

MUD CONCRETE PAVING BLOCK FOR PEDESTRIAN PAVEMENTS IN TROPICAL CLIMATIC CONDITIONS

MASTER OF SCIENCE

IN

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

CONSTRUCTION PROJECT MANAGEMENT

G.H.Galabada

Department of Civil Engineering

University of Moratuwa

Sri Lanka

April 2016

MUD CONCRETE PAVING BLOCK FOR PEDESTRIAN PAVEMENTS IN TROPICAL CLIMATIC CONDITIONS

By

G.H.Galabada



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk
Supervised by
Dr. R.U.Halwatura

The dissertation was submitted to the Department of Civil Engineering of the University of Moratuwa in partial fulfilment of the requirement of the Degree of Master of Science.

Department of Civil Engineering
University of Moratuwa

Sri Lanka

April 2016

Declaration

I declare that this is my own work and this thesis does not incorporate without acknowledgement 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 the University of Moratuwa, the non-exclusive right to reproduce and distribute my thesis/dissertation, in whole or in part, in print, electronic or other medium. I retain the right to use this content in whole or in part in future works (such as articles or books).

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

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

Signature of the supervisor:

Date

Abstract

The road network of Sri Lanka has been developing rapidly in recent years. Parallel to the expansion of the road network, most of the urban areas are also being upgraded with township development. Some of these developments follow a proper master plan, while there are others which do not pay attention to proper strategies. The attention paid for sustainable, low cost materials has been minimal. Hence, these unplanned developments are causing severe environmental issues such as global warming, heat island effect, lowering the ground water table, losing the natural appearance etc. Therefore, it is essential to invent new sustainable and low cost materials to counter balance the stated issues.

This research is focused on developing a paving block using mud concrete as a replacement for existing artificial paving materials used in urban walkways along the road network and within recreation areas. The main aim of this research is to produce a mud concrete paving block that can withstand the required strength according to the SLS standard, and which has a wet compressive strength of 15 N/mm^2 . The suitability of the developed block is then evaluated for their thermal performance and skid resistance. The current research status is identified through a literature survey. An online questionnaire survey is carried out to identify public perceptions on pedestrian pavements and paving materials used in them. A field survey was carried out among the paving block manufacturers to identify the cement percentage used by them. This was then used to develop the mix-designs for the laboratory experimental work.

In the laboratory, blocks are cast in three stages and are tested for four variables, viz: cement content, soil composition, moisture content and vibration time. Temperature measurements are taken of different pavement systems to evaluate their performance. The skid resistance of the block surfaces is measured using the Pendulum Skid Resistance Tester. Results have proven that the mud concrete paving block is a good alternative to pedestrian walkways while reducing thermal impact on the surrounding environment.

Key words: *pedestrian pavements, paving materials, user comfort, heat island effect, sustainability*

Acknowledgement

First, I am immensely grateful to my research supervisor, Dr. R.U. Halwatura of the Department of Civil Engineering for his invaluable guidance and support throughout the research period.

The support given by Prof. S.M.A Nanayakkara (Head, Department of Civil Engineering), Dr. L.L.Ekanayake (Head, Division of Construction Management and Research Coordinator, Department of Civil Engineering) is greatly appreciated.

I wish to extend my heartfelt gratitude to Dr.(Mrs) W.B.M. Thoradeniya (Senior Lecturer, ITUM) for her invaluable encouragement and guidance.

The support given by Dr. R.U. Halwatura's group of Research Assistants is also greatly appreciated.

I also extend my kind appreciation to all the academic and non-academic staff of the Department of Civil Engineering, and to everyone who helped me in completing this research successfully.

Finally, I would like to thank my husband for his unwavering support throughout my studies, and my three daughters for uncomplainingly sacrificing some of their entitled time with me.

Table of Contents

Declaration	i
Abstract	ii
Table of Contents	iii
List of Tables	vii
List of Annexes	xi
Chapter 1	1
1 Introduction	1
1.1 General	1
1.2 Objectives	3
1.3 Methodology	4
1.4 Major findings	6
1.5 Arrangement of the report	6
Chapter 2	7
2 Literature Review	7
2.1 General	7
2.2 Resource usage in the construction industry and its impacts	7
2.3 Sustainability in outdoor development and construction	9
2.4 Heat Island Effect caused by outdoor development	10
2.4.1 Heat Island mitigation	12
2.5 Methods of pavement construction	14
2.6 Paving material in outdoor developments	16
2.6.1 Cement based materials.	17
2.6.2 Soil based materials	20
2.6.3 Other materials	24
2.7 Pedestrian pavements	26

2.8 Summary	27
Chapter 3.....	30
3 Opinion Survey	30
3.1 Methodology	30
3.2 Results & Discussion	31
3.2.1 Public preferences for separate walkways, their visual separation and separate recreation areas	32
3.2.2 Public preferences on materials for walkways.....	34
3.3 Summary	38
Chapter 4.....	39
4 Experimental work	39
4.1 General.....	39
4.2 Field survey.....	40
4.2.1 Methodology	40
4.2.2 Results.....	40
4.3 Laboratory experiments for mix design	41
4.3.1 Soil Tests.....	41
4.3.2 Production of Mud Concrete Paving Block	44
4.4 Comparison of thermal performance	61
4.4.1 Methodology	61
4.4.2 Results.....	61
4.5 Skid Resistance Test	72
4.6 Cost analysis	75
4.7 Summary	76
Chapter 5.....	78
5 Conclusion and Recommendation.....	78



5.1 Conclusion	78
5.1.1 User perceptions and awareness	78
5.1.2 Suitability of the Mud Concrete Paving Block	78
5.2 Recommendations	79
5.3 Limitations	79
References	80
Annexes.....	85



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

List of Tables

Table 1 : Association of public preference to have separate walkways with experience as drivers / pedestrians	33
Table 2 : Association of public preference to have visual separation between walkways and roads with the experience as drivers / pedestrians	33
Table 3 : Association of public preference to have separate recreation areas with gender.....	34
Table 4: Association of gender with public preference on paving materials.....	36
Table 5 : Association of road experience with public preference on material.....	37
Table 6 : Cement concrete paving block manufacturing data.....	40
Table 7 : Sieve analysis.....	42
Table 8 : Selected soil composition for 10% fine particles.....	45
Table 9 : Average wet compressive strength for clay containing 10% fine particles..	50
Table 10 : Soil composition for fine 5%.....	55
Table 11 : Wet compressive strength for fine 5%.....	56
Table 12 : Summarized wet compressive strength.....	58
Table 13: Average wet compressive strength	60
Table 14 : Wet compressive strength.....	61
Table 15 : Greater London Council skid test criteria for pedestrian surfaces.....	73
Table 16 : Suggested minimum skid resistance values (<i>SKID RESISTANCE TEST</i> , n.d.)	73
Table 17 : The measured values of four blocks	74

List of Figures

Figure 1 : Methodology	5
Figure 2 : Percentage distribution of the sample's age groups	31
Figure 3: Respondents preferences on walkways	32
Figure 4 : Preferred material for walkways and recreational areas.....	35
Figure 5 : Weighted Average preference for paving materials.....	35
Figure 6 : Sedimentation layers	41
Figure 7 : Particle size distribution	43
Figure 8 : The sample selection pattern for casting test cubes in Stage One.....	46
Figure 9: Dry soil cement mix	47
Figure 10: Wet mud concrete mix ready to be poured in to moulds, and prepared moulds.....	48
Figure 11 : Mud concrete test cubes	48
Figure 12: Compressive strength test.....	49
Figure 13 : Variation of wet compressive strength with the moisture content for mix No. 1.....	51
Figure 14: Variation of wet compressive strength with the moisture content for mix No. 2.....	51
Figure 15: Variation of wet compressive strength with the moisture content for mix No. 4.....	52
Figure 16 : Variation of wet compressive strength with the vibration pattern for mix No. 1.....	53

Figure 17: Variation of wet compressive strength with the vibration pattern for mix No. 2.....	53
Figure 18: Variation of wet compressive strength with the vibration pattern for mix No. 3.....	54
Figure 19: Variation of wet compressive strength with the vibration pattern for mix No. 4.....	55
Figure 20: Variation of wet compressive strength with the moisture content for mix No. 5.....	56
Figure 21 : Variation of wet compressive strength with the moisture content for mix No. 6.....	57
Figure 22 : Variation of wet compressive strength with vibration time for mix No.2 & No. 6.....	58
Figure 23 : Sample selection pattern for casting test cubes in Stage Two.....	59
Figure 24 : Variation of wet compressive strength with sand content.....	60
Figure 25: Areas paved with different paving materials.....	62
Figure 26: Painted paved areas with different paving materials.....	63
Figure 27: Temperature variation in the burnt brick paved area.....	64
Figure 28: Temperature variation in the concrete slab paved area	65
Figure 29 : Temperature variation in the cement block paving area	65
Figure 30 : Temperature variation in the asphalt paving area	66
Figure 31 : Temperature variation in the mud concrete block paving area	67
Figure 32 : Temperature variation in natural ground.....	67

Figure 33: Comparison of temperature variation on top surfaces of paving areas, natural ground and ambient temperature.	69
Figure 34: Comparison of temperature variation at a level above 300mm height from top surfaces, natural ground and ambient temperature.	70
Figure 35 : Temperature variation at a level above 300mm height from top surfaces, natural ground and ambient temperature during 9 hr to 16 hr.	70
Figure 36 : Skid resistance testing process	74



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

List of Annexes

Annex 1: Questionnaire survey on pedestrian walk ways on urban area.....	85
Annex 2: Details of existing paving block.....	87
Annex 3: Cost analysis for mud concrete paving block.....	88



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

Chapter 1

1 Introduction

1.1 General

Today, technological developments in many sectors have made the human lifestyle more comfortable but complicated. Many of these developments follow a proper master plan, while there are many others that have not paid attention to proper strategy. Compared to these strategies, the attention paid to sustainable low cost materials has been very poor. According to Scudo and Dessi (2006), in the planning period of development projects, developers or local authorities seem to be concerned only about the technical and economic viability rather than the environment or the user comfort of those who are the end users of these developed spaces. Hence, these unplanned developments are causing severe environmental issues such as global warming, heat island effect, lowering the ground water table, losing the natural appearance etc. On the other hand, with new science and technology development, people use modern technology and facilities to fulfill their requirements, regardless of whether they are complex or simple. As a result, people engage in very less physical activities during their daily life and it may ultimately affect their health. Further, our technology choices have turned out to be wasteful because decisions were based on short term, narrow goals rather than a holistic view of the full range of consequences from the use of that technology. Though these environmental changes and health impacts brought on by urbanization have been studied by several researchers in the medical, agriculture, geography and climatology fields, the application of this knowledge in the field of urban planning and design has been limited. As a result, problems such as energy used in buildings and deteriorating human comfort have received very little attention among urban planners and designers (Emmanuel and Johansson, 2006). With this background, Rehan (2013) suggests that the sidewalk, which is one of the most valuable items in outdoor urban development, should be designed to provide safe, attractive, interesting and comfortable spaces for pedestrians in order to motivate them to use these walkways in both road and recreational areas.

Appropriate design can increase both the quality and quantity of walking. Minimizing motorized transport by motivating walkers and encouraging increased walking or cycling can achieve environmental benefits while also providing an opportunity to improve human health, thus improving the quality of life (Li et al., 2014).

Selection of construction materials is vital with respect to sustainable outdoor development. Thus the attention paid towards properties of materials which are used in outdoor development is very important. Several materials such as granite, asphalts, concrete etc. exist in modern outdoor development; block paving are available in numerous shapes and colours. It is remarkable that during the past few years the number of types of blocks, especially those with decorative characteristics, has greatly increased. However, since recent times, concrete block pavements have become an attractive engineering and economical material in the construction of walkways worldwide (Gencel et al., 2012). This is because concrete blocks are considered to be economical, consistent and durable (Mendoza et al., 2012). Though there have been several researches geared towards the improvement of engineering properties of existing paving materials, less attention has been paid towards user comfort and environment impacts that can be created due to the use of artificial material in outdoor development.



Sri Lanka is a developing country, and its infrastructure is developing rapidly. This is one of the key aspects that can be used to evaluate the development of a country. Along with infrastructure developments, the road network started developing rapidly in recent years. Parallel to road network expansion, most urban areas are also upgraded to match township development. As pedestrian walkways are one of the main elements with respect to outdoor development, it is important to understand the performance of such walkways. In the recent past, concrete paving blocks were introduced for these developments as attractive paving material. This is becoming more and more common, especially in so-called out door developments. However some developments seem to be done simply with simply the developer's and local government's requirements in mind rather than considering important factors such as pedestrian safety, user satisfaction, human health and environmental effects after development. Though concrete paving blocks are more common in our country, there are many drawbacks relating to our climate: issues like urban heat island effect can

create major adverse conditions against the environment and human health. Hence, it is highly essential to invent new materials as well as strategies to counter balance the stated issues. Therefore, the study of the effect on the temperature of the materials used for outdoor developments is important, especially with regard to user satisfaction while maintaining the sustainability and features that affecting micro climatic conditions.

In the beginning, concrete blocks were produced based on basic concrete constituents, i.e. Portland cement, natural fine and coarse aggregates. In recent years, many investigations in to concrete paving have increasingly been directed towards both delineating the structural characteristics and developing design procedures with different constituencies. As well as researches towards the use of solid waste material as aggregate for making concrete paving block, studies have been directed towards solid waste management to consequently prevent environmental pollution. As soil is the most abundant and inexpensive natural resource, it may also be an effective and more economic construction material.

1.2 Objectives



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

The main goal of this research is to develop a ‘Mud Concrete Paving Block’ with minimized adverse effects produced by heat. The sub-objectives are:

- To understand the user awareness and effectiveness of paving blocks in Sri Lanka.
- To determine a suitable mix for the Mud Concrete Paving Block.
- To investigate the thermal performance and how the proposed paving block will affect the heat island effect.
- To evaluate the technical aspects and cost of the Mud Concrete Paving Block.

1.3 Methodology

The main steps of the methodology are:

- Literature survey, to identify the available paving materials and their performances with regard to thermal effect, durability, load carrying capacity etc.
- Opinion survey and Field survey, to identify the user perception, requirements, use of materials and demand of existing paving blocks in walkways and other applications.
- Cast and test the paving blocks with different ratios of mud: cement: coarse aggregate, and controlling the water content to identify the best mix.
- Carry out field tests and laboratory tests to investigate thermal performance and technical aspects.
- Cost analysis to determine the cost for production of the proposed Mud Concrete Paving Block.

Figure 1 shows the layout in brief.



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

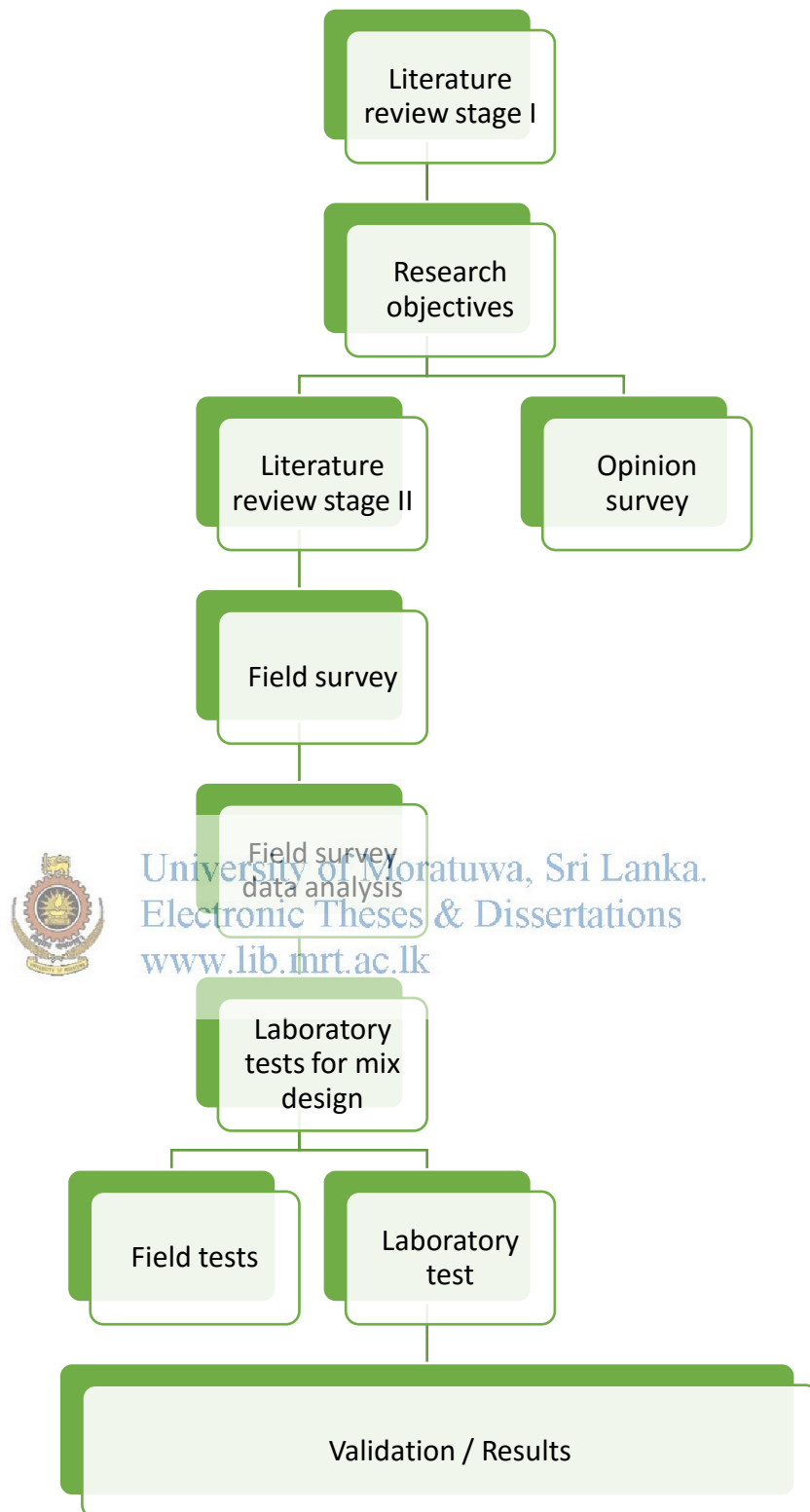


Figure 1 : Methodology

1.4 Major findings

This research explored the possibility of making Mud Concrete Blocks for paving outdoor areas using locally available technology with a relatively low cost and as a method of sustainable construction. The main finding is that the proposed mud concrete paving block satisfies the strength requirement of the SLS 1425 standard for pedestrian pavements. The other findings are that the block gives comparatively positive responses with respect to thermal characteristics, skid resistance and cost of production of the block.

1.5 Arrangement of the report

Chapter 2 of this report presents a detailed literature review covering the main topic related to the research. This chapter addresses the world population and their resources usage; global environment and environment pollution; outdoor development and its sustainability; effect of heat island and its mitigation; existing methods and materials of pavement construction; and the requirements of pedestrian pavements.

Chapter 3 demonstrates the detailed methodology and results obtained from the opinion survey carried out in order to identify the user perception, requirements, use of materials and demand for existing paving blocks in walkways and other applications.

Chapter 4 demonstrates the detailed methodology and results obtained by the different laboratory experiments, field experiments and the cost analysis.

Chapter 5 describes the conclusions, recommendations and limitations which have been proposed based on this research.

Chapter 2

2 Literature Review

2.1 General

The main goal of this research is to introduce a sustainable material for pedestrian pavements. Therefore as an approach, a comprehensive literature survey was carried out. The knowledge and data collected from the literature were used as the entry point to the process of introducing a new sustainable material for pedestrian pavements. The literature survey encompassed the following areas:

- World population and their usage of resources
- Global environment and environment pollution
- Sustainability in outdoor development
- Heat Island Effect caused by outdoor development and its mitigation
- Existing methods and materials for pavement construction
- Requirement of pedestrian pavements



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

2.2 Resource usage in the construction industry and its impacts

It has become even more important to pay close attention to construction materials and equipment due to the remarkable growth of the rate of population. At the beginning of the 20th Century, the world's population was 1.5 billion; by the end of the century it had risen to 6 billion. Furthermore, at the beginning of the century, approximately only ten percent of the population lived in cities; by the year 2010, nearly fifty percent of the population resided in and around the cities. The population will be doubled (i.e. 10 billion) by the year 2050 (United Nations et al., 2014) and resource consumption is expected to go up by fivefold. Therefore, the total resource requirement in 2050 will be 10 times that of the year 2000. Further, to meet the total resource consumption by the growing population in 2050, 3.8 more earths have to be found and resource consumption has to be reduced by a factor of 4/1 (*OVERCONSUMPTION? Our Use of World's Natural Resources*, 2009) . This large and continuously increasing world's population that lives in cities uses its share of

resources disproportionately. Additionally, the demand for goods and resources by city inhabitants, both historically and today, changes the natural land by deforestation, developing surface pavements, buildings and drainage patterns etc. Also, they usually consume large energy resources to be comfortable. These expansions are usually unsustainable expansions (Grimmond et al., 2010). Therefore, the cities and their inhabitants seem to be the key drivers of global climatic change, both directly and indirectly. Several studies carried out by different scholars indicate that the world climate reached higher temperatures during the last two decades (Urban Heat Island Effect, 2010; Ranasinghe and Halwatura, 2013). Further, our technology choices have turned out to be wasteful because decisions are based on short term, narrow goals rather than a holistic view of the full range of consequences of the use of a technology. With respect to the global flow of materials, only around 6% of them end up in consumer products whereas much of the remaining materials are returned to the environment in the form of harmful solid, liquid and gaseous wastes. The usage of resources can be optimized by minimizing the waste of resources at the point of generation, converting unavoidable wastes to products with economic value and by innovation and creativity. As a result, the greatest environmental challenges today are the effects of human-made climate change.



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

Construction is not an environmentally friendly process by nature. It is one industry which contributes to environmental pollution and according to Li et al. (2010), it is the third largest industry sector in terms of contributions to greenhouse gas emissions in the United States. Therefore, assessments of the life cycle environmental impacts of construction activities will help decision makers to identify major environmental impact factors and make environmentally friendly construction plans in the early stages of construction. According to Li et al. (2010), these impacts can be examined in two aspects of a typical construction process: as construction equipment and materials. Further, they categorized these environmental impacts into three safeguard subjects: ecosystems, natural resources and human health.

2.3 Sustainability in outdoor development and construction

The sustainability of the outdoor environment is one of the determining factors in the success of a city. It can be achieved by improving air and water quality, reducing light pollution and heat island effects. Maintaining social happiness is also an important factor for success of a city and can be achieved by making the outdoor environment fit enough for people to be encouraged to pursue outdoor activities such as walking, jogging etc., thereby improving people's health and consequently their quality of life. Li et al. (2010) claimed that the development of urban areas with a pedestrian-friendly environment where walking is promoted as a sustainable transportation method, is under pinned by the concept of sustainable outdoor development.

The use of sustainable materials is one approach applied by the cities that successfully refresh their outdoor environment by giving particular attention to sustainability which is necessary to create cities to live, work, and entertain. The use of recycled material for paving and manufacturing tree grate are some examples for the use of sustainable material. Pavements made out of recycled glass, waste marble, recycled concrete aggregate and crushed clay brick are some other examples (Poon and Chan, 2006; Gencel et al., 2012; Rehan, 2013; Ling and Poon, 2014).

Although many researches and experimental data are available relating to the sustainability of indoor conditions of buildings, very limited information is available relating to outdoor conditions including sustainable construction materials used in open urban areas. This is mainly due to the difficulty in describing the outdoor spaces due to their conditions which often undergo rapid changes. Outdoor development includes many elements such as sidewalks, street corners, tree and landscape strips, street furnishing, benches, signage, trash receptacles, lighting, bus shelters, medians, curbs, bicycle facilities, crossings, public art, and cafe spaces (Rehan, 2013). Therefore numerous design criteria have to be considered in the design of sustainable outdoor environments. Rehan (2013) mentioned that there are four main principles in sustainable urban designs. The first type is Urban Principles, which include many elements such as legibility, comfort, safety and attractiveness. The second type is Social Principles which includes liveliness and supports healthy urban communities.

The third is the Economical Principle where the economical level of material, i.e. sustainability of material, as well as the consumption of material resources should be taken into account. The final type is the Environmental Principle to achieve sustainability via reducing impacts on environmental resources, energy consumption, light pollution and the improvement of water quality. However, recent urban redevelopments are often reported to have unpleasant environmental performances because these developments are often carried out not with concerns for sustainability, but to only to address the concerns of the developers and the local authority's requirements. Scudo and Dessi (2006) stated that modern and contemporary public and semi-public urban spaces (eg: squares, courts, streets, commercial and transit centres) seem to have very poor thermal comfort performances when compared to that of traditional urban spaces. Therefore, for urban developments to be sustainable, they should be designed to meet the technical, economic and social requirements of not only the developers but also the users. Further, the designs also should identify suitable construction solutions and urban planning methods which minimize environmental impacts and harmful impacts to human health. Rosheidat and Bryan (2010) highlighted that developing and implementing energy-efficient production methods and equipment, and promoting the use of suitable materials can minimize the negative effects produced by artificial outdoor surfaces.

2.4 Heat Island Effect caused by outdoor development

The Urban Heat Island (UHI) phenomenon was first discovered in the early 1800's in London and has been studied for many years by agencies including the U.S. Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), Lawrence Berkeley National Laboratory (LBNL), the Royal Meteorological Society and the French Centre for Meteorological Research of Meteo-France (Killingsworth Sr et al., n.d.). The UHI effect is an incident in which surface and air temperatures are elevated due to the retention and emittance of solar heat from hardscapes such as roads, buildings and other structures. Heat islands are typically created when either the cities grow or are modified by replacing natural land cover with manmade pavements, buildings and other infrastructure (Wan et al., 2012). This is one of the phenomenon that contributes to the considerable temperature increase in urban areas and consequently creates outdoor thermal discomfort conditions as

artificial surfaces warm the surrounding air to undesirable levels, especially in warm, humid, and tropical climatic conditions. Pavements (including roads, pedestrian walkways etc.) are one of the main hardscapes contributing to the UHI effect and to the energy balance of the urban surface (Wan et al., 2012). Paving material is thus one of the main contributors to the phenomenon of the UHI effect (Rosheidat and Bryan, 2010). Paving material in urban areas have high thermal mass capacity, thus allowing them to absorb and retain a huge amount of thermal energy from the sun during the day. This causes surface temperatures to reach values as high as 60°C. When the pavements become considerably hotter than the ambient canopy temperature, the excess heat is radiated back into the atmosphere throughout the day and night, resulting in a higher ambient temperature in the cities in comparison to rural areas (Wan et al., 2012). Further, Halwatura and Jayasinghe (2007) claimed that the main drawback of air-conditioning is the shifting of heat from indoors to outdoors, thus contributing to warmer air in the immediate surroundings. This in turn may contribute to the Heat Island effect. As such the development of heat islands is increasingly becoming an additional and highly-complex environmental issue. It was also recently recognized that heat has a divesting impact on human health. Therefore, heat negatively influences the standard of living and the health of city dwellers (Grimmond et al., 2010). Again, Santamouris et al. (2012) and Babic et al. (2012) showed that it is a well-studied and well documented phenomenon of climate change and that it occurs due to higher urban temperatures compared to that of surrounding suburban areas. Further, Grimmond et al. (2010) mentioned that heat is considered a deadly weather-related phenomenon in much of the developed world. Apart from the negative effects of UHI on human health, UHI is also intimately connected to the demand and use of energy in cities.

Therefore it is essential to understand the mechanism of UHI which influences the near surface air temperature with the increase of temperature in urban areas. Temperature in urban areas are increased as a result of urbanization and by the use of pavement structures with poor thermal properties which prevent natural processes. This leads to the critical formation in developed urban zones. The typical natural ground heats up during the day, but it releases heat during the night. This natural process and its balance are disturbed once the natural ground is built up with high heat storage absorbing materials such as asphalt and concrete (Rosheidat and Bryan, 2010).

Heat is normally transferred in three ways, namely, by conduction, convection and radiation. In pavement structures, heat is transmitted by radiation. Higher pavement surface temperature influences heat emission, which results in higher air temperature (Babić et al., 2012; Wan et al., 2012). Factors which influence warming of pavement surfaces and the air above them are: solar radiation, solar reflection (albedo) and infrared radiation.

2.4.1 Heat Island mitigation

New urban development has received attention because it creates high urban surface temperatures and is considerably important for the planning and mitigation of the UHI effect for human comfort, better environment and reduced energy use. In new urbanism, the pavement is one of the main elements that can have a significant influence on the UHI effect (Li et al., 2014). The use of advanced mitigation techniques highly contributes to decreased temperatures and improved comfort in open urban areas (Santamouris et al., 2012).

Strategies used to reduce the UHI effect are many. An example is the proper design and material selection for roof structures. Some examples for pavement surfaces are the incorporation of more tree planting and landscaping elements in urban communities and the provision of shade or canopies over pavements etc. To this effect, the U.S. Department of Energy (DOE) provides several recommendations for reducing UHI; they suggest that the temperature in urban areas can be significantly reduced by replacing dark colored pavements and roofing with light and heat-reflective concrete based materials, along with careful planting of trees (Killingsworth Sr. et al., n.d.).

Babić et al. (2012) proposed three directions to be followed in order to mitigate negative phenomenon due to the UHI effect at the urban development level:

- a) development of urban forestry
- b) use of reflective materials for the roof, which preset lower temperatures on average due to their increased reflective characteristics
- c) use of cool pavements (pavement made out of materials with high albedo)

According to Halwatura and Jayasinghe (2007), the behavior of vegetation is quite different from that of artificial surfaces because it releases moisture to the surrounding atmosphere by converting most of the solar radiation to latent heat by evapotranspiration. Therefore, vegetation can mitigate UHI effects not only by cooling the air, but also by warming the air less during daytime.

Further, Rosheidat and Bryan (2010) said that the UHI effects can be reduced by the construction of porous pavements and pavements with a more luminous surface, and by extensive tree planting. Though tree planting is a cheap approach and the extensive tree canopy is beneficial in providing daytime shade for pedestrians, it may reduce the pavement surfaces' sky-view factor during the night, thereby reducing the rate of night time radiation to the sky. From the UHI mitigation viewpoint, tree planting may be more beneficial if low height vegetation is used where the sky view factor is not reduced as large shade trees.

In addition to this, Rehan (2013) stated that planting urban-tolerant canopy trees is important in mitigating the UHI effect in large areas of pavement. Such trees are helpful in keeping the outdoor climate cool and they minimize the negative impacts of the outdoor climatic conditions.



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

Materials presenting a high reflectance to solar radiation together with a high emissivity factor are known as cool materials. Such materials may be used in paths, roads, other urban structures and also in building rooftops. According to various recent studies, cool materials can significantly contribute to the reduction of surface temperatures up to several degrees (Santamouris et al., 2012). Therefore, the use of cool pavements is another efficient mitigation strategy for reducing the intensity of heat island in urban areas. The cool pavements not only create outdoor thermal comfort in urban spaces, but they also improve global environmental quality (Li et al., 2014). Researchers at Lawrence Berkeley National Laboratory (LBNL) have estimated that every 10 percent increase in solar reflectance could decrease surface temperatures by 7°F (4°C) (Killingsworth Sr et al., n.d.) .

Further, numerous researchers have suggested that material used in urban surfaces should have a high albedo value (a measure of the solar reflectivity of the material) wherever possible (Gajda and Van Geem, 1997; Babić et al., 2012; Halwatura et al.,

2013). According to Santamouris et al. (2012), the calculated reduction of peak air temperature is estimated at 0.57–2.3 °C for every 0.1 increase in urban albedo. Although various studies have clearly linked human discomfort with the effects of the “hot pavements”, the slow progression of technologies in this area limits urban planners and building owners in planning ways to mitigate this problem (Wan et al., 2012).

2.5 Methods of pavement construction

There are mainly two methods of pavement construction: impervious and pervious.

The materials most commonly used today for pavement constructions are asphalt and concrete. These are known as “dense” or impervious pavements because they allow very little air or water to pass through them. There are many environmental problems related to dense impervious pavements; an example is water pollution. Pollutants from the atmosphere, vehicles and animal waste build up on the surface of dense pavements, and some paving materials wash away during rain into the surrounding waterways. Therefore, impervious pavements are considered as the most significant generators of urban polluted runoff. On the other hand, water and air cannot penetrate through impervious pavements and in to the ground; consequently trees cannot be planted in urban areas.

As a result of the continually increasing pavement cover, there is a pressing need for alternatives to impervious pavements. Introducing porous pavements is one solution. Porous pavements are also known as permeable or pervious pavements. Unlike conventional pavements, porous pavements have voids, which allow water and air to pass through them to the ground below. Permeability has the advantages of permitting rain water to be stored in the earth. It is also one solution to reduce the problems of flooding and is a best management practice for reducing surface runoff, improving storm water quality and recharging ground water. Another benefit is that these surfaces tend to restrain noise (Pomerantz et al., 1997; James et al., 2003).

As one potential cool pavement type, permeable pavements have many environmental benefits beyond the conventional impermeable pavements with regard to mitigating local heat islands. The cooling effect of permeable pavements highly depends on the rate of evaporation of the pavement materials. Therefore, it is of great interest to

explore and better understand the evaporation rate of different pavement materials used for permeable pavements (Li et al., 2014).

Water permeable pavement blocks can be used to minimize the far reaching negative effects produced by sealing off the natural water balance (Beeldens and Herrier, 2006). In view of an overloaded sewer system, a permeable pavement is one of the considerable ecological solutions as it helps to prevent the overloading of sewer lines and also the entering of water with pollutants (Borgwardt, 2006). Thus, the development of a permeable pavement is an essential part of sustainable urban development through proper drainage systems in traditional and modern urban renewals (Borgwardt, 2006; Scholz and Grabowiecki, 2007).

Permeable pavement systems are suitable for a wide variety of residential, commercial and industrial applications, yet are confined to light duty and infrequent usage. The general principle of permeable pavement is simply to collect, treat and infiltrate freely any surface runoff in order to support groundwater recharge. In comparison to traditional drainage systems, storm water retention and infiltration is a sustainable and cost effective process suitable for urban areas. Permeable pavements are used as a technology for pollutant control concerning surface runoff from areas used as roads or parking spaces (Scholz and Grabowiecki, 2007).

The trees planted in islands surrounded by dense pavement tend to be small and unhealthy. However, porous pavements allow trees to grow to their full height and live much longer, creating the possibility of a true urban forest. These pavements are not only beneficial to the environment; they can be used to create uniquely beautiful urban landscapes.

Pervious concrete was first used after World War II and pervious asphalt was invented not long after. These paving systems were originally developed to address problems with storm-water management. However, later those practitioners were to realize the other environmental benefits that porous pavements had to offer. Recent innovations have allowed us to see new potential for porous pavements systems.

A porous asphalt or macadam pavements looks similar to conventional asphalt, but is relatively porous. A porous concrete pavement contains aggregates and a portland cement binder. Soil mixed with grass seeds or porous aggregates, Modular

interlocking concrete blocks with external open drainage cells are some examples for this type of pavement (Scholz and Grabowiecki, 2007)

Grass pavements are also one type and this type of pavement has added desirable qualities; the grass evapotranspires and thus cools the air above it while being decorative. However, a grassy pavement has many disadvantages: it becomes soft when it becomes wet, is easily rutted permanently and cannot survive frequent traffic. Further, all grass pavements must have sufficient water year-round and it may entail a cost (Pomerantz et al., 1997).

2.6 Paving material in outdoor developments

Unlike in many rural areas where plant cover and evaporation of soil moisture may have moderate temperatures, large portions of urban areas which consist of dry impervious materials in pavement or buildings have increased surface temperatures which occur when solar radiation is absorbed. Developing and implementing energy-efficient production methods and equipment, and promoting the use of suitable materials can minimize the negative environmental effects produced by artificial outdoor surfaces. According to Roshaidat and Bryan (2010), the temperature of urban areas can be in the range of 1.11°C - 4.44°C higher than the surrounding natural landscape.

Asphalt concrete and cement concrete play a significant role in pavement construction. They are usually used for construction of all outdoor development such as road parking lots, walkways etc. (Liu et al., 2013). However, the albedo value of construction material is one of the most important factors to be considered when selecting a material for outdoor development, especially in countries with hot climatic conditions. Further, according to Mendoza et al., (2012), pavement design with a long functional lifetime reduces its overall primary energy demand and global warming potential due to lower maintenance and repair requirements. However, long-lived construction solutions do not ensure a lower life-cycle primary energy demand and global warming potential than for shorter-lived designs; these values depend on the environmental suitability of the materials chosen for paving.

2.6.1 Cement based materials.

Cement concrete: Concrete blocks were used in the 1940s to supplement lawns, making them capable of supporting traffic. Plastic grids used for the same purpose were created in the late '70s and early '80s. Concrete sidewalks are the most common type worldwide because they are considered consistent, durable and economic (Mendoza et al., 2012). Concrete is an important and sustainable construction material that can be used to mitigate the UHI and is proven to be economical through life-cycle cost analysis (Killingsworth Sr et al., n.d.). Durability is an important engineering property of concrete and determines the service life of concrete structures significantly (El Nouhy and Zeedan, 2012).

According to (Babić et al., 2012), the albedo value of cement concrete pavement surfaces ranges from 5% to 40% , which means that these materials absorb 95% to 60% of solar energy. However (Pomerantz et al., 1997) mentioned in his report the albedo value of fresh cement concrete is 35% - 40%. It is also stated that when cement concrete ages, it tends to get darker because of dirt, and the albedo value reduces to 25% - 30%. In addition to this, he suggested that it is possible to produce concrete with visible reflectivity approaching 68 % by using whiter cements and aggregates.

Killingsworth Sr. et al. (n.d.) reported that weathered concrete goes up to a temperature of 155°F (68°C). The concrete base reaches a temperature lower than 5°C of the temperature of asphalt. Concrete is less hot than asphalt, both in maximum and constantly high (summer) temperatures. This makes it more favorable for use in cities due to its warming properties (Babić et al., 2012).

Smith (2000) claimed in a review of skid resistance literature that concrete pavements show better skid resistance compared to asphalt, further highlighting its ability to reduce accidents and increase safety.

The concrete sidewalk demonstrates a lower Global Warming Potential (GWP) and lower Primary Energy Demand (PED) than asphalt and granite solutions. Therefore, when compared with granite and asphalt sidewalks, the concrete sidewalk is the most environmentally friendly solution to reduce long-term impacts. However, concrete

sidewalks account for Green House Gas (GHG) emissions that are higher than those of asphalt sidewalks. The impact of concrete slabs is mainly associated with the cement content which is the largest impact contributor for all cement based materials used in sidewalks (Mendoza et al., 2012).

Soutsos et al., (2011) mentioned that concrete block pavements can tolerate a significantly larger deflection than asphalt pavements without cracking. A concrete sidewalk is therefore the most environmentally friendly solution to reduce long term impacts. However large energy consumption, CO₂ emission and dust emission are the biggest environmental concerns with regard to cement and concrete products. In order to minimize these environmental impacts, it is better to reduce the use of concrete in construction ("ENVIRONMENTAL IMPACT OF CONCRETE - ProQuest", n.d.).

Cement concrete with recycled and waste materials: Some of the major consequences of the rapid growth of population, economics and industrialization are the vast use of natural resources and the huge generation of solid wastes and by-product materials. As a result of this, waste material disposal has become increasingly problematic (Ling, 2012).

Several research studies have shown that it is possible to make use of most of the industrial solid wastes (Sukontasukkul and Chaikaew, 2006; Gencel et al., 2012; Ling and Poon, 2014) and construction & demolished waste in the production of concrete block products (Poon and Chan, 2006).

Most of the waste materials in cement concrete are used as full or partial replacement of aggregate or as a material which improves the engineering properties of the concrete. According to Gajda and Van Geem (1997) some examples of these materials are fly ash, silica fume, Ground Granulated Blast-Furnace Slag (GGBFS), porcelain and clay masonry.

In some cases, engineering properties of concrete can be maintained or increased by the partial replacement of the cement with waste material such as pozzolans (eg: fly ash and silica fume) which act as binders.

Another material which produces waste in considerable quantities is rubber. Rubber products increase every year and will be a problem faced by most municipalities

around the world in the future due to its non-readily biodegradable nature (Ling, 2012). Generally, the cheapest and easiest way to decompose waste or used rubber product is by burning them. However, the pollution and enormous amount of smoke generated by this method makes burning quite unacceptable. Thus, the conventional solution is to store them on empty land, which indirectly creates several other problems because they become a fire hazard or prone to insect and animal habitation. Sukontasukkul and Chaikaew (2006) stated in their research that during the last 20 years, much research was carried out in an attempt to reuse the abandoned rubber product in asphalt, sealants and rubber sheets or in cementitious materials like concrete. Their research shows that the resulting blocks are not as strong as plain concrete blocks. In the case of mechanical properties, both compressive and flexural strength are found to decrease with increased rubber content while the toughness increases. However, it has non-structure crack resistance, shock wave absorption, resistance to acid, lower heat conductivity, noise level reduction and better skid resistance when compared to conventional concrete. A disadvantage of this concrete is that it has less abrasion resistance. Further, Ling (2012) showed that some of the unique properties of concrete paving blocks produced using rubber aggregate were its light weight, higher impact resistance, toughness and plastic deformation which might offer a great potential for it to be used in sound barriers and pavement structures. Further, he claims that it is impossible to achieve “zero” porosity by increasing the rubber particles in the mixtures.

Construction waste is another problem in the developing world. Currently most of these waste materials are used as land fill worldwide. With limited landfill space, there is a need for immediate innovative solutions to meet such challenges. Clay brick generated from construction sites is one type of construction waste which is usually delivered to landfill sites for disposal. Therefore, immediate solutions need to be found for the possible use of crushed clay brick as a new civil engineering material. Recycled concrete aggregate and crushed clay brick are used as aggregates in the production of paving blocks in order to facilitate the recycling of construction and demolition (C&D) waste. Research indicates that the incorporation of crushed clay brick reduced the density, compressive strength and tensile strength but increased water absorption than that of normal concrete paving blocks. Also, Initial Surface Absorption (ISA) and chloride diffusion were found to be significantly higher for

concrete prepared with brick aggregates when compared with the normal concrete. The use of fly ash as a partial replacement of aggregates increased the compressive strength and reduced the skid resistance of the resulting paving blocks (Poon and Chan, 2006).

(Ling, 2012) says in his research that several authors have reported that incorporating recycled glass in concrete paving block is one possibility for waste glass recycling. Accordingly, one conventional block making manufacturer could use as much as 1000 tons of recycled glass per day as a replacement for natural aggregates in the production of blocks. Such previous research has found that it is possible to produce blocks containing up to 100% glass as aggregate.

Red mud is a by-product generated during the process of alumina production and is also a serious environmental problem. The use of red mud and fly ash as fine aggregate replacement in making compacted concrete block paving has also been studied. Results show that these blocks were environmentally safer in terms of leaching of toxic and non-toxic metals (Kumar and Kumar, 2013).

2.6.2



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

Soil based materials

Construction with earth is one ancient technology which still remains alive. Even though earth is an ancient construction material, the composition of earth varies drastically around the world because of climatic conditions. There are some undesirable properties of soil as a construction material (Jayasinghe and Kamaladasa, 2007). Historically, mud is a material that was extensively used in construction even before the advent of cement and concrete. The technical characteristics of earth as a construction material have both advantages and disadvantages depending on the requirements, applications and context. Some of the main advantages of earth are: availability in large quantities, low price, good fire resistance etc. The short comings are principally low mechanical characteristics, unsatisfactory resistance to weathering and liability to volume changes, especially in the case of clayey soils. Of course, these can be corrected with combined chemical and mechanical action, technically known as soil stabilization (Reddy and Krishnaiah, 2008).

The economic value of construction materials is one factor to be considered in sustainable development. However with the rising cost of construction, there is a need to develop low cost material and technology for the construction industry. Earth as a construction material has been used for thousands of years all over the world (Deboucha and Hashim, 2011).

Brick is one of the most popular construction materials in many countries due to its valuable properties such as durability, relatively low cost, availability, sound and heat insulation, acceptable fire resistance, attractive appearance and adequate resistance to weathering. Bricks can be either conventional type or alternative types. The conventional type can be identified as burnt clay bricks and is the major type used for construction worldwide (Jayasinghe and Mallawaarachchi, 2009). The alternative types can be identified as compressed stabilized earth. The soil type 'laterite' is identified for its special ability to stabilize with a relatively low percentage of cement and is readily available in countries with tropical climatic conditions located closer to the equator such as Sri Lanka, India and Thailand (Jayasinghe and Mallawaarachchi, 2009).



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

Burnt Brick: The brick industry is very old and goes back to about 5000 years. Brick is a ceramic material used in the construction industry. Though it is one of the most important construction materials, energy consumption and pollution are the main disadvantage with respect to environment and cost concerns (Deboucha and Hashim, 2011). The process of manufacturing burnt clay bricks requires high energy to burn. Also, CO₂ gas is emitted as a result of this process and this is a huge environmental problem (Reo and Kannaujiya, 2014). The theoretical amount of energy for this is estimated to be 0.85 MJ/kg of brick (Schilderman, 2007). The production of brick uses firewood as its main source of energy and 1 kg of firewood releases 1.8 kg of CO₂. As the world is already facing an energy crisis, the alternatives to wood such as coal are not cheap either. In any case, these are desperately needed for other purposes including cooking. Hence, there is a need for an alternative way of using soil construction (Reddy and Krishnaiah, 2008).

Stabilized Earth Block: In the search for sustainable green building material, compressed earth stabilized brick has received attention for its low levels of carbon emission, especially in the production stage. Additionally, earth is a local material and

the soil should preferably be extracted from the site itself; if not, the soil should not be transported too far away. Therefore, the compressed stabilized soil block is a cost and energy efficient product (Reo and Kannaujiya, 2014). There is a growing interest in stabilized earth construction material development with respect to energy conscious and ecological design (Deboucha and Hashim, 2011). According to Jayasinghe and Kamaladasa (2007), it is indicated that laterite soil is better than clayey soil for cement stabilization. Amongst the variety of soil stabilizers used, cement has been the most popular stabilizer.

As soil is the basic ingredient of the soil cement block, the properties of the soil greatly affect the strength and durability characteristics of the block. The major ingredients of soil are sand, silt and clay which influence the soil properties and in turn the properties of the soil cement blocks (Reddy and Krishnaiah, 2008). Further, he stated that for a given percentage of cement, there is a range of clay content within which the blocks satisfy the strength requirement. Above and below this range, the strength will be less. The soil cement blocks with 3% of cement satisfy the dry compressive strength requirement only with a clay content of 9%. However, additional admixtures are required in order to increase the wet compressive strength and durability of the soil cement blocks.

Compared to cement, the use of lime as a stabilizer has not found popularity even though lime can be used as a stabilizer especially for clayey soils and were found to have long-term strength gain. However, Reo and Kannaujiya (2014) reported that after an optimum value of lime content, any further increase in lime will not be so beneficial in gaining strength of the blocks.

Any material used for construction should have adequate strength and erosion resistance. These properties can be imparted to the soil by stabilizing it with cementitious admixtures such as cement and lime. The properties of stabilized soil can be further improved by the process of compaction. The process of compaction leads to higher densities, thereby higher compressive strength and better erosion resistance can be achieved. Exploring the stabilization and compaction techniques, a cheap yet strong and durable material for construction is the stabilized pressed block. The merits of this block are: low cost, no requirement for burning or firing, the use of locally available soil as raw material, the ability for bricks to be made at site with no

transportation of blocks, and moreover the simplicity in the manufacturing process with no requirement for special skills.

Sandy soils with 4% cement and also 3% cement, + 2% lime and + 4% fly ash have given satisfactory strengths for making blocks. The strength and durability of soil cement blocks improve as the curing time is increased. Also, higher strengths can be obtained by increasing the percentage of cement. Both compressive and flexural strengths increase with the decrease of the moisture content of the block (Reddy and Krishnaiah, 2008).

The compressive strength of pressed soil blocks increase with the increase in compaction pressure. Also, higher strengths can be obtained by curing the lime soil blocks at higher temperatures for a few hours. There is a steady increase in the wet strength as sand content is increased up to 65%. The dry strength steadily decreases with the increase in sand content, except that there is a small peak at 65% sand content for 5% and 10% cement (Reddy and Krishnaiah, 2008).

The presence of finer particles of clay cause swelling and shrinkage but this can be limited to tolerable levels with quite small quantities. The best soils for cement stabilization are therefore those which have only a small clay content and consist mostly of gravel and sand particles. These soils also tend to be very suitable for mechanical compaction.

Soil stabilization in the broadest sense is the alteration of any property of a soil to improve its engineering performance. The chief factors affecting the quality of soil-cement blocks are soil type, cement content, compaction and method of mixing.

2.6.3 Other materials

Asphalt: One effect of covering streets with dark asphalt surfaces is the increased heating of the city by sunlight (Pomerantz et al., 1997). Halwatura and Jayasinghe (2007) noted that the asphalt-paved road could reach a temperature of 50°C. Immediately after sunset, this asphalt-paved surface remained at 38°C while the ambient temperature is 30°C. At midnight, the road temperature was 5°C higher than the ambient temperature of 25°C. This indicates that asphalt surfaces can act as heated bodies, promoting higher surrounding air temperature during both day and night. Killingsworth Sr et al. (n.d.) measured and studied the temperature of various pavement types during a hot 90°F (32°C) summer day and found that dark asphalt had a temperature of 195°F (90°C) at the material surface and it was 40°F (32°C) hotter than the concrete pavement. Wan et al. (2012) found in their research that the asphalt roads and pavements are able to heat up as high as 60°C and radiate the excess heat back into the environment. Further, they mentioned that dark coloured pavement coating with high albedo, named “*PerfectCool*”, recently developed by NIPPO Corporation Co., Ltd in Japan had a low heat conductivity of 0.252 W/mK (Watts per meter Kelvin) and had a high emissivity value of 0.828. Emissivity is a measure of the efficiency in which a surface emits thermal energy. It is defined as the fraction of energy being emitted relative to that emitted by a thermally black surface (a black body). A black body is a material that is a perfect emitter of heat energy and has an emissivity value of 1 (“Emissivity,” 2016). It was able to reduce peak surface temperatures by up to 5°C and to reduce asphalt surface temperatures to about 38°C. This is a temperature reduction of up to 17°C when compared to a normal asphalt surface without *PerfectCool*. *PerfectCool* was able to prevent a built-up of heat within asphalt roads. This is clearly supported by the low sub-surface temperatures of 34°C which is 16°C lower than that of the asphalt roads.

The albedo value of an asphalt pavement surface is in the range of 5% to 20%, which means that these materials absorb 80% to 95% percent of solar energy (Babić et al., 2012).

Normally, asphalt concrete tends to get lighter as it ages, because the black asphalt wears away to reveal the lighter aggregate. The albedo value measured of an old asphalt pavement is 15% (Pomerantz et al., 1997). However, Erell et al. (2014) stated that by changing surface albedo alone with the application of white paint to dark asphalt, the daily surface temperature can be reduced by a maximum of 7°C. Additionally, Erell et al. (2014) mentioned that fresh asphalt has been observed to reach temperatures as high as 65–70°C at mid-day and may be warmer than the air by as much as 35°C while light-colored paving tiles may be only 5–7°C warmer than the air under the same conditions. Asphalt, which has a lower thermal admittance than concrete, heats up more quickly during daytime and conversely cools down more rapidly at night.

While the colour of the material plays an important role with respect to the thermal characteristics of outdoor pavement surface, dark asphalt is the most unfavourable material when taking into account its thermal characteristics. However dark asphalt converted to light in colour by painting (in white) has more favourable thermal characteristics (Babić et al., 2012). Through the asphalt surface is the most unfavourable in terms of thermal characteristics, it is the most environmentally suitable option to reduce long-term GWP (Mendoza et al., 2012).

The PED and GHG emission of the asphalt sidewalk would be lower than that of concrete slabs and granite. Asphalt sidewalks are chosen for their initial low cost, but they are more susceptible to damage from weather. Therefore, they normally require more maintenance, thus increasing their economic cost over time (Mendoza et al., 2012).

Granite sidewalks: Granite is the natural stone which is most commonly used for exterior paving due to its hardness, durability and aesthetics. Though this material is aesthetically more pleasing than concrete or asphalt sidewalks, their construction cost is normally higher. A granite sidewalk with a top layer has a PED value less than that of an asphalt sidewalk.

The amount of energy required for quarrying and processing is the main contributor to the environmental burden of granite slabs.

The contribution of granite slabs to GWP is also relatively low with regard to its PED. Mendoza et al. (2012) stated that granite is the best solution for outdoor paving as it minimizes both long-term PED and GWP.

2.7 Pedestrian pavements

Pavements are a part of our everyday lives though they are not paid any attention. Pavements currently occupy about twice the area of buildings. Every year, paves or repaves are growing. Moreover a comfortable environment on the pedestrian pavements makes a journey by foot pleasant and enjoyable. However, pedestrians worldwide are facing many problems while using walkways, mostly because the planners and researchers mainly focus on solving the issues of motorized vehicles. Therefore, the pedestrians are neglected with regard to their safety as well as convenience. Nonetheless, currently a lot of achievements have been made with many models and techniques for designing pedestrian ways or sidewalks around the world. Rahaman et al. (2005) claimed the qualitative level of comfort of the pedestrians may be covered by six broad categories of roadside walking environment: safety, security, convenience and comfort, continuity of the walkway, system coherence and attractiveness by some specific facilities.



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

Traditionally, many roads in developing and undeveloped countries are left unpaved. This creates problems throughout the year, in both the rainy and dry seasons. During the rainy season, the roads become waterlogged because there exists little or no provision for adequate surface or subsurface drainage of the roads, and during the dry season dust is raised. It is a major environmental and health hazard (Okunade, 2008). The use of paving blocks would reduce these problems on such roads. Burnt clay brick pavers could be manufactured locally, without complicated technology. A large number of features of the pedestrian environment which has an influence on pedestrian activity and walkability can be identified. According to Kelly et al. (2011), there are three main categories of these features: a) poor quality of pedestrian environment, b) inadequate pedestrian safety, and c) inadequate personal security.

2.8 Summary

Paying close attention to construction materials and equipment is even more important due to the remarkable growth of rate of the population. This large and continuously increasing population of the world lives in cities and share resources disproportionately. In addition, the demand for goods and resources by city inhabitants, both historically and today, changes the natural land by deforestation, developing surface pavements, buildings and drainage patterns etc., and they usually consume large energy resources to be comfortable. Therefore, expansions are usually unsustainable. Construction is not an environmentally friendly process by nature. It is one industry that contributes to environmental pollution.

The sustainability of the outdoor environment is one of the determining factors in the success of a city. Although many researches and experimental data relating to the sustainability of the indoor conditions of buildings are available, very limited information is available relating to outdoor conditions including construction materials used in open urban areas for sustainability.



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

Pavements (including roads, pedestrian walkways etc.) are one of the main hardscapes contributing to the UHI effect and the energy balance of the urban surface. Paving material is the one of main contributors to the phenomenon of the UHI effect.

There are many strategies used to reduce the UHI effect, such as proper design and material selection for roof structures and for pavement surfaces, incorporation of more tree planting and landscaping elements in urban communities and the provision of shade or canopies over pavements etc.

Developing and implementing energy-efficient production methods and equipment, and promoting the use of suitable materials can minimize the negative environmental effects produced by artificial outdoor surfaces.

In the development of new materials, it is first important to understand the researched issues of available construction materials.

Cement based materials are more common in the construction industry. Cement concrete and cement concrete with recycled and waste materials are the two construction materials used.

Cement concrete blocks were used in the 1940s to supplement lawns, making them capable of supporting traffic. Plastic grids used for the same purpose were created in the late 1970s and early 1980s. Concrete sidewalks are the most common type worldwide because they are considered consistent, durable and economic.

Some of the major consequences of the rapid growth of population, economics and industrialization are the vast use of natural resources and huge generation of solid wastes and by-product materials.

Soil is another construction material. Construction with earth is one ancient technology which still remains alive. Even though earth is an ancient construction material, composition of the earth varies drastically around the world because of climatic conditions.

Brick is one of the most popular materials for construction in many countries due to its valuable properties such as durability, relatively low cost, availability, sound and heat insulation, acceptable fire resistance, adequate resistance to weathering and attractive appearance.

In the search for sustainable green building material, compressed earth stabilized brick has received attention for its low carbon emission, especially in the production stage.

Therefore, compressed stabilized soil block is a cost and energy efficient product. There is a growing interest in stabilized earth construction material development with respect to energy conscious and ecological design.

A comfortable environment on the pedestrian pavements makes a journey by foot pleasant and enjoyable. Considerable achievements have been made in this respect with many models and techniques for designing pedestrian walkways around the world. Nevertheless, it seems that further attention is warranted during design and planning, and also in research to address the issues of pedestrians' safety as well as convenience in our cities.

Zee (1990) defines recreation as “refreshment of body and mind by activities, or a planned inactivity, undertaken because one wants to do it, without any moral, economical, social or other pressure”. Parks and recreation areas are perceived as especially important in urban areas to promote human health and wellness (Garcia et al., 2003).



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

Chapter 3

3 Opinion Survey

3.1 Methodology

A questionnaire survey is one of the many methods which may help to understand how persons responds to outdoor development (Kelly et al., 2011). An on-line questionnaire prepared on the 'Survey Monkey' platform was employed to elicit the user perceptions on the research objectives. It is particularly designed to understand, (a) the user perceptions on the requirement of pedestrian walkways along the roads and on the importance of having better visual identification between pedestrian walkway and the traffic pathway (b) the preferred material for pedestrian walkways and for recreational areas. Annex 1 show the format used for the opinion survey.

The data obtained through this questionnaire survey was statistically analyzed using the Chi-Square test for the following null hypotheses.

- a) H_{01} : The public preference to have a separate walkway along roads has no association with whether a person is a pedestrian or a driver.
- b) H_{02} : The public preference to have visual separation between walkways and roads has no association with whether a person is a pedestrian or a driver.
- c) H_{03} : The public preference to have separate areas for recreation is not gender specific.

Further, five pavement construction materials (three artificial - Asphalt, Concrete, Clay Brick; and two natural - Soil, Turf) commonly used in Sri Lanka were selected to obtain public preferences. The preferences of the surveyed sample were analyzed using percentage plots and with the following two null hypotheses tested using Chi-square analysis to draw conclusions.

a) H_{04} : The public preference on paving material on walkways has no association with the gender.

b) H_{05} : The public preference on paving material on walkways has no association with experience as a pedestrian or a driver.

In the development of a better pavement material, thermal characteristics play an important role. The comfort of a pavement is impacted by its heat emission which is indicated by temperatures.

3.2 Results & Discussion

149 persons responded to the online survey, leading to a response rate of 42%. Of this, 5 responses were discarded as they had failed to respond to all the important questions other than demographic questions. The investigation deliberately focused on main cities in Sri Lanka such as Colombo, Gampaha, Kandy, Galle and Kurunegala. The respondent sample consisted of both males and females in a ratio of 71% : 29%. The respondents were categorised into five age groups and the majority (84%) was from age group 20-30 years (Figure 2).



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

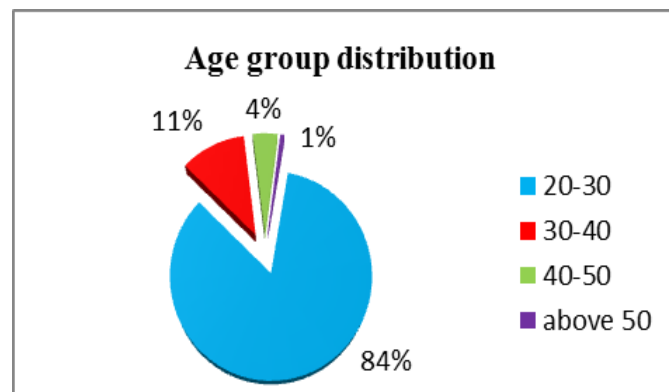


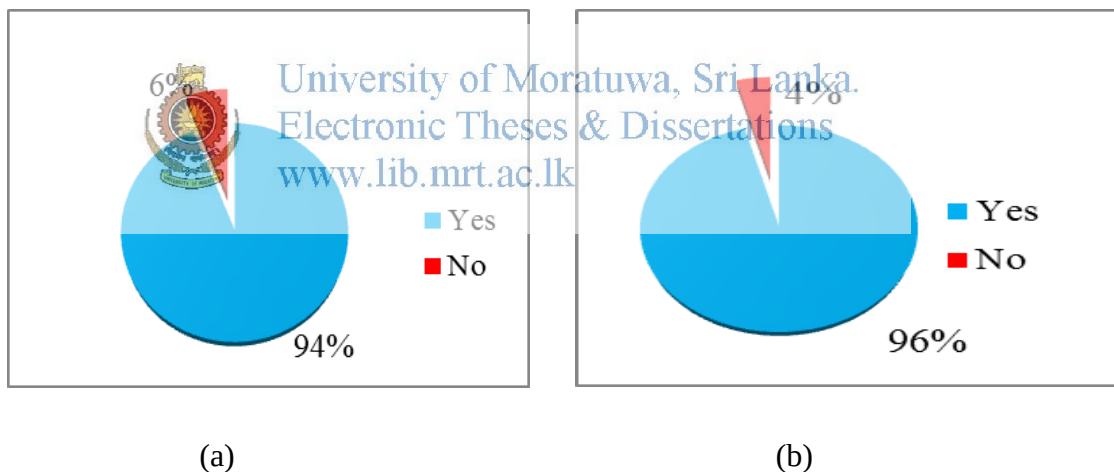
Figure 2 : Percentage distribution of the sample's age groups

The respondents had varying degrees of professional and educational qualifications; 52% were employed and the others were students at tertiary level. The professional roles of employed respondents included engineers, medical officers, nurses and teachers. Their experiences on the road were three fold: (a) only as pedestrians, (b)

only as drivers and (c) with both experiences. For the purposes of this study, the respondents were divided into two groups; those who possess driving experience and those who possess only pedestrian experience. The ratio of these two groups was 36% (52): 64% (92) respectively.

3.2.1 Public preferences for separate walkways, their visual separation and separate recreation areas

Responses were sought to elicit the preference for having separate pedestrian walkways along the road and the preference for having visual identification between the walkway and the traffic path (road). The analysed results shown in Figures 3(a) and 3(b) indicate that 94% of respondents are in favour of having separate pedestrian walkways and 96% of them wish to have visual identification between the pedestrian walkway and the vehicle path.



(a) Separate walkway along the road
(b) Visual identification between walkway and traffic path

Figure 3: Respondents preferences on walkways

The three null hypotheses H_{01} , H_{02} and H_{03} formed from the public preference were tested using Chi-square tests for the respective data given in Tables 1 to 3. The Chi-square statistics are shown below each table.

Hypothesis 1

H₀₁: The public preference to have a separate walkway along roads has no association with whether a person is a pedestrian or a driver.

H₁₁: The public preference to have a separate walkway along roads has an association with whether a person is a pedestrian or a driver.

Table 1 : Association of public preference to have separate walkways with experience as drivers / pedestrians

Perception use \ Road	Driver	Pedestrian	Total
Separation required	51	87	138
Separation not required	1	5	6
Total	52	92	144

Chi-Sq = 1.026, DF = 1, P-Value = 0.314

Hypothesis 2

H₀₂: The public preference to have visual separation between walkways and roads has no association with whether a person is a pedestrian or a driver.

H₁₂: The public preference to have visual separation between walkways and roads has an association with whether a person is a pedestrian or a driver.

Table 2 : Association of public preference to have visual separation between walkways and roads with the experience as drivers / pedestrians

Perception use \ Road	Driver	Pedestrian	Total
Visual Separation required	51	89	140
Visual Separation not required	1	3	4
Total	52	92	144

Chi-Sq = 0.220, DF = 1, P-Value = 0.639

Hypothesis 3

H₀₃: The public preference to have separate areas for recreation is not gender specific.

H₁₃: The public preference to have separate areas for recreation is gender specific.

Table 3 : Association of public preference to have separate recreation areas with gender

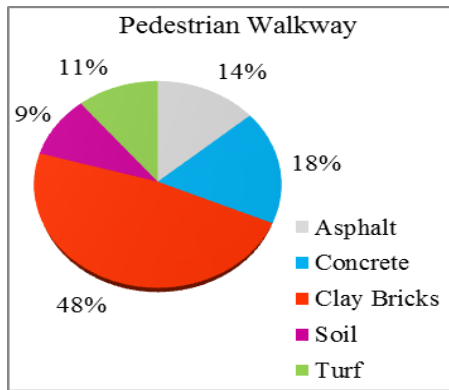
Gender	Recreation Area		Total
	Required	Not required	
Male	88	8	96
Female	40	2	42
Total	128	10	138

Chi-Sq = 0.554, DF = 1, P-Value = 0.456

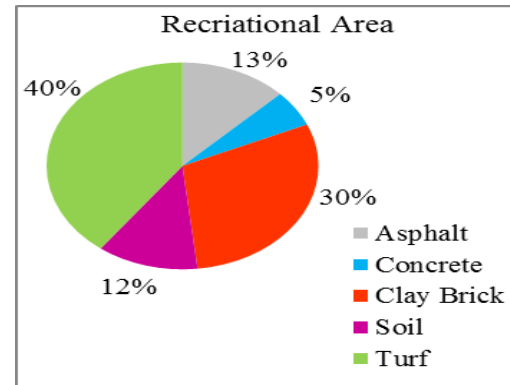
For all tests, the Chi-square values (1.026, 0.220, and 0.554) are less than the table value of Chi-square statistic for degree of freedom 1, (3.84) at 95% levels of confidence and show no evidence to reject the null hypotheses.

3.2.2 Public preferences on materials for walkways

An important aspect of this survey was to obtain responses to understand the preferences for five different materials which are used for pedestrian walkways and in recreational areas, viz.: asphalts, concrete, clay brick, soil and turf. Responses were elicited by requesting respondents to rank the five materials in their order of preference based on the materials' suitability as a paving material, first for pedestrian walkways and second in recreational areas. The first preferences converted to percentages are illustrated in Figures 4(a) and 4(b) and the Weighted Average Scores (WAS) for the five materials are given in Figures 5(a) and 5(b).

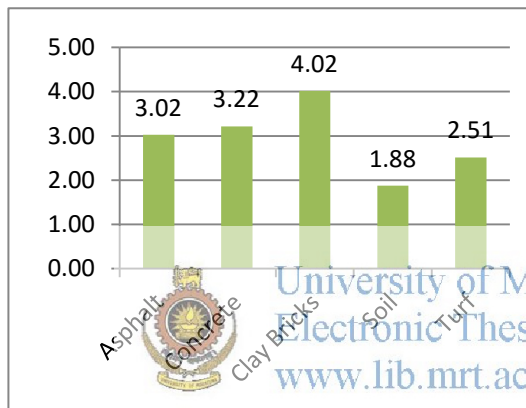


(a) Materials for walkways

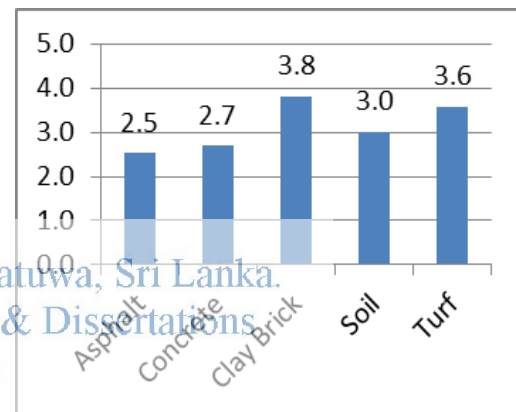


(b) Materials for recreational areas

Figure 4 : Preferred material for walkways and recreational areas



(a) Materials for walkways



(b) Materials for recreational areas

Figure 5 : Weighted Average preference for paving materials

The survey found that clay brick was the highest preferred material with 48% of the respondents placing it as their first choice for pedestrian walkways, followed by concrete, asphalt and turf respectively. In contrast, in the case of recreational areas, 40% voted for turf followed by 30% for clay bricks. Asphalt, soil and concrete were received less than 13% of votes as a preferred paving material. Even when the next best alternatives were considered, the highest preferred material was clay brick (WAS = 4.02) and soil was the least preferred material (WAS = 1.88) for the walkways on pavements. However, the preferences for recreational areas showed a remarkable difference where clay bricks, turf and soil were preferred over concrete and asphalt. Further analyses were made to understand the association of gender and road use

experience on the public preferences of paving material by testing the two null hypotheses H_{04} and H_{05} for the data presented in Tables 4 and 5.

Hypothesis 4

H_{04} : The public preference on paving material on walkways has no association with gender.

H_{14} : The public preference on paving material on walkways has an association with gender.

Table 4: Association of gender with public preference on paving materials

Gender	Material					
	Asphalt	Concrete	Clay Brick	Soil	Turf	Total
Male	15	14	49	10	15	105
Female	5	12	19	4	1	41
Total	20	26	70	14	16	146

Chi-Sq = 7.999, DF = 4, P-Value = 0.092

Hypothesis 5

H_{05} : The public preference on paving material on walkways has no association with the respondents' experience as a pedestrian or a driver.

H_{15} : The public preference on paving material on walkways has an association with the respondents' experience as a pedestrian or a driver.

Table 5 : Association of road experience with public preference on material

Road Experience	Material					
	Asphalt	Concrete	Clay Brick	Soil	Turf	Total
Driver	9	4	28	5	6	52
Pedestrian	11	22	40	9	10	93
Total	20	26	69	14	16	145

Chi-Sq = 6.297, DF = 4, P-Value = 0.178

In both tests, the Chi-square values (7.999 and 6.297) are less than the Table Value of Chi-square statistic for degree of freedom 4, (9.49) at 95% levels of confidence and show no evidence to reject the null hypotheses.



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

3.3 Summary

The online survey responses and their analyses lead to a number of important findings. The first important findings are the Chi-square test results which established that separate pedestrian walkways are preferred by the public irrespective of their experiences as pedestrians or drivers. Secondly, it is also established that the public preference is to have visual separation between pedestrian walkways and roads irrespective of their experiences as pedestrians or drivers. Thirdly, it is shown that separate recreation areas are preferred by public irrespective of their gender. These three findings emphasize the importance placed by the public on separate pedestrian walkways with visual separations as well as separate recreation areas, irrespective of their experiences or gender. Such importance placed by the public warrants investigating into new sustainable and efficient materials for constructing walkways and recreation areas.

The public perceptions received through the opinion survey clearly showed the low preference given to soil, asphalt and concrete as construction materials for both walkways and recreation areas. Turf received mixed preferences with a low preference for walking and a high preference in recreation. In contrast, clay bricks have received the first and the second preferences in both areas indicating any new material developed need to either be based on clay bricks or should closely emulate the positive characteristics of clay bricks.

Chapter 4

4 Experimental work

4.1 General

One possible approach towards more sustainable construction is to promote the use of alternative, low-energy and renewable material such as earth. Therefore the main goal of this research is to create a new soil based material to produce paving blocks as a replacement for existing unnatural paving and to evaluate their thermal performance compared to existing paving systems. Though soil is a natural and locally available resource, all soils are not suitable for construction 'as it is' because soil itself does not have the required strength and durability. Therefore, it has to be strengthened by adding some other stabilizer. One of the methods of stabilization is to compact the soil to reduce the voids in the finished block. Further, soil products can be strengthened by the addition of chemical stabilizers which help bind the particles together. There are many chemical stabilizers used in the industry; cement is the most popular stabilizer among them. Though cement is more common, lime, bitumen, gypsum, alkalis, sodium chloride, calcium chloride, aluminium compounds, silicates, resins, ammonium compounds, polymers and agricultural and industrial wastes are also used as stabilizers in the industry. For this research, Portland cement was used as stabilizer to produce a new soil based paving block, viz.: a mud concrete paving block.

The mud concrete paving block is a combination of soil and Portland cement that are mixed together with the addition of water. Therefore, the main scope of this research is to find the best ratio of the soil - cement combination in order to produce a mud concrete paving block for pedestrian pavements.

4.2 Field survey

4.2.1 Methodology

A field survey for identifying proper mix designs was carried out as an approach to the laboratory experimental work. Data were collected to identify the use of materials and demand for blocks from the cement concrete paving block manufactures as the cement concrete block is the most commonly used pedestrian pavement material in Sri Lanka. The main focus of this investigation was to know the cement percentage used for manufacturing cement concrete paving blocks. Cement concrete paving block manufacturers were interviewed for this investigation. The detail formats used in the field survey are shown in Annex 2.

4.2.2 Results

Cement concrete block manufacturers at four different places were investigated. The data collected in the field investigation are summarized in Table 6. It was found that all the manufactures have used more than 30% cement in their block manufacturing process.

Table 6 : Cement concrete paving block manufacturing data

		Manufacturer			
		A	B	C	D
Material (by percentage)	Course aggregate	21	27	30	25
	Fine aggregate	79	73	70	75
	Cement	33	40.5	30	35

4.3 Laboratory experiments for mix design

4.3.1 Soil Tests

The suitability of soil as a construction material depends on its constituent (i.e. gravel, sand, silt and clay proportions of the soil). Too much clay will cause cracks and too much sand will cause the blocks to crumble (Nehdi, 2014). Since the main objective of this research is to innovate new soil based construction material for outdoor development in Sri Lanka, it is very essential to explore the constituents of available soil. Therefore in this research two laboratory tests are conducted to determine the constituent of the soil. These tests are expected to present a preliminary picture of the properties and constituents of soil to be used in producing mud concrete paving block. The two tests are the sedimentation test and the dry sieve analysis.

Sedimentation Test Procedure: A transparent cylindrical jar of 0.5 litre capacity is filled with soil and water to an approximate ratio of 1/4 : 3/4. It was shaken well with the top sealed by placing a hand on it. It was then left to stand for one day after which the sedimentation layers were observed for the relative proportions. Hence, percentages of each fraction can be determined by measuring the depth of each layer.

In the sedimentation test, gravel was deposited at the bottom followed by sand, silt and clay at the top. The depth of each layer gives an indication of the proportion of each type of material. These proportions are only approximate: the layer of gravel, which contains many voids, seemed relatively "deep" compared to that of clay, which has very few voids. After one day, it was observed that the soil used for the experiment contained approximately 22% fine particles, 28% sand and 50% gravel.

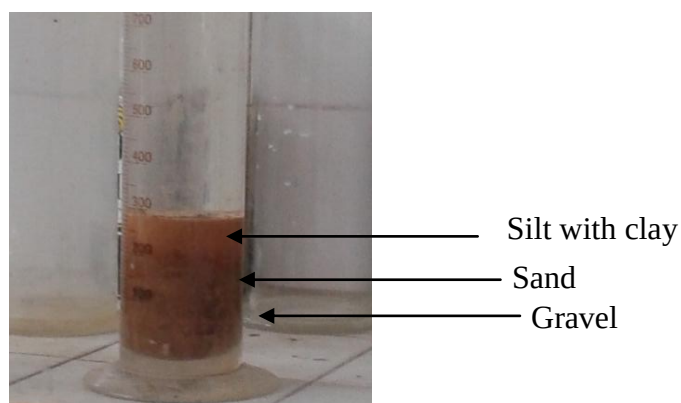


Figure 6 : Sedimentation layers

Sieve Analysis Procedure: First, a 1 kilogram sample of the soil that is used for the casting process was thoroughly mixed. All the sieves were well cleaned and arranged in descending order. Then the soil sample was placed on the top sieve and the test sieves were agitated so that the sample rolled in an irregular motion over the test sieves. Particles may be hand placed to see if they will fall through but they are not to be pushed through. Care was taken so that only the individual particles were retained. The soil amount retained on the test sieves was weighed, of which the total should be within 0.1% of the total soil mass.

Sieve analysis was done for two samples collected arbitrarily for the casting process. Table 7 and Figure 7 show the results which were obtained.

Table 7 : Sieve analysis

Sieve size in mm	Percentage passing	
	Sample A	Sample B
4.75	60.10	59.10
2.36	50.60	48.80
1.18	32.10	28.90
0.60	15.00	13.30
0.43	9.50	9.10
0.30	5.40	5.50
0.15	1.20	2.10
0.08	0.70	1.00

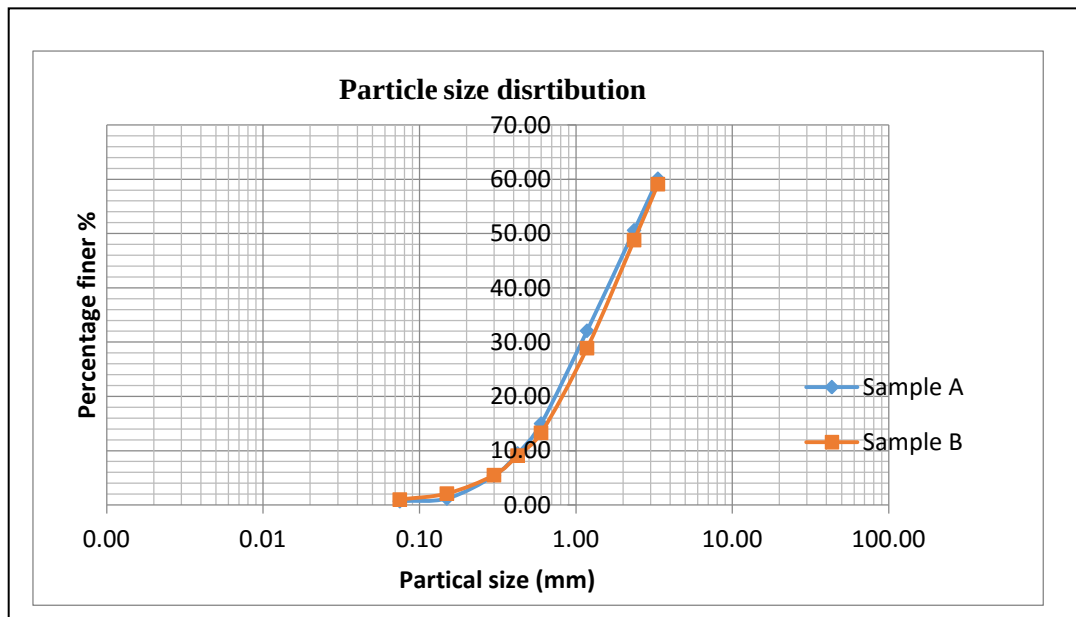


Figure 7 : Particle size distribution



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

4.3.2 Production of Mud Concrete Paving Block

According to the SLS 1425 PART I: 2011, the average compressive strength required for a pedestrian pavement (i.e. strength class 04 of concrete paving block) is 15 N/mm². The main aim of developing a mud concrete paving block in this research is to achieve a paving material of the required strength according to SLS 1425. In the laboratory, blocks are tested for the following four variables.

Cement Content: Based on literature (Reo and Kannaujiya, 2014) and field investigation results, the starting cement percentage is desired to be known. The cement used in this research was Portland cement. Several literature reported that the wet compressive strengths were 1.32 N/mm², and 1.97 N/mm² for 3.5% and 7% cement respectively (Reddy and Krishnaiah, 2008). In order to have the minimum required wet compressive strength (i.e. 15 N/mm²) and to be economical, 18% cement was taken as stabilizer at the initial stage.

Water content: For the compressed stabilized cement blocks, the optimum moisture content is 14%. (Reddy and Krishnaiah, 2008). Based on this water content value, samples were cast for three different moisture contents.



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

Compaction pattern: The compaction effect used in this experiment series is the application of vibration. Three different vibration patterns were applied, viz.: no vibration (i.e. zero vibration), vibration for 15 second duration and vibration for 30 second duration. The vibration was applied using an electrically operated vibration table.

Soil composition: According to the soil investigation results, the native soil contained fine particles (i.e. particle size in 0.002 to 0.06 mm) in the range of 10% to 05%. Therefore, two marginal fine particle values (i.e. 10 % and 05%) are selected for the initial casting.

Stage One

In this stage, the cement percentage of the mud concrete paving block mix was kept constant and the cast blocks were tested for wet compressive strength by systematically varying the other three variables mentioned above.

The first variable was the soil composition where the sand content was varied in 10% increments on a range of values (40% to 70%) for fixed fine particle contents. Here two fine particle contents were selected; 10% and 5%. The results obtained for 10% fine particles helped with deciding the sample mix proportions for the 5% fine particle mix. Selected percentages of sand and gravel for the four mixes are shown in Table 8. Each mix was then added with three different moisture contents to cast test cubes of 70 mm x 70 mm x 70 mm. The test cubes were then compacted under the three different compaction methods described above. The process of casting blocks by varying the soil composition, moisture content and the compaction effect is shown in Figure 8.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations

www.lib.mru.ac.lk

Table 8 : Selected soil composition for 10% fine particles

Mix No	Sand %	Gravel %
1	70	20
2	60	30
3	50	40
4	40	50

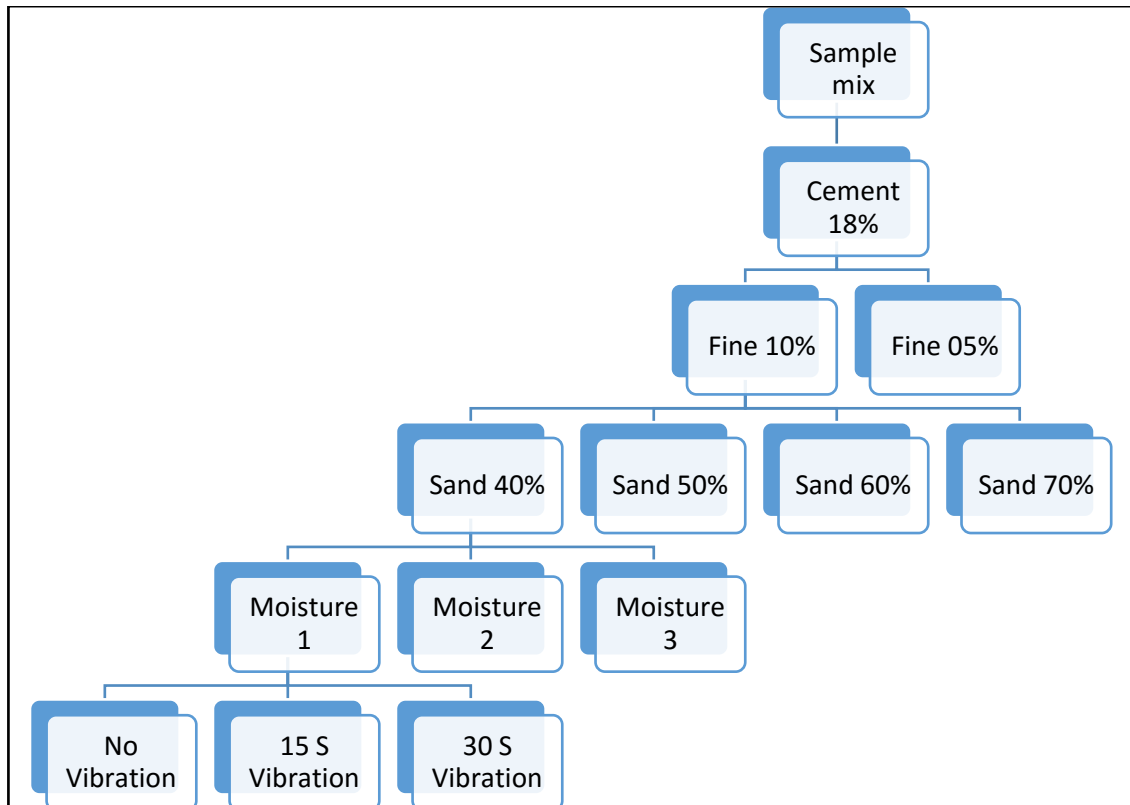


Figure 8 : The sample selection pattern for casting test cubes in Stage One



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

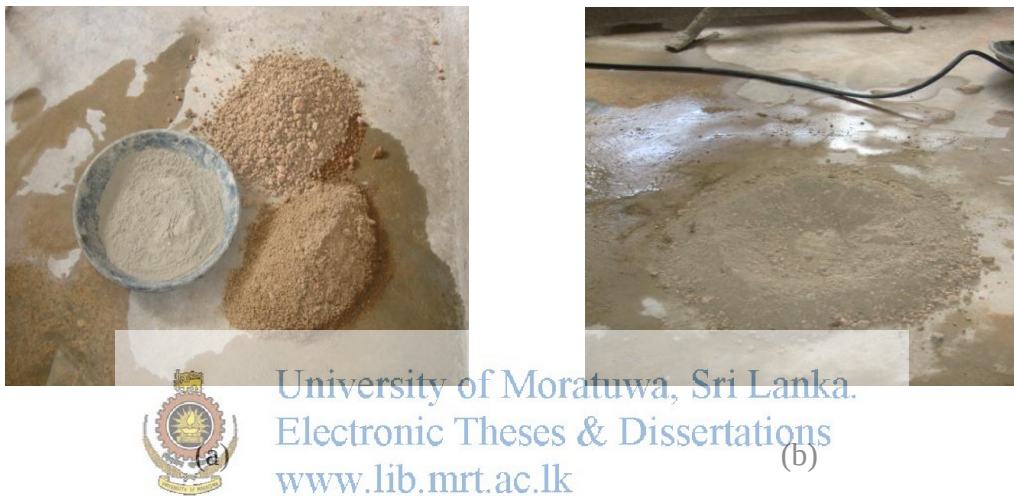
Preparation of soil mix and test cubes: Soil samples were obtained from the university premises from homogenous layers 150 mm below the top of soil to make sure that organic matter is not included in the sample. Soil contains various sizes of grain, from very fine dust up to pieces that are still too large to use in the construction of blocks. The oversized soil particles were removed using a 20 mm sieve.

The composition of existing soil used in this experiment series was taken according to the sedimentation test and sieve analysis. Soil was then modified by adding or deducting sand and gravel to achieve the required composition ratios of fine particles, sand and gravel mention in the above Table 8. 10 Kg of dry soil is then measured to cast 12 test cubes of size 70 mm x 70 mm x 70 mm for each trial mix following the procedure given in Figure 8.

The prepared dry soil mix was thoroughly mixed manually. Then 18% cement (by weight) from the total dry soil mix was spread on the surface and mixed again. Then a

volume of water measured to have the required moisture content was added little by little while mixing thoroughly in order to have a uniformly wet soil mix.

The prepared wet soil mix was poured in to the prepared moulds by applying mould oil in two layers and cast by applying the above mention compaction pattern using the vibration table. Samples from the prepared wet soil mix were kept for 24 hours in the oven to calculate the moisture content. After 24 hours from the time of casting, the cubes were de-moulded and the test cubes were kept 28 days under proper curing. Figure 9 shows the prepared dry soil cement mix.



(a) Weight dry material, (b) Dry materials after mixing

Figure 9: Dry soil cement mix

Figure 10 shows the wet mud concrete mix ready to be poured in to moulds, and the moulds prepared by applying mould oil on the vibration table.



(a)



(b)

(a) Wet mud concrete mix (b) Prepared steel moulds

Figure 10: Wet mud concrete mix ready to be poured in to moulds, and prepared moulds

Figure 11 shows the cast cubes, demoulded cubes and mud concrete test cubes soaked in water



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



(a)



(b)



(c)

(a) Cast cubes (b) Demoulded cubes (c) Cubes soaked in water

Figure 11 : Mud concrete test cubes

Wet compressive strength test: After 28 days, the test cubes were soaked in water for 24 hours and tested in the compressive strength testing machine for wet compressive strength.

Figure 12 shows the cubes ready to be tested in the compressive strength testing machine and the cracked pattern after being tested.



(a)  University of Moratuwa, Sri Lanka. Electronic Theses & Dissertations (b)
www.lib.mrt.ac.lk
(a) Cube in the testing machine for the test (b) Crack pattern after testing

Figure 12: Compressive strength test

Results obtained from the wet compressive strength test in step one, casting for mix with 10% fine particles, is tabulated in Table 9. This was used to plot graphs in order to evaluate the variation of wet strength with moisture content and the variation of wet strength with vibration effect (see Figure 13).

Table 9 : Average wet compressive strength for clay containing 10% fine particles

Sand	Gravel	Moisture %	Average Wet Compressive Strength (N/mm ²)		
			NO vib	15s	30s
70	20	12.04	5.7	2.7	4.8
		14.10	7.8	7.1	10.8
		15.64	5.9	7.2	7.2
60	30	10.30	2.8	1.4	1.9
		13.90	11.2	10.8	11.2
		14.80	12.8	10.6	12.5
50	40	12.73	4.6	2.6	8.0
		13.54	9.7	9.7	10.9
		14.24	11.8	13.5	11.2
40	50	14.22	6.1	7.0	8.2
		15.15	7.4	8.6	7.8
		16.39	6.1	6.5	5.2

Figure 13 shows the variation of wet compressive strength with the moisture content for the proportion of sand 70%, gravel 20% and clay 10% (Mix No.1, Table 8). According to the results obtained, the best wet compressive strength values were shown when the moisture content was between 14% and 15% for all three different vibration patterns. The maximum wet compressive strength value reached up to 10.8 N/mm² for this mix proportion with the 14.1% moisture and 30s vibration.

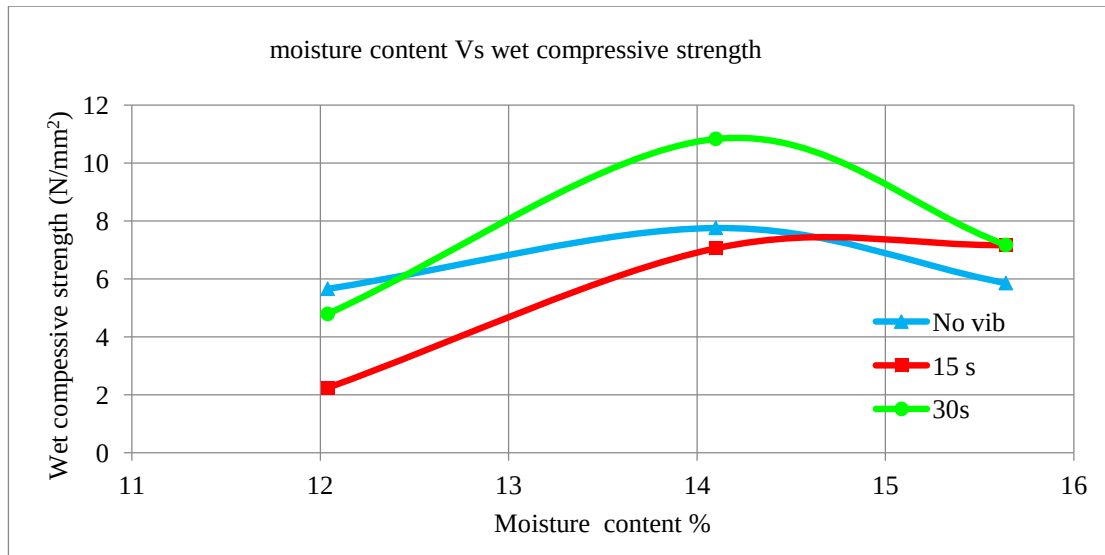


Figure 13 : Variation of wet compressive strength with the moisture content for mix No. 1

Figure 14 shows the variation of wet compressive strength with the moisture content for the mix proportion of sand 60%, gravel 30% and clay 10% (Mix No. 2, Table 8). According to the results obtained, the best wet compressive strength values were shown when the moisture content was between 14% and 16% for all three different vibration patterns. The maximum wet compressive strength value reached up to 12.8 N/mm² for this mix proportion with 14.8% moisture and without vibration.

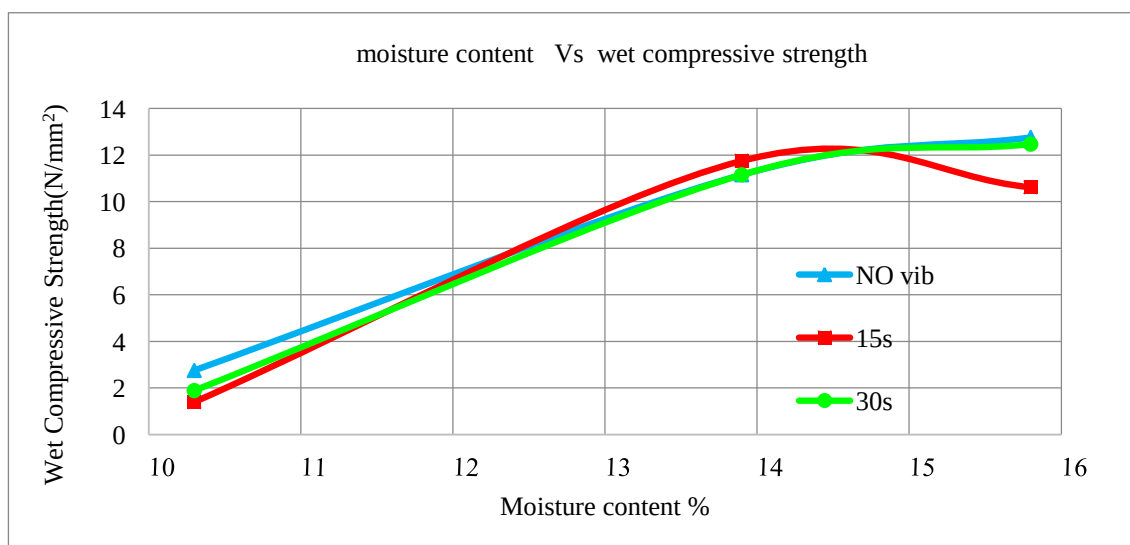


Figure 14: Variation of wet compressive strength with the moisture content for mix No. 2.

Figure 15 shows the variation of wet compressive strength with the moisture content for the mix proportion of sand 40%, gravel 50% and clay 10% (mix No.4, Table 8). According to the results obtained, the best wet compressive strength values were shown when the moisture content was between 15.5% and 16.5% for all three different vibration patterns. The maximum strength value reached up to 8.6 N/mm² for this mix proportion with the 15.15% moisture and 15s vibration effort.

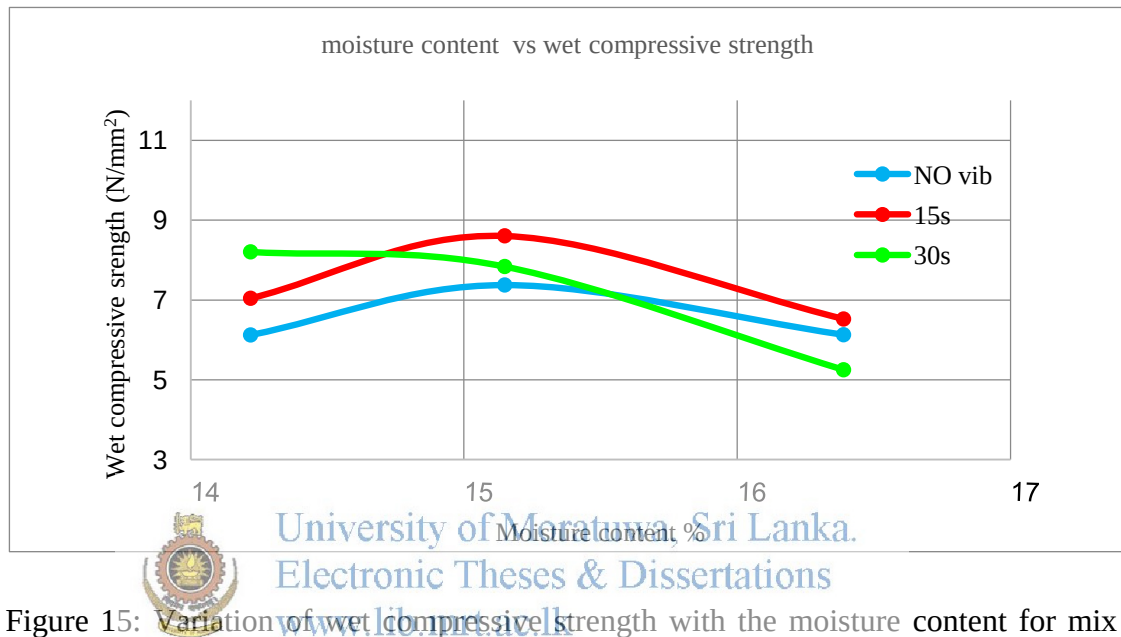


Figure 15: Variation of wet compressive strength with the moisture content for mix No. 4.

Figure 16 shows the variation of wet compressive strength with the vibration pattern for mix No.1. According to the results obtained, the wet compressive strength decreased from no vibration up to 15s vibration, and then it increased for the 30s vibration effort for the moisture content values of 12.04% and 14.10%. When the moisture content goes up to 15.64%, the wet compressive strength increased from no vibration up to 15s vibration, and then it decreased for the 30s vibration effort.

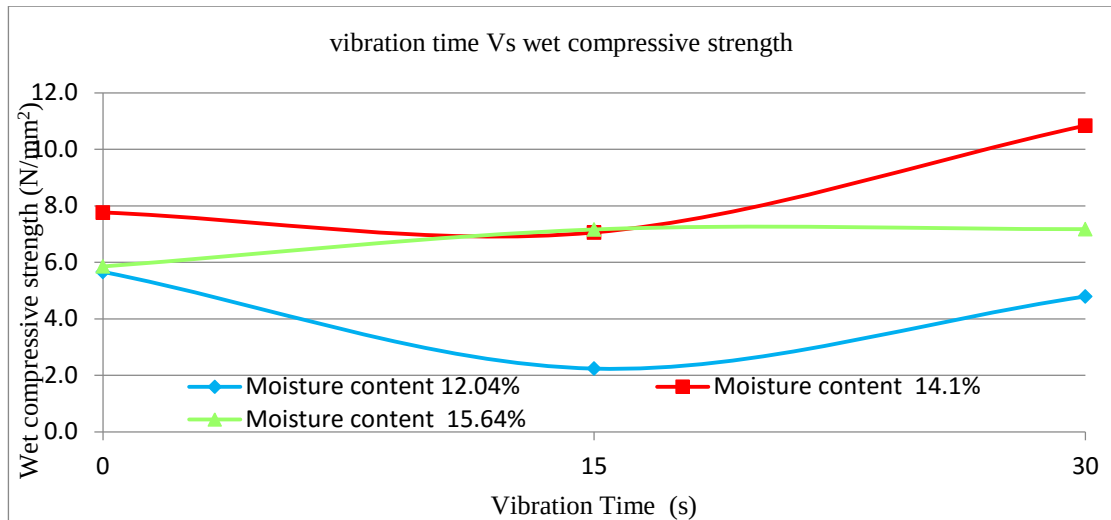


Figure 16 : Variation of wet compressive strength with the vibration pattern for mix No. 1

Figure 17 shows the variation of wet compressive strength with the vibration pattern for mix No. 2. According to the results obtained, the wet compressive strength decreased from no vibration up to 15s vibration, and then it increased for the 30s vibration effort, for the moisture content values of 10.3% and 15.8%. When the moisture content was 13.9%, the wet compressive strength increased from no vibration up to 15s vibration, and then it decreased for the 30s vibration effort.

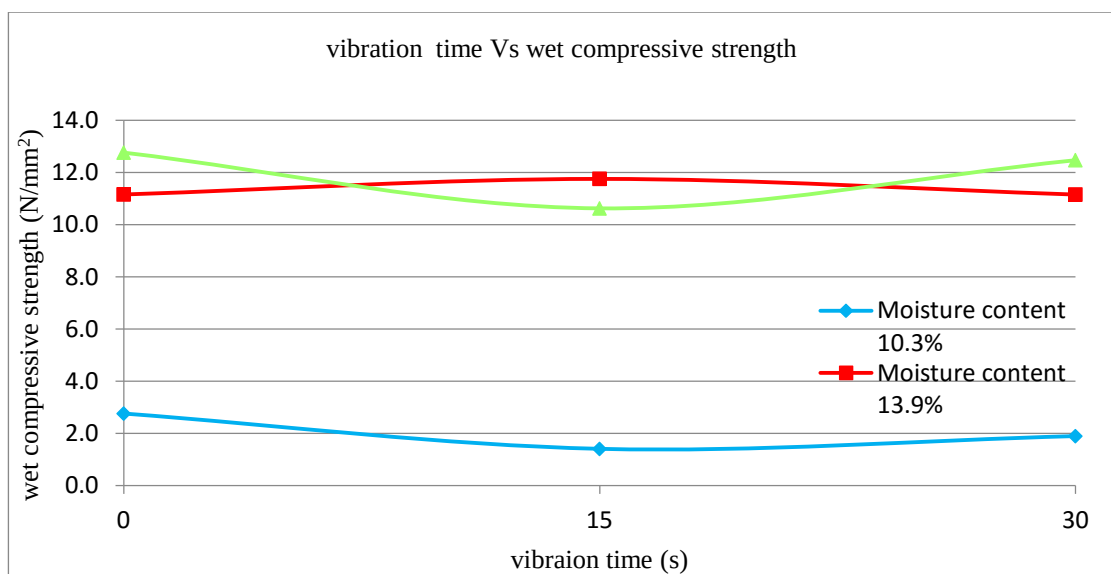


Figure 17: Variation of wet compressive strength with the vibration pattern for mix No. 2

Figure 18 shows the variation of wet compressive strength with the vibration pattern for mix No. 3. According to the results obtained, wet compressive strength decreased from no vibration up to 15s vibration, and then it increased for the 30s vibration effort for the moisture content values of 12.73% and 13.54%. When the moisture content went up to 14.24%, the wet compressive strength increased from no vibration up to 15s vibration, and then it decreased for the 30s vibration effort.

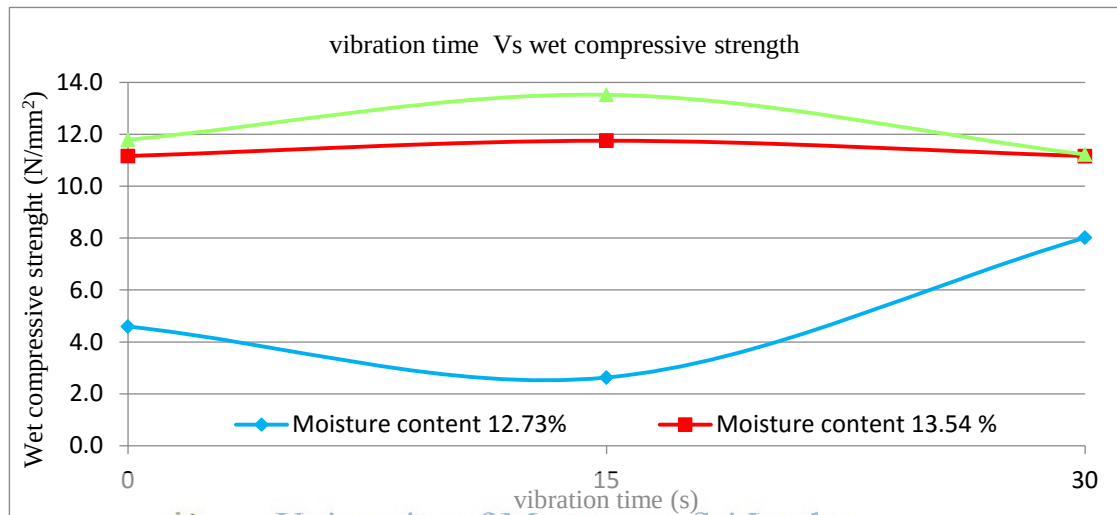


Figure 18: Variation of wet compressive strength with the vibration pattern for mix No. 3

Figure 19 shows the variation of wet compressive strength with the vibration pattern for mix No. 4. According to results obtained, the wet compressive strength increased from no vibration up to 15s vibration, and then it decreased for the 30s vibration effort for moisture content values of 15.15% and 16.39%. When the moisture content is 14.22%, the wet compressive strength increased from no vibration up to 30s vibration.

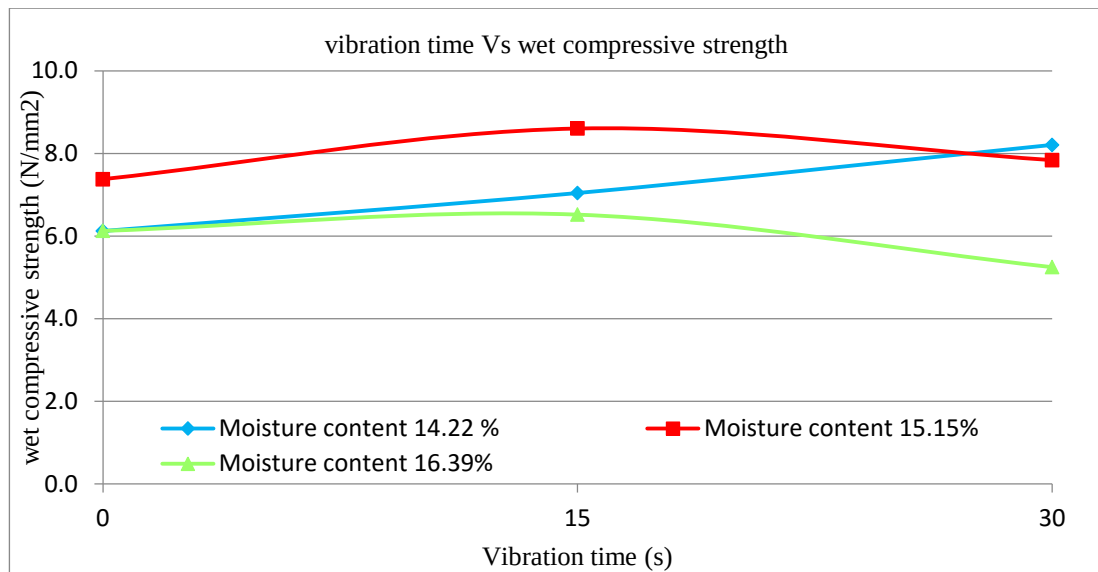


Figure 19: Variation of wet compressive strength with the vibration pattern for mix No. 4

According to the analysis, it can be concluded that the maximum wet compressive strength was achieved when the moisture content was between 13 % and 15%. It was also found that the changing vibration time does not show a significant effect on the strength of the blocks.



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

Therefore within this moisture content range, samples were cast for 5% fine particle content and for a sand content of 60%, which was the sand content which showed a maximum wet compressive strength (i.e. 12.8 N/mm²) without vibration in the Stage One analysis, in order to identify the behaviour of strength with the variation of fine particle content. Soil composition selection for fine particle at 5% is shown in Table 10 and the results were tabulated in Table 11.

Table 10 : Soil composition for fine 5%

Mix No	Sand %	Gravel %
5	65	30
6	60	35

Table 11 : Wet compressive strength for fine 5%

Sand	Gravel	Moisture %	Average Wet Compressive Strength (N/mm ²)		
			No vib	15s	30s
65	30	12.72	5.8	6.6	7.4
		14.8	11.5	10.5	10.1
		15.2	10.2	8.0	9.9
60	35	13.5	10.7	11.0	9.2
		14.2	13.0	11.1	12.3
		15.06	13.7	7.0	7.2

Figure 20 shows the variation of wet compressive strength with the moisture contents for mix No. 5. According to the results obtained, the best wet compressive strength values were shown when the moisture content was between 14% and 15% for all three different vibration patterns. The maximum strength value reached up to 11.5 N/mm² for this mix proportion with the 14.8% moisture content and without vibration effort.

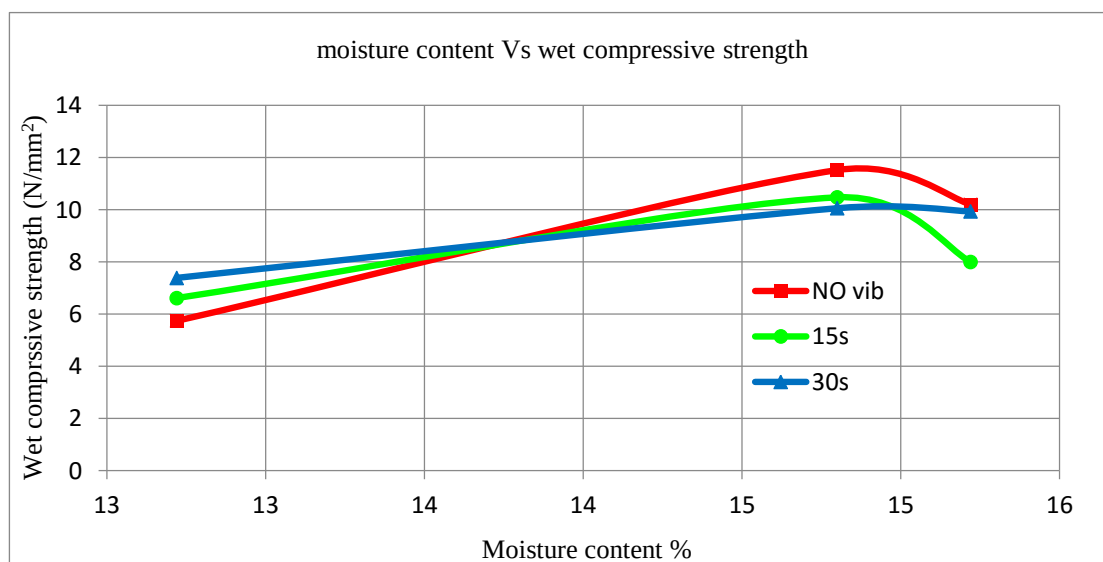


Figure 20: Variation of wet compressive strength with the moisture content for mix No. 5

Figure 21 shows the variation of wet compressive strength with the moisture content for mix No. 6. According to the results obtained, the best wet compressive strength values were shown when the moisture content was between 14% and 15% for all three different vibration patterns. The maximum strength value reached up to 13.7 N/mm² for this mix proportion with 15.06% moisture and without vibration.

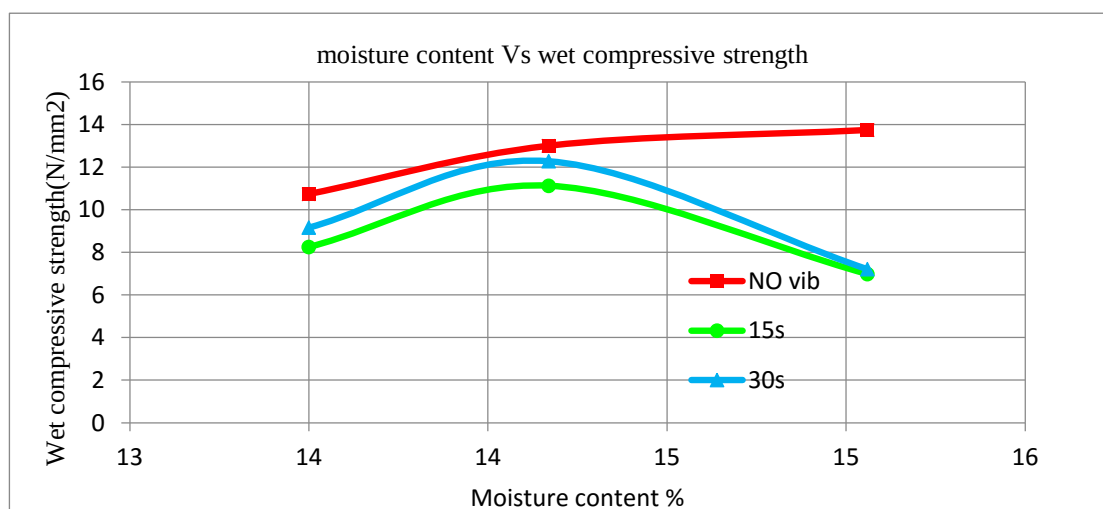


Figure 21 : Variation of wet compressive strength with the moisture content for mix No. 6.



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

According to these results it can be concluded that for the mud concrete paving block, 5% clay content showed better strength than that of 10%. Further, a maximum strength of 13.7 N/mm² was achieved when the sand content was 60%.

The same results with sand content at 60% were plotted in support of a better conclusion for the behaviour of a mud concrete paving block's strength with vibration pattern. Table 12 shows the summarized wet compressive strength values and Figure 22 shows the variation of wet strength with vibration pattern.

Table 12 : Summarized wet compressive strength

Moisture Content	Wet Compressive Strength (N/mm ²)		
	No vib.	15 s	30s
Clay 5% (Mix No. 6)			
14.17	13.0	11.1	12.3
13.5	13.7	11.0	10.2
Clay 10% (Mix No. 2)			
13.90	11.2	10.8	11.2
14.80	12.8	10.6	12.5



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

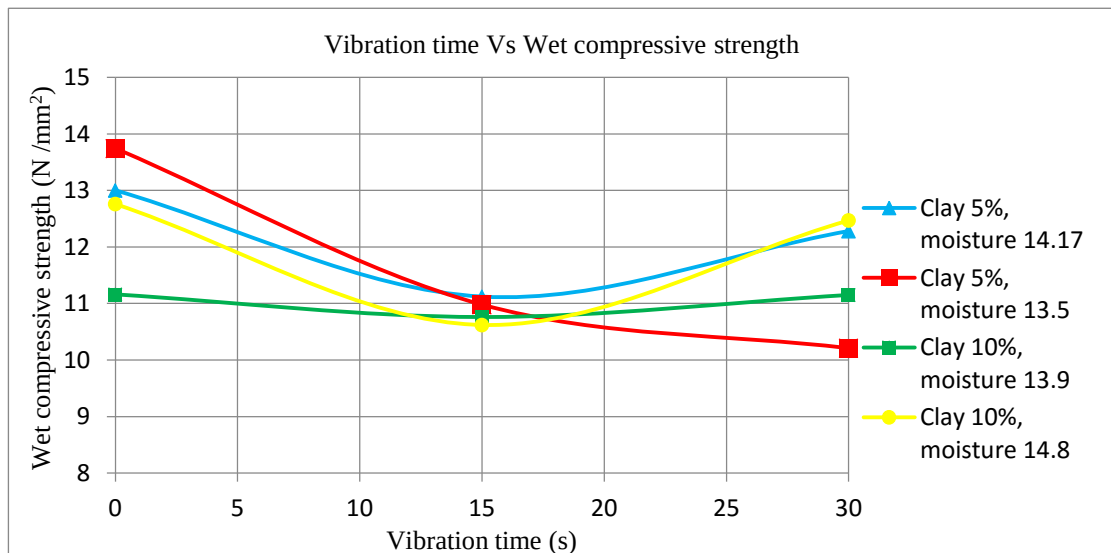


Figure 22 : Variation of wet compressive strength with vibration time for mix No.2 & No. 6

It was proven that the strength of mud concrete paving blocks can be achieved without applying vibration. With all the obtained results, it was found that the cement content should be increased and optimized to achieve the required strength (i.e. 15 N/mm²).

Stage Two

In this stage, mixes were tested for cement optimization. Mix proportions for samples were selected according to the results obtained in Stage One. Test cubes of same size were used for this stage with a similar procedure followed in the mixing, moulding, de-moulding and testing of wet compressive strength. The sample selection pattern for Stage Two is shown in Figure 23.

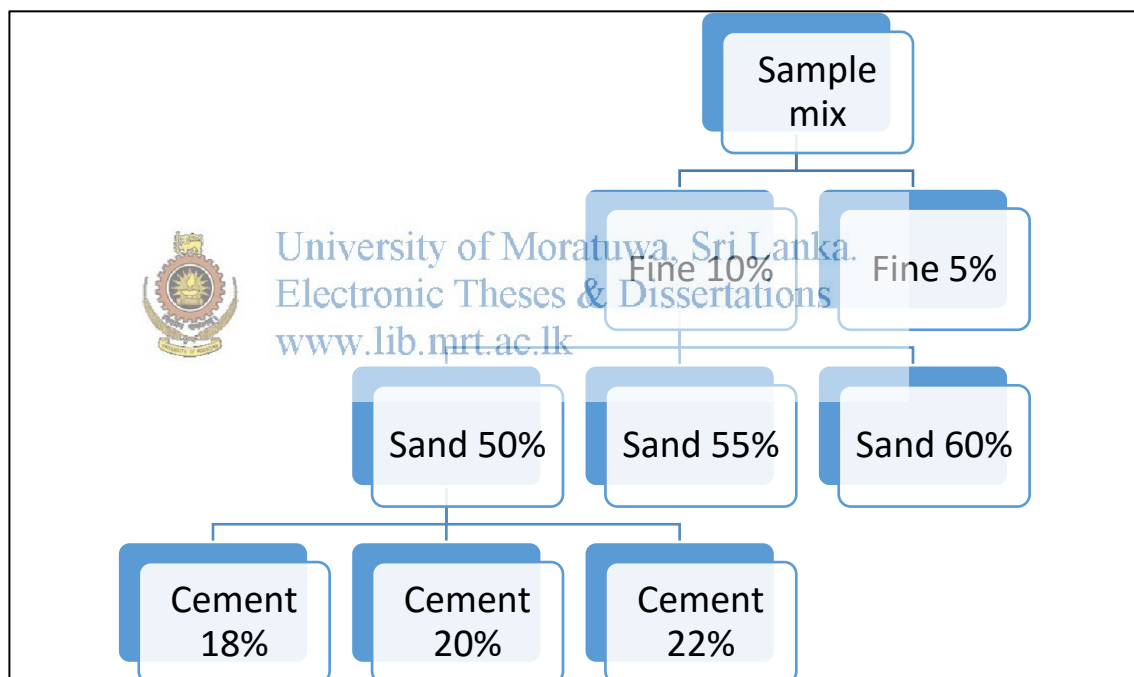


Figure 23 : Sample selection pattern for casting test cubes in Stage Two

In this stage, the cement percentage was increased to 20% and 22%. According to the results obtained in Stage One, the selections were the mix proportions with a fine particle content of 5% and sand content varying from 55% to 65% in 5% increments. Average values obtained from the wet compressive strength test are shown in Table 13, and Figure 24 shows the variation of wet compressive strength with sand content.

Table 13: Average wet compressive strength

Average wet compressive strength (N/mm ²)		
Sand %	Cement	
	20%	22%
55	12.7	14.3
60	13.3	15.1
65	12.8	14.1

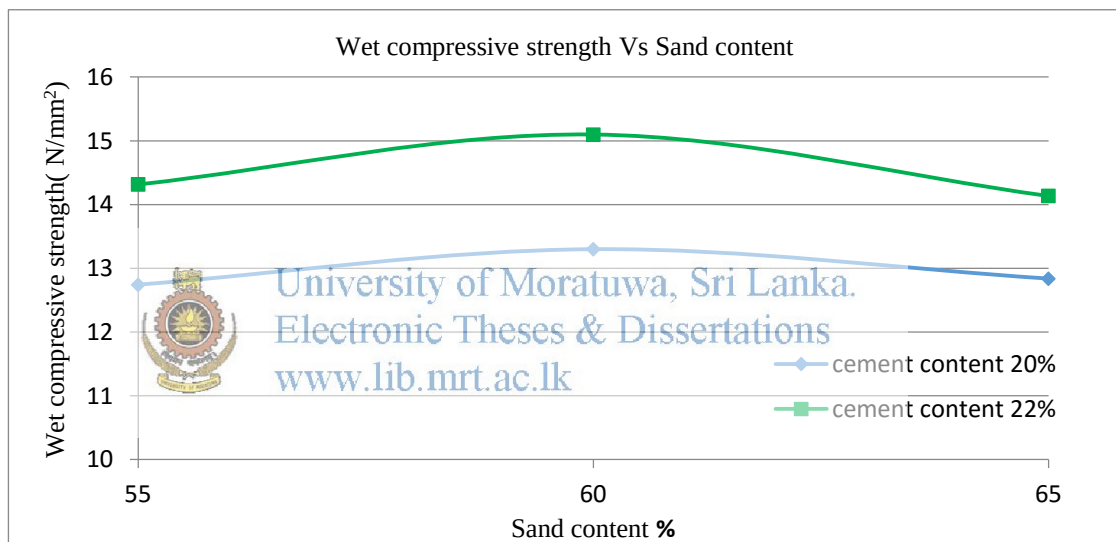


Figure 24 : Variation of wet compressive strength with sand content

The results indicated that the use of sand content in the range of 55% to 65% and 22% cement can achieve the required strength. It also indicated that the best sand content is 60%.

4.4 Comparison of thermal performance

4.4.1 Methodology

According to Stage Two results, it was concluded that the selection mix should be as follows: clay content of 5%, sand content of 60% and 22% cement content for the proposed mud concrete paving block. In this stage, paving blocks in actual size were cast in two sets in two days to obtain the required numbers of paving block for the evaluation of thermal performance and skid resistance test.

Comparative thermal performance of the mud concrete paving block was examined by paving a 1.0 m x 1.0 m area with mud concrete paving blocks, and with different other paving materials that are available in the present industry and are kept under normal exposure conditions. The selected paving materials were burnt bricks, cement concrete blocks, 110 mm thick cement concrete slabs and asphalt. Temperatures were measured on the top surface and bottom surfaces of the areas paved with the above mentioned materials. Natural ground surface temperature and ambient temperature were also measured as controls. Additionally, temperature measurements were taken at a height 300 mm above each paving area to identify the reflectivity of the materials. Temperatures were measured using a data logger for 24 hours.

4.4.2 Results

Compressive strength test results for the two sets are shown in Table 14.

Table 14 : Wet compressive strength

Sample	Wet compressive strength (N/mm ²)	
	1st set	2nd set
1	15.02	15.12
2	15.53	15.49
3	15.78	14.93
Av. Strength	15.44	15.18

Temperature variations were measured on the top surface, bottom surface and a level above 300 mm from the top surface for each paving areas, along with the separate measurement of the ambient temperature. Figure 25 shows the paving area which was

prepared for measuring the temperature. Paving areas with above mention materials were painted in same colour to match the colour of Mud Concrete Paving Block and temperature variations were measured on the top surface of the painted paving area. Figure 26 shows the painted paving areas in same colour. Next, the temperature measurements were analysed for comparison.



Figure 25: Areas paved with different paving materials

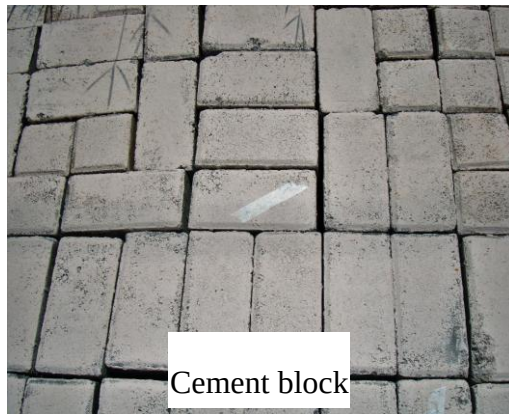


Figure 26: Painted paved areas with different paving materials

Figure 27 shows the temperature variations on the burnt brick paved area for 24 hours. After 7.00 hr the temperatures increased rapidly. The maximum temperature on the top of the surface was 57.8°C at 13.00 hr, and at the same time the bottom surface

reached its maximum value of 45.8°C . The difference between the top and bottom surfaces was 12.0°C . At this time the ambient temperature was 33.23°C . It was the maximum ambient temperature of the day. At the same time, the temperature at a height of 300 mm above the top surface reached 33.8°C , showing a difference of 0.57°C between them. Again after 19.00 hr, the temperatures of the top surface and at a height of 300 mm above the top surface became nearly the same in terms of ambient temperature while the bottom surface remained at a minimum of about 4.0°C higher than that. During the night time, 16 hr up to 7 hr, the bottom surface temperature was higher than that of the top surface.

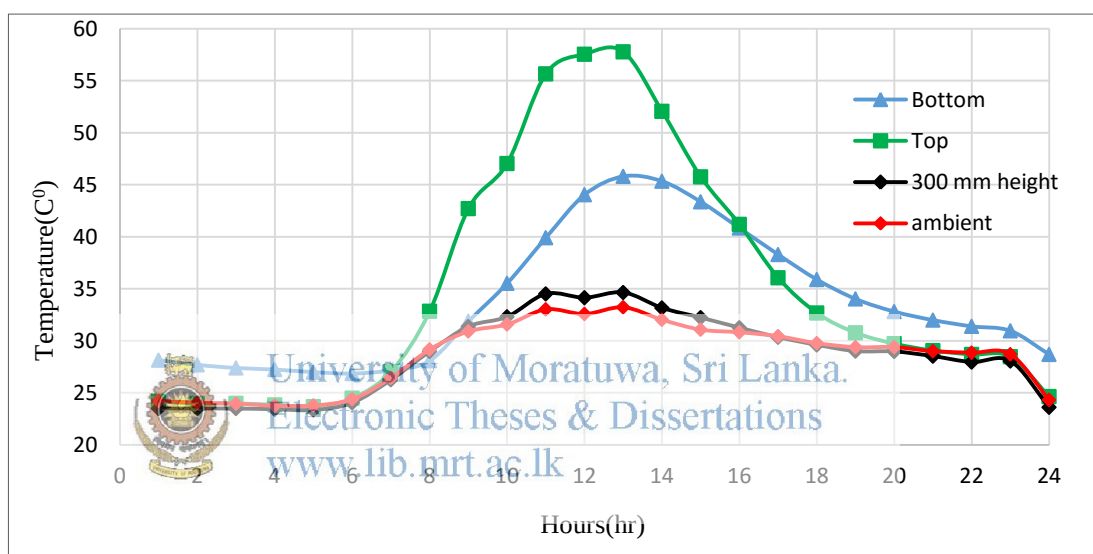


Figure 27: Temperature variation in the burnt brick paved area

Figure 28 shows the temperature variation in the concrete slab paved area. After 8.00 hr the temperatures showed a rapid variation. The top surface temperature reached its maximum of 47.4°C at 13.00 hr. The bottom surface temperature reached its maximum of 41.4°C at 15.00 hr. At 13.00 hr, temperature 300 mm above the top surface reached its maximum of 34.1°C , showing a difference of 0.87°C with the ambient temperature. During the night time, 16 hr up to 7 hr, the bottom surface temperature was higher than the top surface temperature.

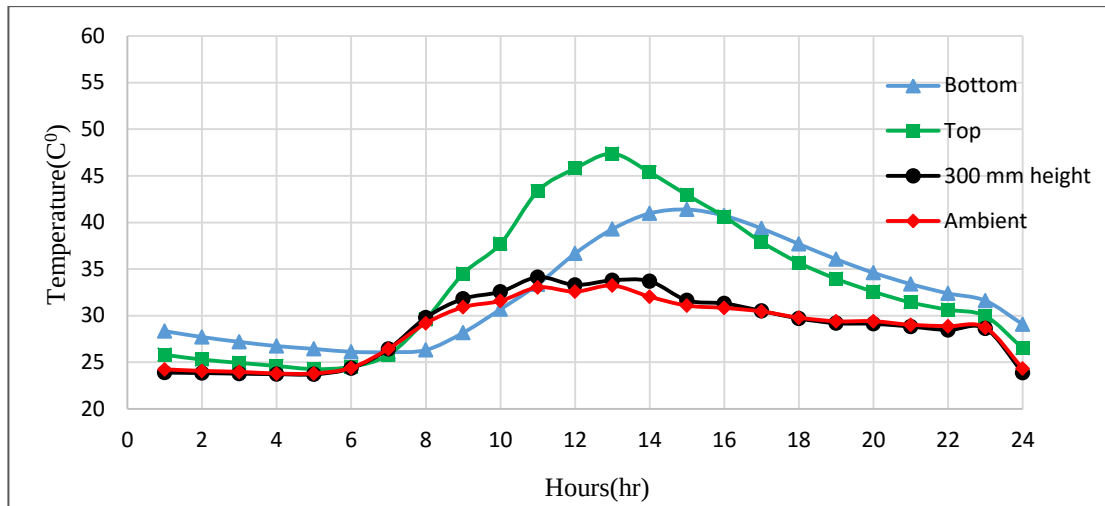


Figure 28: Temperature variation in the concrete slab paved area

Figure 29 shows the temperature variation in the cement block paved area. It shows that the temperature at 300 mm above the top surface and the ambient temperature are nearly the same throughout the day. After 8.00 hr, the temperatures varied rapidly. The top surface temperature reached its maximum of 52.10°C at 13.00 hr. The bottom surface temperature reached its maximum of 46.0°C at 14.00 hr. The temperature at 300 mm above the surface reached its maximum at 34.1°C , showing 0.87°C higher than the maximum ambient temperature at the same time. During night time, 16 hr up to 7 hr, the bottom surface temperature was higher than the top surface, and it was about 3.0°C .

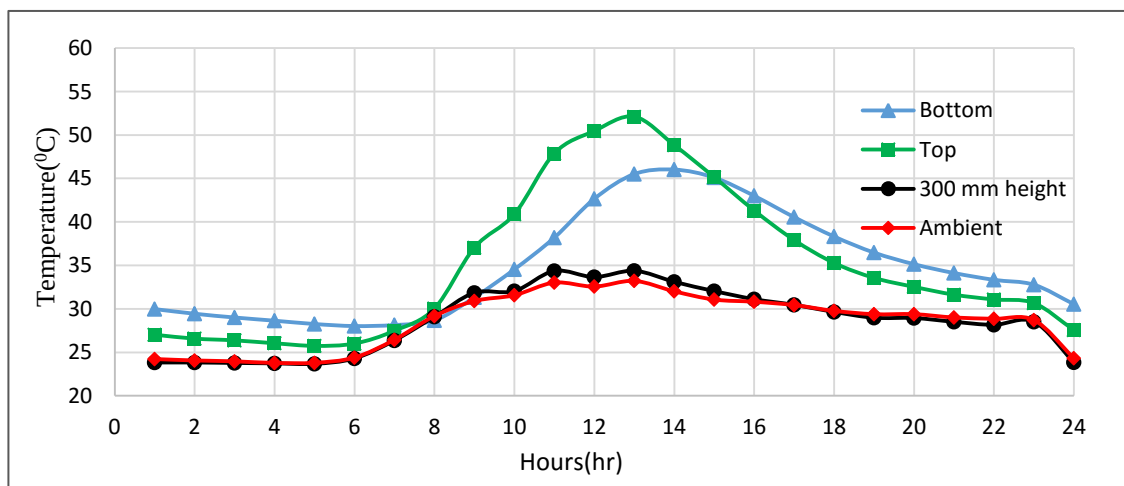


Figure 29 : Temperature variation in the cement block paving area

Figure 30 shows the temperature variation of the asphalt paved area. It shows that the temperature of the top surface, surface at 300 mm height above the top surface and the ambient temperature are nearly the same during night time from 20 hr to 7 hr. After 7.00 hr, the temperatures varied rapidly. The top surface temperature reached its maximum and it was 59.9°C at 13.00 hr. At the same time, the bottom surface, the top surface and level at 300 mm (1ft) height from the top surface reached their maximum temperatures of 50.6°C and 37.9°C respectively. During day time, 7 hr to 18 hr, the temperature on the asphalt pavement at 300 mm (1ft) high from top surface was higher than the ambient temperature average of about 3.0°C . This was also higher than the maximum ambient temperature at the same time. During night time, 17 hr up to 7 hr, the bottom surface temperature was higher than the top surface and it was about 2.5°C .

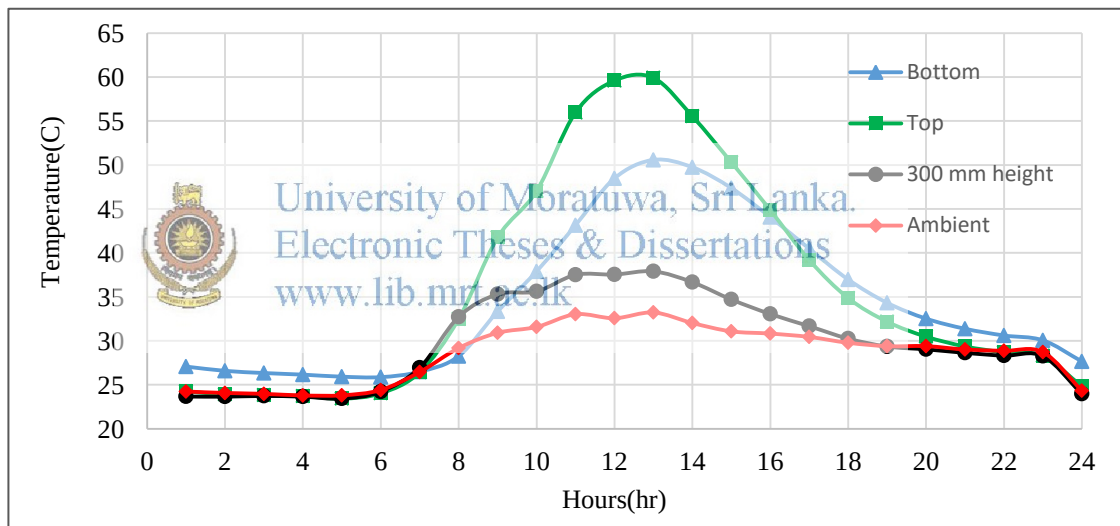


Figure 30 : Temperature variation in the asphalt paving area

Figure 31 shows the temperature variation in the mud block paved area. It shows that the temperature at 300 mm (1ft) height from the top surface and ambient temperature are nearly the same throughout the day. After 8.00 hr, the temperatures varied rapidly. The top surface temperature reached its maximum and it was 50.0°C at 13.00 hr. The bottom surface temperature reached its maximum and it was 41.8°C at 14.00 hr. The temperature at 300 mm above the top surface reached its maximum at 34.4°C , showing 1.20°C higher than the maximum ambient temperature at the same time. During the night time, 16 hr up to 7 hr, the bottom surface temperature was higher than the top surface temperature, and it was about 3.0°C .

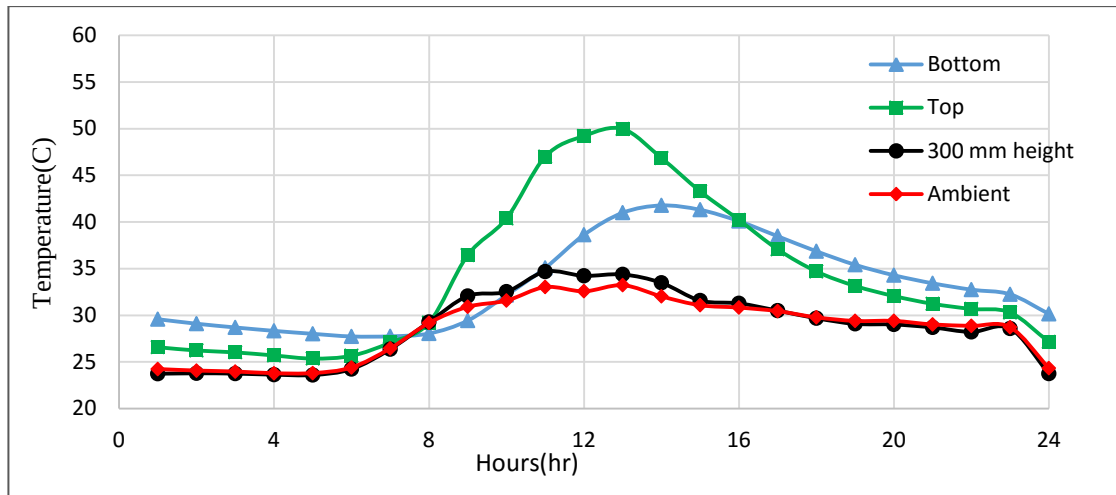


Figure 31 : Temperature variation in the mud concrete block paving area

Figure 32 shows the temperature variation of the natural ground. It shows that the temperature of a surface at a height of 300 mm from the top surface and the ambient temperature were nearly the same throughout the day. After 8.00 hr, the top surface temperatures began to vary rapidly and reached its maximum of 48.4 °C at 13.00 hr. The bottom surface temperature reached its maximum of 35.1 °C at 15.00 hr. The temperature at the level of 300 mm (1 ft) from top surface reached its maximum of 34.6 °C, showing 1.40 °C higher than the maximum ambient temperature at the same time. During night time, 16 hr up to 7 hr, the bottom surface temperature was higher than the top surface and it was about 6.0 °C.

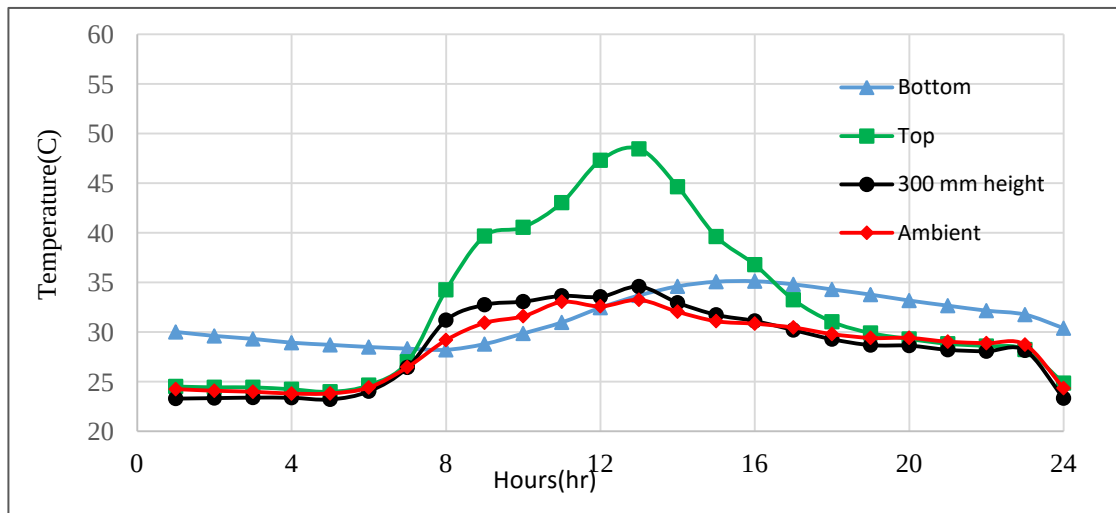


Figure 32 : Temperature variation in natural ground

Figure 33 shows the comparison of temperature variation on the top surface of all five types of paving areas, natural ground and ambient temperature. Though almost all the surfaces showed a close surface temperature during the early morning (i.e. 01 hr to 07 hr), asphalt, burnt brick and cement concrete block paving surfaces heated up quicker than the natural ground surface and ambient temperature. Nonetheless, the mud concrete and concrete slab pavements showed closer surface temperature values with the natural ground temperature. At peak temperature during day time (at 13hr), the asphalt surface showed the highest temperature with a difference of 11.5 °C with natural ground. In the case of brick and cement block surfaces, they showed the second and third highest values which were 9.4 °C and 3.7 °C higher than that of the natural ground temperature respectively. However, mud concrete blocks showed an increase of only 1.6 °C higher than the natural ground temperature.

The results indicated that the colour of the surface influenced the thermal performance. The darkest asphalt (black) became very hot rapidly compared to all the other surfaces. Burn brick (red) surface showed the second largest temperature value while the lighter colour (white) concrete slabs showed the lowest temperature. Further, Bryan et al. (2011) confirmed that the material colour affected thermal performance and that the lighter coloured concrete performed better than the darker coloured asphalt in terms of surface temperature.

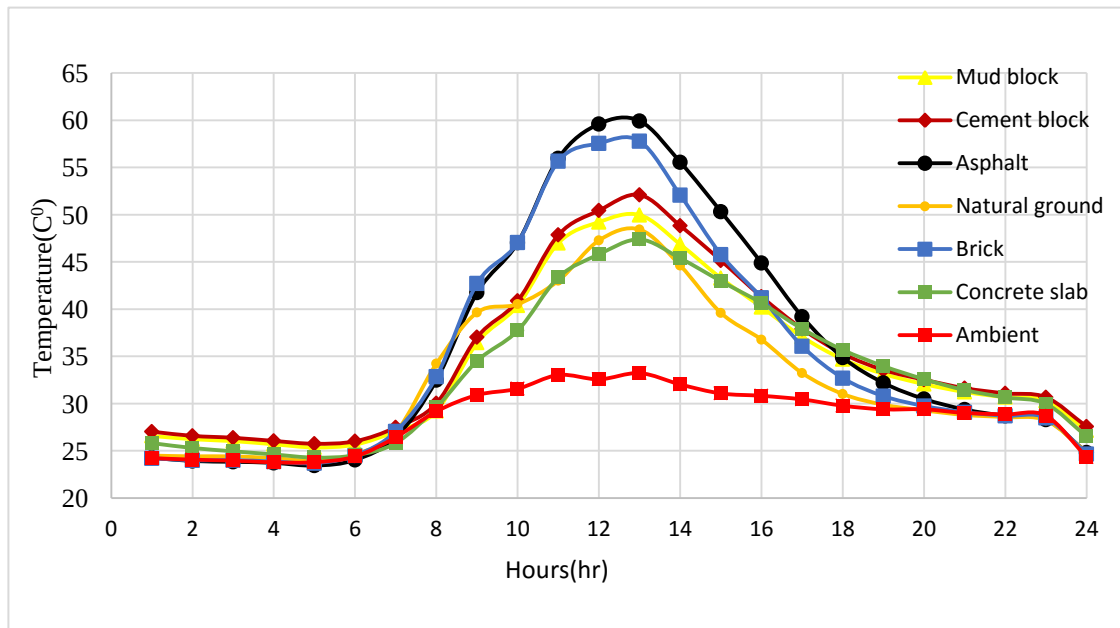


Figure 33: Comparison of temperature variation on top surfaces of paving areas, natural ground and ambient temperature.

Figure 34 shows the comparison of temperature variation on a level above 300mm height from top surfaces of all types of paving areas, natural ground and ambient temperature. Though almost all the surfaces showed close surface temperature during 00.00 hr to 9.00hr and 16.00hr to 00hr, the temperature between 9.00hr to 16.00 hr was higher than the ambient temperature. For better identification of temperature differences, the temperature variation from 9.00 hr to 16.00 hr were plot separately as shown in Figure 35.

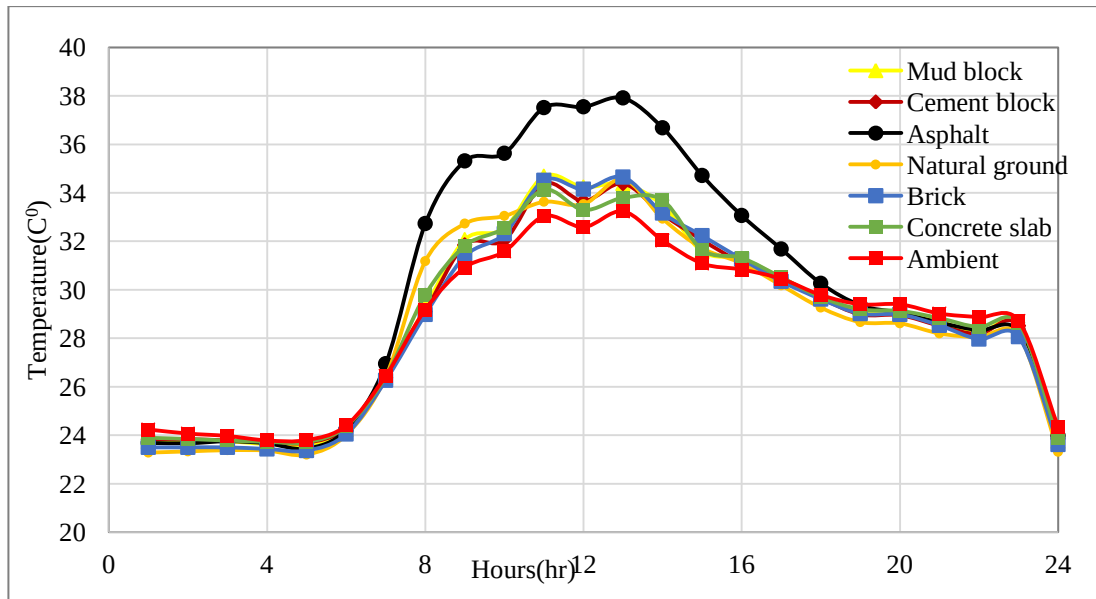


Figure 34: Comparison of temperature variation at a level above 300mm height from top surfaces, natural ground and ambient temperature.

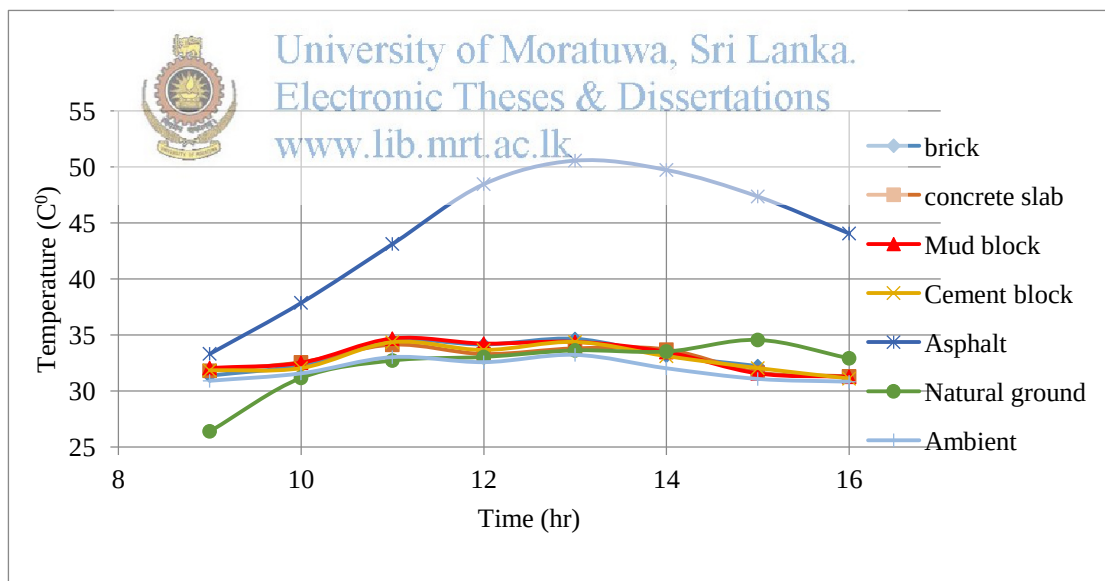


Figure 35 : Temperature variation at a level above 300mm height from top surfaces, natural ground and ambient temperature during 9 hr to 16 hr.

The level at height 300 mm from top surfaces of asphalt paving area heated up quicker than all other surfaces and ambient temperature during day time (09 hr to 16 hr). At the peak temperature in the day at 13hr, 300 mm height from top surfaces of asphalt paving area showed the highest temperature. The difference between other surfaces temperatures was at an average of 3.4 °C. According to this temperature variation, during day time, the surrounding temperatures of artificial surfaces were higher than the ambient temperature.



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

4.5 Skid Resistance Test

Skid resistance is described as the ability of a surface to provide friction compared with reference to a tyre or slider, usually measured under wet conditions. Skid resistance is primarily dependent upon the surface macro and microstructure, environmental conditions including surface contaminants and temperature, physical properties of the paving materials, age of pavement etc. (*Skid resistance of Residential Concrete Paving Surfaces*, 2002).

Skid resistance is important for the safety of pedestrians on walkways, both road-side and in recreational areas. Surface characteristics are very important among the many variables which influence skid resistance. The Skid Resistance Test was conducted to determine the qualities of mud concrete paving blocks and to determine whether the particular surface finish is appropriate for application. The tests were carried out in a laboratory of the Road Development Authority (RDA). There are two approaches to measure skid resistance, as static and dynamic (*Slip and Skid Resistance of Interlocking Concrete Pavements*, 2015). The common device used for static measurement is the British Pendulum Skid Resistance Tester which was used in this process in the RDA laboratory. Four numbers of mud concrete paving blocks were prepared in size 200 x 100 x 80 mm and were tested. To perform a test, the test surface is wetted, the pendulum was pulled back and the shoe rubbed across the surface. Friction resistance is read on a scale on the machine as the British Pendulum Number (BPN).

According to *Skid resistance of Residential Concrete Paving Surfaces* (2002), there are no statutory requirements for skid resistance. However skid resistance levels were introduced in the UK for different site categories as shown in Table 15. They further suggest minimum values for skid resistance measured by a portable British Pendulum Skid Resistance Test as shown in Table 16. Additionally, *Slip and Skid Resistance of Interlocking Concrete Pavements* (2015) mentioned in their report that a BPN rating between 45 and 55 indicates a satisfactory surface in only favourable weather and vehicle conditions. A rating of 55 or greater indicates a generally acceptable skid

resistance in all but the most severe weather conditions. A 65 and above, the rating indicates a good to excellent skid resistance in all conditions.

Table 15 : Greater London Council skid test criteria for pedestrian surfaces.

Skid Resistance Value (SRV)	Description of surface
Below 19	Dangerous
20–39	Marginal
40-74	Satisfactory
Above 75	Excellent

Table 16 : Suggested minimum skid resistance values (*SKID RESISTANCE TEST*, n.d.)

Category	Type of site	Minimum SRV (Surface wet)
A	 University of Moratuwa, Sri Lanka. Electronic Theses & Dissertations www.lib.mrt.ac.lk (A) Difficult sites such as 1 Roundabouts 2 Bends with radius less than 150 m on unrestricted roads 3 Gradients 1 in 20 or steeper of lengths greater than 100 m 4 Approaches to traffic lights on unrestricted roads	65
B	Motorways, trunk and class 1 roads and heavily trafficked roads in urban areas (carrying more than 2000 vehicles per day)	55
C	All other sites	45

The skid resistance of the surface of blocks is measured using the Pendulum Skid Resistance Tester. Figure 36 shows the testing process in the RDA laboratory. The measured values are shown in Table 17. The skid resistance values are the mean value of three readings. The results show that all the values achieved higher than the above mentioned requirements. Thus, it can be concluded that the newly invented mud

concrete paving block fulfilled the skid resistance requirements and is thereby suitable to be used to construct pedestrian pavements.



Figure 36 : Skid resistance testing process



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

Table 17 : The measured values of four blocks

Block no	Mean pendulum value
1	65
2	65
3	70
4	70

4.6 Cost analysis

A cost analysis was carried out to determine the cost of production of the proposed mud concrete paving block. Materials (i.e. cement and soil) and labour prices used are current market values. For the formwork, 4 mm thick 8' X 4' steel plate is used assuming that it can be used 200 times repetitively. The price was calculated accordingly. Also, it is assumed that the blocks can be cast 4 times per day with 3 labourers.

Pomerantz et al. (1997) mentioned that the cost of material depends on the size of the job, the distance between the site and the source of the materials and the relative cost of different materials. These were considered the most useful pieces of information.

It eliminates the transportation cost since the soil can be extracted within the site or not far from the site. Workers with little or poor knowledge and experience can be used for the manufacture of this mud block. Hence, this cost can be reduced.

According to the final results obtained from the mix design (which is gravel 35%, sand 60% and clay 5% with 22% cement) for the production of mud concrete paving block in size of 200 x 100 x 80 mm, the price is estimated at Rs. 29.40 per block with a 25% of profit margin. Detailed calculations are shown in Annex 3.



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

4.7 Summary

From the data collected during the field investigation, it was found that all the manufacturers were using more than 30% cement in their block manufacturing process.

According to results obtained from the wet compressive strength test in Stage One casting, the best wet compressive strength values were shown with moisture content between 14% and 15%. It was shown that when the moisture content increased further, the strength decreased because of segregation. It was also found that the changing vibration time did not show a significant effect on the strength of the blocks.

Therefore, within this moisture content range, samples were cast for 5% fine particle content and for a sand content of 60%, which is the sand content which showed maximum wet compressive strength (i.e. 12.8 N/ mm²) in the Stage One analysis, in order to identify the behaviour of strength with fine particle content. With all these results, it was found that the cement content should be increased and optimized to achieve the required strength (i.e. 15 N/mm²).

In stage two, the cement percentage increased to 20% and 22%. According to the results obtained in Stage One, the selected mix proportions of fine particles content 5% and sand content which varied from 55% to 65% in 5% increments. According to the results, it was concluded that the selected mix should include clay content 5%, sand content 60% and 22% cement content for the proposed mud concrete paving block.

With this mix proportions, blocks in actual size were cast in Stage Three, and they were used for temperature measurements and underwent a skid resistance test.

Results obtained from temperature measurements were first plotted and analysed to compare the temperature variation for each and every paving area separately. Next, the temperature measurements were analysed to compare each system.

The results indicated that the colour of surface influenced thermal performance. The darkest asphalt (black) became very hot rapidly compared to all the other surfaces.

Burn brick (red colour) surface showed the second largest temperature value while the lighter colour (white colour) concrete slab showed the lowest temperature.

The skid resistance of the blocks' surfaces was measured using the Pendulum Skid Resistance Tester in the RDA laboratory and the measured values were 65 and 70.

The estimated cost for the production of a mud concrete block with the selected mix and at a size of 200 mm x 100 mm x 80 mm is Rs. 29.40 with a profit of 25%.



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

Chapter 5

5 Conclusion and Recommendation

5.1 Conclusion

This research study was undertaken to develop a new paving material ‘mud concrete paving block’ for outdoor constructions. The most desired characteristic of the new material is its ability to minimize the adverse effects produced by heat. While fulfilling the major objective above, the researcher also desired to understand the user perceptions and user awareness of outdoor construction and its materials. The following sections present the conclusions on the findings of various aspects of the study.

5.1.1 User perceptions and awareness

Separate pedestrian walkways and recreation areas are highly preferred by the public irrespective of their experience as drivers or pedestrians, and also their gender. Clay bricks are the most preferred construction material for pedestrian walkways and artificial material for recreation areas. Therefore, further research in the development of new paving materials should either be based on clay bricks or its preferred characteristics.

5.1.2 Suitability of the Mud Concrete Paving Block

According to the results obtained in the laboratory tests for mix design, it can be concluded that the new block can be produced using soil with 5% of fine particles and 55% to 65% sand particles, 22% cement by weight together with a moisture content between 14% to 15%. Further production of the new paving block does not need compaction or vibration effects to be used with the above mix. Based on the results obtained in laboratory experiments conducted for the mix design, the production of mud concrete blocks consume only 22% cement. The other ingredient of a mud block

is natural soil; thus, once the new product is demolished, it can be exposed to the natural ground with less harmful impacts to the environment.

Further, the production of the new block is fully manual and does not use any kind of energy except for the production of cement. So the embodied energy is much less compared to other materials, especially cement concrete blocks which is the most commonly used material. Even more important is that the mud concrete paving block can be produced without more skilled labour while material is readily available even within the site. So the material transportation and labour costs are also less when compared to other material.

5.2 Recommendations

It is recommended that further analyses are carried out in order to find out (a) reasons as to why walkway users are more accepting of soil based products than other materials, and (b) factors affecting user comfort. Further studies are recommended to observe detailed public perceptions on thermal discomfort of walkways and the observed discrepancy between high heat emission by clay bricks and the high public preference for it.



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

Further, it is recommended that the thermal performance of the developed block is evaluated using computer simulations. Analysis of long-term performance and performance with respect to durability is also recommended. Improvement of the block so that it can be used in traffic paths is also recommended.

5.3 Limitations

The proposed mud concrete paving block mix is designed and tested only for the pedestrian walkway and recreational area. Therefore, the developed mud concrete paving block cannot be used for areas where vehicle traffic is anticipated.

References

- Babić, S., Deluka-Tibljaš, A., Cuculić, M., Šurdonja, S., 2012. Analiza zagrijavanja kolničkih površina urbanih područja. *Grad Jevinar* 64, 125–132.
- Beeldens, A., Herrier, G., 2006. Water pervious pavement blocks: The Belgian experience, in: *Proceedings of the 8th International Conference on Concrete Block Paving*, San Francisco, CA, USA. pp. 6–8.
- Borgwardt, S., 2006. Long-term in-situ infiltration performance of permeable concrete block pavement, in: *Proceedings of the 8th International Conference on Concrete Block Paving*, San Francisco, CA, USA.
- Bryan, H., Agarwal, F.V., Deshmukh, A., Kapur, V., Webster, A.K., n.d. COOL ARCHITECTURAL MATERIALS AND ASSEMBLIES FOR OUTDOOR URBAN SPACES. *Red* 30, 40.
- Deboucha, S., Hashim, R., 2011. A review on bricks and stabilized compressed earth blocks. *Sci. Res. Essays* 6, 499–506.
- El Nouhy, H.A., Zeedan, S., 2012. Performance evaluation of interlocking paving units in aggressive environments. *HBRC J.* 8, 81–90. doi:10.1016/j.hbrcj.2012.09.003
- Emissivity, 2016. . Wikipedia Free Encycl.
- Emmanuel, R., Johansson, E., 2006. Influence of urban morphology and sea breeze on hot humid microclimate: the case of Colombo, Sri Lanka. *Clim. Res.* 30, 189–200.
- ENVIRONMENTAL IMPACT OF CONCRETE - ProQuest [WWW Document], n.d. URL <http://search.proquest.com/openview/8c34bf1820a6898df081c0063cf61dd1/1?pq-origsite=gscholar> (accessed 2.29.16).
- Erell, E., Pearlmutter, D., Boneh, D., Kutiel, P.B., 2014. Effect of high-albedo materials on pedestrian heat stress in urban street canyons. *Urban Clim.*, ICUC8: The 8th International Conference on Urban Climate and the 10th Symposium on the Urban Environment 10, Part 2, 367–386. doi:10.1016/j.uclim.2013.10.005
- Gajda, J.W., Van Geem, M.G., 1997. A Comparison of Six Environmental Impacts of Portland Cement Concrete and Asphalt Cement Concrete Pavement. *PCA RD Ser.*

- Garcia, R., Flores, E.S., Chang, S.M., 2003. Healthy Children, Healthy Communities: Schools, Parks, Recreation, and Sustainable Regional Planning. *Fordham Urban Law J.* 31, 1267.
- Gencel, O., Ozel, C., Koksall, F., Erdogmus, E., Martínez-Barrera, G., Brostow, W., 2012. Properties of concrete paving blocks made with waste marble. *J. Clean. Prod.* 21, 62–70. doi:10.1016/j.jclepro.2011.08.023
- Grimmond, C.S.B., Roth, M., Oke, T.R., Au, Y.C., Best, M., Betts, R., Carmichael, G., Cleugh, H., Dabberdt, W., Emmanuel, R., Freitas, E., Fortuniak, K., Hanna, S., Klein, P., Kalkstein, L.S., Liu, C.H., Nickson, A., Pearlmutter, D., Sailor, D., Voogt, J., 2010. Climate and More Sustainable Cities: Climate Information for Improved Planning and Management of Cities (Producers/Capabilities Perspective). *Procedia Environ. Sci., World Climate Conference - 3 1*, 247–274. doi:10.1016/j.proenv.2010.09.016
- Halwatura, R.U., Jayasinghe, M.T.R., 2007. Strategies for improved micro-climates in high-density residential developments in tropical climates. *Energy Sustain. Dev.* 11, 54–65. doi:10.1016/S0973-0826(08)60410-X
- James, W., James, W.R.C., von Langsdorff, H., 2003. COMPUTER -AIDED DESIGN OF PERMEABLE CONCRETE BLOCK PAVEMENT FOR REDUCING STRESSORS AND CONTAMINANTS IN AN URBAN ENVIRONMENT, in: *Proceedings of the 7th International Conference on Concrete Block Paving(PAVE AFRICA 3002)*. Sun City, South Africa.
- Jayasinghe, C., Kamaladasa, N., 2007. Compressive strength characteristics of cement stabilized rammed earth walls. *Constr. Build. Mater.* 21, 1971–1976. doi:10.1016/j.conbuildmat.2006.05.049
- Jayasinghe, C., Mallawaarachchi, R.S., 2009. Flexural strength of compressed stabilized earth masonry materials. *Mater. Des.* 30, 3859–3868. doi:10.1016/j.matdes.2009.01.029
- Kelly, C.E., Tight, M.R., Hodgson, F.C., Page, M.W., 2011. A comparison of three methods for assessing the walkability of the pedestrian environment. *J. Transp. Geogr., Special section on Alternative Travel futures* 19, 1500–1508. doi:10.1016/j.jtrangeo.2010.08.001
- Killingsworth Sr, B., Director, P.S., Lemay Sr, N.L., Peng Sr, T., Director, S., n.d. *The Urban Heat Island Effect*.

- Kumar, A., Kumar, S., 2013. Development of paving blocks from synergistic use of red mud and fly ash using geopolymerization. *Constr. Build. Mater.*, 25th Anniversary Session for ACI 228 – Building on the Past for the Future of NDT of Concrete 38, 865–871. doi:10.1016/j.conbuildmat.2012.09.013
- Li, H., Harvey, J., Ge, Z., 2014. Experimental investigation on evaporation rate for enhancing evaporative cooling effect of permeable pavement materials. *Constr. Build. Mater.* 65, 367–375. doi:10.1016/j.conbuildmat.2014.05.004
- Ling, T.-C., 2012. Effects of compaction method and rubber content on the properties of concrete paving blocks. *Constr. Build. Mater.* 28, 164–175. doi:10.1016/j.conbuildmat.2011.08.069
- Ling, T.-C., Poon, C.-S., 2014. Use of recycled CRT funnel glass as fine aggregate in dry-mixed concrete paving blocks. *J. Clean. Prod.* 68, 209–215. doi:10.1016/j.jclepro.2013.12.084
- Liu, Y., You, Z., Li, L., Wang, W., 2013. Review on advances in modeling and simulation of stone-based paving materials. *Constr. Build. Mater.* 43, 408–417. doi:10.1016/j.conbuildmat.2013.02.043
- Li, X., Zhu, Y., Zhang, Z., 2010. An LCA-based environmental impact assessment model for construction processes. *Build. Environ.* 45, 766–775. doi:10.1016/j.buildenv.2009.08.010
- Mendoza, J.-M.F., Oliver-Solà, J., Gabarrell, X., Rieradevall, J., Josa, A., 2012. Planning strategies for promoting environmentally suitable pedestrian pavements in cities. *Transp. Res. Part Transp. Environ.* 17, 442–450. doi:10.1016/j.trd.2012.05.008
- Nehdi, M.L., 2014. Clay in cement-based materials: Critical overview of state-of-the-art. *Constr. Build. Mater.* 51, 372–382. doi:10.1016/j.conbuildmat.2013.10.059
- Okunade, E.A., 2008. Engineering properties of locally manufactured burnt brick pavers for Agrarian and rural earth roads. *Am. J. Appl. Sci.* 5, 1348–1351.
- OVERCONSUMPTION? Our Use of World's Natural Resources, 2009. . Sustainable Europe Research Institute.
- Pomerantz, M., Akbari, H., Chen, A., Taha, H., Rosenfeld, A.H., 1997. Paving Materials for Heat Island Mitigation (No. LBL--38074). Lawrence Berkeley National Lab., Berkeley, CA (United States).

- Poon, C.S., Chan, D., 2006. Paving blocks made with recycled concrete aggregate and crushed clay brick. *Constr. Build. Mater.* 20, 569–577. doi:10.1016/j.conbuildmat.2005.01.044
- Rahaman, K.R., Ohmori, N., Harata, N., 2005. Evaluation of the Road side Walking Environment in Dhaka City, in: *Proceedings of the Eastern Asia Society for Transporation Studies*. pp. 1751–1766.
- Ranasinghe, A.W.L.H., Halwatura, R.U., 2013. User comfort on urban roads.
- Reddy, P.S., Krishnaiah, S., 2008. Effect of Clay on Soil Cement Blocks. Presented at the The 12th International conference of International Association for Computer Methods and Advances in mechanics, Goa, India, pp. 4362–4368.
- Rehan, R.M., 2013. Sustainable streetscape as an effective tool in sustainable urban design. *HBRC J.* 9, 173–186. doi:10.1016/j.hbrcj.2013.03.001
- Reo, C., Kannaujiya, V.K., 2014. A review on bricks and compressed stabilized earth blocks. *Glob. J. Eng. Sci. Res.* 1.
- Rosheidat, A., Bryan, H., 2010. Optimizing the effect of vegetation for pedestrian thermal comfort and urban heat island mitigation in a hot arid urban environment, in: *Fourth National Conference of IBPSA-USA*. New York, New York: *SimBuild*.
 University of Moratuwa, Sri Lanka
 Electronic Theses & Dissertations
www.lib.mrt.ac.lk
- R.U.Halwatura, A.s, A., Chandrathilake, S.R.M.S.R., 2013. Effect of Albedo on surface temperature of concrete interlocking paving blocks in mitigating urban heat lands, in: *ResearchGate*. Presented at the Proceedings on 4th International Conference on Structural Engineering and Construction Management.
- Santamouris, M., Gaitani, N., Spanou, A., Saliari, M., Giannopoulou, K., Vasilakopoulou, K., Kardomateas, T., 2012. Using cool paving materials to improve microclimate of urban areas – Design realization and results of the flisvos project. *Build. Environ.* 53, 128–136. doi:10.1016/j.buildenv.2012.01.022
- Schilderman, T., 2007. Sustainable Small-Scale Brick Production-A Question of Energy.
- Scholz, M., Grabowiecki, P., 2007. Review of permeable pavement systems. *Build. Environ.* 42, 3830–3836. doi:10.1016/j.buildenv.2006.11.016
- Scudo, G., Dessì, V., 2006. Thermal comfort in urban space renewal. *Proceeding 23th PLEA*.

- Skid resistance of Residential Concrete Paving Surfaces, 2002. . CEMENT CONCRETE AND AGGREGATE AUSTRALIA, Australia.
- SKID RESISTANCE TEST (Laboratory - Pavement Materials), n.d. . Nanyang Technological University.
- Slip and Skid Resistance of Interlocking Concrete Pavements (Technical specification), 2015. . Interlocking Concrete Pavement Institute.
- Smith, D.R., 2000. RECENT SKID RESISTANCE EVALUATIONS OF CONCRETE BLOCK PAVING IN NORTH AMERICA. Japan Interlocking Block Pavement Engineering Association.
- Soutsos, M.N., Tang, K., Khalid, H.A., Millard, S.G., 2011. The effect of construction pattern and unit interlock on the structural behaviour of block pavements. Constr. Build. Mater. 25, 3832–3840. doi:10.1016/j.conbuildmat.2011.04.002
- Sukontasukkul, P., Chaikaew, C., 2006. Properties of concrete pedestrian block mixed with crumb rubber. Constr. Build. Mater. 20, 450–457. doi:10.1016/j.conbuildmat.2005.01.040
- Tech_Spec_13_-_Slip_and_Skid_Resistance.pdf, n.d.
- United Nations, Department of Economic and Social Affairs, Population Division, 2014. World urbanization prospects: the 2014 revision : highlights.
- Urban Heat Island Effect (Summary Report), 2010. . City of Las Vegas Office of Sustainability.
- Wan, W.C., Hien, W.N., Ping, T.P., Aloysius, A.Z.W., 2012. A study on the effectiveness of heat mitigating pavement coatings in Singapore. J. Heat Isl. Inst. Int. Vol 7, 2.
- Zee, D. van der, 1990. The complex relationship between landscape and recreation. Landsc. Ecol. 4, 225–236. doi:10.1007/BF00129830

Annexes

Annex 1

Questionnaire survey on pedestrian walkways in urban areas

Date Time

1 Please tick the respondent category you belong to

1.1 Gender ☐ ☐

1.2 Age Group

15-20	21-25	26-30	31-35	36-50	Above 50
☐	☐	☐	☐	☐	☐

1.3 Experience as a Pedestrian ☐ Driver ☐

2 Location (City)

3 Profession / Educational level

4 Do you prefer to have a **separate pedestrian walkway** along the road?

Yes ☐ No ☐

5 Should there be a **visual identification** between the pedestrian walkway and vehicle path?

Yes ☐ No ☐

6 Your favourite material for a pedestrian walkway

(Place numbers 1 to 5 according to your favourite, insert 1 for the most favourite option)

6.1	Asphalt	
6.2	Concrete	
6.3	Clay Brick	
6.4	Soil	
6.5	Turf	

7 Do you prefer to have a separate recreational area?

Yes ☐

No ☐

8 Your favour material for recreational area

(Place number 1 to 5 according to your favourite, insert 1 for the most favourite option)

8.1	Asphalt	
8.2	Concrete	
8.3	Clay Brick	
8.4	Soil	
8.5	Turf	

9 Please mark the most uncomfortable time of the day on urban walkways



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

8.00 – 9.00 am		2.00 – 3.00 pm	
9.00 – 10.00 am		3.00 – 4.00 pm	
10.00 – 11.00 am		4.00 – 5.00 pm	
11.00 – 12.00 am		5.00 – 6.00 pm	
12.00 – 1.00 pm		6.00 – 7.00 pm	
1.00 – 2.00 pm			

Annex 2

Detail s of Existing Paving Blocks

Manufacturer				
Shape / Type				
Size in mm	length			
	width			
	thickness			
Unit price				
No of units per m ²				
Colour				
Usage	pedestrian			
	car park			
	gardening			
	other			
Strength achieved (N/mm ²)				
Standard used				
Output per day				
Manufacturing method				
No of blocks per cement bag				
Demand				
Mix proportions				
Course aggregate (Chip) (Kg or cube)				
Fine aggregate (Sand) (Kg or cube)				
Cement (kg)				
Water (l)				
Admixtures				

Annex 3

Cost Analysis for mud concrete paving block

Current Price of materials

Soil

Current industry soil price	= Rs. 3500 per 3 cubes
Lose Soil density	= 1440 kg / m ³
Price of Soil	= Rs. 3500 / (3*2.83*1440)
	= Rs. 0.30 per kg

Cement

Current industry cement price	= Rs. 900.00 per bag
Price of cement	= Rs. 900/50
	= Rs. 18.00 per kg

Current labour wage

The mud concrete paving block can be produced without skilled labour because of its simple production method. Therefore, the current labour wage of unskilled labour in construction industry can be assumed at Rs. 1000.00 per 8 hr day.



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

Price for form work material

In the manufacturing process of this block, a well prepared steel mould with several blocks can be used. For the production of the mould, a 4 inches thick, 8 ft x 4 ft in size steel plate is used. The price of a steel plate in the current market is Rs. 12,500.00 and the production of the mould may cost Rs. 7,500.00. Therefore, the total cost of the mould will be Rs. 20,000.00. This steel plate mould can be used for 80 numbers of mud concrete paving blocks.

Cost for mud concrete paving block

Block size	= 200 mm x 100 mm x 80 mm
Volume of block	= 200 x 100 x 80 mm ³
	= 0.0016 m ³
Measured actual weight of block (average)	= 3.66 kg

According to the mix proportions

Soil = 100 kg

Cement = 22 Kg

Total weight = 122 Kg

Therefore, actual requirement for a block:

Material cost

Soil weight = $(100 \times 3.66) / 122 = 3.0\text{kg}$

Cost for soil = $\text{Rs. } 0.30 \times 3 \text{ kg} = \text{Rs. } 0.90$

Cement weight = $(22 \times 3.66) / 122 = 0.66\text{Kg}$

Cost for cement = $\text{Rs. } 18.00 \times 0.66 \text{ kg} = \text{Rs. } 12.00$

Total material cost = cost for Soil + cost for cement

= $\text{Rs. } (12.00 + 0.90) = \text{Rs. } 12.90$

Form work cost

Assume steel mould can be used 200 times repetitively and 80 numbers of block mould can be assembled with the above mentioned size one steel plate.

Cost for use of one time = $\text{Rs. } 20,000.00 / 200$
= $\text{Rs. } 100.00$

Form work cost for a block = $\text{Rs. } 100.00 / 80$

= $\text{Rs. } 1.25$

Labour cost

Assume blocks can be cast four times a day with three numbers of labourers.

Nos of block cast per day = 80×4

= 320

Cot for labour for a block = $\text{Rs. } (1000.00 \times 3) / 320$

= $\text{Rs. } 9.38$

Total cost for production of mud concrete block = (material cost + form work cost + labour cost)

= $\text{Rs. } 23.53$

Add 25% profit = $\text{Rs. } 23.53 \times 25\%$

Total cost for block = $\text{Rs. } 29.41$

= $\text{Rs. } 29.40$