining systems and implementing appropriate drainage measures, erosion can be prevented, and the underlying soil can be safeguarded from erosion. When choosing and designing earth retaining systems for railway infrastructure, it is crucial to take into account the specific conditions of the site. This includes considering factors such as soil properties, water table levels, and geological characteristics. Evaluating aspects such as load-bearing capacity, flexibility, and construct-ability is essential to determine the most suitable solution for each project. (Indraratna, et al. 2018)

Hence, the use of efficient earth retaining systems is essential in guaranteeing the safety and durability of railway infrastructure. By implementing appropriate design and construction methods, railway authorities and engineers can ensure the consistent and sustainable functioning of railway systems, bringing benefits to both the transportation industry and the communities they serve.

A. Research Background and Context

Retaining systems have been an essential part of railway infrastructure since its early development. As railways expanded, engineers faced challenges like steep slopes, unstable soil, and the need for level tracks. Railway infrastructure projects involve building and maintaining tracks, bridges, embankments, and cuttings, among other elements.These projects face various geotechnical and environmental factors that can lead to issues like soil erosion, slope instability, and ground movements.In the 19th century, traditional retaining walls such as gravity walls and masonry walls made of stone or brick were commonly used. Over time, engineers developed different types of retaining walls, including crib walls, gabion walls, and reinforced concrete walls, to suit specific site conditions.

In the 20th century, the use of reinforced concrete and steel revolutionized railway retaining systems, enabling stronger and more flexible structures like reinforced soil walls, anchored walls, and mechanically stabilized earth walls. Advancements in geotechnical engineering introduced techniques such as soil nail walls, soil improvement, and Geo-synthetic reinforcement to enhance stability and performance.(Smith, J., & Johnson, A. 2019)

The history of retaining systems in railway infrastructure demonstrates a continuous evolution driven by engineering advancements, material innovations, and a better understanding of soil behaviour. The goal has always been to ensure the stability, safety, and long-term effectiveness of railway tracks, bridges, embankments, and cuttings in different geotechnical conditions.(Smith, J., & Johnson, A. 2019)

Despite advancements, there are knowledge gaps in using earth retaining systems for railways. Existing research lacks focus on railway-specific applications. This dissertation aims to fill these gaps, offering best practices and recommendations to improve stability and durability of railway infrastructure. The goal is to benefit the industry and transportation network through enhanced understanding and strategies for effective earth retaining systems in railway projects. (Haghshenas, D. F., Moayed, R. Z. et al, .2019).

B. Aims and Objectives

➢ *Research Aims*

To comprehensively explore earth retaining systems within railway infrastructure, covering their technical aspects, recent progress, benefits, obstacles, and ultimately offer recommendations to enhance their application, selection, overall effectiveness and sustainability.

➢ *Research Objectives*

The main objective of this research is to investigate the utilization of earth retaining systems in railway infrastructure, focusing on their advantages and implications. The specific research objectives are as follows:

- To explore the technical aspects and application of earth retaining systems in railway infrastructure, encompassing various types, design principles, and suitability for different railway contexts.
- To review recent developments and advancements tailored for earth retaining systems in railway projects.
- The research aims to assess the benefits and advantages of employing earth retaining systems in railway projects.
- Identifying the challenges and limitations associated with the implementation of earth retaining systems in railway contexts.
- Lastly, the research seeks to provide suggestions and practical advice for using earth retaining systems effectively in railway infrastructure.

C. Research Questions

This research aims to answer several important questions related to the use of earth retaining systems in railway infrastructure:

- What technical factors should be considered when using earth retaining systems in railway projects, and how do they vary depending on project characteristics and site conditions?
- What recent advancements have been made in the design, construction, and maintenance of earth retaining systems specifically for railways, and how do they improve the overall performance and resilience of the infrastructure?
- What are the benefits of using earth retaining systems in railway projects, such as preventing slope instability, controlling erosion, managing groundwater, and ensuring the structural integrity of the infrastructure?
- What challenges and limitations exist in implementing earth retaining systems in railway contexts, including cost, construction difficulties, environmental concerns, and the need for specialized expertise?
- What are the recommended strategies, best practices, and innovative approaches for effectively using earth retaining systems in railway infrastructure, considering the identified challenges and specific project requirements?

D. Significance of the Study

Using earth retaining systems in railway infrastructure is very important for the field of geotechnical engineering and the overall functioning of railway networks. It's essential to know the advantages and difficulties related to these systems to make sure that railway tracks, embankments, and other parts of the railway stay safe, stable, and last a long time.

The study provides geotechnical engineers with insights on designing, constructing, and monitoring earth retaining systems for railway projects. By understanding the unique challenges of railways, engineers can create stable and effective structures that perform well under various conditions, leading to better decision-making in their implementation. (Smith, J., Johnson, A., & Anderson, B. 2018).

This research investigates the effectiveness of earth retaining systems in stabilizing railway infrastructure, analysing real-life examples and studies to understand various retaining structures' strengths and weaknesses. It explores their impact on slopes, embankments, cuttings, and water management to inform engineers and project managers in making smart choices for safer and more stable railway networks.(Brown, C., Thompson, R., & Williams, G. 2016).

This study aims to create practical guidelines for using earth retaining systems in railway projects. By analysing real-life cases and existing knowledge, it identifies success factors and areas for improvement. These guidelines will help professionals in railway planning and design make better choices for stable and sustainable infrastructure.(Johnson, D., Smith, L., & Wilson, P. 2019).

E. Scope and Limitations of the Study

This research examines the effectiveness and challenges of using earth retaining systems in railway infrastructure, exploring design, construction, performance, and sustainability aspects through specific case studies to benefit railway projects.

The research findings will be context-specific and may not be universally applicable to all railway projects globally due to varying environmental and geological factors. The study will focus on a specific time frame to assess the use of earth retaining systems effectively within that period.

This research acknowledges limitations in data availability and access to specific case studies, as well as practical constraints like time and resources. Despite these challenges, the study aims to provide valuable insights into earth retaining systems' application in railway infrastructure.

Lastly the research will focus on earth retaining systems in railway infrastructure, providing insights into their advantages, challenges, and best approaches. It aims to improve decision-making, project planning, and civil engineering knowledge in this specific context.

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➢ *Research Structure*

- Introduction: This section introduces the research topic, providing context and detailing the aims, objectives, questions, significance, and scope.
- Literature Review: In this chapter, the Earth retaining systems in railway infrastructure are explored, including types, applications, advantages, disadvantages, and relevant case studies.
- Research Methodology: This chapter explains the methods used in the research, such as data collection, ethical considerations, and research limitations.
- Case Study Analysis and Result: This chapter analyses a specific case study (Balcombe Embankment) in depth, covering project details, design, geological properties, and includes both hand calculations and software analysis.
- Conclusion and Recommendation: Here, the research findings are summarized, and future research recommendations are provided.
- References: A list of all sources cited in the dissertation is included.
- Appendices: Supplementary materials, including maps, photographs, and data related to the research, are attached here.

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CHAPTER TWO
LITERATURE REVIEW

A. Introduction to Earth Retaining System in Railway Infrastructures

In the context of railway infrastructure, earth retaining systems are important for keeping the railway tracks stable and safe. They help prevent slope failures and maintain the integrity of the railway structure by resisting the lateral pressure from soil or other materials. (ElGawady, M.A., et al 2016). These systems play a crucial role particularly in areas with challenging terrain or where elevation changes are required. They provide support to prevent soil erosion, landslides, and sinking, which can cause problems for the railway.

The employment of earth retaining systems involves the selection and installation of various techniques and structures to retain and stabilize the surrounding soil or rock masses. These systems may include retaining walls, slopes stabilization measures, gee-synthetics, ground anchors, and soil reinforcement techniques.(Ghazavi, M., et al. 2018).

The choice of earth retaining system for railway infrastructure depends on various factors like the conditions of the soil and rocks, the forces acting on the structure, the available space, and the project requirements. (Indraratna, B., et al 2018). There are different types of earth retaining systems that can be used, including gravity walls, cantilever walls, sheet pile walls, and mechanically stabilized earth (MSE) walls.

To successfully use earth retaining systems in railway infrastructure, it's important to have a good understanding of the site conditions, design factors, construction methods, and long-term performance. Factors like drainage, soil properties, ground movement, and the effects of moving trains should be taken into account (Lu, M., et al 2020).

B. Types And Application of Earth retaining Systems in Railway Infrastructure

Earth retaining systems plays an important role in enhancing the stability and functionality of railway infrastructure. These systems are designed to provide structural support and prevent soil movement in areas where there are significant height differences, such as embankments, cuttings, and retaining walls. Various types of earth retaining systems are employed in railway projects, each offering unique advantages and suitable applications they include:

➢ *Gravity Walls*

Gravity walls are commonly employed in railway infrastructure as a type of earth retaining system. These walls derive their stability primarily from their own weight and the friction between the wall and the backfill soil. They are typically made of massive concrete, masonry blocks or mass cast in-situ concrete that are designed to resist the lateral pressure exerted by the soil behind them. Gravity walls are widely used in railway projects due to their simplicity, cost-effectiveness, and suitability for low to moderate retaining heights. (Federal Highway Administration (FHWA). 2008). These walls are suitable over a wide range of foundation conditions; in areas of poor ground, foundation soils can be improved with well-established methods. These walls typically have a footprint (base width) from 0.7 to 1.0 times the wall height and are founded at shallow depths, preferred when there are no space constraints. (Bryan Duevel, et al AREMA 2014).

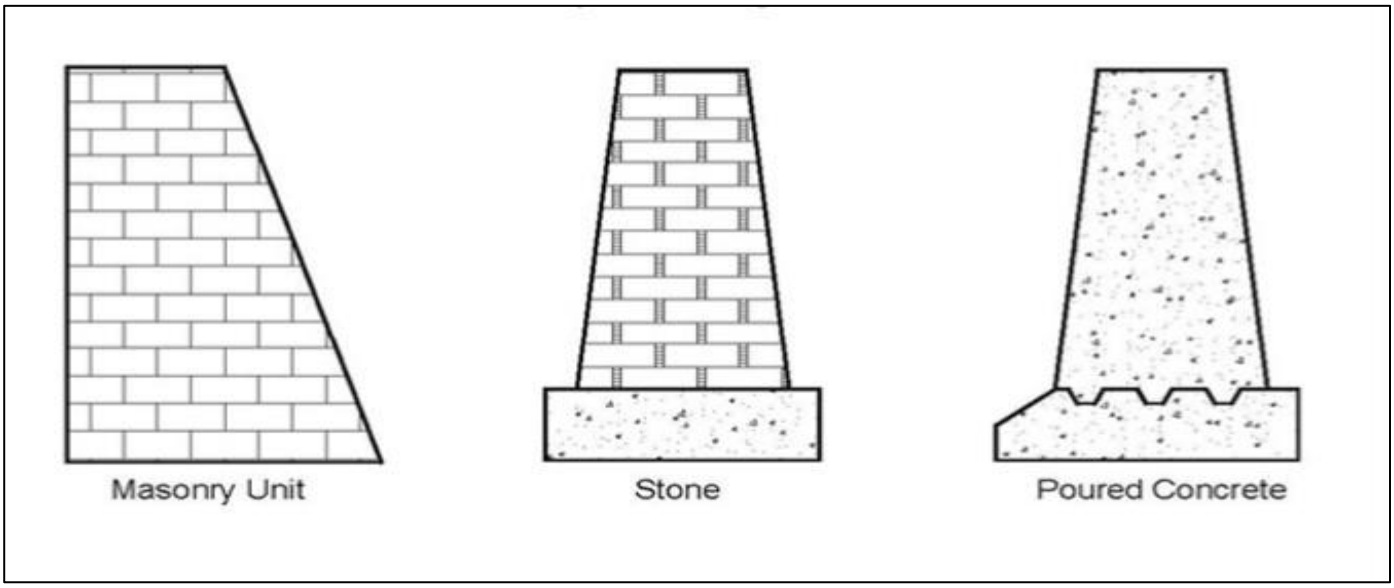

Fig 1: Gravity Retaining Wall from Masonry Unit, Stone or Mass in-Situ Concrete (Tensar Website)

➢ *Components of Gravity Walls (AREMA, 2014)*

Gravity walls consist of several essential components that work together to ensure stability and resistance against lateral soil pressure. These components include:

- ***Wall Structure:*** The main part of a gravity wall made of materials like concrete or stone, providing strength and stability for retaining soil.
- ***Base:*** The bottom of the wall, wider than the top, distributing weight and preventing settlement for overall stability.
- ***Backfill Material***: Space behind the wall filled with suitable soil, adding lateral resistance for stability.
- ***Drainage System:*** Ensures water doesn't accumulate behind the wall, reducing lateral pressure and preventing instability. Includes weep holes or pipes for water flow.
- ***Reinforcement (Optional):*** Additional elements like steel bars or geosynthetic materials to strengthen the wall based on design requirements and anticipated loads.

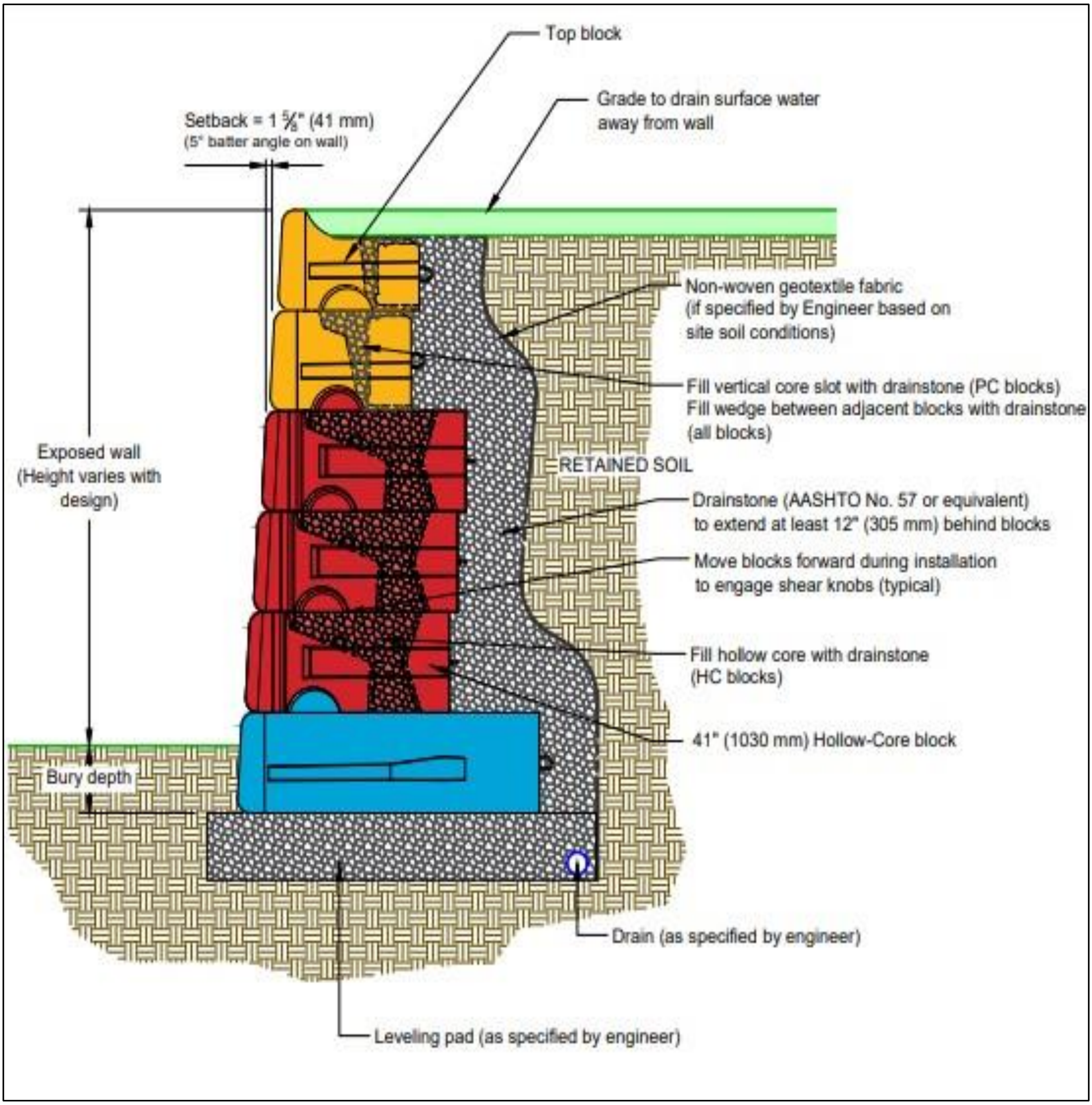

Fig 2: Typical Gravity Wall Detail with Hollow-Core Blocks (Redi-Rock 2020)

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➢ *Gravity Wall Design and Construction:*

Gravity walls are designed and built using the principles of statics and soil mechanics to ensure they remain stable and withstand the lateral pressure from the soil..Factors such as the height, thickness, and setback of the wall are determined based on soil properties, desired stability, and appearance. The foundation of the wall is designed to distribute its weight and the weight of the soil over a larger area, minimizing settlement and ensuring long-term performance.

NB; The relationship between thickness of base and wall height can be expressed: (NCMA 2023)

$$\frac{L^2}{H^2} = \frac{Q}{W}$$

Where:
H = height of gravity retaining wall, in. (mm)
L = width of gravity retaining wall at base, in. (mm)
Q = equivalent fluid pressure of retained material acting horizontally as overturning moment, (kg/m³)
W = average weight of masonry, soil and other material acting vertically to retain soil, (kg/m³)

The correlation between the height of gravity retaining walls and the width of their base is depicted in Figure 2, considering various ratios of horizontal to vertical unit loads. This relationship is utilized when determining the dimensions of gravity retaining walls with heights up to eight feet (1.8 to 2.4 meters). The height-base proportions are chosen based on (Figure 3), the preliminary design undergoes analysis to ensure safety against overturning and sliding, assess the bearing pressure on the soil, and evaluate the flexural and shear stress experienced by the wall. (NCMA 2023)

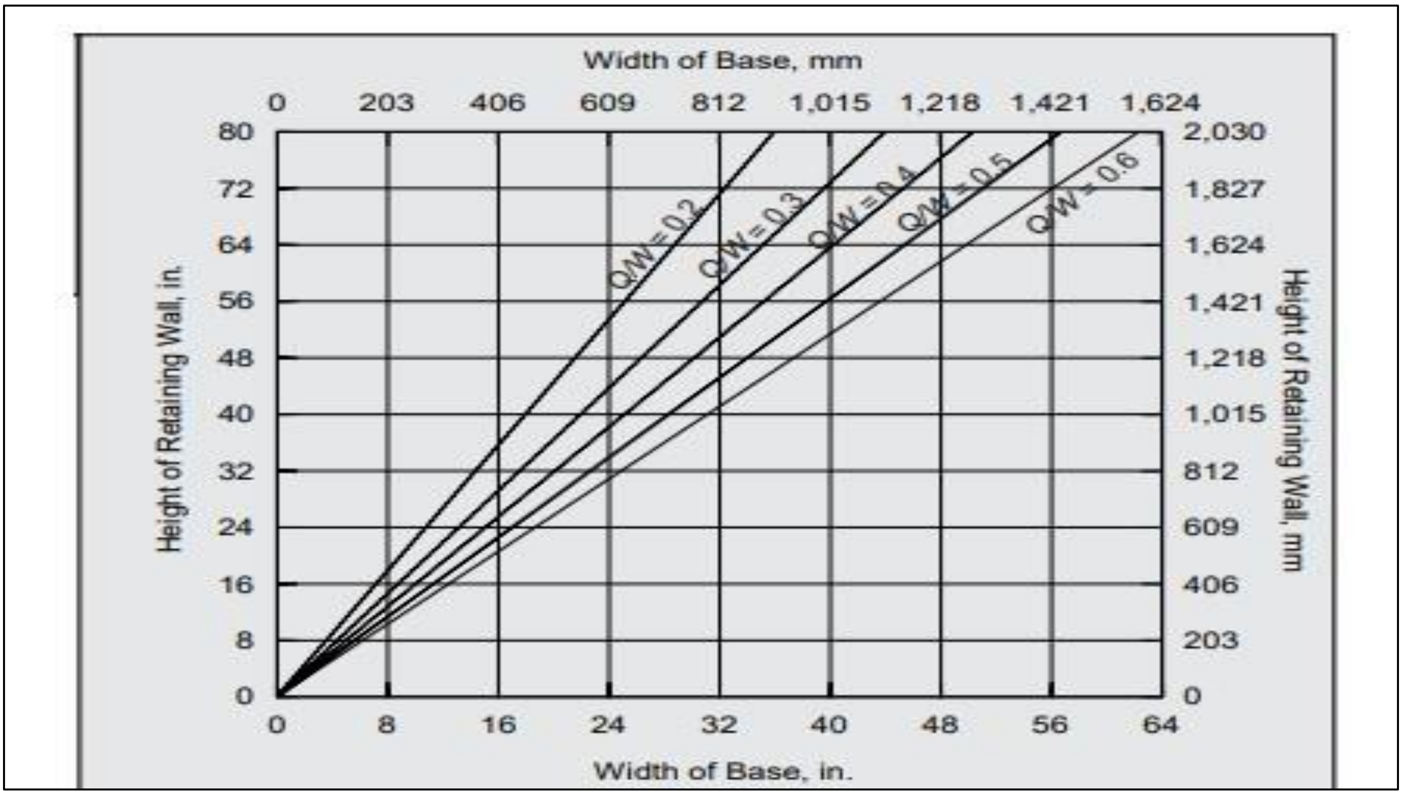

Fig 3: Relationship of Gravity Retaining Wall Height to Width at Base (NCMA 2023)

➢ *Drainage System*

Essential drainage in railway gravity walls prevents water buildup, maintaining stability. Drainage pipes or weep holes allow water to flow out, and backfill with good drainage properties helps water move away. Design considers factors like rainfall, groundwater, and surface runoff. Proper drainage system removes water from the wall materials, ensuring durability and performance. (Álex Darío Tituaña Ugsha 2017). One of its primary purposes is to reduce the overall active pressure exerted on the retaining wall. The total active thrust acting on a retaining structure (Berry, 1993)

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$E_\alpha = E_{\alpha 1} + E_w + E_s$

Where
$E_{\alpha 1}$ =: is the thrust generated by the ground behind the retaining structure.
E_w: is the thrust generated by the presence of water or hydrostatic pressure.
E_s: corresponds to the thrust generated by seismic forces to which it can be subjected.

What is intended is to eliminate as far as possible the thrust generated by the hydrostatic pressure (Ew) and consequently to partially reduce the pressures that a structure of this type has to endure. (Berry, 1993)

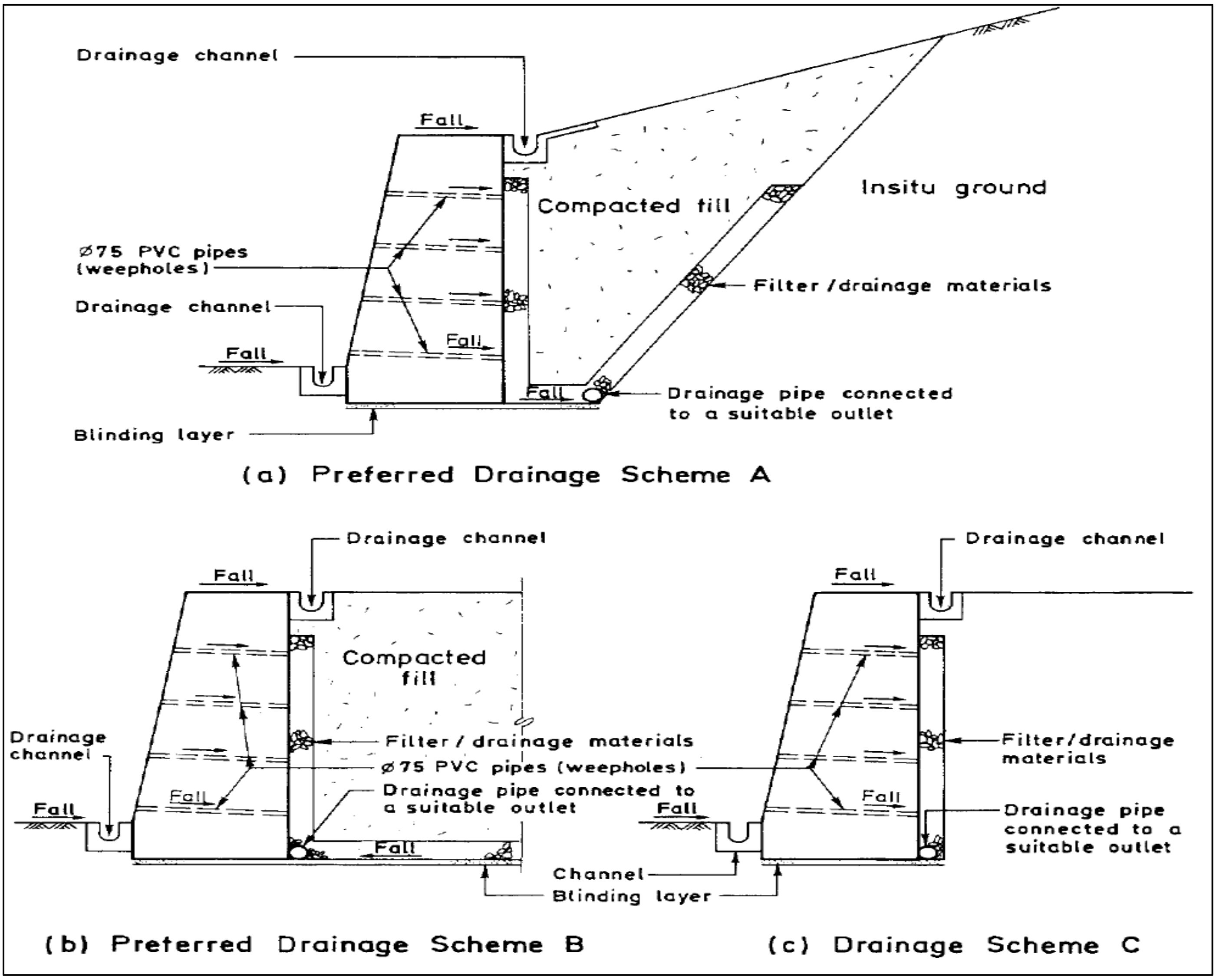

Fig 4: Drainage Schemes for Gravity Retaining Walls (geotechnical Engineering Office, (1993)

- For the preferred drainage scheme A, the extent of the inclined drain is dependent on the design groundwater level behind the retaining wall. To intercept infiltration, the inclined drain should be installed to a level of at least two-thirds of the height of the wall.
- The filter/drainage layers may be omitted if a free-draining granular backfill is used. However,a drainage pipe should be provided to discharge water safely.
- The vertical and horizontal filter/drainage layers may be replaced by suitable prefabricated drainage composites.
- For a retaining wall with level backfill, the top 1.5 m layer of the fill should be a suitable material of relatively low permeability. For sloping backfill, the same provision should be made for a vertical thickness of at least 3 m. (geotechnical engineering office,1993)

➢ *Application and Advantages of Gravity walls (FHWA, 2008)*

- *Applications;*

✓ Gravity walls are crucial for embankments as they support elevated railway tracks, prevent soil erosion, and maintain slope stability.
✓ When railway lines traverse natural slopes, gravity walls provide stability, preventing slope failures and ensuring safety.
✓ Gravity walls serve as retaining structures for bridges, supporting and stabilizing adjacent railway components, maintaining structural integrity and stability.

- *Advantages:*

✓ Gravity walls are cost-effective in railway projects as their weight resists soil pressure, reducing the need for expensive reinforcements and materials, leading to cost savings.
✓ Gravity walls are easy to construct due to their simple design, requiring no complex techniques or specialized equipment, making them suitable for a wide range of railway projects with efficient construction processes.
✓ Gravity walls can be aesthetically pleasing as they can be designed with architectural finishes and various materials, seamlessly blending with the environment and enhancing the visual appeal of railway infrastructure.

➢ *Limitation and Disadvantages of Gravity Walls (FHWA, 2008)*

- Gravity walls are suitable for retaining moderate heights up to approximately 10 to 15 feet (3 to 4.5 meters), but for higher requirements, alternatives like cantilever walls or mechanically stabilized earth walls with greater load capacity are more appropriate.
- Gravity walls typically have inclined or stepped profiles, requiring more space compared to other retaining systems, making it vital to explore alternative solutions in constrained railway environments to optimize space utilization.
- The performance of gravity walls relies on site-specific geotechnical conditions, including soil types, groundwater levels, and seismic activity, necessitating thorough geotechnical investigations and analyses during the design process to ensure their appropriate design and desired performance.

➢ *Mechanical Stabilize Earth (MSE) Walls*

In railway infrastructure, Mechanically Stabilized Earth (MSE) walls are widely used as an efficient and reliable earth retaining system. MSE walls consist of layers of soil and reinforcement elements, such as geosynthetic materials (geogrids or geotextiles), which work together to provide stability and resist lateral earth pressures.By employing MSE walls, the potential for soil settlement or differential movements can be easily mitigated, making it a favorable approach. (Bailleul Guillaume and Laga Matthias, 2017)

Mechanically Stabilized Earth (MSE) walls are commonly used in railway projects for managing changes in elevation, like embankments and cuttings. MSE walls offer benefits such as cost-effectiveness, easy construction, and design flexibility. They provide stability and support to areas where lateral soil pressure needs resistance by incorporating reinforcing elements within the soil mass to enhance strength and stability.(Koerner, R.M. 2018).

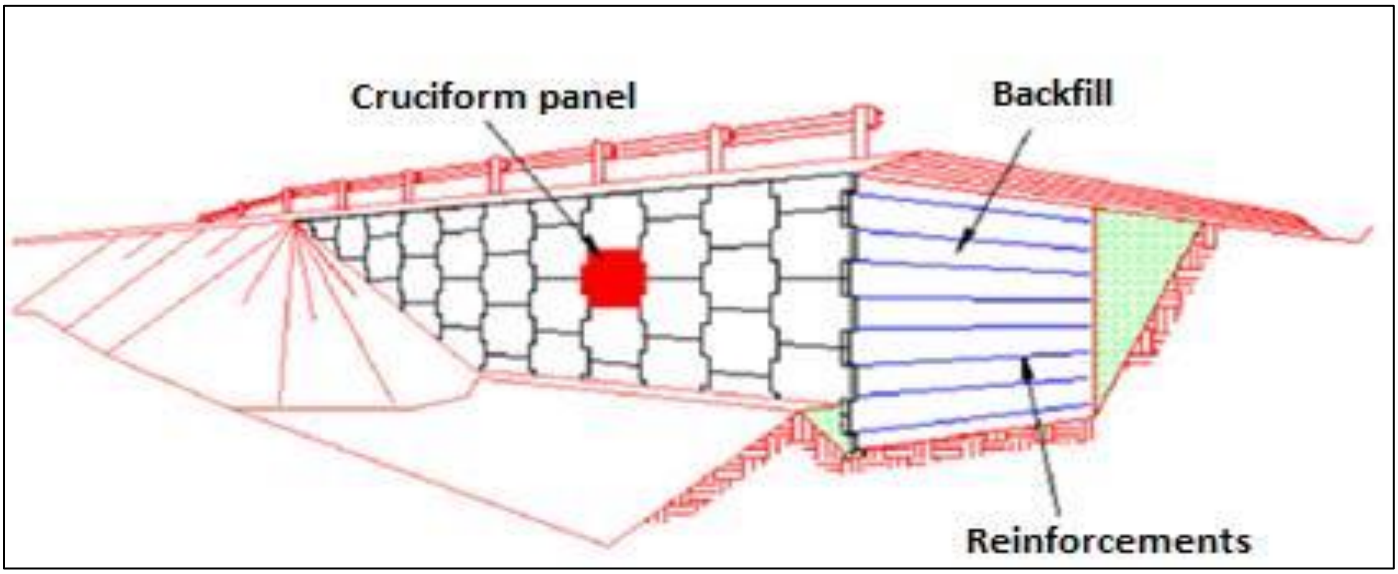

Fig 5: MSE Walls System (Alhajj Chehade et al., 2019)

Fig 6: MSE Walls Used As Railway Retaining System-Courtesy of Charley Chambers (AREMA 2023)

- *Component of MSE Walls*

The construction of reinforced soil retaining walls necessitates a comprehensive understanding of its components, as they directly impact its performance. There are three primary components that play a crucial role:

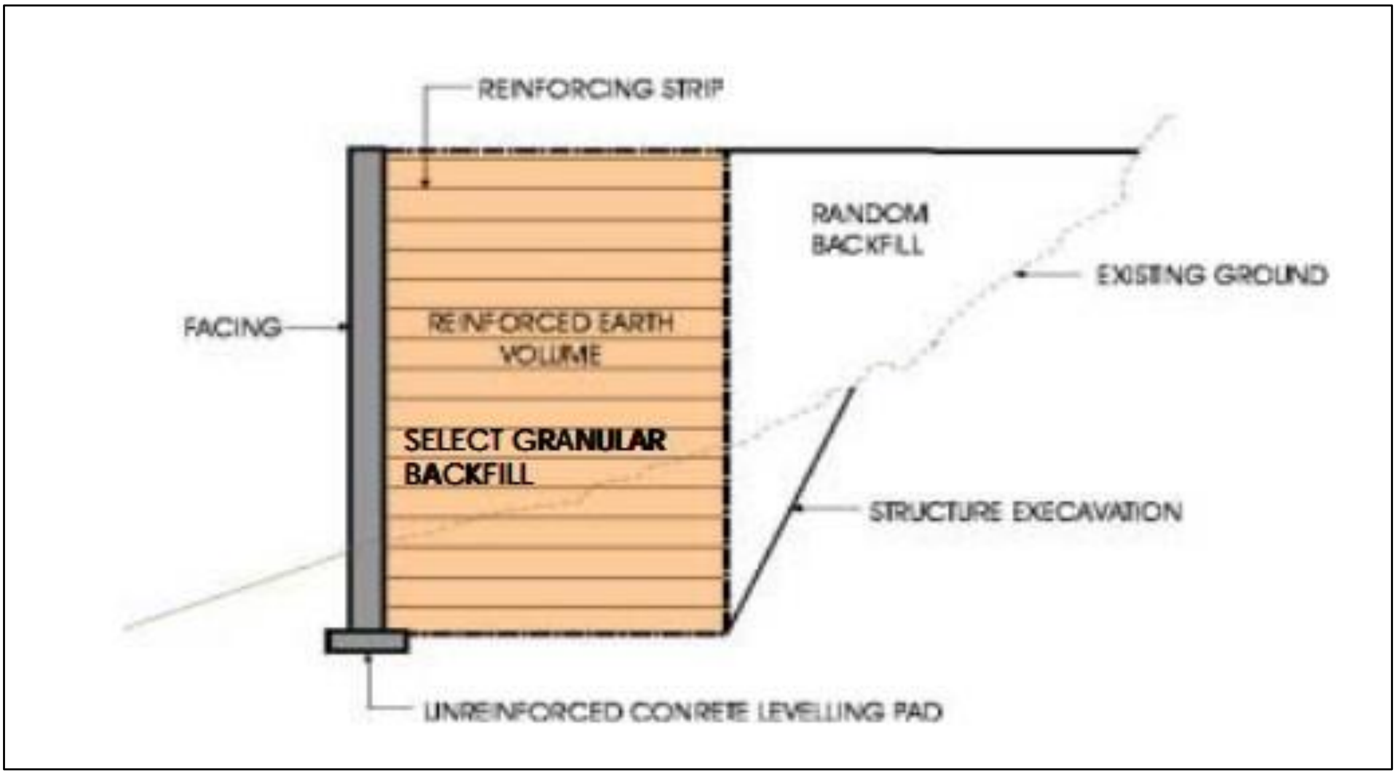

Fig 7: Component of Mechanical Stabilized Earth Walls (Keith Brabant, 2001)

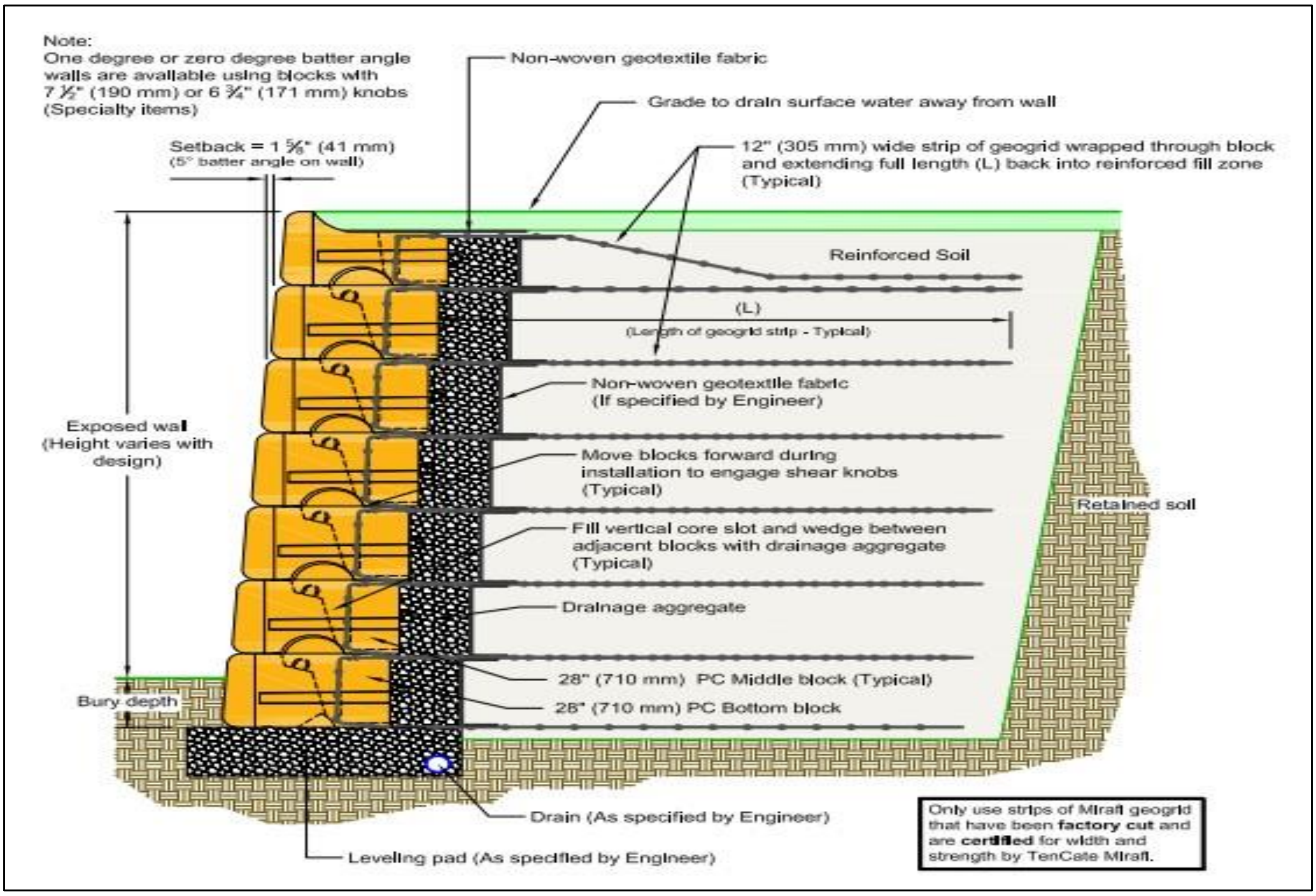

Fig 8: Typical Mechanical Stabilize Earth Wall Section (Redi-Rock 2020)

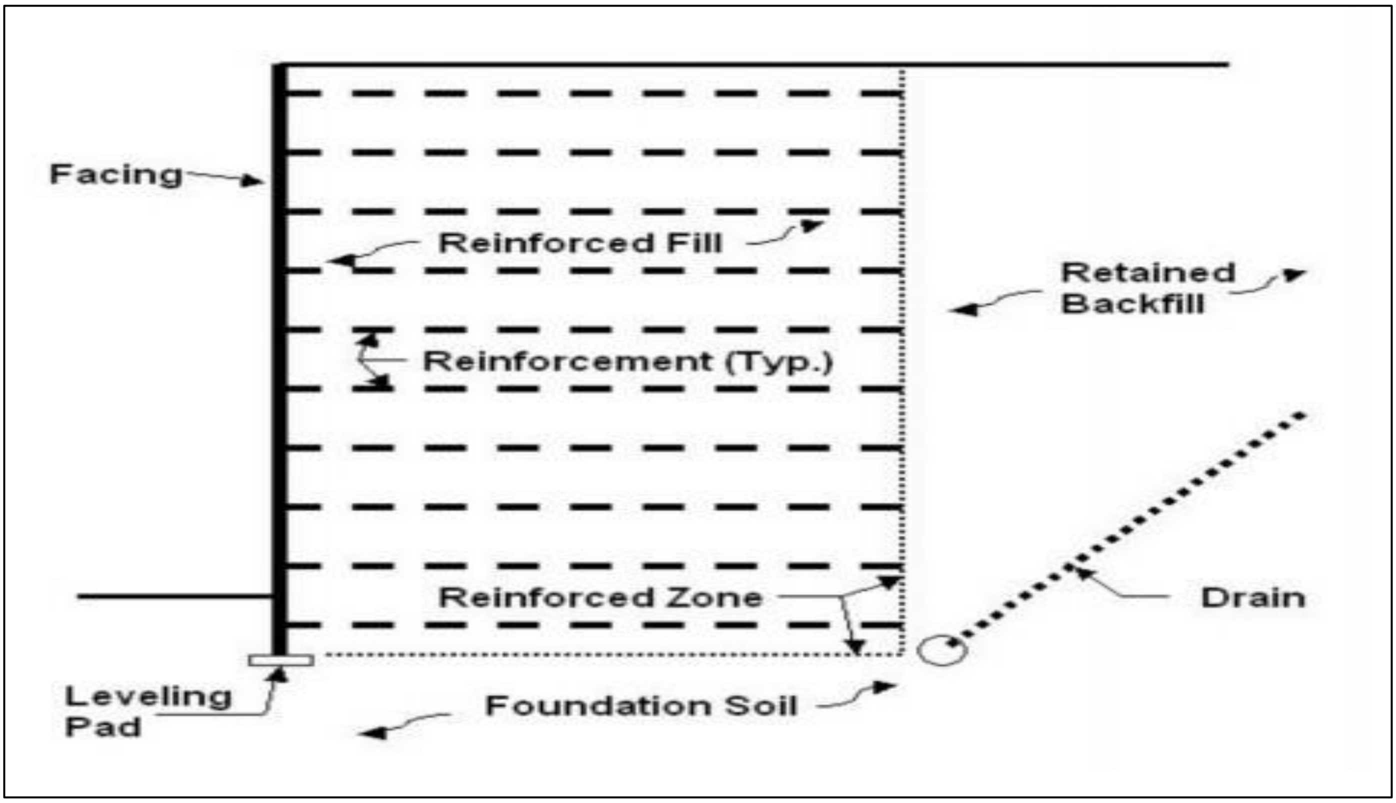

Fig 9: Element of Mechanical Stabilized Earth Walls (Bailleul Guillaume Laga Matthias (2017)

➢ *Reinforcement Elements*

Reinforcing elements are introduced into the soil in horizontal layers to enhance its behavior. These elements come in various types, configurations, and sizes and can be described or classified based on their material type, extensibility, and geometry. (Hicham Alhajj Chehade et al 2016).

Retaining walls utilize metallic (steel) and polymeric (geosynthetic) materials for reinforcement. Steel strips and geosynthetic materials are commonly used, with steel being suitable for silty or clayey soils. Additional reinforcements, such as grids, mesh, bars, rods, anchors, ladders, or welded wire meshes, may be needed for adequate frictional resistance in specific applications. Carbon fiber reinforcement is also explored for certain cases.(Bailleul Guillaume and Laga Matthias, 2017)

- *Steel Reinforcement*

Generally, the wall facing is connected to the reinforcement strip, ladder, rod, mesh or bar which is situated in the adjacent soil body, (Figure 9). The steel reinforcement may be treated with a galvanizing coating to mitigate the effect of corrosion.

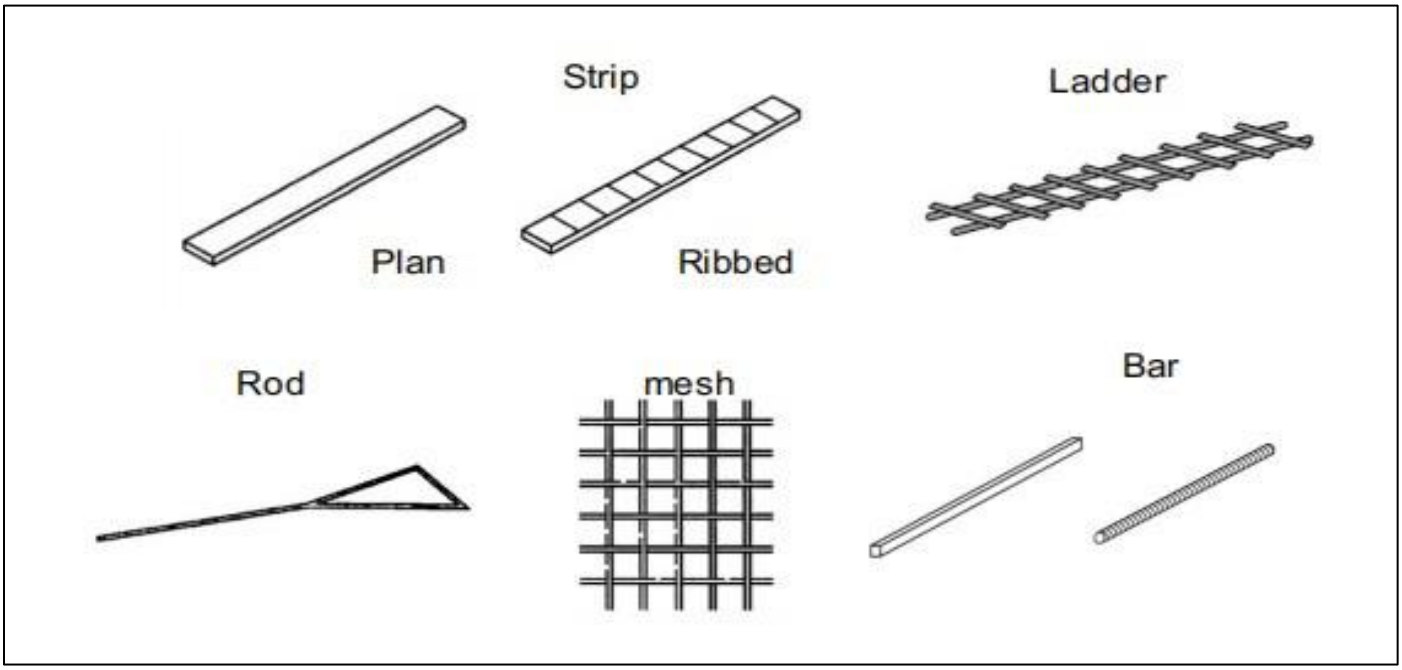

Fig 10: Steel Reinforcement Types (Bailleul Guillaume and Laga Matthias, 2017)

- *Polymeric Reinforcement*

Polymeric reinforcements offer flexibility and may not need direct connection to facing elements. Polyester and polyolefins are commonly used, and different geosynthetic materials can also be employed, including strips, grids, and sheets. (Figure 10). These polymeric elements have high tensile capacity and favorable friction characteristics. Certified design strength values should align with the expected service life and temperature conditions of the reinforced fill, similar to steel reinforcement.(Bailleul Guillaume and Laga Matthias, 2017)

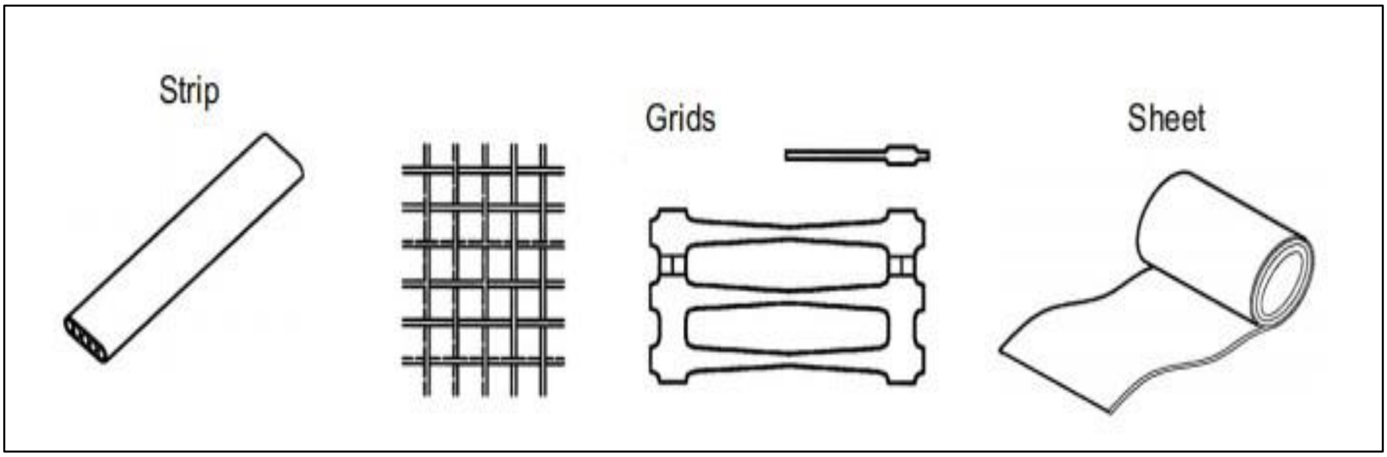

Fig 11: Polymeric Reinforcement Types (Bailleul Guillaume and Laga Matthias, 2017)

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➢ *Facing System*

The facing system of a wall serves two purposes: providing an appealing visual element and offering protection to the soil backfill, ensuring its stability. Various materials like concrete panels, segmental blocks, or natural stone veneers can be used for the facing. Apart from enhancing visual appeal, the facing system significantly contributes to the overall stability and appearance of the wall. It can be made of hard, deformable, or soft units, such as concrete elements, steel grids or meshes, and geosynthetic sheets or grids. (Bailleul Guillaume et al, 2017).

- *Prefabricated Concrete Elements;*

The production of prefabricated concrete elements for retaining walls is focused on ensuring proper dimensions and a defect-free structure to ensure optimal performance. Various shapes, such as full height, partial height, sloping panels, and segmental blocks, are available for these concrete units. (Figure 11).

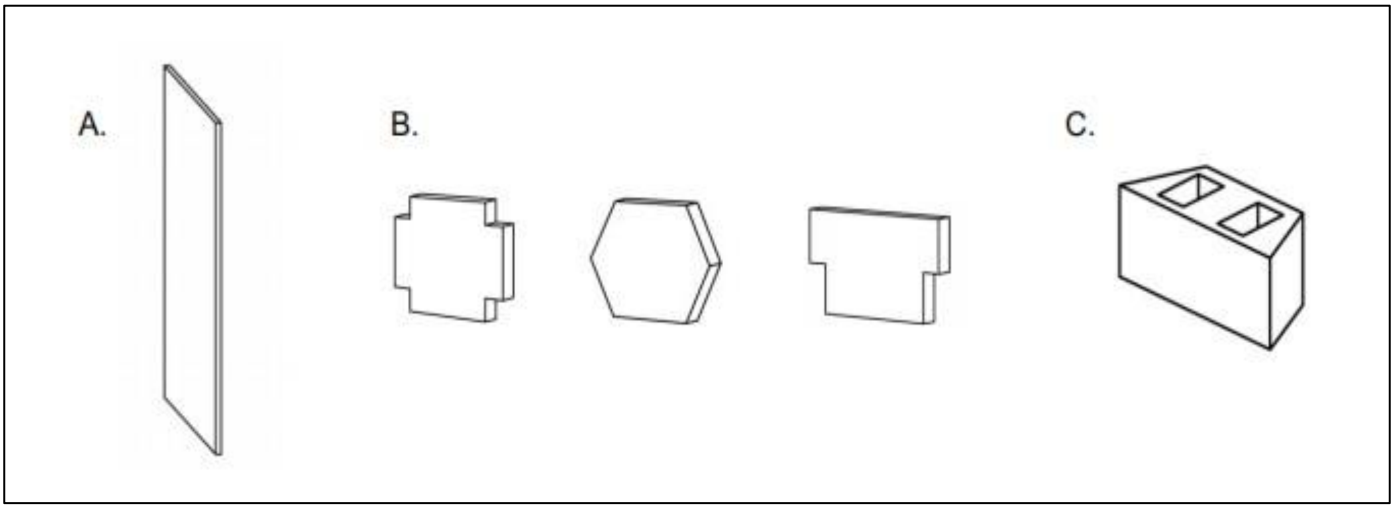

Fig 12: A. Full Height Panels – B. Partial Height Panels – C. Segmental Blocks (Bailleul Guillaume and Laga Matthias, 2017)

- *Steel Facing Units;*

Steel facing units serve as a component of MSE walls and are designed to provide support and reinforcement to the facing system. They are typically made of robust and durable steel materials, such as steel sheets or panels. The purpose of these units is to withstand the forces exerted by the soil backfill and ensure the stability of the wall. See (Fig. 12).

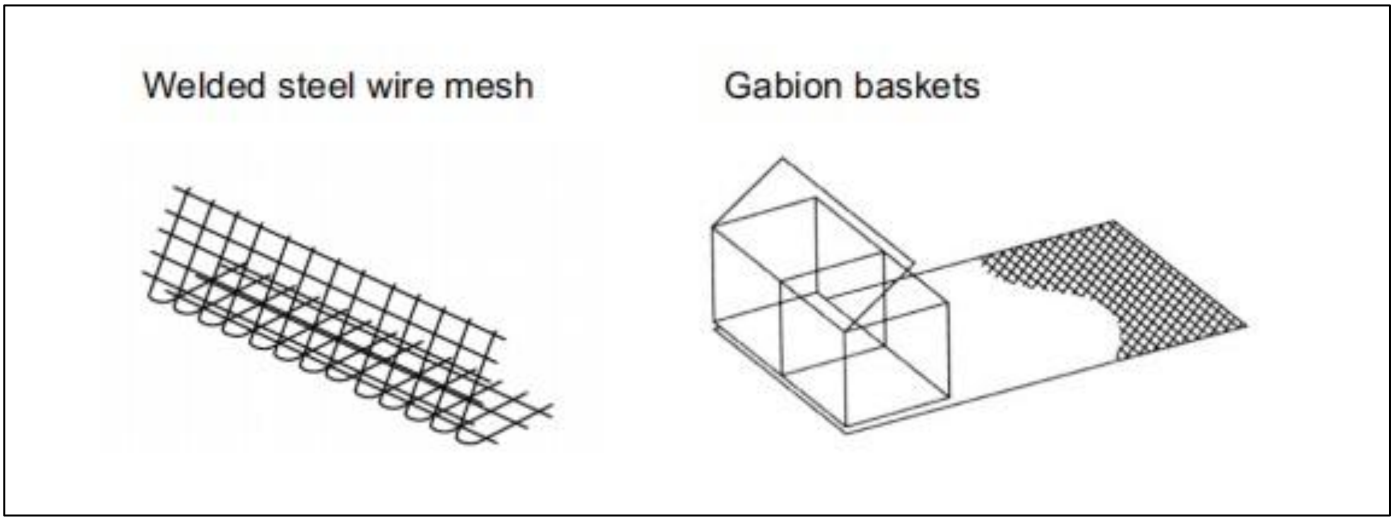

Fig 13: Mechanical Stabilized Earth Steel Facing Unit (Bailleul Guillaume and Laga Matthias, (2017)

➢ *MSE Walls Design and Construction*

The design of an MSE (Mechanically Stabilized Earth) retaining structure consists of several key components, including backfill, retained fill, foundation soil, reinforcing material, and optional facing panels. Certain recommended properties need to be considered during the design process. For instance, the length of the reinforcement should typically be equal to or less than 0.6 to 0.7 times the height of the wall. The backfill material should be well-draining and devoid of any organic substances (M. Hulagabali , 2016 et al).

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The backfill used in an MSE structure plays a critical role in determining its overall performance. To meet the required performance standards, various specifications from organizations such as AASHTO, FHWA, NCMA, and EU code outline the desired characteristics of the backfill material. Typically, the recommended specifications call for a granular material with a maximum size of 100 mm and less than 15% fines content. The assumed unit weight of the backfill is around 20 kN/m³, while the maximum friction angle is assumed to be 34 degrees (M. Hulagabali , 2016 et al).

➤ *Advantages and Application Of MSE Walls (FHWA, 2001)*

Mechanically Stabilized Earth (MSE) walls offer several advantages in railway infrastructure:

- MSE walls are cost-effective due to the use of reinforced soil and lightweight materials, resulting in construction cost savings.
- They are versatile, adapting to various site conditions, slopes, heights, and soil types, optimizing space and meeting project requirements.
- MSE walls exhibit durability against environmental factors like freeze-thaw cycles, seismic activity, and soil movements, thanks to high-strength reinforcement and construction techniques.
- Construction efficiency is enhanced as they can be built quickly, owing to their modular system and lightweight materials.
- MSE walls can be aesthetically pleasing with different facing materials, blending harmoniously with the landscape.
- They offer sustainability by incorporating recycled materials, reducing environmental impact.
- MSE walls are flexible and can accommodate settlements and ground movements, ensuring resilience and structural integrity.

MSE walls find extensive application in railway infrastructure for various purposes, including:

- MSE walls stabilize embankments along railway tracks, preserving their integrity and preventing soil erosion.
- They secure cuttings, preventing soil movement and landslides, ensuring railway safety.
- MSE walls support bridge abutments, maintaining structural integrity and proper track alignment.
- Special features in MSE walls, like acoustic barriers, reduce noise and vibration near railway tracks, enhancing passenger comfort.
- At railway stations, MSE walls create level platforms and add visual appeal with customized facings.
- MSE walls with vegetated facings control soil erosion in vulnerable areas adjacent to tracks.
- In grade separation projects, MSE walls provide support for elevated or lowered tracks, ensuring smooth train movements.
- They facilitate platform extensions, adding space to existing railway platforms without compromising safety.

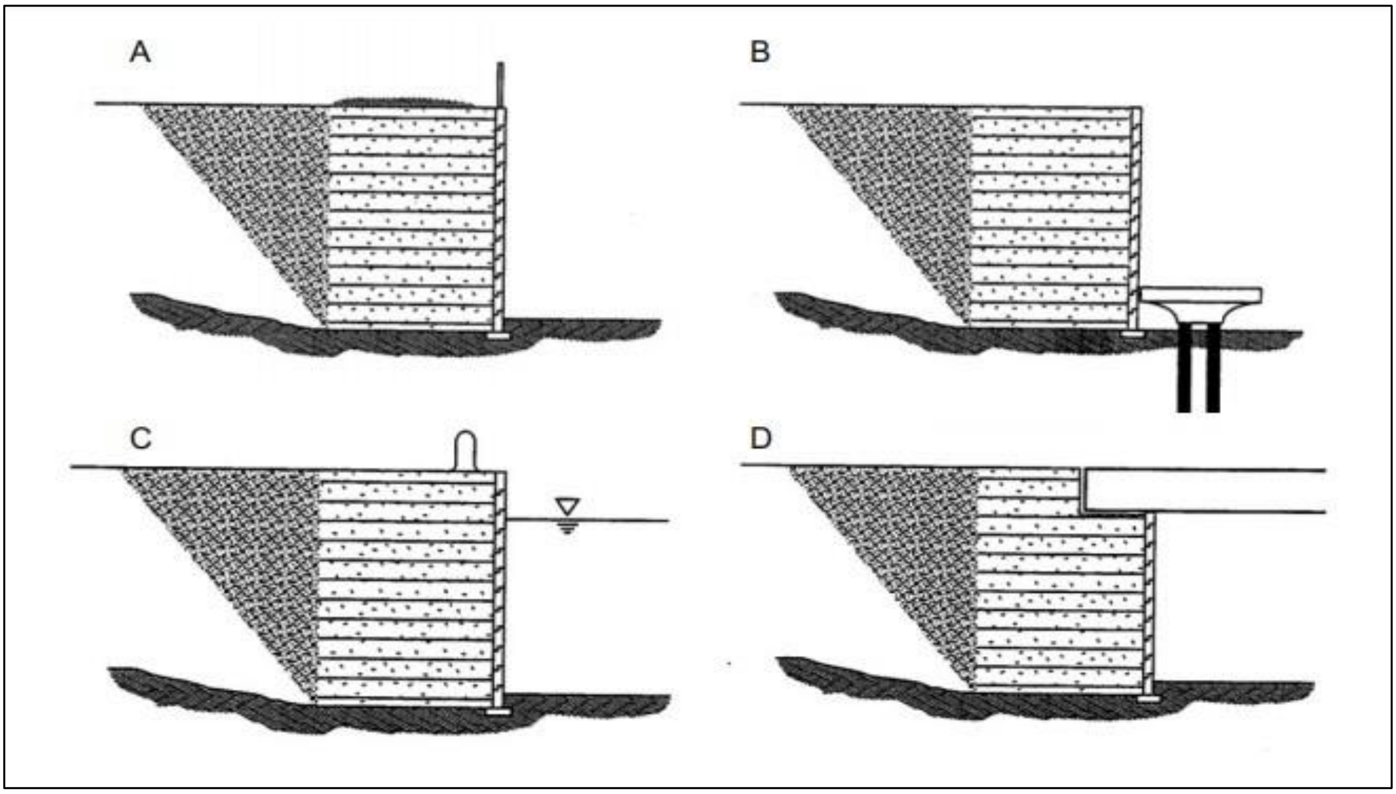

Fig 14: MSE Wall Applications (A) Retaining Wall; (B) Access Ramp; (C) Waterfront Structure; and (D) Rail Infrastructure / Bridge Abutment [6] (Bailleul Guillaume and Laga Matthias (2017)

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- *Limitations and Disadvantages of MSE Walls (FHWA, 2001)*

- ✓ While MSE walls offer many advantages in railway infrastructure, they also have certain limitations that should be considered. Some limitations of MSE walls in railway infrastructure includes:
- ✓ MSE walls have height limitations of around 20-30 feet (6-9 meters); taller walls may require alternative systems for stability.
- ✓ Limited space in railway corridors can make MSE wall construction challenging due to the need for adequate backfill placement and reinforcement layers.
- ✓ Differential settlement may cause deformations in MSE walls, impacting their performance in areas with varying soil conditions or ground movements.
- ✓ Maintaining MSE walls in railway environments can be challenging due to restricted access for maintenance activities.
- ✓ Proper drainage management is crucial for MSE wall stability; inadequate drainage can lead to excessive hydrostatic pressure.
- ✓ Designing MSE walls for railways involves complex analysis and modelling to ensure structural integrity under varying loading conditions and train effects.

- *Sheet Pile Walls*

Sheet pile walls are extensively utilized in railway infrastructure to serve as retaining structures, providing essential support and stability to embankments, cuttings, and other areas adjacent to railway tracks. These walls are constructed by driving interlocking steel sheet piles into the ground, creating a continuous barrier that resists lateral soil or water pressure. (G. H. Koraim and M. H. Hussein, 2017).

In railway infrastructure, the primary purpose of sheet pile walls is to retain the soil and counteract the lateral forces exerted by soil or water, effectively preventing slope failures and ensuring the overall stability of the railway track alignment. (P. E. Lamont-Black, R. J. Jardine, and G. R. Mortimore, 2002). This is especially valuable in regions with soft or unstable soils, where conventional earth embankments may be susceptible to erosion, settlement, or shifting.

Fig 15: Sumerset Railway Embankment Stabilized Using Sheet Pile Walls (geplus.co.uk 2021)

- *Component of Sheet Pile Walls*

- ✓ *Sheet Piles:* Sheet piles are made of durable materials like steel or vinyl. They are long, thin, and interlocking sections that are driven vertically into the ground to create a continuous wall. The sheet piles are designed to provide lateral support and resist the pressure exerted by the surrounding soil. Sheet-pile sections may be Z, deep arch, low arch, or straight web sections. The interlocks of the sheet-pile sections are shaped like a thumb-and-finger or ball-and-socket joint for watertight connections.Interlocks. (Figure 14a) is a schematic diagram of the thumb-and-finger type of interlocking for straight web sections. The ball-and-socket type of interlocking for Z section piles is shown in (Figure 14b).

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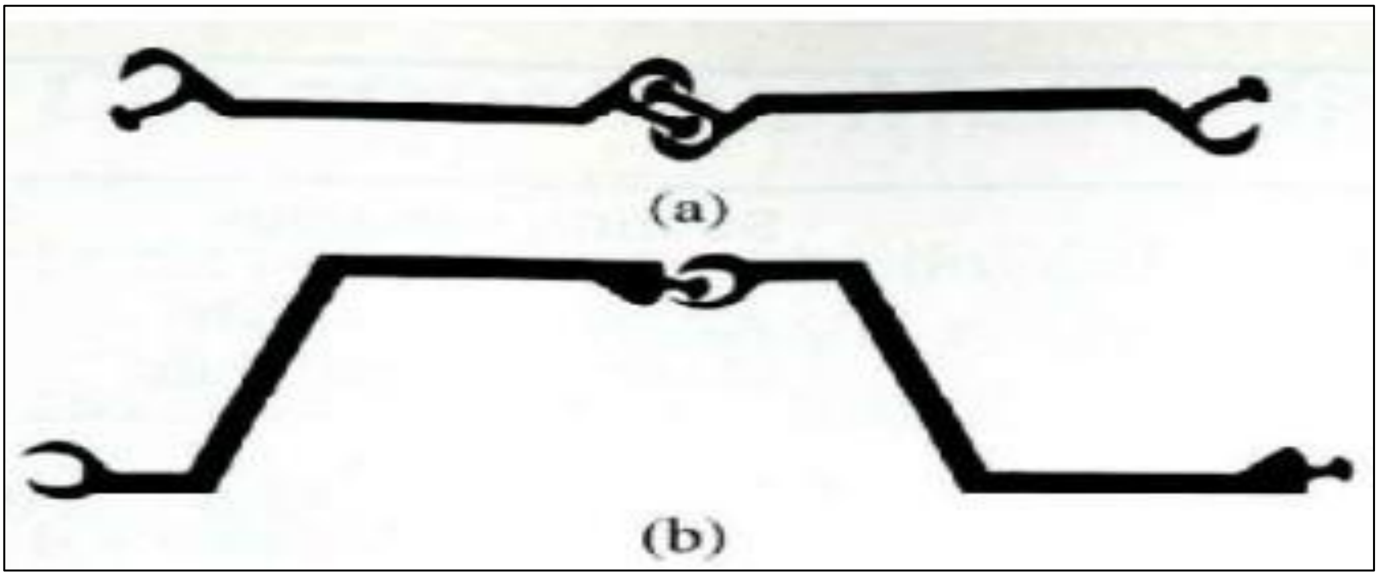

Fig 16: Thumb-and-Finger Type Sheet-Pile Connection; (b) Ball-and-Socket Type Sheet-Pile Connection
(Mohsen Keramati, 2016)

Sheet piles are equipped with interlocking mechanisms at their edges, enabling them to be connected and form a continuous barrier that ensures proper alignment, prevents soil infiltration, and enhances their stability.

- ***Anchoring Systems*** (Optional): Sheet pile walls may be reinforced with anchoring systems, like ground anchors or tiebacks, installed behind the wall and connected to the sheet piles. These anchors resist lateral forces, providing added stability based on soil conditions and design requirements.

Fig 17: Anchoring System of Sheet Pile Walls Courtesy of db-excel.com, (2017)

- ***Tie Rods (Optional):*** Tie rods, threaded rods installed horizontally through the sheet piles, can be used alongside the wall to provide extra reinforcement. They transfer lateral forces, enhancing stability, and are beneficial in situations with higher loads or challenging soils.
- ***King Piles (Optional):*** Larger and heavier-duty king piles, installed at intervals along the sheet pile wall, provide additional strength and stiffness to the system. They evenly distribute forces, improving overall performance and stability.
- ***Soil Struts (Optional):*** Horizontal soil struts, or waters, added to sheet pile walls act as temporary or permanent bracing elements. They resist lateral pressures, reduce deflection, and enhance stability, especially during construction or when extra reinforcement is necessary.

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- *Construction Sequence*
  There are two main categories of sheet-pile walls:

- Cantilever
- Anchored.

During construction, the sheet pile can be driven into the ground first, followed by placing backfill on the land side. Alternatively, the sheet pile can be driven first, and the soil in front of it can be dredged. In both cases, the backfill used behind the sheet-pile wall is typically granular, while the soil below the dredge line can be sandy or clayey. The surface of the soil on the water side is commonly known as the mud line or dredge line. Hence, construction methods for sheet-pile walls can generally be categorized as back-filled structures or dredged structures. (Mohsen Keramati, 2016)

➢ *The Construction Sequence for a Back-Filled Structure is as Follows: (see Figure)*

- ***Step 1:*** Remove the in-situ soil in front and back of the intended structure by dredging.
- ***Step 2:*** Drive the sheet piles into the ground.
- ***Step 3:*** Backfill the area up to the level of the anchor, and install the anchor system if required.
- ***Step 4:*** Continue back-filling until reaching the top of the wall.

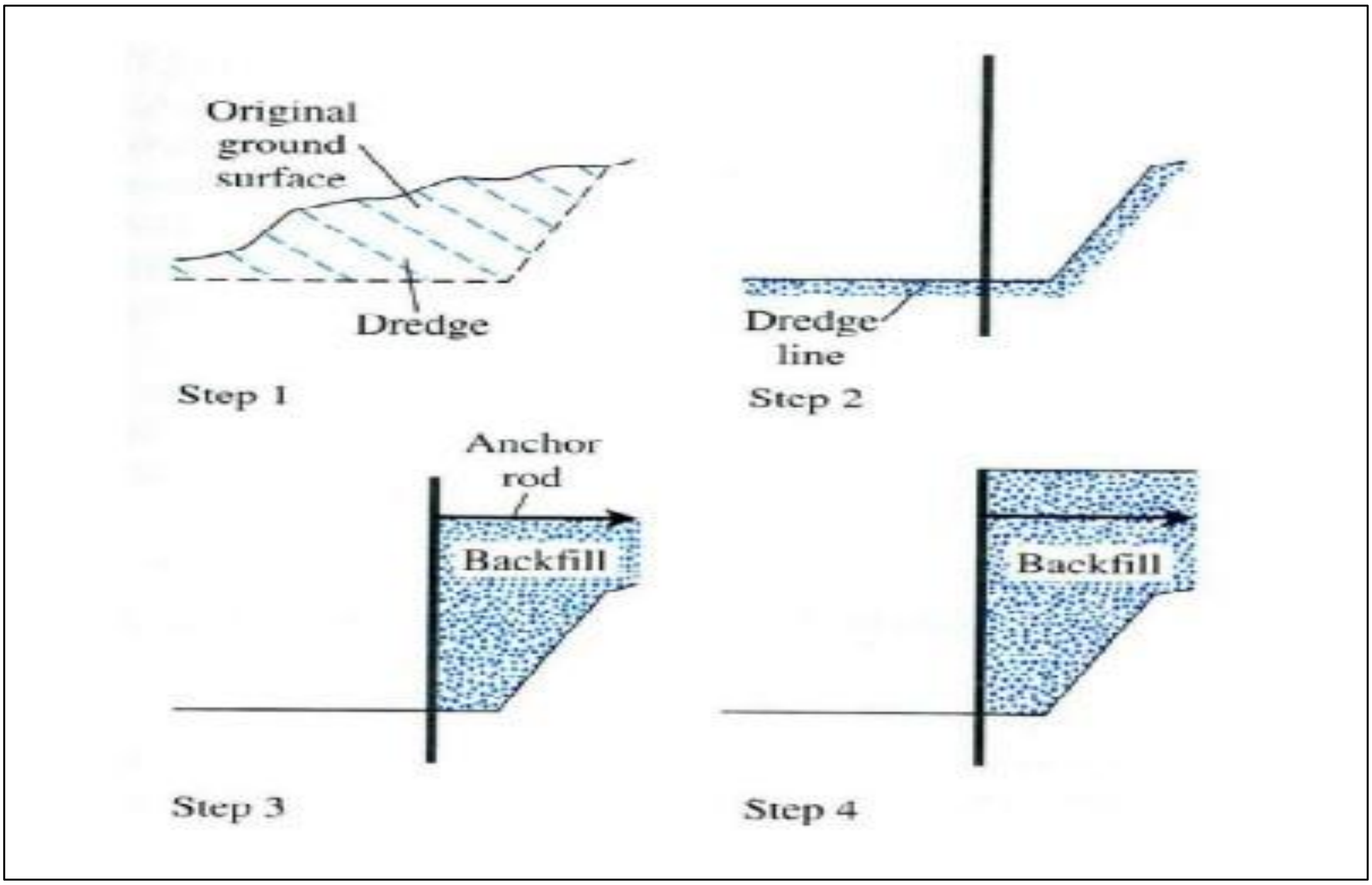

Fig 18: Construction Sequence for a Back-Filled Structure (Ahmed H.A 2017)

For a cantilever type of wall, only Steps 1, 2, and 4 are relevant. The construction sequence for a dredged structure is as follows: (See Figure)

- ***Step 1:*** Drive the sheet piles into the ground.
- ***Step 2***: Backfill the area up to the anchor level and install the anchor system, if necessary.
- ***Step 3:*** Continue back-filling until reaching the top of the wall.
- ***Step 4:*** Dredge the front side of the wall.

In the case of cantilever sheet-pile walls, Step 2 is not necessary.

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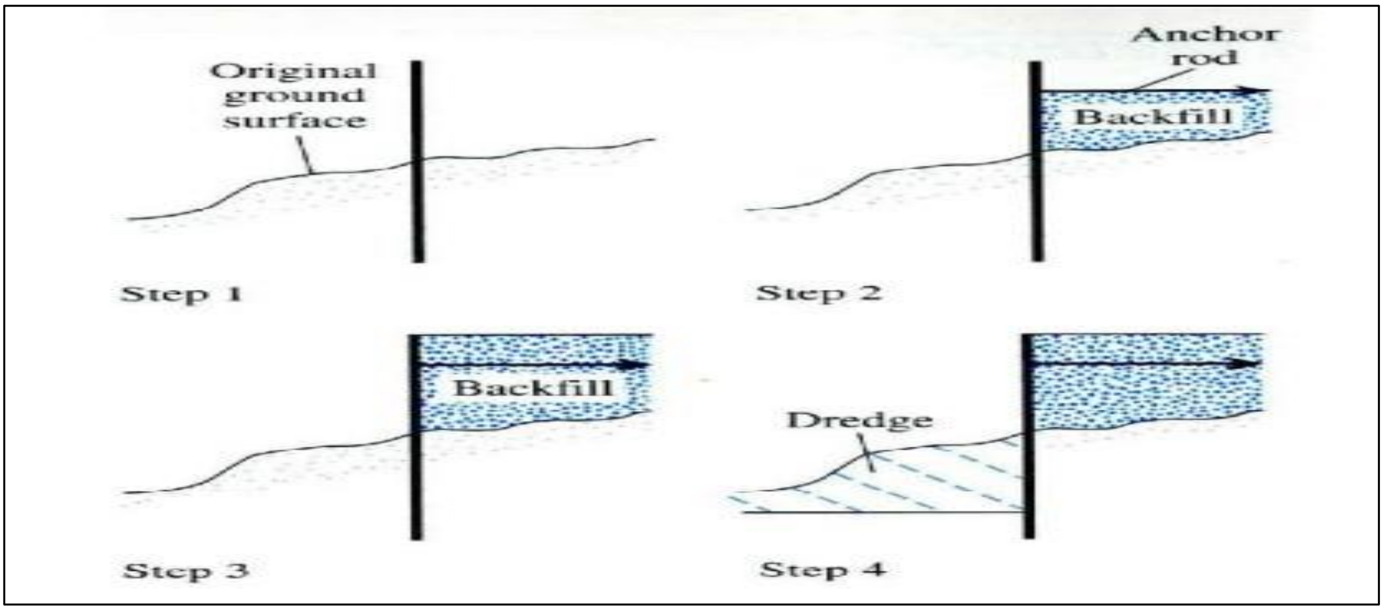

Fig 19: Construction Sequence for a Dredged Structure (Ahmed H.A 2017)

- *Advantages and Application of Sheet Pile Walls*

Sheet pile walls have various advantages in railway infrastructure projects, they include:

- ✓ Space Optimization: Sheet pile walls have a slender design, maximizing available space along railway tracks while offering effective support, optimizing land use.
- ✓ Quick Installation: Rapid installation using vibrating or impact hammers allows for efficient construction, minimizing disruptions to railway operations and shortening project duration.
- ✓ Adaptability: Sheet pile walls can be installed in various soil conditions, making them versatile and suitable for diverse project requirements in railway corridors.
- ✓ Strength and Durability: Constructed from sturdy materials like steel, sheet piles provide high strength, resistance to external forces, and long-term stability.
- ✓ Design Flexibility: Offering flexibility in height, alignment, and shape, sheet pile walls can be tailored to suit specific site conditions and project needs.
- ✓ Suitable for Confined Spaces: Ideal for restricted areas like narrow railway corridors, sheet pile walls' compact size and installation method make them suitable for projects with limited workspace.
- ✓ Reduced Excavation: Requiring minimal excavation, sheet pile walls minimize disruption to existing railway tracks and utilities, reducing earthwork needs.
- ✓ Cost-Effective Solution: With efficient installation, reduced material requirements, and potential reuse, sheet pile walls offer a cost-effective option for retaining in railway infrastructure.

Sheet pile walls are commonly used in various applications within railway infrastructure projects. Some key applications of sheet pile walls in railway infrastructure include:

- ✓ Retaining Walls: Sheet pile walls stabilize embankments and cuttings along railway tracks, providing lateral support, preventing soil erosion, and maintaining railway alignment integrity.
- ✓ Bridge Abutments: Serving as abutments for railway bridges, sheet pile walls offer structural support to the bridge deck, accommodating height differences between the bridge and surrounding terrain.
- ✓ Underpasses and Tunnels: In railway projects, sheet pile walls stabilize the soil and prevent water infiltration during underpass and tunnel construction activities.
- ✓ Noise Barriers: Sheet pile walls act as noise barriers along railway tracks, reducing noise transmission to nearby areas and enhancing the surrounding environment.
- ✓ Retention of Railway Embankments: Sheet pile walls retain railway embankments, ensuring stability and preventing soil movement in challenging soil conditions or areas with significant height differences.

- *Limitations And Disadvantages Of Sheet Pile Walls*

While sheet pile walls offer numerous advantages, they also have certain limitations and disadvantages that should be considered in railway infrastructure projects.

- ✓ Height Constraints: Sheet pile walls have limitations on their maximum height due to increased forces and stability considerations for taller walls.
- ✓ Limited Flexibility: Sheet pile walls are rigid structures, which may not accommodate significant ground movements or settlements, necessitating consideration of alternative wall systems in such areas.
- ✓ Corrosion Risk: Steel sheet piles are susceptible to corrosion in aggressive soil or water environments, necessitating corrosion protection measures for long-term durability.
- ✓ Noise and Vibrations: Sheet pile wall installation using impact hammers can produce disruptive noise and vibrations near railway communities, requiring mitigation measures for minimizing impacts.
- ✓ Environmental Considerations: The materials used in sheet pile walls can have environmental implications during production and disposal, prompting the use of sustainable materials and construction practices.
- ✓ Limited Aesthetic Options: Sheet pile walls may lack desired architectural or landscaping features, limiting their aesthetic appeal in railway projects.
- ✓ Maintenance Requirements: Regular inspection and maintenance are essential to address corrosion, damage, or potential failures and uphold the long-term integrity of sheet pile walls.

- *Benefits and Challenges of Employing Earth Retaining Systems in Railway Infrastructure*

Earth retaining system in railway infrastructure offers several key benefit these includes:

- ✓ Earth retaining systems like MSE walls or sheet pile walls enhance railway infrastructure stability by resisting lateral soil pressures, stabilizing embankments, cuttings, and slopes, and mitigating the risk of slope failures and soil erosion. (Tuthill, L., & Collin, J. (2018).
- ✓ Earth retaining systems save valuable space in congested railway corridors by minimizing the footprint of retaining structures, allowing for more efficient use of land for tracks, stations, and other railway components.(Mahmoodi, A., & Mukhtar, B. (2017).
- ✓ Earth retaining systems in railway projects provide cost advantages through the use of local materials and efficient construction methods, leading to reduced transportation, labour, and construction time costs. (Briaud, J. L., & Gibson, D. C. (2002).
- ✓ Earth retaining systems in railway projects offer design flexibility, allowing customization of height, alignment, and facing materials to accommodate diverse site conditions and geometric constraints, ensuring adaptability to changes in ground conditions. (Federal Highway Administration. (2018).

While earth retaining systems offer numerous Benefits, there are also certain challenges that should be considered in railway infrastructure projects.

- ***Design Complexity:*** Designing earth retaining systems in railway infrastructure requires comprehensive geotechnical investigations, analysis, and adherence to design standards and guidelines. Factors such as soil properties, groundwater conditions, and dynamic train loads need to be considered for optimal performance. (Sołtys, A., & Jaśkiewicz, M. (2019).
- ***Construction Constraints:*** Construction of earth retaining systems in railway environments may face logistical challenges, including limited access, proximity to operating tracks, and restricted working hours. Coordination with railway authorities and careful planning are necessary to ensure minimal disruption to train operations during construction. (Wiesener, S., Eilers, S., & Wagner, N. (2017).
- ***Maintenance and Monitoring:*** Earth retaining systems require regular inspection and maintenance to identify any signs of distress or degradation. Monitoring of factors like settlement, drainage, and facing integrity is essential to ensure the long-term performance and safety of the structures. (Abdelrahman, W. E., & Abdelrahman, H. E. (2019).
- ***Environmental Considerations:*** Earth retaining systems in railway infrastructure must incorporate environmental considerations, including erosion control, sediment management, and the use of sustainable materials, to meet regulatory requirements and promote ecological balance.. (Tran, H. N., & Wang, L. (2018)

C. Previous Case Studies and Best practices

➢ *General Classification of Walls*

With reference to the aims and objectives of this study, the following previous case studies were used as a guide:

- Bryan Duevel, Heather Stewart, and Rick Smith (2014) classified earth retaining systems employed in railway embankment into two.

- ✓ Gravity walls
- ✓ Non-gravity walls

According to Bryan Duevel et al (2014), gravity walls in railroad applications primarily resist loads through their own weight. Various types of gravity walls are used, including cast-in-place concrete walls, cantilever walls, modular block walls, T-Walls (R), soil nail walls, and mechanically stabilized earth (MSE) walls. These walls typically have a base width ranging from 0.7 to 1.0 times the wall height and are founded at shallow depths.Gravity walls offer advantages such as suitability for various foundation conditions

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and the ability to improve poor ground using established methods. Compared to non-gravity walls, they are easier to construct and less expensive when considering only the cost of the structure itself. Gravity walls are particularly preferred in situations where space constraints are not a concern.A visual representation of a typical gravity wall and the loads it experiences is provided in Figure 1.

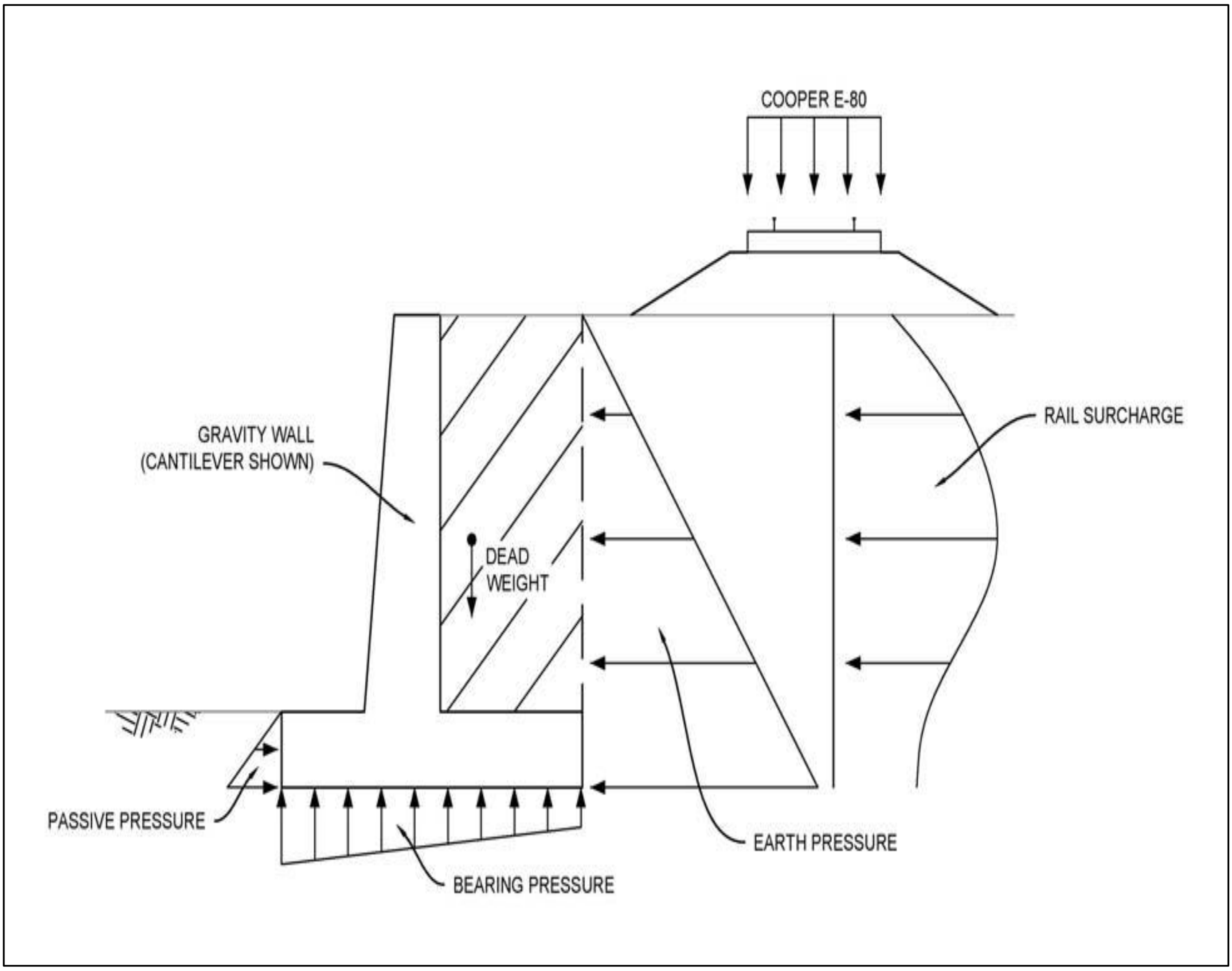

Fig 20: Gravity Retaining Wall Schematic Bryan Duevel et al (2014)

Nongravity walls in railroad applications rely on below-grade structural components, such as passive soil or rock resistance, anchors, or struts to resist loads. Examples include cantilever sheet pile and soldier pile walls, anchored sheet pile and soldier pile walls, and secant pile walls. These walls consist of vertical elements (such as steel H-piles) with lagging spanning between them. The wall thickness is typically the width of the vertical element and facing, and they may extend a minimum of 2 to 3 times the exposed wall height below the ground surface. Nongravity walls require specialized equipment for construction and are more complex and costly compared to gravity walls. (Figure 2) illustrates a typical nongravity wall and applied loads.

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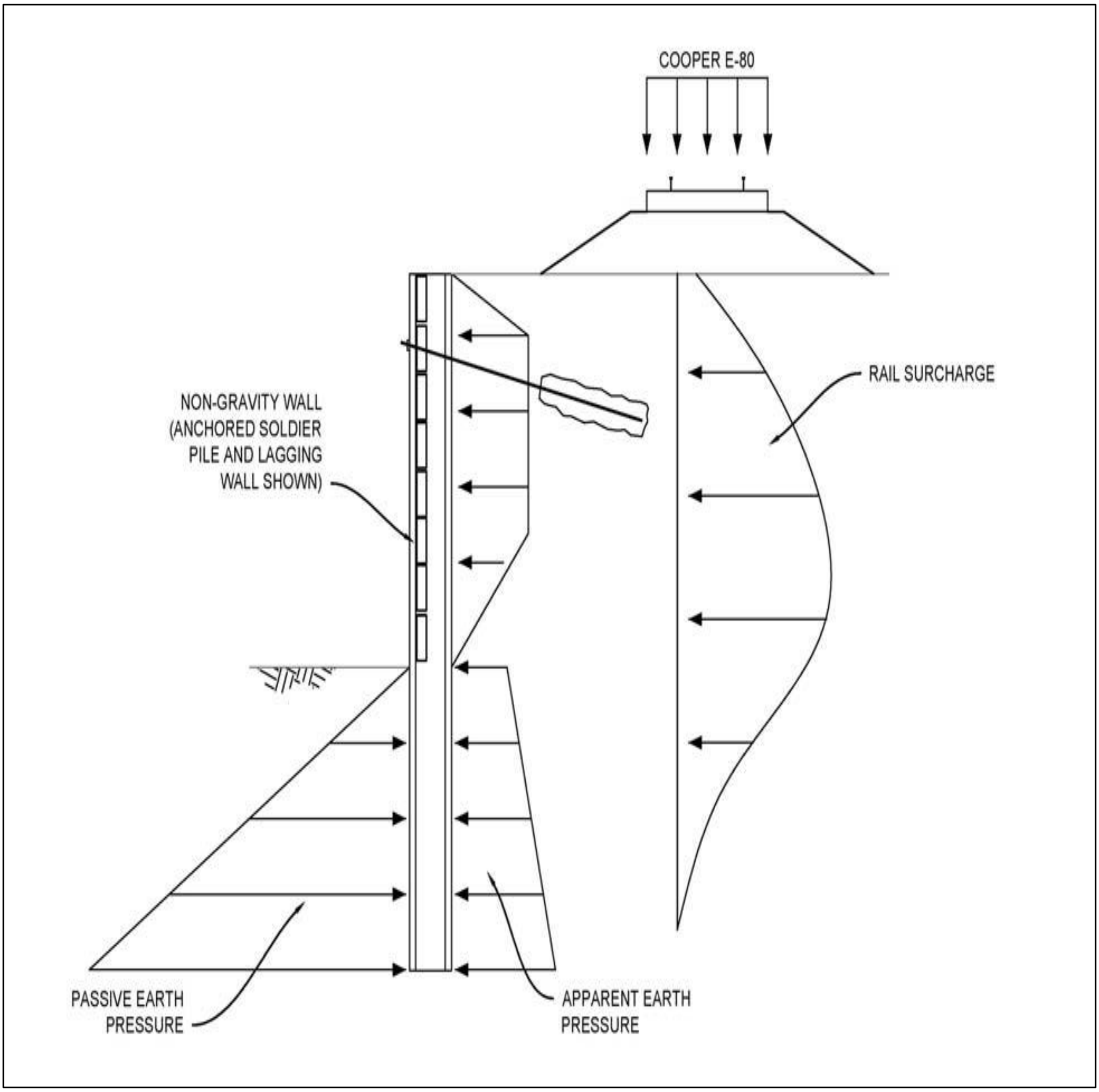

Fig 21: Non-Gravity Retaining Wall Schematic Bryan Duevel et al (2014)

Bryan Duevel et al (2014) further discussed about the common railroad design Challenges which includes,

- *Surcharge*

Retaining walls near railway tracks experience significant surcharge loads, particularly from train traffic. The design consideration for these walls includes the Cooper E80 train live-load surcharge, which can be estimated at approximately 1,880 pounds per square foot per foot (psf/ft) of rail. In comparison, this surcharge is much higher than the typical highway live load surcharge, which is usually simplified to 250 psf/ft. The train live-load surcharge can exceed the pressure exerted by the retained earth, highlighting the importance of appropriately accounting for these large surcharge loads in retaining wall design.

The guidelines in "Guidelines for Temporary Shoring (1)" specify that the inclusion of Cooper E80 loading in shoring design is necessary for structures located in Zone A. These guidelines propose a zone of influence that is larger than the typical zone of influence considered by geotechnical engineers. In this context, the guidelines recommend a more extensive area to be taken into account when designing shoring systems. See (Figure)

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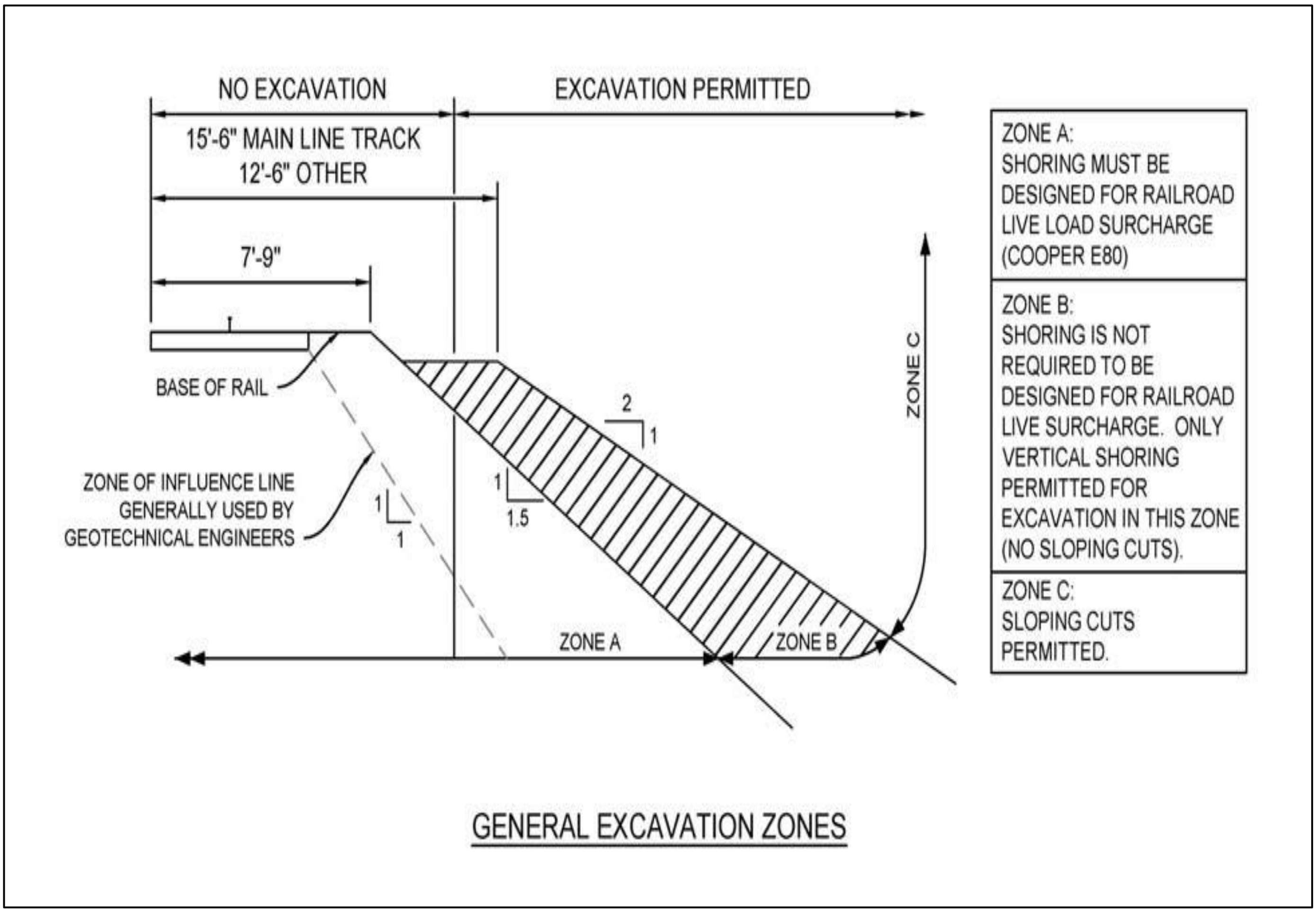

Fig 22: Railroad Surcharge Influence for Temporary Shoring Bryan Duevel et al (2014)

- *Limited Rows*

In many railroad projects, there is limited right-of-way (ROW) available for modifications or expansions. The boundaries of the ROW were established when the embankments were initially constructed, without considering future expansion needs. As a result, adjacent infrastructure or uncooperative landowners may restrict the available space for track modifications or additions. This limitation forces the construction of retaining walls in close proximity to the tracks, leading to higher surcharge loads on the walls.

- *Wetlands*

Railroad expansion projects often encounter the issue of wetlands surrounding existing infrastructure. During the original construction of railroads, wetlands and environmental considerations were not taken into account, and wetland areas were simply filled to create embankments. However, current regulations and environmental concerns make it challenging to expand tracks near wetland boundaries. Construction in wetlands poses technical difficulties due to weak soil conditions, and obtaining permits for wetland impacts can cause significant project delays. To mitigate the impact on wetlands, retaining walls may be constructed instead of expanding embankments. Although constructing walls is more expensive, it may be a more viable option considering the potential delays associated with environmental permitting.

- *Utilities*

Railroad corridors were the earliest linear connections spanning great distances and provided the easiest crossing over difficult terrain. As such, railroad corridors are also often utility corridors. The presence of critical utilities presents another logistical and geometric constraint to wall designers.

- *Existing Rail Infrastructure*

Railroad infrastructure, including bridges, retaining walls, and embankments, often exceeds its intended design life and may not meet current standards. When making modifications or additions to these structures, adherence to current design requirements is crucial to ensure their stability and safety in line with modern standards.

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- *Retaining Walls on Slopes*

Designing retaining walls on slopes to optimize right-of-way usage and reduce wall heights presents challenges due to geotechnical constraints. Walls on slopes have reduced bearing capacity and stability, and variable soil quality in existing embankments complicates construction, requiring wider bases and deeper embedment, leading to increased difficulty and cost of wall construction.

Bryan Duevel et al (2014) finally discussed about the consideration factors in selecting a retaining wall.

❖ *Site Constraint*

- *Site Width:* The available width for the new retaining wall should be considered, with a guideline suggesting that if the horizontal distance between the existing track structure and the proposed wall is more than 2.5 times the required wall height, a gravity wall and temporary cut can be feasible.
- *ROW Acquisition:* The potential for acquiring additional right-of-way (ROW) should be assessed, as expanding the ROW can make wall construction easier and less expensive.
- *Permitting:* The presence of wetlands and involvement of other jurisdictional agencies can impact the permitting process. Costs and delays may be incurred in obtaining the necessary permits, especially if wetlands are affected.
- *Temporary/Permanent Easements:* The need for easements, whether for construction access or subsurface wall elements like tiebacks or soil nails, should be evaluated. Easements may be required, adding to the overall project considerations.

❖ *Technical Feasibility*

- *Geotechnical Conditions:* It is important to assess whether the site soils and project geometry can support the new loads imposed by the wall and if anticipated settlement aligns with the chosen wall system.
- *Wall Stability:* The wall should effectively resist earth pressures and surcharge loads while maintaining an acceptable factor of safety for global stability.
- *Suitable System:* The selected wall system should align with railroad standards of practice to ensure its suitability for the specific railway infrastructure project.

- Bailleul Guillaume and Laga Matthias (2017) studied the Design of 16.5m retaining system for support of highway/railway bridges. Discussed in this studies about retaining system schemitization and stated that Combining both externally and internally stabilised systems creates a composite retaining structure which comprises elements of more than one uniform structure. Typical examples are earth structures reinforced by tendons, geotextiles or grouting, structures with multiple rows of ground anchorages or soil nails.

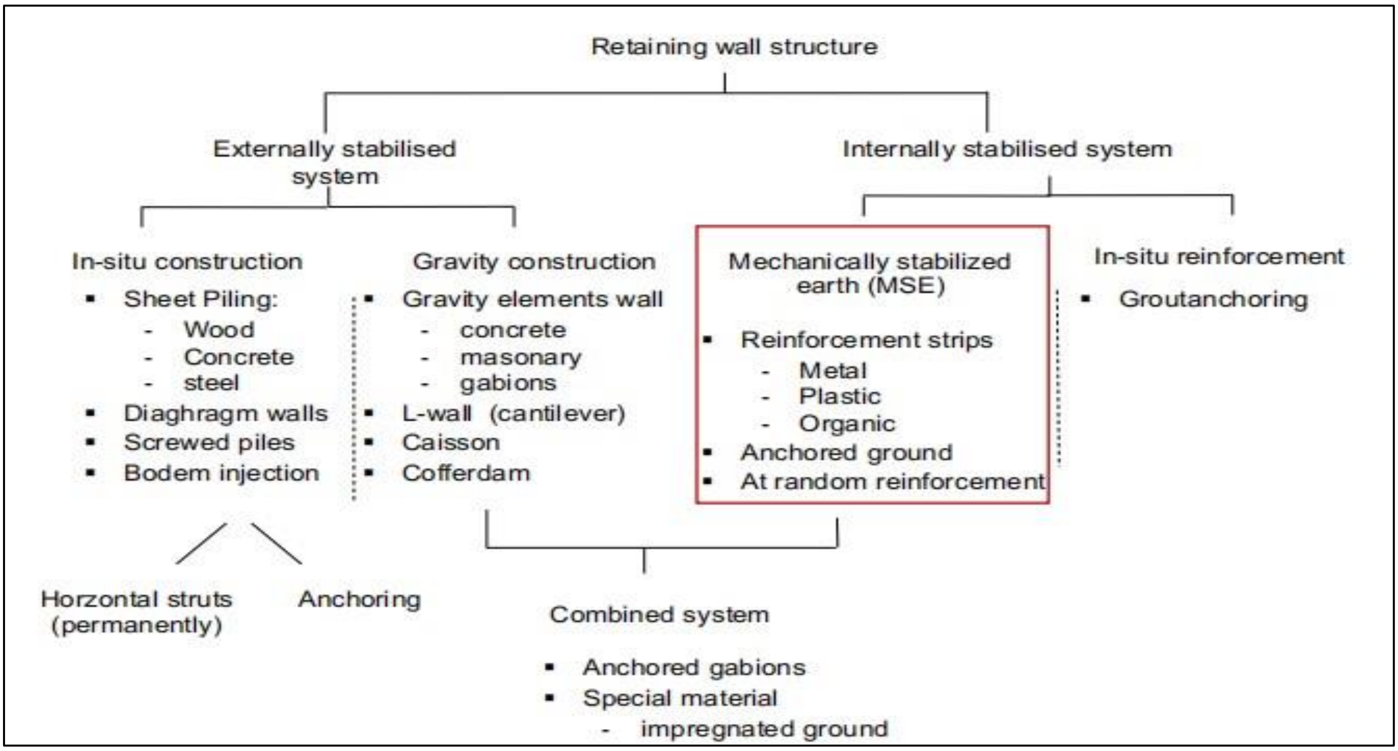

FIg 23: Retaining System Schemitization Bailleul Guillaume and Laga Matthias (2017)

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- Clemente Fuggini et al (2016) analysed the potential use of innovative geotextiles for the protection of railway embankment that are more and more subjected to failures, landslides and uneven settlements due to natural hazards (e.g. heavy rain, floods, earthquakes, etc.) and climate changes effects that are increasing the disruptive potential of common hazards.

Fig 24: Collapse of Railway Embankment along Plymouth Rd, Ann Arbor, US, in May 2011 after an Heavy Rain on Already Saturated Ground (Left); Massive Landslide in Hokkaido Leaves Railway Tracks Hanging in Mid-Air, April 2012 (Right). (Clemente Fuggini et al 2016)

Fig 25: Landslip Rail Line in UK, February 2013: View of the Railway (Left); Top View of the Area (Right). (Clemente Fuggini et al 2016)

✓ *Sensors Integrated Geotextiles*

Clemente Fuggini et al (2016) stated that, railway infrastructures are vulnerable to both progressive and sudden failures, which require different monitoring and detection approaches. Static sensors can be useful in monitoring soil settlements and understanding trends in progressive failures. On the other hand, highly precise and dynamic measuring sensors are crucial for early warning information in sudden failures, allowing appropriate decisions to be made, such as stopping train traffic to ensure safety. Combining sensors with reinforcing solutions is essential to gather real-time data and implement mitigation measures. Multifunctional geotextiles, capable of providing both strengthening and monitoring functions, are being explored as an optimized solution for sub-grade reinforcement. Below are the uses of geotextiles in railway retaining systems

- *Classical Use*

Geotextiles are traditionally used in embankments to reduce settlement and increase bearing capacity. However, a new approach called "geosynthetic-reinforced and pile-supported embankment" has been developed. This method involves placing pile-like elements through the soft soil and reinforcing the embankment with geosynthetics before filling. The combination of arching effects and membrane effects from the reinforcement leads to stress relief in the soft soil. (Indraratna, B. et al 2005).

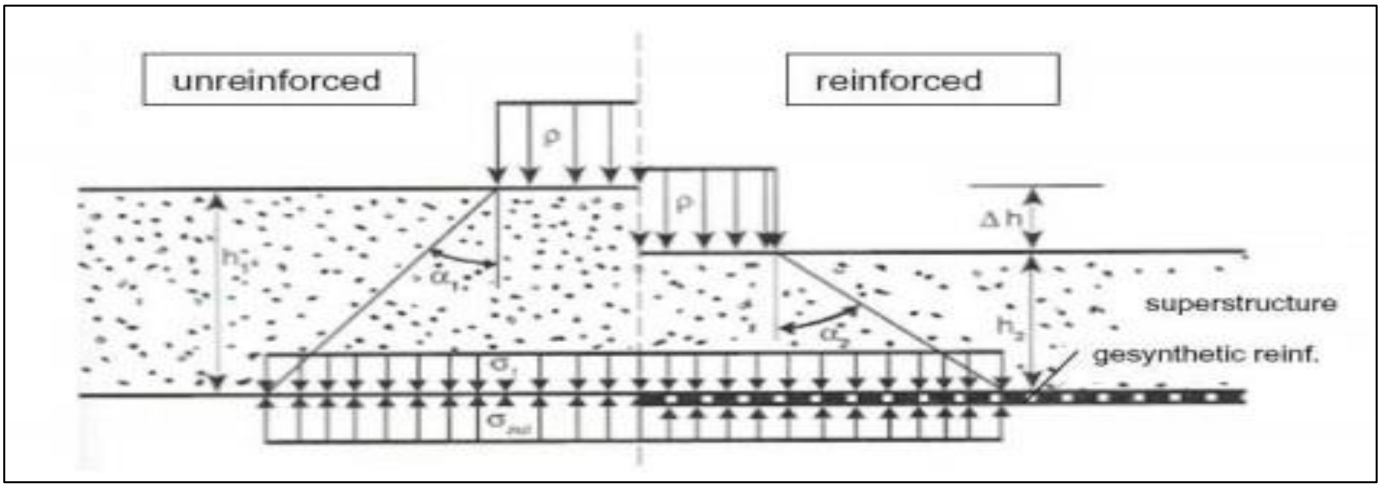

Fig 26: Use of Geotextiles for Soil Reinforcement
(Clemente Fuggini et al 2016)

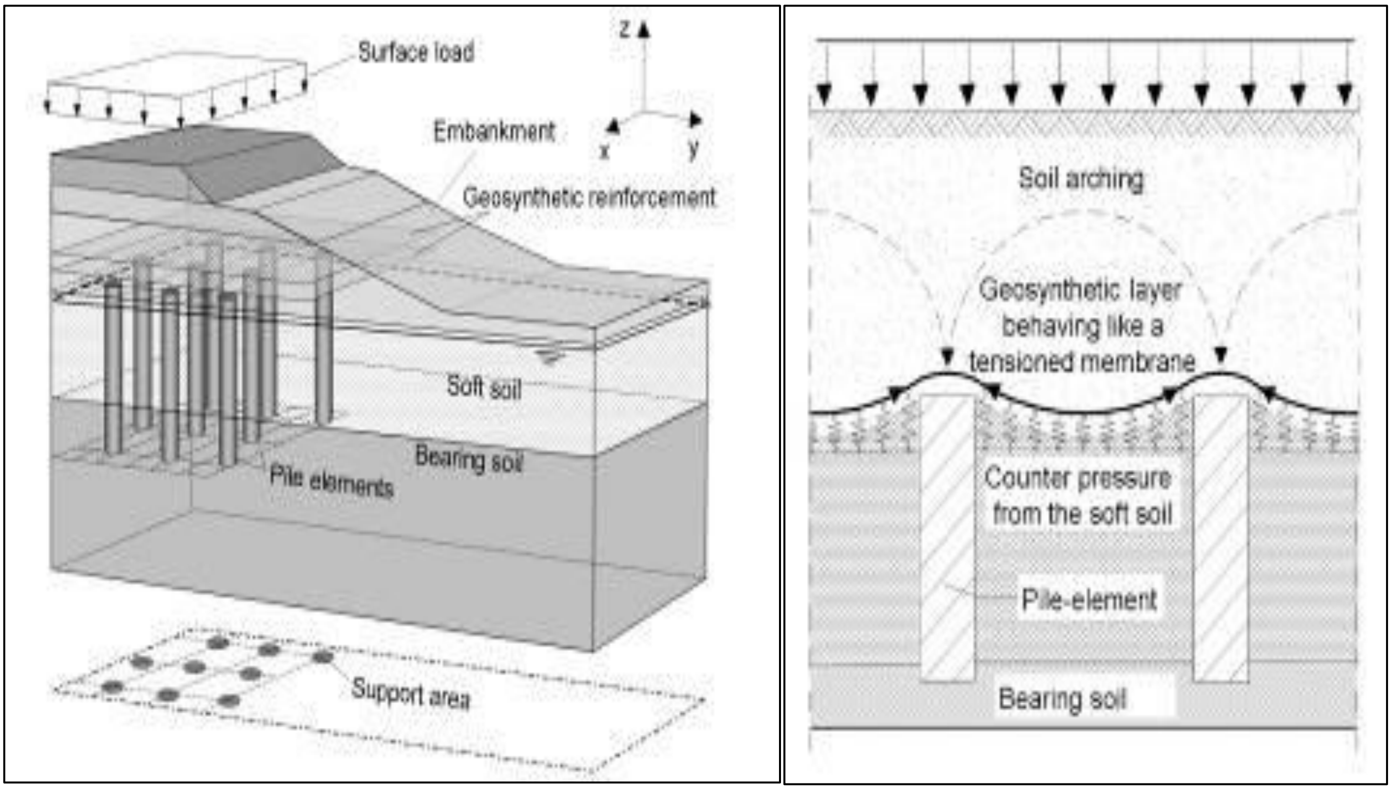

Fig 27: Geosynthetic-Reinforced and Pile-Supported Embankment
(Clemente Fuggini et al 2016)

- *Innovative Use*

Modern geotechnical engineering standards emphasize the need for monitoring the stability and performance of geotechnical structures. Multifunctional geotextiles have been developed to fulfill this requirement by providing both stability and monitoring functions. Sensor Integrated Geotextiles incorporate distributed Fiber Optics Sensors (FOS) within the geogrid structure, allowing for continuous or periodic monitoring of the infrastructure. The FOS can detect structural damage, distinguish it from environmental disturbances, and generate warning alarms. Geotextiles are typically made of plastic materials such as polypropylene, polyester, or fiberglass, and warp knitting technology enables reinforcement and sensor incorporation. (Zangani, D., et al. 2015)

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Clemente Fuggini et al (2016) further discussed the The benefits of using the proposed innovative Sensors Integrated Geotextiles within the railway substructure as follows:

- Indicate impending failure and provide a warning
- Reveal unknowns
- Evaluate critical design assumptions
- Assess contractor's means and methods
- Minimize damage to adjacent structures
- Provide data to help select remedial methods to fix problems
- Document performance for assessing damages
- Inform stakeholders
- Satisfy regulators
- Advance state-of-knowledge

- *Field Testing*

Clemente Fuggini et al (2016), studied the test performance of sensor integrated geotextile as initiall development within the EU-funded research project Polytect (Zangani 2008), Field tests were conducted at a railroad curve near Chemnitz, Germany, which experiences high traffic volume. The embankment section, over 100 years old, was reconstructed in 2007-2008. The field tests aimed to expose the multifunctional geotextiles to dynamic loads induced by real railway traffic, develop installation methods, and assess long-term performance under varying weather conditions.

Fig 28: View of the Sensors and Acquisition Unit at the Test Side.
(Clemente Fuggini et al (2016)

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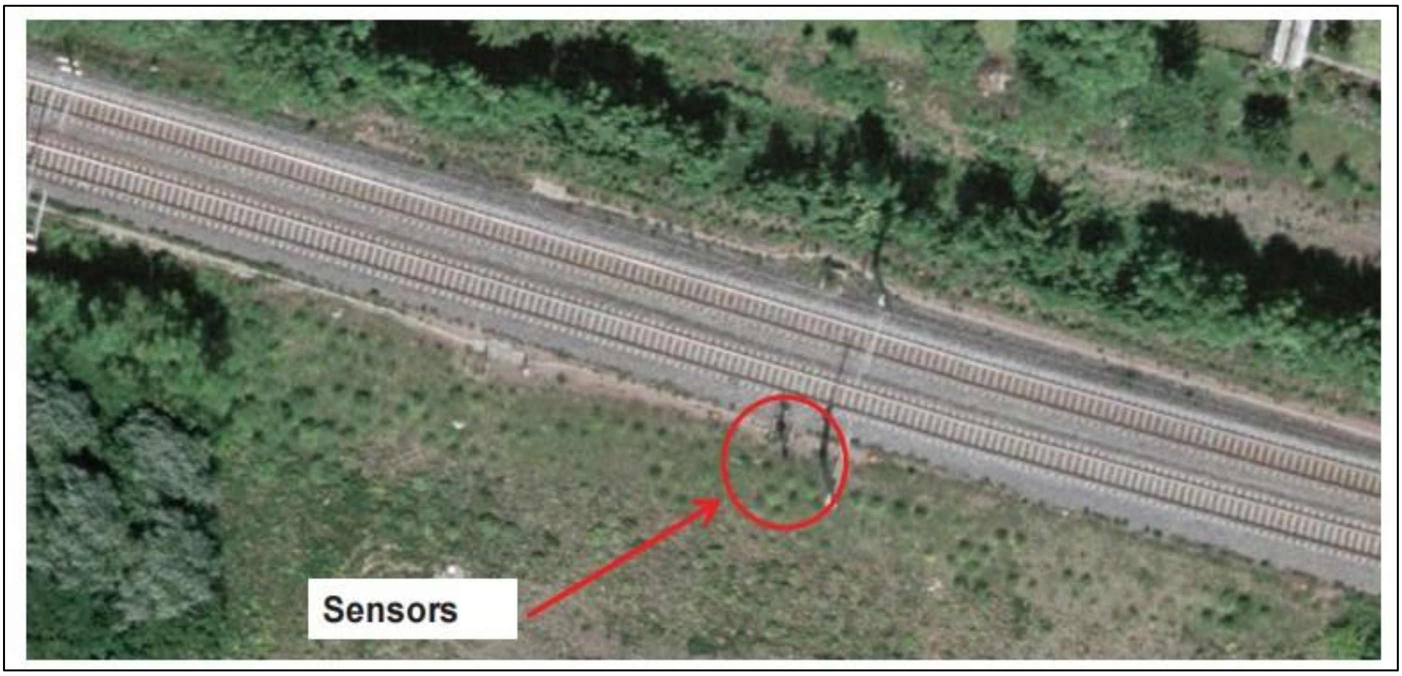

Fig 29: View of the Test Site Near Chemnitz with Sensors Location (Google Maps) (Clemente Fuggini et al 2016)

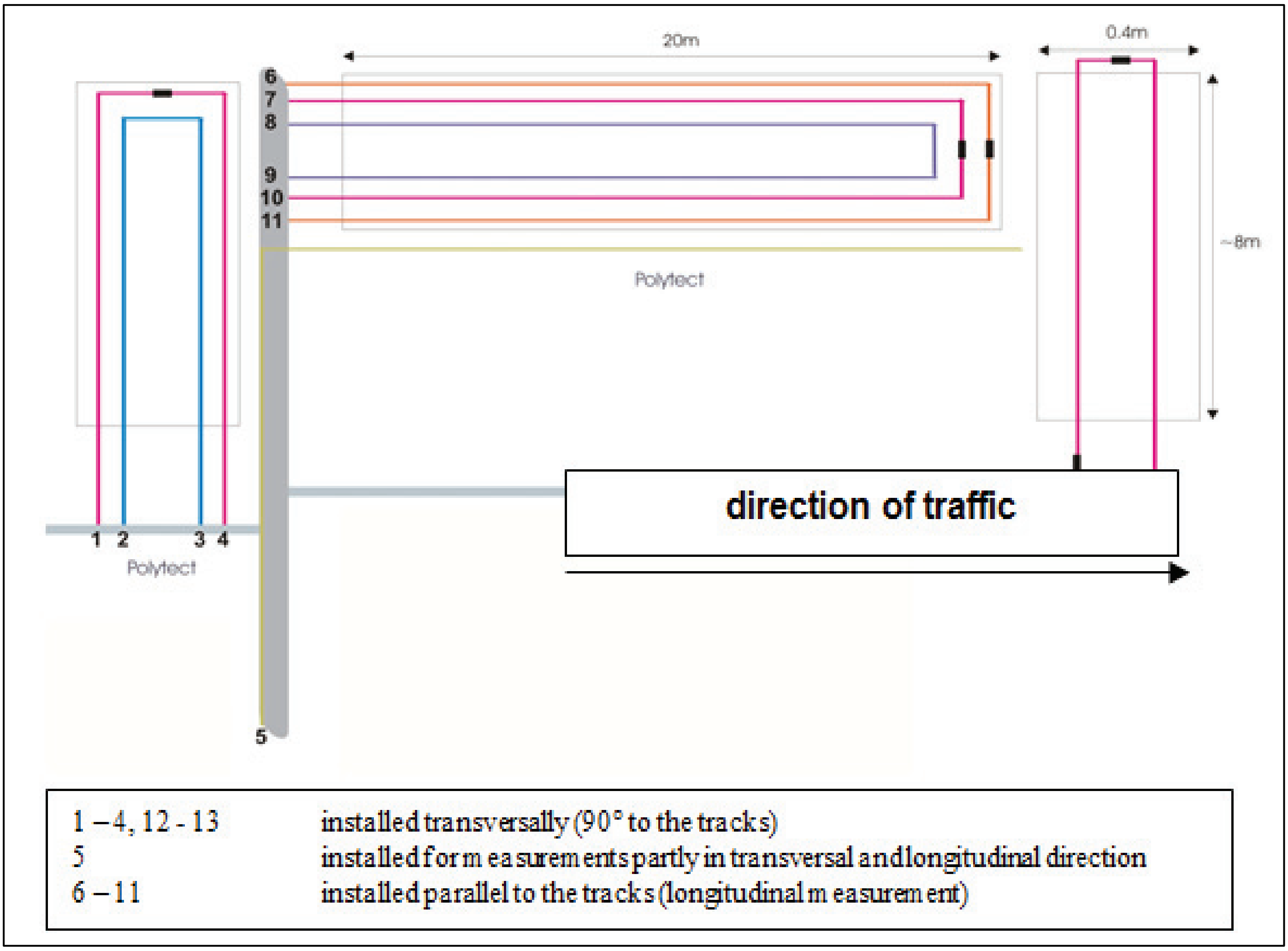

Fig 30: Position of the Sensors in the Test Side (Clemente Fuggini et al 2016)

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(Fumio Tatsuokao et al 1996) explores the damage and performance of the different types of retaining walls in railway embankments. The masonry retaining walls, being the oldest type, were found to be the most vulnerable, with many of them suffering significant damage or complete collapse. Leaning-type unreinforced concrete retaining walls also exhibited large tilting and damage, particularly near bridge abutments. Gravity-type unreinforced concrete Retaining walls experienced serious damage, including overturning and tilting. Cantilever-type or inverted T-shaped reinforced concrete retaining walls demonstrated better performance but still suffered damage, while geogrid reinforced soil retaining walls showed minimal to no damage. The review emphasizes the importance of seismic design and highlights the need for alternative reinforced wall solutions such as geogrid reinforced soil retaining walls for improved stability and resilience in seismic-prone areas.

- (Mahesh Sharma,et al 2019), studied soil nailing, in this article, it was the component of soil nailing includes the following; *Soil Nails, Centralizers and coupler, Grout , Corrosion Protection, Nail Head, Facing, Connectors, Drainage Systems.*

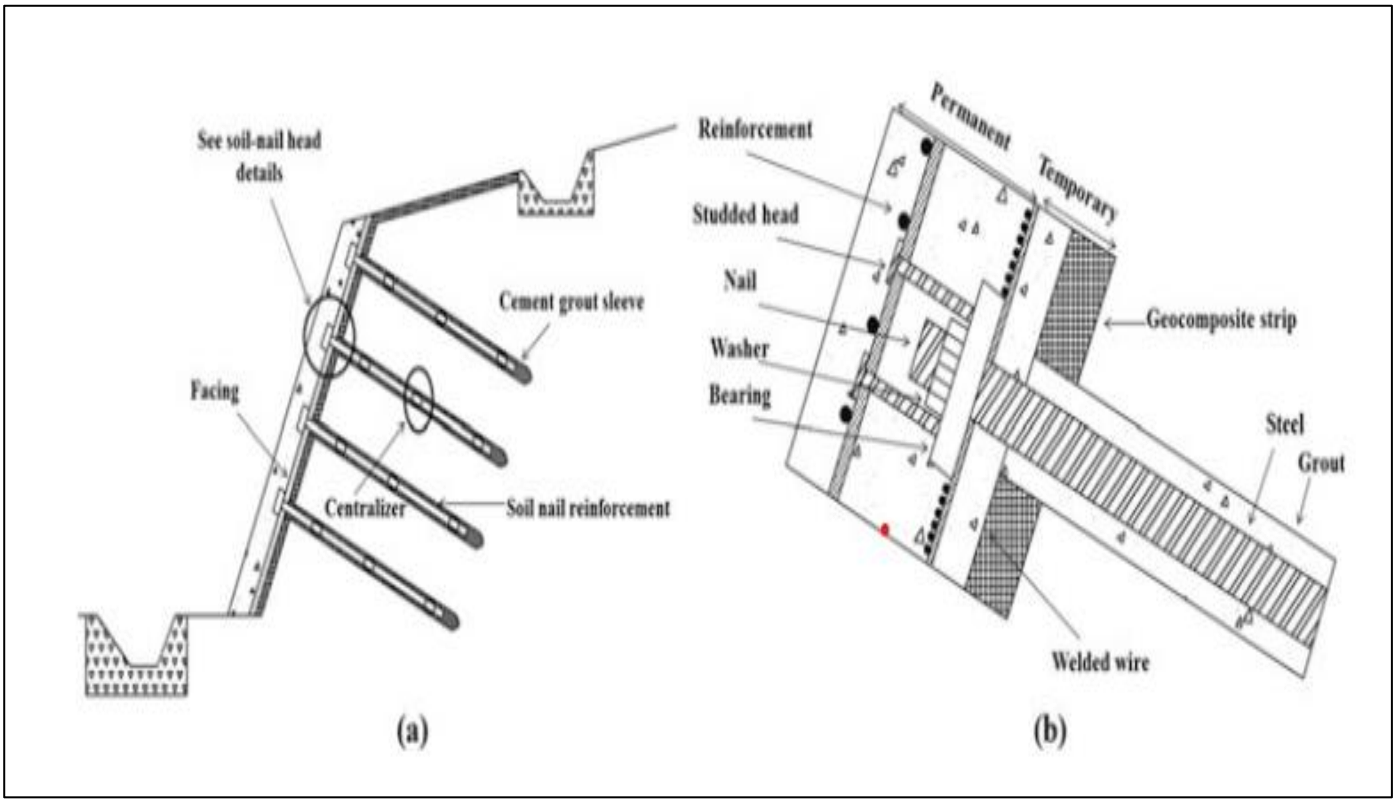

Fig 31: Schematic View of the Soil Nailed Slope (a) Cross Sectional View and (b) Details of Soil Nail Head (Mahesh Sharma,et al 2019)

(Mahesh Sharma,et al 2019), further discussed the advantages and limitation of soil nailing considering the following points.

- ✓ Soil nailed wall installation is quick and environmentally friendly.
- ✓ The design parameters can be easily adjusted to site conditions, making it adaptable to various constraints.
- ✓ It is cost-effective, especially in challenging access areas, and can accommodate bends and curves during construction.
- ✓ Soil nailed walls are flexible, allowing for large settlements and better performance under seismic conditions with ductile failure, providing early warnings. Additionally,
- ✓ they are more cost-effective than conventional concrete gravity walls and ground anchors, saving 10–30% compared to tieback walls..

(Mahesh Sharma,et al 2019), also gave the different possible failure mechanism of the soil nailed structure as shown in the figure below courtesy of FHWA.

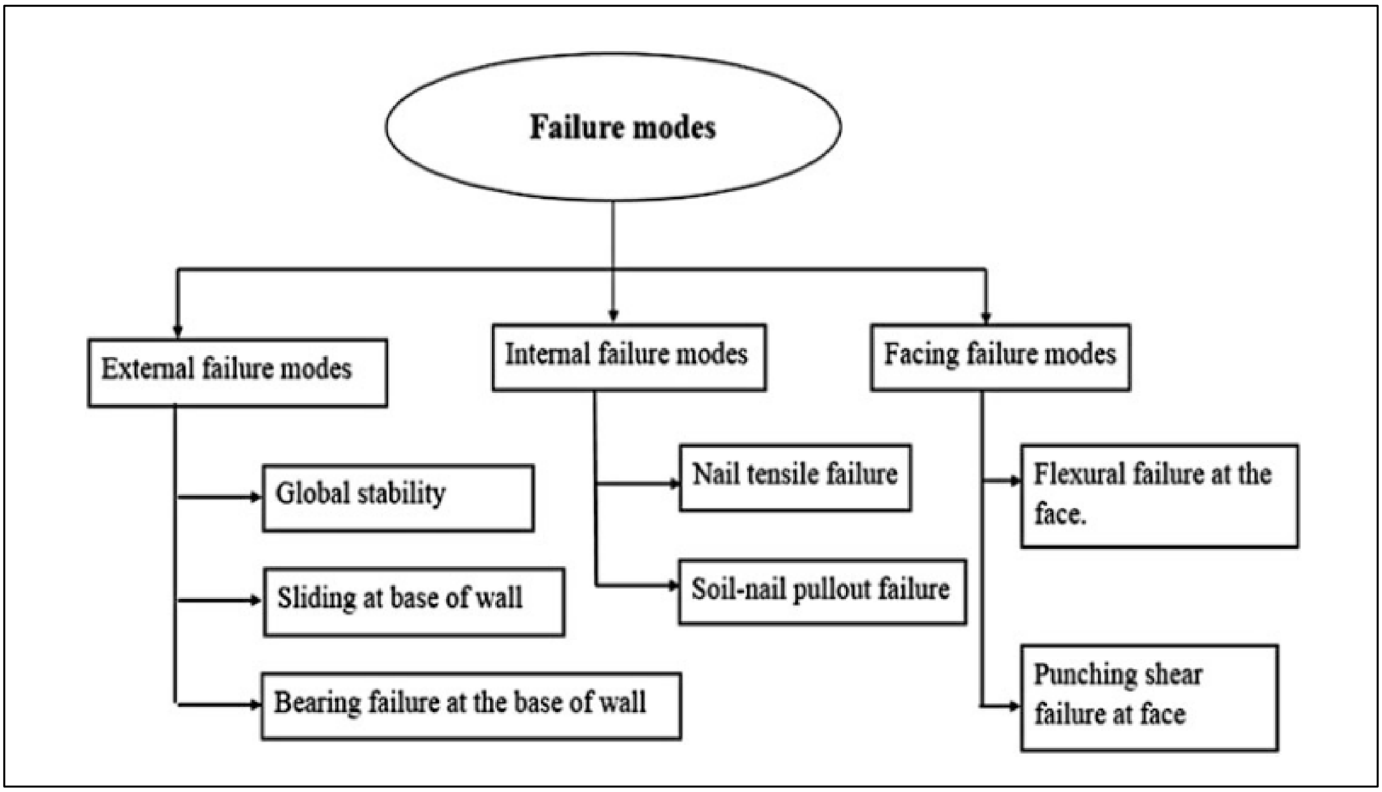

Fig 32: Failure Modes of Soil Nailing System
(Mahesh Sharma,et al 2019)

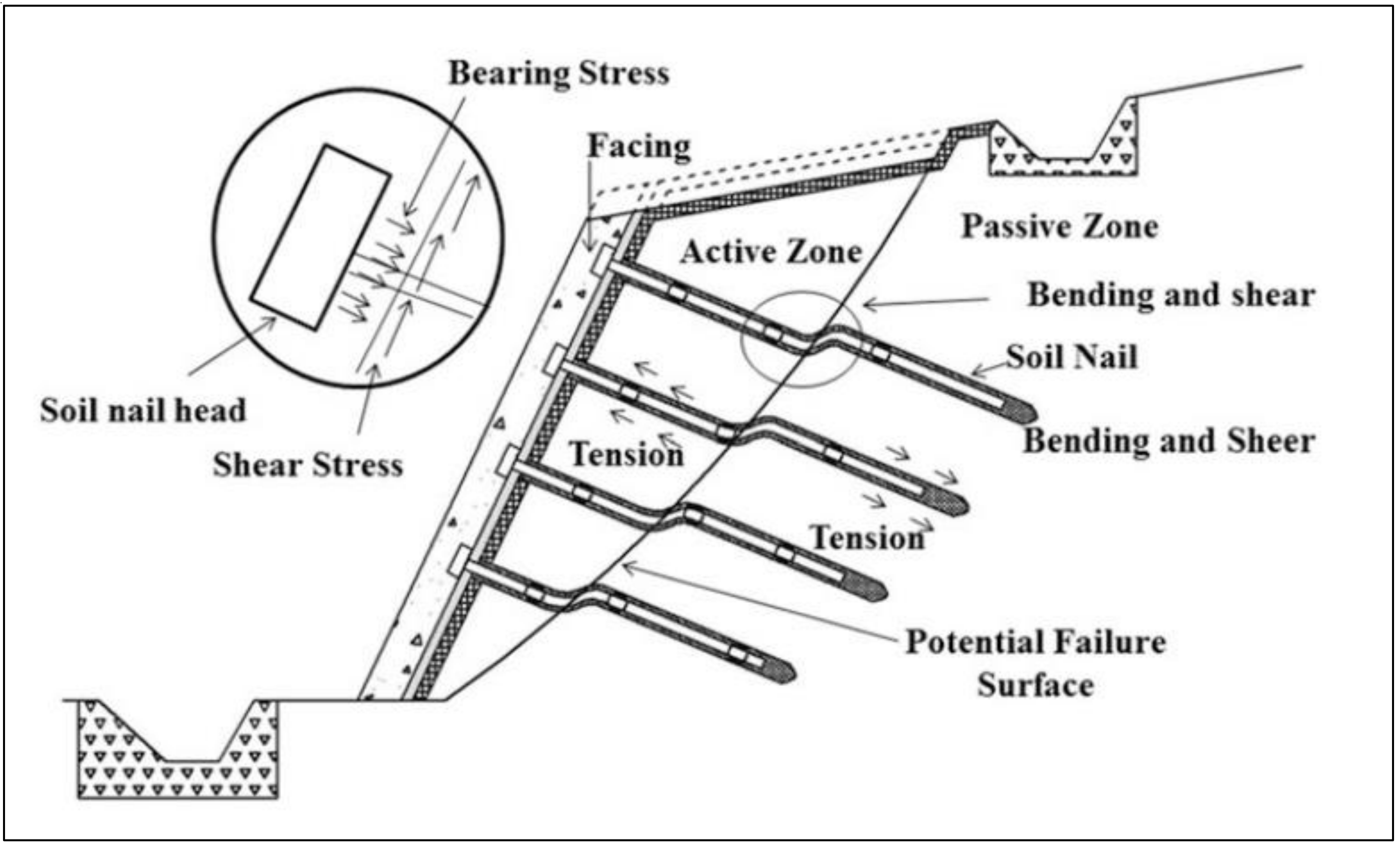

Fig 33: Failure Mechanism of Soil Nail System (Mahesh Sharma,et al 2019)

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CHAPTER THREE
RESEARCH METHODOLOGY

A. Research Design

The chosen approach is a case study methodology, which aligns with the research objectives of enhancing the employment of earth retaining systems in railway infrastructure. Data for this dissertation will be collected from the Balcombe Embankment case study located in West Sussex, south West of UK. The study site experienced deep-seated rotational slope movement, and the research aims to identify appropriate mitigation measures for high-risk earthworks.

A mitigation solution involved a piled retaining wall and a 3.2 m high gravity wall to arrest embankment movement and prevent failure. Geotechnical parameters, including c' and φ' values, were determined for the design. The proposed solution aimed to enhance stability and mitigate risks caused by rainfall events.

Overall, the case study research design, will facilitate and provide alternative and enhanced mitigation measure as possible solution. The use of reinforced soil walls as an alternative mitigation measure has been proposed for the course of this research in place of the already proposed piled retaining wall and gravity wall as pre-emptive mitigation measures. The methodology aims to provide valuable insights for railway infrastructure projects facing similar challenges and potential threats from slope movements.

B. Case Study Selection and Justification

The specific railway infrastructure project, Balcombe Embankment, was chosen as the case study based on several criteria. Firstly, its location in West Sussex, on the Victoria to Brighton line, provided accessibility and proximity to the researcher. Additionally, the embankment's history of deep-seated rotational slope movement and previous re-mediation through grouting offered valuable insights into the performance of earth retaining systems.

By focusing on the Balcombe Embankment, this research aims to contribute meaningful insights into the design, monitoring, and implementation of earth retaining systems, ensuring the efficient and effective employment of such systems for the benefit of railway infrastructure.

- *Rational for Choosing Case Study*

Choosing this case study over other alternatives was driven by its relevance to the research objectives. Balcombe Embankment exhibited ongoing movements leading to track quality deterioration, making it a high-risk site. This characteristic allowed for an in-depth analysis of pre-emptive mitigation measures, offering practical implications for railway infrastructure projects facing similar challenges.

C. Data Collection

Data for this research was collected primarily from the Balcombe Embankment case study using multiple approaches, ensuring a comprehensive understanding of the earth retaining systems' performance in railway infrastructure.

- *In-clinometer Monitoring:*

Inclinometers installed at strategic locations within the embankment continuously measured ground movement and slope behaviour. Regular readings will provide valuable data on the embankment's stability, identifying any potential rotational or translational movements.

- *Ground Investigation:*

Comprehensive ground investigations was conducted at the site to assess the geological and geotechnical properties. This include soil and rock sampling, laboratory testing, and geological mapping, enabling a detailed characterization of the embankment's foundation and surrounding ground conditions.

- *Geotechnical Analysis:*

The data collected from ground investigations was analysed to determine the embankment's soil properties, including shear strength, stiffness, and settlement characteristics. Geotechnical analysis helped to identify potential failure mechanisms and the impact of various factors on the embankment's stability.

- *Site Observations:*

Visual observations of the Balcombe Embankment was carried out to assess its condition, identify signs of distress, and understand the effects of environmental factors, such as rainfall and temperature, on its behavior.

D. Data Analysis

For the data analysis in this research, a combination of software and hand calculations was employed to provide a thorough evaluation of the earth retaining systems' performance at Balcombe Embankment.

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➢ *Software Analysis:*

Geotechnical software GEO-5 2023, was utilized to perform the numerical modelling and simulate the embankment's behaviour under various conditions. Finite Element Method (FEM) was employed to analyse stability, deformation, and failure mechanisms of the earth retaining systems. The software also aid in interpreting ground investigation results.

➢ *Hand Calculations:*

Hand calculations was conducted to verify the results obtained from the software analysis and to cross-check critical parameters. Hand calculations may include slope stability analyses and bearing capacity calculations, Manual calculations was also used to verify factors of safety and stability of the proposed pre-emptive mitigation measures.

E. Ethical Consideration

- ***Informed Consent***: Obtaining permission from all relevant stakeholders involved in the case study to use their data and insights for research purposes.
- ***Confidentiality:*** Safeguarding the privacy and identity of participants by anonymity and securely storing all collected data.
- ***Data Integrity:*** Ensuring the accuracy and reliability of data collection methods and analysis to uphold the integrity of the research.
- ***Conflict of Interest:*** Being transparent about any potential conflicts of interest that may arise during the research process to maintain objectivity and credibility.

F. Limitations And Delimitation

➢ *Limitations*

- ***Sample Size:*** The case study findings may not be broadly applicable to other railway projects due to the specific conditions of the Balcombe Embankment site.
- ***Soft ware Limitation;*** Software Limitations: The use of specific software tools for data analysis may have limitations, affecting the depth and accuracy of certain analyses.
- ***Data Availability:*** The availability of historical data for the Balcombe Embankment could impact the analysis comprehensiveness.
- ***External Factors:*** Unforeseen circumstances or weather events could influence data collection and analysis.

➢ *Delimitations:*

- ***Focus on Earth Retaining Systems:*** The research concentrates solely on the impact of earth retaining systems on Balcombe Embankment stability, excluding other factors like track design and traffic loads.
- ***Geographic Scope:*** The study is limited to the Balcombe Embankment case in West Sussex and may not apply universally to other embankments.
- ***Pre-emptive Mitigation Measures:*** The research emphasizes identifying high-risk earthwork mitigation measures without evaluating their long-term implementation.
- ***Data Collection Methods:*** The study primarily relies on inclinometer monitoring, ground investigation, and geotechnical analysis, omitting other data collection approaches like geophysical surveys.

CHAPTER FOUR
CASE STUDY ANALYSIS AND RESULT

A. Introduction to the Balcombe Embankment Case Study

The Balcombe Embankment, located in West Sussex along the Victoria to Brighton railway line, serves as a significant case study for investigating the application of earth retaining systems in railway infrastructure. This section provides an introduction to the Balcombe Embankment, outlining its location, historical significance, and the challenges it has encountered over time.

The embankment is situated approximately 500 meters south of Balcombe Station and was constructed over an area known as 'sidelong ground.' Rising to a maximum height of 15 meters and gradually reducing to 8.5 meters, the embankment exhibits slope angles ranging from 34 to 37 degrees. Notably, in 1975, a noteworthy rotational slope movement was observed on the Upside slope, prompting re mediation through grouting.

Since then, the embankment has undergone monitoring due to observed movements affecting track quality. Recent inclinometer data from 2020 indicated significant movements during specific periods, notably January-February and June-July 2021, which were correlated with heavy rainfall. Persistent down slope movements, averaging between 0.5 to 1.5 millimetres per month, have been documented, hinting at potential acceleration and risk of failure under certain conditions.

B. Description of the Railway Infrastructure Project

The Balcombe Embankment spans a small valley, extending over Head deposits and resting atop Wadhurst Clay. The fill material consists of sandy silty clay, with varying layers of track ballast over time. Ground investigations highlighted variable embankment fill overlying the Wadhurst Clay, with indications of possible soft material at the interface between the embankment fill and the foundation formation.

Mechanisms detected through inclinometer readings suggest the presence of softened material at this interface, potentially contributing to slope movements. Additionally, data interpretation from inclinometer readings indicated a rotational movement reoccurance of the 1970s incident, which was treated through grouting. Furthermore, a transitional slip mechanism was identified at the foundation level based on inclinometer data.

Considering the challenges posed by embankment instability and the potential for rapid failure, a mitigation solution was proposed. This solution involved a comprehensive design considering geotechnical parameters, effective strengths, pore water pressures, and embankment fill characteristics. A piled retaining wall strategy was devised, supported by concrete blocks and drainage measures, aiming to arrest movement and secure the embankment's stability.

The proposed design involved cast in-situ reinforced concrete piles and a gravity wall, along with strategic modifications to the embankment's slope geometry but the use of reinforced soil wall (RSW) has been suggested for the sake of this research as an appropriate and more effective and viable measure. The integration of these measures represents a comprehensive approach to reduce the challenges posed by the Balcombe Embankment's movement and potential failure.

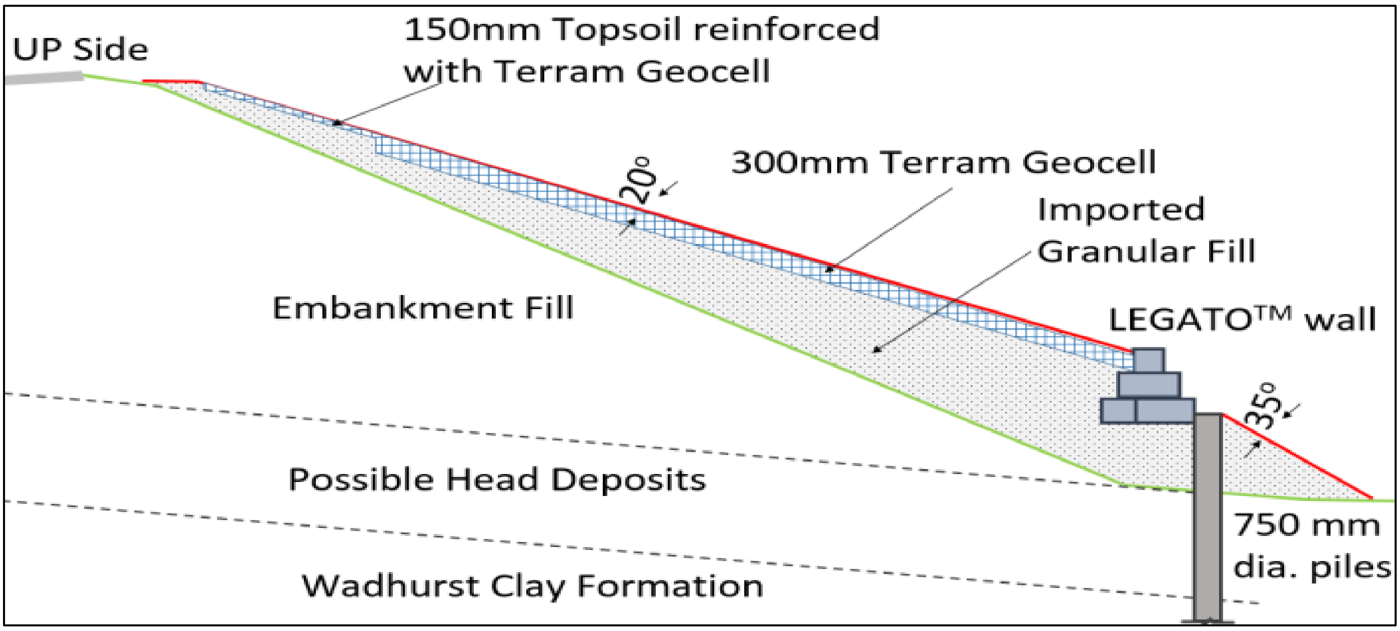

Fig 34: Proposed Case Study Design of the Balcombe Embankment (B. Burcin Avar et all 2023)

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C. Implementation of Reinforced Soil Wall System

The Balcombe Embankment case study has prompted the consideration of an innovative approach to earth retaining systems, specifically the adoption of a reinforced soil wall system. This section delves into the details of the implementation of the reinforced soil wall system at the Balcombe Embankment, highlighting its design, construction, and anticipated benefits.

➢ *Design Considerations for the Reinforced Soil Wall*

In response to the embankment's ongoing movements and potential failure risks, the decision was made to implement a reinforced soil wall system as a viable earth retaining solution. This approach offers advantages in terms of flexibility, adaptability, and structural integrity. The design process involved a meticulous assessment of geotechnical parameters, embankment characteristics, and load distribution to ensure the effectiveness of the proposed system.

Key design considerations included the determination of optimal reinforcement materials, such as geogrids or geotextiles, and the selection of appropriate backfill materials to create a stable and cohesive structure. Factors like surcharge loads, drainage provisions, and the integration of the reinforced soil wall with the existing embankment geometry were also integral to the design process.

➢ *General Construction Procedure (Bailleul Guillaume and Laga Matthias 2017)*

- Site preparation, including excavating and replacing unsuitable material with compacted fill, along with setting up drainage systems.
- Creating a smooth, unreinforced concrete levelling pad at each foundation level. Using a chalk line on the pad as a reference for the structure's face.
- Placing and bracing the initial course of facing panels, alternating between half- and full-height panels. Using two sturdy lumber braces for full panels and those over 1m, and a single brace for panels under 1m in height. Figure 33.

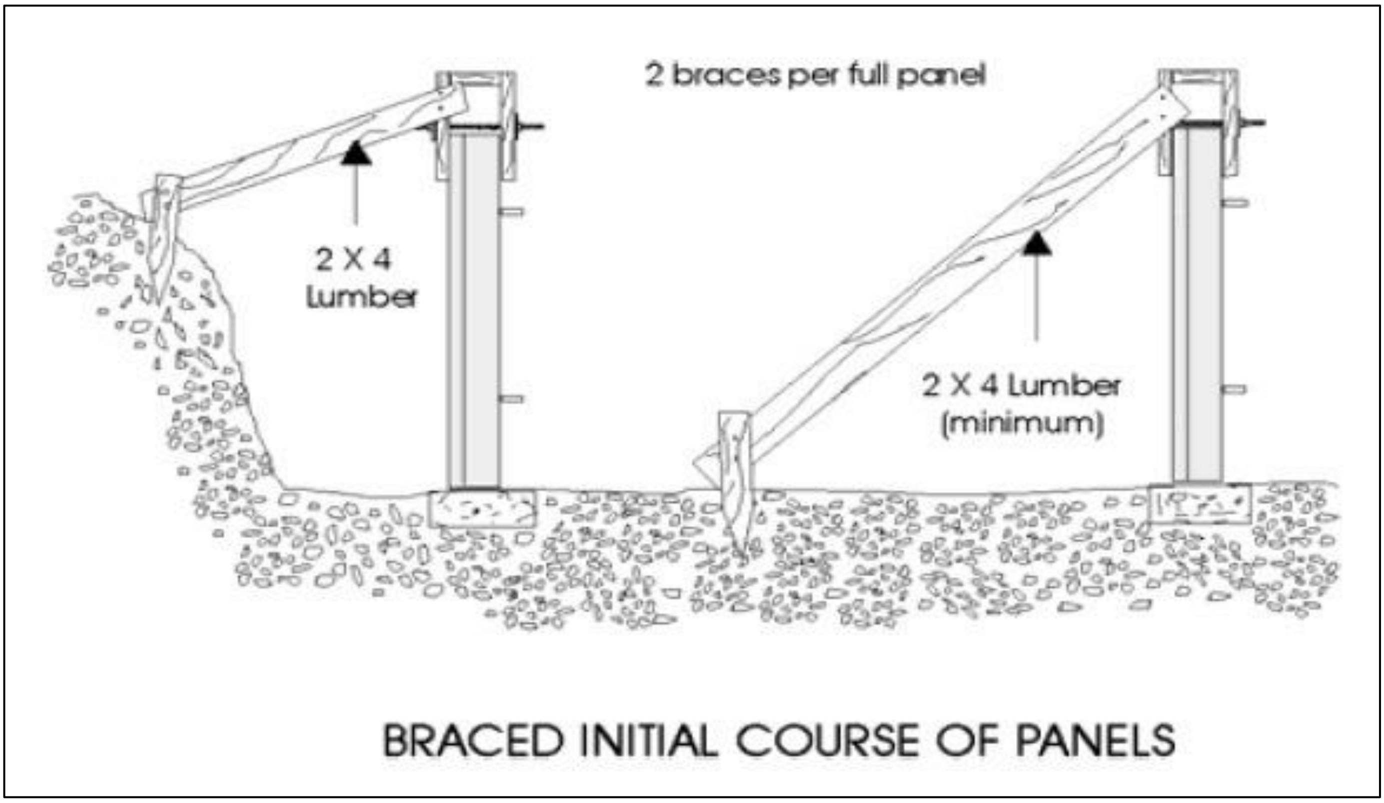

Fig 35: Placing of the Lumbers (Bailleul Guillaume and Laga Matthias 2017)

A wooden spacer of 20mm is used between panels at the base of the wall's front face, to be removed after backfilling. After placing ten panels, the wall's alignment is checked.

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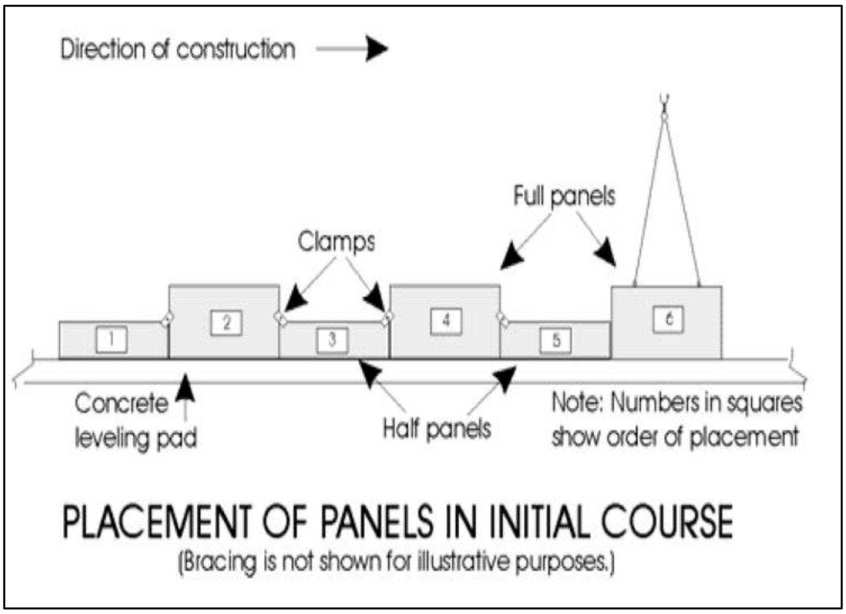

Fig 36: Positioning the Panels in the Starting Row onto the Concrete Levelling Pad.(Bailleul Guillaume and Laga Matthias 2017)

- Joint materials are used to prevent the loss of fine backfill particles while maintaining drainage. Bearing pads prevent direct contact between concrete surfaces, and filler cloth joint materials are placed from the structure's backside.
- Backfilling and compaction are conducted in lifts up to the lowest panel tie strip level.

✓ Initial backfill lifts are not placed or compacted against the panels to prevent displacing braced panels.
✓ Backfilling and compaction are carried out only after connecting the first layer of reinforcing strips to the panel. Compaction near panels is done with a hand-operated vibratory compactor, while further areas are compacted with a drum vibratory roller (except for uniform sands, which use a smooth-drum static roller).

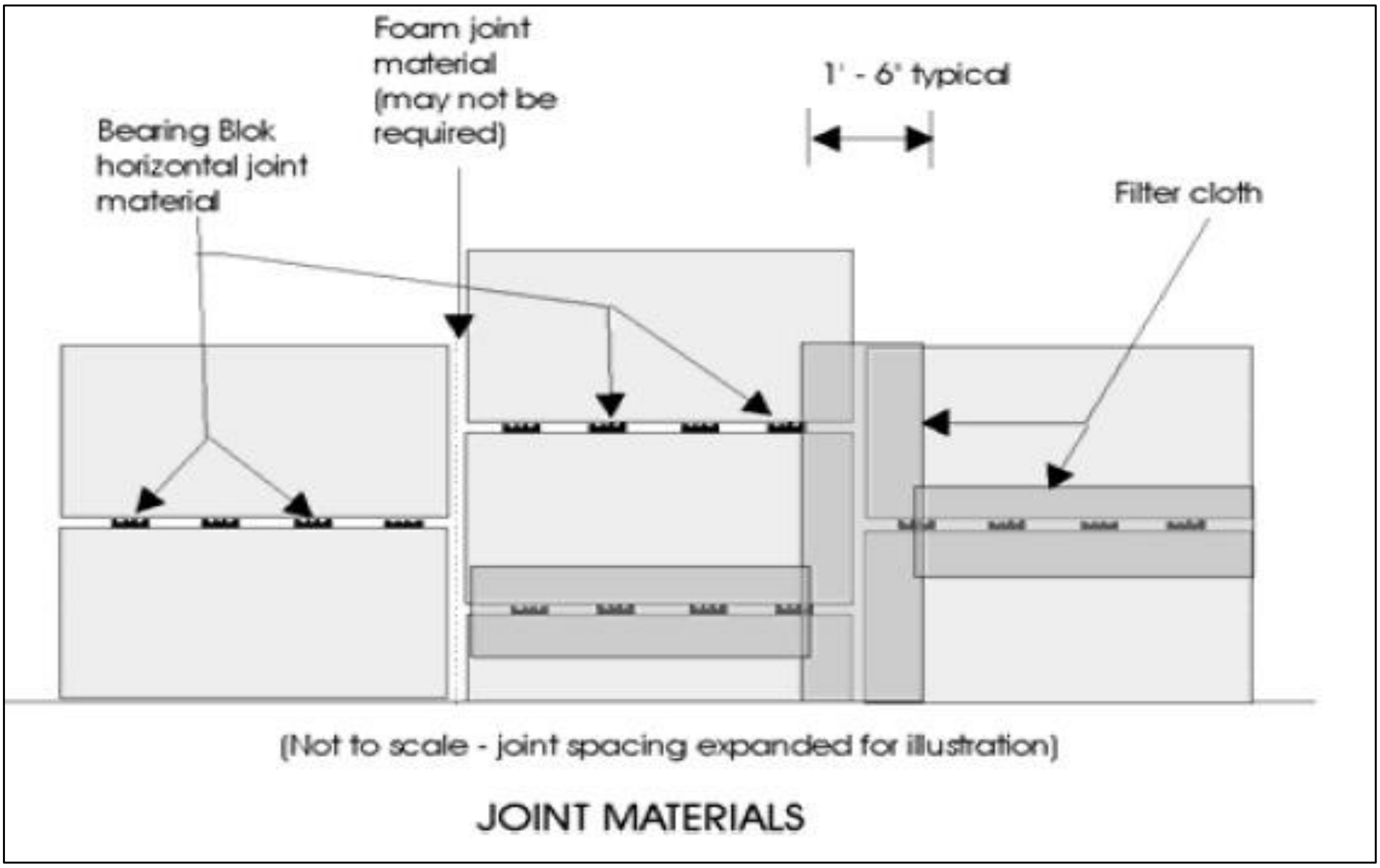

Fig 37: Use of Bearing to Avoid Concrete to Concrete Contact (Bailleul Guillaume and Laga Matthias 2017)

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- Reinforcing Strips;

❖ Reinforcing strips are placed perpendicular to the panels on compacted backfill, connected to embedded panel tie strips.

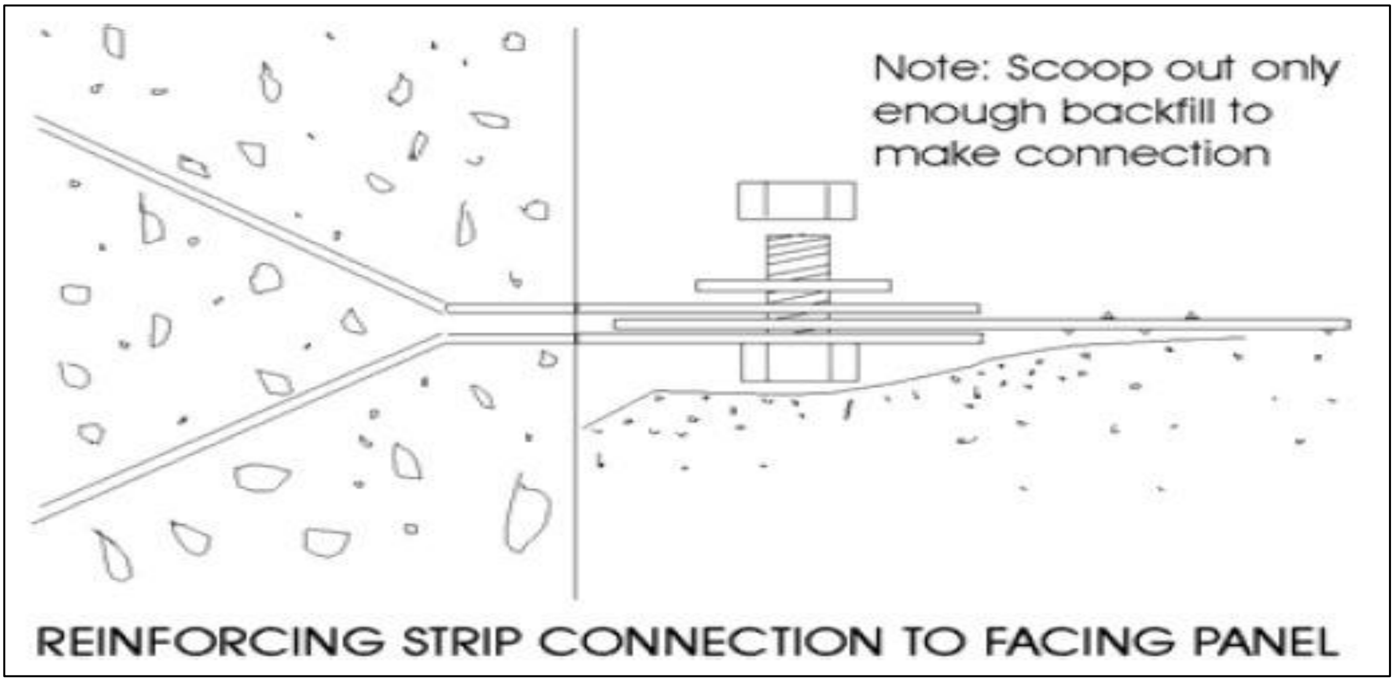

Fig 38: Connection of Reinforcing Strips to the Facing Panels (Bailleul Guillaume and Laga Matthias 2017)

❖ Spread and compact the backfill material in layers until it reaches the upper part of the half panels. Keep the backfill mound's edge about 1m away from the panels. Spread the backfill by pushing it alongside the panels and creating windrows.

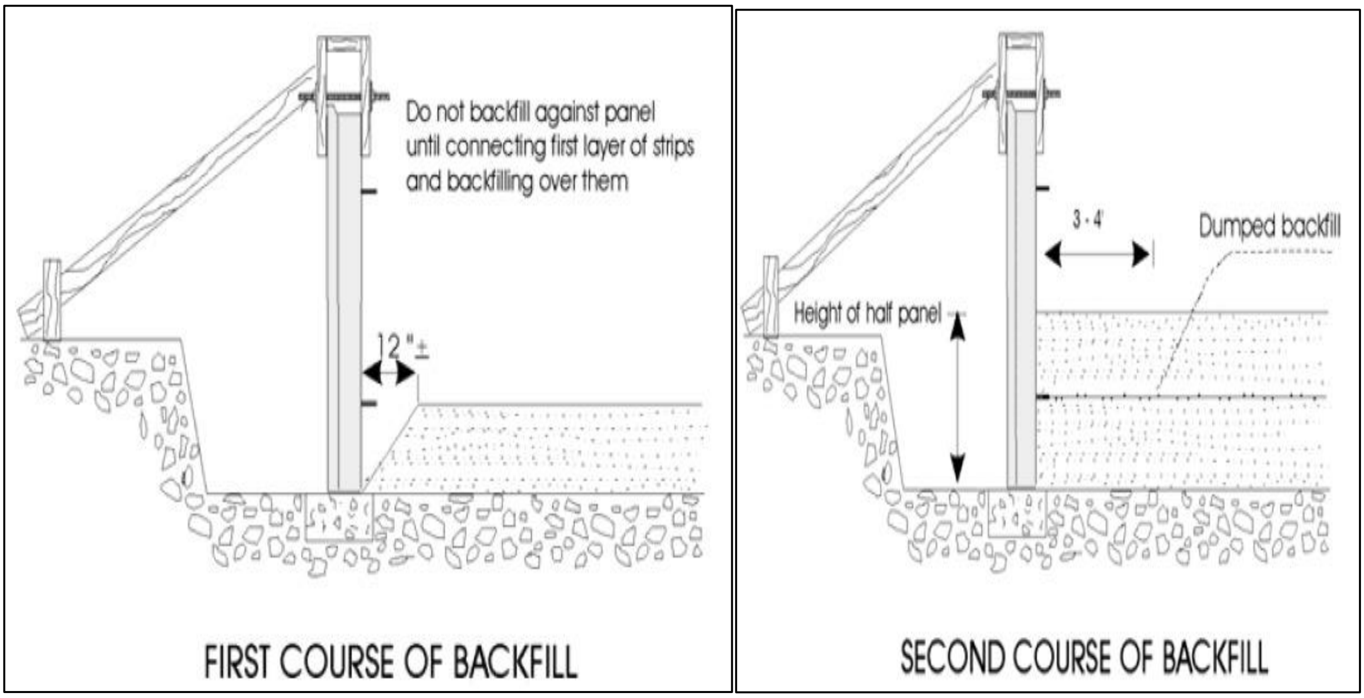

Fig 39: Placement of Backfill in Lifts to the Top of the Half Panels (Bailleul Guillaume and Laga Matthias 2017)

- Install the second course of full panels only after completing backfilling and compaction. It's crucial to avoid removing clamps from panels that haven't been fully backfilled, as this could cause instability and misalignment.

❖ Remove the clamp holding the full panel to the half panel.
❖ Place the full panel on the half panel, ensuring the correct batter, and clamp it to the initial course.

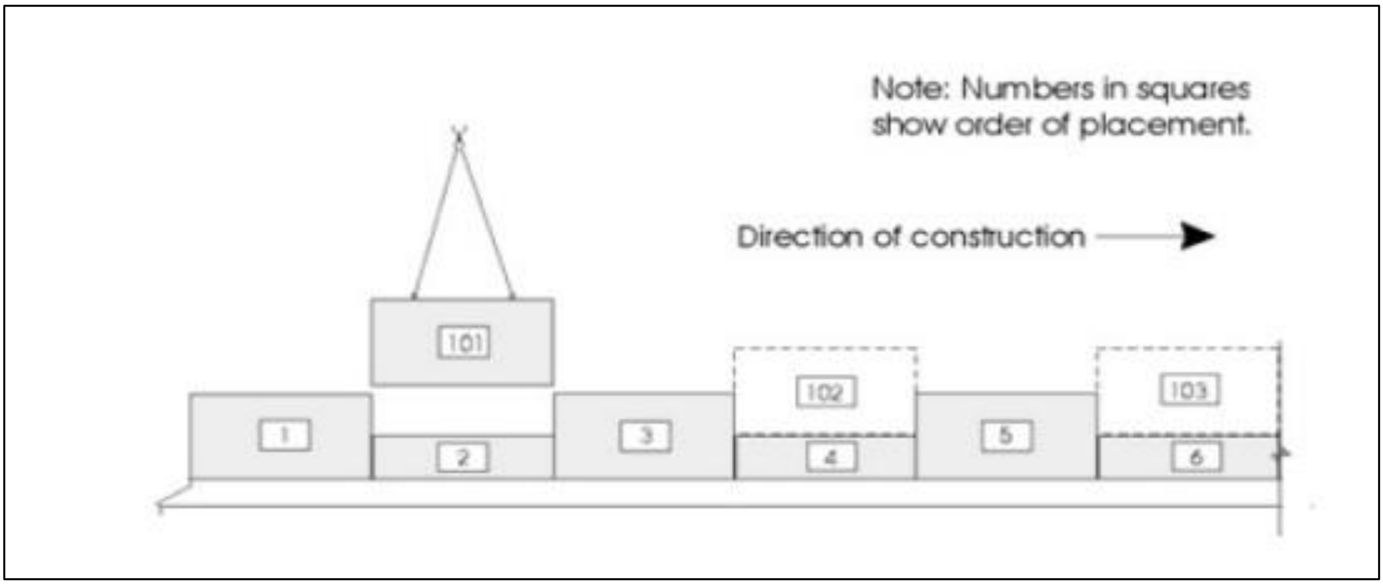

Fig 40: Placement Pattern of Facing Panels for Second Course (Bailleul Guillaume and Laga Matthias 2017)

- ❖ Once the panel course is completed and vertical joint material is in place, backfill up to the level of the tie strip.

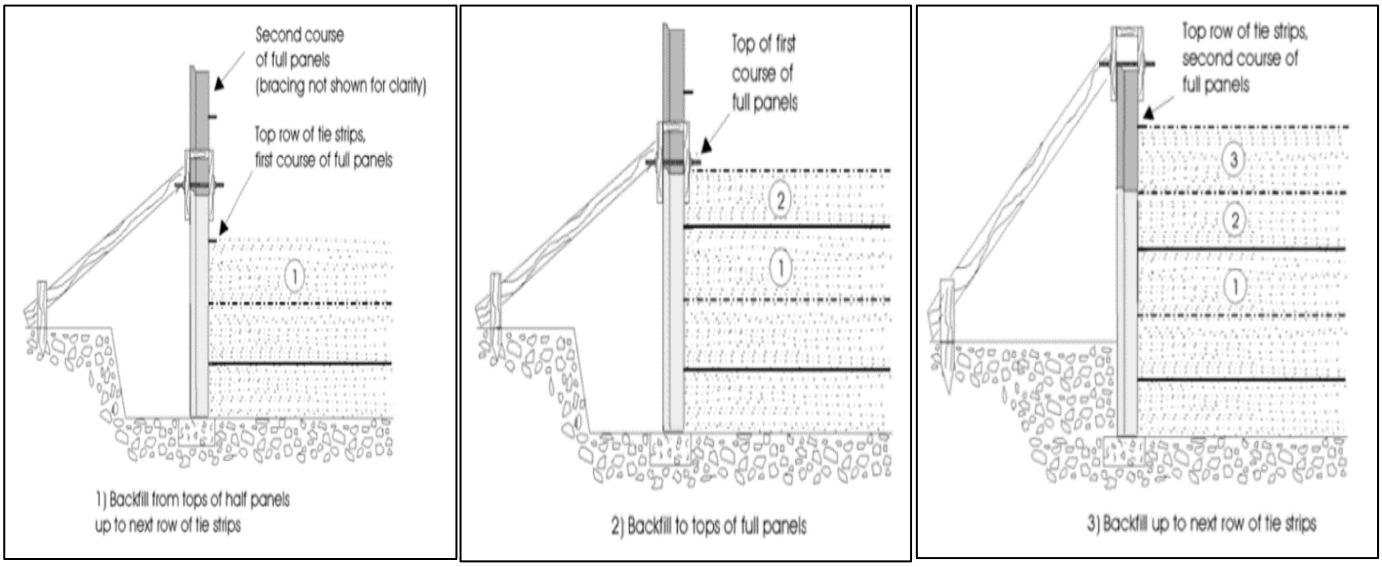

Fig 41: Adding Backfill in Layers Until It Reaches the Level of the Tie Strip

- ❖ Check alignment, then attach the next set of reinforcing strips.
- ❖ After backfilling to the top of the full height panels in the initial course, remove the bracing from the initial course.
- ❖ Adjust the batter of the second course to ensure the second row becomes vertical.
- ❖ Immediately place and compact part or all of the berm or embedment at the lower front surface of the structure to prevent erosion. This should be done before the wall reaches 50% of its height.

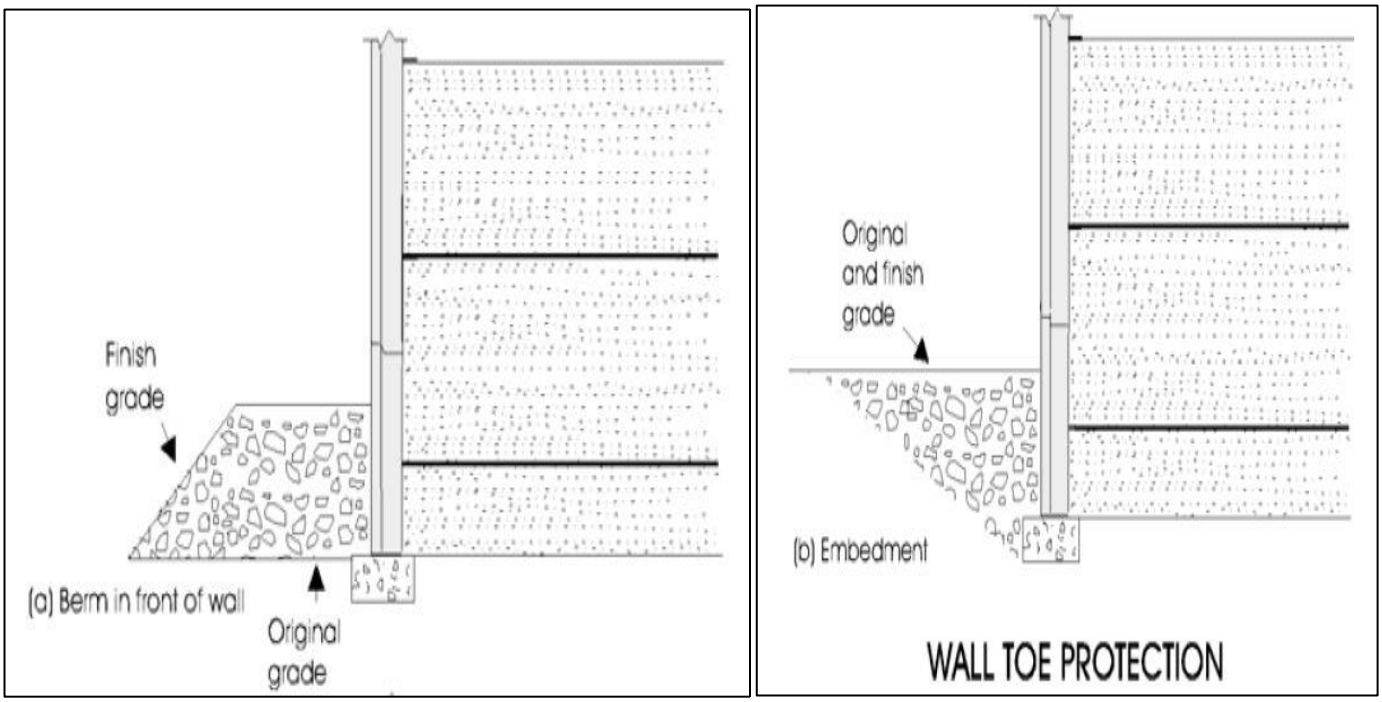

Fig 42: Placement and Compaction of an Embedment at the Lower Front Surface
(Bailleul Guillaume and Laga Matthias 2017)

- Repeat the process of adding backfill in layers, compacting, connecting strips, and placing panels until the desired design height is achieved.
- After finishing each course, take out the wooden wedges from the panels three levels below.
- Place the uppermost panels, connect the strips, finish adding backfill, and compact it.
- Take out all the wedges and clamps.
- Finalize the wall construction by installing the top wall treatment:

- ❖ If needed, pour-in-place items like concrete coping or traffic barriers.
- ❖ Alternatively, use precast coping.

D. Geological Description and Geotechnical Properties of the Soil

At the initial phase of a geotechnical project, a soil survey is conducted, and the soil characteristics are documented in a soil survey report. As depicted in Figure 42, the construction site is composed of four distinct soil layers denoted as 0, I, II, and III, consisting of soft clay, high plastic clay, wadhurst clay, and robust wadhurst cay mud-stone, respectively. Specific soil properties such as friction, angle (ϕ), soil weight density (γ), and cohesion (Cu) are outlined in Table 1 for each layer.

The dotted line in Figure 42 marks the designated location for the wall's construction. It's important to note that groundwater considerations will not be factored into the calculations. To erect the wall, excavation of the soil will be essential, as shown in Figure 43. The brown area indicate the removed soil. The blue area will be backfilled and eventually transformed into reinforced soil. It's noteworthy that the uppermost weak layer (0) will be entirely excavated and subsequently refilled with unreinforced backfill material, as shown in Figure 44.

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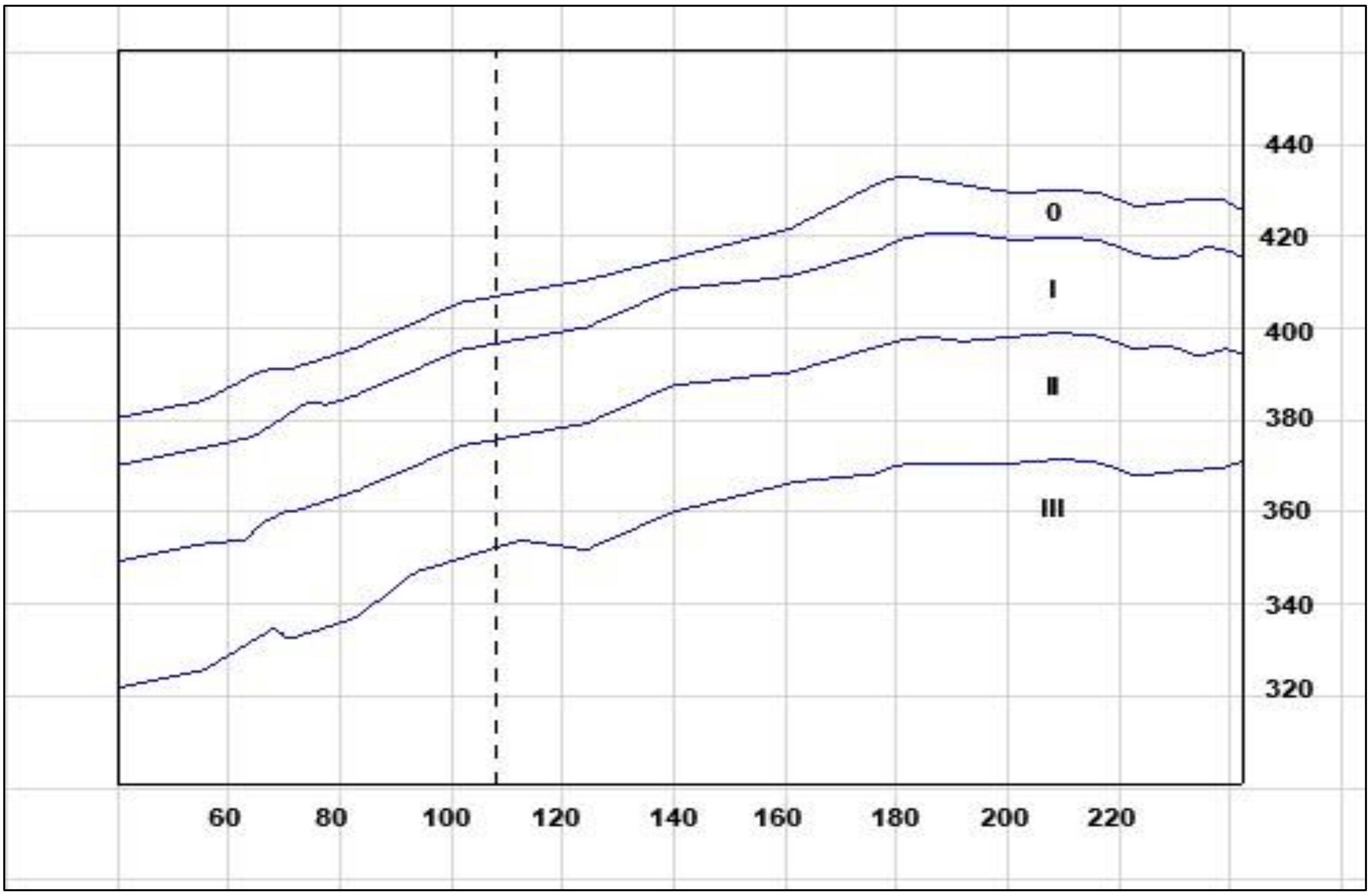

Fig 43: Soil Layers before Excavation (Archi-cad 2019)

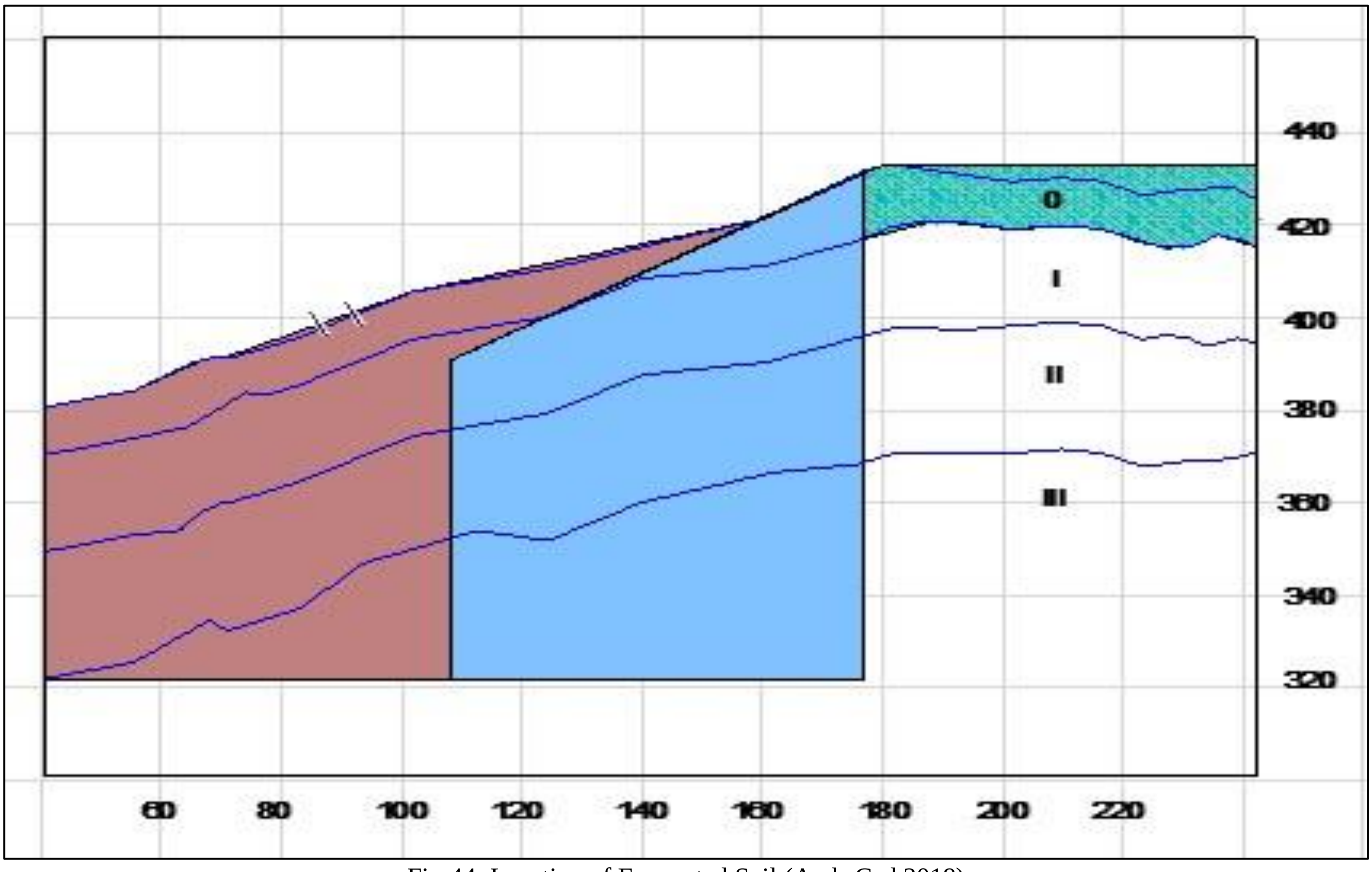

Fig 44: Location of Excavated Soil (Arch-Cad 2019)

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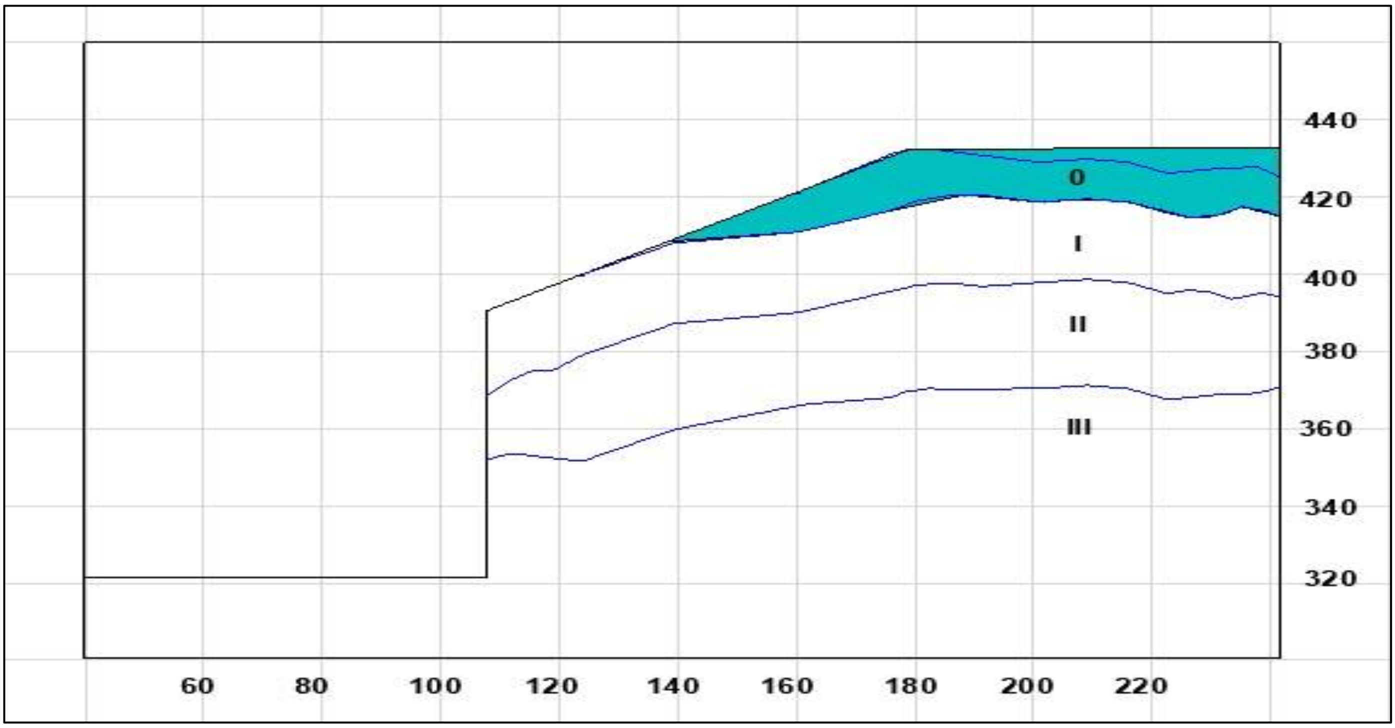

Fig 45: Destination of Soil Backfill (Arch-Cad 2019)

Table 1; Soil Parameters for Each Layer

No.	Soil	φ (°)	ɣ (KN/m^3)	C_u (Kpa)	E Modulus (Mpa)
0	Soft Clay	17	15	25	25
I	Plastic Clay	19	18	35	35
II	Wadhurst Clay	22	20	65	45
III	High Wadhurst Clay	35	25	120	60

E. Design Simplification and Limitations

In practical scenarios, due to variations in soil layer thickness, achieving a completely accurate model isn't feasible. To facilitate approximated calculations, the design of the reinforced wall, as illustrated in Figure 45, will be subject to simplification, as shown in Figure 46.

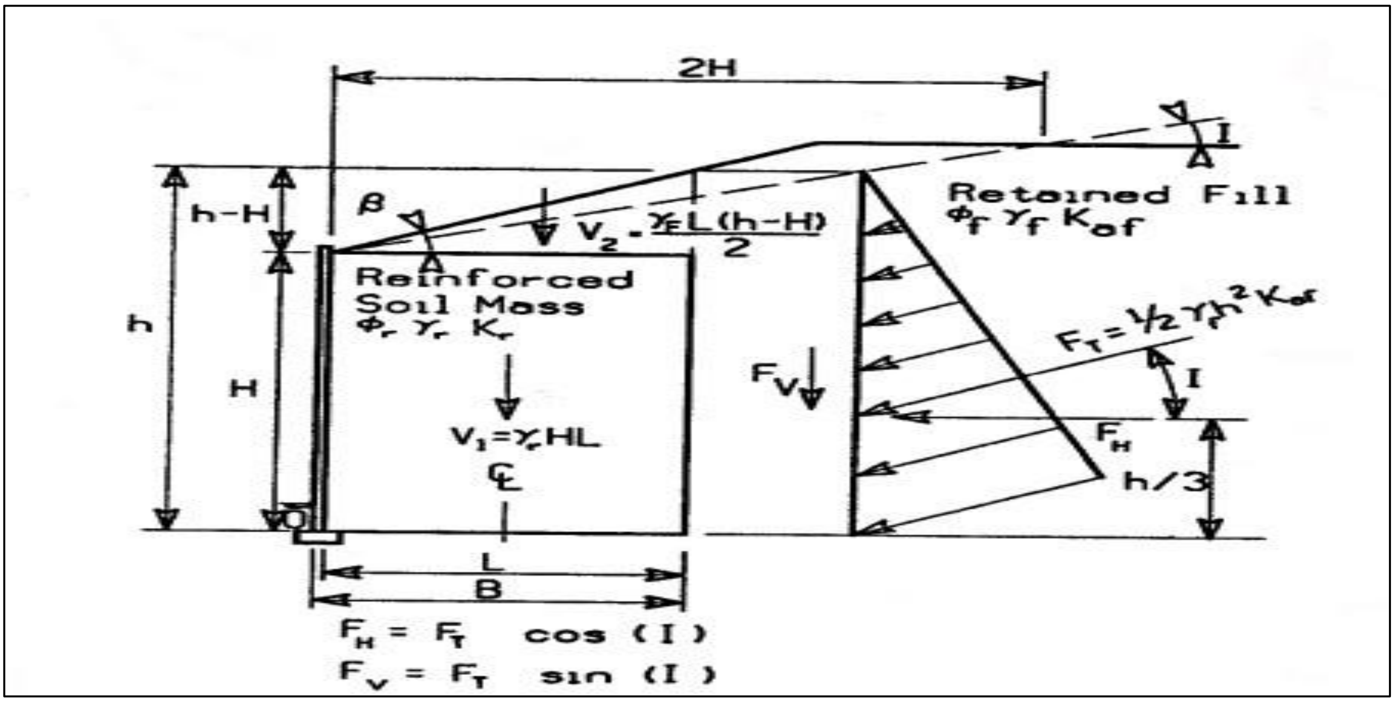

Fig 46: Sloping Back-Slope Case of the (RSW)

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The model was vertically divided into segments of 15 meters. This arrangement incorporates a reinforced backfill (RBF) of 5.95 meters at the upper portion and 5.95 meters at the lower portion. Subsequently, the soil type 0 from Figure 44 will be excavated and replaced with backfill material (BF) up to the top level of RBF. Soil types I and II will remain unaffected.

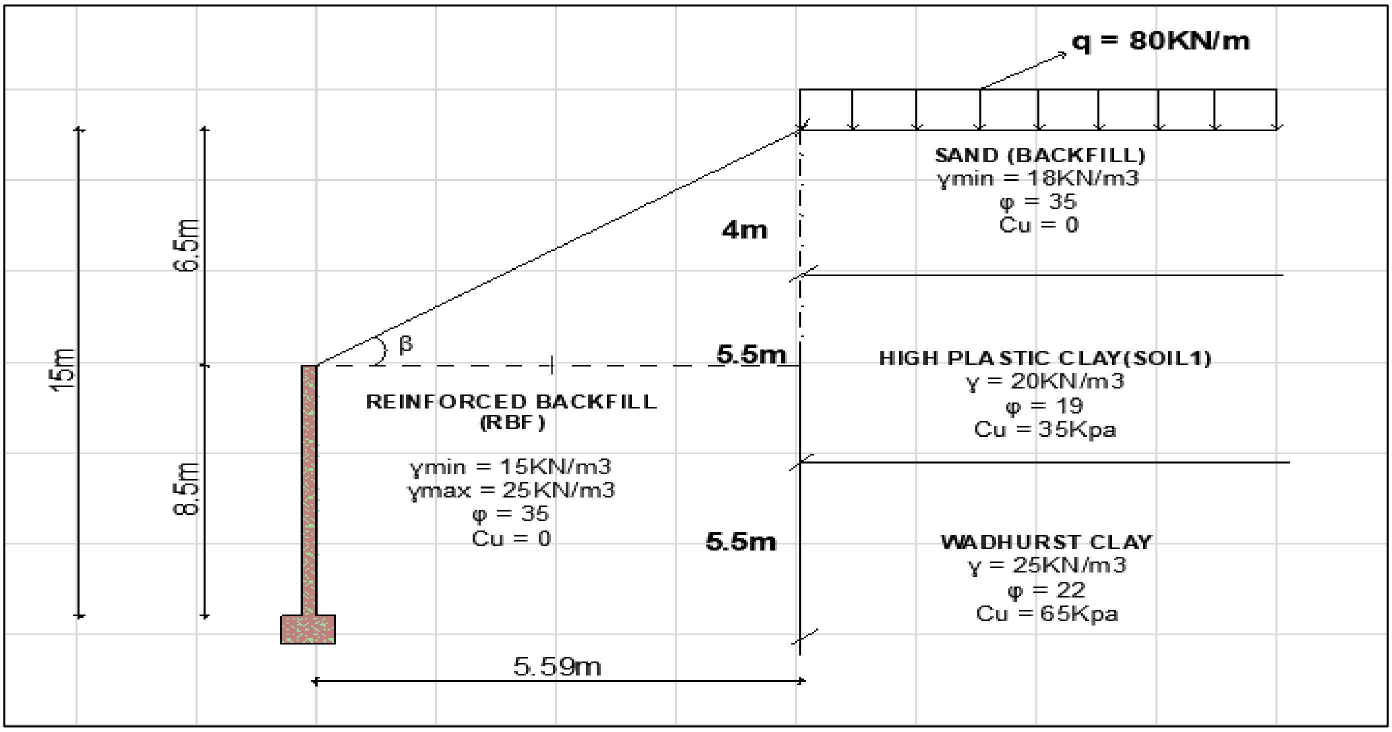

Fig 47: Section of the Wall to be Considered (Arch-Cad 2019)

➢ *Determination Of Coefficient of Active Pressure*

$$K_{aC} = \frac{\cos^2(\varphi' - \eta)}{\cos^2\eta \cos(\eta+\delta)\left[1+\left\{\frac{\sin(\varphi'+\delta)\sin(\varphi'-\beta)}{\cos(\eta+\delta)\cos(\eta-\beta)}\right\}^{1/2}\right]^2}$$

For sloping Back Slope Case Equ. 1

Where;
 = angle between wall and RBF (Ƞ = 0)
β =slope angle
φ = soil friction angle
$\delta = \varphi_1 + \varphi_2 / 2$

Backfill layer (0 - 4m): $\delta = = \frac{37+37}{2} = 37°$

$$Ka = \frac{cos^2\,(37-0)}{cos^2\,(0)cos\,(0+37)\,\{1+\{\frac{sin(35+37)sin(37-35)}{cos(0+37)cos(0-35)}\}^{\frac{1}{2}}]2}$$

$K_{a1} = 0.532$

Soil 1 (4 - 9.5 m): $\delta = = \frac{37+19}{2} = 28°$

$$Ka = \frac{cos^2\,(28-0)}{cos^2\,(0)cos\,(0+28)\,\{1+\{\frac{sin(19+28)sin(35-19)}{cos(0+28)cos(0-35)}\}^{\frac{1}{2}}]2}$$

$K_{a2} = 0.378$

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Soil 2 (9.5 - 15m): $\delta = = \frac{37+22}{2} = 29.5°$

$$Ka = \frac{cos^2\,(29.5-0)}{cos^2\,(0) cos\,(0+29.5)\,\{1+\{\frac{sin(35+29.5)sin(35-29.5)}{cos(0+28)cos(35-0)}\}^{\frac{1}{2}}]2}$$

$K_{a3} = 0.481$

- *Determination of Active Lateral Pressure at the Back of the Wall*

$P_a = K_a\,(\gamma \times z + q) - 2C\sqrt{K_a}$ Equ. 2

Where;
K_a = coefficient of active pressure
γ = unit weight of soil
Z = height of soil layer
q = Surcharge (Rail track, Ballast etc. Assumed to be 80KN/m^2)
C = Soil cohesion

At 0m (Backfill) $P_{a1} = 0.532\,(18 \times 0 + 80) - 2 \times 0 \times\sqrt{0.532} = 42.86$ KN/m^2
At 4m (Backfill) $P_{a2} = 0.532\,(18 \times 4.0 + 80) - 2 \times 0 \times\sqrt{0.532} = 80.86$ KN/m^2
At 4m (Soil 1) $P_{a3} = 0.378\,(18 \times 4.0 + 80) - 2 \times 35 \times\sqrt{0.378} = 14.42$ KN/m^2
At 9.5m (Soil 1) $P_{a4} = 0.378\,(18 \times 4.0 + 20 \times 5.5 + 80) - 2 \times 35 \times\sqrt{0.378} = 55.60$ KN/m^2
At 9.5m (Soil 2) $P_{a5} = 0.481\,(18 \times 4.0 + 20 \times 5.5 + 80) - 2 \times 65 \times\sqrt{0.481} = 35.86$KN/m^2
At 15m (Soil 2) $P_{a6} = 0.481\,(18 \times 4.0 + 20 \times 5.5 + 25 \times 5.5 + 80) - 2 \times 65 \times\sqrt{0.481} = 102$ KN/m^2

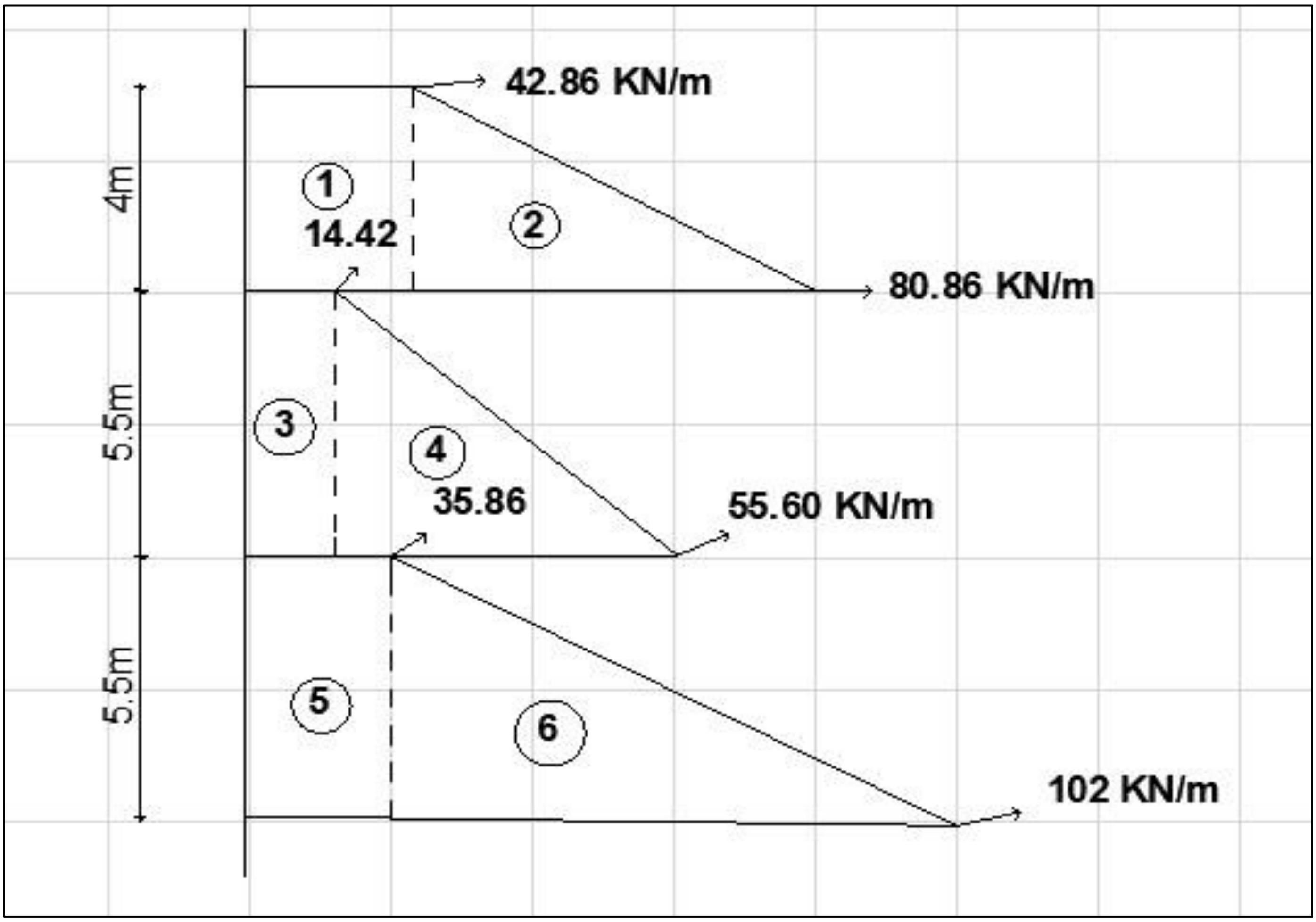

Fig 48: Active Pressure Distribution (APD) (Arch-Cad 2019)

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- *Calculation of Forces from APD Diagram Above*

F = Pa x h Equ. 3
F_1 = 42.86 x 4 = 171.44KN/m
F_2 = 0.5 (80.86 - 42.86) x 4 = 78KN/m
F_3 = 14.42 x 5.5 = 79.31KN/m
F_4 = = 0.5 (55.60 - 14.42) x 5.5 = 113.25KN/m
F_5 = 35.86 x 5.5 = 197.23KN/m
F_6 = = 0.5 (102 - 35.86) x 5.5 = 181.89KN/m

Total forces (∑ F) ≈ 821KN/m

- *Calculation of Moment*

m = F x d Equ. 4
m_1 = 171.44 x (4/2 + 11) = 2057.28KNm
m_2 = 78 x (4/3 + 11) = 962KNm
m_3 = 79.31 x (5.5/2 + 5.5) = 654.31KNm
m_4 = 113.25 x (5.5/3 + 5.5) = 830.50KNm
m_5 = 197.23 x (5.5/2) = 542.38KNm
m_6 = 181.89 x (5.5/3) = 333.47KNm

Total moment (∑ m) ≈ 5379.94KN/m

- *Line Of Action of Force 'x'*

$x = \frac{(\sum m)}{(\sum F)}$ Equ. 5

$x = \frac{5379.94}{821} = 6.55m$

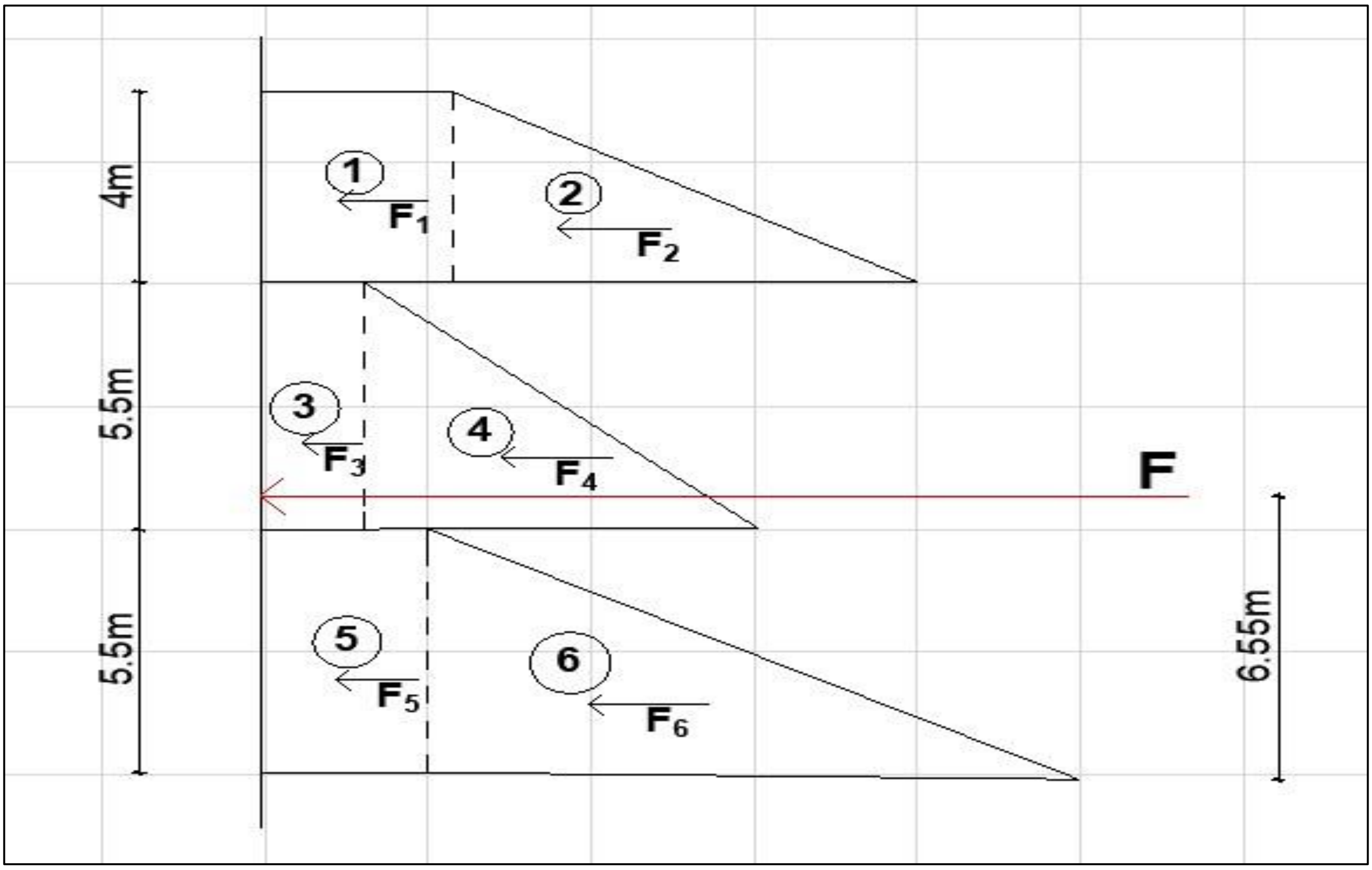

Fig 49: Line of Action of Force (F) (Arch-Cad 2019)

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F. Hand Calculation - Reinforce Soil Wall

➢ *External Stability Calculation, Considering Figure 46.*

- *Step 1; Design Height and External Load*

✓ Total design height (H) = 8.5m
✓ Traffic Surcharge = 80KN/m

- *Step 2; Engineering Properties of Foundation Soil*

✓ φ = 35° , ɣ = 25KN/m
✓ Allowable bearing capacity $q_a = q_{ult}$ / FS

- *Step 3; Engineering Properties of the Retained and Reinforced Backfill*

✓ φ = 35° , ɣ = 18KN/m (retained fill)
✓ φ = 35° , ɣ = 25KN/m (RBF)

- *Step 4; Design Factor of Safety*

✓ *External Stability (FS)*

▪ Sliding = 1.5
▪ Maximum foundation pressure ≤ allowable bearing capacity
▪ Eccentricity (e) ≤ $\frac{L}{6}$

✓ *Internal Stability (FS)*

▪ Pullout ≥ 1.5
▪ Allowable Stress = 0.55fy
▪ Design life = 75 years

- *Step 5: Selection of Facing, Reinforcement Spacing, and Type*

Considering the urban setting, a pre-cast concrete facing with an architectural finish is mandated. The maximum allowable dimensions for panels are 1.5 x 1.5 m (5 ft x 5 ft), with joint widths not exceeding 19 mm (¾-inch) to maintain aesthetics. Given an estimated differential settlement and the use of pre-cast panels, a 19 mm (¾-inch) joint width is acceptable.

To address drainage challenges, linear galvanized ribbed strip reinforcements are preferred in the initial design due to various subsurface obstacles. Although other reinforcement types are technically possible.

Considering the panel dimensions, an efficient vertical spacing of 0.75 m is chosen, enabling 2 rows of reinforcements per panel. The first row is positioned 375 mm from the topmost panel, with an additional 300 mm for barrier to pavement grade.

- *Step 6; Preliminary Length for Reinforce Strip*

For horizontal backfill slope,

L = 0.7H is reasonable

Therefore,
L = 0.7 x 8.5 = 5.95m

- *Step 7; Check External Stability for L = 5.95m*

✓ Compute K_a for retained back fill with φ = 35° and ɣ = 25KN/m

▪ $K_a = \tan^2 (45 - φ/2) = 0.27$

✓ Sliding FS at the base

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- $FS = \frac{V1 \times \tan\varphi}{\sum F_H}$ Equ. 6
- $V_1 = \gamma_f \times H \times L$ Equ. 7
  $= 25 \times 8.5 \times 5.95 = 1264.38KN/m$
- $V_2 = 0.5 \times \gamma_f \times L \times (h - H)$ Equ. 8
  $= 0.5 \times 25 \times 5.95 \times 15 - 8.5 = 483.44KN/m$
- $F_1 = 0.5 \times \gamma_f \times H^2 \times K_a$ Equ. 9
  $= 0.5 \times 25 \times 8.5^2 \times 0.27 = 243.84KN/m$
- $F_2 = q \times H^2 \times K_a$ Equ.10
  $= 80 \times 8.5 \times 0.27 = 183.60KN/m$
- $\sum F = F_1 + F_2 = 243.84 + 183.6 = 427.44KN/m$

- Therefore; $FS = \frac{1264.38}{427.44} = 2.07 > 1.5$ (adequate)

- *Step 8; Eccentricity At The Base.*

$e = \frac{L}{2} - (\frac{\Sigma M_R}{\Sigma V} - \frac{\Sigma M_0}{\Sigma V})$ NB; ($e \leq \frac{L}{6}$) Equ. 11

M_o = Overturning moment about the centre of the failure circle
M_R = Resistance moment provided by the strength of the soil

Where;
$M_R = V_1 \times \frac{L}{2}$ Equ. 12
$= 3751.53$ KN/m

$M_o = F_1 \times \frac{H}{3} + F_2 \times \frac{H}{2}$ Equ. 13
$= 690.88 + 780.30 = 1471.18KN/m$

Therefore; $e = \frac{5.92}{2} - (\frac{3761.53 - 1471.18}{21264.38 + 483.44})$
$e = 1.3 > \frac{L}{6}$ hence; $e = \frac{5.95}{6} = 0.99$
$L' = L - 2e$
$L' = 5.95 - 2 \times 0.99 = 3.93m$

- ✓ Overturning FS

$FS_{overturning} = \frac{M_R}{M_o}$ Equ. 14

$FS_{overturning} = \frac{3751.52}{1471.18} = 2.55 > 2.0$ {OK}

- *Step 9; Bearing Capacity of Foundation Soil*

- ✓ $q_{ult} = C_f Nc + 0.5 (L - 2e) \gamma_f N_\gamma$ Equ. 15
- ✓ $C = 0$, $N_\gamma = 45.41$ (from table 2)
- ✓ $q_{ult} = 0.5 \times 3.97 \times 25 \times 45.41 = 2253.47KN/m^2$
- ✓ $q_a = \frac{q_{ult}}{FS} = \frac{2253.47}{1.5} = 1502.31KN/m^2$

- *Bearing Capacity at the Base*

$\sigma_v = \frac{\sum V}{L - 2e}$ Equ. 15

$= \frac{1264.38 + 483.44}{3.53} = 521.73KPa < 1502.31KPa$ {OK}

- *Bearing capacity FS*

$FS_{bearing\ capacity} = \frac{\sigma_v}{q_{ult}}$ Equ. 16

$\frac{1502.31}{521.73} = 2.89 > 2.5$ {OK}

Table 2: Terzaghi Bearing Capacity Table

Terzaghi Bearing capacity —Eqs. (4.15), (4.13), and (4.11).*

ϕ'	N_c	N_q	N_γ*	ϕ'	N_c	N_q	N_γ*
0	5.70	1.00	0.00	26	27.09	14.21	9.84
1	6.00	1.10	0.01	27	29.24	15.90	11.60
2	6.30	1.22	0.04	28	31.61	17.81	13.70
3	6.62	1.35	0.06	29	34.24	19.98	16.18
4	6.97	1.49	0.10	30	37.16	22.46	19.13
5	7.34	1.64	0.14	31	40.41	25.28	22.65
6	7.73	1.81	0.20	32	44.04	28.52	26.87
7	8.15	2.00	0.27	33	48.09	32.23	31.94
8	8.60	2.21	0.35	34	52.64	36.50	38.04
9	9.09	2.44	0.44	35	57.75	41.44	45.41
10	9.61	2.69	0.56	36	63.53	47.16	54.36
11	10.16	2.98	0.69	37	70.01	53.80	65.27
12	10.76	3.29	0.85	38	77.50	61.55	78.61
13	11.41	3.63	1.04	39	85.97	70.61	95.03
14	12.11	4.02	1.26	40	95.66	81.27	115.31
15	12.86	4.45	1.52	41	106.81	93.85	140.51
16	13.68	4.92	1.82	42	119.67	108.75	171.99
17	14.60	5.45	2.18	43	134.58	126.50	211.56
18	15.12	6.04	2.59	44	151.95	147.74	261.60
19	16.56	6.70	3.07	45	172.28	173.28	325.34
20	17.69	7.44	3.64	46	196.22	204.19	407.11
21	18.92	8.26	4.31	47	224.55	241.80	512.84
22	20.27	9.19	5.09	48	258.28	287.85	650.67
23	21.75	10.23	6.00	49	298.71	344.63	831.99
24	23.36	11.40	7.08	50	347.50	415.14	1072.80
25	25.13	12.72	8.34				

*From Kumbhojkar (1993)

- *Internal Stability (Hand Calculation)*

Now, it's necessary to assess the stability of the reinforced soil block itself. To illustrate the fundamental concepts, we'll start with simplified assumptions. Let's consider that an "active wedge" takes shape behind the vertical surface within the reinforced soil.

Assuming once more that φ' = 30 degrees, we can deduce that the angle of the wedge concerning the horizontal is 60° (45 + 30/2). As a result, the width of the block at ground level becomes 0.58hw. This implies that, following external equilibrium principles, the active wedge will entirely reside within the reinforced soil. See figure 49.

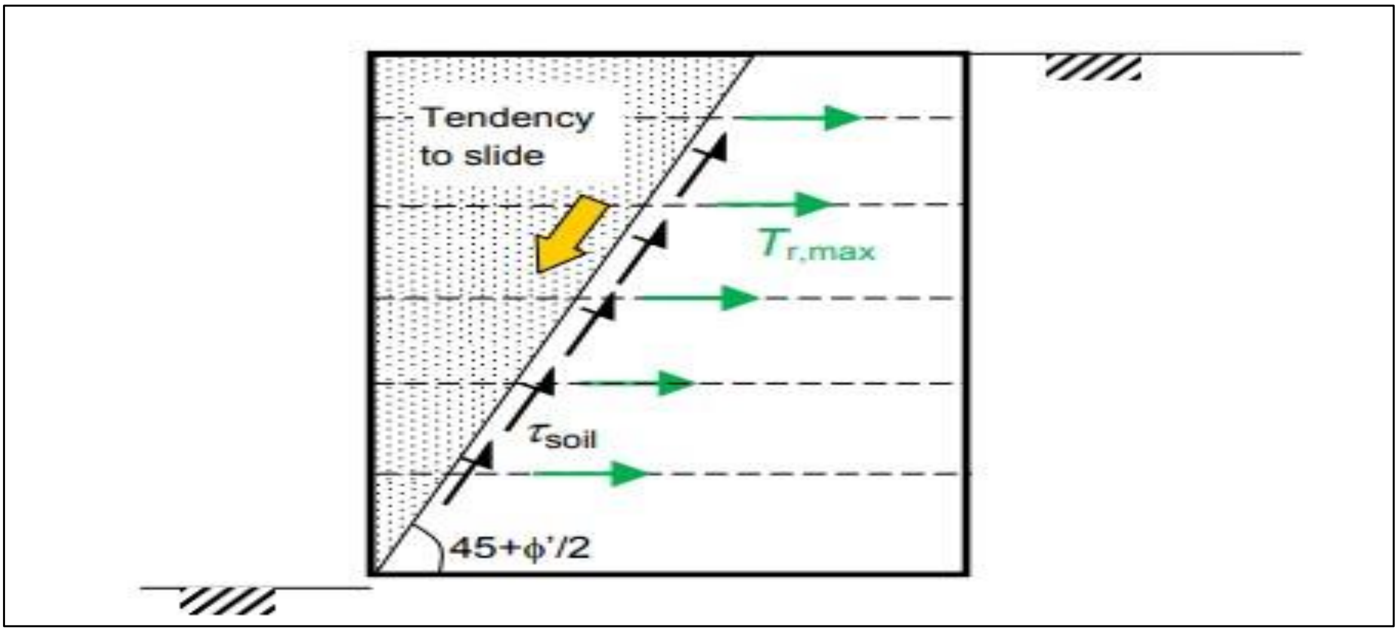

Fig 50: The Active Wedge Leads to Active Earth Pressure by Trying to Slide Downward and Outward, but this is Counteracted by Soil Shearing and the Tension in Reinforcing Elements that Anchor it

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- *Tension in Reinforcement*

Next, we need to calculate the maximum tension in the reinforcement, which we'll assume occurs at the back of the active wedge. This tension is a result of both the normal stress on the face transferred to the reinforcement through the connection to the face, and the shearing stress on the reinforcement itself within the active wedge. This maximum tension is given by the equation

$T_{r,max} = K_a \sigma' v\ Af$,

Where;
Af = Area of the vertical face related to each individual reinforcing element,
σ'v = vertical effective stress at the depth of the reinforcing element.

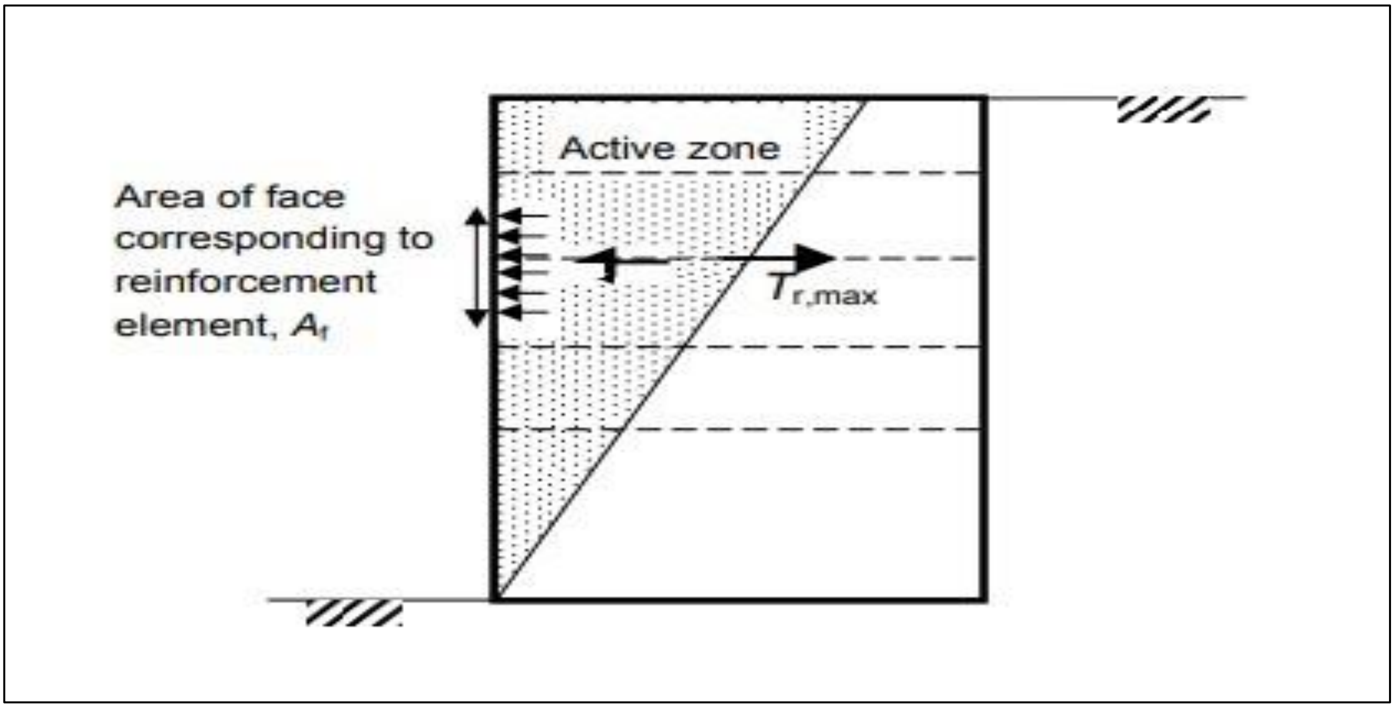

Fig 51: The Stresses Applied to the Facing and Reinforcing Element within the Active Wedge are Countered by the Maximum Tension T_{rmax} at the Back of the Wedge

Considering the reinforced zone figure 46,the values given for geogrid strength are design values. Therefore for tensile failure FS ≥ 1.0 will be satisfactory. However FS ≥ 1.5 is required for pullout. Assume a high polyester (PET) geogrid is used with design strength of 150KN/m and the geogrid soil interface angle is 80% of the soil friction angle (i.e) $\delta_r = 0.8 \times 35 = 28°$. each layer of the centre panel is reinforced at midpoint by one layer of geogrid.

➢ *Preliminary Design*

- *Tension Failure;*

$T_{rmax} = K_a \text{ x } \sigma_v' \text{ x } A_f$ Equ. 16

$= K_a \text{ x } (\gamma z + q) \text{ x } A_f$

Where;
T_{rmax} = maximum tension in individual reinforcement element
K_a = coefficient of active pressure
σ_v' = effective vertical stress
A_f = Area of face corresponding to a reinforcement element
Z = depth of the considered layer of the geogrid

Assume we are considering 10 layers of geogrid and taking into account layer 4 of 10 (at depth z = 3.4m)

Hence,

$$Ka = \frac{1 - sin\varphi}{1 + sin\varphi}$$ Equ. 17

$= \dfrac{1 - sin35}{1 + sin35} = 0.27$

Therefore;

$T_{rmax} = 0.27 \text{ x } (25 \text{ x } 3.4 + 80 \text{ x } 2.25) = 100.24KN/m$

$FS = \dfrac{T_{rdesign}}{T_{rmax}}$ Equ. 18

$= \dfrac{150}{100.24} = 1.49$

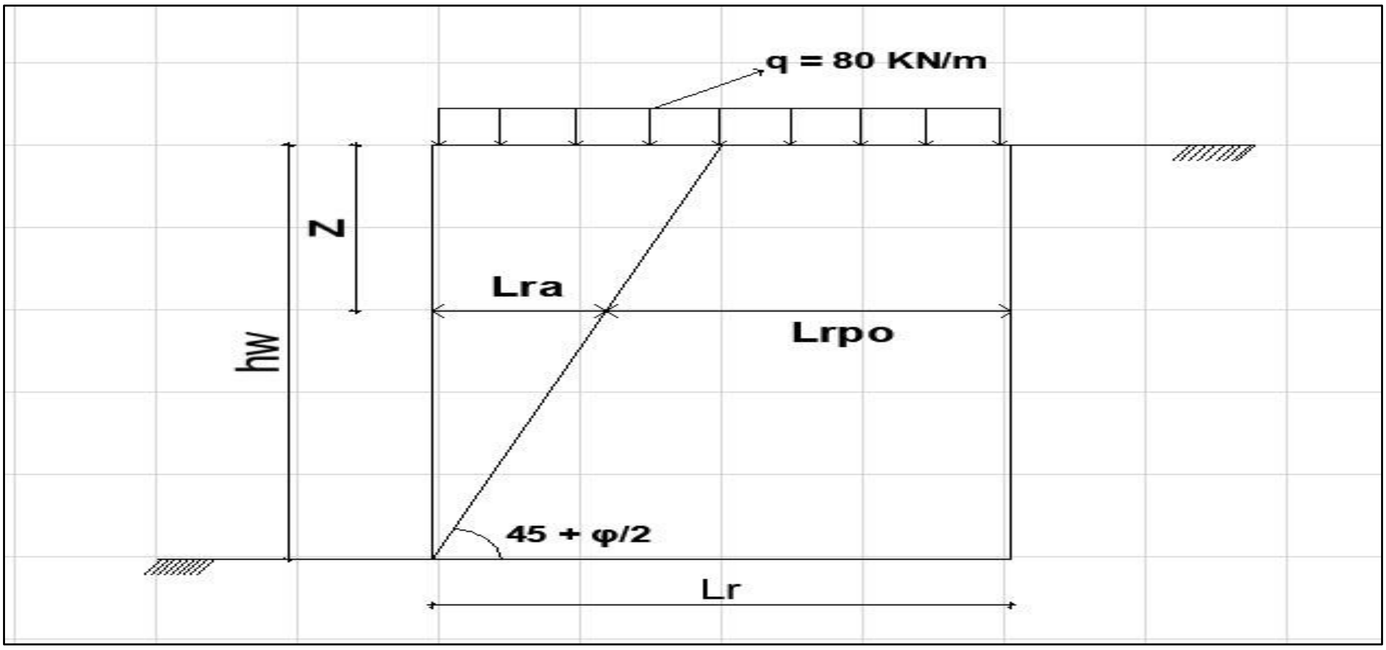

Fig 52: Illustration of the Reinforced Zone

- *Pull-Out*

From fig 51
$T_{rpo} = 2 \text{ x } b_r \text{ x } L_{rpo} \text{ x } \sigma_v' \text{ x } \tan(\delta_r)$ Equ. 19
$L_{rpo} = L_r - L_{ra}$ Equ. 20

Where;
b_r = width of 'discrete' (non-continuous) reinforcing element
L_{rpo} = length of reinforcement providing resistance to pull out (in the 'resistant zone', and taking account of e as necessary for rectangular stress distribution)
L_{ra} = length of reinforcement in active zone
L_r = length of reinforcement (in direction normal to wall
δ_r = interface friction angle for reinforcement and soil

And,
$L_{ra} = (hw - z) \text{ x } \tan(45 - \varphi/2)$ Equ. 21
$= (8.5 - 3.4) \text{ x } \tan(45 - \frac{35}{2}) = 2.65m$

Hence,
$L_{rpo} = (5.95 - 2.65) = 3.3m$
$T_{rpo} = 2 \text{ x } 1 \text{ x } 3.3 \text{ x } (25 \text{ x } 3.4 + 80)\tan(28)$
$= 579.03KN/m$

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Therefore;

$FS = \frac{T_{rpo}}{T_{rmax}}$ Equ. 22

$FS = \frac{579.03}{100.24} = 5.78$

➢ *Detailed Design*

- *Tension Failure;*

From $T_{rmax} = Ka \times \sigma_v' \times A_f$

If K_a is modified to a depth less than ($h_w = 8$.m) (i.e) at Z = 3.4m

$K = K_o - (\frac{h_w}{z}) \times (K_o - K_a)$ Equ. 23

$= 0.43 \times (\frac{3.4}{8.5}) \times (0.43 - 0.27)$

= 0.366

Given; $\sigma_v' = \frac{\gamma z}{1 - 2\,(e/lr)}$; recall e = 0.99 Equ. 24

$= \frac{25 \times 3.4}{1 - 2\,(0.99/5.95)} = 127.39$KN/m

$T_{rmax} = 0.366 \times 127.39 \times 2.25 = 104.91$KN/m

Thus; $FS = \frac{T_{rdesign}}{T_{rmax}} = \frac{150}{104.91} = 1.43 > 1.0$ **(** OK **)**

- *Pull-Out*

- ✓ $T_{rpo} = 2 \times b_r \times L_{rpo} \times \sigma_v' \times \tan(\delta_r)$
- ✓ Where; $L_{rpo} = L_r - L_{ra} - 2e$
- ✓ $L_{ra} = (hw - z) \times \tan(45 - \varphi/2) \leq 2.4$m
- ✓ = (8.5 - 3.4) x (45 - 30/2)
- ✓ = 2.65m > 2.4m hence, $L_{ra} = 2.4$m
- ✓ $L_{rpo} = 5.95 - 2.4 - 2 \times (0.99)$ 1.57m
- ✓ $T_{rpo} = 2 \times 1 \times 1.57 \times 104.91 \tan 28 = 175.15$KN/m
- ✓ $FS = \frac{T_{rpo}}{T_{rmax}} = \frac{175.15}{104.91} = 1.67 > 1.5$ **(** OK **)**

G. Computer Aided Analysis

A critical aspect of the design process was examined using computer aided software (GEO 5). This software was used to determine the stability analysis of the reinforced soil wall system. Both internal and external stability factors were assessed to ensure that the system could withstand the applied loads without sliding,overturning or failing due to bearing capacity (bearing capacity failure)

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➢ *Model Description*

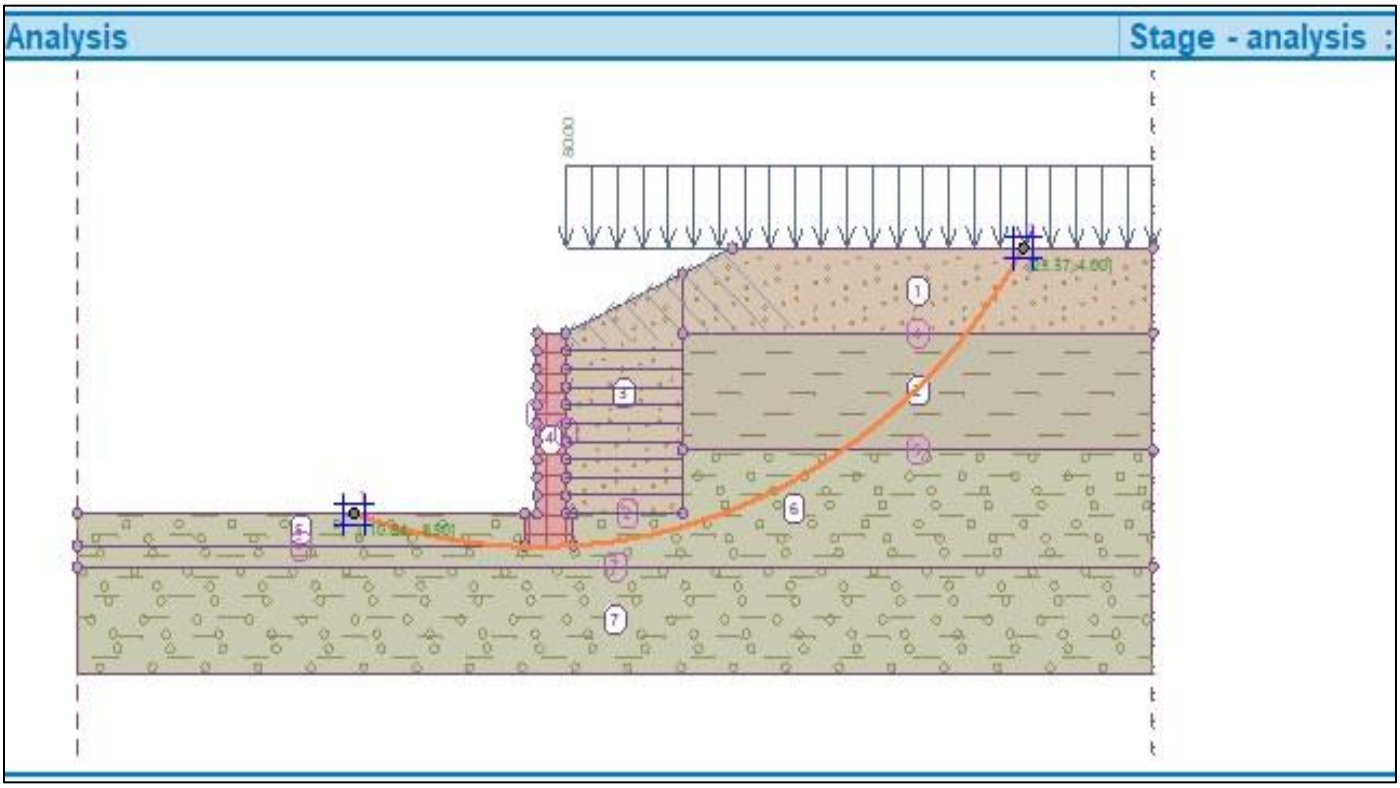

Fig 53: Model Description of the Wall (GEO 5, 2023.)

➢ *External Stability Analysis Using (GEO 5) Software*

- *Check For Overturning and Sliding Of Wall*

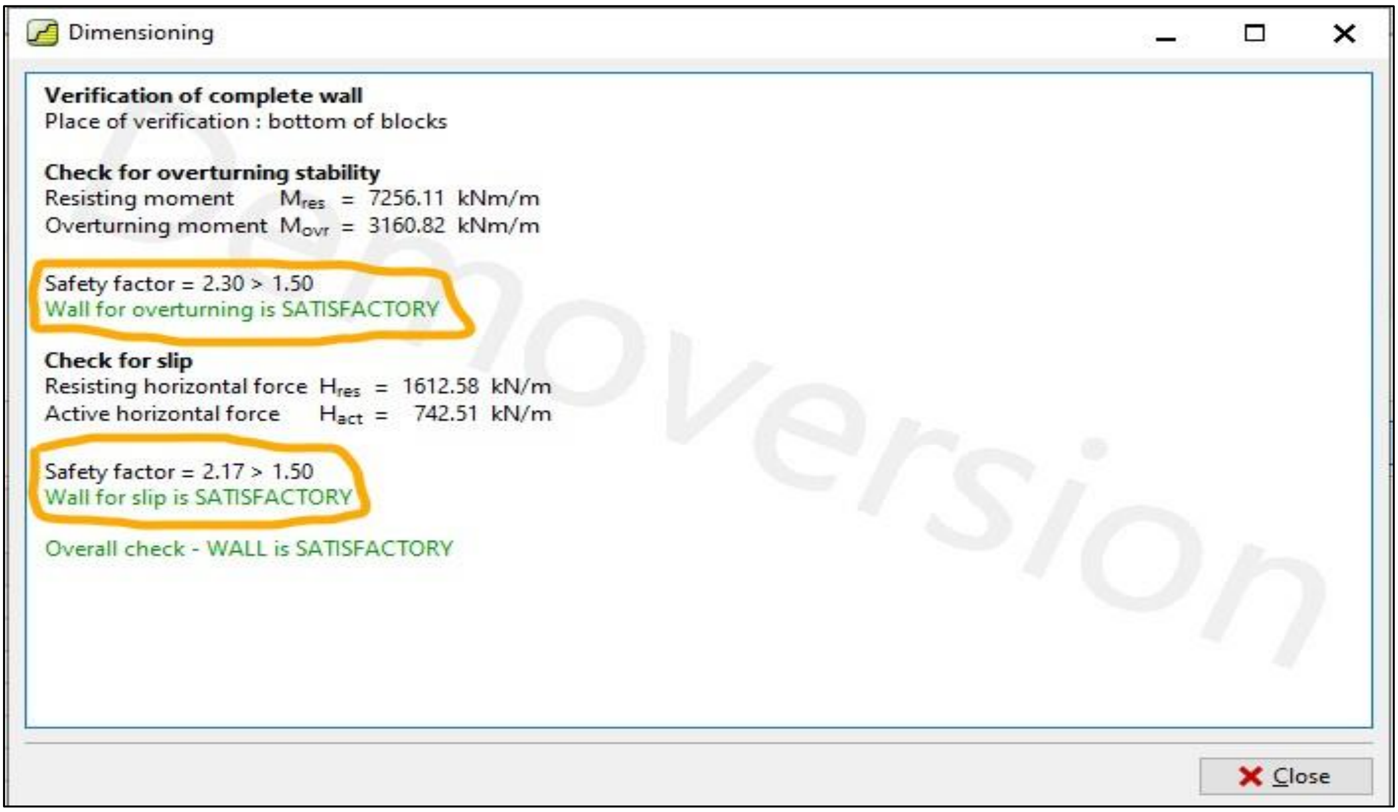

Fig 54: Overturning and Sliding Stability Result (GEO 5, 2023.)

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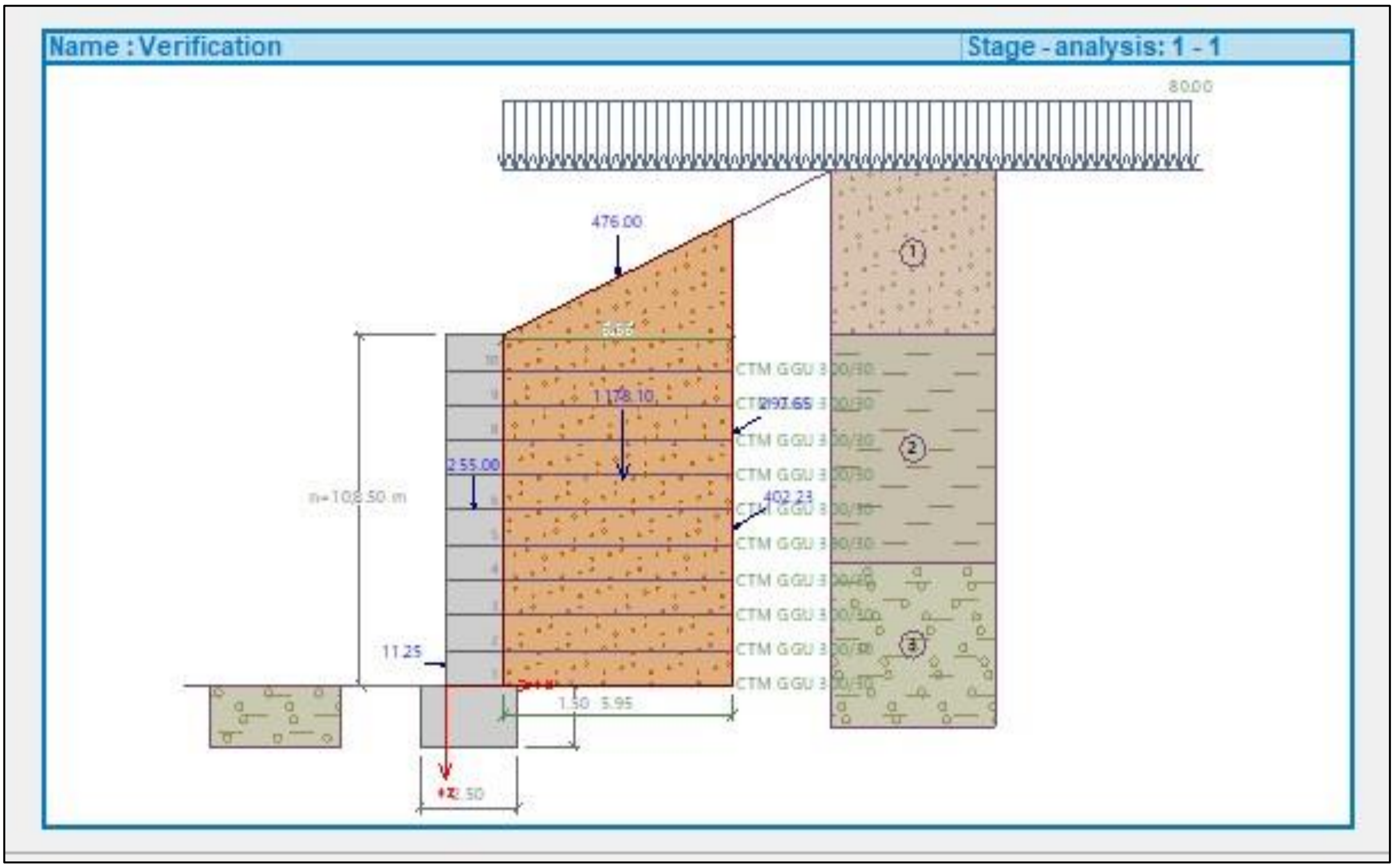
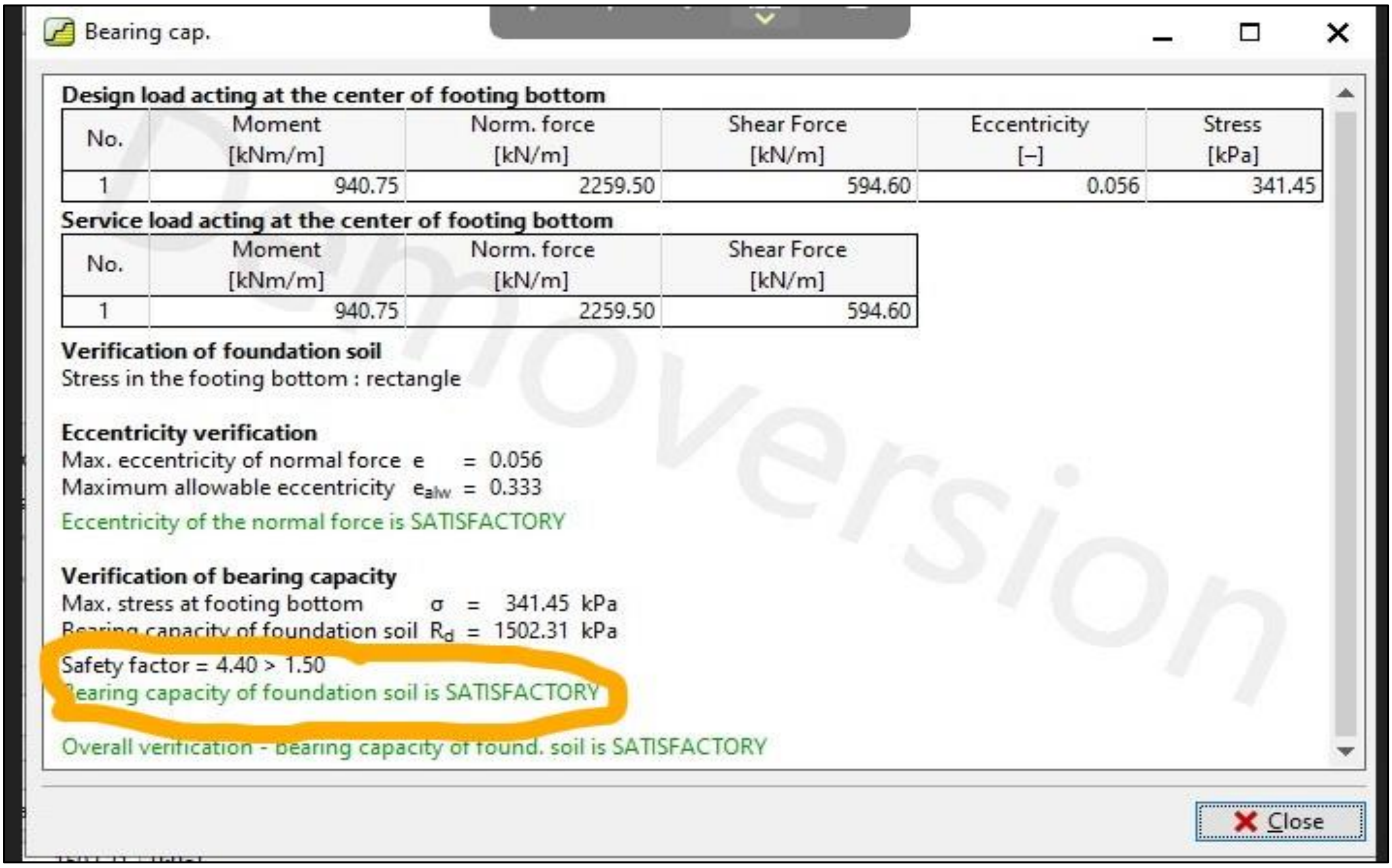


Fig 55: Overturning and Sliding Stability Model (GEO 5, 2023.)

- *Bearing Capacity Check*


Bearing cap.

Design load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]	Eccentricity [–]	Stress [kPa]
1	940.75	2259.50	594.60	0.056	341.45

Service load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]
1	940.75	2259.50	594.60

Verification of foundation soil
Stress in the footing bottom : rectangle

Eccentricity verification
Max. eccentricity of normal force e = 0.056
Maximum allowable eccentricity e_{alw} = 0.333
Eccentricity of the normal force is SATISFACTORY

Verification of bearing capacity
Max. stress at footing bottom σ = 341.45 kPa
Bearing capacity of foundation soil R_d = 1502.31 kPa
Safety factor = 4.40 > 1.50
Bearing capacity of foundation soil is SATISFACTORY

Overall verification - bearing capacity of found. soil is SATISFACTORY

Close

Fig 56: Result of Bearing Capacity (GEO 5, 2023.)

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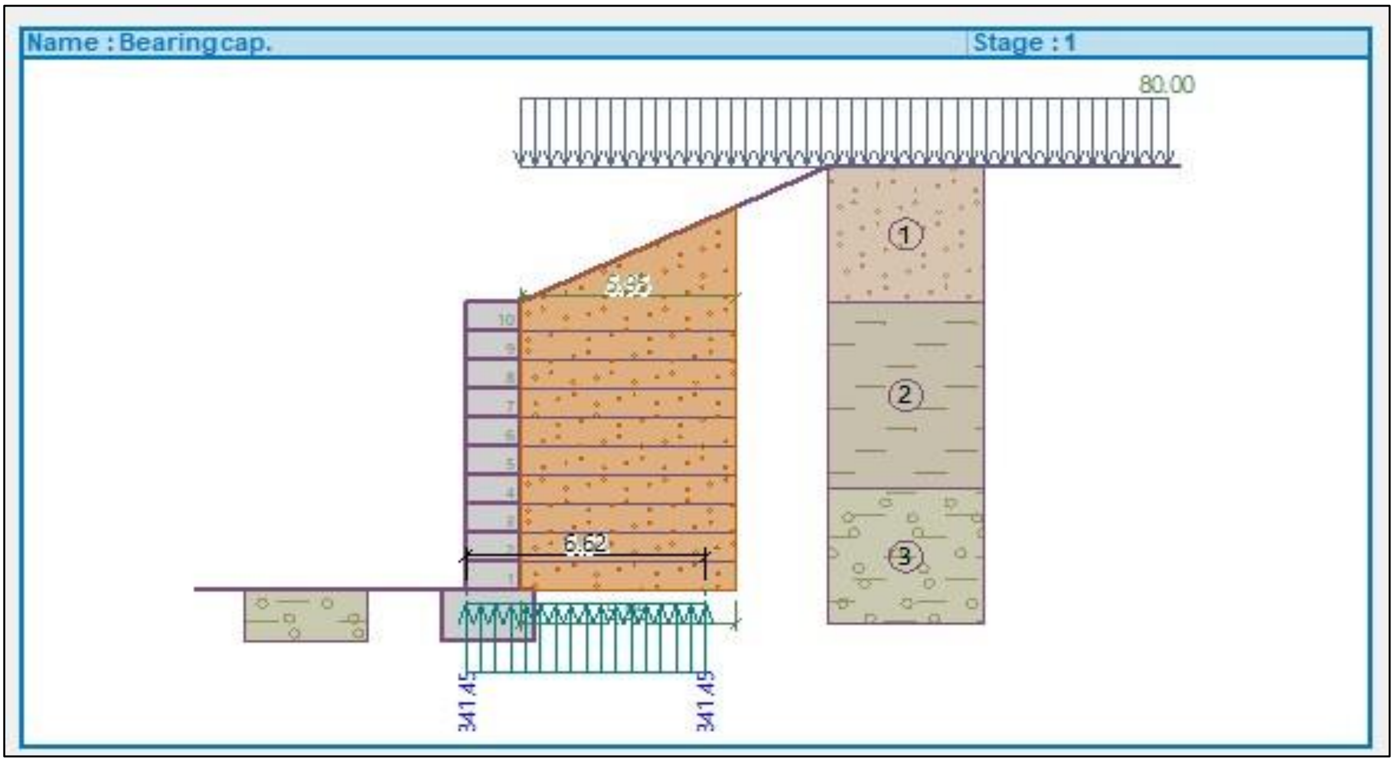

Fig 57: Bearing capacity model (GEO 5, 2023.)

➢ *Internal Stability Analysis (GEO 5) Using (GEO 5) Software*

- *Check for Tensile Strength and Pullout in Reinforcement*

Internal stability

Calculated forces and strength of reinforcements

No.	Name	F_x [kN/m]	Depth z[m]	R_t [kN/m]	Utiliz. [%]	T_p [kN/m]	Utiliz. [%]
1	CTM GGU 300/30	-35.41	8.50	150.00	35.41	1088.28	4.88
2	CTM GGU 300/30	-67.53	7.65	150.00	67.53	924.44	10.96
3	CTM GGU 300/30	-63.14	6.80	150.00	63.14	773.91	12.24
4	CTM GGU 300/30	-58.75	5.95	150.00	58.75	636.70	13.84
5	CTM GGU 300/30	-54.36	5.10	150.00	54.36	512.82	15.90
6	CTM GGU 300/30	-49.97	4.25	150.00	49.97	402.25	18.63
7	CTM GGU 300/30	-45.58	3.40	150.00	45.58	305.00	22.42
8	CTM GGU 300/30	-41.19	2.55	150.00	41.19	221.07	27.95
9	CTM GGU 300/30	-36.80	1.70	150.00	36.80	150.47	36.69
10	CTM GGU 300/30	-46.97	0.85	150.00	46.97	93.18	75.62

Check for tensile strength (reinforcement No.2)

Tension strength R_t = 150.00 kN/m

Force in reinforcement F_x = 67.53 kN/m

Safety factor = 2.22 > 1.50

Reinforcement for tensile strength is SATISFACTORY

Check for pull out resistance (reinforcement No.10)

Pull out resistance T_p = 93.18 kN/m

Force in reinforcement F_x = 46.97 kN/m

Safety factor = 1.98 > 1.50

Reinforcement for pull out resistance is SATISFACTORY

Overall verification - reinforcement is SATISFACTORY

Close

Fig 58: Tensile Strength and Pullout Resistance Result (GEO 5, 2023.)

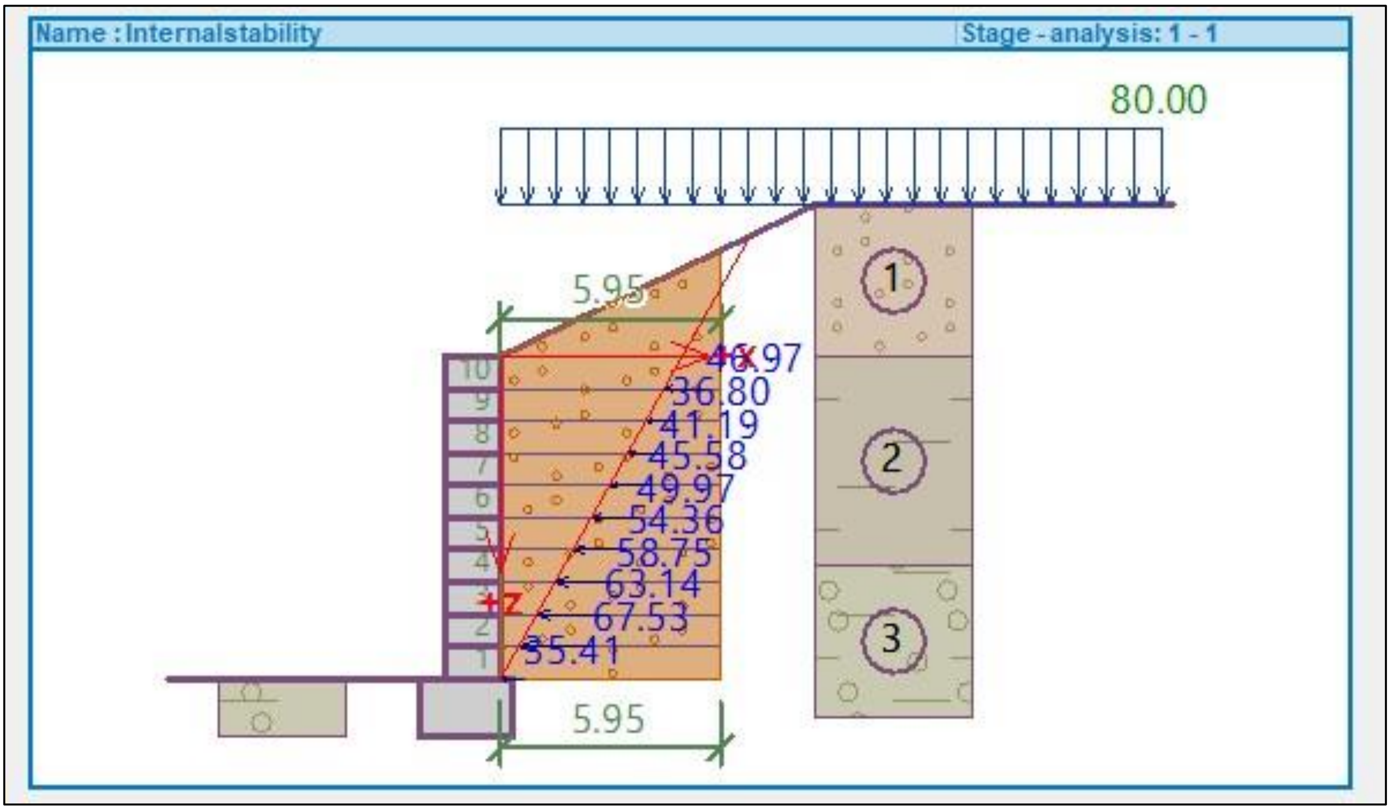

Fig 59: Tensile Strength and Pullout Resistance Model (GEO 5, 2023.)

- *Slip on Geo-Reinforcement*

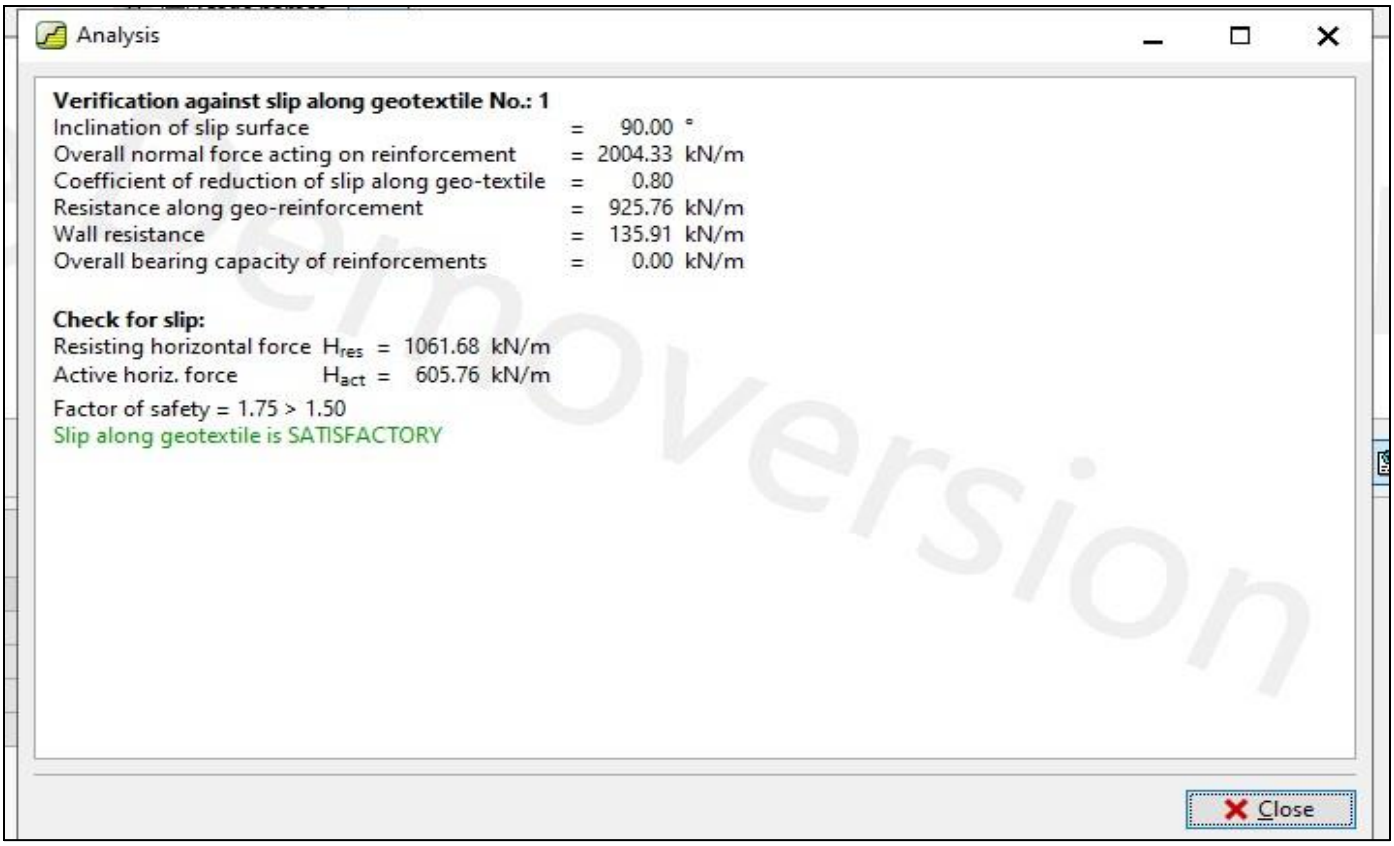

Fig 60: Safety Factor of Geo-Reinforcement (GEO 5, 2023.)

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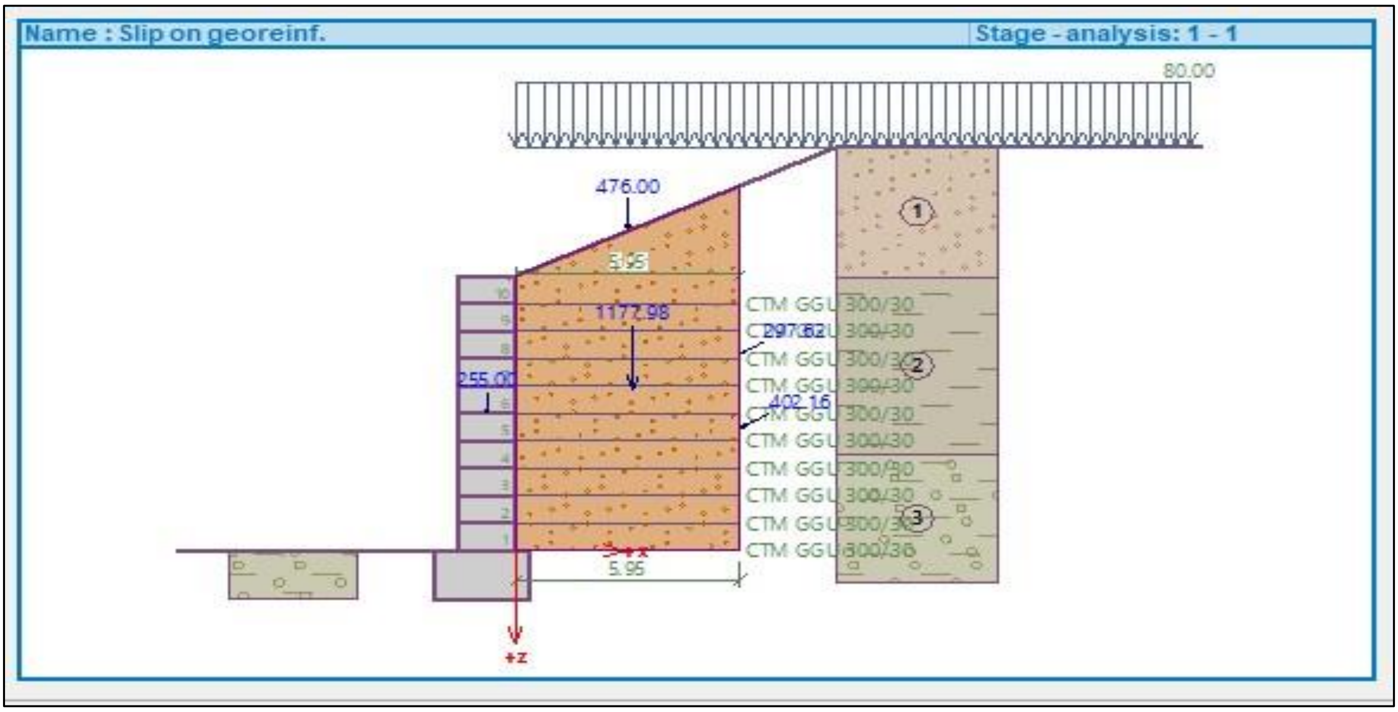

Fig 61: Geo-Reinforcement Model (GEO 5, 2023.)

- *Slope Stability Analysis Using (Geo 5) Software*

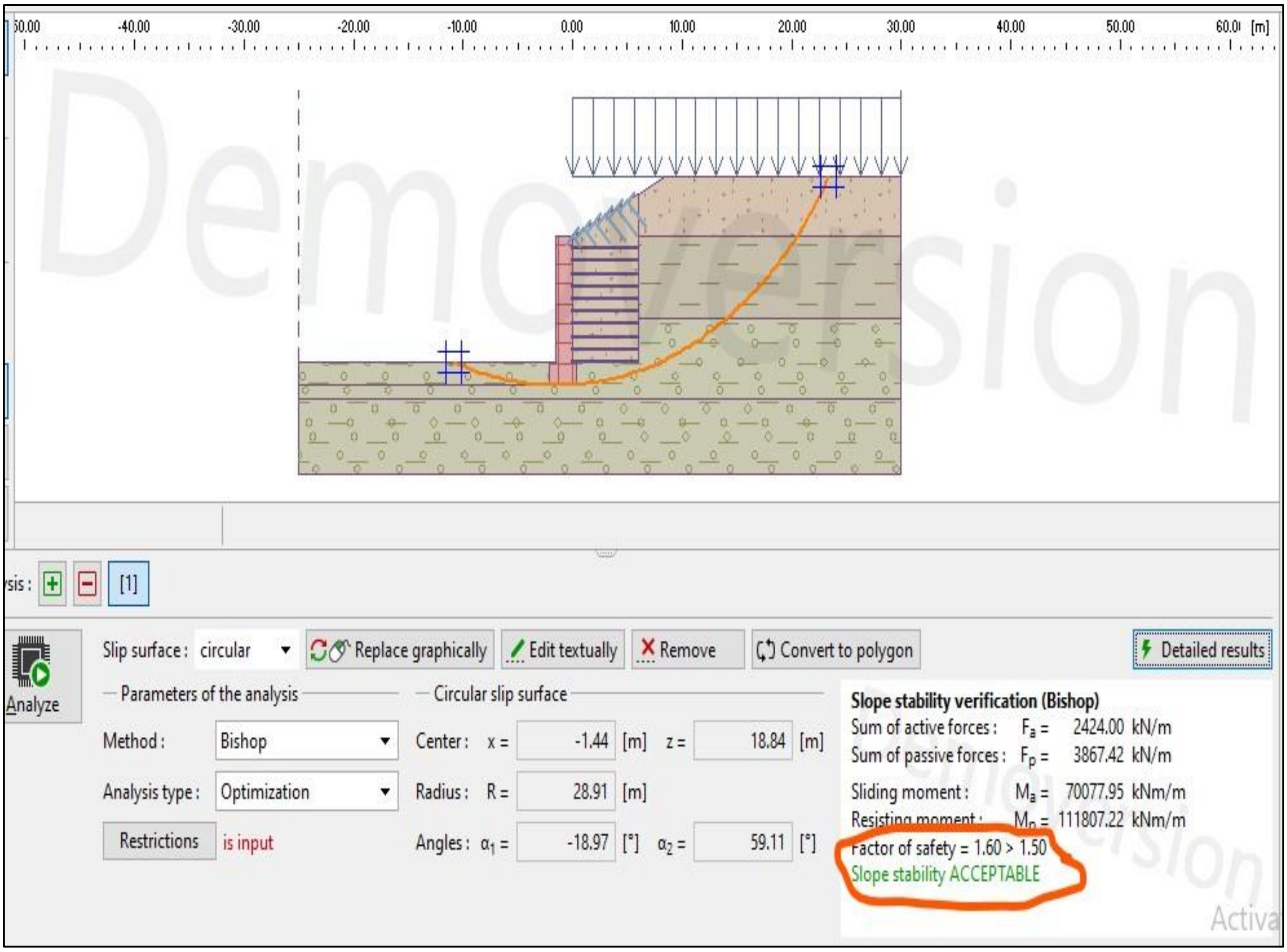

Fig 62: Model and Result of Slope Stability Analysis (GEO 5, 2023.)

H. Comparison and Analysis of Results (Hand Calculation And GEO 5)

In the quest to perfect the design and ensure the stability of the reinforced soil wall system at the Balcombe Embankment, it's crucial to compare and analyse the outcomes obtained using two different methods: doing calculations by hand and using the GEO 5 software. This section focuses on looking at where these methods agree, where they differ, and what these variations mean for how well the earth retaining system will work for the railway project.

➢ *External Stability Comparison*

Table 3: Comparison of Safety Factor for External Stability

Result	Overturning FS	Sliding FS	Bearing Capacity
Hand Calculation	2.55	2.07	2.89
GEO 5	2.30	2.17	4.40

➢ *Internal Stability Comparison*

Table 4: Comparison of Safety Factor for Internal Stability

Result	Tesile Strength	Pullout
Hand Calculation	1.43	1.67
GEO 5	2.22	1.98

➢ *Stress and Moment Comparison*

Table 5: Comparison of Effective Stress, Resisting and Overturning Moment

Result	Eff. Stress on Wall Base (KN/m^2)	Resisting Moment (KNm)	Overturning Moment (KNm)
Hand Calculation	521.73	3751.53	1471.18
GEO 5	341.45	7256.11	3162.32

➢ *Analysis and Implication Of Result*

Table 3 illustrates a comparison of safety factors for external stability between hand calculation and GEO 5 analysis. Notably, the safety factors for overturning, sliding, and bearing capacity are presented. The safety factors obtained from both methods reveal some interesting observations:

- ***Overturning FS:*** Hand calculations yielded a safety factor of 2.55, while GEO 5 analysis resulted in a slightly lower value of 2.30. Although there is a disparity, both values comfortably exceed the threshold of 1.0, indicating stability against overturning.
- ***Sliding FS:*** The sliding safety factors are 2.07 (hand calculation) and 2.17 (GEO 5). Again, both values surpass the minimum requirement of 1.0, indicating resistance to sliding.
- ***Bearing Capacity:*** The bearing capacity safety factor derived from hand calculations is 2.89, while GEO 5 analysis provides a substantially higher value of 4.40. This indicates a notable difference in the assessment of bearing capacity between the two methods.

Table 4 outlines the comparison of safety factors for internal stability, focusing on tensile strength and pull-out. The results from hand calculation and GEO 5 analysis for internal stability are as follows:

- ***Tensile Strength:*** Hand calculation yields a safety factor of 1.43, while GEO 5 analysis produces a notably higher safety factor of 2.22. This suggests that the GEO 5 analysis predicts a greater margin of safety against tensile failure within the reinforced soil wall.
- ***Pullout:*** Hand calculation provides a safety factor of 1.67, while GEO 5 results in a slightly lower safety factor of 1.98. Here, GEO 5 still suggests a sufficient margin of safety against pullout failure.

Table 5 delves into the comparison of effective stress at the base of the wall, resisting moment, and overturning moment. The results highlight significant differences:

- ***Effective Stress on Wall Base:*** Hand calculation predicts an effective stress of 521.73 KN/m^2, while GEO 5 estimates a lower effective stress of 341.45 KN/m^2. This discrepancy could have implications for the structural response of the reinforced soil wall.
- ***Resisting Moment:*** Hand calculation indicates a resisting moment of 3751.53 KNm, while GEO 5 suggests a substantially higher resisting moment of 7256.11 KNm. This points to varying expectations in terms of the system's resistance to external forces.

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- ***Overturning Moment:*** Hand calculation reports an overturning moment of 1471.18 KNm, whereas GEO 5 calculates a significantly higher overturning moment of 3162.32 KNm. These variations in the prediction of overturning moments could have implications for stability under lateral forces.

In essence, these variations emphasize the importance of thorough analysis and real-time monitoring to ensure the reinforced soil wall system's optimal performance and long-term stability. Continuously monitoring and adjusting based on field conditions are crucial to confirming the system's adequacy and effectiveness in safeguarding the Balcombe Embankment and the railway infrastructure.

CHAPTER FIVE
SUMMARY, RECOMMENDATION AND CONCLUSION

A. *Summary of Research*

The research aimed to thoroughly investigate the use of earth retaining systems in railway infrastructure. It started by exploring the different types and uses of these systems, recognizing both their potential benefits and difficulties. By critically reviewing existing literature and conducting an in-depth case study, the study examined how these systems are applied in real-world railway projects and their overall impact.

The study results highlight the importance of earth retaining systems in enhancing the durability, safety, and stability of railway infrastructure. The case study provided specific advantages, such as decreased erosion, enhanced track stability, and cost-efficient construction methods, finally a software and hand calculation analysis of the case study was carried out and a comparison between the both methods was establish to backup this research.

B. *Recommendations for Future Research*

➢ *As We Conclude this Study, We Recognize that Several Avenues for Future Research Emerge from our Work:*

- ***Long-Term Performance*** Analysis: Future studies can focus on the long-term performance of earth retaining systems in railway contexts to assess their durability and resilience.
- ***Comparative Studies:*** Comparative analyses of different types of earth retaining systems can provide insights into the most effective solutions for specific railway scenarios.
- ***Sustainability Assessment:*** Investigating the environmental sustainability of earth retaining systems in railway projects is a pertinent area for future research.
- ***Policy and Regulation:*** Research on the development of policies and regulations governing the use of earth retaining systems in railway infrastructure can be beneficial.

Conclusion

In conclusion, this comprehensive research successfully achieved its stated objectives. It embarked on a thorough investigation into the utilization of earth retaining systems in railway infrastructure, examining both their technical intricacies and practical applications. Through an exhaustive exploration of various system types, design principles, and their relevance in diverse railway contexts, the research provided a robust understanding of these systems.

Furthermore, the study meticulously reviewed recent developments and advancements in the field of earth retaining systems tailored for railway projects, staying current with the evolving landscape of this critical infrastructure component.

Importantly, this research substantiated the numerous benefits and advantages associated with the integration of earth retaining systems in railway projects. These benefits include enhanced durability, safety, and stability of railway infrastructure, along with notable advantages like erosion reduction, improved track stability, and cost-effective construction methods.

The research also identified and analyzed the challenges and limitations inherent in implementing earth retaining systems in railway contexts. This critical examination provides valuable insights into areas where further research or innovative solutions may be necessary to overcome obstacles.

Ultimately, this study concludes with practical recommendations and advice for the effective use of earth retaining systems in railway infrastructure. These insights can serve as a valuable resource for railway engineers, planners, and policy-makers, guiding them in making informed decisions to enhance the overall performance and sustainability of railway projects.

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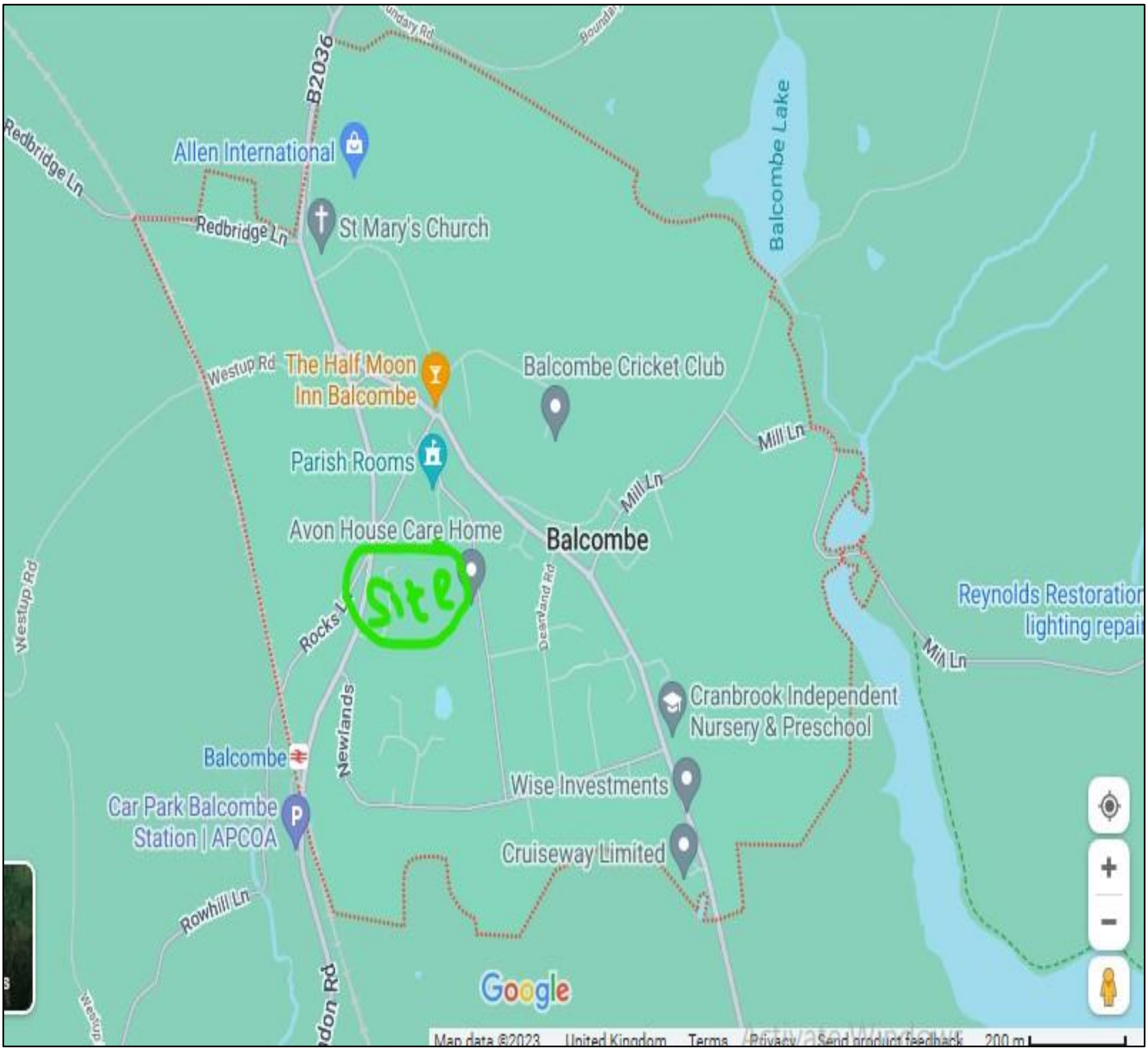
APPENDIX I
LOCATION OF CASE STUDY ON MAP



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APPENDIX II
PHOTOGRAPHS OF CASE STUDY

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APPENDIX III
PHOTOGRAPH OF SLIP SURFACE AND INCLONOMETER DATA