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Cyclic strength of sand mixed with biochar: Some preliminary results

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Abstract

Biochar is a recycled material obtained through the thermal degradation of any organic biomass in the manufacture of bio-fuel inside a reactor in a process known as pyrolysis. It is an organic material that can endure in soil for thousands of years. Given its aromatic nature, biochar is highly recalcitrant, and has been considered to have great potential to sequester carbon and reduce greenhouse gas emissions. This material has been commonly used in environmental and agricultural applications, as it can store plant minerals in its pore spaces and provide a large water-holding capacity. However, little research has been done on the geomechanical properties of the resulting mixture of biochar and soil. Some studies have shown that biochar can increase the shear strength of clays and desaturate soil particles, and it may be possible that it can also increase the resistance to liquefaction in loose sand. Therefore, it would be very interesting to assess whether this material is able to present a more environmentally friendly alternative for improving the properties of soil. In this study, samples of pure sand are dry-mixed with 0%, 3%, and 5% biochar by weight and tested under cyclic undrained shearing using a simple shear test apparatus. The preliminary results indicate that biochar can increase the cyclic resistance of sand.

Keywords: Biochar; Simple shear test; Soil properties; Soil liquefaction; Mitigation

1. Introduction

Soil liquefaction is one of the causes of great damage during earthquakes; it is a complex phenomenon that occurs due to seismic shaking. Soil liquefaction is a process in which loose saturated soil, which has a tendency to contract under shaking or rapid loading (undrained load), experiences an increase in excess pore water pressure and a consequent reduction in effective stress. In cohesionless contractive materials, the resistance is completely suppressed and the soil behaves like a fluid with no shear resistance. As a result, the granular material is transformed from a solid state to a liquid state, and the effective stress and the soil shear strength and stiffness are reduced dramatically. The soil is unable to resist the load and behaves like a fluid, allowing it to deform largely and cause damage to the infrastructure.

Soil liquefaction is often associated with sand boils, flow failure slides, ground settlements, lateral spreading, foundation and retaining wall failures, and the lifting of buried structures. These manifestations have cost millions of dollars and caused significant damage to infrastructures around the world during the largest earthquakes, such as in Alaska in 1964, in Niigata, Japan in 1964, in San Fernando, California in 1971, and more recently in Maule, Chile in 2010, in Christchurch, New Zealand in 2011, and in Tohoku, Japan in 2011. Furthermore, the impact to such areas can be increased when damage is done to lifeline structures, such as hospitals, electrical power plants, telecommunication centres, transportation facilities, water and sewage facilities, oil and gas pipelines, and waste storage systems. The 1964 earthquakes in Alaska ($M_w = 9.2$) and in Niigata, Japan ($M_w = 7.4$), that produced devastating damage due to liquefaction, raised for the first time the

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urgency to understand and mitigate this phenomenon. Since then, great progress has been made in understanding the dynamic behaviour of soil and in developing methods to improve ground conditions. However, the liquefaction of soil still occurs and its effects continue to cause severe damage to infrastructures worldwide. There are still lessons to be learned, especially in a world where cities are growing, which necessitates the use of reclaimed land and requires more sustainable solutions.

The conventional techniques for mitigating the occurrence of liquefaction include: soil replacement, increasing soil density (soil densification, sand compaction, and vibro-compaction), providing drainage (gravel columns), desaturation (air injection, biogas, and electro-osmosis), providing bonding to the grains (deep mixing, bio-cementation, and other grouts in general), restraining shear deformation (cut-off walls), and making structural improvements. Among these, compaction and densification are the most popular methods for improving soil conditions. However, with the increase in global carbon emissions, more environmentally friendly solutions are needed. The consequences of not adopting a sustainable approach in the designs and applications may not be costly over the short term; however, they would be very costly for society over the long term.

In addition, in recent times, it has become more and more necessary to make use of less suitable soil for construction, like reclaimed land or land close to lakes or other water bodies, which are highly susceptible to soil liquefaction. With the development of new cities and technologies, there are challenges that new trends to mitigate liquefaction should answer in order to facilitate the mitigation in a non-disruptive manner, namely, in a more environmentally friendly way with a lower volume of carbon emissions. The use of interdisciplinary efforts and new environmentally friendly technologies can offer more sustainable solutions to mitigate liquefaction. For these reasons, the use of both new and recycled materials has begun to be studied as an alternative way to mitigate liquefaction.

Given the fact that contamination and waste are increasing at an alarming rate, the importance of providing further uses for recycled material is gaining recognition. Much solid waste, such as wood and other types of biomass, is 100% renewable. It can be reused and recycled many times for a variety of applications. And, when it cannot be reused any more, it can then be utilised for energy production or energy recovery. There are several methods currently being employed for this purpose. Most of them involve the thermal degradation of waste biomass inside a reactor by heating at different temperatures for specific times and under low oxygen conditions. Among these, gasification and pyrolysis are the most common techniques. In gasification, the biomass is heated at extremely high temperatures (800–900 °C) and mostly gas is obtained, called syngas (Bridgwater, 2007a). In pyrolysis, the temperatures are lower (300–700 °C) and the residence time for the biomass is variable, from 10 min (fast pyrolysis) to several hours (slow pyrolysis). In this case, liquid fuel (bio-oil) is the main product, but gas and solid can also be obtained (Bridgwater, 2007b). Biochar is the term used to refer to the high carbonaceous solid product (or co-product) of pyrolysis. It can be obtained from different biomass materials, such as bones, agricultural waste (crop residues), livestock manure, sewage sludge, compost or wood waste. Given its recalcitrant nature, it can endure in soil for hundreds of years (Lehmann et al., 2006). When it is used as a soil amendment, it provides additional pore volume, resulting in an increased water-holding capacity (Brown et al., 2006; Downie et al., 2009). Depending on how it is produced and the origin of the feedstock used in the pyrolysis process, it can possess a high surface area (Major et al., 2009), making it suitable for use as an effective adsorbent for a variety of chemicals in soil and water (Reddy et al., 2014; Sarmah et al., 2010; Sun et al., 2011; Zhang et al., 2013).

This material has been commonly used in environmental and agricultural applications (Devereux et al., 2012; Hseu et al., 2014; Troeh and Thompson, 2005), and its potential as a carbon sequester agent has brought more attention given the growing concern for anthropogenic carbon emissions (Lehmann et al., 2006; Winsley, 2007). Biochar has been shown as a sustainable alternative in this matter as it can sequester 1.8 Gton of carbon per year, that is, a contribution of 12% of the total CO_2 global emissions (15 Gton/yr) (Woolf et al., 2010). In other studies, its mechanical properties have also been studied in uniaxial compression (Byrne and Nagle, 1997) and the results indicate that carbonized wood has 28% more resistance than their respective feedstock and 37% less stiffness. Moreover, some new research studies have explored the mechanical properties of biochar particles through nano-indentation (Das et al., 2015; Zickler et al., 2006), and a large variation among the different types of biochar has been observed. In general, with an increase in the pyrolysis temperature, the hardness and elastic modulus are higher.

Regarding its geotechnical properties, direct shear tests performed on clay soil mixed with biochar indicated an increase in shear strength, with suitable application for backfill in slopes (Reddy et al., 2015; Sadasivam and Reddy, 2015), and an ability to control the volumetric changes in expansive clays (Lu et al., 2014; Zong et al., 2014). In general, an increase in the internal friction angle has been observed and, in some cases, a tendency to decrease cohesion in clays (Lu et al., 2014; Reddy et al., 2015; Sadasivam and Reddy, 2015; Zong et al., 2014). To date, despite some recent work to assess the geotechnical properties of soil mixed with biochar, no studies have been conducted on its effect on sand under dynamic loading.

In the present study, the results of preliminary tests conducted on sand treated with wood waste biochar are presented and the effect of the addition of biochar on the geomechanical properties of the sand is reported. The main objective is to assess whether this material could be used to mitigate soil liquefaction.

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