PERFORMANCE OF UNDERSIDE SHAPED CONCRETE BLOCKS FOR PAVEMENT

AZMAN BIN MOHAMED

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Dedicated to Allah S.W.T,
my beloved wife Nur Hafizah Binti Abd Khalid
and my gorgeous kids,
Puteri Nurina Akhtar, Putera Naqib Akhtar and Ariff Akhtar.
Thanks for your valuable sacrifice and love.

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~~~~~ Love you all ~~~~~
~~~~~

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ABSTRACT

This study presents an innovative concrete block pavement (CBP) of rectangular blocks with grooves and web on the underside of the underside shaped concrete block (USCB). This new concrete block concept intends to address known causes of failure for CBP due to vertical, horizontal and repetitive traffic loading. Interaction between CBP and underlying bedding sand layer may lead to significant pavement deformation due to vertical traffic loading. The USCB provides an additional underside mechanical interlocking, compared with traditional rectangular concrete block. Twelve USCB with different groove depths (15 mm, 25 mm, and 35 mm) and four different bottom shapes (Shell – Rectangular (Shell–R), Trench Groove – Triangular (TG–T), Trench Groove – 2 Rectangular (TG–2R), and Trench Groove – 3 Rectangular (TG–3R)) were prepared. These USCB were mechanically tested to investigate the effects of groove depth, groove volume, and groove shape on their mechanical properties. To investigate their interlocking performance, a series of push-in loading test, pull-out loading test, horizontal loading test, and accelerated trafficking test were conducted using the Highway Accelerated Loading Instrument (HALI). A control pavement and with only stretcher bond laying pattern was built to allow for comparisons. The results indicate that triangular grooves exhibit promising compressive strength while rectangular grooves performed better in flexural, with the increase up to 25 % respectively when compared to control block. The optimum USCB groove depth is found at 15 mm and the Shell USCB has the best mechanical properties and resilience under all conditions due to their unique shape. The function of the grooves and web as spike has enhanced the mechanical properties of USCB and improved the interlocking mechanism between CBP and its underlying bedding sand layer. The study shows that USCB is a highly potential concrete block that could enhance pavement performance.

ABSTRAK

Kajian ini membentangkan suatu penurap inovatif untuk turapan blok konkrit (CBP) dalam bentuk blok konkrit segi empat tepat dengan alur dan web pada bahagian bawah bagi blok konkrit terubahsuai permukaan bawah (USCB). Konsep blok konkrit baru ini dibangunkan untuk menangani kegagalan CBP yang berpunca daripada beban menegak, mendatar, dan beban ulangan lalu lintas. Interaksi antara CBP dengan lapisan pasir pengalas boleh mengubah bentuk turapan dengan ketara disebabkan oleh beban menegak lalu lintas. USCB memberi daya rintangan tambahan terhadap penguncian mekanikal permukaan bawah yang tidak disediakan oleh blok konkrit segiempat tradisional. Dua belas USCB dengan kedalaman alur yang berbeza (15 mm, 25 mm dan 35 mm) dan empat bentuk alur yang berbeza (Cengkerang–Segi Empat Tepat (*Shell*–R), Alur–Segi Tiga (TG–T), Alur–2 Segi Empat Tepat (TG–2R), dan Alur–3 Segi Empat Tepat (TG–3R)) telah disediakan. USCB ini diuji secara mekanikal bagi mengkaji kesan kedalaman alur, isipadu alur, dan bentuk alur kepada sifat mekanikal USCB. Untuk mengkaji prestasi penguncian blok-blok tersebut, satu siri ujian yang terdiri daripada ujian bebanan tekan masuk, ujian bebanan tarik keluar, ujian daya mendatar dan ujian lalu lintas dipercepatkan telah dilakukan dengan menggunakan *Highway Accelerated Loading Instrument* (HALI). Satu turapan kawalan dan dengan corak ikatan usungan dipilih untuk tujuan perbandingan. Hasil kajian menunjukkan bahawa alur segi tiga memberikan kekuatan mampatan yang paling baik manakala alur segi empat tepat berfungsi dengan lebih baik di bawah lenturan, masing-masing dengan peningkatan sehingga 25 % berbanding blok kawalan. Kedalaman alur optimum adalah 15 mm dan USCB *Shell* mempunyai sifat mekanikal yang terbaik serta berdaya tahan di bawah semua keadaan kerana bentuknya yang unik. Fungsi alur dan web sebagai pemakuan telah meningkatkan sifat mekanikal USCB dan memperbaiki sifat penguncian antara CBP dan lapisan pasir pengalas. Kajian ini telah menunjukkan USCB merupakan sejenis blok konkrit yang berpotensi untuk meningkatkan prestasi turapan.

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LIST OF ABBREVIATIONS

2D - Two-dimensional
3D - Three-dimensional
AASHTO - American Association of State Highway and Transportation Officials
ASTM - American Society for Testing and Materials
BS EN - British Standard Institution European
BS - British Standard Institution
CB - Control block
CBP - Concrete block pavement
CBR - California Bearing Ratio
CF - Correction factor
Ch - Channel
CMA - Concrete Masonry Association
CMAA - Concrete Masonry Association of Australia
COV - Coefficient of variation
ESA - Equivalent standard axle
HALI - Highway Accelerated Loading Instrument
HMA - Hot Mix Asphalt
ICPI - Interlocking Concrete Institute
LL - Liquid limit
LVDT - Linear variable differential transducer
MOR - Modulus of rupture
MOR_C - Modulus of rupture for control block
MOR_G - Modulus of rupture for grooved block
MS - Malaysia Standard
OPC - Ordinary portland cement

P - Point
PI - Plastic index
PL - Plastic limit
PVC - Poly-vinyl chloride
R^2 - Regression
RCPB - Rubberized concrete paving block
rpm - Rotation per minute
SD - Standard deviation
Shell-R - Shell-Rectangular groove
TG-2R - Trench-2Rectangular groove
TG-3R - Trench-3Rectangular groove
TG-T - Trench-Triangular groove
USCB - Underside shaped concrete block

LIST OF SYMBOLS

μ_G - Coefficient of groove block surface friction
$\mu_{G_{\max}}$ - Coefficient of groove block surface friction at maximum force
μ - Coefficient of block surface friction
F_S - Friction force
δ_{Disp} - Displacement
F - Force / damage factor - applicable to axle load
$F_{S_{\max}}$ - Friction force at maximum
F_N - Normal force
n_d - Number of internal web
P_S - Standard axle load
$\overline{y}$ - Central axis of the area
$\mu_{BS\max}$ Coefficient of sided and underside surface control block friction at maximum force
A - Mass of oven-dried sample in air/ effective area of concrete block /tyre contact area
a - Mass of tin
A_e - Groove’s effective area
ARD - Apparent relative density
b - Mass of tin and wet bedding sand
B - Mass of surface-dried sample in air after immersion
B,b - Width of specimen
B_G - Groove width
C - Apparent mass in the water

c - Mass of tin and dry bedding sand
d - Internal web / average depth of specimen / distance between groove
D - Diameter
e - Edge web
h, h_c - Block thickness
h_0 - Height of loose bedding sand
h_1 - Height of bedding sand and USCB after laying
h_2 - Height of bedding sand and USCB after first compaction
h_3 - Height of bedding sand and USCB after second compaction
h_e - Effective thickness
h_G - Groove depth
I - Moment of inertia,
J - Average connection distance
L - Span length / length
L_G - Groove length
M - Bending moment,
$m.g$ - Force of gravity
MOR - Modulus of rupture
n - Relative damage exponent
n - Notch planck
N - Traffic repetitions
NA - Neutral axis,
n_b - Concrete block unit

n_G - Number of groove
$Ø_{avg}$ - Average of bedding sand density
$Ø_c$ - Minimum and maximum characterization
ODD - Oven-dry density
P - Maximum load / axle load / breaking load / load
q - Load equivalency exponents
S - Equivalent standard axle
S_{ett} - Settlement
SSD - Saturated surface-dry density

T_{hk} - Thickness

v - Volume of bedding sand

V_C - Control block volume

V_G - Groove volume

w - Mass of bedding sand

W - Load

ρ - Density

σ - Compressive strength / standard deviation

σ_B - Bending stress

σ_{block} - Stress on the block

σ_c - Compressive strength of control block

σ_f - Flexural strength

σ_G - Compressive strength of grooved block

σ_{HALI} - Stress on highway accelerated loading instrument

σ_{site} - Stress by tyre loading

π - Pi = 3.145

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete block pavement (CBP) is an accepted engineering product used mainly as a paving material in pavement applications. Many previous studies on CBP had attempted to modify the traditional rectangular concrete block, introduce additional side interlocking features, and develop better interlocking shapes. CBP is utilized globally because it is durable, non-skidding and dimensionally accurate; available in many sizes; and has good structure and colour. Additionally, these CBP can be installed by unskilled labourers and can be re-used on the same site or elsewhere.

1.2 Background of Study

In developing countries, utilization of CBP as paving material is widespread. Studies on traditional CBP and side shaped CBP have been widely conducted, but there are still a number of research on beneath CBP and its characterizations. Such beneath CBP, termed as Underside shaped concrete block (USCB) in this study, can actually become a type of innovative paving material. The development of this USCB corresponds to current research trend in modification of existing conventional and side-shaped concrete block to increase paver interlocking and mechanical properties and improve mechanical-laying ability as studied by Emery and Lazar, (2003).

This study presents an innovative paver system featuring groove locking beneath a rectangular concrete block. The overall product is the aforementioned USCB. This new paver concept is intended to resolve known problems associated with small element paving. This USCB is unique because it provides mechanical interlocking additional to underside interlocking commonly provided by most traditional rectangular pavers except sided pavers. During the USCB development process, various groove depths had been tested to test their effectiveness in enhancing interlocking between pavers and bedding sand with improved mechanical properties. To investigate its interlocking performance, the push-in loading test, pull-out loading test, horizontal loading test and accelerated trafficking test were involved. These types of test substantiate the claim made by similar tests on the conventional rectangular concrete block. The use of stretcher bond pattern without edge restraint in this study has also been recognized as having substantial influence on horizontal movement or creep.

1.3 Problem Statement

The main failure criterion for CBP is its serviceability. Most of the time, failure may result in generalized areas of uneven settlement. Block paving reflects movement in the substructure, thus it's very important that the sub-base layer is adequately compacted and to a uniform level. Inadequate vibration of the blocks into the bedding sand layer during the final construction operations can also lead to problems of local settlements. Moreover, if the bedding sand layer is not of a consistent loose density before laying the blocks, local settlement or punching may occur. This is mainly due to voids beneath the CBP that arise with trafficking in the bedding sand layer that will cause increased deflection. If there is an absence or deterioration of load transfer devices, deflections at both sides of the joints will also be worsened. To tackle this problem, the USCB is a good choice as it can reduce deflection and develop better interlocking between the CBP and bedding sand layer.

Traffic loading is also another major problem for block pavements in areas of channelized traffic like bus stops, fuel terminals and freight terminals. In these areas, failure of CBP is mostly caused by the vertical and horizontal traffic loading as well as repetitive loading. The high pressure load imposed (vertical loading) on the CBP can cause changes in the position of the concrete blocks and lead to undesired settlement. Horizontal movement is induced by horizontal loading caused by vehicle braking and accelerated action. Repetitive loading can cause some sands to break down into finer particles. Another problem often encountered in CBP applications is the wash-out of fine materials between the blocks by rainwater; loss of materials accelerates the production of ruts under traffic load and creep problems.

1.4 Aim and Objectives

The aim of this study was to investigate the potential of USCB to be used as concrete block pavement. The objectives of this study were as follows:

i. To characterize the engineering properties of different type of USCB.
ii. To examine the effects of groove depth, groove volume and groove shape on the interlocking mechanism of USCB under various loadings.

iii. To evaluate the structural performance including rutting and deformation of USCB under Highway Accelerated Loading Instrument (HALI).

1.5 Scope of Study

The scope of this study was established to achieve the objectives mainly through experimental works. The testing methods and procedures were specified according to those recommended by the American Society for Testing and Materials (ASTM), British Standard Institution (BS) and some were proposed by previous researchers as follows:

i. Push-in loading test by Marios *et al.*, (2011) and Emery and Lazar (2003).
ii. Pull-out loading test by O'Grady (1983), Emery and Lazar (2003) and Ling (2008).
iii. Horizontal loading test by Rachmat (2006).
iv. Accelerated trafficking test by Shackel (1980b) and Ling (2008).

The scopes of the study were divided into three major parts:

i. Part 1- Development of USCB to characterize their engineering properties.

In order to establish the required information regarding USCB, the following aspects were considered:

a. Shape development:
  - Number of grooves,
  - Groove depth: 15 mm, 25 mm, and 35 mm of groove depth,

- Groove category: Shell- Rectangular Grooved, Trench-Triangular Grooved and Trench-Rectangular Grooved, and
- Groove area or groove volume.

b. Mechanical properties:
  - Block compression behaviour (28-days compressive strength),
  - Block flexural behaviour,
  - Block density, and
  - Water absorption.

c. Physical properties:
  - Block dimension,
  - Cracks assessment, and
  - Mode of failures.

ii. Part 2- Interaction mechanism between USCB and bedding sand layer.

To investigate interaction between USCB and bedding sand layer, three types of tests were considered:

a. Push-in loading test - Local settlement and deformation of USCB pavement,
b. Pull-out loading test – Local settlement and deformation of USCB pavement, and
c. Horizontal loading test- Horizontal resistance of USCB pavement.

iii. Part 3 - Application of USCB as a structural system to investigate the structural performance

Investigation of USCB structural performance was based on:

a. Accelerated trafficking test:
  - Longitudinal and transverse rutting profiles,

- Three and two-dimension surface deformation,
- Rut depth under wheel path, and
- Open joint width.

1.6 Limitations of Study

All experimental works and research programme were conducted in this study according to some limitation parameters as listed in Table 1.1.

Table 1.1 : Study limitations

Parameter	**Limitation**
Concrete block thickness	80 mm
Blocks gap	2 mm to 4 mm
Laying pattern	Stretcher bond
Jointing sand	Passing 2 mm sieve size (dry)
Bedding sand	Passing 5 mm sieve size
Bedding sand layer thickness	70 mm (loose sand)
Base course	Steel base plate with 3 mm neoprene sheet (stimulate 6 % CBR)

1.7 Significance of Study

The significance findings of this study can benefit researchers as follows:

i. To enhance the use of CBP as an attractive alternative to shaped pavers or other traditional pavers in their interlocking system or other applications.
ii. To provide database of USCB for future pavement applications.
iii. To assist the engineers and fabricators in improving the interlocking system of concrete pavers and to provide an established database for paver design work in the future.
iv. To develop an innovative USCB product that has better engineering properties and comparable service performance in comparison with existing CBP.

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