UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A SUB-SURFACE STORMWATER STORAGE-INFILTRATION SYSTEM

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By

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

July 2007

Dedicated to my Parents,

to my wife

to my Son; Imad and daughter; Reem

to my family.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy

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Chairman: **Associate Professor Abdul Halim Ghazali, PhD**

Faculty: **Engineering**

Floodings due to the increase in impervious areas as a result of urbanization are still a main problem in many countries, including Malaysia. The lack of open space in urban areas may hinder the use of typical stormwater detention/retention systems, which are normally constructed above ground. Systems installed below the surface (subsurface) have great potential in such areas. Subsurface detention/retention systems such as pipe systems, arch chamber systems, and storage tanks systems are available in some countries abroad, such as Australia and the U.S.A, and importing such systems is not cheap and it involves the outflow of funds from the country. In this research a new subsurface detention/retention system has been developed for the purposes of reduction of volume and flow rate of stormwater runoff and recharging groundwater. It may also be able to minimise the environmental impact on water quality. Developing a new system that is manufactured locally and based on a readily available material in the local market also encourages the growth of local industry and faster achievement for the aim to reduce the flooding and pollution in urbanized areas in the country. The system that has been developed in this research is called the Stormwater Infiltration Block (SWIB)

system and the following criteria have been considered in its development; the system is designed to be installed in subsurface, it has high structural strength and storage capacity, it allows water to infiltrate at high rates, it is light in weight and cost effective, it requires low maintenance, and it is simple and easy to install. The SWIB system is composed of the Stormwater Infiltration Blocks (SWIBs) to store and infiltrate stormwater runoff, geotextile, geogrid, adequate soil cover, and porous pavement surface. The SWIB is formed by nine hollow plastic pipes held vertically together by two plastic holders, one each at the top and the bottom. Both, the pipes and holders are made from rigid polyvinyl chloride (PVC-U). The design of the holder takes into consideration the following criteria; the holder must be strong enough to sustain, transfer and distribute the loads applied on the holder to the pipes, it is able to allow for SWIBs to be stacked above each other to achieve the desired height and provide firmly connected SWIBs, it must hold the pipes tightly without fasteners, and it should have high percentage of open space to allow water to flow into the SWIB very easily.

Experimental tests were carried out in the laboratory to investigate the structural and hydraulic performance of the SWIB system. A total of 20 experimental tests were carried out to investigate the structural performance of the SWIB system under different conditions. Some of these tests were done to evaluate the system ability to sustain the design axial compression load of 93 kN, which is the maximum load expected when the system is installed in a parking area and the results demonstrate that the system has the strength to sustain the load applied. Ultimate strength tests were also conducted and they proved that the SWIB has an ability for support the axial compression loads up to 486 kN, which is five times larger than the design load. No significant reduction in the SWIB strength was found when its height was increased from 348 mm to 648 mm. Lateral loads tests reveal that the SWIB has good ability for supporting lateral loads

equivalent to the lateral soil pressure of up to 3 m depth below the ground surface without any damage observed in the SWIB system. For all the tests performed under the design load no critical stress that may lead to the SWIB failure occurred and no failure was observed in the SWIB geogrid or geotextile.

Another 20 experimental tests were carried out to investigate the hydraulic performance of the SWIB system under different conditions. Some of these tests were done to evaluate the infiltration rate through the system which revealed that the system has high infiltration rate and demonstrates an excellent efficiency in preventing the ponding of water on the surface area even under high rainfall intensities that varied from 300 mm/hr to 420 mm/hr for 5 min and 10 min rainfall durations. The type of block pavement surface used on top of the system significantly affect its infiltration rate, therefore, the correct pavement surface should be selected. The block pavement type which can give the highest infiltration rate is the open-celled type. Evaluation of the system capacity to store water demonstrates that the system has high storage capacity that reaches a value of 93% of the total volume of the SWIB.

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

PEMBANGUNAN SISTEM PENYIMPANAN-PENYUSUPAN AIR HUJAN BAWAH PERMUKAAN

Oleh

ABDULLAH ALI NASSER AL-HAMATI

Julai 2007

Pengerusi: **Profesor Madya Abdul Halim Ghazali, PhD**

Fakulti: **Kejuruteraan**

Kejadian banjir yang disebabkan oleh pertambahan kawasan tak telap air hasil daripada pembandaran sesuatu kawasan merupakan satu masalah utama dalam banyak negara, termasuk Malaysia. Kekurangan ruang terbuka dalam kawasan bandar boleh menghalang penggunaan sistem tahanan air hujan tipikal, yang biasanya dibina di atas permukaan tanah. Sistem yang diwujudkan di bawah permukaan (bawah tanah) mempunyai potensi yang besar bagi kawasan seumpama itu. Sistem tahanan bawah tanah seperti sistem paip, sistem kebuk arka, dan sistem tangki simpanan boleh diperolehi daripada beberapa negara luar, seperti Australia dan Amerika Syarikat, tetapi untuk mengimpot sistem tersebut bukanlah murah dan ia melibatkan aliran keluar ringgit daripada negara. Di dalam penyelidikan ini, satu sistem tahanan/penyusupan baharu dibangunkan bagi tujuan mengurangkan isipadu dan kadar alir larian air hujan dan mengecas semula air bumi. Membangunkan satu sistem yang bersandarkan bahan yang boleh didapati dalam pasaran tempatan juga menggalakkan pertumbuhan industri tempatan dan mempercepatkan pencapaian matlamat untuk mengurangkan banjir dan pencemaran di kawasan bandar dalam negara.

Sistem yang dibangunkan dalam penyelidikan ini dipanggil sistem Blok Simpanan-Penyusupan (SWIB), dan kriteria berikut telah diambilkira dalam pembangunannya: sistem ini direka bentuk untuk digunapakai di bawah permukaan, ia mempunyai kekuatan dan kapasiti simpanan yang tinggi, ia membenarkan air menyusup pada kadar yang tinggi, ia adalah ringan dan menjimatkan, ia memerlukan penyenggaraan yang rendah, dan ia adalah mudah untuk ditempatkan. Sistem SWIB mengandungi Blok Simpanan-Penyusupan (SWIB), geotekstil, geogrid, tutup tanah yang mencukupi, dan permukaan turapan telap air. SWIB dibentuk oleh sembilan batang paip plastik yang dipegang secara menegak oleh dua pemegang, satu di atas dan satu lagi di bawah. Kedua-dua paip dan pemegang diperbuat daripada klorida polyvinyl tegap (PVC-U). Reka bentuk pemegang mengambil kira kriteria berikut: ia mesti mempunyai kekuatan mencukupi untuk menanggung beban, serta memindah dan menagihkan beban tersebut kepada paip, ia boleh membenarkan SWIB disusun secara bertingkat untuk mencapai ketinggian yang dikehendaki dan menghasilkan SWIB yang bersambung, ia mesti dapat memegang paip dengan kemas tanpa sebarang bahan pelekat, dan ia mesti mempunyai peratusan ruang terbuka yang tinggi untuk membenarkan air mengalir ke dalam SWIB dengan mudah.

Ujikaji dilakukan di makmal untuk menilai prestasi sturuktur dan hidraulik sistem SWIB. Sejumlah 20 ujikaji telah dilaksanakan untuk menilai kekuatan struktur sistem SWIB di dalam keadaan berlainan. Sebahagian daripada ujian ini dilakukan untuk menilai keupayaan sistem SWIB untuk menanggung beban mampatan reka bentuk sebanyak 93 kN, iaitu beban jangkaan maksimum apabila sistem ini digunapakai sebagai kawasan letak kereta dan keputusan menunjukkan sistem ini mempunyai kekuatan yang mampu menanggung beban itu. Ujian kekuatan muktamad telah juga dilakukan dan hasilnya menunjukkan sistem ini mampu menanggung beban sehingga

486 kN, iaitu lima kali ganda lebih besar daripada beban jangkaan. Tiada pengurangan ketara telah didapati apabila ketinggian blok ditambah daripada 348 mm kepada 648 mm. Ujian beban sisi menunjukkan bahawa SWIB mempunyai keupayaan yang baik untuk menanggung beban sisi yang bersamaan dengan tekanan tanah sehingga 3 m dalam, tanpa sebarang kerosakan pada sistem SWIB ini. Bagi semua ujian yang dilakukan menggunakan beban reka bentuk tiada tegasan kritikal yang boleh menyebabkan kegagalan SWIB berlaku dan tiada kegagalan didapati pada geogrid dan geotekstil.

Sebanyak 20 ujikaji yang lain telah dilakukan untuk menilai prestasi hidraulik sistem SWIB di dalam keadaan yang berlainan. Sebahagian daripada ujian itu dilakukan untuk menentukan kadar penyusupan melalui sistem ini, yang mana hasilnya menunjukkan bahawa sistem ini mempunyai kadar penyusupan yang tinggi dan keupayaan yang baik untuk mengelak air bertakung di atas permukaan walaupun dalam keadaan keamatan hujan yang tinggi, iaitu di antara 300 mm/jam dan 420 mm/jam, dalam tempoh hujan selama 5 minit dan 10 minit. Jenis permukaan turapan yang digunakan pada bahagian atas sistem ini memberi kesan yang besar ke atas kadar penyusupan, oleh itu permukaan turapan yang betul mesti digunakan. Turapan yang menghasilkan kadar penyusupan yang paling tinggi adalah jenis sel terbuka. Penilaian ke atas keupayaan sistem ini untuk menyimpan air menunjukkan bahawa ia boleh mencapai 93% daripada keseluruhan isipadu SWIB.

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I certify that an Examination Committee has met on 18th July 2007 to conduct the final examination of Abdullah Ali Nasser AL-Hamati on his Doctor of Philosophy thesis entitled "Development of a Sub-Surface Stormwater Storage-Infiltration System" 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 degree of Doctor of Philosophy.

Members of the Examination Committee were as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

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Date: 13 September 2007

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.

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ABDULLAH ALI NASSER AL-HAMATI

Date: 1 March 2007

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