Sustainability in Geotechnical Engineering

Module Developed for Geotech Tools Website

By

Sustainability in Geotechnical Engineering (SGE) Committee

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Contents

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PREFACE

Geotechnical Engineers contribute to a wide range of critical infrastructure sectors including government and commercial facilities sector, dams' sector, energy sector, defense sector, water and wastewater systems sector, and the transportation sector. As a result, the geotechnical profession needs to be able to adapt to the changing demands of these sectors. The demand for sustainable development has been increasing in all of these sectors and geotechnical engineers are well positioned to contribute to this demand. In addition, legislation is poised to become a large driver of sustainability in the coming years. Hence, it is very important that geotechnical engineers have a basic understanding of sustainability, as well as what sustainability means from a geotechnical engineering perspective.

This module presents a number of key terms and definitions along with a geotechnical perspective of sustainability. The module lists various sustainability frameworks and tools applicable to geotechnical engineering. It also includes examples of using some tools on geotechnical engineering projects. The module is not intended to be an exhaustive compilation of sustainability aspects applicable to geotechnical engineering. The goal is to be a technical reference for geotechnical engineers to help understand sustainability and make them aware of the potential for geotechnical contributions to sustainable development.

Overall, sustainability should be a holistic approach balancing the environmental, social, economic aspects that accounts for both the present and the future. However, geotechnical engineers should be aware that sustainability priorities and impacts vary by stakeholder, geological site conditions, and geography. Consequently, to be most effective, geotechnical engineers must work with their stakeholders to achieve a sustainably beneficial end product that meets everyone's needs.

KEY TERMS & DEFINITIONS

To understand and communicate sustainability effectively this report starts with some key terms and definitions and what they mean to geotechnical engineers. This section highlights key sustainability definitions, policies, goals, and principles from various sources.

Sustainability

Sustainability has several definitions but the most original and relevant one is the one provided by Brundtland Commission in 1987, which defines sustainability as “the development that meets the needs of the present without compromising the ability of future generations to meet their needs”(Brundtland 1987). The American Society of Civil Engineers (ASCE) has adopted the definition for sustainability as “a set of environmental, economic, and social conditions (the ‘Triple Bottom Line’) which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely, without degrading the quantity, quality or the availability of natural, economic, and social resources” (*Sustainability at ASCE*).

Life Cycle Assessments

As per (ISO 14040: 2006), Life Cycle Assessment (LCA) is a method to assess the environmental aspects and potential environmental impact throughout a products life cycle. LCA involves the collection and evaluation of input and output parameters relative to a product or service and assessing the environmental impacts of these parameters at various phases of the products life cycle. Please note that LCA is a part of sustainability assessments but does not account for the economic and social aspects.

Life Cycle Cost Analysis

Life-cycle cost analysis (LCCA) is a method to assess the most cost-effective alternative among competing technically viable choices to purchase, own, operate, maintain, and dispose of an object or process. LCCA is performed using discounted rates and usually converted to a present-day value known as net-present-value (NPV). Several manuals including National Institute of Standards and Testing (NIST) Handbook #135 (Kneifel and Webb 2022), and FHWA’s LCCA Primer (US DOT 2002) are available for reference.

ASCE’s Sustainability Related Policies

ASCE’s related policy statements include Policy 418, the Civil Engineer’s role in sustainable development, and Policy 517, sustainable development goals. Policy 418 discusses the use of the Triple Bottom Line, life cycle assessment, social equity, and resiliency (*ASCE Policy Statement 418*, 2021). Policy 517 describes an engineer's responsibility to supply solutions for basic human needs, preserve environmental diversity and resources, and to use them sustainably (*ASCE Policy Statement 517*, 2019).

Ethics and Sustainability

It is important to remember the ASCE code of ethics when practicing geotechnical engineering. ASCE's goals, codes, and policies are directly applicable to geotechnical engineering practice. Their code of ethics mentions that engineers should "create safe, *resilient*, and ***sustainable*** infrastructure" (ASCE Code of Ethics, 2020).

1 GEOTECHNICAL ENGINEERING IN SUSTAINABLE DEVELOPMENT

The United Nations has set up 17 goals targeting sustainable development by 2030, Figure 1 (UN 2015). These sustainable development goals (SDGs) are combined with 169 different targets aimed at governments to achieve various environmental, social, and economic standards. The SDGs are holistic, they address all areas of sustainability while ensuring that improvements to one area of sustainability do not result in negative impacts elsewhere. SDGs are well used and communicated both in government, among companies and increasingly by investors, enabling corporate stakeholders to engage with these targets. It is important for geotechnical engineers to be cognizant of these goals and make a conscious effort to contribute towards these goals.

Figure 1: UN's Sustainable Development Goals (UN, 2015)

Sustainability as defined by Graedel (Graedel 1994) and Kibert (Kibert 2008) is the judicious use of natural resources at reasonable cost with control of emissions. A similar definition provided by Misra and Basu (Misra and Basu 2011) is where sustainable geotechnical engineering is identified as strong construction and design that incorporates the least financial responsibility and inconvenience to society; a minimum utilization of resources in various phases like planning, design, construction and maintenance; use of eco-friendly materials and measures; and reuse of existing facilities to reduce waste. Geotechnical engineers can contribute to sustainability by creating designs and construction that involves:

- minimal burden financially with a resulting economic growth and an increase in jobs (SDG 8)
- minimal social burden with inclusive, all accessible designs (SDG 5, 10, 15 & 16)
- responsible use of resources and energy (SDG 7 & 12)
- recycling of existing facilities as much as possible (SDG 9, 11, & 12)

- minimal negative impacts on the environment (SDG 11, 12, 13, 14 & 15)

It is clear that geotechnical engineering contributions to SDGs are tied to the construction industry as well. As per Abreu et al. (Abreu et al. 2008) geotechnical engineering is an important part of the construction industry and has potential for making major impacts on sustainable development. As geotechnical engineering is often the first link in the chain of construction, it can set the principles of impact reduction through the construction process and has the potential for minimizing environmental impacts. To harness this potential, geotechnical engineers must be aware of the principles of sustainable development and incorporate them in designs.

2 SUSTAINABLE DEVELOPMENT PRINCIPLES

The principles on which sustainable development is targeted depend on the priorities and focus of a given organization. Different researchers and research organizations have laid out principles to guide sustainable development. Gagnon et al. (Gagnon et al. 2008) compiled thirteen different sustainability principles from various organizations worldwide that are applicable to engineering. These can be seen in *Table 1*. As per Basu et al. (Basu et al. 2015), the following steps can positively contribute to a sustainable geotechnical development at a project level:

1. *Stakeholder involvement*: Involving all the stakeholders early on during the planning stage of the project can help align all aspects of the project to sustainable development. Some of the aspects that need to be considered are, pollution control (during and after construction), financial impact on the affected community, choice of environment-friendly materials, aesthetic acceptability, acceptability of the project to the local community, etc. On the social side of sustainability, incorporating businesses owned by economically disadvantaged individuals (DBE), women (WBE), minorities (MBE), veterans (VBE or VOSB), and/or LGBTQ+ individuals (LGBTBE) into projects as well as local companies will address social equality (SDG 5 & 10);
2. *Appropriate site characterization* so that the geologic uncertainties and associated hazards are minimized;
3. Robust and reliable analysis, design and construction that involve *minimal financial burden and inconvenience* to all the stakeholders;
4. *Optimal use of materials and energy* in planning, design, construction, and maintenance;
5. Use of materials and methods that cause *minimal negative impact on the ecology and environment*;
6. *Reuse of existing geotechnical elements* (e.g., foundations and retaining structures) to minimize waste;
7. *Appropriate and adequate instrumentation, monitoring*, and maintenance to ensure proper functioning of the facility; and
8. *Performing adequate checks against resilience* (which may include engineering, social, economic, and ecological resilience) and redesigning if necessary.

Table 1: Sustainable Development Principles (Gagnon et al. 2008)

Reference	**Principle**
World Commission on Environment and Development (1987)	Our Common Future marks the emergence of sustainable development as an authorized concept. The report lists seven strategic imperatives encompassing what is now known as the economic, social, and environmental dimensions of sustainable development.
Ceres (1989)	The Ceres principles are a 10-point code of conduct for companies: protection of the biosphere, sustainable use of natural resources, waste reduction and disposal, energy conservation, risk reduction, safe products and services, environmental restoration, information for the public, management commitment, audits and reports.
United Nations (1992)	The Rio Declaration on Environment and Development contains 27 principles dealing with: environmental protection, poverty alleviation, international collaboration, production and consumption, capacity-building, participation, precaution, and peace.
Haughton (1999)	There are five key equity principles to sustainable development: equity within and between generations, geographic equity or cross-border responsibility, procedural equity, and equity between species composing biodiversity.
Earth Charter Initiative (2000)	The Earth Charter is based on four themes: respect and care for the community of life; ecological integrity; social and economic justice; democracy, nonviolence and peace. These four themes are then each broken down into four more detailed principles
Valentin and Spangenberg (2000)	Principles of sustainable development are structured around four thematic imperatives (one for each dimension, i.e., economic, social, environmental and institutional) and six inter-thematic links (one for each bidimensional interconnection).
Robert et al. (2002)	Ten authors present four principles of sustainability making up the Natural Step Framework, as well as 13 principles of sustainable development which can be applied in more practical terms
Parris and Kates (2003)	Three elements are to be sustained (nature, life support. and community) and three elements are to be developed (people, economy and society). Two or three goals are defined for each element, for a total of 17 sustainable development goals.
Becker (2005)	Sustainable systems are assumed to have three general characteristics (resilience, self-sufficiency, and collaboration), which in turn, are subdivided into three indicators to facilitate their measurement.
Swiss Federal Statistical Office (2005)	Sustainable development is defined by three main elements (social solidarity, economic efficiency, and ecological responsibility) and by 45 postulates classified in 20 categories.
United Kingdom Government (2005)	The UK sustainable development strategy contains five principles: living within environmental limits; ensuring a strong, healthy and just society; achieving a sustainable economy; promoting good governance; and using sound science responsibly. Many countries (Sweden, France, Columbia, etc.) adopted such strategies.
Government of Manitoba (1997) and Government of Quebec (2006)	The Government of Manitoba and Quebec adopted Sustainable Development Acts respectively defining 13and 16 principles. Other governments passed similar legislation: Estonia (1995), Belgium (1997), Oregon (2001), Luxemburg (2004), and Canada (2008).
Villeneuve (2006)	Four dimensions (ecological, economic, social, and ethical) are used to define sustainable development and eight multidimensional objectives are derived from these definitions.

2.1 Examples of geotechnical engineering contributions to sustainable development

There are several ways in which geotechnical engineers can and have contributed to sustainable development. A few examples of how geotechnical engineers are contributing to this cause are presented here, please note that this is not an exhaustive list.

Recycled Materials: Aydilek and Wartman (Aydilek and Wartman 2004) compiled articles highlighting the developments in the rapidly evolving field of recycled materials in geotechnics. Utilizing different materials for construction like coal and fly ash (Sridharan and Prakash 2010), lignosulfonate to stabilize erodible soils (Vinod et al. 2010), recycled glass-crushed rock blends for pavement subbase applications (Ali et al. 2011), and mixed glass & plastic in segmental retaining walls (Meegoda 2011) are all examples of recycling and sustainable solutions. Vieira and Pereira (Vieira and Pereira 2015) reviewed the use of recycled construction and demolition materials in geotechnical applications.

Ground Improvement: Spaulding et al. (Spaulding et al. 2008) compared three alternative ground improvement techniques: deep dynamic compaction, controlled modulus columns, and cement bentonite cutoff walls with conventional deep foundation and concluded that alternative techniques provided superior economy as well as a reduced carbon footprint. Egan and Slocombe (Egan and Slocombe 2010) demonstrated the effective environmental viewpoint of vibro-replacement stone columns over deep foundations. Serridge (Serridge 2005) studied the application of recycled materials for vibro stone column techniques as part of achieving environmental sustainability in ground treatment.

Reuse and Recycle: Reusing and retrofitting existing foundations have been increasing in popularity due to their cost, impact, and reduced disturbances from construction during the process. For instance, removing an old foundation would cost as much as four times as much as reconstructing an existing pile foundation, plus the additional damage to the adjacent building and backfill (Anderson et al. 2006; Butcher et al. 2006; Clarke et al. 2006; John and Chow 2006; Katzenbach et al. 2006; Lenon et al. 2006; Tester and Fernie 2006). Chittoori et al (Chittoori et al. 2012) studied the sustainable reutilization of excavated trench material for pipeline construction applications.

Life Cycle Assessments: Several researchers (Giri and Reddy 2014; Goldenberg and Reddy 2014, 2017; Reddy and Giri 2015) advocated the use of LCA as a decision-making tool for projects involving geotechnical projects. Goldenberg and Reddy (Goldenberg and Reddy 2014) assessed the sustainability of excavation & disposal method versus in situ stabilization of heavy metal-contaminated soil at a superfund site in Illinois using LCA method. A whole life cycle cost (WLC) study was done by Butcher et al. (Butcher et al. 2006) for various design alternatives for foundation design like design for partial reuse, no reuse, and full reuse and concluded that WLC for reuse has a lesser WLC than the no reuse option, and also the embodied energy consumed is nearly half for the reuse option; however, the initial cost was slightly greater. A study by Leung et al. (Leung et al. 2011) suggested an algorithm for the optimization of configurations for new pile foundations along existing piles considering material economics and load safety.

Underground Space and Usage: Research into the use of underground systems has been prolific. Underground systems can provide energy efficiency, lessen the burden on limited resources, and protect against human-inflicted and natural disasters (Carmody and Sterling 1985; Sterling 1982). Several countries like Hong Kong, Japan, and Singapore have already implemented such methods while the most notable is the Norwegian Tunneling Society. They use underground systems for hydropower powerhouses(Broch 2005), telecommunications centers (Rygh and Bollingmo 2006), storage of hydrocarbons(Grov 2006), and wastewater treatment plants (Neby et al. 2006; Ronning 2006). Additional benefits to underground systems include enhanced security, reduced environmental burden, easy maintenance, reduced disturbance to traffic and city life, and better economy. Future suggestions include the use of underground systems for utility and transportation infrastructure and storing energy to include solar, tidal and wind (Fragaszy et al. 2011; Holt et al. 2009).

2.2 Resilience in Sustainable Development

Resiliency is the capacity to bounce back from any hazards or incidents in the least amount of time as possible to reduce the impact on the public (Basu et al. 2015). Any disruptive events that could occur include deterioration, damage from loading or stress, increased demand, terrorism, climate change, increase in population density, constraints in funding, and natural disasters (Allen et al. 2012). Sustainable systems must be able to ensure it is able to recover back to functionality regardless of the level of damage it may be subjected to. In *Figure 2,* a graph presents how a resilient system will function over a period of time.

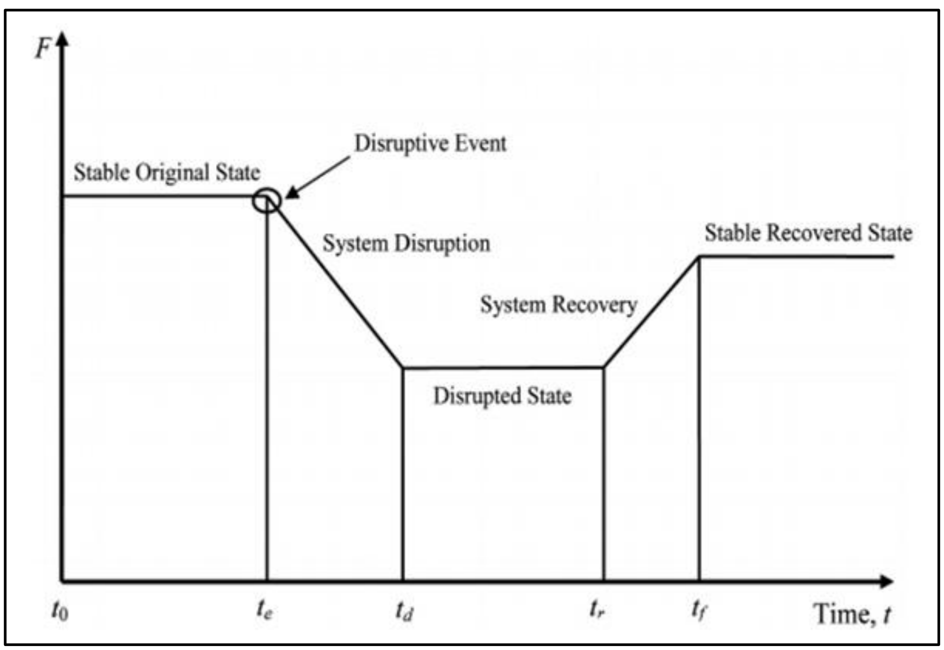

Figure 2: Resilience of a System Over a Period of Time (Basu et al. 2015)

Sometimes sustainability and resiliency can be confused for one another or simply considered the same thing. *Table 2* presents a side by side comparison so they can easily be compared and contrasted.

Table 2: Resiliency & Sustainability Comparison (Bocchini et al. 2014)

	Resilience	**Sustainability**
Keywords	Recovery, extreme events, disaster management, functionality, infrastructure, lifelines, networks, communities	Holistic, green, life cycle, life-cycle assessment, life-cycle costing, social costing, sustainable development, indicators, rating
Dimensions	Technical, organizational, social, economic	Environmental, economic, social
Objectives	Achieving robustness against disturbances and rapidity in recovery	Reduction of impacts and resource consumption in the three dimensions, inter-and intra-generational fairness
Quantification Methods	Quantified by index as a function of performance indicators	Mostly based on indices summarizing different quantitative and qualitative indicators; result is a score
Spatial Scale	Community and network level	Building level
Instruments & Calculation Methods	Life cycle costing, external costs, user costs, extreme event simulation	Life cycle assessment, life cycle costing, external costs, user costs, and multi-criteria analysis

Specifically, to geotechnical engineering, both sustainability and resiliency should be considered in order to reduce impacts on the public. Key infrastructure to be considered includes foundations, embankments, levees, dams, earth retaining structures, and tunnels.

Resiliency is connected to sustainability and each relies on one another for success. As defined by Bocchini et al. (Bocchini et al. 2014), resiliency is “a metric that measures the ability of a system to withstand an unusual perturbation and to recover efficiently from the damage induced by such perturbation”. Resilience can be depicted into different aspects called the four R’s of resilience: robustness, redundancy, resourcefulness, and rapidity. Robustness is the “ability of the system to withstand a given level of stress and/or demand”; redundancy is the “measure of the inherent substitutability” or the extent to which a component is substitutable in the event of damage; resourcefulness is the “measure of the capacity to mobilize resources in the event of disruption”; and rapidity is “measure of the capacity to contain losses or prevent further degradation in a timely manner" (Minsker et al. 2015). Resilience in sustainable development will be discussed in further detail in a subsequent section.

3 SUSTAINABILITY ASSESSMENT TOOLS (SATS)

A *Sustainability Assessment* is not currently included in most traditional geotechnical designs. A *Sustainability Assessment* can serve as a comparison tool for alternative designs which leads to a better decision on the most sustainable design (Misra and Basu 2011). *Figure 3* shows the design stages of a geotechnical project and where the sustainability assessment would fit in.

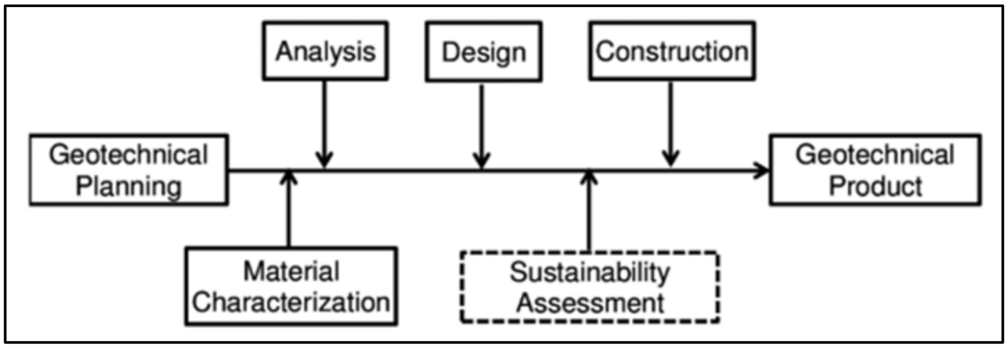

Figure 3: Geotechnical Design Stages (Misra and Basu, 2011)

There are various different assessment tools that may not all be applicable to geotechnical engineering specifically; therefore, it will be up to the engineer to decide what will best fit their project. The tools also vary between both quantitative and qualitative and use either indicators or metrics. Some examples of rating-based tools include LEED, EnvisionSP, BREEAM, and Greenroads, to name a few. There are tools such as carbon footprint analyzers like the Deep Foundation Institute's (DFI) Carbon Calculator (**EFFC/DFI Carbon Calculator**). Finally, frameworks like the Life Cycle Assessment (LCA) are also used as sustainability assessment tools to identify main contributors to environmental impacts and allow for improvements. Some of the most common rating-based tools are compared below in *Table 3*.

Table 3: Rating-based Sustainability Assessment Tools

	Description	**Rating Categories**
LEED	LEED (Leadership in Energy & Environmental Design) is a green building certification program (*LEED rating system*)	• sustainable sites • water efficiency • energy & atmosphere • materials & resources • indoor environmental quality • innovation & design process
Envision	Infrastructure rating system to evaluate and recognize projects for their contributions to a more	• quality of life • leadership • resource allocation

	sustainable future (*Envision the Solution)*	• natural world • climate & risk
BREEAM	Building Research Establishment Environmental Assessment Method is for new and existing buildings (*Responsible Sourcing in BREEAM*)	• management, health & wellbeing • energy • transport • water, waste & materials • land use, ecology & pollution • innovation
Greenroads	Greenroads is internationally recognized as a sustainability assessment tool for transportation infrastructure (*Greenroads Rating System*)	• environment & water • materials & design • construction activities • access & livability • utilities & controls

4 EXAMPLES OF USING SATS IN GEOTECH PROJECTS

To help practicing engineers understand the use of some of the Sustainability Assessment Tools (SATs) the following case studies are presented. The intent here is to help see how a particular SAT could be used on geotechnical engineering aspects of a project. Raza et al (Raza et al. 2021) studied different assessment techniques/tools and technical aspects of geotechnics to develop Geotechnical Sustainability Assessment Tools to ensure the lack of research encompassing global sustainability goals.

4.1 Case Study 1: Collapsible Soils Ground Improvement

4.1.1 Introduction

The overall project was a large warehouse-type structure located in the American Southwest. The ground conditions under the structure were collapsible soils, a soil type that is not uncommon in the arid southwest. The targets for the foundation design were to provide 5,000 psf bearing capacity under the building footings, mitigate the risk associated with the collapsible soil, limit impacts to a nearby neighborhood, limit environmental impacts, and meet the aggressive construction schedule required by the client.

4.1.2 Sustainability Assessments:

Three alternative ground improvement techniques were considered for the project. These techniques were over excavate & compact, vibro stone columns, and deep dynamic compaction (DDC). All three techniques have been used in the area, with over-excavate and compact being the most commonly used. The alternatives were assessed based on schedule, cost, risk, impact to community, embodied carbon, and environmental impacts beyond carbon. To assess embodied carbon, the EFFC/DFI Carbon Calculator was used. A streamlined energy and emissions assessment model (SEEAM) which is based on life cycle analysis (LCA) methods was developed at Virginia Tech by Shillaber and Mitchell (Shillaber et al. 2016). They used this model for supporting an earthen embankment by deep soil mixing (DSM) elements. Inputs included materials (quarrying and trucking to site), estimated fuel for mobilization, installation, and demobilization, estimated worker commute distances, and waste haul-off. Simplified ratios were used for the carbon contribution of the assets and mob/demob for the overexcavate and compact option. The values inputted into the carbon calculator are provided in Table 4.

Table 4. EFFC/DFI Carbon Calculator Inputs for Ground Improvement Alternatives

	Improvement Technique		
	Overexcavate and Compact	Vibro Stone Columns	DDC
Project Information			
Work Days	72	35	46
Workforce (FTE)	4	5	4
Materials			
Water (gal)	67,000,000		
Aggregate (lb)		12,000,000	
- Distance (mi)		20	
- Load (lb)		42,000	
- Empty-return Rate (%)		100	
Sand (lb)		12,000,000	
- Distance (mi)		20	
- Load (lb)		42,000	
- Empty-return Rate (%)		100	
Energy			
Diesel (gal)	17,100	9,262	5960
Mob/Demob			
Diesel (gal)		488	371
Simplified Ratio (%)	3		
People Transportation			
Car Roundtrips per Day	4	5	4
Average distance (mi, one-way)	50	50	50
Assets			
Estimated Simplified Ratio (%)	3.3	3.3	3.3
Waste			
Material (lb)		24,000,000	
- Distance (mi)		20	
- Load (lb)		42,000	
- Empty-return Rate (%)		100	

4.1.3 Results and Discussion:

The results of the assessment are provided in *Table 5*. The budgetary estimate was similar among the methods and the mitigation of risk related to soil collapse could be addressed by all three methods, so these metrics were not relevant as selection criteria. The over-excavate and compact method was not selected due to its longer installation window relative to the other two solutions. The large amount of water needed for moisture conditioning was not ideal but did not have a significant impact on the decision. The DDC method was not selected because vibration issues would put the schedule at risk if operations had to halt due to concerns or complaints from the community, deeming the solution unviable. Vibro stone columns provided the shortest installation window, which was a top priority for the client and, therefore, this method was selected. For bearing capacity, vibro stone columns excelled because this solution provided the most certainty with regards to achieving the capacity requirements.

Table 5. Results from assessment of three different ground improvement solutions.

Solution Type	Schedule	Budgetary Estimate	Soil Collapse Risk Concerns	Bearing Capacity Concerns	Impact to Community	tCO_{2e} (EFFC/DFI Carbon Calculator)	Environmental Impacts Beyond of Carbon
Overexcavate and Compact	12 weeks	~$750k	- Likely to mitigate the risk of soil collapse - Strict QA/QC is required to ensure the recompacted soil is not still collapsible	Ground improvement may still be needed under heavily loaded footings	Dust during excavation is of concern for adjacent neighborhood	240	- 8M gallons of water is needed to moisture condition the soil for compaction - General air pollution from diesel equipment
Vibro Stone Columns	8 weeks	~$750k	- Will not mitigate the risk of soil collapse but will mitigate the impact to the foundations if soil collapse occurs - Strict adherence to drainage designs and lining of water pipelines under the slab are required to mitigate soil collapse	Bearing capacity requirements will be achieved	Trucking of stone to site will impact local roads	240	- General air pollution from diesel equipment - Spoil material trucked to landfill
DDC	9 weeks	~$750k	- Likely to mitigate the risk of soil collapse	Ground improvement may still be needed under heavily loaded footings	Vibrations of concern for adjacent neighborhood	86	- General air pollution from diesel equipment

The embodied carbon of all three solutions was relatively low compared to other ground improvement methods as these solutions did not require Portland cement or steel. A chart with the CO_{2e} contributions from different aspects of each method is provided in Figure 4. Based on the research used to create the EFFC/DFI Carbon Calculator, for concrete and steel methods the materials can be the source of over 90% of the total carbon emissions. As is depicted in *Figure 4*, for the three methods, the materials have little to no contribution to the carbon emissions. As a point of reference, if the dimensions of the stone columns remained constant but the columns were filled with concrete instead of stone the embodied carbon would be 1700 tCO_{2e} – a sevenfold increase. DDC had the lowest carbon footprint by a factor of three, but, again, the schedule risk associated with this method made it unviable. As the embodied carbon of the over-excavate and compact and vibro stone columns methods were equal, this metric was used to confirm the low carbon intensity of these solutions but did not provide a carbon advantage for either method.

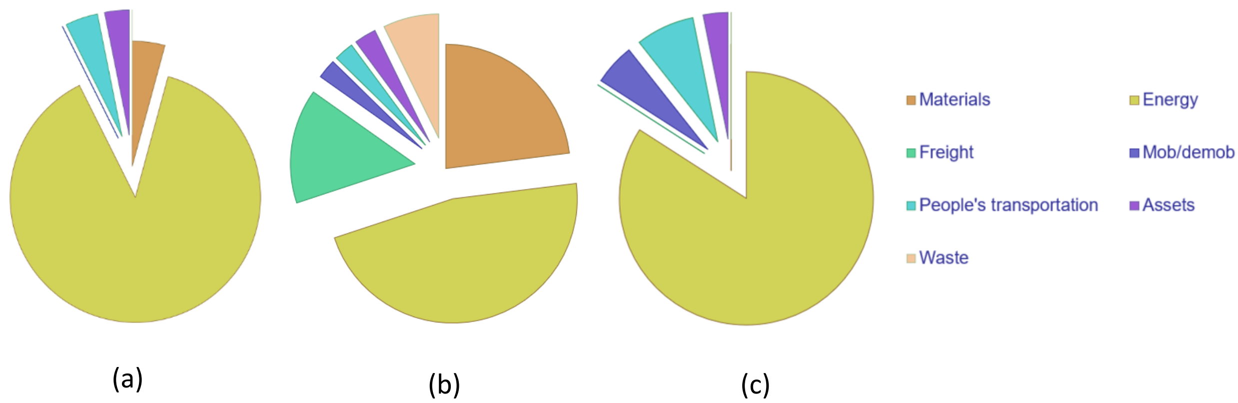

Figure 4. Relative contribution to carbon emissions from different aspects of each method for a) Overexcavate and Compact, b) Stone Columns, and c) DDC.

4.1.4 Findings/Conclusions:

Incorporating carbon calculations into the overall assessment when selecting a ground improvement method for a project is a useful exercise. From a big picture perspective, by presenting this information to the Client they can make more educated decisions about the ground improvement method and foundation design for their next project. For example, an important lesson from this project is that DDC is a very low carbon solution but can only be used when the schedule can allow for more risk, therefore, the Client may allot an additional schedule for ground improvement for their next project. Further, highlighting other environmental impacts like water, dust control, and pollution raises awareness for impacts that directly relate to our local communities. Lastly, this assessment did not include the social side of sustainability. Future work should attempt to capture that aspect, potentially by addressing the diversity of the project team and the diversity along the supply chain.

4.2 Case Study 2: Driven Spun Concrete Piles

4.2.1 Introduction

The project was a biodiesel refinery expansion in Singapore. The ground conditions were highly variable across the site and included areas of reclaimed land. In addition to meeting the technical requirements for bearing capacity and settlement control, the client required a short installation window and economical solution. Further, a low carbon solution was preferred for congruency with the final product – a plant which will produce sustainable products. The standard approach for foundations in this area is installing driven spun concrete piles. This was taken as the base case foundation type for this project.

4.2.2 Sustainability Assessments:

Driven spun piles provided one foundation solution for the entire project site. In order to optimize for cost and carbon reduction, two types of ground improvement were proposed as an alternative. The first method was vibro compaction for the areas reclaimed with clean, loose sands. This low carbon solution requires little additional material to be trucked to site and installed as it simply compacts the existing material until the bearing capacity and settlement requirements are met. The solution proposed for underlying marine clay layers was vibro stone columns. The stone columns reinforced the clay while also providing a drainage path for quicker consolidation of the clay. Vibro stone columns are considered a low carbon solution as the stone has little embodied carbon relative to cement or steel. The alternatives were assessed for cost, schedule, and carbon. The carbon assessment was performed using the EFFC/DFI Carbon Calculator.

4.2.3 Results and Discussion:

The vibro solutions yield estimated time and cost savings of between 20 and 30% as compared to the piling solution. In terms of carbon assessment, the results are provided in *Figure 5*. The vibro solution was able to save 3400 tCO2e as compared to the driven pile solution. The carbon savings is the equivalent to driving an average car 350 times around the earth's equator. The carbon emissions were also broken down by scope and are provided in *Figure 6.* Scope 1 emissions are emissions that occur on site from fuel use, Scope 2 emissions are from grid electricity used on site, and Scope 3 emissions are the emissions embodied in the materials. The majority of the carbon emissions for the driven piles comes from the material manufacturing (Scope 3), while for the vibro solution the majority of the carbon emissions comes from direct fuel emissions on site (Scope 1). This is because the cement in the piles is a carbon-intensive material but the stone used in the vibro methods has a relatively low carbon footprint. Further, the vibro compaction method used only in situ material, thereby eliminating Scope 3 emissions for that technique. Neither method had Scope 2 emissions as grid electricity would not be used for either installation.

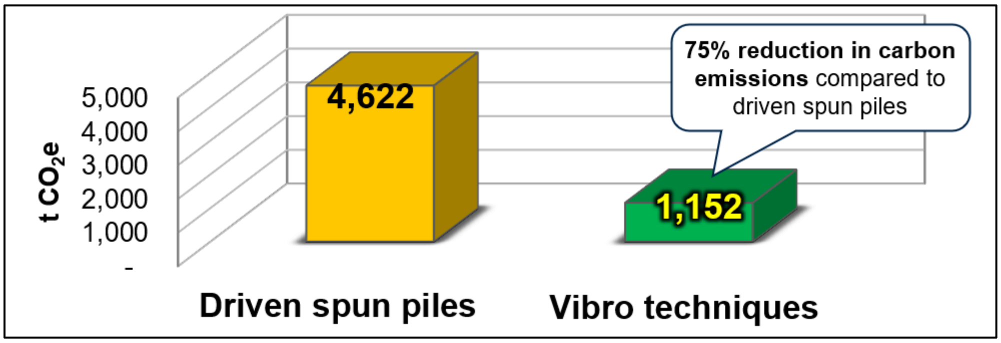

Figure 5. Embodied carbon comparison of driven spun concrete piles versus the vibro ground improvement solution.

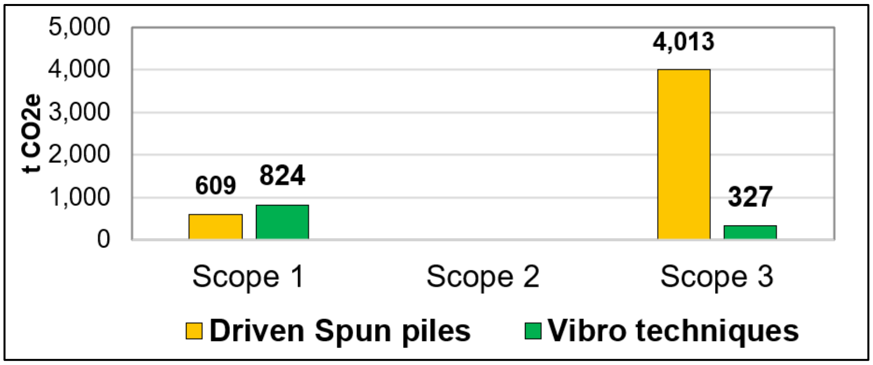

Figure 6. Carbon contribution broken down by scope for driven spun piles and the vibro ground improvement solution.

4.2.4 Findings/Conclusions:

The ground improvement solution which required no cement or steel to implement was able to cut total carbon emissions by 75% as compared to the baseline case of driven concrete piles. Further, the ground improvement solution met and/or exceeded the cost and schedule requirements for the project. An additional benefit of the ground improvement solution was that the structural engineers were provided flexibility as their designs progressed because shallow foundations could be used anywhere over the improved ground rather than having to put foundations at specific locations where driven piles were installed. As heavy equipment technology advances, electric rigs may come available which would further reduce the carbon emissions from vibro solutions as Scope 1 emissions had the highest contribution for this method.

4.2.5 3.2.5 Limitations of the Carbon Calculator

The EFFC/DFI Carbon Calculator tool provides a simple way to calculate the embodied carbon for most foundation solutions. Although this is a useful metric for environmental impact, this tool does not cover all environmental impacts, for example water use an important impact metric discussed in the first case study, nor does it cover the social impact of foundation design. To take a more holistic approach to sustainability, it is recommended that project teams use Envision. This is an ASCE-sponsored sustainability rating tool for infrastructure projects. Even if project teams do not choose to apply for an Envision rating, the tool can be used to help guide the project team in sustainability best practices.

5 SUMMARY

This module presents key terms and definitions for application to sustainability in geotechnical engineering. UN's sustainable development goals are presented and discussed in relation to geotechnical engineering contribution. Various principles of sustainable development were presented and ways in which geotechnical engineers can contribute towards sustainable development are discussed. Examples of how geotechnical engineers are contributing to sustainable development are presented. Several contributions involve use of contemporary materials or methods to minimize environmental and economic impacts. The relationship between resiliency and sustainable development is discussed. A variety of Sustainability assessment tools are presented and their relevance to geotechnical engineering discussed.

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