OPPORTUNITIES FOR SUSTAINABLE GEOTECHNICAL ENGINEERING PRACTICE: TWO CASE STUDIES FROM AUSTRALIA

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ABSTRACT

Geotechnical design elements are major consumers of energy and natural resources in civil and infrastructure projects. However, by applying appropriate levels of engineering and investigation, opportunities exist for more sustainable and resilient solutions that better understand the ground and geo-structure characteristics. This paper presents two project examples from Australia to illustrate such opportunities.

The first example is a residential complex development project proposed over a reclaimed land with underlying soft marine deposits in Sydney. An advanced site investigation revealed an opportunity to use preload and surcharge ground improvement methodology instead of the initially proposed extensive piled slabs. The earthworks were nearly completed, and geotechnical monitoring confirmed the design assumption. A project-specific earthwork specification was developed, considering the site won material characteristics and performance requirements of different zones of earthworks. Through collaboration between the designer and contractor, most of the site-won material could be used in specified zones of the earthworks on site, with or without treatment, without compromising the performance requirement.

The second example is a major new highway project, where value engineering led to a review of the concept design bridge foundations, retention systems, and site investigation results. Alternative structure types and amendments to the earthwork specification were recommended and justified by the local road authority. The proposed changes significantly reduced the construction cost and carbon footprint of the project, making it viable for ministerial approval. The paper presents a comparison of the CO emissions between the alternative solutions proposed and those initially considered, highlighting the contributions made in these projects to global and local sustainability goals.

1 INTRODUCTION

In an era marked by environmental challenges and the urgency of climate action, the importance of integrating sustainability principles into civil engineering projects cannot be overstated. Civil projects, often characterized by their substantial resource consumption and long-lasting impact, have a significant role to play in shaping a more resilient and environmentally conscious future. One of the key aspects of sustainability is the reduction of carbon footprint, which directly addresses the critical issue of climate change. By minimising carbon emissions throughout the lifecycle of a project, from construction to operation and eventual decommissioning, civil engineering can significantly contribute to global efforts to mitigate climate change. Embracing sustainable practices not only demonstrates a commitment to environmental responsibility but also yields economic benefits through enhanced efficiency, reduced operational costs, and increased project longevity. The incorporation of sustainability into civil projects is no longer a choice but a necessity to safeguard our planet for current and future generations.

In this paper, some of the global and local sustainability goals requirements are explained, some of the example methods to contribute to these goals in civil and, in particular, geotechnical engineering practice are materialised, and then two project examples from Australia are presented that exemplify how geotechnical engineering practices can align with the global and local sustainability goals, contributing to a more sustainable and resilient built environment. These examples demonstrate how considering ground and geo-structure characteristics can lead to innovative and environmentally conscious solutions addressing local and global challenges.

2 GLOBAL AND LOCAL SUSTAINABILITY GOALS

2.1 UNITED NATION SUSTAINABILITY GOALS

The United Nations (UN) has recognised the importance of sustainable development and has set forth 17 Sustainable Development Goals (SDGs) as part of the 2030 Agenda for Sustainable Development. These goals aim to address global challenges, including poverty, inequality, climate change, environmental degradation, peace, and justice (UN, 2023). Civil engineering projects have a significant role in contributing to several of these goals. Geotechnical engineering, being a vital aspect of infrastructure projects, can contribute to achieving these goals. The following SDGs out of 17 are listed below, which, to the authors, civil and geotechnical engineers could contribute most:

- Goal 6: Clean Water and Sanitation
  Civil engineering projects can promote access to clean water and sanitation, ensuring adequate water supply and wastewater treatment for communities. Efficient water management, rainwater harvesting, and sustainable drainage solutions, using recycled water sources for the construction of infrastructures are among the approaches that can support this goal.

- Goal 7: Affordable and Clean Energy
  By incorporating renewable energy sources and energy-efficient technologies, civil engineering projects can help promote affordable and clean energy access, reducing greenhouse gas emissions and mitigating climate change. Geotechnical engineers play a crucial role in achieving this goal by providing tailored geotechnical solutions for various infrastructures. This includes designing more sustainable foundations for onshore and offshore wind turbines, optimizing setups for solar farms, enhancing dam structures for hydroelectric power, and harnessing wave energy. Their expertise ensures that these energy projects are not only efficient but also environmentally responsible, contributing significantly to the global pursuit of affordable and clean energy.

- Goal 9: Industry, Innovation, and Infrastructure
  Infrastructure development is at the heart of Goal 9, and civil engineering projects can contribute by creating resilient, sustainable, and inclusive infrastructure that supports economic growth and societal needs, as further discussed in this paper.

- Goal 11: Sustainable Cities and Communities
  Civil engineering plays a crucial role in designing and developing sustainable urban areas, including efficient public transportation, green spaces, and resilient infrastructure, which are all essential components of sustainable cities and communities.

- Goal 13: Climate Action
  Addressing climate change is a top priority, and civil engineering projects can contribute by adopting climate-resilient design and construction practices, promoting low-carbon technologies, and implementing climate adaptation measures, as further exemplified in this paper.

- Goal 15: Life on Land
  Infrastructure development often involves land-use changes. Civil engineering projects can contribute to preserving biodiversity and ecosystems by adopting sustainable land-use practices and integrating green infrastructure.

2.2 INFRASTRUCTURE RATING SCHEME

Various regions around the world have established specific requirements and classifications to ensure sustainable practices in civil engineering projects. In Australia and New Zealand, the Infrastructure Sustainability Council (ISC) has played a leading role in setting standards and guidelines for sustainable infrastructure projects.

The ISC provides a comprehensive rating system known as the Infrastructure Sustainability (IS) Rating Scheme. This scheme assesses and certifies the sustainability performance of infrastructure projects across various sectors, including transportation, water, energy, and social infrastructure.

The IS Rating Scheme evaluates projects based on various sustainability categories, covering aspects such as governance, environmental impact, economic viability, and social outcomes (ISC,2023). The key categories typically include:

- Management and Governance: This category assesses the project's commitment to sustainability, including the implementation of sustainable policies, resource management, and stakeholder engagement.
- Environmental: The environmental category evaluates the project's impact on natural resources, biodiversity, greenhouse gas emissions, and water management, encouraging practices that minimize environmental harm.
- Economic: The economic category considers the project's life cycle cost analysis, economic efficiency, and value for money, ensuring that long-term financial benefits are considered.
- Social: Social aspects, such as community engagement, safety, and workforce welfare, are evaluated to promote projects that benefit and engage with local communities.

- Innovation: This category recognises projects that incorporate innovative solutions and technologies to enhance sustainability and efficiency.
- Liveability: Focusing on the end-users, this category assesses the project's impact on improving the quality of life for people who use or are affected by the infrastructure.

The IS Rating Scheme provides a rigorous framework for evaluating the sustainability credentials of infrastructure projects in Australia. It encourages stakeholders to adopt sustainable practices, promote innovation, and deliver long-term benefits for the community and the environment.

For civil engineering projects in New South Wales (NSW), compliance with ISC's sustainability requirements is becoming increasingly important for gaining approvals and achieving positive public perception. By adhering to the IS Rating Scheme, projects can demonstrate their commitment to sustainability and align with global goals, such as the UN's Sustainable Development Goals.

3 HOW CAN CIVIL ENGINEERS/GEOTECHNICAL PRACTITIONERS DRIVE SUSTAINABILITY ACROSS A PROJECT LIFECYCLE?

In the realm of civil and geotechnical engineering practices, the pursuit of sustainability has evolved into a cornerstone of responsible design and construction. This commitment to sustainable practices unfolds across various project phases, from conception to completion, and draws insights from a wealth of literature and research in the field.

3.1 PLANNING FOR SUSTAINABILITY

In the pursuit of sustainability, geotechnical practitioners hold a pivotal role right from the initial planning phase. This critical stage acts as a guiding compass, laying the foundation for subsequent decisions and offering a prime opportunity to infuse projects with environmentally conscious considerations. Through comprehensive analyses, rigorous risk assessments, and thorough feasibility studies, practitioners pave the way for identifying sustainable pathways while optimising overall project efficiency. This planning not only establishes the project's goals but also determines its potential to stand as a beacon of sustainability.

Geotechnical engineers play a significant role in promoting sustainability during the planning stage through several key strategies (Basu et al., 2015):

Early Stakeholder Engagement: Engaging stakeholders at the outset of the planning process serves as a crucial step. This involves involving individuals or groups with vested interests in the project, such as landowners, residents, businesses, and government agencies. By soliciting their input early on, geotechnical engineers can ensure that their unique needs are addressed, averting potential conflicts and project delays.

Thoughtful Evaluation of Environmental Impacts: Geotechnical engineers must meticulously assess the environmental consequences of various options. This encompasses an in-depth consideration of diverse factors, including the use of different materials, construction methodologies, and maintenance practices. It is important to note that the most sustainable choice may not always be the most obvious, underscoring the necessity for a comprehensive evaluation of all available options. For instance, in their selection of more sustainable options, engineers must thoroughly consider all aspects from start to finish. Take 'precast retaining wall panels' as an example: they might appear as a sustainable choice if the precasting is done on-site or in a nearby factory. However, for a project where the prefabricated panels need to be transported from a distant location, the energy consumption during transportation might outweigh their sustainability benefits. Another illustration could be the use of certain types of foundation systems, which may have lower material requirements but higher installation energy costs, leading to a nuanced evaluation of their overall environmental impact.

Integration of Sustainable Materials and Practices: Geotechnical engineering offers a wealth of opportunities for integrating sustainable materials and practices. For example, incorporating recycled aggregates into concrete compositions and employing bio-based geopolymers as binders are potent avenues (Chindaprasirt, 2022). Additionally, the adoption of sustainable construction practices can substantially reduce waste generation and optimise energy utilisation. There are some challenges in using sustainable materials which are further discussed later in this paper.

By adhering to these best practices, geotechnical engineers significantly strengthen the sustainability aspect of geotechnical projects. This proactive approach not only aligns with contemporary environmental imperatives but also contributes to the long-term resilience and success of projects in a rapidly evolving global landscape.

3.2 DESIGNING FOR A GREENER FUTURE

Transitioning into the design stage, the endeavour to embed sustainability fuses creativity with pragmatic engineering. The central wisdom lies in crafting solutions that are not only functional but also sustainable, without compromising performance. Engineers navigate through an array of green materials and innovative techniques, selecting those that harmonise with ecological consciousness and structural efficacy. Design decisions carry the torch of sustainability, illuminating the path to a greener future.

Further to key strategies mentioned above for the planning stage, which are valid in the design stage, there are further key strategies that geotechnical engineers could adopt to result in more sustainable solutions (Basu et. al, 2015):

Design for longevity: Geotechnical practitioners can design projects to last longer using durable materials and construction methods. This can help to reduce the need for maintenance and repairs, which can have a positive environmental impact.

Design for resilience: Geotechnical practitioners can design projects to be more resilient to extreme events, such as floods, earthquakes, and storms. This can help to protect people and property from damage.

Design for adaptability: Geotechnical practitioners can design projects to be adaptable to changes in the environment or in the needs of the community. Design for adaptability is a design approach that aims to make a structure or system able to adapt to changes in its environment or use over time. This can be achieved by using flexible materials and components, designing for future expansion or modification and incorporating redundancy into the system. This can help to ensure the project remains sustainable over time (Vahidifard et al., 2021).

3.3 CONSTRUCTING SUSTAINABILITY

As the project embarks on the construction stage, the focus on sustainability remains unwavering It is here that practitioners take a multidimensional approach, considering methodologies, materials, energy consumption, and waste management. Carefully curated construction techniques, materials sourced with sustainability in mind, and strategies that minimise waste and toxicity collectively foster an environment of responsible construction. The construction stage becomes an arena where principles are translated into tangible results.

3.4 COMMISSIONING FOR THE LONG HAUL

Beyond completion, the torchbearers of sustainability shift their focus to the operation stage. The legacy of sustainable practices extends into this phase, where choices made during planning, design, and construction shape the ongoing operational efficiency of the project. Here, the emphasis rests on continual monitoring, maintenance, and optimisation to ensure that the project upholds its commitment to sustainability. Every operation becomes a testament to the far-reaching impact of thoughtful decisions taken earlier in the project lifecycle.

4 SUSTAINABLE MATERIAL SELECTION: GUIDING ENGINEERS TOWARDS A LOW CARBON FOOTPRINT

The use of sustainable materials in geotechnical engineering is a growing field, with many opportunities to reduce the environmental impact of geotechnical projects. However, there are also some challenges associated with using these materials, such as their lack of availability, high cost, and uncertainty about their long-term.

For instance, bio-based polymers, often lauded for their reduced environmental impact, may raise questions about their longevity and performance under varying conditions. Similarly, recycled plastics, while contributing to waste reduction, can prompt inquiries about their resilience in harsh environments. Additionally, the reduced use of coal as a fuel source, a sustainable practice, may lead to a limited future source of fly ash and slag for replacing Portland cement in concrete. These examples underscore the need for thorough assessments and ongoing monitoring to ensure sustainable materials maintain their environmental benefits over extended periods.

Despite these challenges, there are many reasons to use sustainable materials in geotechnical engineering. These materials can help to reduce the use of virgin materials, minimise waste, and conserve energy. They can also save money in the long run by reducing the need for maintenance and repairs, and by increasing the lifespan of structures. Additionally, sustainable materials can help to improve the quality of life for people and the environment by reducing pollution, creating jobs, and promoting sustainable development.

Some specific examples of sustainable materials that are being used in geotechnical engineering include recycled aggregates, bio-based geopolymers, and low-carbon concrete. As the demand for sustainable materials grows, the availability and cost of these materials is likely to decrease, and their performance and standardisation will improve. As a result, the use of sustainable materials in geotechnical engineering is likely to become more common in the future (Mills and Attoh-Okine, 2014).

4.1 CARBON FOOTPRINT HIERARCHY OF MATERIALS

One of the critical factors in achieving sustainability across the lifecycle of a project lies in the careful selection of materials. Each material employed in construction bears a unique carbon footprint, reflecting its environmental impact from production to disposal. It is imperative to increase awareness among engineers regarding this material hierarchy, aiding them to make conscientious choices that align with sustainability goals.

Figure 1 below illustrates the material hierarchy for typical materials utilised in the civil engineering project (WSP,2023), which underscores the varying carbon footprints associated with different materials. This hierarchy serves as a guiding principle for engineers, as they navigate the landscape of material selection.

Metals, such as steel and aluminium, stand at the higher end of the hierarchy, carrying significant carbon footprints due to energy-intensive extraction and processing. Plastic, another high-carbon material, joins this tier due to its petroleum-based origins and limited recyclability. Notably, concrete, despite its ubiquity in construction, holds a considerable carbon footprint, primarily owing to the energy-intensive cement production process.

Conversely, materials like earth fill and treated timber emerge as the flagbearers of low carbon footprints. This insight underscores the wisdom of harnessing natural resources that demand fewer energy inputs for extraction and processing.

To further diminish carbon footprints, the integration of recycled materials emerges as a transformative strategy. Utilising byproducts of industries, such as coal fly ash and iron furnace slag, as pozzolanic additives in concrete not only enhances its performance but also reduces the environmental impact by utilising materials that would otherwise go to waste.

In conclusion, the journey towards sustainability demands a keen understanding of material hierarchy. Engineers possess the power to sculpt a project's environmental legacy by making sensible material choices. This entails a conscious shift towards low carbon footprint materials, recycling, and judicious utilisation of industrial byproducts. As engineers learn this attitude into their practice, each project takes steps towards a future defined by sustainable ingenuity and responsible construction practices.

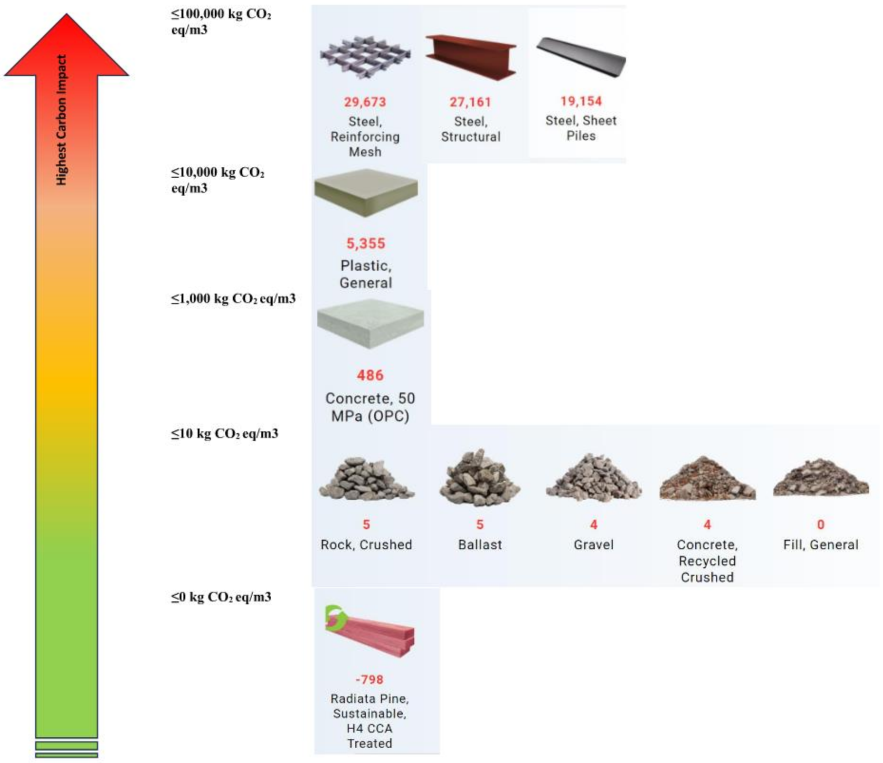

Figure 1: Material hierarchy in carbon impact

In the following sections of this paper, we will demonstrate how geotechnical engineering practices can contribute to sustainable infrastructure development in accordance with the IS Rating Scheme, using case studies from Australia as examples of successful implementation. These projects exemplify how sustainable geotechnical solutions can not only meet the requirements of the ISC but also help advance the broader goals of sustainability and resilience in civil engineering projects.

5 CASE STUDY 1: RESIDENTIAL COMPLEX DEVELOPMENT IN SYDNEY

5.1 PROJECT DESCRIPTION

A residential complex project was proposed on reclaimed land with underlying soft marine deposits in Sydney. This project encompasses four separate multi-storey residential buildings, each with one or two-level basements, along with a communal garden zone and associated civil works. The civil works include the construction of new access roads within the site, a subsurface drainage system, underground utilities, and landscaping efforts. The proposed construction has been planned in different stages, with Stage 1 involving the construction of Block D on the eastern end of the site, as well as three access roads, as highlighted in Figure 2.

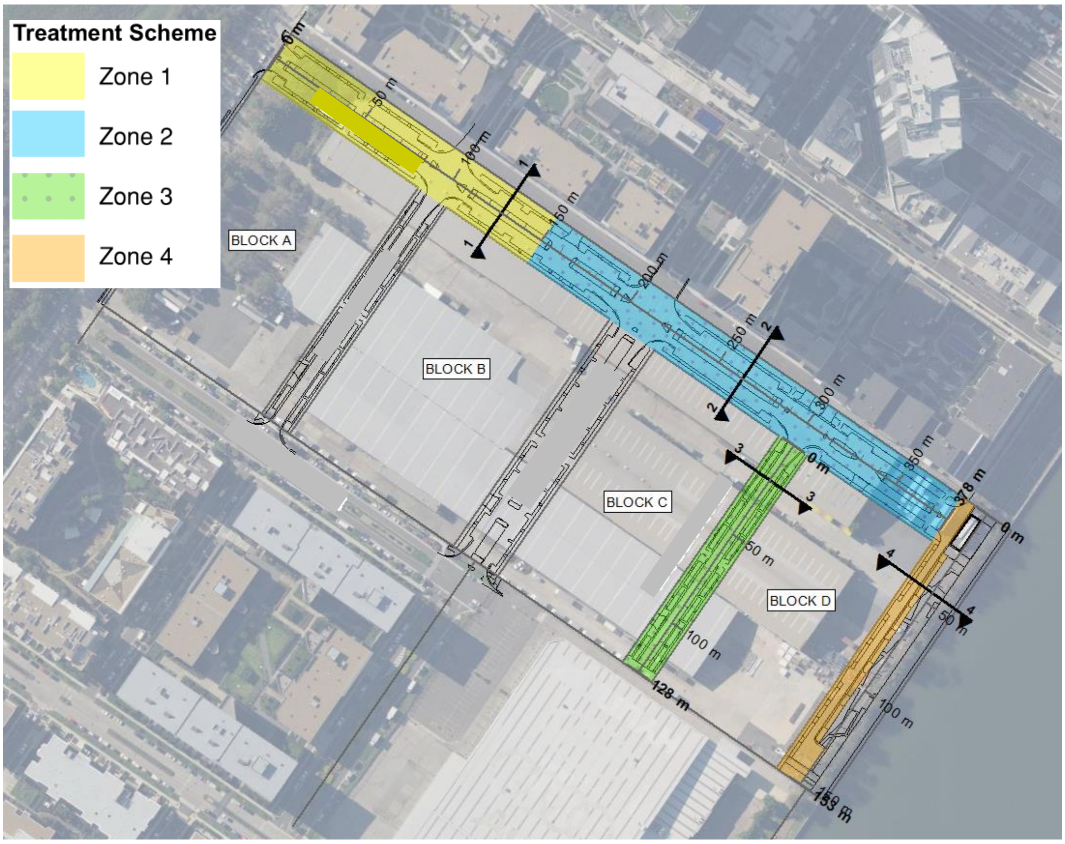

Figure 2: Proposed Stage 1 access roads

Available geotechnical data indicated that the site was underlain by compressible materials comprising a variable thickness of very soft to firm clay/peat (estuarine, alluvial, and/or dredged fill) and loose to medium-dense sand. The upper few meters of the soft soil were inferred to be associated with the reclamation and filling works undertaken on site between the 1930s and 1950s (Figure 3). Further information about the site geology and history has been presented by Johnston and Terzaghi (2021). The site was occupied with warehouse buildings used for the storage of goods. It has a history of ongoing settlement issues, with some warehouse structures and access roads across the site having undergone excessive settlements, resulting in cracks in internal partitions, floor slabs, and tension in the steel frameworks. These issues warranted repair and rectification works.

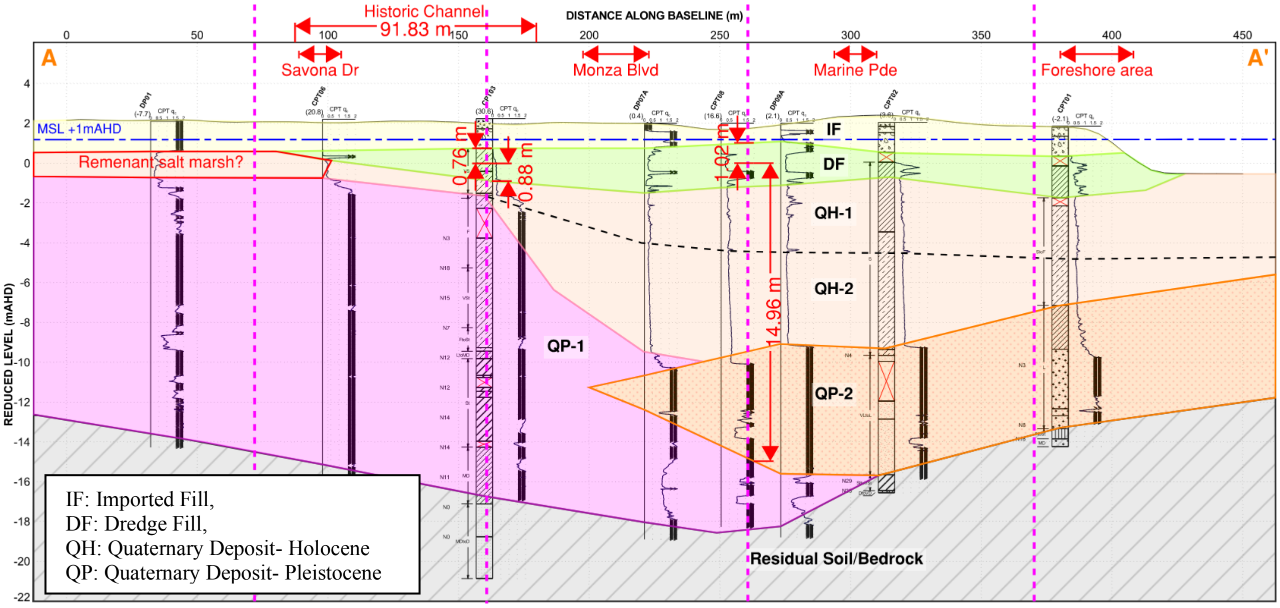

Figure 3: Inferred subsurface profile at the project site.

5.2 SUSTAINABILITY CONSIDERATIONS

Planning Stage

The concept design by another consultant considered a structural solution, including suspended slabs founded on bored piles that extended into the sandstone bedrock along all access roads (see Figure 4). This approach aimed to mitigate the impact of anticipated long-term consolidation and creep settlements. It was influenced by the solution adopted in neighbouring developments and concerns regarding the long-term settlement of the proposed access road. There was also apprehension about the risk of lateral squeeze and its potential adverse effects on the foundations of neighbouring properties and an adjacent box culvert with piled foundations. The available geotechnical investigations had been planned and executed with this in mind, focusing primarily on confirming the top of the bedrock and characterising the sandstone. As a result, they provided very limited data on the underlying soft soil layers.

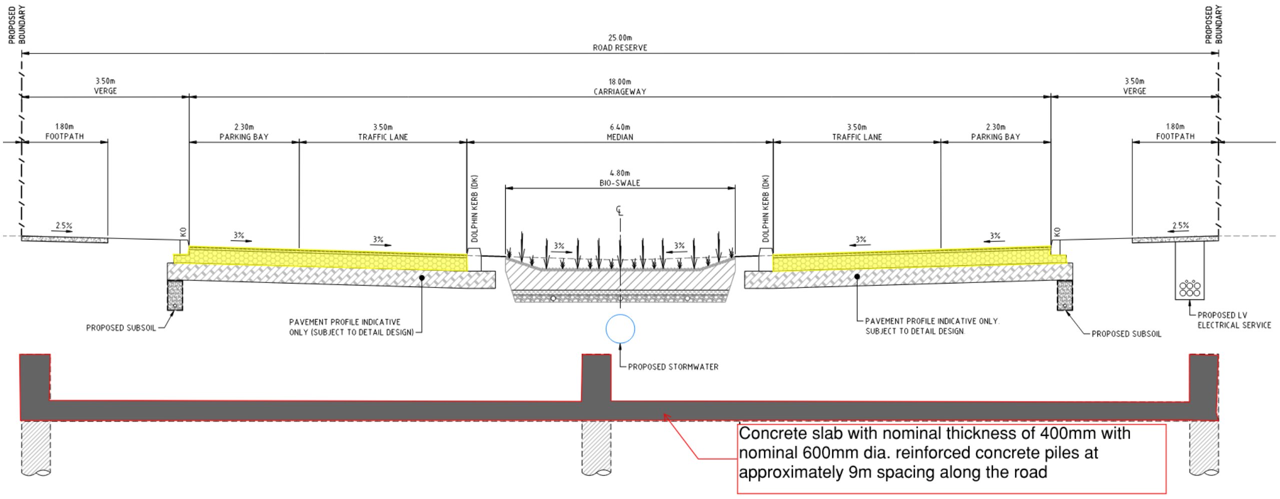

Figure 4: Typical section of piled slab solution proposed by others

A due diligence study by the authors considered other feasible, more sustainable, and cost-effective solutions, such as preload/surcharge and rigid inclusions, instead of the extensive piled option. Following a subsequent desktop study on the site's history and geology (refer to Johnstone and Terzaghi, 2021), as well as an advanced site investigation, an opportunity emerged to employ preload and surcharge ground improvement methods in lieu of extensive piled slabs for the proposed concept design. A site walkover around the site and neighbouring developments was conducted, which highlighted potential issues associated with a piled option. This included cracks in civil and landscape structures, along with differential settlements observed at the interface of the piled structures, access roads, pathways, stairways, and other areas integrated into the landscape that were founded on natural untreated ground. This also underscored the advantages of preloading the site, further affirming the merit of this soft option compared to the initially proposed rigid piled option.

Design Stage

A comprehensive geotechnical investigation was meticulously planned and executed. This included boreholes, Seismic Piezocone Penetration Tests (SCPTu) and Seismic Dilatometer Marchetti Tests (SDMT), as well as laboratory testing on undisturbed samples retrieved from the underlying soft soils. The information garnered, coupled with desktop studies on the site's history, geology, and anecdotal data regarding previous settlements on site, enabled us to accurately characterise the variable subsurface profiles across the site. This exercise applied advanced knowledge in soft soil engineering beyond standard engineering practices.

Finite Element Modelling using Plaxis was employed to assess potential long-term settlements at the proposed road embankments and their impact on existing structures and utilities. The soft soil creep material models utilised in Plaxis were extensively calibrated against available information on site loading and settlement history. Ground improvement strategies for the proposed earthworks were designed, incorporating preload and surcharge methods, as outlined in Table 1 (refer Figure 2 above for the extent of treatment zones on the site plan).

Table 1: Summary of analysis results

Treatment Zone	Treatment Scheme	Preload Duration	Residual Settlement After Removal (Note 1)
Zone 1	Preload	6 months	15-20mm
Zone 2	Preload with 0.5m surcharge	6 months	40-50mm
Zone 3	Preload with 0.5m surcharge and 2.0m spaced wick drains	9 months	30-50mm
Zone 4	Preload with 0.5m surcharge	9 months	40-50mm

Note: 1. Variable settlement anticipated in each zone due to variable thickness and potentially different stress history of soft soil layer at each zone.

A geotechnical instrumentation and monitoring plan was developed and implemented during the construction phase. This plan encompassed settlement plates and extensometers placed strategically across the fill embankments, along with inclinometers positioned near sensitive structures and utilities, as well as along the site boundaries. The results of this monitoring closely aligned with the predicted outcomes. This alignment signifies a well-founded characterisation of the site's subsurface condition and validates the efficiency of the selected approach. This correlation between actual and anticipated outcomes provided confidence in the accuracy of the subsurface assessment and the appropriateness of the chosen methodology.

Construction Stage

Earthwork specifications are crucial documents that outline the precise requirements for earthwork activities, encompassing excavation, fill, material properties and compaction. They play an instrumental role in ensuring construction safety, durability, and performance of earthworks, while upholding necessary standards. Nevertheless, challenges often emerge during their development.

One prominent issue arises from blindly copying specifications from unrelated sources or amalgamating more stringent requirements from literature or other projects without considering their relevance to the specific site. This can lead to the inclusion of unnecessary or impractical requirements for the project, resulting in needless costs, complications during implementation, and potentially less sustainable solutions. Moreover, specifications may stipulate materials without a comprehensive assessment of their impact and associated expenses. This can inadvertently lead to the selection of costlier or harder-to-acquire materials, overlooking more feasible and sustainable alternatives.

Furthermore, specifications may occasionally overlook site-specific constraints and opportunities for value engineering. For instance, a specification might insist on extensive excavation without considering the potential for reusing excavated material elsewhere on the site. These oversights can lead to inefficiencies and missed opportunities for cost savings or reducing the project's carbon footprint.

To tackle these challenges, a collaborative approach is imperative. Involving all stakeholders, including the geotechnical engineer, contractor, and owner, ensures that specifications are tailored to the project's unique needs. Regular reviews are essential to maintain their relevance and feasibility.

Additional strategies for effective specification development include clarity and conciseness, adherence to industry standards and codes, flexibility to accommodate evolving project needs, and seeking feedback from contractors who bring valuable practical insights.

By adopting these practices, earthwork specifications can be crafted to not only meet the necessary standards but also streamline operations, control costs, and enhance overall project efficiency and performance.

In this project, a project-specific earthwork specification was devised, considering the site-won material characteristics and performance requirements for fill to be used in different zones of the proposed earthworks (e.g., fill within the zone of influence of pavement, pathway subgrade, structural backfill, swale, or garden beds), as well as project constraints. Collaborative efforts between the designer, contractor, and developer allowed us to develop an earthwork specification and design documents that enabled the reuse of most site-won material on site, with or without treatment, without compromising the performance requirements.

5.3 SUSTAINABILITY OUTCOMES

The proposed ground improvement, utilising preload and surcharge methodology, led to saving of over 7000 m^3 of concrete and more than 800 tons of reinforcement steel in this project, as opposed to the initially considered pile slab solution. This not only resulted in a substantial cost saving but also a significant reduction in carbon emissions - a reduction of over 5500 tons. It is worth noting that this figure does not account for any potential reduction in carbon emissions due to decreased imported fill volume and re-use of demolition and excavation materials on site.

6 CASE STUDY 2: MAJOR HIGHWAY PROJECT

6.1 PROJECT DESCRIPTION

The other example case was a new highway project, which its details cannot be disclosed. The scope of works comprised major cut and fill, several bridge construction and tunnelling works. Value engineering prompted a review of concept design bridge foundations, retention systems, and site investigation results to seek alternative structural solutions and earthworks specifications to make the project commercially viable.

6.2 SUSTAINABILITY CONSIDERATIONS

The following are some of the sustainability considerations that were made in the reference design of this project:

- **Use of more sustainable structural alternatives:** The project team considered a variety of structural alternatives, including those that used recycled materials or that were designed to be more energy efficient. The team selected a structural solution that was both cost-effective and sustainable. For example, some of the bridge structure systems were changed and optimised and concrete retaining walls were replaced with soil nail walls.
- **Reducing the amount of rock that needed to be processed:** The initial cost estimate of the project assumed that all the excavated rock from the tunnelling works would need to be processed into earth fill. However, a literature review was undertaken on the specifications of earthworks used globally and on the rearrangement of rock fill particles as well as subsequent settlements. Based on this research, the team concluded that maximum particle size of rock fill materials could be revised in the specification so some of the site-won rock could be used in lower portions of high fill embankments or noise mounds without being processed. This reduced the amount of rock that needed to be processed, which saved energy and reduced the environmental impact of the project.
- **Providing opportunities for innovation:** The road authority provided opportunities for the tenders to propose and use more innovative solutions. This helped to ensure that the most sustainable solutions were implemented.

6.3 SUSTAINABILITY OUTCOMES

The exemplary approach taken in the value engineering and reference design of this project not only ensured its financial viability but also led to substantial sustainability benefits. These outcomes were achieved through a combination of strategic decisions and innovative practices, highlighting how the project aligns with and contributes to broader sustainability goals.

- **Reduction in material processing for lower energy consumption**

The decision to utilise site won rock without extensive processing was a pivotal sustainability move. It substantially curtailed the energy-intensive processes required for material crushing, grinding, and other forms of processing. This reduction in energy consumption not only would lower the project's carbon footprint but also minimise its environmental impact, aligning with global efforts to conserve energy and reduce emissions.

- **Local and site won material utilisation for reduced traffic movements**

By prioritising the use of locally sourced materials and use of site-won materials, the project would significantly reduce the need for long-distance transportation of construction materials. This not only curtails associated carbon emissions from transportation but also bolsters the local economy by supporting nearby material suppliers.

- **Innovation: departure from standard procedures**

The project's willingness to depart from conventional practices and consider alternative solutions demonstrated a commitment to innovation. This mindset not only would lead to more sustainable outcomes but also set a valuable precedent for future projects. By fostering an environment of creativity and open-mindedness, the project would contribute to a culture of continual improvement and adaptation within the industry, thereby advancing the cause of sustainability.

7 CONCLUSIONS

In an era defined by environmental challenges, integrating sustainability into civil engineering is paramount. Projects' long-lasting impact demands a commitment to a resilient, eco-conscious future. This includes minimising carbon emissions throughout a project's life cycle, a critical step in combating climate change.

Geotechnical engineering plays a vital role in this pursuit. Aligning with global and local sustainability goals, it exemplifies practices like the Infrastructure Sustainability Rating scheme. Through strategic planning, thoughtful design, and conscientious construction, geotechnical engineers lead the way.

Hierarchy of materials in terms of carbon footprint, importance of project specific specifications thoughtfully developed and tailored for a project were discussed and elaborated in this paper.

Case studies presented which highlighted these principles in action and it was demonstrated that such considerations during planning, design and construction phase of a project could result in substantial cost savings and emissions reduction. Earthwork specifications tailored to site-specific conditions further enhanced sustainability.

In essence, geotechnical engineering embodies innovation, environmental consciousness, and responsible construction. Practitioners are the guardians of a greener future, where engineering aligns with ecological wisdom.

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