Proceedings of the 7th World Congress on Civil, Structural, and Environmental Engineering (CSEE'22)
~~Lisbon, Portugal~~ Virtual Conference – April 10 – 12, 2022
Paper No. ICGRE 236
DOI: 10.11159/icgre22.236

A Simulation of Embodied CO_2 Emission of Ground Improvement Technique Using Life-Cycle Assessment in Runway Construction

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Abstract **-** The ground improvement technique has become the most popular method in geotechnical engineering design. To incorporate sustainable development goals into the design, the construction method through quantitative assessment of environmental impacts is needed to meet project performance. A life cycle assessment model provides geotechnical engineering for calculating carbon dioxide (CO_2) emissions in ground improvement techniques. However, simplified methods for assessing impact to the environment have remained a largely unfulfilled need for targets of the Sustainable Development Goals (SDGs). This paper presents the boundary conditions and methodology for ground improvement techniques to evaluate the combined technology benefit to application prefabricated vertical drain combined stone columns in Runway construction. The results show that the design of prefabricated vertical drain combined stone column has the higher saving CO_2 emissions up to 99.5 % compared with the prefabricated vertical drain combined bored case in situ pile, this study is showing a percentage of 7.8 % up to 99 % saving CO_2 emissions with the other ground improvement techniques. The performance criteria are met for quantitative information about environmental impacts, such as saving embodied CO_2 emissions, and it is useful for making geotechnical decisions for sustainable development.

Keywords**:** Ground improvement, life-cycle assessment, CO_2 emission, PVD, stone column

1. Introduction

Ground improvement is an established and expanding sector of geotechnical engineering work that involves large quantities of materials, and therein lie opportunities for meaningful reductions in environmental impact [1]-[4]. Runway construction is one of the important sectors to develop sustainability goals, and the sustainable development is the process by which sustainability is achieved over time. The ground improvement method is one of the design selections that is typically based on performance assessment and the associated monetary cost, with much less regards given to environmental impacts or other social concerns [3]. Final performance requirements established for the project must be met by any relevant design alternative, therefore, ground improvement alternatives are identified that will meet the project performance requirements, monetary cost and environmental impacts together remain as key considerations for the geotechnical aspects of sustainable development.

To develop the quality, reliable, sustainable, and resilient infrastructure to support economic development, and human well-being is one of Sustainable Development Goals (SDGs) targets By 2030, upgrading infrastructure and retrofitting industries to make them sustainable is one of the targets especially in Indonesia, where is identified potential to alignment between the targets, actions, policy measures and needs in countries' Nationally Determined contributions (NDCs) and the targets of the Sustainable Development Goals (SDGs) [5].

The emissions assessment model compiles existing environmental impact assessment principles and methods into a methodology geotechnical engineering field can readily use to incorporate sustainable development principles into the ground improvement planning and design decision-making process. The objective of this research to calculate the embodied carbon dioxide (CO_2) emissions for ground improvement to involve the first determining the relevant using Life Cycle Assessment (LCA) stages for the subject of interest and defining boundaries in Runway construction. LCA is a quantitative method to evaluate the environmental impacts of a product or process over its whole life, from cradle to the grave [6], by considering factors such as raw material extraction, processing, use recycling, reuse, and ultimately [7].

2. Literature review and methods

2.1. Embodied CO_2 emissions implications for ground improvement practice

The ground improvement techniques can be a more sustainable geotechnical construction alternative relative to some more traditional foundation systems because they have the potential to reduce construction time, material use, fuel consumption, and labour [8], based on study combined technology such as prefabricated vertical drain combined stone column design compared with other ground improvement technique with the same function will be calculated to know embodied CO_2 emission.

In geotechnical construction for projects considering both the economic cost and environmental impact when deciding between design alternatives that meet performance criteria can lead to more sustainable projects. To that end, life cycle embodied CO_2 emissions are proposed as two relevant factors for quantifying the global environmental impact of ground improvement in a simple and transparent manner. Making ground improvement and other geotechnical design decisions that consider impacts of CO_2 emissions in addition to monetary cost and final performance requirements can advance the geotechnical profession in achieving sustainable development goals. The life cycle can be considered to extend from raw material extraction to the completion of construction and based on [9] embodied CO_2 Emission associated with ground improvement projects and its application illustrated by an example.

2.2. Limitation of the study

The following factors can make it challenging to calculate embodied CO2 Emission of geotechnical engineering design, especially in ground improvement technique modified by [10]: Geotechnical design is strongly based on site-specific and standard in contraction area, Fewer design varieties are available only in contraction area, the installation process described at the design stage often does not reflect what happens on the construction area, the service life is often longer than that construction design is required.

2.3. Methodology

The stages describing the life cycle assessment include (1) Material and Equipment; (2) Ground improvement construction with transportation between and within sites and processes constructions, including an allocation of the machinery manufacturing, operation and maintenance processes, and disposal or recycle energy after the demolition. The following methods of ground improvement and piling considered in this study are shown in Fig 1.

The boundaries and methodology are used for quantifying environmental impact factors for geotechnical construction for embodied CO_2 emission, based on site-specific in Runway construction.

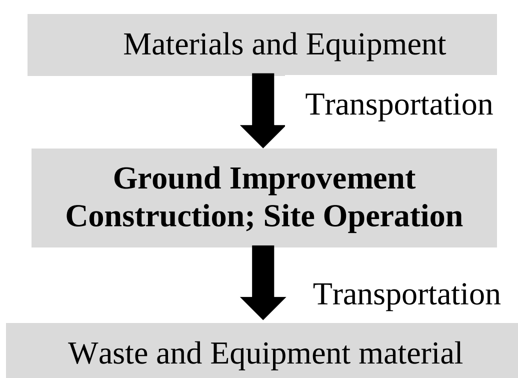

Fig. 1 Flow chart of the boundary condition for analysis

2.4. Life cycle assessment in runway construction

LCA is a quantitative method to evaluate the environmental impacts of a product or process over its whole life, from cradle to grave [11], [12] by considering factors such as raw material extraction, processing, use, recycling, reuse, and ultimately, final disposal [7]. Therefore, it makes sense for geotechnical engineers to utilize LCA streamlining when conducting environmental impact assessments of their designs, which can be accomplished through simplifying the analysis be considering specific environmental impact factors. The following section discusses embodied CO_2 emissions, which are demonstrated to be useful impact factors to consider in streamlined LCA of geotechnical works.

The quantifying embodied CO_2 emissions is a skill in which [4] predict geotechnical engineers will need to be proficient as sustainability considerations mature. The following subsections discuss definitions and current methods for quantifying energy and CO_2 emissions due to construction, laying for methodology of ground improvement presented in a companion paper [9].

In terms of building and civil infrastructure construction, embodied CO_2 emission may be classified as either indirect or direct. Embodied energy may further be classified as either primary or delivered.

Table 1 Embodied carbon values used for analysis

Material	EC-kg CO_2/kg	Reference
High Density Polyethylene (HDPE)	1.60	Inventory of Carbon & Energy (ICE) V.1.6a, University of Bath, UK [12], [13]
Stone Gravel	0.017	
Concrete	0.130	
Steel (Reinforcement steel)	1.77	
Sand	0.005	
Soil-cement (DMS)	0.14	
Slag (U.S)	0.021	Slag cement Association 2014
Fuel – Diesel *Diesel density is taken as 0.83 kg/l	3.25	Carbon calculator V.3.1.1, Environmental Agency, UK [13]

Table 2 Average fuel consumption of construction [14], [15]

Description of vehicle	Truck class (1-8)	Average fuel consumption (km/L)
Light heavy-duty truck	7	2.72
Heavy-duty truck	8	2.42

Since these terms are widely used, they are defined where M_{mi} = Mass volume of material, C_{mi} = coefficient of material. where CO_{2_m}= total embodied CO_2 emission of consuming material; CO_{2_T} = total embodied CO_2 emission of consuming for transportation, F_{cmi} = Fuel consuming of transportation, C_{fmi} = coefficient of transportation from the supplier to the site.

$$CO_{2_m} = \sum_{i=1}^{n} [(M_{mi} \times C_{mi})] \tag{1}$$

$$CO_{2_T} = \sum_{j=1}^{m} \left[\left(F_{cmi} \times C_{fmi}\right)\right] \tag{2}$$

The total quantity of a particular fuel (e.g., diesel), the average fuel consumption of construction is shown in Table 1. The CO_2 emissions are computed following the same approach used for embodied CO_2 emission. Overall total CO_2 emissions are determined in Equation. (3).

$$Total_{CO_2e} = CO_{2_m} + CO_{2_T} \tag{3}$$

3. Results and discussions

In the civil infrastructure and geotechnical works, there is the standards permit the use of emissions coefficients for GHGs. One of the largest database available for construction materials is the Inventory of Carbon and Energy (ICE) version 2.0, developed by [6] for construction materials in the United Kingdom. The data base present many available studies for each material as possible, including minimum, maximum, average, and standard deviation of EECs for each material, giving an indication of the spread in the available data from published sources. [13], indicated that data can be used for international use, because the EE values in the ICE database are more reliable than the CO_2 emission values.

In this study the coefficient using the ICE database for runway construction project has location in 3000 x 60 m for runway construction in soft soil in 1 km is part of the runway, analysis shown in Table 3. The lower the percentage indicate the less accurate the estimate for total embodied CO_2 emission shown in Fig 2.

Table 3 Calculation embodied carbon by ground improvement technique

Ground improvement technique	**Material consumption (ton)**	**Embodied CO_2 (ton)**	**Fuel consumption for installation (kg/l)**	**Total Embodied CO_2 (ton)**
Stone column	210206.15	3573.50	3046.65	6997.84
Prefabricated vertical drain	0.047	0.076256	4248.40	4248.48
Granulated Blast Furnace Slag	532917	11191.26	600.87	11792.14
Bored cast in situ pile	1275400.65	2120127	1209.88	2121337
Deep mixing soil	213166.80	29843.35	609.00	30452.36
Sand drain	236852	1184.26	600.88	4608.59

4. Conclusion

There is a recognized need for improving geotechnical construction material and transportation energy to embodied carbon dioxide (CO_2) emissions, thereby improving the sustainability of the natural systems on which society depends on site-specific and standard in contraction area. The authors use the boundary and methodology CO_2 emissions as environmental impact factors to compare quantifying environmental impacts such as CO_2 emission for different alternative in ground improvement. The results show that the prefabricated vertical drain combined stone column design has higher saving CO2 emissions until 99.5 % than the prefabricated vertical drain combined bored case in situ pile, this study shows a percentage of 7.8 % until 99 % saving CO2 emissions with other ground improvement techniques. Geotechnical ground improvement projects, considering of environmental impacts when deciding between design alternatives that meet performance criteria can lead to more sustainable projects.

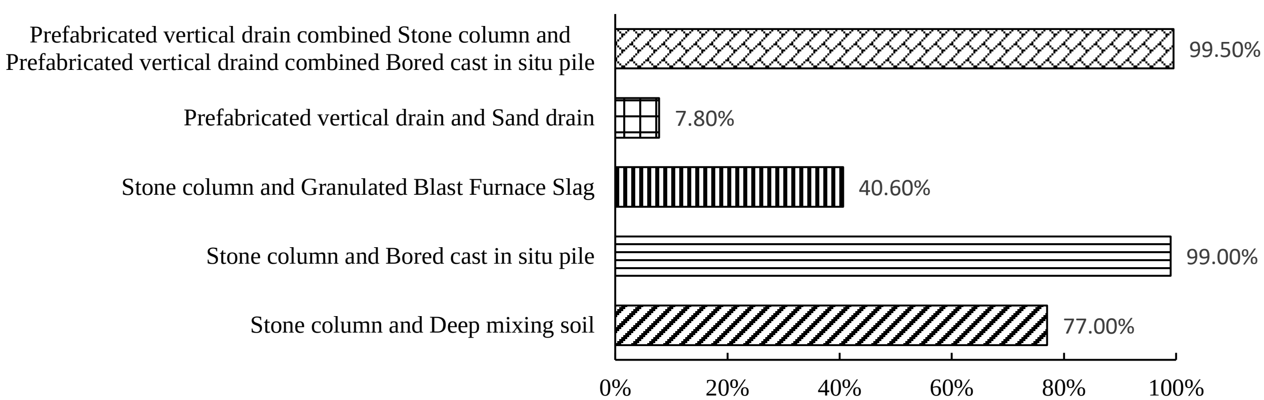

Fig. 2 The total saving embodied CO2 emission

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