

**GEOTECHNICAL BEHAVIOR OF SHELL FOOTINGS**

**By**

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**Thesis Submitted to the School of Graduate Studies, University Putra Malaysia,  
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

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*TO MY PARENTS, WIFE, SONS, BROTHERS AND SISTERS*

Abstract of thesis presented to Senate of University Putra Malaysia in fulfilment  
of the requirement for the degree of Doctoral of Philosophy

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**Chairman: Professor Bujang Kim Huat, PhD**

**Faculty : Engineering**

Shell foundations have been considered as the best shallow foundations for transferring heavy load to weak soils, where a conventional shallow foundation undergoes excessive settlement. Due to its economic competitiveness or advantage in areas having high material-to-labor cost ratio, using shell foundations as an alternative to conventional foundations have gained acceptance or adoption in many countries. As it is not economical to study experimentally the geotechnical behaviour of various types of shell footing with different variables, an attempt was made to propose a 2-D non-linear finite element (FE) model by using a commercially available package to assess the geotechnical behaviour of shell footings. Due to configuration complexity of isolated pyramidal and conical shell footings, 3-D non-linear FE models have been proposed. Full-scale tests on shell footings under vertical load were judiciously planned to validate the proposed FE models for modified triangular strip shell footings. Present study also developed equation to estimate the ultimate bearing capacity of inverted triangular shell footings.

2-D and 3-D FE finite element (FE) models for different types of shell footings namely flat footings, triangular strip shell footings, inverted triangular strip shell footings, conical shell footing and pyramidal shell footings have been developed. Elasto-plastic behaviours of soil and foundation have been modelled by Drucker-Prager yield criterion and modified Von Mises Criterion. Comparative study between the proposed FE models and published data has been conducted on different existing types of strip shell footings. An experimental work on field has been conducted to study the real behaviour of the proposed shell footings (inverted triangular strip shell footings, triangular strip shell footing and flat footing) under the effects of load transferred from double story residential house. A theoretical model to predict the ultimate bearing capacity equation of the proposed inverted triangular strip shell footings has been developed using theoretical derivations and rupture surface obtained from the FE results.

Based on 2-D and 3-D results obtained, a modified shell footings (inverted triangular strip shell footings) has been proposed and found to be 15 % higher load carrying capacity compared to triangular shell footings. Results also showed that pyramidal shell footings have higher load carrying capacity by 20 % compared to the conical shell footings. The field test results showed that contact pressure of inverted triangular strip shell footings have better distributions when compared to triangular strip shell footings. The stress caused by inverted shell was 20% less than that obtained for triangular shell. An equation for predicting the ultimate bearing capacity of inverted triangular shell footings has been developed. The obtained results have been found in good agreement between FE simulations and field test results.

The results of this study suggest that shell footings should come into wider use in the geotechnical field as a serious alternative to shallow and even deep foundations.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia  
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

## **KELAKUAN GEOTEKNIK ASAS SHELL**

Oleh

**ADEL AHMED AL-RAZIQUI**

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Asas shell didapati asas cetek yang terbaik bagi mengagihkan beban yang tinggi melalui tanah yang lemah, dimana asas cetek yang sedia ada selalunya mengalami mendapan yang berlebihan. Kawasan yang mempunyai persaingan ekonomi yang disebabkan oleh nisbah bahan kepada buruh yang tinggi, penggunaan asas shell telah diterima di kebanyakan negara sebagai alternatif kepada asas yang biasa digunakan.

Oleh kerana tidak praktikal dan ekonomi untuk mengkaji kelakuan geoteknik asas shell yang berlainan jenis disamping variasi yang berlainan maka cubaan dengan menggunakan model unsur terhingga yang tak lurus (non-linear finite element-FEM) yang ada dipasaran telah digunakan untuk menguji kelakuan geoteknik asas shell dengan darjah ketepatan yang munasabah. Ujian berskala penuh untuk asas shell dibawah beban paksi yang dirancang dengan bijak untuk menyokong model unsur terhingga yang disaran bagi asas shell jalur segitiga terubahsuai. Kajian semasa juga telah dibangunkan untuk menganggar keupayan galas muktamad asas shell segitiga terbalik.

Model 2-D dan 3-D unsur terhingga untuk asas shell yang berlainan jenis (asas rata, asas shell segitiga jalur, asas shell segitiga jalur terbalik) telah dijalankan. Tanah dan

asas telah dimodel sebagai masalah terikan biasa manakala kelakuan elastik-plastik tanah telah dimodel dengan kriteria alah Drucker-Prager dan criteria Von Mises terubahsuai. Kajian perbandingan antara model unsur terhingga yang disaran dan data yang diterbitkan telah dijalankan pada pelbagai asas shell jalur yang sedia ada. Kerja eksperimen tapak telah dijalankan untuk mengenalpasti kelakuan sebenar asas shell (asas shell segitiga terbalik, asas shell segitiga jalur dan asas pad) dibawah tindakan beban dari rumah dua tingkat. Satu model teori berdasarkan kelakuan tak lurus asas shell terbalik untuk meramal kapasiti tanggungan muktamad bagi asas shell jalur segitiga terbalik yang dicadang telah dibangunkan. Keputusan yang diperolehi mempunyai hubung kait yang baik antara simulasi unsur terhingga dan keputusan eksperimen. Berdasarkan pada keputusan 2-D dan 3-D yang diperolehi, asas shell terubahsuai (asas segitiga jalur terbalik) telah disarakan dan didapati mempunyai 15% keupayaan menanggung beban lebih tinggi daripada asas shell segitiga. Keputusan juga menunjukkan asas shell pyramid berupaya menanggung 20% beban lebih tinggi daripada asas shell kon. Keputusan ujian tapak menunjukkan tekanan sentuhan bagi asas shell segitiga terbalik mempunyai agihan yang lebih baik daripada asas shell segitiga jalur. Tegasan yang dihasilkan shell terbalik adalah 20% lebih rendah daripada shell segitiga. Satu persamaan mengganggu keupayaan galas muktamad telah dibangunkan.

Keputusan yang diperolehi mempunyai persamaan yang rapat dengan simulasi unsur terhingga dan keputusan ujian tapak. Keputusan kajian ini menunjukkan bahawa asas shell boleh digunakan secara meluas dalam bidang geoteknik sebagai salah satu alternatif bagi asas cetek dan asas dal.

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I certify that an Examination Committee has met on 13<sup>th</sup> October 2006 to conduct the final examination of Adel Ahmed Al-Raziqi on his Doctor of Philosophy thesis entitled “Geotechnical Behavior of Shell Footings” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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## **DECLARATION**

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

---

**ADEL AHMED AL-RAZIQUI**

Date: 18 DECEMBER 2006

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