HOW GROUND IMPROVEMENT CONTRIBUTES TO THE GREEN BUILDING MOVEMENT

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ABSTRACT: Owing to the tremendous efforts of the United States Green Building Council (USGBC) and the development of the LEED Rating System, a mechanism has been created to evaluate construction projects from a "green building" standpoint. Using a free, foundation industry-specific carbon calculator tool for this study, the carbon footprint of a theoretical project was evaluated for four separate foundation options on the given site, using consumption data from real projects. Two methods of ground improvement, dynamic compaction and aggregate piers were the first two options considered, the third option was driven pile foundations, and the final option was a full removal of the unsuitable fill material and replacement with imported structural fill. Results of the study indicated that under the assumed conditions, ground improvement programs can have a carbon footprint on the order of 2 to 6% of the footprint associated with full removal of the fill material to send to a landfill. As such, this paper recommends that further evaluation be given towards establishing a new LEED credit related to geotechnical construction issues, or at minimum, establishing a carbon footprint reduction scorecard that could be incorporated into the existing LEED infrastructure.

INTRODUCTION

As we continue forward in the 21st Century, the concept of sustainability has come to the forefront as a generation of engineers, architects, and scientists wrestle with ways to reduce our impact on the environment, and conserve our natural resources. As part of the LEED Rating System (presently on v4 for Building Design and Construction – the focus of this paper), new structures can achieve varying levels of certification, based on the level of points achieved on the LEED scorecard. Points can be obtained as they relate to the site, transportation access to a site, to the energy features of a building, to water efficiency, the materials and resources used in construction of a building, and to indoor air quality.

From a geotechnical engineering standpoint, however, there are very few ways to directly contribute points towards the LEED certification of a building. Sure, steel piles can count towards material reuse credits if the material is recycled, or energy piles can be considered as part of a geothermal design, but when it comes to what is in the ground or the earthwork aspects of a project, the LEED rating system does not have a clear way to account for sustainable aspects of geotechnical design and construction.

Those familiar with the foundation industry are aware that there are generally two types of foundation conditions which can exist. First, you can have soils with suitable bearing characteristics on which shallow foundation systems are constructed. Alternatively, if poor soils are present, deep foundation elements can be installed to transfer the structural loads to more suitable bearing layers at depth. In the middle of these two alternatives, however, lies the field of ground improvement. Utilizing a wide variety of ground improvement techniques, marginal soils can be improved to allow for the use of shallow foundation construction with minimal long-term settlements.

When considering sustainable aspects of geotechnical construction, ground improvement is one of the first aspects that comes to mind. The entire intent of ground improvement is to utilize and improve the in situ soils at a site, rather than removing them or installing foundation systems which bypass them. In doing so, it is possible to divert a significant stream of materials from either being removed from a site and sent to a landfill, or cause the need for resources to be expended constructing more substantial and more costly deep foundation systems.

In 2012, the European Federation of Foundation Contractors (EFFC) and the Deep Foundations Institute (DFI), the EFFC-DFI Carbon Calculator Tool, which is used to evaluate the carbon footprint for common foundation-related techniques (both from a ground improvement and deep foundation standpoint) that are used throughout the industry. In creating the calculator, EFFC-DFI developed a way of evaluating geotechnical aspects of construction projects in a manner that could potentially be used to contribute towards LEED certification points on a project, if properly utilized.

LEED v4 FOR BUILDING DESIGN AND CONSTRUCTION

Presently, there are eight main categories which comprise the LEED v4 checklist: Location and Transportation, Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation, and Regional Priority. Out of the eight categories (which comprise a total of 12 prerequisites and 46 credits), only four prerequisites/credits tangentially touch on geotechnical-related aspects of a construction project, and none relate specifically to the sustainable aspects of ground improvement and foundation design.

A brief summary of each prerequisite/credit that relates to geotechnical aspects of construction is as follows:

- *Energy and Atmosphere Credit – Renewable Energy Production* – This credit is loosely related to geotechnical construction when it comes to geothermal aspects of foundations. A new and emerging technology is the use of "energy piles", which utilize pile foundations as individual geothermal elements.

- *Materials and Resources Prerequisite – Construction and Demolition Waste Management Planning* – In the materials and resources section, the second prerequisite requires the preparation of a plan as it relates to the reuse and recycling of as much construction and demolition waste as possible on a project.

- *Materials and Resources Credit – Construction and Demolition Waste Management* – The overall intent of this credit is to recycle and/or salvage nonhazardous construction and demolition materials. It specifically excludes, however, excavated soils and land-clearing debris.

- *Innovation Credit* – This final credit of the LEED v4 scorecard is a catch-all innovation credit. It allows for points to be earned for achieving "significant, measurable environmental performance using a strategy not addressed in the LEED green building rating system." At present, this credit presents the only potential option for achieving LEED points related to geotechnical construction.

As can be seen, there are limited opportunities, at best, for geotechnical components of a project to contribute to the LEED certification of a building, as the system is currently comprised.

EFFC-DFI CARBON CALCULATOR TOOL

Over the last 15 years or so, several methods of calculating the carbon footprint of an organization, product, or project have been developed. All methods generally fall into one of two categories: corporate standards or product standards. Corporate standards are more geared towards an organization, whereas product standards are more geared towards a particular project or product. Regardless of the differing standards, all calculators are based on a single underlying principle, as shown in Equation 1:

$$\text{Carbon Footprint} = \sum[(\text{Activity Data})*(\text{Emission Factors})] \qquad (1)$$

In calculating the carbon footprint, the summation of the data represents the boundary condition for which all activities within are included, and then each activity is multiplied by an emission factor which converts the emissions of each activity into an equivalent tonnage of carbon dioxide (CO_2eqv). The difference between standards then boils down to establishment of the perimeter (i.e. which activities are included) and which emissions factors are used.

Presently, there are several entities within the foundation industry that have developed carbon calculator tools for their own uses. The EFFC and DFI, with the assistance of Carbone 4, recently teamed to develop a carbon calculator tool for the foundation industry which uses a sector-specific carbon accounting methodology which can be used in a consistent manner across all foundation-related projects. The initial version of the calculator was made available in 2012; version 2.1, released in 2013, is the most current version of the calculator.

Emissions generally fall into two main categories: primary and secondary emissions. Primary emissions include manufacturing of materials, their transportation to a job site, and then the emissions generated as part of the construction process.

Secondary emissions include items such as transportation of people and equipment to and from a site, depreciation of equipment, and the transportation and treatment of waste materials from a site. As such, six main categories are used as part of the EFFC-DFI calculator tool: materials, energy used on site, people's transportation, freight transportation, assets depreciation, and waste. It should be noted, that the emissions factored into the EFFC-DFI calculator focus on from the manufacturing phase through the installation phase. Emissions factors from the use and end-of-life aspects of the life cycle are not included as part of this specific calculator.

EXAMPLE PROJECT – SINGLE-STORY WAREHOUSE STRUCTURE

In an effort to highlight the contributions that ground improvement can make to a project from a sustainability point of view, a theoretical project was examined using the EFFC-DFI Carbon Calculator Tool, using consumption data from actual projects. This project was based on the construction of a single-story warehouse building having a footprint of 50,000 square feet (4,645 square meters) on a site where 15 feet (4.6 meters) of miscellaneous fill material exists. Four foundation scenarios were evaluated as part of this study:

- Building founded on shallow foundations following dynamic compaction program to improve the fill;
- Building founded on shallow foundations after installing aggregate piers through the fill;
- Building founded on shallow foundations bearing on structural fill placed once the miscellaneous fill was removed and sent to a landfill;
- Building founded on pile foundation system.

Based on actual project information for a similar site, structural loads for the building were assumed to be 150 kips (667 kN) per column, 500 pounds per square foot (psf) (24 kPa) of live load on the floor slabs, and 5,000 pounds per linear foot (plf) (74 kN per meter) around the perimeter footings. Column bays were assumed to be on a 50-foot by 50-foot spacing (15.24-m by 15.24 m). A description of each of the four evaluations, including the input data specific to each case is provided below.

Scenario No. 1 – Dynamic Compaction

In this scenario, the in-place miscellaneous fill was assumed to have been improved using a dynamic compaction program. Fill material typically improved by dynamic compaction consist of sand and gravel materials with generally less than 20% minus 200 type material. Based on sites with similar soil conditions, a program consisting of two passes using a 10-ton weight dropped from a height of 50-feet (15.24 m), with 5 to 7 drops per point on a 12-foot (3.66 m) grid spacing was considered. Based on an average assumed production of 5,000 square feet (465 square meters) a day, a total of 10 working days was estimated to complete the dynamic compaction program.

The equipment used to be as part of a dynamic compaction program described consists of an American 700 series (60-ton) crawler crane and a crew of three men. Average fuel consumption is about 75 gallons of diesel per day, or about 750 gallons over a two week period. Three low-boy trucks are required to mobilize the crane to the job site, and so a total of six round trips was included for mobilization/demobilization. No raw materials are used during this process, and no waste is generated.

Scenario No. 2 – Aggregate Piers

The second ground improvement scenario considered was to install aggregate piers to improve the fill and provide the necessary vertical support for the structure. For this study, it was assumed that 30-inch diameter piers were installed to a depth of 15 feet (4.57 m) (through the fill material). The aggregate material used in these types of piers generally consists of 2-inch minus well-graded stone material. This material is generally a quarry-processed type aggregate, given the need for relative uniformity of the piers. The vertical working load for each pier was anticipated to be 70 kips, based on project data. Based on the building loads described above, a total of 36 piers would be needed for the twelve columns, 64 piers around the perimeter footing, and using a 12-foot by 12-foot (3.66 m by 3.66 m) spacing for floor slab support, and additional 347 piers for slab support. In total, 450 piers were anticipated to be required for this project. Expecting that 30 piers could be installed per day, a total of 15 working days was estimated to complete the aggregate pier program.

Equipment used to install aggregate piers consists of a backhoe-type machine, fitted with the aggregate pier drilling equipment along with a front end loader to deliver stone to the hopper of the drilling machine. A four man crew is typical for this type of aggregate pier program. Average fuel consumption for the two pieces of equipment is about 75 gallons of diesel per day, for a total of about 1,125 gallons of diesel for the entire job. Each piece of equipment is delivered to the site on a single truck, and so four round trips were included for mobilization and demobilization. From a material standpoint, approximately 2.75 cubic yards (2.1 cubic meters) of stone is required per pier, or approximately 1,250 cubic yards total; however, no waste is generated from this process.

Scenario No. 3 – Driven H-Pile Foundations

The third foundation option for the site being considered was to install driven steel H-piles for structural support. In this case, it was assumed that Grade A36 Steel HP10x42 piles could provide allowable axial capacity of 50 tons (445 kN) per pile for 30-foot (9.1 m) long piles. Based on the estimated building loads, a total of 36 piles were estimated for the column loads, another 45 piles for the perimeter wall footing, and a total of 250 floor slab piles based on the tributary area associated with a 500 psf floor loading. In total, approximately 331 piles would be required for this particular building. Anticipating that 25 piles could be installed per day, a total of 15 working days was estimated for pile installation.

Equipment used in pile driving operations generally consists of a conventional crawler crane with pile leads and hammer attached and a loader to move piles around the site from the stockpile to installation location. Average fuel consumption for the two pieces of equipment was estimated to be about 75 gallons of diesel fuel per day, for a total of about 1,125 gallons of diesel over a three week period. The pile driving rig was assumed to be delivered on three trucks, with the loader requiring a fourth truck. In total, eight round trips were included for the project. HP10x42 piles have a weight of approximately 42 pounds per linear foot. Assuming 331, 30-foot long piles, approximately 417,000 pounds of steel is needed for scenario, and no waste was assumed to be generated.

Scenario No. 4 – Removal of the Miscellaneous Fill and Replacement with Select Fill

The final foundation scenario considered was the complete removal of the miscellaneous fill material for off-site disposal, and replacement with select granular fill material. Following the completion of the removal and replacement program, the building would be founded on typical shallow foundations. For the purposes of this study, it was estimated that this work could be completed in a 15-day span.

Utilizing a treatment footprint of 50,000 square feet, and assuming that the 15 feet of fill is removed, a total of approximately 28,000 cubic yards of material would be exported as waste and then imported for placement as structural fill. In the Carbon Calculator, the trucking associated with the export and import operations is addressed in the waste and materials sections, respectively. During the on-site operation, it is assumed that a bulldozer, a dump truck, and a compactor would be in operation full-time during the 15-day period, and use an average collective fuel consumption of 75 gallons of diesel fuel, for a total of approximately 1,125 gallons of fuel on the project.

Results

Using the assumptions outlined above, the EFFC-DFI Carbon Calculator was used to estimate the total carbon footprint associated with each of the four scenarios. A tabular summary of the pertinent carbon components is provided in Table A.

Table A. Summary of Carbon Output for Each Foundation Scenario

	Dynamic Compaction	**Aggregate Piers**	**Pile Foundations**	**Removal and Replacement**
Materials	0	20	354	453
Energy	10	15	15	15
Freight	0	9	3	195
Mob/Demob	2	1	2	1
Transportation	1	2	3	3
Assets	0	0	0	0
Waste	0	0	0	80
Totals	**13**	**47**	**380**	**750**

*Note – all values provided are in tons of Carbon Dioxide Equivalent (tCO_2eqv).

The carbon dioxide equivalent for each component was calculated by multiplying the activity data outlined in each of the scenarios by the emission factor included in the calculator tool. The factors chosen by the creators of the calculator were the ones calculated using the most closely aligned methodology to the individual component. Sources included in the calculator database were obtained from Ecoinvent, Bilan Carbone V7, Sustainableconcrete, ICE v2, DEFRA, IEA 2012 and EcoTransit.

It is important to note, that the results for the four cases outlined above are based on real consumption data and boundary conditions from projects similar to the ones described and considered herein. However, given the fact that most projects do not implement multiple foundation systems on the same site, it was not feasible to provide results from a single site for comparison purposes.

CONCLUSIONS

As can been seen in Table A, there is a significant variation in the carbon footprints associated with each of the four foundation scenarios evaluated. At either end of the spectrum, the dynamic compaction program had a footprint that was less than 2% of the footprint associated with a full removal and replacement program, with the aggregate pier and pile options falling in between and representing 6% and 51%, respectively. One conclusion that can clearly be drawn from the data is that the successful implementation of a ground improvement program can significantly reduce the carbon footprint of a project, when compared to a deep foundation system or full removal and replacement.

So what are the next steps with respect to geotechnical construction and sustainability? One option could be to create a new credit in the Materials and Resources section which establishes threshold values for reduction compared to a baseline that, if achieved, can earn points on the LEED scorecard. Alternatively, in the absence of a new credit, a similar type of scoring system could be utilized with some consistency within the Innovation Credit. In doing so, it could ease the process for gaining points, by not having to recreate a job-specific scoring system on every project where ground improvement is being considered.

Regardless of the avenue chosen, it stands to reason that implantation of ground improvement programs can contribute significantly to a project from a sustainability standpoint, and should be considered as part of the LEED scorecard in some manner.

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KEYWORDS

Sustainability, dynamic compaction, aggregate piers, ground improvement, LEED v4 for Building Design and Construction, Carbon Calculator Tool

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