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A review of sustainable approaches in transport infrastructure geotechnics ☆

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ABSTRACT

Transportation geotechnics associated with constructing and maintaining properly functioning transportation infrastructure is a very resource intensive activity. Large amounts of materials and natural resources are required, consuming proportionately large amounts of energy and fuel. Thus, the implementation of the principles of sustainability is important to reduce energy consumption, carbon footprint, greenhouse gas emissions, and to increase material reuse/recycling, for example. This paper focusses on some issues and activities relevant to sustainable earthwork construction aimed at minimising the use of energy and the production of CO_2 while improving the in-situ ground to enable its use as a foundation without the consumption of large amounts of primary aggregate as additional foundation layers. The use of recycled materials is discussed, including steel slag and tyre bales, alongside a conceptual framework for evaluating the utility of applications for recycled materials in transportation infrastructure.

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Introduction

Transport infrastructure consists of facilities such as roads, highways, bridges, airports, railways, waterways,

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canals and terminals, that place heavy demands on material resources, and is undergoing a market transformation in terms of the planning, design, construction, maintenance and exploitation of more sustainable structures. This infrastructure has an effect on the earth's resources and environment but also changes the land use pattern that has persisted for centuries and affects the societal values of a community [1]. Thus, geotechnical aspects and related activities are of primary importance from the earliest planning and design stages of an infrastructure project in achieving overall sustainable development in construction projects to: (1) meet basic human needs; (2) use resources effectively; and (3) preserve/restore the surrounding ecosystems [2]. This means that the main contribution of geotechnical engineers in achieving sustainability at a project level lies in efforts to utilise limited resources and explore ways of reducing processes that result in adverse impacts on sustainability. A few such areas are energy efficiency of the materials and methods used; potential reuse, recycling and re-engineering of materials and wastes; carbon footprint analyses; and the control of air, water and soil pollution [3]. A brief overview of geotechnical examples covering some of these areas are addressed in this paper. This includes sustainable ground improvement methods, earthworks constructed by minimising the use of energy and the production of CO_2, and the use of recycled alternative materials, foundation reuse, and rehabilitation and maintenance without the consumption of large amounts of primary natural geomaterials.

Ground improvement

Improving or modifying ground conditions to suit the engineering needs of construction projects has been practiced for decades. This practice often results in cost savings and other tangible benefits for both the project and the owner. Today, there are several ground improvement methods encompassing shallow, medium and deep soil treatments and involving drainage, reinforcement and soil improvement techniques available for geotechnical engineers to choose from, contingent to construction project needs. This practice has become such an important toolkit in the armoury of the geotechnical engineer that the *Proceedings of the Institution of Civil Engineers* in the UK now devotes an entire journal, *Ground Improvement*, to the subject (http://www.icevirtuallibrary.com/content/serial/grim); other related practices are more specifically targeted at transportation geotechnics [4–6]. The selection of a ground improvement method for a particular project is usually made in deference to the project cost and timelines. Nowadays, this decision is also made from the sustainability standpoint as well. Engineers can select two or three ground improvement alternatives for a given project and then perform a comprehensive analyses of the carbon footprint, life cycle cost and energy consumption of each of the methods and then determine the one that proves to be the most sustainable [7].

Sustainable earthworks

Reuse of natural geomaterials

Earthworks seek to reuse and incorporate as much as possible of the geomaterial already existing on the construction site as is practicable [8]. This will avoid the disposal of such materials and save on the consumption of natural resources, which include high quality and other quarried materials, as well as minimising the demand for land and transport. Although not explored in detail in this paper, issues surrounding the acceptability of natural earthworks materials form an important part of the earthworks planning and implementation process and their correct application can have a fundamental effect on achieving sustainable earthworks construction. Similarly, where natural earthworks materials (including glacially deposited materials) incorporate large particle sizes (soil–rock fill mixtures), account must be made of differences between the limited particle size ranges of the samples tested at the planning (ground investigation) and construction stages and the materials that are actually placed [9–11]. Failure to do so can lead to failure of the earthworks process and significant additional costs and energy consumption.

Nevertheless, the first step in determining whether a material can be used is to evaluate whether the excavated geomaterial meets the specification(s) for the specific application. However, if it does not meet the specifications, mechanical and chemical treatments may be considered to render the material suitable. Amongst chemical treatments, lime is commonly used in many countries to allow the reuse of very wet or soft fine soils in the construction of embankments, road foundation capping layers, and other applications [6,8,12–15]. An immediate improvement in the soil properties is expected and the treatment increases workability and assists compaction during earthworks. This technique has been common practice in Europe for several decades but the long term effects of lime treated soils have not been generally taken into account in design. Even mixing rather small amounts of lime with soils induces pozzolanic reactions that may continue over a period of years, resulting in a continuous increase of strength and stiffness [16,17]. The results presented in Flores et al. [16,17] show that for a silty soil treated with 3% quicklime only four days after construction (and thus four days of curing) the slope factor of safety increased from 1.5 for the untreated soil to 2.5 for the treated soil. This evolution continued with time and values of the factor of safety close to 4 and 10 were reached after 3 months and one year (in constant humidity and temperature conditions, 20 °C), respectively. Neglecting this long-term development resulting from pozzolanic reactions between lime, water, and the silica and alumina that exist in the clayey particles, has a direct impact on the costs of the earthworks, for example, as slope stability, erosion, bearing capacity will be underestimated. Although these reactions and their products are now well established, their influence on the evolution of the geomechanical properties of the treated soil has, until recently, been relatively unexplored. As a