Faculty of Engineering

Numerical Modelling on Load Bearing Performance of Combined Stone Column-Piled Raft Foundation in Soft Clay Soil

Danish Ahmed

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Signature

Name: Danish Ahmed

Matric No.: 17010168

Faculty of Engineering

Universiti Malaysia Sarawak

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ABSTRACT

An important problem encountered by foundation engineers involves soft to very soft (compressible) soils which possess low in-situ undrained shear strength (i.e., cu < 25 kPa). Foundation design in such soils is difficult at best. In many cases, deep foundations may be required to transmit foundation loads to suitable bearing strata below the soft soil deposit. Furthermore, stone columns, which consist of granular material compacted in long cylindrical holes, can be used as a technique for improving the strength and consolidation characteristics of these soils. Their costs are relatively moderate, and their installation requires medium-priced equipment. Stone columns occupy an important place and have a major role in ground treatment methods. Their use for more than 50 years in reinforcing soft soils has demonstrated their usefulness and makes them one of the most attractive methods in improving bearing capacity and reducing settlement. Unlike pile foundations, stone columns make very efficient use of the soil near the surface. These stone columns are ideal for supporting light loads, but less effective when it comes to supporting heavy loads because stone columns cannot transfer the applied stresses to the deeper layers of soil. For heavy constructions, where it is needed to transfer the applied stresses to deeper layers, piles are the most recommended foundation system. However, piles are costly, and their use is expensive. To overcome these technical and economic issues, it might be more appropriate to combine both foundations in one combined foundation system (i.e., stone column and piles used conjugally under raft foundation). In the literature, very limited work has been reported regarding the use of such a system to reinforce soft and compressible soils. Furthermore, no study was carried out to investigate the behaviour of such combined foundation system, to optimize the configuration of stone columns/piles group as combined foundation system, and to develop a theoretical model to predict the carrying capacity of the combined foundation system in soft soil capped with rigid raft foundation. Therefore, the objectives of this numerical investigation are to study the behaviour (i.e., modes of failure) of this new foundation system in order to optimize the configuration of stone columns/piles to get optimum soil improvement. For this reason, parametric study was conducted to examine the effect of the configuration and arrangement of the combined foundation system on the performance of this type of foundation system on soft soils. Also, an optimization study was conducted aiming to display the geometrical layout of stone columns/pile foundations exhibiting the superlative improvement of the performance of soil foundation. It was observed from the parametric study that combining stone columns and piles in one foundation system, improve the carrying capacity of the system, modify the soil foundation to a new upgraded composite ground, and certainly can reduce the cost of the geotechnical works. Overall, 680 combinations were investigated for this parametric study and based on the optimization study, chief leading sets were selected to get optimum soil improvement. It was noticed that these chief leading sets can increase the bearing capacity of the raft foundation by almost 50% to 90% compared to that of raft foundation resting on stone columns only. Based on the results of the optimization study, the behaviour (i.e., modes of failure) of such combined foundation system under loading was examined and it was observed that the combined foundation system fails by shear in the stone columns and soft soil, and by bearing and shear failure of pile’s tip under the rigid raft. The outcome of the observed behaviour (i.e., modes of failure) was used to develop an analytical model for predicting the carrying capacity of the combined system in soft soil.

Keywords: Combined foundation system, Stone columns, Piles, Raft foundation, Performance, Soft soil, Failure Mechanism, Improvement Factor, Parametric study, optimization study, Numerical investigation, Analytical model.

Pemodelan Berangka pada Prestasi Menanggung Beban Asas Rakit Bercorak Tiang Batu Gabungan dalam Tanah Tanah Liat Lembut

ABSTRAK

Masalah penting yang dihadapi oleh jurutera asas melibatkan tanah lembut hingga sangat lembut (boleh mampat) yang mempunyai kekuatan ricih tak bersaliran in-situ yang rendah (iaitu, cu < 25 kPa). Reka bentuk asas dalam tanah sedemikian adalah paling sukar. Dalam kebanyakan kes, asas dalam mungkin diperlukan untuk menghantar beban asas ke strata galas yang sesuai di bawah deposit tanah lembut. Tambahan pula, tiang batu, yang terdiri daripada bahan berbutir yang dipadatkan dalam lubang silinder panjang, boleh digunakan sebagai teknik untuk meningkatkan kekuatan dan ciri penyatuan tanah ini. Kos mereka agak sederhana, dan pemasangannya memerlukan peralatan berharga sederhana. Tiang batu menduduki tempat yang penting dan mempunyai peranan utama dalam kaedah rawatan tanah. Penggunaannya selama lebih daripada 50 tahun dalam mengukuhkan tanah lembut telah menunjukkan kegunaannya dan menjadikannya salah satu kaedah yang paling menarik dalam meningkatkan kapasiti galas dan mengurangkan penyelesaian. Tidak seperti asas cerucuk, tiang batu menggunakan tanah berhampiran permukaan dengan sangat cekap. Tiang batu ini sesuai untuk menyokong beban ringan, tetapi kurang berkesan apabila ia datang untuk menyokong beban berat kerana tiang batu tidak dapat memindahkan tegasan yang dikenakan ke lapisan tanah yang lebih dalam. Untuk pembinaan berat, di mana ia diperlukan untuk memindahkan tegasan yang dikenakan ke lapisan yang lebih dalam, cerucuk adalah sistem asas yang paling disyorkan. Walau bagaimanapun, cerucuk adalah mahal, dan penggunaannya mahal. Untuk mengatasi isu teknikal dan ekonomi ini, mungkin lebih sesuai untuk menggabungkan kedua-dua asas dalam satu sistem asas gabungan (iaitu, tiang batu dan cerucuk yang digunakan secara bersambung di bawah asas

rakit). Dalam literatur, kerja yang sangat terhad telah dilaporkan mengenai penggunaan sistem sedemikian untuk mengukuhkan tanah lembut dan boleh mampat. Tambahan pula, tiada kajian telah dijalankan untuk menyiasat kelakuan sistem asas gabungan tersebut, untuk mengoptimumkan konfigurasi tiang batu/kumpulan cerucuk sebagai sistem asas gabungan, dan untuk membangunkan model teori untuk meramalkan daya tampung sistem asas gabungan dalam bentuk lembut. tanah ditutup dengan asas rakit tegar. Oleh itu, objektif penyiasatan berangka ini adalah untuk mengkaji tingkah laku (iaitu, mod kegagalan) sistem asas baharu ini untuk mengoptimumkan konfigurasi tiang/cerucuk batu untuk mendapatkan pembaikan tanah yang optimum. Atas sebab ini, kajian parametrik telah dijalankan untuk mengkaji kesan konfigurasi dan susunan sistem asas gabungan terhadap prestasi sistem asas jenis ini pada tanah lembut. Juga, kajian pengoptimuman telah dijalankan bertujuan untuk memaparkan susun atur geometri tiang batu/asas cerucuk yang mempamerkan peningkatan superlatif prestasi asas tanah. Ia diperhatikan daripada kajian parametrik bahawa menggabungkan tiang batu dan cerucuk dalam satu sistem asas, meningkatkan daya tampung sistem, mengubah suai asas tanah kepada tanah komposit baru yang dinaik taraf, dan pastinya dapat mengurangkan kos kerja-kerja geoteknik. Secara keseluruhan, 680 kombinasi telah disiasat untuk kajian parametrik ini dan berdasarkan kajian pengoptimuman, set peneraju utama telah dipilih untuk mendapatkan pembaikan tanah yang optimum. Adalah diperhatikan bahawa set peneraju utama ini boleh meningkatkan kapasiti galas asas rakit sebanyak hampir 50% hingga 90% berbanding asas rakit yang terletak pada tiang batu sahaja. Berdasarkan keputusan kajian pengoptimuman, tingkah laku (iaitu, mod kegagalan) sistem asas gabungan tersebut di bawah beban telah diperiksa dan diperhatikan bahawa sistem asas gabungan gagal dengan ricih dalam tiang batu dan tanah lembut, dan dengan galas dan kegagalan ricih hujung cerucuk di bawah

rakit tegar. Hasil daripada tingkah laku yang diperhatikan (iaitu, mod kegagalan) telah digunakan untuk membangunkan model analitikal untuk meramalkan kapasiti tampung sistem gabungan dalam tanah lembut.

Kata kunci: *Sistem asas gabungan, Tiang batu, Cerucuk, Asas rakit, Prestasi, Tanah lembut, Mekanisme Kegagalan, Faktor Penambahbaikan, Kajian parametrik, kajian pengoptimuman, Penyiasatan berangka, Model analisis*

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