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Predicting the Behaviour of Fibre Reinforced Cement Treated Clay

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Abstract
Treating soft clay with cement and fibre has become an effective ground improvement technique for transport infrastructure. Application of recycled fibres in deep soil mixing columns in soft soil sections of road and rail projects is being considered by designers and clients as an efficient technique. However, the combined effect of cement and fibre at failure requires further investigation. As the effective stresses increase to a sufficiently high stress, the effect of cementation is diminished due to the degradation of cementation bonds and the fibre exhibits failure due to either complete pull-out or breakage from the soil matrix. Thus, the failure envelope of the reinforced soil gradually merges with that of un-reinforced soil at higher stresses. In this paper, a constitutive model is proposed to simulate the behaviour of the cement treated-fibre reinforced soil based on the Critical State Soil Mechanic and the Modified Cam Clay model. In particular, the proposed model captures the beneficial effects of cementation and fibre reinforcement such as the improvement in strength and ductility while the cementation degradation and the failure mechanism of the fibre are also considered. In addition, a series of un-drained triaxial tests were conducted to verify the performance of the proposed model. This paper concludes that adding fibre into the cement treated soil clearly improves its residual strength, thus, a significant increase in ductility is observed and well simulated. In this study, by modifying the mean effective stress to include the cementation degradation and the fibre failure mechanism, the proposed model results in realistic prediction for the behaviour of soil treated with cement and fibre.

*Keywords:*cement treated fibre reinforced soils, constitutive modeling, cementation degradation, fibre failure mechanism

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1 Introduction

Stabilising soft soil with cement has become an effective ground improvement technique to strengthen the properties of the soft soil which involves mixing in-situ soil with cement to form soil-cement column. According to Porbaha (1998), the cement treated clay generally has higher strength, lower permeability and controlled deformation as compared to the un-treated soft soil. The properties of the cement treated clay are improved mainly due to the chemical interaction between cement and the soil particles to enhance the structure of the soil-cement matrix (Kamruzzaman et al., 2009). However, the cement treated soil becomes more brittle as compared to the un-treated soil due to the addition of cement. The brittle behaviour of cement treated soil is unfavourable as the strength suddenly drops to the residual strength (Lorenzo and Bergado, 2006).

In recent years, the use of fibre reinforcement to improve the strength and particularly the ductility of soft soil with and without cement treatment has been carried out by a number of researchers such as Michalowski and Cermák (2003)andTang et al. (2007). In particular, as reported by Michalowski and Cermák (2003) for fibre improved sand, the peak and residual strengths of both cohesive and cohesionless soil increase due to fibre reinforcement. While most of the previous studies focused on the improvement of fibre inclusion on sand and cement treated sand, only a few number of researchers such as Cai et al. (2006) and Fatahi et al. (2012)have focused on the fibre reinforced cement treated clay. Preliminary results suggested that the addition of fibre improves the overall performance of the cement treated clay, particularly the material ductility (Cai et al., 2006). Tang et al. (2007)explained that, the effect of fibre reinforcement is to increase the load transfer capacity from the soil-cement matrix to the fibre body, consequently the fibre connects the soil-cement clusters and provides the bridging effect preventing any further cracks within the sample. Thus, the large cracks which are normally observed in the failure of the cement treated clay are replaced by smaller cracks leading to an increase in material ductility. However, the behaviour of the cement treated clay reinforced with fibre under triaxial condition requires further investigation, particularly the failure mechanism of fibre and the effect of cementation degradation at high effective confining pressure. Thus, in this study, an undrained triaxial compression tests were conducted on cement treated clay and the results were reported for 5% cement and reinforced with 0% and 0.5% fibre to examine the effect of fibre reinforcement on the behaviour of cement treated clay.

Furthermore, this paper proposes a constitutive model to simulate the behaviour of cement treated clay reinforced with fibre. In the proposed model, the mean effective stress is modified to consider the combined effect of fibre and cement contribution to the shear strength, together with the effect of cementation degradation and the failure mechanism of the fibre. Moreover, an associated plastic flow rule and a general stress-strain relationship are proposed following the framework of Critical State Soil Mechanics and the basis of the Modified Cam Clay model. The proposed model is verified against the reported triaxial test results on cement treated fibre reinforced Kaolin clay. In this paper the cement treated fibre reinforced clay is referred to as the improved clay composite for reader convenience.

2 Effect of Cementation Degradation and Fibre Failures

Research shows that the shear strength of the cement treated clay increases as compared to the un-treated clay due to the effect of cementation and the formation of cementation bonds (Lorenzo and Bergado, 2006). According to Lorenzo and Bergado (2006), the treated soil can attain a higher yield stress as compared to the un-treated soil at the same void ratio in isotropic compression. However, as the confining pressures continue to increase beyond the initial yield stress, the void ratio reduces as the soil-cement clusters collapse and the cementation bonds begin to break. Furthermore, when the treated sample is deformed under shearing at high mean effective stress (or effective confining pressure) where plastic deformation occurs, the contribution of cementation to the shear strength diminishes due