Adverse Effects of Expansive Soils on Road Infrastructure and Evaluation of Chemical Remediation Techniques

by Hayder Abbas Hasan

Thesis submitted in fulfilment of the requirements for the degree of **Doctor of Philosophy**

under the supervision of A. Prof. Hadi Khabbaz and A. Prof. Behzad Fatahi

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Hayder Abbas Hasan declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the school of Civil and Environmental Engineering, Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

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Abstract

Using waste materials and creating novel methods to minimise the adverse effects of expansive soils reduces the cost of building foundations and also reduces their impact on the environment and landfill. Continuous swelling and shrinking cause cracks to form in structures built on expansive soils such as road pavements and embankments. This study describes how a combination of lime and sugarcane bagasse ash, a waste product of the sugar industry, is used to stabilise expansive soils. Since the amount of research addressing the effect of bagasse ash on soil stabilisation was limited, a comprehensive attempt has been made on expansive soils using bagasse ash to improve their engineering properties and reduce the need for traditional additives such as lime. There are large gaps with regards to the optimum amount of bagasse ash that can be used for lime treated soil, the most effective ratio between bagasse and the amount of lime, and the properties of soil treated with bagasse ash, and with or without lime. An array of tests to quantify the shear strength of treated soils, the durability of treated soils using different drying and wetting cycles, and the soil water characteristic curves of treated soils were carried out.

Two types of expansive soils were used in this experimental program; this first type came from a road construction site in Queensland (Soil Q) and is classified as a high plasticity clay; the second type was created in the laboratory by mixing 80% kaolin and 20% bentonite (Soil C). It was also defined as high plasticity clay. These samples were prepared by integrating soil with a mixture of hydrated lime (L) from 0 to 6.25% and up to 25% of bagasse ash. These combinations of lime to bagasse ash were prepared with different ratios (e.g. 1:1, 1:2, 1:3 and 1:4). A combination of lime and bagasse ash was added to the soil samples as a stabiliser at ratios of 6%, 10% 18% and 25%, based on the dry weight of soil. To determine how hydrated lime and bagasse ash affects the engineering properties of treated soils, tests such as particle size distribution, specific gravity, Atterberg limits, compaction, linear shrinkage, the free swell ratio, unconfined compressive strength (UCS), durability, the California bearing ratio

(CBR), free swell, swell pressure, consolidation, and direct shear and suction tests were carried out.

The results indicate that the dry density of natural and artificial soils decreases as the amount of additives increase, and the linear shrinkage, free swell ratio, free swelling and swell pressure of soils treated with a combination of lime and bagasse ash decreased more than soils treated only with lime or bagasse ash. The UCS and CBR of soil increased as the amount of additives and curing time increased, and when bagasse ash was added to soil treated with lime under various cycles of wetting-drying, it became more durable than soil treated just with lime. Moreover, the addition of bagasse ash to soil treated with lime reduced the gap between soaked and unsoaked CBR. The pre-consolidation pressure (σ_c'), the coefficient of consolidation (C_v), the compression index (C_c), the swell index (C_s), and the cohesion and friction angle of soils improved as the amount of additives (bagasse ash and/or lime) increased. The matric suction was determined based on the gravimetric water content and degree of saturation, using the filter paper technique. The air entry value parameter (a) of soils increased after adding 6.25% lime, but the highest a value was for soil samples treated with 6.25% L and 18.75% BA.

PLAXIS software was used to calculate the deformation and to evaluate the slope stability of a proposed embankment placed on top of the target expansive soil (Soil Q) under a fill embankment. Five models were developed to estimate the settlement of soil and assess the slope stability of a fill embankment under traffic loads. The Mohr-Coulomb model was used to simulate a fill embankment as well as treated soil and dense sand, while a soft soil model was applied to untreated soil with an over consolidation ratio of 1.2. These numerical models indicated that treating soil reduced its vertical displacement (settlement) due to an increase in its strength parameters, whereas the reduction in time is associated with an increase in its permeability. The slope stability of the fill embankment decreased slightly as the layer of treated soil was made thicker.

This study offers a promising way of using bagasse ash as an eco-friendly stabiliser for treating expansive soils, particularly in conjunction with lime for treatment of weak subgrade of roads.

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Dedication

I would like to dedicate this Doctoral dissertation to my family, particularly my son, Ali, and my daughter, Huda. They have made me stronger, better and more fulfilled than I could have ever imagined. I love them to the moon and back. I equally dedicate this thesis to my wife Taqwa Al-Khafaji for her love, support and understanding.

List of Publications

- Hasan, H., Khabbaz, H., & Fatahi, B. (2016). Impact of quicklime and fly ash on the geotechnical properties of expansive clay. *4th Geo-China International Conference 2016,* pp. 93-100.
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- Hasan, H., Khabbaz, H., & Fatahi, B. (2017). Strength Property of Expansive Soils Treated with Bagasse Ash and Lime. *Springer International Publishing, Sustainable Civil Infrastructures,* pp. 22-35: Innovative Infrastructure Geo-technology.
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