

**A STUDY ON THE RESPONSE OF  
UNDERGROUND PIPES DUE TO BLAST  
LOADS**



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UNIVERSITI MALAYSIA SABAH  
2013**

**A STUDY ON THE RESPONSE OF  
UNDERGROUND PIPES DUE TO BLAST  
LOADS**

**OLAREWAJU AKINOLA JOHNSON**



**THESIS SUBMITTED IN FULFILLMENT FOR  
THE DEGREE OF DOCTOR OF PHILOSOPHY**

**SCHOOL OF ENGINEERING AND  
INFORMATION TECHNOLOGY  
UNIVERSITI MALAYSIA SABAH**

**2013**

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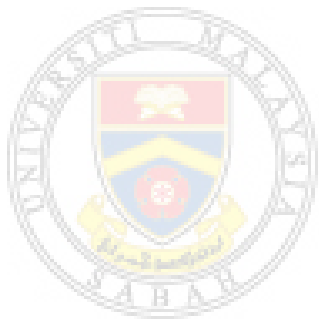
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## CERTIFICATION

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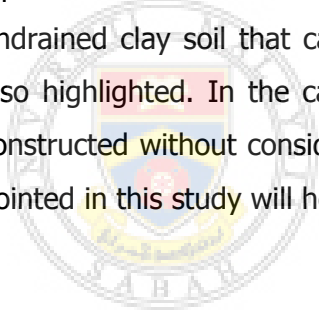
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## **ABSTRACT**

### **A STUDY ON THE RESPONSE OF UNDERGROUND PIPES DUE TO BLAST LOADS**

Underground pipes are used for services. Loads emanating from blast can create sufficient tremors to damage substructures over a wide area. Blast loads from explosives translate to loadings which the explosive charge (i. e. from surface blast or underground blast) delivers to the buried structures whether in the form of pressure or loading wave velocity. The main sources of blast are war, accidental explosion from military formation, etc. This study is aimed at determining the response of empty underground pipes due to blast loads by simulation using finite element method. Different types of blast and blast loads ranging from 10 kg TNT to 250 kg TNT were considered in this study. Using Unified Facilities Criteria (2008) for surface blast and analytical method for underground blast for the commonly used explosives at various stand-off points, ground movement parameters were determined. In this study, soil and pipe materials were considered as elastic, homogeneous and isotropic. Geotechnical and material properties as revealed by several researchers and pipe manufacturers were used. After validating existing model studied using SAP-80, response of underground pipes due to various categories of blast were studied using time integration technique in ABAQUS/Explicit, a finite element numerical code. Displacement, pressure, stress, strain at the crown, invert and spring-line of underground pipes buried at different embedment ratios in loose sand, dense sand and undrained clay were computed. Parametric studies were carried out and the results of the various responses were analyzed using dimensional analysis. Various mitigation measures were also suggested. In the whole work, a total of 639 models were analyzed. From the result of this study, blast load parameters estimated could be used in the evaluation of blast loads for design of underground pipes to resist the effects of blast loads. In addition, depths play a prominent role in the response of underground pipes due to blast loads. With increasing depth of burial of pipes, observed parameters reduced. These observed parameters reduced at embedment ratios of 3 to 5 for the blast scenarios considered. In addition to this, the reduction in the observed parameters

of the response of underground pipes due to blast loads is more in loose sand compared to dense sand. As a result of this, loose material in the form of tire-chip backfill round the buried pipes could be used to mitigate the consequence of blast loads on underground pipes. Furthermore, undrained clay was observed to be problematic because the reduction in the observed parameters is least in the pipes buried in undrained clay and as a result of this, grouting and ground improvement techniques could be adopted as mitigation measure. In addition, for underground steel pipes to resist the effects of internal explosion, minimum of 20 mm thick is recommended. Finally, coefficient of friction of average of 0.4 could be used for the design of pipes buried in sand while coefficient of friction of average of 0.8 could be used for the design of pipes buried in undrained clay. The findings of this study will contribute to the existing academic literature, locally and internationally, considering the fact that this is a new area of research. The guidelines arrived at in this study can be applied by practicing engineers and professionals for design of underground pipes to resist the effects of blast loads. In addition to this, attention to be given to undrained clay soil that can be problematic in the design of underground pipes is also highlighted. In the case of underground pipes that are already designed and constructed without consideration to the effects of blast loads, mitigation measures pointed in this study will help in reducing the impact of blast loads.



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## **ABSTRAK**

### **KAJIAN TENTANG TINDAKBALAS PAIP-PAIP BAWAH TANAH AKIBAT BEBAN-BEBAN LETUPAN**

*Paip-paip bawah tanah digunakan untuk pembekalan air, pembekalan minyak dan gas, pembentungan, dsb. Beban-beban yang berpunca daripada letupan boleh mengakibatkan gegaran yang cukup kuat untuk merosakkan substruktur di kawasan luas. Beban letupan daripada bahan letupan diterjemahkan sebagai beban-beban yang diakibatkan oleh beban letupan (melalui letupan permukaan atau letupan bawah tanah) terhadap struktur yang ditanamkan dalam bentuk tekanan atau halaju gelombang beban. Sumber-sumber utama letupan adalah peperangan, serangan pengganas, letupan tidak bersengaja daripada formasi ketenteraan, dsb. Kajian ini adalah bertujuan untuk menentukan tindakbalas paip-paip bawah tanah kosong akibat beban-beban letupan menggunakan simulasi dengan kaedah unsur terhingga. Letupan yang berlainan jenis dan beban letupan yang berjulat daripada 10 kg TNT kepada 250 kg TNT telah dipertimbangkan dalam kajian ini. Dengan menggunakan "Unified Facilities Criteria" (2008) untuk letupan permukaan dan kaedah analitikal untuk letupan bawah tanah bagi bahan letupan yang biasa digunakan pada beberapa titik pemerhatian, parameter-parameter pergerakan tanah telah ditentukan. Dalam kajian ini, tanah dan bahan-bahan buatan paip dianggap kenyal, homogen, dan isotropi. Sifat geoteknik dan bahan yang didapati oleh ahli-ahli pengajian dan pengilang-pengilang paip telah digunakan. Selepas pengesahan model yang sedia ada dengan menggunakan perisian SAP-80, tindakbalas paip-paip bawah tanah akibat beberapa kategori letupan dikaji dengan menggunakan "teknik pengamiran masa" dalam perisian ABAQUS/Explicit, iaitu sejenis kod berangka unsur terhingga. Sesebaran, tekanan, tegangan, tarikan di bahagian puncak, tengah dan bawah keratan rentas paip bawah tanah yang ditanamkan pada nisbah penerapan dalam pasir longgar, pasir tumpat dan tanah liat bertakungan air yang berlainan telah dikomputasikan. Kajian-kajian berparameter dijalankan dan keputusan beberapa tindakbalas dianalisis dengan analisis berdimensi. Beberapa langkah penebatan juga dicadangkan. Dalam*

*kajian ini, sebanyak 639 model telah dianalisis. Berdasarkan keputusan dalam kajian ini, parameter-parameter beban letupan yang dianggarkan boleh digunakan dalam penilaian beban letupan untuk rekabentuk paip-paip bawah tanah untuk menentang kesan-kesan daripada beban letupan. Tambahan pula, kedalaman memainkan peranan yang menonjol dalam tindakbalas paip-paip bawah tanah akibat beban-beban letupan. Dengan penambahan kedalaman paip-paip yang ditanamkan. Parameter-parameter yang diperhatikan berkurangan pada nisbah penerapan 3 kepada 5 dalam senario letupan yang ditetapkan. Tambahan pula, pengurangan parameter-parameter tindakbalas paip-paip bawah tanah akibat beban letupan adalah lebih banyak dalam pasir longgar berbanding dengan yang dalam pasir tumpat. Oleh itu, bahan longgar dalam bentuk cip tayar yang mengelilingi paip-paip yang ditanam boleh digunakan untuk mengurangkan akibat beban letupan terhadapnya. Lebih-lebih lagi, tanah liat bertakungan air didapati bermasalah kerana pengurangan dalam parameter-parameter yang diperhatikan adalah paling sedikit bagi paip-paip yang ditanamkan di dalamnya dan oleh itu, grouting dan teknik-teknik pembaikan tanah boleh digunakan sebagai langkah penebatan. Sebagai penambahan, ketebalan minimum 20 mm dicadangkan dalam paip-paip keluli bawah tanah untuk menentang kesan-kesan letupan dalaman. Akhirnya, purata pekali geseran sebanyak 0.4 boleh digunakan untuk rekabentuk paip yang ditanamkan di dalam pasir sedangkan purata pekali geseran sebanyak 0.8 boleh digunakan bagi rekabentuk paip yang ditanamkan di dalam tanah liat bertakungan air. Penemuan dalam pengajian ini akan menyumbangkan kepada literasi akademik yang sedia ada, sama ada tempatan ataupun antarabangsa, memandangkan bahawa ini merupakan sesuatu bidang yang baru dalam penyelidikan. Garis panduan dan parameter yang dicapai dalam pengajian ini boleh diaplikasikan oleh jurutera-jurutera dan profesional yang terlibat dalam perekaciptaan paip-paip bawah tanah untuk menentang kesan-kesan beban letupan. Di samping itu, perhatian yang diberikan kepada tanah liat tidak tersalir yang dapat menjadi masalah dalam perekaciptaan paip-paip bawah tanah juga diserlahkan. Mengenai paip-paip bawah tanah yang telah direkacipta dan dibina tanpa pertimbangan terhadap kesan-kesan beban letupan, langkah-langkah penebatan yang tercatat dalam pengajian ini akan membantu dalam mengurangkan kesan beban letupan.*

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