

**FINITE ELEMENT MODEL APPROACH TO
DETERMINE THE OPTIMUM DIMENSIONS FOR
INTERLOCKING CONCRETE BLOCKS USED FOR
ROAD PAVING**

Mapa Mudiyansele Dhanushika Vidarshane Gunatilake



138025X
University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Thesis/Dissertation submitted in partial fulfilment of the requirements for the degree
Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

July 2014

Declaration

I hereby declare that this is my own work and this thesis does not incorporate without acknowledgement to any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works.

Signature

Date

.....

.....

Gunatilake M. M. D. V.

The above candidate has carried out research for the Masters thesis under my supervision.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Signature of the supervisor

Date

.....

.....

Abstract

Concrete Block Paving (CBP), which is a predominant construction method used nowadays, is based on the ancient road construction technology “Stone Paving”. The use of CBP is a common sight in most of the developing countries due to its economic adaptability. Although it has emerged as a cost-effective paving material, it is yet being developed as a full-fledged construction technique. The aim of this research was to determine optimum dimensions for concrete blocks using a finite element model, evaluating the deflections and stresses in pavement with the application of loads.

A three-dimensional finite element model was built to measure the elastic deflection basin with ANSYS finite element modelling software. The reason for developing a finite element model is, as the construction of concrete block pavements for experimenting is costly and challenging, a finite element model simulating the field conditions could be used to overcome these issues and perform further research. Previously developed finite element models and laboratory models were studied. The results obtained from the developed finite element model were verified with the deflection values obtained in a laboratory scaled model. Similar deflection basins could be observed for different load cases.

Several block types were considered initially and block dimensions with best performance were identified. Based on those results a new block type which optimizes the performance was proposed carrying out finite element analysis. An alternate block type to the proposed block type was also analysed and it could only be recommended for non-traffic areas.

In addition, the effects of wheel path on concrete block pavement in both longitudinal and transverse directions were considered to have an idea about the variation of stress and deflection at different locations of the pavement. Although no significant values were observed with the block orientation, closer the wheel path to the edges higher the stresses obtained.

Key words: Concrete Block Paving, Block shapes, Block dimensions, Loading position

Dedication

To my dear father, mother and my husband



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Acknowledgement

The opportunity given to carry out research studies as postgraduates should be highly appreciated. This experience would benefit me immensely in the future, when I will be involved in researches further. Therefore, I would like to express my sincere gratitude to my supervisor, Dr. W. K. Mampearachchi of Transportation Engineering Division, Department of Civil Engineering, University of Moratuwa for the meticulous supervision, constant advice, help and encouragement given throughout the research. I also would like to acknowledge and appreciate the advice given by Prof. J. M. S. J. Bandara, Dr. H. R. Pasindu, Mr. L. Perera of Transportation Engineering Division, University of Moratuwa and Mr. A. A. Senadeera, Road Development Authority, Sri Lanka.

I am grateful to the Director – Postgraduate Studies, Prof. (Mrs.) C. Jayasinghe and Research Coordinator, Prof. S. Thilakasiri for the guidance provided in fulfilling tasks related to the research. My sincere gratitude is to Prof. A. Nanayakkara, Head, Department of Civil Engineering, University of Moratuwa for the support given throughout.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations

www.lib.mru.ac.lk

I would like to convey my gratitude to the concrete block manufacturers for their contribution in carrying out the survey. My heartfelt appreciation is expressed Mr. C. K. Rankoth, Mr. P. Gamage Mr. C. Hettiarachchi and Mr. C. Jayasekara for the assistance provided in familiarizing to ANSYS software.

Special thanks are to my fellow postgraduate research students at Transportation Engineering Division, Ms. R. M. Jayarathne and Ms. C. Jayasuriya, for the support given throughout the research. I wish to convey my gratitude to the non – academic staff and the supportive staff of Department of Civil Engineering, University of Moratuwa for their assistance to carry out the study.

M. M. D. V. Gunatilake

Table of Contents

Declaration	i
Abstract	ii
Dedication	iii
Acknowledgement.....	iv
Table of Contents	v
List of Figures	ix
List of Tables.....	xiii
CHAPTER 1 INTRODUCTION.....	1
1.1 General.....	1
1.2 Objectives	2
1.3 Significance of the research.....	2
1.4 Scope of the report.....	2
CHAPTER 2 LITERATURE REVIEW.....	4
2.1 General.....	4
2.2 Advantages of CBP over other paving methods.....	5
2.3 Main structural components and structural behaviour of CBP.....	7
2.3.1 Concrete block	8
2.3.2 Bedding sand.....	8
2.3.3 Joint filling sand.....	8
2.3.4 Sub base	8
2.3.5 Subgrade.....	9
2.3.6 Edge restraints.....	9
2.4 Interlocking mechanism of CBP.....	9
2.4.1 Rotational mechanism.....	10
2.4.2 Translational mechanism	10
2.4.3 Principle of interlock.....	10
2.5 Properties of CBP	11
2.5.1 Thickness of blocks.....	12

2.5.2	Size of blocks	12
2.5.3	Strength of blocks	13
2.5.4	Block shape	14
2.5.5	Laying pattern and laying angle	18
2.6	Construction practices	21
2.6.1	Structural design.....	21
2.6.2	Construction procedure	22
2.7	Maintenance and rehabilitation of CBP.....	24
2.7.1	Maintenance	24
2.7.2	Rehabilitation	24
2.8	Finite element modeling	24
2.8.1	Approach to finite element modelling.....	24
2.8.2	Laboratory scale CBP model and SAP model (by Mampearachchi & Gunarathna, 2010).....	25
2.8.3	Results.....	28
2.9	Gap leading to the research study.....	30
CHAPTER 3 SURVEY ON CONCRETE BLOCK PAVING		31
3.1	General.....	31
3.2	Survey	31
3.3	Ranking of the block shapes	31
3.4	Strength of blocks	32
3.5	Damages to blocks.....	32
3.6	Summary of survey.....	34
CHAPTER 4 DEVELOPMENT OF A 3-D FINITE ELEMENT MODEL BY ANSYS.....		35
4.1	General.....	35
4.2	Development of 3-D FEM.....	35
4.3	3-D model by ANSYS Mechanical APDL.....	35
4.3.1	Material properties	36
4.3.2	FEM dimensions	36

4.3.3	FEM loading procedure.....	37
4.3.4	FEM Analysis	37
4.4	3-D model by ANSYS Workbench 12.1	39
4.5	Verification of the ANSYS Workbench FEM.....	40
4.6	Stress Variation.....	41
CHAPTER 5 FEM ANALYSIS TO DETERMINE OPTIMUM DIMENSIONS FOR CONCRETE BLOCKS		42
5.1	General.....	42
5.2	Block types used for the study.....	42
5.3	Development of 3-D models.....	44
5.3.1	Analysis of maximum vertical deflection variation of cobble shape dimensions	44
5.3.2	Analysis of maximum vertical deflection variation of uni shape dimensions	47
5.3.3	Comparison of maximum vertical deflection variation with block shape dimensions	49
5.3.4	Analysis of maximum equivalent stress variation of block shape dimensions	50
5.3.5	Comparison of maximum equivalent stress variation with block shape dimensions	52
5.4	Introduction of new block shapes	52
5.4.1	Analysis of maximum vertical deflection variation.....	53
5.4.2	Analysis of maximum equivalent stress variation	54
5.4.3	Stress values at different loading positions.....	54
5.4.4	Laying pattern of new block	55
5.4.5	Alternative blocks	56
5.5	Effect of angles of uni shape blocks.....	58
CHAPTER 6 DETERMINATION OF THE EFFECT OF WHEEL PATH ON CBP		61
6.1	General.....	61
6.2	1m x 1m 3-D model.....	61
6.2.1	Load moving in the longitudinal direction.....	61

6.2.2	Load moving in the transverse direction.....	63
6.3	3m x 1m 3-D model.....	65
6.3.1	Load moving in the longitudinal direction.....	65
6.4	Effect of wheel path on several locations of the pavement (in longitudinal direction).....	67
6.5	Effect of wheel path on several locations of the pavement (in transverse direction).....	69
6.6	Summary of results.....	71
CHAPTER 7 CONCLUSION		73
7.1	General.....	73
7.2	Future study	76
References		77
Appendix A: Survey on Concrete Block Manufacturing.....		79
Appendix B: Results obtained from FEMs		81



University of Moratuwa, Sri Lanka.
 Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Figures

Figure 1.1: Development of rural road network in Sri Lanka (Progress report 2013, Ministry of Highways)	1
Figure 2.1: The Roman Appian way early interlocking pavement	4
Figure 2.2: Use of pavers worldwide (in millions of square meters per annum).....	5
Figure 2.3: Main structural componets of CBP	7
Figure 2.4: Deflection shape of block pavement (Panda & Ghosh 2000a).....	9
Figure 2.5: Type of interlocking	11
Figure 2.6: Effect of block thickness on block pavement (Panda & Ghosh 2002b)..	12
Figure 2.7: Effect of block size on block pavement (Panda & Ghosh 2002b).....	13
Figure 2.8: Effect of block strength on block pavement (Panda & Ghosh 2002b)....	13
Figure 2.9: Details of block shapes used in study (Panda & Ghosh 2002b).....	14
Figure 2.10: Effect of block shapes on behaviour of block pavement.....	15
Figure 2.11: Types of blocks.....	16
Figure 2.12: Concrete block shapes commonly used in industry.....	16
Figure 2.13: Effect of block shapes on deflection (Mameparachchi & Senadeera, 2014)	17
Figure 2.14: Effect of block shapes on deflection profile (Mameparachchi & Senadeera, 2014).....	17
Figure 2.15: Effect of block shapes on block displacement (Mameparachchi & Senadeera, 2014).....	18
Figure 2.16: Concrete block laying patterns	19
Figure 2.17: Effect of block laying pattern on deflection (Mameparachchi & Senadeera, 2014).....	19
Figure 2.18: Effect of block laying pattern on deflection profile (Mameparachchi & Senadeera, 2014).....	20
Figure 2.19: Effect of block laying pattern on displacement (Mameparachchi & Senadeera, 2014).....	20
Figure 2.20: Section view of laboratory model.....	26
Figure 2.21: Experimental set up (Mampearachchi & Gunarathna, 2010)	26
Figure 2.22: Loading arrangements (Mampearachchi & Gunarathna, 2010)	27
Figure 2.23: SAP model (Mampearachchi & Gunarathna, 2010).....	28

Figure 2.24: Verification of Test 1 (Mampearachchi & Gunarathna, 2010)	29
Figure 2.25: Verification of Test 2 (Mampearachchi & Gunarathna, 2010)	29
Figure 2.26: Verification of Test 3 (Mampearachchi & Gunarathna, 2010)	29
Figure 2.27: Verification of Test 4 (Mampearachchi & Gunarathna, 2010)	30
Figure 2.28: Effect of laying pattern on the pavement (Mampearachchi & Gunarathna, 2010).....	30
Figure 3.1: Block shapes widely used for the construction	31
Figure 4.1: FEM with the subgrade	37
Figure 4.2: FEM without the subgrade	38
Figure 4.3: Geometry of the pavement (by SolidWorks 2012).....	39
Figure 4.4: Mesh (Workbench 12.1)	39
Figure 4.5: Deflection basin of the FEM	40
Figure 4.6: Verification of the ANSYS model.....	41
Figure 4.7: Stress variation of the FEM	41
Figure 5.1: Cobble shape in stretcher bond pattern	44
Figure 5.2: Effect of Cobble shape dimensions on max. vertical deflection (in stretcher bond pattern).....	45
Figure 5.3: Cobble shape in herringbone bond pattern	45
Figure 5.4: Effect of Cobble shape dimensions on max. vertical deflection (in herringbone bond pattern).....	46
Figure 5.5: Comparison of deflection variation of cobble shape dimensions in two laying patterns	46
Figure 5.6: Uni shape in stretcher bond pattern	47
Figure 5.7: Effect of Uni shape dimensions on max. vertical deflection (in stretcher bond pattern)	47
Figure 5.8: Uni shape in herringbone bond pattern.....	48
Figure 5.9: Effect of Uni shape dimensions on max. vertical deflection (in herringbone bond pattern).....	48
Figure 5.10: Comparison of deflection variation of uni shape dimensions in two laying patterns	49
Figure 5.11: Comparison of deflection variation of block shape dimensions in two laying patterns	49

Figure 5.12: Effect of block shape dimensions on max equivalent stress (in stretcher bond pattern)	50
Figure 5.13: Effect of block shape dimensions on max equivalent stress (in herringbone bond pattern)	51
Figure 5.14: Comparison of stress variation of block shape dimensions in two laying patterns	52
Figure 5.15: New block shape.....	53
Figure 5.16: Comparison of max. vertical deflection of Uni3 and new block.....	53
Figure 5.17: Comparison of max. equivalent stress of Uni2 and new block	54
Figure 5.18: Stress variations of new block	54
Figure 5.19: Loading positions of new block.....	55
Figure 5.20: Laying pattern of new block.....	55
Figure 5.21: Laying pattern of alternative block.....	56
Figure 5.22: Suggested alternative block pattern	56
Figure 5.23: Comparison of maximum vertical deflection variation of new blocks .	57
Figure 5.24: Comparison of maximum equivalent stress variation of new blocks	57
Figure 5.25: Comparison of maximum shear variation of new blocks	58
Figure 5.26: Effect of Uni shape dimensions on max. vertical deflection.....	59
Figure 5.27: Effect of Uni shape dimensions on max. equivalent stress	59
Figure 6.1: Load moving in the longitudinal direction	61
Figure 6.2: Loading positions (in longitudinal direction)	62
Figure 6.3: Effect of loading position on deflection variation (in longitudinal direction)	62
Figure 6.4: Effect of loading position on equivalent stress variation (in longitudinal direction).....	63
Figure 6.5: Load moving in the transverse direction	63
Figure 6.6: Loading positions (in transverse direction)	63
Figure 6.7: Effect of loading position on deflection variation (in transverse direction)	64
Figure 6.8: : Effect of loading position on stress variation (in transverse direction).	64
Figure 6.9: Load moving in the longitudinal direction (3mx1m model)	65
Figure 6.10: Loading positions (3mx1m model).....	65

Figure 6.11: Effect of loading position on deflection variation (3mx1m model)	66
Figure 6.12: Effect of loading position on equivalent stress variation (3mx3m model)	66
Figure 6.13: Considered locations in (longitudinal direction)	67
Figure 6.14: Effect of wheel path on deflection of the pavement (longitudinal direction)	68
Figure 6.15: Effect of wheel path on stress variation of the pavement (longitudinal direction)	69
Figure 6.16: Considered locations in (transverse direction)	69
Figure 6.17: Effect of wheel path on deflection of the pavement (transverse direction)	70
Figure 6.18: Effect of wheel path on stress variation of the pavement (transverse direction)	71



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Tables

Table 2.1: Thickness of concrete block related to application (Precast Concrete Paving and Kerb Association, 2005).....	22
Table 2.2: Material properties of SAP FEM (Mampearachchi & Gunarathna, 2010).....	27
Table 3.1: Ranking of block shapes according to the demand.....	32
Table 3.2: Blocks manufactured per day.....	32
Table 4.1: Element types used	36
Table 4.2: Material properties used.....	36
Table 5.1: Dimensions of the block shapes used	43
Table 5.2: Values of the angle in Uni 3 block	59



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk