

STRUCTURAL PERFORMANCE OF ASPHALT BLOCKS PAVEMENT
AS RELATED TO THICKNESS, BINDER TYPES, AND JOINT WIDTH

AHMED SALAMA ELTWATI

A thesis submitted in fulfilment
of the requirements for the award of the degree of
Doctor of Philosophy (Civil Engineering)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

MAY2015

*Dedicated to Allah S.W.T,
my beloved Mother and Father
Thanks for your support and love.*

ACKNOWLEDGEMENT

First and foremost, I would like to thank Allah S.W.T for blessing me to complete this important step in my life.

Special thanks and my sincere appreciation to my main supervisor Prof. Dr. Hasanan Bin Md. Nor for encouragement guidance, critics and friendship. Without his continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to the highway laboratory technicians and my fellow postgraduate students at Universiti Teknologi Malaysia (UTM), who showed their concern and support all the way. I would like to thank in particular Dr. Azman Bin Mohamed whose views and tips were useful indeed. Finally, I am grateful to all my family members.

ABSTRACT

Asphalt block pavement is an innovative alternative to asphalt pavements. This study investigated the performance of asphalt paving blocks with a number of variables: block thickness, bitumen types and joint width between blocks. The effect of dynamic and static loads and their transfer from one block to another on the behaviour of asphalt block pavements were studied. Asphalt blocks were laid on sand bedding, but direct laying on a base course was also investigated. The experiments conducted in the laboratory were push-in test, pull-out test, and accelerated trafficking test. Two types of bitumen were used as binder to produce asphalt blocks: normal bitumen (60/70) and modified bitumen (PG 76) and different block thicknesses: 70 mm, 80 mm, and 90 mm. Asphalt blocks were laid in stretcher bond with various joint widths: no joint spacing, 2 mm, and 3 mm. The instruments of the push-in test and pull-out test were constructed within a steel box of 1.0 metre square; the push-in vertical load was increased from 0 to 30 kN on the samples of asphalt blocks. The accelerated trafficking loading test was conducted in a steel platform of 1.0 m \times 5.0 m, the loaded wheel was moved over the pavement model and the deflection was taken at specific intervals. The results indicate that asphalt blocks have a great performance after being exposed to static load and dynamic load. The study shows that placing asphalt blocks directly on the base course resulted in uneven surface; therefore the bedding sand layer is a necessary component in the structure of asphalt block pavements. From the statistical results, the thickness of the block has insignificant impact on the structural performance. However, there is a trend that a change in block thickness from 70 to 90 mm decreases the deflection and displacement of asphalt block pavement which could be due to a greater frictional area and load transfer, thus increase the response of the pavement. The results also show the type of bitumen used in this study has insignificant impact on the structural performance. However, it has an impact on the compressive strength and density of the block. The finding reveals that placing blocks with no joint spacing is found to yield the best performance.

ABSTRAK

Turapan blok asfalt adalah inovatif yang alternatif kepada turapan asfalt. Kajian ini dijalankan untuk mengkaji prestasi struktur turapan blok asfalt dengan beberapa perubahan seperti ketebalan blok, jenis-jenis bitumen dan jarak antara blok yang digunakan. Kesan dinamik dan beban statik dan pemindahan dari satu blok ke blok lain pada prestasi blok turapan asfalt turut dikaji. Blok asfalt disusun atas lapisan pasir pengalas, tetapi turapan terus ke atas fondasi jalan juga dikaji. Eksperimen yang dijalankan adalah ujian bebanan tekan masuk, ujian bebanan tarik keluar, dan ujian lalu lintas dipercepatkan. Dua jenis bitumen digunakan untuk menghasilkan blok asfalt: bitumen biasa (60/70) dan bitumen diubahsuai (PG 76) dan ketebalan blok yang berbeza iaitu 70 mm, 80 mm dan 90 mm. Blok asfalt diletakkan bersama dalam corak ikatan usungan dengan tiada jarak di antara blok, 2 mm, dan 3 mm. Ujian bebanan tekan masuk dan ujian bebanan tarik keluar dilakukan dalam kotak keluli 1.0 meter persegi, dengan tekanan beban tegak ditingkatkan daripada sifar kepada 30 kN atas sampel blok asfalt. Ujian lalu lintas dipercepatkan dilakukan dalam platform keluli 1.0 m \times 5.0 m di mana defleksi diambil secara khusus bila tayar-tayar melalui model turapan tersebut. Selepas didedah kepada beban statik dan dinamik, kajian telah menunjukkan bahawa blok asfalt mempunyai prestasi yang baik. Kajian tersebut menunjukkan bahawa blok asfalt yang diletakkan di atas lapisan fondasi menyebabkan permukaan yang tidak sekata. Oleh itu, lapisan pasir pengalas adalah satu komponen yang penting dalam struktur turapan blok asfalt. Dari keputusan statistik, ketebalan blok tidak memberikan kesan pada struktur prestasi. Walau bagaimanapun, keputusan ada menunjukkan kecenderungan di mana perubahan ketebalan blok dari 70 mm ke 90 mm menurunkan defleksi dan anjakan turapan blok asfalt. Blok tebal mengakibatkan geseran yang lebih luas dan perpindahan beban yang lebih besar, seterusnya meningkatkan tindak balas turapan. Pengujian tersebut menunjukkan bahawa jenis bitumen yang digunakan dalam kajian ini tidak banyak menghasilkan kesan dalam struktur prestasi. Walau bagaimanapun, ia mempunyai kesan ke atas kekuatan mampatan dan ketumpatan blok. Keputusan ujikaji menunjukkan tanpa menjarakkan blok asfalt antara satu sama lain dapat menghasilkan kesan yang paling baik.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xiii
	LIST OF FIGURES	xv
	LIST OF ABBREVIATIONS	xxviii
	LIST OF SYMBOLS	xxix
	LIST OF APPENDICES	xxx
1	INTRODUCTION	1
1.1	Background	1
1.2	Problem Statement	2
1.3	Objectives	3
1.4	Scope of the Study	3
1.5	Significance of the Study	5

2	LITERATURE REVIEW	7
2.1	Introduction	7
2.2	Block Pavement Components and Structure	8
2.2.1	Paving Blocks	10
2.2.1.1	The Effect of Block Shape	10
2.2.1.2	The Effects of Block Thickness	13
2.2.1.3	The Effect of Blocks Laying Pattern	14
2.2.2	Bedding Sand layer	15
2.2.2.1	The Effect of Bedding Sand Thickness	16
2.2.2.2	The Effect of Bedding Sand Grading and Angularity	17
2.2.2.3	The Effect of Moisture Content of Bedding Sand	19
2.2.3	Jointing Sand	19
2.2.4	Width of Jointing Sand	20
2.2.5	Function of the Joints in Interlocking of Block Pavement	22
2.2.6	Edge Restraints	22
2.2.7	Base and Sub-base Course	23
2.2.8	Subgrade Course	24
2.3	Compaction	24
2.4	Block Pavement Construction	25
2.5	Interlocking Mechanism	26
2.8.1	Vertical Interlocking	26
2.8.2	Horizontal Interlocking	27
2.8.3	Rotational Interlocking	28
2.6	Types of Block Pavement Failures	29
2.7	Block Deflections Behaviour	31
2.8	Types of Trafficking Tests on Block Pavements	32
2.8.1	Accelerated Trafficking Tests	32
2.8.1.1	Vehicles Design Loads	34
2.8.1.2	Axle and Wheel Loads	34
2.8.1.3	Tyre Pressures	37
2.8.1.4	Load Repetitions	40

2.8.1.5 Existing Accelerated Trafficked Loading Tests	40
2.8.2 Static Plate Load Tests	41
2.8.2.1 Push-in Loading Test	41
2.8.2.2 Pull-out Loading Test	43
2.8.3 Actual Block Pavements Traffic Tests	46
2.9 Concluding Remarks	46
3 METHODOLOGY	48
3.1 Introduction	48
3.2 Material Properties	51
3.2.1 Aggregate	51
3.2.2 Bitumen	52
3.3 The Mixture Type and Properties	53
3.4 Manufacturing of the Paving Blocks	53
3.4.1 Materials Preparation and Mixing	54
3.4.2 Mixture Compaction	56
3.5 Testing the Block Properties	61
3.5.1 Density	61
3.5.2 Voids Analysis	62
3.5.2.1 Voids in Minerals Aggregate (VMA)	62
3.5.2.2 Voids in Total Mix (VTM)	63
3.5.2.3 Voids Filled with Bitumen (VFA)	63
3.5.3 Compressive Strength	64
3.6 Structural Performance of Asphalt Pavement	66
3.6.1 Highway Accelerated Load Instrument (HALI)	66
3.6.1.1 Description of HALI	66
3.6.1.2 Calibration of HALI	68
3.6.1.3 Test Procedure	69

3.6.1.3.1	The Construction of Block Pavement	71
3.6.1.3.2	Accelerated Trafficking Test Procedure	75
3.6.2	Push-in Test	78
3.6.2.1	Description of the Test	78
3.6.2.2	Test Procedure and Deflection Measurement	78
3.6.3	Pull-out Test	82
3.6.3.1	Test Description	82
3.6.3.2	Test Procedure and Deflection Measurement	82
3.6.4	Water Seepage Test	86
4	LABORATORY INVESTIGATION OF ASPHALT PAVING BLOCKS PROPERTIES	88
4.1	Introduction	88
4.2	Results and Discussion	89
4.2.1	Aggregate Gradation	89
4.2.2	Washed Sieve Analysis	89
4.2.3	Specific Gravity of Aggregate and Water Absorption	90
4.2.3.1	Coarse Aggregate	90
4.2.3.2	Fine Aggregate	91
4.2.3.3	Filler Specific Gravity	91
4.2.4	Bulk and Apparent Specific Gravity of Blend Aggregate	92
4.2.5	Specific Gravity of Asphalt	92
4.2.6	Theoretical Maximum Density	93
4.2.7	The Optimum Bitumen Content (OBC)	93
4.3	Density	95
4.4	Air Voids	96
4.5	Compressive strength	97

4.6	Summary	100
5	STRUCTURAL PERFORMANCE OF ASPHALT BLOCK PAVEMENT	101
5.1	Introduction	101
5.2	Placement of asphalt paving blocks directly on the base course	102
5.3	Results and Discussion	106
5.3.1	Push-in Test	106
	5.3.1.1 Effect of Block Thickness	106
	5.3.1.2 Effect of Joint Width	111
	5.3.1.3 Effect of Bitumen Type	116
5.3.2	Pull-out Test	122
	5.3.2.1 Effect of Block Thickness	123
	5.3.2.2 Effect of Joint Width	129
	5.3.2.3 Effect of Bitumen Type	134
5.3.3	HALI Accelerated Trafficking Test	140
	5.3.3.1 Transverse Analysis	140
	5.3.3.2 Longitudinal Analysis	147
	5.3.3.3 Effect of Block Thickness	151
	5.3.3.4 Effect of Bitumen Type	154
	5.3.3.5 Mean Rut Depth in Wheel Track	157
	5.3.3.6 Two and Three-dimensional Views of Asphalt Block Pavement Deflection	161
5.3.4	Water Seepage Test	164
5.4	Comparison between Asphalt Paving Blocks and Concrete Paving blocks	168
5.5	Summary	173
6	CONCLUSIONS AND RECOMMENDATIONS	177
6.1	Introduction	177
6.2	Conclusions	178

6.3	Recommendations for Future Research	179
-----	-------------------------------------	-----

REFERENCES	181
-------------------	------------

Appendices A - J	188 - 245
------------------	-----------

LIST OF TABLES

TABLE NO.	TITLE	PAGE
1.1	Study Scopes	5
2.1	Components of concrete block pavement	9
2.2	Sand grading for bedding sand; Source	18
2.3	Maximum single axle loads permitted around the world	35
2.4	Standard axle loads	37
3.1	Sieve analysis of aggregates	52
3.2	VMA requirements	63
3.3	The number of repetitions	70
3.4	Bedding and jointing sand grading requirements	72
3.5	Number of push-in test repetitions	81
3.6	Number of pull-out test repetitions	85
4.1	Result of washed sieve analysis	89
4.2	Specific gravity of coarse aggregate	90
4.3	Specific gravity of fine aggregate	91
4.4	Bulk and apparent specific gravity of blend aggregate	92
4.5	Theoretical maximum density result	93
4.6	The optimum bitumen content	94

4.7	Marshall Mix design results for different mixtures	94
4.8	Density of asphalt blocks	95
4.9	Statistical analysis (t-test) for significance of bitumen type On density	96
4.10	Air voids in asphalt blocks	97
4.11	Statistical analysis (t-test) for significance of bitumen type On compressive strength	99
5.1	The elevation of asphalt paving blocks	104
5.2	Statistical analysis (ANOVA) for effect of block thickness	107
5.3	Statistical analysis (ANOVA) for effect of joint width	112
5.4	Statistical analysis (t-test) for significance of bitumen type	117
5.5	Statistical analysis of variance (ANOVA) for effect of block thickness on pull out load	124
5.6	Statistical analysis of variance (ANOVA) for effect of block thickness on displacement	125
5.7	Statistical analysis (ANOVA) for effect of joint width under pull out load	130
5.8	Statistical analysis (ANOVA) for effect of joint width on block displacement	130
5.9	T-test for effect of bitumen type on pull out load	135
5.10	T-test for effect of bitumen type on block displacement	136
5.11	ANNOVA results for effect of block thickness	152
5.12	T-test results for effect of bitumen type	155
5.13	ANNOVA results for effect of joint width	165
5.14	Comparison of rut depth in different paving blocks	172

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Different types of block pavements	8
2.2	Components of block pavement	10
2.3	Shapes of paving block	11
2.4	The effects of block shape on deflection.	12
2.5	Effect of block thickness on block pavement performance	13
2.6	Laying patterns of blocks	14
2.7	The effect of laying patterns	15
2.8	Effects of bedding sand thickness on block pavement	16
2.9	The effects of the bedding sand thickness on block pavement	17
2.10	The effect of bedding thickness and joint width on jointing sand	20
2.11	The effect of joint widths on block pavement deflection	21
2.12	Types of movements of block at the joints	22
2.13	Vertical interlocking mechanism	27
2.14	Horizontal interlocking mechanism	28
2.15	Rotational interlocking mechanism	29
2.16	Block movements under loading	29

2.17	Distributions of truck axle loads	36
2.18	Contact surface between tyre and road surface	38
2.19	Forces affected on pavement surface	39
2.20	The distribution of load from tyre to pavement layers	40
2.21	Relationship between applied stress and vertical displacement	43
2.22	Relationship between pull-out loads and block deflection	44
2.23	Pull-out loading test equipment	45
2.24	Relationship between pull-out loads and block displacement	45
3.1	Research programme flowchart	50
3.2	Asphalt blocks making machine	54
3.3	The effect of compaction time on density of mixture	57
3.4	The effect of compaction time on total air voids VTM of mixture	57
3.5	Steel mould of asphalt blocks	58
3.6	The hot mixture is poured in the steel mould	59
3.7	The hot mixture is compacted	59
3.8	Extracting of asphalt block from steel mould by jacking	60
3.9	Asphalt blocks after extraction from steel mould	61
3.10	Compression strength test	65
3.11	Highway Accelerated Load Instrument	68
3.12	Grid lines and positions of measurement the deformation	71
3.13	Placing the bedding sand in HALI platform	73
3.14	Placing and compacting asphalt blocks on bedding sand	74

3.15	The blocks are placed and marked with points for measuring the rutting	75
3.16	Measurement of pavement deformation by using the dial gauges connected to a data logger.	77
3.17	Push-in test setup	79
3.18	Distributions of the transducers on the pavement model	80
3.19	Screwing and fixing the block steel holder with hydraulic plunger	84
3.20	Pull-out test setup and arrangement	84
3.21	Locations of tested points of water seepage test	87
3.22	Water seepage test.	87
4.1	Compressive strength results for asphalt block made With different thicknesses and binders	98
5.1	The locations of elevation measurement of asphalt blocks	103
5.2	The surface of asphalt blocks placed on base course	105
5.3	Relationship between the deflection of pavement and vertical loads on blocks made of PG 76-22 and laid with no joint width between blocks	108
5.4	Relationship between the deflection of pavement and vertical loads on blocks made of PG 76-22 and laid with 2 mm joint width between blocks	109
5.5	Relationship between the deflection of pavement and vertical loads on blocks made of PG 76-22 and laid with 3 mm joint width between blocks	109
5.6	Relationship between the deflection of pavement and vertical loads on block made of AC 60/70 and laid with no joint width between blocks	110
5.7	Relationship between the deflection of pavement and vertical loads on block made of AC 60/70 and laid with 2 mm joint width between blocks	110
5.8	Relationship between the deflection of pavement and vertical loads on block made of AC 60/70 and laid with 3 mm joint width between blocks	111

5.9	Relationship between the deflection of pavement and vertical loads on blocks made of PG 76-22 and thickness of 70 mm	113
5.10	Relationship between the deflections of pavement and vertical loads on blocks made of AC 60/70 and thickness of 70 mm	114
5.11	Relationship between the deflection of pavement and vertical loads on blocks made of PG 76-22 and thickness of 80 mm	114
5.12	Relationship between the deflection of pavement and vertical loads on blocks made of AC 60/70 and thickness of 80 mm	115
5.13	Relationship between the deflection of pavement and vertical loads on blocks made of PG 76-22 and thickness of 90 mm	115
5.14	Relationship between the deflection of pavement and vertical loads on blocks made of AC 60/70 and thickness of 90 mm	116
5.15	Relationship between the deflection of pavement and vertical loads on blocks of 70 mm thick and laid with no joint spacing	118
5.16	Relationship between the deflection of pavement and vertical loads on blocks of 70 mm thick and laid with 2 mm joint width	118
5.17	Relationship between the deflection of pavement and vertical loads on blocks of 70 mm thick and laid with 3 mm joint width	119
5.18	Relationship between the deflection of pavement and vertical loads on blocks of 80 mm thick and laid with no joint spacing	119
5.19	Relationship between the deflection of pavement and vertical loads on blocks of 80 mm thick and laid with 2 mm joint width	120
5.20	Relationship between the deflection of pavement and vertical loads on blocks of 80 mm thick and laid with 3 mm joint width	120
5.21	Relationship between the deflection of pavement and vertical loads on blocks of 90 mm thick and laid with no joint spacing	121

5.22	Relationship between the deflection of pavement and vertical loads on blocks of 90 mm thick and laid with 2 mm joint width	121
5.23	Relationship between the deflection of pavement and vertical loads on blocks of 90 mm thick and laid with 3 mm joint width	122
5.24	Relationship between block thicknesses and block resistance to maximum load: blocks laid with no joint spacing	126
5.25	Relationship between block thicknesses and displacement of block laid with no joint spacing	126
5.26	Relationship between block thicknesses and block resistance to maximum load: blocks laid with 2 mm joint width	127
5.27	Relationship between block thicknesses and displacement of block laid with 2 mm joint width	127
5.28	Relationship between block thicknesses and block resistance to maximum load: blocks laid with 3 mm joint width	128
5.29	Relationship between block thicknesses and displacement of block laid with 3 mm joint width	128
5.30	Relationship between block thicknesses and block resistance to maximum load on blocks 70 mm thick	131
5.31	Relationship between block thicknesses and displacement of block 70 mm thick	132
5.32	Relationship between block thicknesses and block resistance to maximum load on blocks 80 mm thick	132
5.33	Relationship between block thicknesses and displacement of block 80 mm thick	133
5.34	Relationship between block thicknesses and block resistance to maximum load on blocks 90 mm thick	133
5.35	Relationship between block thicknesses and displacement of block 90 mm thick	134

5.36	Relationship between types of bitumen and block resistance to maximum load on blocks laid with no joint spacing	137
5.37	Relationship between types of bitumen and displacement of the block laid with no joint spacing	137
5.38	Relationship between types of bitumen and block resistance to maximum load on blocks laid with 2 mm joint width	138
5.51	Relationship between types of bitumen and displacement of block laid with 2 mm joint width	138
5.40	Relationship between types of bitumen and block resistance to maximum load on blocks laid with 3 mm joint width	139
5.41	Relationship between types of bitumen and displacement of block laid with 3 mm joint width	139
5.42	Transverse section of asphalt block pavement	141
5.43	A plan view of deformation depth measurement points	142
5.44	Rutting along the wheel path	143
5.45	Transverse rut profile of block pavement; 70 mm is the thickness of block, and AC 60/70 is the type of bitumen	144
5.46	Transverse rut profile of block pavement; 80 mm is the thickness of block, and AC 60/70 is the type of bitumen	144
5.47	Transverse rut profile of block pavement; 90 mm is the thickness of block, and AC 60/70 is the type of bitumen	145
5.48	Transverse rut profile of block pavement; 70 mm is the thickness of block, and PG 76-22 is the type of bitumen	145
5.49	Transverse rut profile of block pavement; 80 mm is the thickness of block, and PG 76-22 is the type of bitumen	146
5.50	Transverse rut profile of block pavement; 90 mm is the thickness of block, and PG 76-22 is the type of bitumen	146
5.51	Longitudinal view of asphalt block pavement	147

5.52	Longitudinal rut profile of block pavement; 70 mm is the thickness of block, and AC 60/70 is the type of bitumen	148
5.53	Longitudinal rut profile of block pavement; 80 mm is the thickness of block, and AC 60/70 is the type of bitumen	148
5.54	Longitudinal rut profile of block pavement; 90 mm is the thickness of block, and AC 60/70 is the type of bitumen	149
5.55	Longitudinal rut profile of block pavement; 70 mm is the thickness of block, and PG 76-22 the type of bitumen	149
5.56	Longitudinal rut profile of block pavement; 80 mm is the thickness of block, and PG 76-22 the type of bitumen	150
5.57	Longitudinal rut profile of block pavement; 90 mm is the thickness of block, and PG 76-22 the type of bitumen	150
5.58	Effect of block thickness on rut depth in wheel path; AC 60/70 is the type of bitumen used, and no joint width between blocks	153
5.59	Effect of block thickness on rut depth in wheel path; PG 76-22 is the type of bitumen used, and no joint width between blocks	153
5.60	Effect of bitumen type on rut depth in wheel path; 70 mm is the block thickness, and no joint width between blocks	156
5.61	Effect of bitumen type on rut depth in wheel path; 80 mm is the block thickness, and no joint width between blocks	156
5.62	Effect of bitumen type on rut depth in wheel path; 90 mm is the block thickness, and no joint width between blocks	157
5.63	Mean rut depth of pavement up to 20,000 load repetitions 90 mm block thickness and PG 76-22 bitumen type	158
5.64	Mean rut depth of pavement up to 20,000 load repetitions: 80 mm block thickness and PG 76-22 bitumen type	159
5.65	Mean rut depth of pavement up to 20,000 load repetitions: 70 mm block thickness and PG 76-22 bitumen type	159

5.66	Mean rut depth of pavement up to 20,000 load repetitions: 90 mm block thickness and AC 60/70 bitumen type	160
5.67	Mean rut depth of pavement up to 20,000 load repetitions: 80 mm block thickness and AC 60/70 bitumen type	160
5.68	Mean rut depth of pavement up to 20,000 load repetitions: 70 mm block thickness and AC 60/70 bitumen type	161
5.69	Rutting in asphalt block pavement model after 20,000 load repetitions	162
5.70	a) 2D view (b) 3D view of rutting in asphalt block pavement after 20,000 load repetitions by using SURFER software	163
5.71	Asphalt blocks integration	166
5.72	Result of the water seepage test at point 1 with different joint widths	166
5.73	Result of the water seepage test at point 2 with different joint widths	167
5.74	Result of the water seepage test at point 3 with different joint widths	167
5.75	Mean rut depth in Concrete block pavement after 2,500 load cycles	169
5.76	Mean rut depth in concrete block pavement after 2,000 load cycles	170

LIST OF ABBREVIATIONS

2D	-	Two-dimensional
3D	-	Three-dimensional
AASHTO	-	American Association of State Highway and Transportation Official
ASTM	-	American Society for Testing and Material
BS	-	British Standard
CBP	-	Concrete Block Pavement
CBR	-	California Bearing Ratio
ESA	-	Equivalent Standard Axle
JKR	-	Jabatan Kerja Raya
HALI	-	Highway Accelerated Loading Instrument
HMA	-	Hot Mix Asphalt
OBC	-	Optimum Bitumen Content
PG	-	Bitumen of Performance Grade
SSD	-	Saturated-surface-dry
TMD	-	Theoretical Maximum Density
VFB	-	Voids Filled with Bitumen
VMA	-	Voids in Mineral Aggregate
VTM	-	Voids in Total Mix

LIST OF SYMBOLS

A	-	Area
D, d	-	diameter
π	-	Pi = 3.14
Gmm	-	Maximum specific gravity
Gmb	-	Bulk specific gravity of a compacted mixture
S.G eff	-	Effective specific gravity of aggregates
σ	-	Stress

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A1	Dry size distribution	188
B1	Specific gravity of coarse aggregate	190
B2	Specific gravity of fine aggregate	191
C1	Theoretical Maximum Density for AC 10	193
C2	Theoretical Maximum Density for PMA 10	194
D1	Marshall Test Result for AC10	196
D2	Marshall Test Result for PMA10	201
E1	Volumetric properties of asphalt block made with bitumen PG 76-22 and 70 mm thick	207
E2	Volumetric properties of asphalt block made with bitumen PG 76-22 and 80 mm thick	208
E3	Volumetric properties of asphalt block made with bitumen PG 76-22 and 90 mm thick	209
E4	Volumetric properties of asphalt block made with bitumen AC 60-70 and 70 mm thick	210
E5	Volumetric properties of asphalt block made with bitumen AC 60-70 and 80 mm thick	211
E6	Volumetric properties of asphalt block made with bitumen AC 60-70 and 90 mm thick	212

F	Compressive strength results	213
G	Testing of base course	217
H	The deflection in push-in test	227
I	The result of pull-out test	237
J	The result of water seepage test	243
K	Publication	245

CHAPTER 1

INTRODUCTION

1.1 Background

The use of small-segment paving to establish a solid surface for pavements has been a unique tradition which can be traced back to the royal roads of ancient Babylon, Greek and Roman eras. The block pavements have been widely used over the past years. The block pavements have been laid broadly along roads, especially where they are constructed on steep slopes or at junctions due to their ability to prevent vehicles from slippery and their resistance to load (Croney and Croney, 1998).

The general global tendency towards a beautification of some town pavements, the speedy rise in construction and maintenance cost have urged road engineers to find an alternative paving material. Furthermore, outstanding engineering properties of paving blocks such as ease of removal, reuse possibility and capability to be used in different weather circumstances have been the most important advantages of paving blocks to be used in a diversity of commercial, municipal and industrial applications.

There are several types of block pavements produced from different materials such as concrete blocks, clay bricks, and wood blocks (Thye, 1979). The asphalt blocks have been known and used along the roads in the USA and Canada for the past decade (Baillairgé, 1964). The bitumen is the main material in producing the asphalt blocks. Appropriate methods of manufacturing the blocks permit the production of a very dense and strong blocks with an ability to resist the worst conditions that may cause serious pavement distresses (Hanover Product Guide., 2012). Asphalt paving blocks are completely engineered consequences made in the factory to deliver consistency and accuracy. In addition, the machine used to produce the paving blocks tends to produce blocks of significantly higher quality than the conventional road pavements with respect to density, compressive strength and durability.

1.2 Problem Statement

Asphalt block pavements have been known and used in some places around the world such as in the United States, Canada, and Germany over the past decades (Baillairgé, 1964), but there have been very limited studies being carried out to evaluate the performance of such pavement.

Furthermore, the conventional (normal) asphalt pavements are constructed by using heavy machines such as paver machine, thereby, it would be beneficial to have an alternative method of laying and paving the roads. So that, asphalt can be formed into small segments (blocks) thus, blocks can be placed by hands.

By producing the asphalt paving blocks in factory, some merits might be achieved. The quality and strength of the paving blocks can be controlled. In other words, by compacting the normal asphalt pavement in open air area, many circumstances, such as rain, snow, and hot weather might affect the compaction,

thereby, it would be useful to control the temperature of compaction of asphalt paving blocks in the factory.

1.3 Objectives

The main aim of this study is to develop asphalt blocks for road pavements and evaluate its structural performance. The main objectives of this study are as follows:

- (i) To characterize the engineering properties of asphalt paving blocks.
- (ii) To assess the structural performance of asphalt paving blocks which are affected by static and dynamic vertical loads with a number of variables: types of bitumen used as a binder of materials to produce asphalt blocks, joint widths (spacing) between the blocks, and thickness of the blocks.
- (iii) To study the feasibility of placing the asphalt blocks directly on the base course instead of on the bedding sand layer.

1.4 Scopes of the Study

To attain the objectives, the scopes of the study are mostly through experimental works. The scopes of this study are:

- (i) Development of asphalt paving blocks to characterize their engineering properties

- a. Mechanical properties
 - Block compressive strength
 - Block density.
 - Air voids.
 - b. Physical properties
 - Block dimensions.
- (ii) The effect of bedding sand layer and evaluate the placement of asphalt paving blocks directly on the base course.
- (iii) Application of asphalt paving blocks as a structural system to evaluate the structural performance.

Assessment of structural performance of asphalt block pavements was based on:

- a. Accelerated trafficking loading test:
 - Longitudinal and transverse rutting profile.
 - The effect of using a number of variables on pavement performance.
Two and three-dimensional deformed surface
 - Rut depth under wheel path.
- b. Push-in loading test.
- c. Pull-out loading test.

The experimental works and research program were carried out in this study with some limitation parameters as shown in Table 1.1.

Table 1.1 : Study scopes

Parameter	Selection
Laying pattern	Stretcher bond
Jointing sand	Passing 2 mm sieve size
Bedding sand	Passing 5 mm sieve size
Bedding sand layer thickness	30 mm (compacted sand)
Base course	Steel base plate with 3 mm neoprene sheet (simulate 6 % CBR)
Traffic accelerated load	12 kN on one wheel

1.5 Significance of the Study

The significant outcomes of this study can aid researchers as follows:

- (i) This research presents the steps and procedures that can be followed to produce asphalt paving blocks with certain engineering properties.
- (ii) Since the studies on asphalt paving blocks are very limited, therefore, this research presents the detailed results of the behaviour and performance of such block under different load conditions: dynamic load and static load.
- (iii) As asphalt blocks are hand-paved (manual paving), therefore, this type of pavement can be a good alternative to the normal (conventional)

asphalt pavement, especially to paving narrow roads where the heavy paver machines have difficulties to get in.

- (iv) This study develops an innovative paving blocks which exhibit better engineering properties and comparable service performance.

REFERENCES

- AASHTO (2011). *Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates*. United States: Transportation Research Board.
- Abdulridha, A. A. (2011). *Fatigue Life of Hot Mix Asphalt Mixtures*. Masters Thesis. Universiti Teknologi Malaysia, Skudai.
- Armitage, R. J. (1988). Concrete Block Pavement with the Falling Weight Electrometer. *Proc. of 3rd Int. Conf. on Concrete Block Paving*, Rome. 203-208.
- Asphalt Institute. (1988). *The Asphalt Handbook* (1989 ed.). College Park, Md., USA: Asphalt Institute.
- ASTM (1990). *ASM handbook* (10th ed.). Materials Park, OH: International Handbook Committee.,ASM International.
- Baillairgé, C. P. F. (1964). *Asphalt Block Pavement* (Vol. 1). Canada.
- Barber, S. D., and Knapton, J. (1980). An Experimental Investigation of the Behaviour of a Concrete Block Pavement with a Sand Sub-base. *Proc. Institution of Civil Engineers*.01 March 1980. 139-155.
- British Standard Institution (1973). *Specification for Aggregates from Natural Sources of Concrete. BS 882, 1201: Part 2*. London: British Standard.
- British Standard Institution (2009). *Pavements Constructed with Clay, Natural Stone or Concrete Pavers - Part 3. BS 7533-3*. London.
- British Standard Institution. (1989). *Precast Concrete Paving Block, Code of Practice for Laying Pattern BS 6717: Part 3*. London: British Standard
- Brown, E. R., Hainin, M. R., Cooley, A., and Hurley, G. (2004). *Relationship of Air Voids, Lift Thickness, and Permeability in Hot Mix Asphalt Pavements*, . USA: National Cooperative Highway Research Program.

- Chai, L. T. (2008). *Engineering Properties and Structural Performance of Rubberized Concrete Paving Block*. Ph.D Thesis. Universiti Teknologi Malaysia, Skudai.
- Chakroborty, P., and Das, A. (2003). *Principles Of Transportation Engineering*. New Delhi: PHI Learning Pvt. Ltd.
- Clark, A. J. (1978). Block Paving - Research and Development. *Journal of Concrete International*, 12, 24-25. The Concrete Society.
- Clark, A. J. (1981). *Further Investigations into the Load-spreading of Concrete Block Paving*. Bucks: Cement and Concrete Association.
- Cliff, N. (1998). *Asphalt Surfacing : A Guide to Asphalt Surfacing and Treatments Used for the Surface Course of Road Pavements*. London ; New York: E & FN Spon.
- Clifford, J. M. (1984). Segmental Block Pavements - Optimising the Joint Width and Joint Material. *Second International Conference on Concrete Block Paving*, Delft. pp 238-249.
- Concrete Masonry Association of Australia. (1997). *Design Guide for Residential Accessways and Roads*. Australia: Cement And Concrete Association Of Australia. .
- Construction Specification. (2000). *Segmental Paving: Development Construction Specification*. C254. New South Wales.
- Croney, P., and Croney, D. (1998). *Design and Performance of Road Pavements* (3rd ed.). New York: McGraw-Hill.
- Dossetor, J. E., and Leedham, A. G. (1976). *Concrete Block Pavements*. Australia: : School of Civil Engineering, South Australian Institute of Technology.
- Dutruel, F., and Dardare, J. (1987). Etude Du Comportement Structural Des Chausses Revetue par Des Paves En Beton. *CERIB Tech Publication 91*.
- Eisenmann, J., and Leykauf, G. (1988). Design of Concrete Block Pavement in FRG. *3rd Int. Conf. on Concrete Block Paving*, Pavitalia: Rome. 149-155.
- Elliott, R. C. (1995). An Assessment of Some Self and Slowly Cementing Industrial By-products for Use in Roadbase. *Unbound Aggregates in Roads*. Nottingham, UK, the University of Nottingham pp. 205-219.

- Emery, J. A. (1993). Stabilization of Jointing Sand in Block Paving. *Journal of Transportation Engineering*, Vol. 119(No. 1), 142-148.
- Freddy, R. L., Kandhal, P. S., Brown, E. R., Lee, D.-Y., and Kennedy, T. W. (1996). *Hot Mix Asphalt Materials, Mixture Design & Construction* (Second ed.). College Station, Tex.: Texas Transportation Institute.
- Garber, N. J., and Hoel, L. A. (2009). *Traffic and Highway Engineering* (4th ed.). United States: Cengage Learning.
- Garrett, C., and Walsh, I. D. (1984). A Comparative Study of Concrete Paving Blocks. *Proc. Second Int. Conf. on Concrete Block Paving*, Delft. pp 61-68.
- Hanover (2011). Guideline Specification Paving and Surfacing Asphalt Block.
- Hanover Product Guide. (2012). Hanover Architectural Products.
- Hasanan Md Nor (2005). *The Development and Application of Concrete Block Pavement*: Int. Seminar and Exhibition on Road Construction (ISERC), Semarang, Indonesia.
- Hassani, A. (2006). Modeling and Structural Design of A Concrete Block Pavement System. *8th International Conference on Concrete Block Paving*, San Francisco, California USA. 389 - 398.
- Hodgkinson, J. R. (1982). *Specification for Construction of Trafficked Interlocking Concrete Pavements*. Technical Note TN41. Cement and Concrete Association of Australia.
- Huber, G. A., and Decker, D. S. (1995). *Engineering Properties of Asphalt Mixtures and the Relationship to their Performance*. Philadelphia ASTM International.
- Hurmann, M. (1997). *Pavement Deformation in Concrete Block Pavements*. Ph.D. Thesis. Delft University Of Technology, Delft, Netherlands.
- Husin, K. A. (2001). *Kajian Pengisi Sambungan dan Penguncian Turapan Block Konkrit*. M.Eng. Thesis. Universiti Teknologi Malaysia, Skudai.
- Interlocking Concrete Pavement Institute (ICPI). (2006). *Structural Design of Interlocking Concrete Pavement for Roads And Parking Lots*. (Spec No. 4), pp. 1-8.
- Interpave (2004). *Construction Of Concrete Block Pavements*. The Precast Concrete Paving and Kerb Association. The British Precast Concrete Federation.

- Jabatan Kerja Raya (2005). *Design of Flexible Pavement Structures*. K.L, Malaysia.
- Jabatan Kerja Raya (2008). *Standard Specification For Road Works*. K.L, Malaysia: Cawangan Jalan, Ibu Pejabat JKR, .
- Jones, R. O. (2004). *Highway Facility Design*. Washington, D.C. : Transportation Research Board, National Academy of Sciences.
- Knapton, J. (1976). *The Design of Concrete Block Roads*. Technical Report. Cement and Concrete Association. UK.
- Knapton, J. (1984). Concrete Block Pavement Design in the UK. *Proc. Second Int. Conf. on Concrete Block Paving*, London, UK. pp 129-138.
- Knapton, J., and Barber, S. D. (1979). The Behavior of a Concrete Block Pavement *Proc. Inst. Civil Engineering*. 227-292.
- Knapton, J., and Barber, S. D. (1980). Uk Research into Concrete Block Pavement Design. *Proc. of the 1st Intl. Conf. on Concrete Block Paving*. 2-5 Sep. Newcastle-upon-tyne.
- Knapton, J., and O'Grady, M. (1983). Structural Behaviour of Concrete Block Paving. *Journal Concrete Society*, 1-2.
- Lavin, P. (2003). *Asphalt Pavements: A Practical Guide to Design, Production and Maintenance for Engineers and Architects*. New York: Taylor & Francis e-Library.
- Lekso, S. (1980). The Use Of Concrete Block Pavements For Highways. *Proc. 1st Int. Conference On Concrete Block Paving*, Newcastle Upon Tyne, pp. 101-103.
- Lilley, A. A. (1980). A Review of Concrete Block Paving in the Uk over the Last Five Years. *Proceeding of First International Conference on concrete Block Pavement*, Newcastle-Upon-Tyne. 40-44.
- Lilley, A. A., and Dowson, A. J. (1988). Laying Course Sand for Concrete Block Paving. *Proc. 3rd Int. Conf. on Concrete Block Paving*, Rome. pp 457-462.
- Mallick, R. B., and El-Korchi, T. (2013). *Pavement Engineering: Principles and Practice* (2nd ed.). CRC Press.
- Miura, Y., Takaura, M., and Tsuda, T. (1984). Structural Design of Concrete Block Pavements by CBR Method and its Evaluation. *Proc. Second Int. Conf. on Concrete Block Paving*, Delft. pp 152-157.

- Molenaar, A. A., Moll, H. o., and Houben, L. J. M. (1984). Structural Model for Concrete Block Pavements. *Paper submitted to Annual Meeting of Transportation Research Board.*
- Mudiyono, R. (2006). *Performance of Concrete Block Pavement on Sloped Road Section*. Ph.D Thesis. Universiti Teknologi Malaysia, Skudai.
- Murali Krishnan, J., and Lakshmana Rao, C. (2001). Permeability and Bleeding of Asphalt Concrete Using Mixture Theory. *International journal of engineering science*, 39(6), 611-627.
- O'Grady, M. (1983). *The Structural Behaviour of Small Element Block Paving*. University Of Newcastle Upon Tyne.
- Panda, B., and Ghosh, A. (2012). Structural Behavior of Concrete Block Paving. II: Concrete Blocks. *Journal of Transportation Engineering*, 128(2), 130-135.
- Panda, B. C., and Ghosh, A. k. (2002). Structural Behaviour of Concrete Block Paving. I: Sand in Bed and Joints. *Journal of Transportation Engineering*, 128 (2), 123-129.
- Rada, G., Smith, D., Miller, J., and Witczak, M. (1990). Structural Design of Concrete Block Pavements. *Journal of Transportation Engineering*, 116,(Issue 5), 615–635.
- Rollings, and S, R. (1982). *Concrete Block Pavements*. Technical Report GL82. US Army Engineer Waterways Experiment Station
- Rowe, G. H. (1979). *Bedding Sands for Concrete Block Paving*. Internal Report GLR 22. New Zealand Concrete Research Association.
- Seddon, P. A. (1980). The Behaviour of Interlocking Concrete Block Paving at the Canterbury Test Track. *Tenth Australian Road Research Board Conference ARRB*, Vermont South, Victoria.
- Shackel, B. (1979a). The Design of Interlocking Concrete Block Pavements. *Australian Road Research Board Report ARRB No. 90*, 53-70.
- Shackel, B. (1979b). An Experimental Investigation of the Response of Interlocking Block Pavements to Simulated Traffic Loading. PP 11-44.
- Shackel, B. (1979c). A Pilot Study of the Performance of Block Paving Under Traffic Using a Heavy Vehicle Simulator.

- Shackel, B. (1980a). An Experimental Investigation of the Roles of the Bedding and Jointing Sand in the Performance of Interlocking Concrete Block Pavements. *Journal Concrete*. 5-15
- Shackel, B. (1980b). The Performance of Interlocking Block Pavements under Accelerated Trafficking. *1st International Conference-Concrete Block Paving*, Newcastle, pp. 113-120.
- Shackel, B. (1981). *The Heavy Vehicle Simulator System in South Africa* (Vol. 11). Vermont South, Victoria: ARRB Group Limited.
- Shackel, B. (1985). The Evaluation and Application of Mechanistic Design Procedure for Concrete Block Pavements. *Proc. of the 3rd Int. Conf. on Concrete Block Paving*. Rome, pp. 114-120.
- Shackel, B. (1987). Accelerated Trafficking Trials of Machine Layable Concrete Block Paving. *17*(No. 1). Australian Road Research.
- Shackel, B. (1990). *Design and Construction of Interlocking Concrete Block Pavements*. New York, NY, USA: Elsevier Applied Science.
- Shackel, B. (1994a). Application and Construction of Concrete Block Pavements *New Directions in Pavement Engineering*. 14-15 November. Kuala Lumpur, Malaysia. pp. 178-184.
- Shackel, B. (1994b). Introduction to Concrete Block Paving. Parkroyal, Kuala Lumpur.
- Shackel, B. (2003). The Challenges of Concrete Blocks Paving As a Mature Technology *School of Civil and Environmental, University of New South Wales, Sydney, Australia*.
- Shackel, B., and Arora, M. (1978). The Evaluation of Interlocking Block Pavements. *Proc. Conference Concrete Masonry Assn of Australia*. Sydney.
- Shackel, B., and Lim, D. O. O. (2003). Mechanisms of Paver Interlock. *Proceeding 7th International Conference on Concrete Block Paving*. South Africa.
- Shackel, B., O'Keeffe, W., and O'Keeffe, L. (1993). Concrete Block Paving Tested as Articulated Slabs. *5th International Conf. on Concrete Pavement Design and Rehabilitation*, Purdue Univ., West Lafayette.
- Shackel, B., and Pearson, A. (2000). Concrete Flag Pavement Design and Construction Guide: Concrete Masonry Association of Australia (CMAA).

- Sharp, K. G., and Armstrong, P. J. (1985). *Interlocking Concrete Block Pavement* Special Report SR31. Australian Road Research Board.
- Sharp, K. G., and Simmons, N. J. (1980). *Interlocking Concrete Blocks* Vol. 10.
- Siddique, R., and Naik, T. R. (2004). Properties of Concrete Containing Scrap-Tire Rubber—An Overview. *Waste management*, 24(6), 563-569.
- Soutsos, M. N., Kang Kang Tang, Khalid., H. A., and Millard., S. G. (2011). The Effect of Construction Pattern and Unit Interlock on the Structural Behavior of Block Pavement. *Construction and Building Materials*, (pp. 3832-3840). . Elsevier.
- Tarhuni, F. S. (2011). *Improving Rutting Resistance Of Concrete Block Pavement*. Master Thesis. Universiti Teknologi Malaysia, Skudai.
- Thoresen, C. A. (2003). *Port Designer's Handbook: Recommendations and Guidelines*. Thomas Telford.
- Thye, C. S. (1979). *The Behaviour of Interlocking Concrete Block Paving Under Traffic Loading*. Civil Engineering --University of Canterbury.
- Wagner, F. T. (1986). *Placement and Compaction of Asphalt Mixtures : A Symposium*. Philadelphia, USA: American Society for Testing and Materials.
- Wallace, H. A., and Martin, J. R. (1967). *Asphalt Pavement Engineering*. United States of America: McGraw-Hill, Inc.
- Wardlaw, K. R. (1992). *Polymer Modified Asphalt Binders*. Philadelphia, PA: ASTM.