Keynote Address

Working Towards Net Zero Emissions – Role of Geo-professionals

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ABSTRACT

The global movement in climate change protection is to work towards Net Zero Emissions by around 2050. Net zero emissions refers to reducing greenhouse gas emissions to zero, or as close to zero as possible and offsetting any remaining emissions (e.g. clean energy projects).

This paper outlines some of the steps geo-professionals should take to understand the project Sustainability and Resilience requirements, and areas where we can influence design and construction to meet or exceed those requirements. Sustainability, in relation to geotechnical and geo-environmental work, is an integrated process that balances the social, environmental and financial aspects of planning, design and construction, while managing risk, safety, quality and durability to acceptable standards. Resilience is the ability to cope with uncertain yet extreme events and climate change that may occur over the life cycle of the infrastructure, and to allow expeditious recovery and reconstitution of critical services with minimum impact to public safety and health, the economy, and national security. Geo-professionals are at the forefront of being able to contribute towards sustainable and resilient infrastructure in areas ranging from innovative investigation techniques, use of alternative sustainable resources, reuse of existing foundations, minimising waste, and efficient designs to minimise construction time and materials. Some examples are given in this paper to illustrate where geotechnical designs have contributed to achieving sustainable outcomes.

Keywords: sustainability, resilience, geo-environmental, engineering, infrastructure, design and construction

1 INTRODUCTION

Brundtland (1987) defines sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It is an integrated process that balances the social, environmental and financial aspects of planning, design and construction, while managing risk, safety, quality and durability to acceptable standards. The Infrastructure Sustainability Council of Australia (ISCA) has added governance to social, environmental and financial aspects to form the quadruple bottom line on sustainable developments. One of the elements of governance that has been high on the agenda lately is the avoidance of modern slavery (i.e. ensuring products are not sourced from sweat shops in third world countries).

The author is of the opinion that designing for resilience goes hand in hand with sustainable developments. Resilience is the ability to cope with uncertain yet extreme events and climate change that may occur over the life cycle of the infrastructure, and to allow expeditious recovery and reconstitution of critical services with minimum impact to public safety and health, the economy, and national security.

Developing sustainable infrastructure strategies is increasingly important because in Australia, around 70% of our greenhouse gas emissions are either directly attributable to, or influenced by infrastructure development which is a major area of work for geo-professionals. Such strategies are typically being developed by government and other agencies such as Australian Sustainable Built Environment Council (ASBEC), ISCA, Green Building Council of Australia and ClimateWorks Australia with the support of large industry partners.

Therefore, the big question is, what role can geo-professionals play in working towards a zero emissions future in sustainable infrastructure development?

Many of us may argue that we have always played a role in sustainable infrastructure development by coming up with cost- and time- effective designs. In some ways this is true – less cost and less time in construction do often equate to the use of less materials and less energy in construction, and may also enhance the social outcome. However, well before the emergence of sustainability awareness in construction in the 1970s, contractors have always demanded engineering design solutions to be cost- and time- effective in order to be price competitive without necessarily thinking about the broader issues of sustainability. The author's opinion is that this is a "business as usual" approach. Sure, this approach does generally contribute to less carbon emission, but it is neither a strategy nor an approach that could help us to achieve Net Zero Emission vision in as short a time as possible.

Fortunately, according to Denis (2019) many large companies in the construction industry are taking a more serious and proactive approach to the climate change protection movement by making Net Zero Emission pledges. A lot of effort is being made in relation to sustainability in the aboveground space (e.g. solar energy, building insolation, LED lighting, internal building materials etc.) but sustainability below the ground has probably lagged behind the aboveground space and there is an opportunity for geo-professionals to really make big leaps forward in this space through looking at what we normally do through a sustainability lens. Geo-professionals are in an excellent position to assist the infrastructure industry to do the same by adopting a more holistic approach, rather than simply continuing the "business as usual" approach. In order to do this, we need to start adopting the following approach:

- Understand the language and the integrated process on sustainable development;
- Gain an appreciation of the project requirements on sustainability;
- Develop the ability to compare carbon emission outcomes for different designs;
- Have greater interaction with sustainability discipline team members on the project;
- Communicate the benefits of the preferred or selected solutions in relation to sustainability to the stake holders.

2 SUSTAINABILITY DESIGN PROCESS

2.1 Categories of Sustainable Designs

Sustainable design involves the balancing of environmental, economic and social factors, so that the geotechnical system developed satisfies the safety and code requirements and can be constructed within the allotted time frame for a competitive price. Such a design involves efficient scheduling, the use of available local resources, and the avoidance of excess material and labour costs that may be inherent in over-conservative design. Thus, a key aspect of sustainability is minimisation of resource use, costs and environmental impacts. For example, sustainability can be enhanced by the following procedures:

- Use of renewable energies such as wind, solar, hydro power generation and geothermal energy;
- Minimising the use of concrete and other manufactured materials;
- Minimising construction time;
- Minimising waste;
- Minimising energy use;
- Minimising "whole-of-life" cost by considering Net Present Value of both capital and future maintenance cost and resources;
- Maximise the use of site won earthworks materials by modification (if necessary) to meet material strength and durability specifications;
- Retrofitting and reusing existing foundations or geo-structures (where appropriate);
- Minimising intrusive geotechnical investigations by the supplementary use of innovative investigation techniques such as geophysics;
- Designing and constructing reliable and resilient geo-structures to cater for natural and man-made hazards.

The concepts of sustainability and resilience should be considered concurrently. Resilience aims to develop robustness against disturbances, and to enable rapid recovery following such disturbances.

The aim should be to ensure that resilience in geotechnical infrastructure is developed while sustainable practices are undertaken.

2.2 Project Sustainability Requirements

Most major infrastructure projects, particularly those initiated and funded by the government, now usually have project specific sustainability requirements. Unfortunately, these are usually considered by the Contractors and their specialist sustainability consultants without input from the geo-professionals at the project development stage. The author is of the opinion that the geo-professionals should start paying more attention to these project requirements so that we can play an early role in identifying potential opportunities.

In these projects, a number of general sustainability requirements are usually specified, which may include those discussed in Section 2.1 above, and a set of project specific targets. An example of a project specific sustainability targets for a recent major Transport for NSW (TfNSW) infrastructure project in NSW is shown in Table 1.

Table 1: Example of Project Specific Sustainable Targets for a recent TfNSW Infrastructure Project in NSW

No	Target
1	Minimum 5 Star Rating using the Green Building Council of Australia Green Star Design & As Built Rating for the Project.
2	Achieve at least 15% improvement in total annual energy consumption over a reference station based on Section J minimum performance requirements as defined by the National Construction Code Building Code of Australia (NCC BCA) using JV3 methodology. The 15% design improvement and reference station must include all building related energy end uses (excluding process, communication and specialist equipment energy loads).
3	Use a minimum 5% bio diesel mix for all diesel powered plant and equipment and a minimum 10% blended ethanol mix for all petrol powered plant and equipment wherever possible.
4	Offset at least 25% of the total electrical needs of the Contractor's Activities using either or a combination of: (i) purchase of Australian Carbon Offset Credits; and / or (ii) purchase of renewable energy from an Accredited Renewable Energy Supplier renewable energy or carbon offsets.

No	Target
5	Reduce greenhouse gas emissions from the Contractor's Activities by at least 20% from the project baseline greenhouse gas footprint, to be demonstrated determined using the "TfNSW Carbon Estimation and Reporting Tool (CERT)"
6	Recycle or reuse at least 95% of inert and non-hazardous construction and demolition recyclable waste, excluding spoil.
7	Beneficially reuse 100% of reusable spoil.
8	Recycle or reuse 60% of office waste.
9	Use a maximum total construction water demand of *[target to be identified in the Sustainability Plan]* kL consisting of *Mains Water Consumption Target to be identified in the Sustainability Plan]* kL of water from potable sources and *[Non-Potable Water Consumption Target to be identified in the Sustainability Plan]* kL of water from non-potable sources.
10	Achieve a predicted operational potable water demand reduction of 33% below a reference station, to be demonstrated using the Green Star Sydney Metro Tool credit 22 Potable Water Reduction Performance Pathway
11	60% of reinforcing bar and mesh used during construction to be produced through energy reduction processes.
12	Greenhouse gas emissions must be less than the Carbon Emission Target of [target to be identified in the Sustainability Management Plan] tCO2e during the Contractor's Activities.
13	A maximum consumption of [Electricity Consumption Target to be identified in the Sustainability Management Plan] kWh of electricity during the Contractor's Activities.
14	A maximum consumption of [Electricity Consumption Target and Fuel Consumption Target to be identified in the Sustainability Management Plan] kWh of electricity and KL of fuel during the Contractor's Activities.
15	A minimum 15% reduction in the environmental footprint of the materials used for the Contractor's Activities, compared to a business-as-usual case.
16	Reduce Portland cement content in concrete by an average of at least 25% through replacement by supplementary cementitious materials such as fly ash or slag. Opportunities for further reduction will be investigated by carrying out trial mixes and testing.

It can be seen from the table above that geo-professionals can have direct influence on Items 5, 6, 7, 12, 13, 14, 15, and 16 by considering alternative designs that could benefit the sustainability outcome during the Contractor's activities. Therefore, it is essential that collaboration and integration of design and construction activities from the geo-environmental engineering and other disciplines such as construction and sustainability specialists take place in order to maximise the sustainability outcomes for each project, and to ensure the sustainability outcomes achieved by the geotechnical design are recognised by the sustainability specialists.

2.3 Holistic Process

Basu et al (2013) consider sustainability can be looked upon as a dynamic equilibrium between four E's - engineering design, economy, environment and equity (same as the "social" aspect used in this paper), as described in Figure 1.

Basu et al (2013) describes that "*the four E's approach of sustainable engineering, the sustainability objectives that may be incorporated in geotechnical projects are: (i) involving all the stakeholders at the planning stage of the project so that a consensus is reached on the sustainability goals of the project (such as reduction in pollution, use of environment friendly alternative materials, etc.), (ii) reliable and resilient design and construction that involves minimal financial burden and inconvenience to all the stakeholders, (iii) minimal use of resources and energy in planning, design, construction and maintenance of geotechnical facilities, (iv) use of materials and methods that cause minimal negative impact on the ecology and environment, and (v) as much reuse of existing geotechnical facilities as possible to minimise waste. This approach aims at reaching a dynamic equilibrium between engineering integrity, economic efficiency, environmental effectiveness, and social acceptability and equity*."

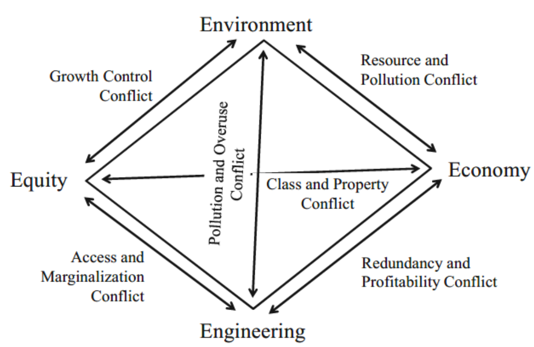

Figure 1. The four E's of sustainability in engineering projects (Basu et al, 2013)

Misra and Basu (2011, 2012) developed a sustainability assessment framework for pile foundation projects. The framework considers a life-cycle view of the pile construction process and a multicriteria framework of geotechnical design as shown in Figure 2.

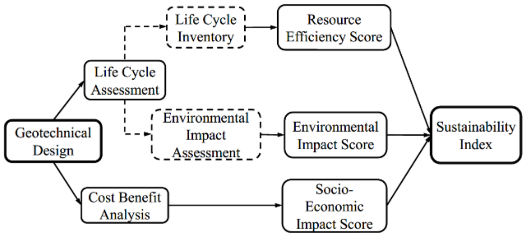

Figure 2. Multicriteria Framework of Pile Foundation Design Proposed by Misra and Basu et al (2011, 2012)

The multicriteria framework of pile foundation design shown in Figure 2 could equally be applied to other geo-environmental projects, and or material production processes.

An essential element of the multicriteria assessment process is the weighting of each criteria in relative importance (Belton and Stewart, 2001) and this must be carried out with all project stakeholders on a project specific basis.

For example, Holm et al (2013) presents a case study on the use of multicriteria framework for the disposal of dredged, contaminated material at the Port of Gothenburg in Sweden. A number of disposal methods including landfill, sea disposal, rock chamber disposal and solidification / stabilisation options were considered. Each option was assessed in relation to energy use and climate impact both of which include the contributory components in production, transport, construction and maintenance. Weighted scores were then given to the environment, social and economic targets and summed to form a total performance score. In that example, economic and environmental criteria were given 2 and 1.5 times the weight of social criteria, respectively, and it was demonstrated through the multicriteria analyses that the rock chamber disposal and solidification / stabilisation options provided the highest performance score. It would appear that various organisations have established in-house multi-criteria analysis to assess sustainability of options in the remediation space, and there is no reason why this approach cannot be used in the geotechnical space.

Another important aspect of sustainability is innovations that are quite often associated with such challenging projects. Innovations are important to sustainable development because they can contribute to social, economic and financial benefits.

2.4 Embodied Carbon/Emission Estimates

The term embodied carbon is the sum of all the greenhouse gas emissions attributed to the materials throughout their life cycle, from extracting from the ground, manufacturing, construction, maintenance and end of life/disposal. It is also called the carbon footprint and is measured by the sum of all green house gases (GHGs) to produce the materials. In order for comparison to be made, an equivalent carbon dioxide emission factor, usually in units of $kgCO_2e$ per m^3 or per tonne, is used for different materials.

The CO_2 emission for different materials will differ from country to country due to different resources available and will also be dependent on the site location with respect to transportation requirements. For concrete, it will also depend on the mix design of the raw materials used for different concrete strengths (Kim et al, 2016, Purnell, 2013). Furthermore, other factors such as CO_2 emission associated with long-term operation of the constructed product may also influence the overall sustainability score of the project. For example, NRMCA (2008) quoted research conducted by the National Resources Council of Canada has shown that heavy trucks traveling on concrete pavement accumulate statistically significant fuel savings, ranging from 0.8% to 6.9%, versus asphalt pavement for major urban arterial highways. These fuel savings lead to reductions in greenhouse gas emissions and air pollutants, with equivalent CO_2 reduction ranging from 1,039 tonnes to 8,950 tonnes over the life of the pavement.

On major infrastructure projects, the estimate of CO_2 emission and/or reduction from a reference design is usually carried out by the project sustainability specialist. However, the contribution from the geo-environmental profession can be over-looked unless there is close collaboration between the different disciplines. For this to take place, it is useful for the geo-professionals to have some awareness of the CO_2 emission factors commonly used for different materials or processes. For example, TfNSW has provided extensive policy and guidelines for sustainability design and construction, including a Carbon Emission Reporting Tool (CERT) v2 (2017) which can be downloaded from the website provided in the reference section of this paper. Some of the CO_2 emission factors used in CERT v2 are summarised in Table 2.

Table 2: Extract of CO_2 Emission Factors used in The Carbon Emission Reporting Tool (CERT) v2 provided by Transport for NSW

Material / Process	**Unit**	**Emission Factor**
Ready mix concrete:		
≤ 20 MPa	$kg.CO_2e/m^3$	257
25 MPa	$kg.CO_2e/m^3$	285
32 MPa	$kg.CO_2e/m^3$	332
40 MPa	$kg.CO_2e/m^3$	398
50 MPa	$kg.CO_2e/m^3$	445
60 MPa	$kg.CO_2e/m^3$	445
80 MPa	$kg.CO_2e/m^3$	539
> 80 MPa	$kg.CO_2e/m^3$	633
Portland Cement	$kg.CO_2e/t$	948
Fine Aggregates	$kg.CO_2e/t$	4.3
Coarse Aggregates	$kg.CO_2e/t$	5.7
Recycled (coarse) aggregates	$kg.CO_2e/t$	4.4
Reinforcement steel bars (Australian product)	$kg.CO_2e/t$	1900

Material / Process	Unit	Emission Factor
Reinforcement steel bars (Imported)	kg.CO_2e/t	2000
Reinforcement steel mesh (Australian product)	kg.CO_2e/t	2600
Reinforcement steel mesh (Imported)	kg.CO_2e/t	2700
Asphalt	kg.CO_2e/t	65
Reinforced concrete pipes	kg.CO_2e/t	280
Steel pipe and tube (Australian product)	kg.CO_2e/t	3000
Steel pipe and tube (Imported)	kg.CO_2e/t	3100
HDPE pipes	kg.CO_2e/t	3025
PVC pipes	kg.CO_2e/t	3569
Timber (structural softwood)	kg.CO_2e/t	-660
Timber (structural hardwood)	kg.CO_2e/t	-737
Timber, MDF/Particleboard	kg.CO_2e/t	-175
Timber, plywood	kg.CO_2e/t	-335
Waste Disposal to landfill:		
Transport (50 km)	kg.CO_2e/t	6.45
Transport to recycling centre (22 km)	kg.CO_2e/t	2.838
Construction and demolition waste (inert)	kg.CO_2e/t	0
Construction and demolition waste (timber and vegetation)	kg.CO_2e/t	600
Construction and demolition waste (mixed waste)	kg.CO_2e/t	200
Transport Emission:		
Rigid truck	kg.CO_2e/tkm	0.129
Articulated truck	kg.CO_2e/tkm	0.0726
Rail	kg.CO_2e/tkm	0.0255
Shipping	kg.CO_2e/tkm	0.00893

3 PROJECT EXAMPLES

Presented below are some examples of engineering projects in which the author considers sustainability outcomes have been achieved. For many of the projects, no specific focus was made on sustainability at the time. Nevertheless, they illustrate that if the requirement to balance the financial, social, and environmental factors are considered, sustainable solutions are often achieved, and that potentially greater success can be achieved in developing sustainable geotechnical solutions if there is more collaboration between the geotechnical engineers and other disciplines, including sustainability specialists.

3.1 Ballina Bypass Alliance

The Pacific Highway Upgrade program was initiated by the NSW Government in the 1990's when there were divided dual carriage ways in each direction for less than 30 per cent of its 700km length. There were many accident blackspots along the route with relatively high rate of fatalities. For example, there were 44 fatal crashes on the highway in 2003, most of which occurred on undivided sections of the highway. It took the state and federal governments considerable will power to allocate joint funding to upgrade the highway to divided dual carriage way in each direction between Hexham in NSW and the QLD border that would see a construction program costing over $10 billion with completion expected around 2021.

In relation to sustainability, the Pacific Highway Upgrade program demonstrates that it is not just money that matters. The upgrade would have saved many lives over the years by reducing accident blackspots and fatal accidents, and cutting considerable travel time for the general public and reduced commercial road-freight costs.

An example the author would like to use is the Ballina Bypass Alliance (BBA) Project. The bypass is a 12km long four-way dual carriageway linking the Pacific Highway in North Ballina with the Bruxner Highway Intersection in South Ballina. It extends from South Ballina to North Tintenbar in NSW, and more than half of the route is underlain by some of the most compressible soils in Australia, and to depths exceeding 25 m.

Previous geotechnical studies on the project had indicated that conventional staged embankment construction to maintain stability and surcharging to limit post-construction settlement to acceptable limits would have required a construction period of 13 years due to the presence of 25 m deep very soft clays at the southern bridge approach to Emigrant Creek North. The author considers some of the following examples of innovations on the project have contributed to sustainable infrastructure development:

Alliance Delivery – The BBA was the first of the Pacific Highway Upgrade program to adopt the alliance delivery model to solve the technical complexity of the soft soil engineering on the project. An alliance delivery model was likely to be more costly than the traditional Design and Construct (D&C) or Design Construct and Maintain (DCM) models, but was chosen because it was considered more likely to develop innovative solutions and avoid costly claims associated with traditional D&C or DCM models. Through close collaboration with the road authority which included capital works and maintenance divisions, contractor and design consultants, the project was completed in a 4.5 year period between 2008 and 2012 (much shorter than the original estimate of 13 years). The total project cost was $640 million. A reduced construction time means lives were saved due to reduction in fatal crashes as well as providing better road user benefits by reductions in travel time (i.e. social benefits). To manage post-construction settlement (see Low Embankment Strategy discussed below), dialogue with the maintenance division of the road authority was engaged, and a $10 million maintenance budget was allocated specifically for this project. To the author's understanding, this was the first time where a dedicated maintenance budget was made for a section of the highway in addition to the usual budget for maintaining all roads statewide. In order to manage public expectations regarding the need for short- and long-term maintenance, a public education program including commercially made videos of soft soil behaviour and ground treatment methods, was implemented. The videos were displayed at the community display centre during the works. This was a first time use of such public education program on the highway upgrade program.

Low Embankment Strategy – over 6 km sections of the route away from bridge approaches were underlain by deep soft soils. The initial cost estimate to treat these sections using conventional soft ground treatment to enable plain concrete pavement to be adopted was in the vicinity of $50 million. If the project budget was increased by this amount, it would have meant that subsequent sections of the highway would have had to be delayed until further funding was available from the state and federal governments. This was considered unacceptable from a social perspective in relation to the urgent priority of reducing accidence blackspots and saving lives. Therefore, instead of conventional ground treatment to enable rigid pavement to be adopted, a low embankment strategy was devised based on a whole-of-life approach. It involved keeping the embankment as low as possible, while maintaining flood immunity for at least one traffic lane in a 1:20 year flood event. To allow for post-construction settlement, a staged, flexible pavement approach, using moisture-resistant pavement material and reshaping after one year of operation, was adopted together with a dedicated maintenance budget allocated for the project as discussed above. The fill was placed as early as possible together with a flood gap strategy which comprised a large bull-dozer purchased and dedicated to the project to ensure parts of the embankment could be removed quickly to allow flood water to pass.

Vacuum Consolidation (VC) – amongst other areas of innovation on this project, the BBA project became the first site in Australia to adopt the vacuum consolidation method (Kelly and Wong, 2009) in reducing post-construction settlement. VC enabled the initial 8 m of filling including surcharge to be placed rapidly without instability issues, followed by a further 6 m without VC to consolidate the soft soils. In total, 6.5 m of settlement was induced from the VC and surcharge at this site. The conventional staged construction to allow strength gain to maintain embankment stability would have delayed the project by many years, and the use of rigid inclusion techniques would be expensive due to the depth of soft soils, and less sustainable from the point of view of concrete usage.

3.2 Woolgoolga to Ballina Pacific Highway Upgrade

Woolgoolga to Ballina is the final link in the Pacific Highway, between Hexham in NSW and the Queensland border, to be upgraded to four lanes to improve traffic safety, reduce travel time and improve amenities to local communities. It is the last 155 km section of the highway upgrade project, with a budget of $4.9 billion to be completed around 2021. Similar to the BBA project described in Section 3.1, there are many social, financial and environmental factors to be considered in such a major infrastructure project.

Approximately 26 km of the route is underlain by soft soils of varying thicknesses and properties. In the author's opinion, the geotechnical engineering associated with the treatment of the soft ground for the embankment and road construction has definitely contributed significantly to a sustainable solution for this project. Many years before construction took place, the NSW road authority had a desire to de-risk the soft soil issues associated with this project from the lessons learnt from the BBA project, and to reduce the cost associated with the need to use hard treatments which are less sustainable due to the high demand for natural materials such as high quality gravel for construction of stone columns, and cement and aggregate for concrete injected columns. The planning led to a study of potential Early Works by preloading and surcharging critical soft soil sites well in advance of the major works in 2014, using interim funding available at the time. The planning study is described in Wong (2012) although the project name was not mentioned at the time due to confidentiality reasons. The Early Works study framework is illustrated in Figure 3, and involved looking at different scenarios of time available for Early Works to target where conventional surcharge may be utilised to achieve post-construction settlement and differential settlement criteria.

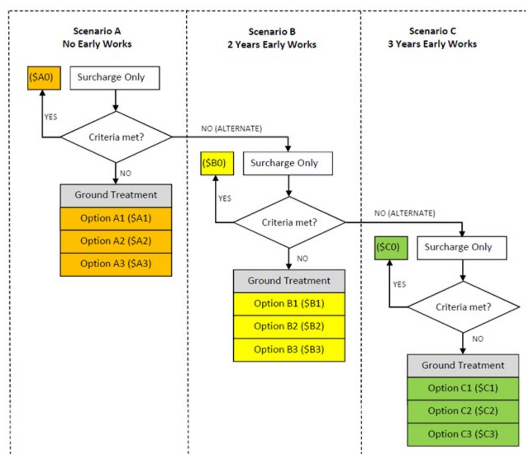

Figure 3. Flowchart showing Framework for Early Works Consideration (Wong, 2012)

A total of 22 sites was considered initially. During the actual project works, the number of Early Works treatment sites were reduced to about half the numbers using a multi-criteria selection process considering land acquisition at the time, material availability and post-construction settlement risk. The Early Works for the selected sites were eventually implemented in 2013 by a number of subcontracts prior to the major works in 2014 via a Delivery Partner model.

By planning and conducting the Early Works on this project, the following sustainable benefits were derived:

- Savings in the use of high emission resources such as cement and concrete used in other hard treatment options.
- Lower cost by adopting conventional earthworks rather than hard treatment, which also amounts to less CO_2 emission;
- Lower risk of unexpected post-construction settlement because response actions were able to be implemented from longer periods of settlement monitoring available prior to pavement construction;
- By reducing the risk of unacceptable post-construction settlement, maintenance cost in the long-term is reduced which also amounts to less CO_2 emission.

3.3 Barangaroo South Pile Foundations

The 3 high-rise commercial towers at Barangaroo South range from 39 to 49 storeys, providing 490,000 m^2 of gross area. It was designed to become one of Australia's first large carbon dioxide-neutral developments. Importantly, all three towers offer 6 Star Green ratings.

The core of each of the three towers is supported on groups of piles ranging from 1 m to 1.5 m in diameter. The outer columns have spacings of up to 10.5 m and carry design working loads and ultimate loads that are in excess of 80 MN and 100 MN. These outer columns are supported on 2.4 m diameter piles. Including the podium structure, there are nearly 1,000 piles to be constructed in a difficult subsurface profile as shown in Figure 4.

The challenges associated with the foundation design for this project include the following:

- The project structural engineer desired a tight settlement criterion of 0.3% of the pile diameter at the pile head to limit distortions of the building façade;
- Rock level ranges from RL+1m to RL-28m, and is overlain by alluvium and filling. Rock levels can vary significantly over short distances and there are potential for buried cliff ledges;
- With about 1000 piles to be constructed in difficult ground (saturated fill and alluvium that are prone to collapse, and the high strength rock is hard to drill); piling represented a major cost and time challenge to the project.

Due to the heavy building loads and stringent settlement criterion, all foundation piles are socketed into the Hawkesbury Sandstone bedrock.
The traditional approach of designing piles in Sydney rock has been to use conventional "Serviceability" bearing pressures that correspond to a settlement within 1% of the pile diameter in accordance with Pells et al (1998) which generally provides economical designs. However, due to the much stricter settlement criterion of 0.3% of the pile diameter on this project, an initial design using factored down serviceability bearing values resulted in long rock socket lengths and costing well above the project budget.

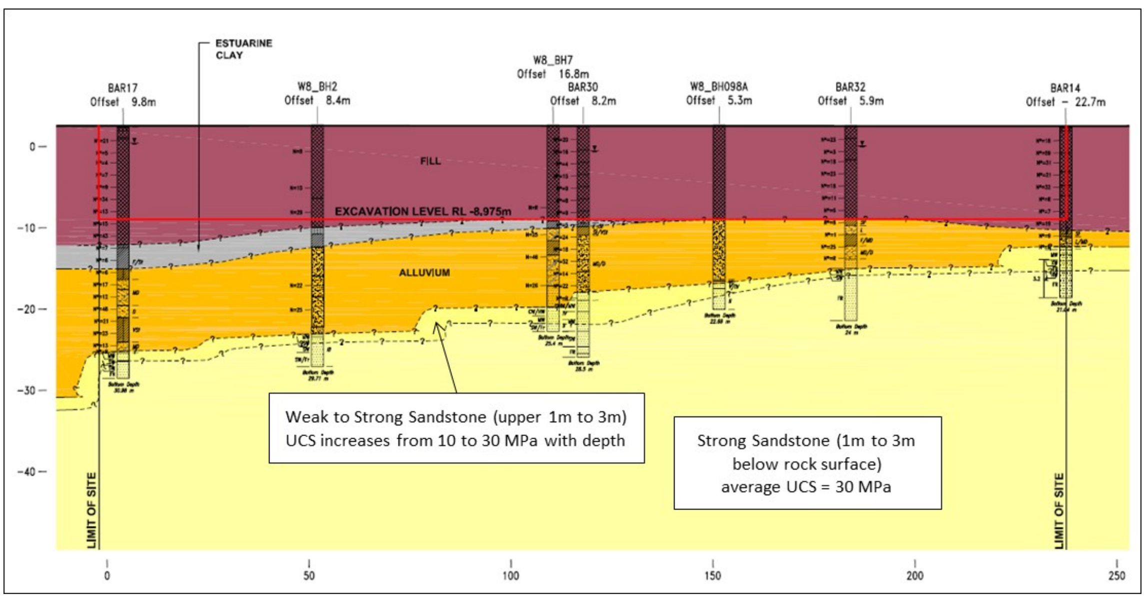

Figure 4. Typical Subsurface Profile at Barangaroo South Commercial Tower Site

A different design approach was therefore adopted using the following strategy:

- Because of high rock strength, strength limit state was not a governing factor for design, enabling the designer to focus on a performance based design;
- Following discussions with the structural engineer, and on the basis that elastic shortening of the pile shaft is relatively small, the design settlement target was changed to 0.3% of pile diameter at the pile base;
- The design was carried out using presumptive rock stiffness values for the various sandstone classes given in Pells et al (1998), and later checked using the results of pile load testing and back-analysis discussed below;
- Two bi-directional O-Cell pile load tests were carried out on prototype 750mm diameter piles (Figure 5), which enabled testing to about 70% of the ultimate base capacity and 100% of the shaft capacity. This enabled the strength limit state to be confirmed and pile stiffness to be back-analysed for checking with building performance requirements;
- A program of proof coring (about 25% of piles within the tower core, and each of the 2.4m diameter tower piles) to confirm the rock profile and assess the potential for cliff ledges;
- Full-time geotechnical presence during piling to confirm founding levels and cleanliness of the pile base, and the use of appropriate drilling tools to achieve a minimum rock socket roughness of 4mm at maximum 200mm spacing.

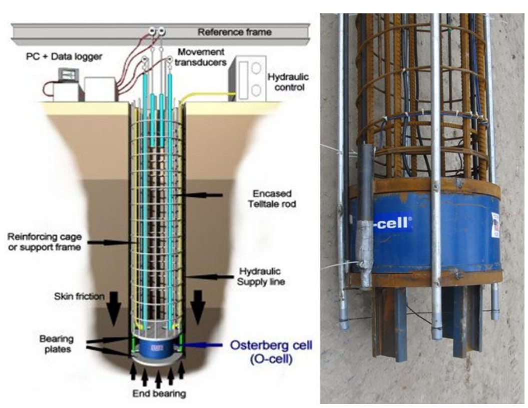

Figure 5. O-Cell Pile Load Testing Arrangement

Descriptions of the O-Cell pile load testing, interpretation and back-analysis results, including non-linear behaviour with load level can be found in Wong and Oliveira (2012) and Wong (2013).

The advantage of utilising this performance based design approach as compared to using a presumptive settlement of 1% of the pile diameter based on published serviceability design values is illustrated in Figure 6 for a 1.8 m diameter pile socketed 6 m into rock (1m in Class V Sandstone, 2m in Class IV Sandstone, and 3m in Class III Sandstone).

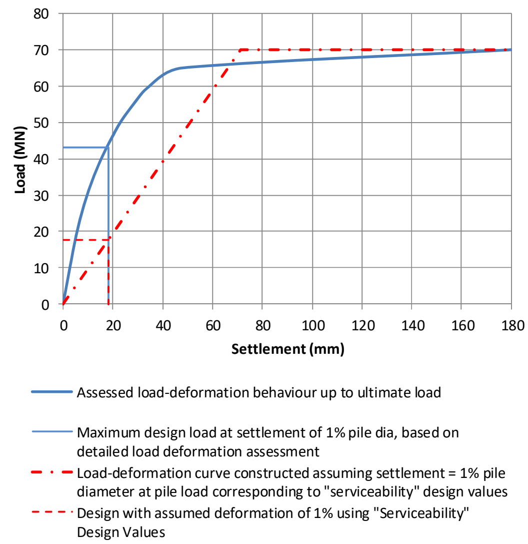

Figure 6. Load-deformation Curves for 1.8 m Dia. Pile with 6 m Rock Socket in Sandstone

It can be seen from Figure 6 that at the same settlement of 18 mm (i.e. 1% of the 1.8 m pile), the actual load based on a proper analysis using appropriate rock properties is over twice the capacity using the simple presumptive approach.

As with most infrastructure projects, the need to optimise the pile foundation design and construction for the Barangaroo project was driven primarily by cost and time. However, in relation to sustainability, we can now reflect on the reduction in CO_2 emission achieved, as described below. This represents a very conservative estimate because only 323 of tower piles (out of nearly 1000 piles in total) are considered, ignoring the podium piles.

- Saving in total rock socket length ~ 40%
- Savings in total pile length ~ 20%
- Total pile length saved ~ 1,200 m
- Total volume of 50 MPa concrete saved ~ 6,264 m^3
- Total steel reinforcement saved ~ 970 tonnes
- Reduction in CO_2 emission ~ 4,635 tonnes

The reduction in CO_2 emission shown above is simply from the savings in concrete and steel, and does not include energy savings associated with not having to drill the additional rock sockets and transportation of materials to site. The savings in transport of materials to site also have an indirect benefit to road users and social well-being of the community due to lesser disturbance from reduced heavy truck movements.

3.4 Barangaroo South Piling Platform

Another example of sustainable design by the geotechnical engineers on the Barangaroo South commercial tower project discussed in Section 3.3 is the use of innovative geotechnical analysis and testing method to eliminate the piling platform for construction of the diaphragm walls and those foundation piles constructed from existing ground level.

Numerous heavy tracked machines were used for the construction of the diaphragm walls for the basement excavation and large diameter piles for the tower foundations. A 600 mm thick working platform constructed using coarse granular aggregates was initially designed for an area of 2 ha due to concerns regarding the uniformity of the existing filled ground. The import of materials, construction, and subsequent excavation and disposal of the materials would have cost an estimated $1 million. The associated CO_2 emission including material transport both ways, construction and disposal would have been approximately 400 tonnes.

Although it was considered likely that a piling platform may not be required because of the granular nature of the existing reclaimed filling at the site, the challenge was to demonstrate the existing ground could withstand an ultimate bearing pressure of up to 437 kPa for a track width of up to 1 m. The solution, as reported in Wong and Moyes (2014) was to use small strain theory with proof rolling at a machine track operating pressure of only 160 kPa, coupled with a program of plate bearing tests to maximum test pressures of 450 kPa to 550 kPa, Benkelman Beam deflection testing, and pre- and post- ground level surveys following the proof-rolling.

The use of the small-strain theory enabled the secant modulus, E_s and tangent modulus, E_t of the ground under the track loading at different pressures to be interpreted from the testing as shown in Figure 7. A load deformation diagram was then able to be produced and tolerable deformation limits set for the proof loading.

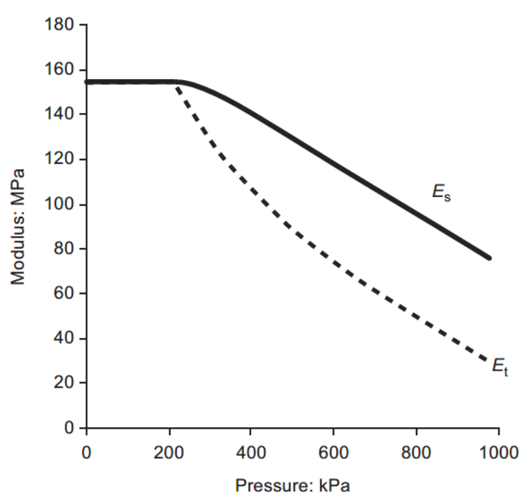

Figure 7. Interpreted average secant modulus, E_s and tangent modulus, E_t from test results using small-strain theory reported in Wong and Moyes (2014)

The innovative methodology adopted successfully eliminated the piling platform for the diaphragm wall pile foundation construction at existing ground level, and identified a soft area which was associated with a poorly backfilled service trench, and enabled this area to be bridged-over using steel plates.

Although the CO_2 emission reduction associated with elimination of the piling platform is not huge (~ 400 tonnes), the cost and time saving, together with other indirect social benefits of reducing heavy vehicle traffic on local roads, noise and vibration reductions certainly made it worthwhile. The learnings from the innovative use of small strain theory also provide benefits with respect to potential adaptation of the technique in future projects.

3.5 Waikato Expressway – Hamilton Section

The Hamilton Section of the Waikato Expressway is a 21.8 km highway around the eastern fringe of Hamilton City in New Zealand. The project is being delivered as an Alliance comprising the project owner, New Zealand Transport Authority (NZTA), contractors Fletcher and Higgins, and designers Beca and Coffey, and is due for completion in around 2021.

Because of the requirement to design for relatively high seismic, low probability (i.e. high return period) earthquake events, a more sustainable, resilient design approach was adopted by the Alliance. As usual, NZTA sets project Minimum Requirements (MR) for each project. The alliance delivery mechanism provided an opportunity to explore potential solutions that cannot strictly meet the MR at a reasonable cost, but one that is considered to have an acceptable risk due to low probability of occurrence and consequence of damage in an adverse earthquake event. In any case, the solution must be sufficiently resilient to enable temporary repairs to be made quickly to enable emergency and essential traffic usage of the road following such an event, and the consequence of damage must not have adverse impact to the environment. A high- level illustration of the design process is shown in Figure 8 below.

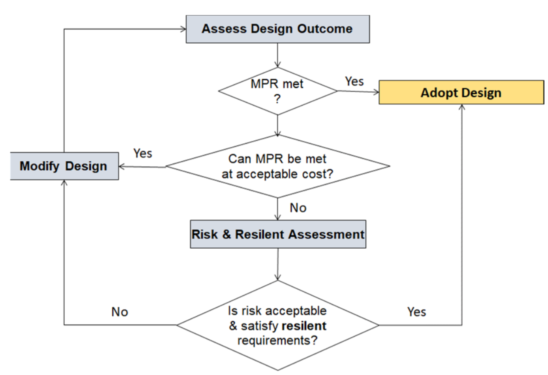

Figure 8. Illustration of Design Process for Resilience

An example of the application of this design process was reported in Wong et. al. (2019) for the northern embankment over the Mangaharakeke gully near the southern end of the project.

The site was underlain by liquefiable soils extending down to about 7.5 m depth. The initial concept design that met the MR was a lattice structure constructed using continuous flight auger (CFA) concrete columns, but this solution was considered by the Contractor to be too expensive and an alternative solution was needed.

The adopted solution was Dynamic Replacement (DR) utilising Greywacke rock which was readily available from local quarries. Even with pre-excavation below the ground surface to 1.5 m, validation testing indicated the DR columns could not reach the full depth of the liquefiable soils. However, risk assessment conducted indicated that the risk was acceptable and the as-constructed ground improvement using DR provided adequate resilience which met the following requirements at SLS and ULS earthquake accelerations of 0.09g and 0.24g, respectively:

- FOS (for embankment stability) ≥ 1.5 under static long-term condition
- FOS ≥ 1.0 for 100% SLS earthquake inertia and pre-earthquake soil strength
- FOS ≥ 1.1 ULS with no earthquake inertia and post-liquefied/cyclic softened soil strength
- FOS ≥ 1.0 with 65% SLS earthquake inertia and post-earthquake soil strength
- FOS < 1 is acceptable for ULS with earthquake inertia, but allowable lateral deformation ≤ 250 mm at critical acceleration for one ULS design earth-quake event.

The benefit of using granular DR columns to reduce the liquefaction potential is illustrated by the study conducted for stone columns by Thevanayagam et al, (2006) who presented the improvement in the normalised and corrected Standard Penetration Resistance $(N_1)_{60cs}$ for soils of different permeability, as reproduced in Figure 9. Essentially, an increase in $(N_1)_{60cs}$ represents an increase in liquefaction resistance of the treated soil.

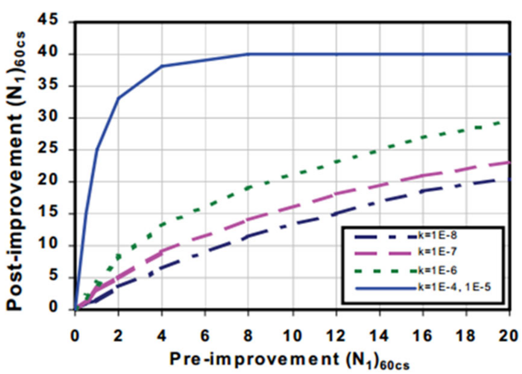

Figure 9. Pre and post improvement (N1) 60cs for stone column replacement ratio of 22.5% presented by Thevanayagam et al (2006)

Figure 9 was used for the concept design of DR for the project, followed by a more detailed design process. Following site trials, the adopted solution comprised 3.6 m diameter columns at 5.8 m centres on a triangular grid to give a design area replacement ratio of 0.35. A more detailed description of the design process and validation testing can be found in Wong et. al. (2019).

Because of the locally available rock for the DR, as compared to the high cost of CFA and high embedded carbon of concrete, the adopted DR solution is considered to be far more sustainable compared to the initial CFA lattice ground improvement.

3.6 One Man's Striving on Sustainability – The 5x4 Hayes Lane Project

The last example given in this paper is from one of the episodes of the TV series "Grand Designs Australia" featured on the Australian Broad Casting (ABC) channel recently (Series 6, Episode 4).

The author has no involvement on this project whatsoever, but was awed and inspired by the owner's focus and strive on maximising sustainability in the design and construction of his home in East Melbourne. The owner builder, Mr. Ralph Alphonso, constructed his 12 m high, 4 storey inner city home on a tiny 5 m x 4 m footprint. His passion in achieving minimum CO_2 emission sees him close to eliminating steel altogether from the structure and building almost entirely from sustainable Australian hardwood, including timber floors, timber walls, timber ceilings, timber structural beams, timber cabinetry, even an engineered timber stairwell that allowed him to go four stories high. The building is designed, built and powered with both passive and active eco-driven processes, materials and performance considerations.

Above all, the author is most impressed by the fact that before the building work started, Mr. Alphonso sank a 65 metre deep geothermal drill hole that will heat and cool his home using heat pump technology. The geothermal system added $30,000 to the cost of the project, so it is by no means an inexpensive solution, but it was a priority in Mr. Alphonso's vision for his eco-friendly house. "*Eventually, the hope is that it will pay for itself*" says Mr. Alphonso on the TV show.

A subsequent paper by Crawford (2018), who studied the energy use of Mr. Alphonso's project over a 3 year period, found that "*the building has resulted in net operational GHG emissions of 13.8 kg CO_2-e per day (assuming the use of fossil fuel-based electricity imported from the grid)"* as compared with an average emission of 18.1 kg CO_2-e per day in Melbourne. Crawford (2018) further concludes that "*there is still room for improvement. Data from individual circuits showed that the geothermal heat pump is responsible for the greatest share of energy use. Improvements to the efficiency of the heat pump system and the pumps used for pumping water through the geothermal pipes are thus two areas where efforts to further reduce energy use within the building should be targeted*."

Mr. Alphonso's striving for minimising the carbon footprint in the design and construction of his home is an inspiration for all geo-professionals.

The area of geothermal energy is one that has been explored extensively but not yet adopted widely. Traditionally, geothermal energy use has been limited to tectonically active regions. For example, electricity was first generated using steam from a geyser in Italy in 1904, and New Zealand started commercial power generation using separated steam in 1958 (Johnston et. al., 2011). In the last 20 to 30 years, use of relatively shallow geothermal energy in non-technic active regions including Australia is starting to take place for heating and cooling of buildings thanks to the invention of the heat pump by Lord Kelvin in 1856.

Johnston et. al. (2011) provided a good summary of the emerging technologies of Enhanced Geothermal Systems (EGS) and Ground Source Heat Pumps (GSHPs) which are important because of their potential for widespread use. A simplified summary of the various forms of geothermal systems illustrated by Johnston et. al (2011) is reproduced as Figure 10 in this paper.

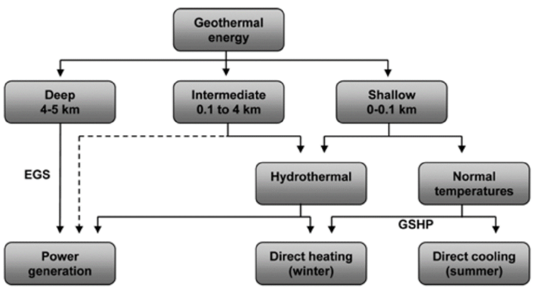

Figure 10. Simplified Summary of the Various Forms of Geothermal Energy by Johnston et. al. (2011) - The dashed line indicates that ground temperatures at intermediate depths (where there are no hydrothermal resources) are not typically high enough for the commercial generation of power using current technology.

Johnston et. al. concluded that "*EGS and direct geothermal heating and cooling using GSHPs are emerging technologies that have the potential to significantly reduce the world's dependence on carbon based energy sources*" and "*Commercial application of EGS technology is some years off but its enormous potential demands investment for further research. GSHP heat pump technology is available now – policy makers need to be educated and the potential of GSHPs demonstrated.*"

Professor Johnston (2020) indicates that the main hindrance in widespread use of GSHP technology in Australia is capital cost of installation and the lack of Government initiatives to subsidise its use as an alternative renewable energy to reduce supply demand, even though it does not generate energy for the grid. Furthermore, Professor Johnston indicates that owners/designers/installers of GSHP systems need to think more smartly about the system requirement according to the temperature range of the region to enable more affordable systems to be installed. For example, he quotes that 90% of the heating in Melbourne is required when the temperature is between 14ºC. and 20ºC. Therefore, over-design (i.e. installing a system that can provide heating at 3ºC temperature) can be avoided by installing a parallel heating system using conventional power that would only be operated for 10% of the time or less.

With respect to infrastructure development, there are good opportunities to use GSHP systems at reduced capital cost via embedment of closed loop systems in in-ground structures such as retaining walls, piled foundations, basement floors and transportation tunnels. Such systems could be used for heating and cooling of transport control centres, metro over-station developments, airport terminals or even potentially extending its use to integrated residential and commercial developments along transportation corridors. Ongoing research and development of geothermal energies will no doubt lower the cost of GSHP systems with time, and hopefully see the use of EGS in generating energy on a viable commercial scale in the near future. It is pleasing to see there are many recent published research works that can be found in publications such as Ferrari and Laloui (2018) on energy piles and other forms of direct geothermal energy use.

Mr. Alphonso sets a perfect example of what one man can achieve with his passion for a sustainable home development in East Melbourne. Imagine what an infrastructure community can achieve with the drive of geo-professionals, architects and other engineering professionals, and with Government support.

4 CONCLUSION

Geo-professionals have always contributed to sustainable infrastructure development, even if subconsciously, via the need to arrive at time- and cost- efficient designs driven largely by contractors in a highly competitive market. The author is of the opinion that this is a business as usual approach, and considers that more sustainable solutions can be achieved if more conscious efforts are made by using a holistic approach. This requires understanding the different competing factors including government policies, time, cost, social and environmental factors. Major infrastructure projects usually have specific sustainability targets that the geo-professionals should make an effort to understand, and work collaboratively with the client and other engineering disciplines to explore opportunities, including the use of multicriteria selection processes where applicable. Innovation forms an important part of developing sustainable solutions and the use of resilient design principles in a whole-of-life design approach should be considered in major infrastructure projects.

Mr. Alphonso's 5x4 Hayes Lane Project, whereby he invested in a geothermal heating and cooling system in his home project, illustrates that capital cost is not everything. Energy savings will eventually recover the capital cost in time, in addition to being eco-friendly. Geothermal energy is one of many areas where geo-professionals can potentially exploit in integrated transportation infrastructure projects for the heating and cooling of residential and commercial developments by embedding geothermal closed loop systems within in-ground structures.

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