MUD CONCRETE AS AN ALTERNATIVE PAVING MATERIAL

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An experimental study has been carried out to find the suitability of using Mud Concrete as a paving material for low-volume rural roads in Sri Lanka

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

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Date: 23 December 2019

The above candidate has carried out research for the Master's dissertation under my supervision.

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Research Supervisor

Prof. Rangika Halwatura

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Date: …………………………..

ABSTRACT

Along with the highways, main roads and connecting roads, rural roads which comprise of the largest portion of roads should also be improved, refurbished and maintained every so often. The limited amount of budgetary allocation will restrict what needs to be done. The conventional methods available at moment are not always within the budget range of regional administration bodies. Thus, some rural roads never see the development they need and will remain remote forever.

The underprivileged communities living in these areas fall behind due to these inaccessible roads thus they sgould be able take matters into their own hand and find the best solution for themselves.

Considering the critical cost factor., most of the road cost goes for the supply of material in each method of paving. In addition, the special machinery used for laying and labour costs will limit its affordability. If a more economical material can be invented which will not require additional manpower, it will be ideal for such communities to implement.

Hence, as a result, Mud Concrete, a paving material which has the same characteristic that of other methods such as Concreting, Concrete blocks etc. is introduced. This study will conduct some experimental studies on this material. i.e on strength, durability and thermal performances and observe how it will behave in actual condition. Finally, feedback/views from the general public will be recorded.

The developed mix design for the mud concrete used consists of laterite soil (sieved with 20 mm sieve) with 5% of clay, 60% of Sand particles and 35% of gravel particles mixed with 18% of cement by weight to obtain a workable mix, layed using the same method of concreting.

The section constructed at the actual condition showed 14.2 N/mm^2 at 28 days showed no signs of thermal cracks. The surface was even, and no weathering was observed. The section was able to withstand different weather conditions and showed no significant damages.

The thermal behavior of the surface was measured and compared with other paving methods such as Asphalt, Primed, Concrete, Concrete blocks. Asphalt and primed sections indicated higher surface temperature peaking highest around 1.00 p.m. to 3.00 p.m. Concrete and concrete block were slightly lesser than above, but Mud Concrete displayed considerably lower temperature rises almost same as the normal gravel ground. The natural surface colour of Mud concrete created an aesthetically appealing sight to the eye.

The pavement was subjected to a heavy load induced by heavy vehicle but did not caused any damages to the surface or the base.

The feedback given by the road users after a half a year, depicted that they are satisfied with how the new material behaved against the more well-known paving materials. Almost all the responders suggested that they would recommend the Mud Concrete to be tested in other similar roads.

Key words*: Mud Concrete, Road pavements, paving materials, sustainability, low-cost*

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B.M.S.D Bandaranayake

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Chapter 1

1.1.Introduction

1.1.1. General

Sri Lanka has a total road network of about 116,000 km as of 2007 excluding Expressways. Out of this more than 75% can be considered as local authority roads (Class E) and unclassified roads controlled by different authorities (Road Development Authority, 2007) . Along the prompt development in rural zones in Sri Lanka, many roads connecting rural communities with nearest municipality are continuously under reconstruction or improvement. In (Galabada, 2016)the Standard of living and quality of life of these rural villages, it is vital to standardize these roads as they also play a major role in a country's economy.

Considering the funding available for rural roads and effect to environment caused by these developments, it is important to go for more economical paving technique with lowest embodied energy possible.

As existing paving methods have their own drawbacks, in this study it is proposed to develop a more environmentally friendly, economical, durable, convenient road paving technique using mud concrete which will endure various climate conditions in Sri Lanka.

This study will observe the strength, surface temperature variation and durability factors of the Mud concrete with compared to four other conventional paving methods

In Sri Lanka, the tendency for constructing roads with different material was spiked to its highest in recent decades. Thus, even the naturally existed footpaths were widened and improved with surface pavements. It was all thanks to the government's interference and massive contribution in developing infrastructure around the country. The officials were keen on experimenting with more convenient methods. Thus, different types were tested, and successful ones were adapted to the sites.

Most of the low volume roads are usually gravel roads which face decades of surface deterioration. Such weathered surfaces make it difficult for smooth mobility and comfort in travelling. Thus, the surfacing method plays a key role in road condition improvement. Hence, more economical and convenient methods should be introduced for surfacing techniques.

1.1.2. Problem Statement

In selecting a suitable road construction technique for these low volume roads, there are major issues to be considered with. As most of the funding for these projects can be limited, a more economical paving technique should be adopted.

Although, most of these roads are considered low volume, they function in more extreme conditions with lowest maintenance, hence prone to rapid wearing and weathering. Thus, the paving material should be strong, water resist, durable with more skid resistance and should be able to withstand temperature variations.

Throughout the last decade, the first choice of road paving technique in rectifying low volume roads is to use concreting. Concreting roads were cost effective, easy to construct etc. But the embodied energy is considerably high, and disposal was not so environmentally responsive. With time another option was introduced i.e. Covering roads using concrete paving blocks. Although it seems more convenient at the time, it led to numerous environmental and durability issues; hence, using concrete paving has been falling out of practice ever since.

With time, some of these low volume roads were upgraded enough to construct using Asphalt concreting, which is very costly, difficult to conduct, takes time, expertise and heavy machinery which made it non practicable to do so with funding availability and site conditions etc.

Although these different techniques have their own advantages, they also show certain drawbacks. Hence, a paving material with optimum required characteristics those should be introduced as an alternative.

1.2.Objective

The main goal of this study is to evaluate the suitability of a mud concrete mix to be use as paving material for rural roads

1.2.1. Sub objectives

- To evaluate its strength and durability of Mud Concrete as paving material
- To compare its thermal behavior compared to other conventional methods
- To study its behavior under normal exposure conditions in long term
- To get feedback and opinion on Mud concrete from the road users in long run.

1.3.Methodology

Following basic procedure was followed in producing this report

- Literature Survey - Similar texts/ contents were referred in arranging the experimental part of this research. Literature on other materials, their performances, characteristics and properties were studied along with the studies done for the material in question
- Experimental work – Laboratory tests were conducted to test the suitability of soil sample, run a trail test for the selected mix design, conduct trail test to get an idea on the water content, mixing method, laying method and assess labour requirement
- Prior Site Experiment - Material extraction, selecting suitable site for the test road section, ground preparation
- During Site Experiment – Base preparation suitable for each material. Casting equal sections of Mud Concrete, Normal Concrete, Concrete Blocks, Asphalt

Concrete and Primed sections. Curing as required. Casting of test cubes for Mud concrete sample used at site.

- Testing – Cube test for 28 days strength. Installation of temperature measuring sensors on each surface. Measuring temperature variation and recording using data logger.
- Loading test after 28 days and 3 months using heavy machinery
- Feedback from the road users after 6 months and observation of the surface conditions

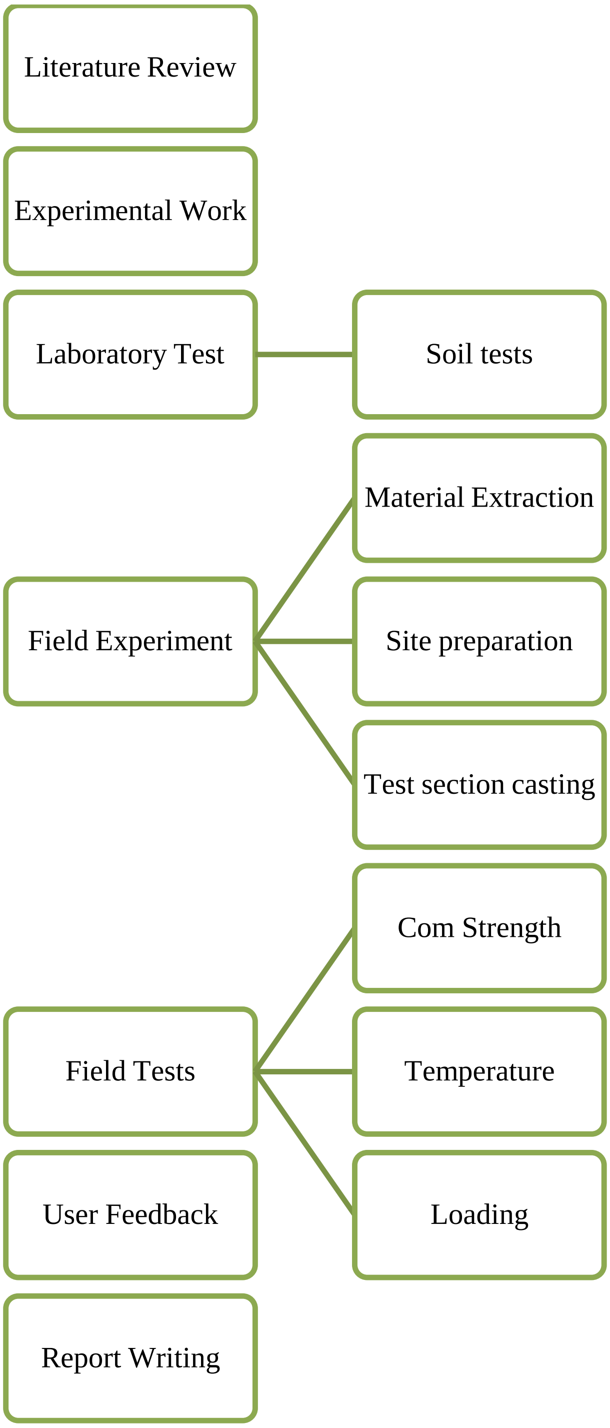

Figure 1- Methodology

1.4.Expected findings

This research focuses on experimenting on the possibility of using Mud Concrete as a paving material in rural roads. Mud Concrete is a mix combining normal soil mixed with cement as a stabilizing agent and water. The primary substance used in the mix (soil) is locally available, low cost and environmentally friendly disposable. This research tends to find whether the processed mix will comprise with the required strength capacities and show desirable temperature variation, withstand actual climatic conditions and loading tests with time.

Finally, it is expected to find the feedback and opinions of the road users who were allowed to use the test road for some time period.

1.5.Arrangement of the report

Chapter 2 - will disclose the literature review done prior to experimental work. It investigates different paving materials, their performances, drawback, testing done for the strength and temperature aspects etc.

Chapter 3- a detailed demonstration of experimental work carried for the research. Laboratory test and results obtained, preparation for field tests, conducting field tests, observation over the time etc.

Chapter 4- data analysis of the results obtained especially temperature variation. Behavior through time and user feedback and opinion on new material

Chapter 5 - includes conclusions, future recommendations and limitations of this experimental work based on.

Chapter 2

1.6.Literature Review

1.6.1. General

Before studying Mud Concrete, it is important to have a clear idea of how its predecessor became the most sort out material in construction world today.

From the invention of the Concrete, people have been using concrete in order to make every construction more convenient. It is general public's opinion that concrete is one of the strongest structural materials ever invented.

Hence concrete has been used for much construction as buildings, bridges, dams, towers etc.

One of another most interesting utilization of concrete is paving roads. Concrete has been used as a paving material for a better part of the last decade. Even in Sri Lanka, most of the rural roads are made of concrete or using paving blocks.

Based on the limited budgetary allocations, it is a somewhat difficult and time-consuming process to get these local roads approved for upgrading. Hence it is important to seek for more and more locally available sustainable techniques to achieve the required.

1.6.2. Concrete paving and interlocking block pavements

In the process of developing more suitable guidelines for construction of low volume concrete roads in Sri Lanka, (Mampearachchi & Priyantha, 2011) carried out a survey to study the practices currently used by the local contractors and their knowledge on constructing concrete roads. Since the results showed poor the today's situations are, they have introduced some best practices which can be adopted easily by the local construction industry.

In this article it was mentioned that since 2007, Concrete paving has been used as THE method for low volume roads in Sri Lanka. Even the government funding allocated for local government agencies are for pumped to construct concrete pavements. In this study they considered relatively low volume roads as roads with an Average Daily Traffic (ADT) of less than 400 vehicles per day. As believed Concrete roads have less maintenance cost and when Life Cycle Cost Analysis (LCCA) is applied, they are far less expensive than Asphalt roads. Hence, at the end Concrete has been stapled as a much more suitable material for low volume roads in Sri Lanka for a long period of time.

Interlocking concrete block is the other most widely used and generally more known method of paving in rural roads in Sri Lanka. It is by far the closest alternative to which a substitution can be introduced with Mud Concrete blocks. Interlocking block paving became more popular around the world as they are easier in constructing and maintain rather than concrete slab roads or asphalt concrete roads. (Bharathi Murugan, Natarajan, & Chen, 2016).

But they have been using for only roads with slow traffic due to its weakening at interlocking joints. Thus, interlocking blocks raise durability issues compared to the above other methods, studying their performance under aggressive environment might shed some light onto how the mud concrete as a material can be improved to withstand similar settings (El Nouhy & Zeedan, 2012). They further states that, the surface can be affected by means such as chemical cause (by chloride attacks etc), physical cause such as exposure to higher temperature variations and mechanical causes usually cause by abrasion. After comparative experiments with a controlled mix, the researchers have found that exposing to air/dry and wet/dry conditions as well as acid attacks increase the compressive strength and reduce water absorption. But none of these subjects in aggressive environments were able to meet ASTM pertaining abrasion.

A Mud Concrete which is going to be explored here is a rigid pavement type which is similar to Concrete pavements; the commonly used rigid pavement method in Sri

Lanka. In their paper (Suja & Marliyas, 2016) have covered over 108 randomly selected rigid pavement roads and identified over 10 different failure types encountered in Sri Lanka. The concrete pavement was introduced to overcome to surface damages to the bituminous layers during heavy rains and dust conditions of gravel roads during dry seasons. Both creates inconveniences to the users regarding safety and health concerns.

Study has found that the most severe failure encountered in rigid pavements are the polished aggregates. Removed finer particles due to vehicle abrasion will expose the aggregate in concrete causing irregularities on the surface. Poor quality material and inexperienced workmanship may cause this problem

Another kind of damage is the scaling which cause potholes without concrete top layer exposing subbase.

Commonly encountered crack types in the pavement were transverse cracks, edge damages which caused due to insufficient provision of transverse joints and excessive loading at edges respectively. When the drainage facilities are not provided properly, the erosion of subgrade at edges also caused the concrete slab itself to fail due to poor ground support.

Since similar failures can be expected to be occur in Mud Concrete pavements it is essential to identify what causes such failures and follow proper procedures to mitigate them starting from the selection of material to construction.

1.6.3. Alternatives

Experiments on incorporating various materials and methods to improve the performances of existing road paving methods has being continuously in action as the demands in transportation sector upsurge day by day. Some of such experiments are further explored below.

(Fykubayashi & Kimura, 2014), in this article the researchers have developed a method to reinforce the base course with “do-nou”, a term used for soil bag, in Japanese. They have confirmed the applicability and limitations of this method through a series of demonstrations conducted in Kenya, for typical sections with flat terrains, sags and gentle slopes where they were damaged during rainy seasons. They also state that this method was experimented to improve accessibility of rural access roads to communities in rural areas of the developing countries. In addition, this method was developed to mobilize local available resources and get the community involved. During the assessments in Kenya, they have found that such methods empowers the community to initiate its own development enables them to utilize their skills and helps them in repairing their own roads improve conditions of the roads by themselves at a low cost.

However, this method was beyond from using for steep slopes.

1.6.4. Cement Stabilized rammed earth for Roads

The following conference paper presented by team of Sri Lankan researchers (Arandara, Jayasinghe, & Jayasinghe, 2010) studies a similar method already in use in Sri Lanka. Though at time CSE method was invented as an experimental material, nowadays it can be seen used in various occasions.

CSE or more widely known as Cement Stabilized Earth is a type of material produced by mixing a certain percentage of cement with normally available laterite soil to enhance its characteristics and performances. The field trial followed this specific research, intended to achieve a road fulfilling the two most important requirements, i.e. strength and durability. The road was constructed in two layers finishing at a minimum thickness of 150 mm, the bottom layer contributing to the strength while top layer acts as a wearing course with lighter colour in order to control heat generation from the surface.

During experiment stages, the clay content found in the soil available at site was found to be 40% which leads to adjustments in soil composition. After improving the soil composition to the recommended range, the soil was kept covered to control moisture content. Based on the results obtained for the cement stabilized soil for rammed earth trials, with 10% cement, a compressive strength of about 2.5 N/mm2 could be achieved. Henceforth the same cement content was used providing an ideal compaction ratio of 1.7.

The wearing course was made more durable by adding 6-8 chips to the cement-soil mix to withstand the weathering by rain and to provide adequate abrasion resistance to traffic. A thickness of 100-150 mm was maintained with 1:4:4 cement, soil and aggregate to avoid shrinkage cracks.

But the roads with stabilized earth must be provided with drainage, preferably with concrete, which is a major difference with mud concrete roads, in which providing drainage is optional.

Over the cause of period of three years in operation, the surface was small wearing occurred with exposed chips which increased the Solar Reflectance index.

The above experiment was done in the main access roads and parking areas of MAS Intimates Thurulie (Pvt) Ltd as one aspect of gaining LEED certification for sustainable design.

1.6.5. Reducing embodied energy with innovative materials

Mud concrete as a material has been tested in block form prior. (Udawattha & Halwatura, 2016) have calculated the embodied energy of Mud concrete blocks against other building materials such as bricks and cement blocks. World today, looks into more energy efficient, environmentally friendly alternatives with low carbon footprint. In countries like ours, construction cost is higher than the operational cost. Thus, the embodied energy of a material will clearly indicate how sustainable the material is. Embodied energy of a certain material can be calculated by summing up the direct and indirect energy consumed throughout its production process. When calculating embodied energy of a wholesome item (say building and road), individual embodied energy of each material incorporated contribute in dissimilar proportions.

According to (Zapata & Gambatese, 2005) for continuously reinforced concrete pavements primarily energy is consumed during cement and steel manufacturing processes. Together it will weigh up to 94% of total embodied energy. They conclude that for Asphalt pavements, 48% of energy goes to mixing and drying of aggregate while about 50% will be consumed by bitumen production. They further suggest that following their findings, innovative new methods will reduce embodied energy of a road pavement.

Through the research of (Udawattha & Halwatura, 2016) it was found that Mud Concrete blocks has the comparatively lowest embodied energy due to readily available raw material and lack of energy required for separate manufacturing process. Reducing the energy required for transportation (since the material are available at site) Mud Concrete comprise lesser embodied energy compared all the other method use today.

Thus, it is important to explore whether a material such as Mud Concrete which is proven to be sustainable can be adopted into road pavements. Hence this study will take a leading step on it.

Another study takes the basic concept of mud concrete (Thamizh Thendral & Dhanalakshmi, 2016) a bit further and cast the blocks with straw to assess its compressive strength. Adding straw does not indicate any significant contribution to the strength and durability of the mix. Hence the option of mixing straw will not be discussed further for this research. (Somarathna, et al., 2012) further confirms that adding has reduced required strength though it reduces the unit weight.

A similar study was carried out by (Jimenez, Ayuso, Galvin, Lopez, & Agrela, 2012) to evaluate the use of recycled aggregate and demolition waste to be used as a paving material for rural roads. After analyzing its bearing capacities and international roughness index, they concluded that CDW with low embodied energy can be recycled into a material that can be utilized as an alternative to the natural aggregate used for road paving.

1.6.6. Stabilized earth

Natural earth is the most versatile material that can be found in construction field. Various types of materials with different characteristics can be added to enhance a certain preferable characteristic of soil based on its use. Study (Guettala, Abibsi, & Houari, 2006) used four of these stabilizers i.e. cement, lime, cement plus lime and cement plus resin and tested its properties in both laboratory and actual climate conditions. Though all specimens showed little to no deterioration in long run but among them cement with resins gives the best results.

(Sitton, Zeinali, Heidarian , & Story , 2018) states that a unit block performance of compressed earth blocks depends on the characteristics of soil and the mix design. After testing for different conditions, the optimal mix contained 10.91 % cement and 11.4% water showed an average compressive strength of 15.15 MPa.

Study (Arooz & Halwatura, 2018) provides a ground basis to the mix on which this research to be advanced from. The primary concept was to develop this new material to incorporate properties (i.e. strength and durability) of ordinary concrete. Experimental work of (Arooz & Halwatura, 2018) determined a mix design with 4% minimum cement as stabilizer for a soil of 10% fine particles, 55-60% sand particles and 30-35% gravel particle containing soil sample for 18-20% water content. The higher water content was used to hydrate cement and maintain a workable mix.

The mix was subjected to an accelerated erosion test for 1 hour and the surface was observed. The results have indicated that there is no significant damages or cavities on surface and appearance remained almost unchanged.

This particular research was done for block solely with the purpose of using for walling material whilst the research (Galabada, 2016) on which this report was based on tested mud concrete blocks for outdoor paving purposes. Thus, as a basis the composition suggested by (Galabada, 2016) was adopted for further experiments

Similar experiments on this concept have been conducted in other counties as well. (Zainal, 2014) investigate on finding a suitable curing method and a compressive strength foe CEIB. Through his finding, it was concluded that drying in sun for 7 days will give the highest compressive strength. Laterite soil, mine sand and cement were used to caste his specimen and mix with cement ratio of 1:5 was able to achieve a compressive strength of 8.6 MPa, which is the highest for his test.

It is common knowledge that natural soil absorbs solar radiation and reflect minimum heat. It is one of the many reasons that in ancient time, soil was the main substance used in build environment. Soil surfaces are much cooler compared to any other material even in common experience.

1.6.7. Surface temperature

One of the drawbacks of modern paving material is their higher heat reflectivity creating heat island effect within their presence. Thus, it is a value added if the new material can reflect comparatively low heat radiation. This perception was experimented further in this.

(Higashiyama, Sano, & Nakanishi, 2016) in their studies address the surface temperature of asphalt pavements with field experiments. They state that pavements covering the majority of urban environments largely affect the heat island phenomenon in urban areas. The authors created a cement based grouting material poured over the voids of asphalt pavements. They achieved a reduction of temperature by 10^0C using this method. A similar, toned down experimental procedure was followed with different paving materials by followed for this research to measure surface temperature distributions with time.

Another study assessing the temperature conditions of the roadway surfacing provides a solution to reduce the socio-economic losses caused due to road traffic accidents by predicting average temperatures to calculate parameters of road surfacing which will help to determine a set of actions to improve road conditions and traffic safety (Lazarev, Medres, Raty, & Bondarenko, 2017). During their experiments and modelling they found that asphalt concrete road surface varies with a great range during the day which gives a negative impact on the performance characteristic of the road surface. The temperature fluctuation of the road surface is proportional to the range of air temperature within a relationship between them

Heating of road surface significantly impacts human factor as well. The temperature 1.0-1.5 m above the surface vary proportionally to the temperature of the surface which can affect pedestrian or divers at days of higher air temperature. Hence, they conclude that being able to control surface temperature is vital in road users' conditions and safety. Thus, it is important to investigate whether the novel material we used will be able to control temperature compared to the asphalt surfaces.

Chapter 3

1.7.Experimental Work

1.7.1. General

Experiments were conducted both in laboratory and in the field. Laboratory tests were conducted to evaluate the properties of the soil sample before using to decide whether it require any improving. Trail tests were done at the laboratory to get familiarize with the soil when it is mixed according to the mix design. The mixing process, approximate water content to obtain a workable mix, placing techniques and labour and time requirements observed during this trial test before starting actual casting at site. For the field test, the road section was selected, the base was prepared by leveling, test sections of Med concrete and other materials were placed parallelly.

Cube test was conducted to the soil mix at site and surface temperature measuring was done comparatively. Loading test was done after 3 months of casting and user feedback was recorded after 6 months of using.

1.7.2. Sample collection

In order to conduct this experiment, the soil samples were extracted from a burrow pit in Beliatta area.

Figure 2- Burrow pit where soil was extracted for testing

Then the collected soil samples were tested for its constituents (i.e. its Gravel, Sand and Silt Proportions) and their gradation. The suitability of using this soil in actual site condition was determined only after obtaining the following test results. Since, this experiment is a follow up for the experiment done on Mud Concrete Blocks (Galabada, 2016), the final properties suggested by the above research were to be achieved. Following its methodology, the same sedimentation test and the dry sieve analysis were conducted on the new samples.

1.8.Material Testing

1.8.1. Soil Tests

Two laboratory tests were conducted on soil sample prior to site experimental work. Initially, the collected soil was air dried for 24 hrs before using it on either test. The properties and constituent were tested using Sedimentation test and gradation using Dry sieve analysis test. All the initial tests for this experiment were done at the RDA-Southern Province- Material Testing Laboratory.

1.8.2. Sedimentation Test

½ *l* transparent measuring cylinder was filled 1:3 Soil: Distilled Water proportions. Then the content was shaken thoroughly and left to rest for 24 hrs. After the soil was regimented, each distinguish layer observed was measured using the scale in cylinder as a depth measurement. The percentages of each segment were calculated proportionate to the layer thicknesses.

Observed as the test proceeds, the Gravel layer is settled at the bottom most part of the cylinder. On top of that rests the Sand layer while Silt with Clay sediments on top. Measuring the thicknesses/depths was taken as an indication for each fragment's proportion. Though this measuring technique has some shortcoming in accuracy wise due to lack of consideration on 'voids', this test can be used as an initial stage in discovering the basic properties of the soil used.

Figure 3- Preparing soil for sedimentation test

Figure 4- Soil kept undisturbed for sedimentation

Sedimentation test was done in several Trials and the mean value is as follows.

Table 1- Sedimentation test results

Particle Type	**Trial 01**	**Trial 02**	**Mean**
Gravel	55.56%	35.71%	45.64%
Sand	22.22%	32.14%	27.18%
Silt/Clay	22.22%	32.14%	27.18%

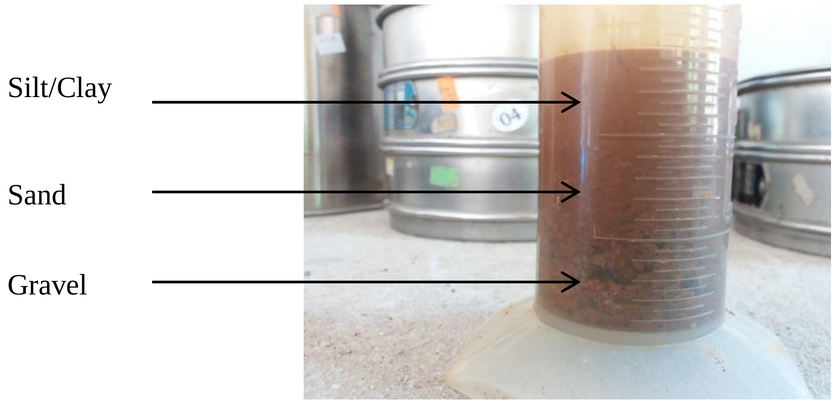

Figure 5-Sedimentation layers

These values are approximate and the experiment (Galabada, 2016) on which this one was based on had approximately 22% fine particles, 28% sand and 50% gravel.

1.8.3. Sieve Analysis Test

A sample for about 4 kg of soil was air dried for 24 hrs by spreading evenly. Then it was mixed thoroughly before testing. The set of sieves were cleaned well and arranged accordingly. Soil sample was weighted before placing in sieves and then the sample was agitated for proper straining. Then the retained proportions in each critical sieve were weighed carefully.

Figure 6 - Air drying for overnight

Figure 7- Sample mixing and dividing


Figure 8- Sieve Analysis 1


Figure 9- Sieve Analysis 2

Since primary objective of this experiment is to calculate exact proportions of gravel, sand, clay segment in soil sample, it is important to decide the exact sieve size in which each particle separate. Following (Galabada, 2016)'s experiment, particles retained in sieves 4.75 mm or above were considered Gravel while proportion retained between 4.75 mm – 0.425 mm were considered Sand. Content passed thorough 0.425 mm sieve and into the pan were considered Clay or Silt.

1.8.3.1. Results

Table 2 Sieve analysis test results

	Percentage retaining %		
Sieve Size	**Sample 01**	**Sample 02**	**Mean**
20 mm	0	0	0
4.75 mm	30.576	35.000	32.788
0.425 mm	63.280	61.270	62.275
Pan	6.144	3.730	4.937

Table 3- Soil composition of the sample soil

Particle Type	**Percentages in soil sample**	**Ideal percentages that should be in sample** (Galabada, 2016)
Gravel	33%	35%
Sand	62%	60%
Clay/Silt	5%	5%

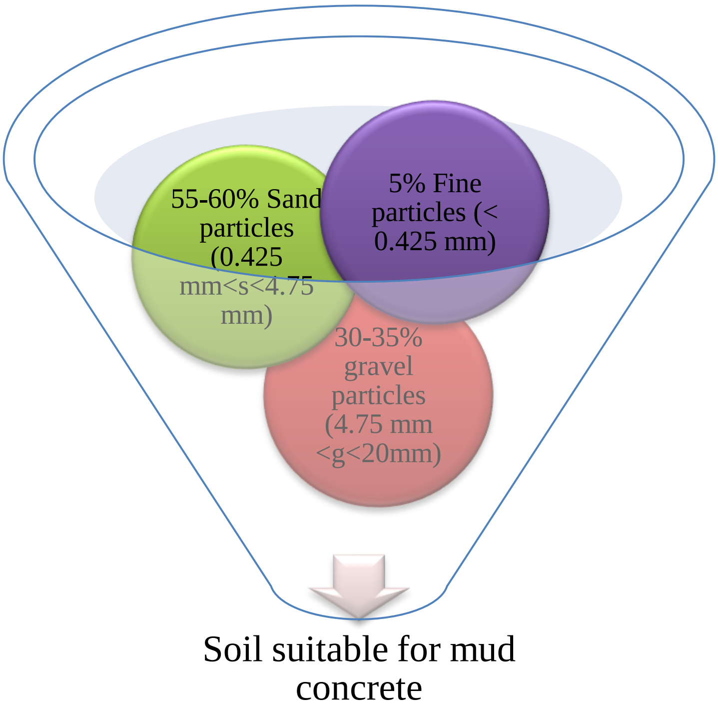

Figure 10- Composition of suitable soil

Thus, it was decided to use the soil sample collected in this experiment without any improvement or alteration.

1.9.Laboratory Experiments for Mix Design

1.9.1. General

According to the research done by (Galabada, 2016), a Mud concrete paving block has been developed to achieve the strength required by SLS 1425 standard. SLS 1425 PART I - 2011 states that 15 N/mm^2 of average strength is required for a strength class 04 concrete paving block pedestrian pavements. According to the ICTAD specifications used by the RDA procedures, minimal water cement ratio for Cement Concrete pavements- Manual oriented construction is generally taken as 0.5 in exercise.

Figure 11- Removing boulder and debris by sieving through 20mm sieve

Figure 12- Cement and soil mixing

Figure 13-Soil cubes are ready for compressive strength testing in dry condition

Figure 14- Prepared test cubes

Prior to constructing the actual road sections, using the soil sample collected sample test cubes were casted at laboratory. The soil collected was sieved through 20 mm sieve to remove the boulders and other debris. Next, a thoroughly mixed sample was separated and air dried for 24 hrs. the test specimens for sedimentation test and test cube casting were extracted from this soil.

Following above standards, and finding of the relevant literature, sample test cubes were casted using the collected soil sample and tested for 7 days and 28 days. For procedure see Figure 11-14.

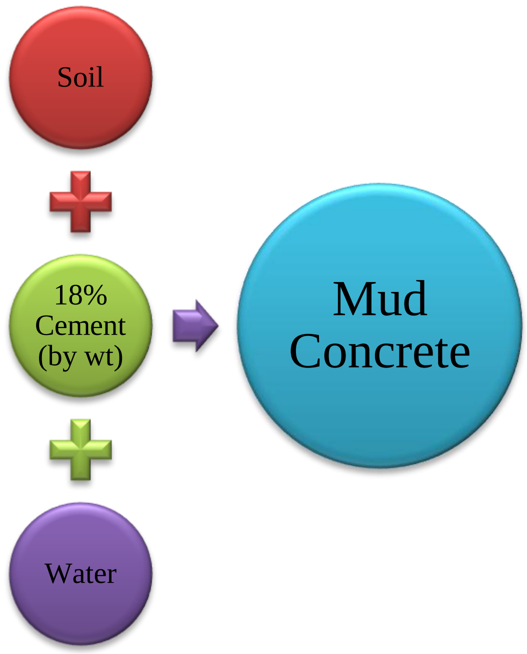

Figure 15-Content in Mud concrete mix

1.9.1.1. Results

Obtained results for the mix of 18% cement by weight for selected soil, showed the following results.

Table 4 - Laboratory compressive strength results

Duration	**Cube No**	**Load (kN)**	**Strength (N/mm^2)**
7 days after casting	01	165.8	7.37
	02	156.4	6.95
	03	167.6	7.45
	Mean		**7.26**
28 days after casting	04	275.3	12.24
	05	302.8	13.46
	06	344.1	15.29
	Mean		**13.66**

1.10. Construction of Mud Concrete Paving Road

1.10.1. Procedure

The on-site experiment was carried out to determine the suitability factors. In order to take a more comparable approach, same size of sample locations with few of the existing paving material were also tested under similar conditions.

An actual access road with about 3m width was selected to caste the sample road sections. Most suitable road section was selected, in order to receive sun rays throughout the daytime. The selected section was divided into equal portions of 2m and paved with different types of paving materials.

Figure 16- Prepared road section

First portion was constructed with laying a 150 mm thick ABC layer, compacted and sealed with a Prime coat of CSS-1. Second layer was constructed the same only to lay a 50mm Asphalt layer with wearing course. The third section was concreted with 1:2:4 concrete mix following the same procedure used for road pavement concreting and cured as per practice. The adjacent section was paved using the Mud Concrete Mix tested for this research (details of mix and laying procedures are described in section 3.3). Last portion was leveled with a sand layer and top layered with conventional Concrete blocks used for usual road paving. Beyond them remains the bare gravel ground. [See Figure 17]. After Concrete and Mud Concrete layers were cured properly for 07 days and 24 hrs respectively, the prepared sections were ready for testing.

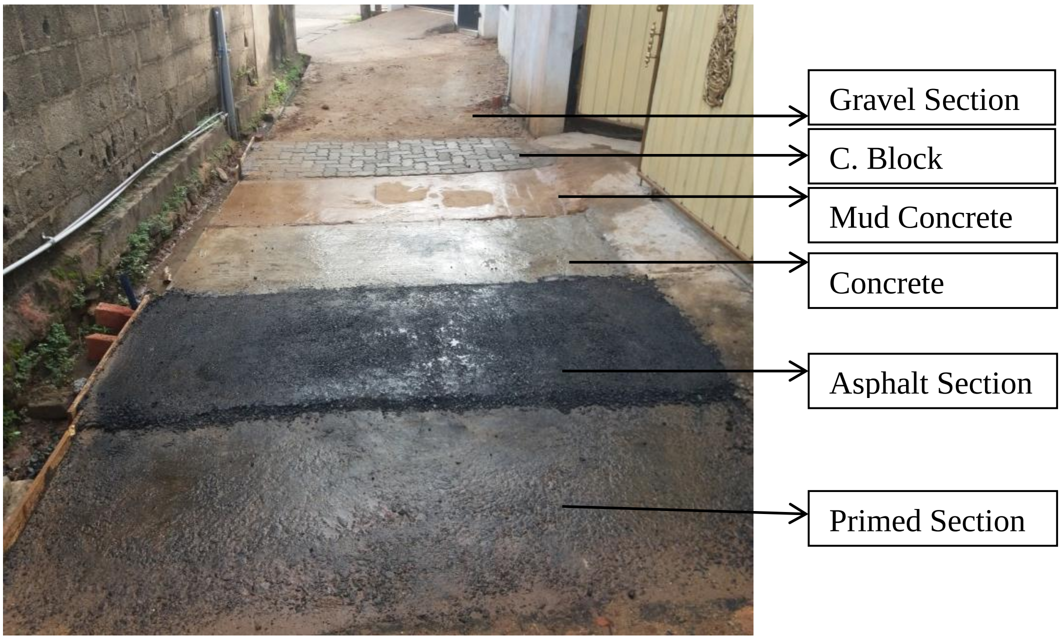

Figure 17- Comparative layers

1.10.2. Construction of testing sections

Figure 19- Low-volume road section selected for testing

Figure 18- Ground preparation for Asphalt and primed sections

Figure 20- Constructing other sections (Asphalt layer)

Figure 21- Dry mixing cement and soil for Mud Concrete

Figure 23-Preparing of Mud Concrete layer

Figure 22- Constructing other sections (Block layer)

Figure 24-Installation of thermal sensors

1.10.3. Cube test for the on-site Mud Concrete mix.

Three 150x150x150 mm cubes were casted for the mud concrete mix used at site. They are to be tested for Compressive strength at 28 days.

Figure 25- Cube casting for Mud concrete at site mix used at site

1.10.4. Loading Test

After 28 days in which all the sections are satisfying achieved their setting time, heavy machinery i.e. JCB 3CX Backhoe Loader– 17515 lb operational weight and 18701 lb max weight (≈ 8 ton) was placed on the prepared Mud Concrete section to observe its behavior (see Figure 25 and 26) under heavy static and moving loads.

Under both static and dynamic conditions, no visible damages/fails were done/occurred to the surface. Providing that all the paving materials specially mud concrete section were able to withstand such loads without even small surface cracks.

Same loading was applied on each section after a period of 6 months after casting, but even then, none of the sections showed any significant failures on the surface.

Figure 26-Loading on Mud Concrete section with heavy machinery vehicle after 28 days

Figure 27- Loading on Mud concrete section with heavy machinery vehicle after 3 months

1.10.5. Comparison of thermal performance

1.10.5.1. Methodology

The temperature on the surface of each paving type was measured using a ‘Data Logger’ for continual 24 hr. These 24 hr periods were measured during random dates and graphed were produced for each.

Data logger was installed at site and data was recorded continuously. On each surface, two sensors each was attached on to the surface and the mean value of two sensors for each material was calculated. All the materials (i.e. Mud Concrete, Concrete, Concrete Block, Asphalt, Primed and Gravel) were kept under similar normal exposure conditions.

Figure 28-Data logger

1.10.5.2. Results

Three separate sets temperature data were sorted from the recorded data for three separate dates with different weather conditions. The mean data were calculated for 30 minutes intervals for each material. (see Annex 1)

The analysis and comparison of these data are further described in section 4.1.2

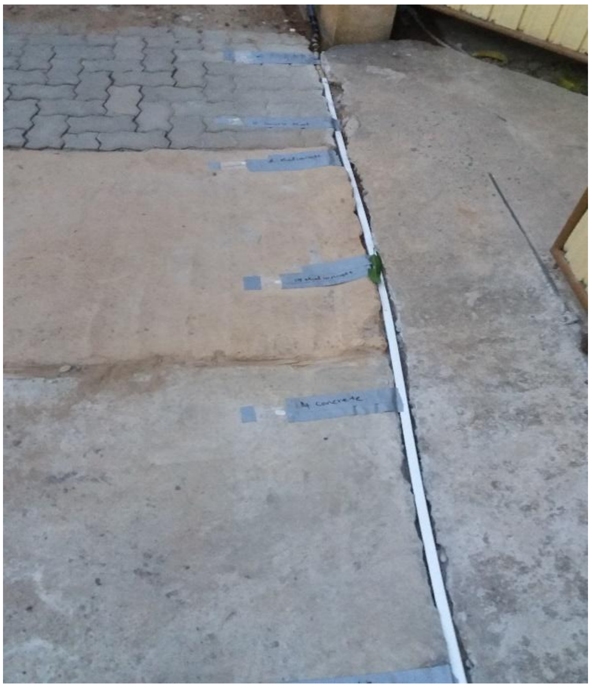

Figure 29- Sensors attached on surface of each material

Chapter 4

1.11. Data Analysis

1.11.1. Compressive Strength

In-situ casted test cubes were tested for calculating compressive strength of mud concrete sample used at the site after 28 days and following results were obtained (see Table 5)

Table 5- Compressive strength result of site sample

Cube No	**Load (kN)**	**Strength (N/mm^2)**
01	287.1	12.76
02	328.5	14.60
03re	342.6	15.23
Mean		**14.20**

Since it reaches the required strength, the in-situ section satisfied the required strength conditions for Mud concrete as per previous studies the sample section is said to have fulfilled compressive strength requirements.

1.11.2. Surface temperature

The surface temperatures measured using the data logger over the cause of three days are sorted and plotted into graphs. (see Figures 30-32)

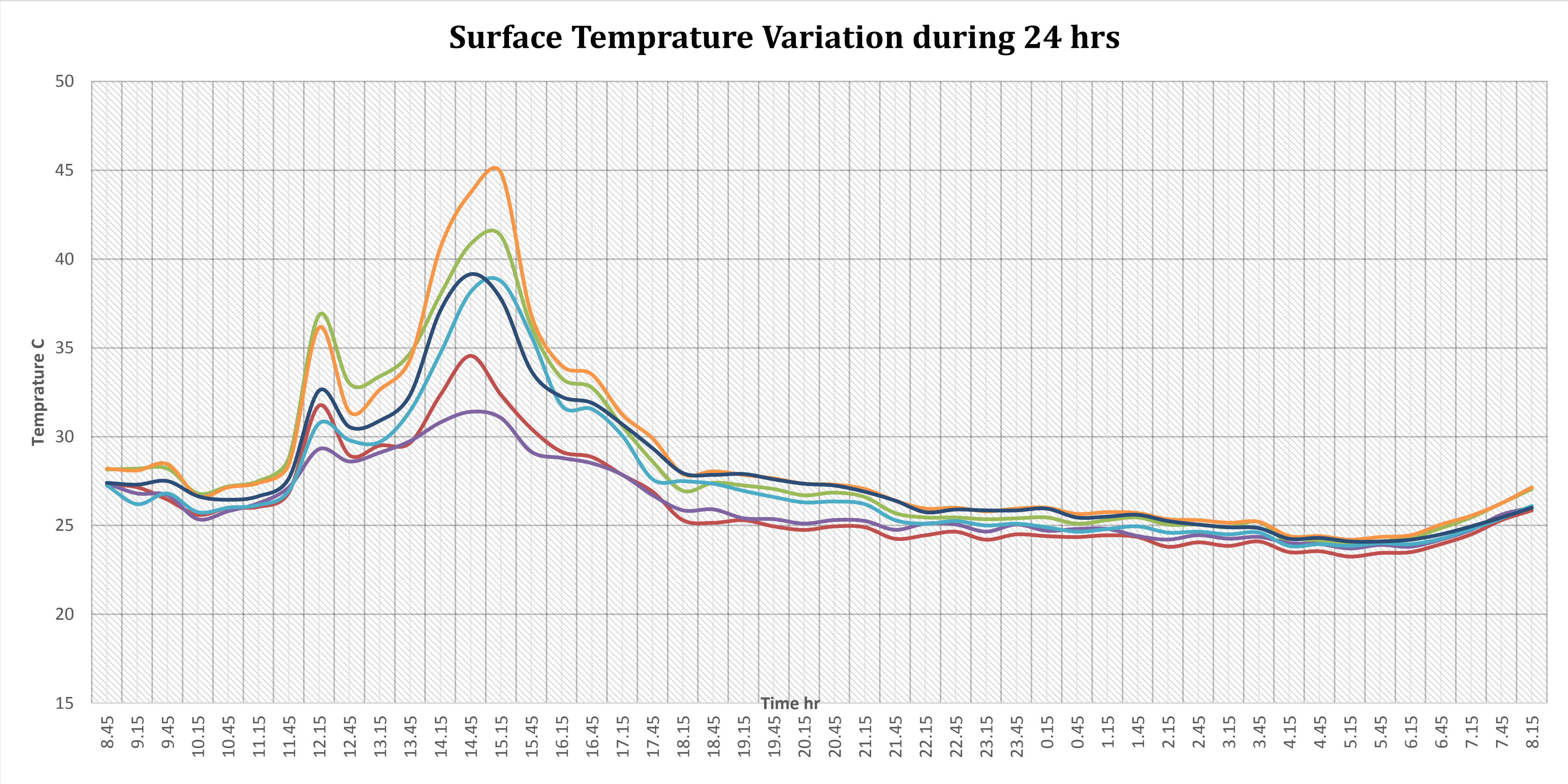

Figure 30- Surface temperature variation – Day 01

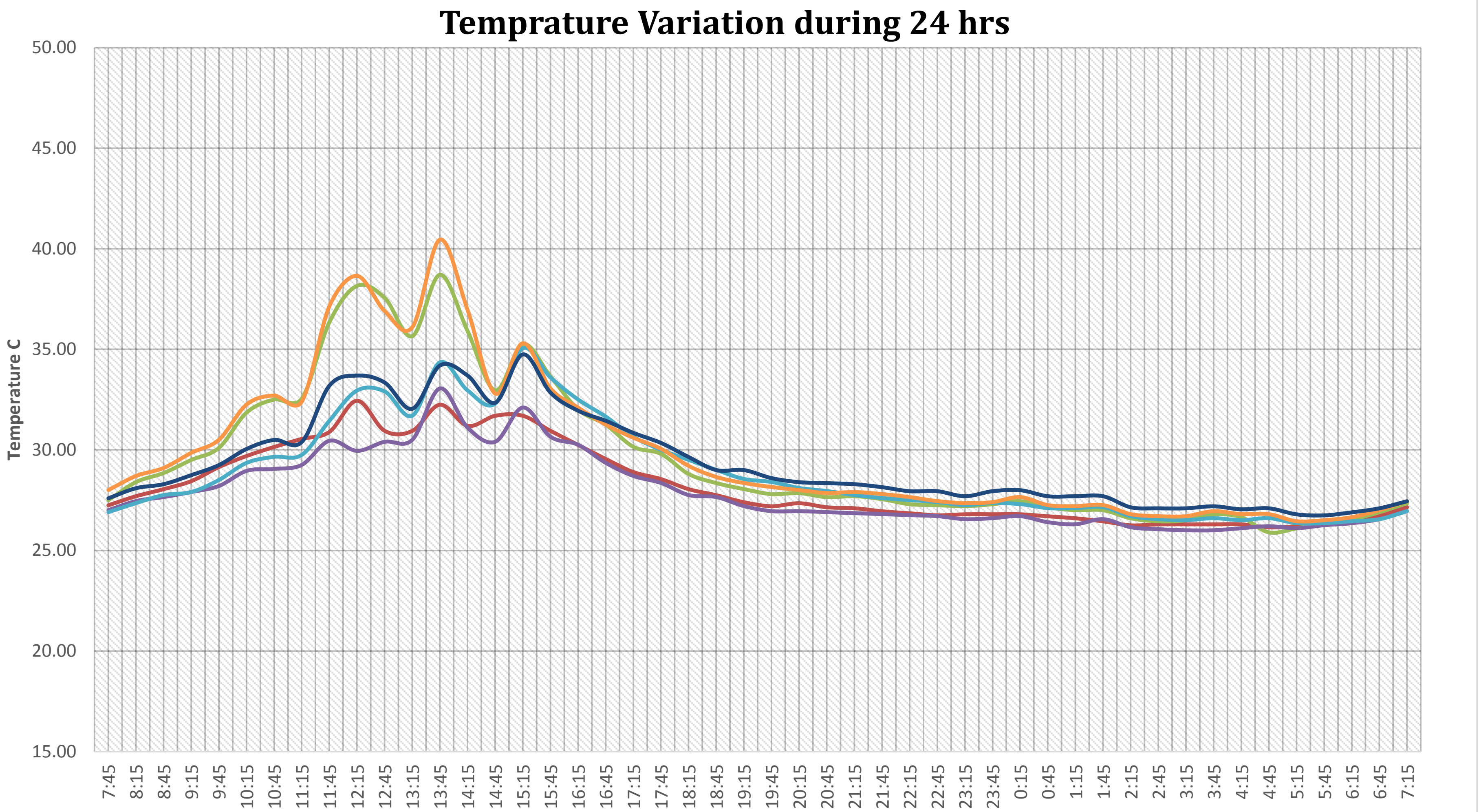

Figure 31- Surface temperature variation – Day 02

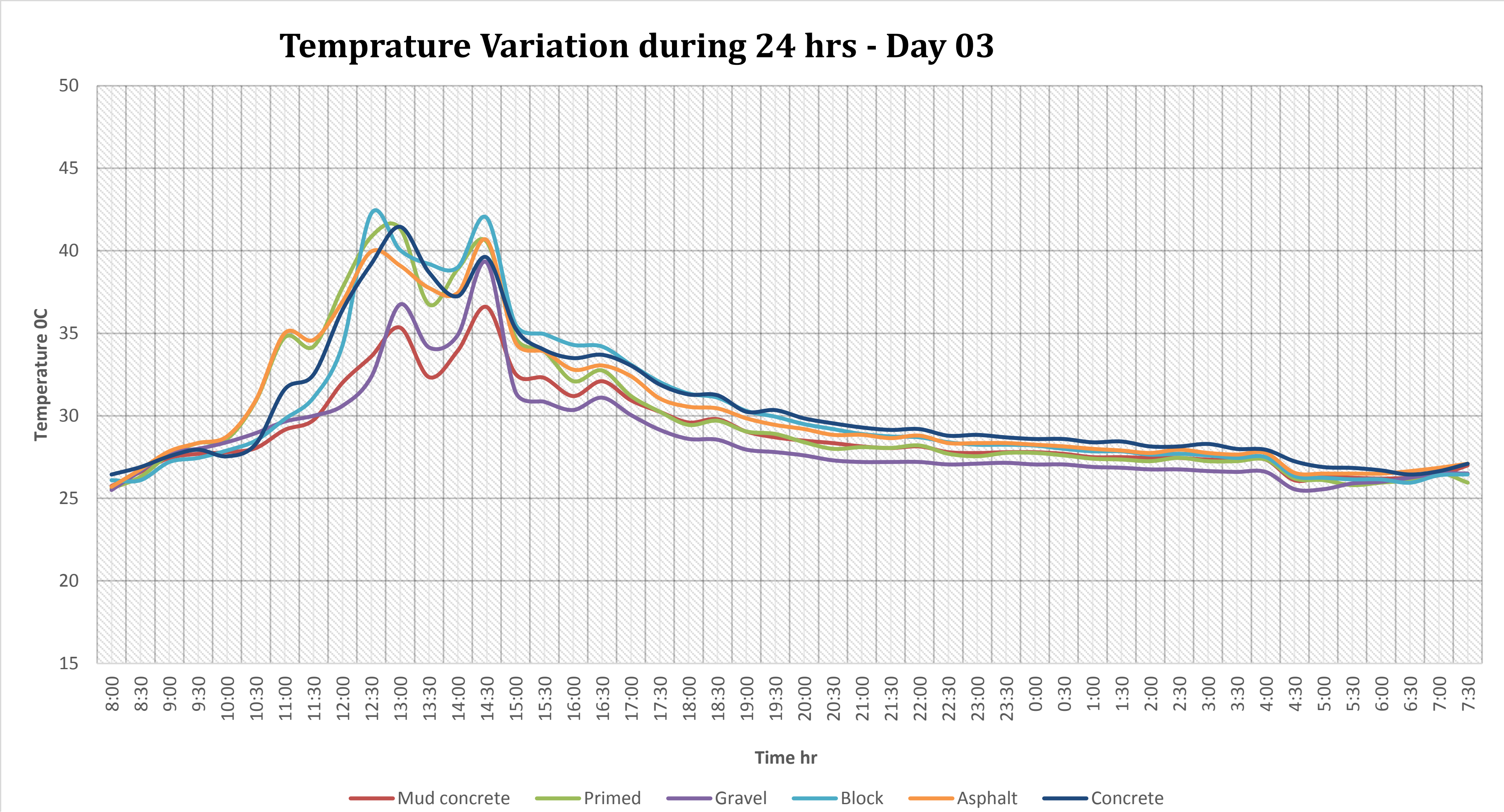

Figure 32- Surface temperature variation – Day 03

Observing the plotted three graphs Day 02 and 03 shows somewhat of an unusual variation during peak hrs. This may have caused due to sudden cloudiness of the sky or sudden shadiness imposed by any external factors. Thus, in analyzing the surface temperature variation, graph for Day 01 is considered mostly since it gives a more reliable smooth variation.

According to Figures 30, analyzing the temperature variation during 24 hrs, the maximum temperature rise is shown in materials such as Asphalted surface and Primed surface. During the peak hrs of 11.00 a.m. to about 3.00 p.m. the temperature scores the highest (nearly 40 ^{0}C) for such paving materials. Just below them, Concrete surfaces and Concrete Block surfaces indicate almost identical temperature variations with average of about 32 ^{0}C during the same time. Relatively Gravel surface and Mud concrete shows slight decrease in temperature compared to others. During the nighttime as well, Gravel and Mud concrete showed lower consistent temperatures compared to other four materials. In each time the difference is about 8-10^{0}C between Mud concrete and the asphalt layers. This is a considerable variation given that the surfaces are exposed to the exact whether condition.

Mud Concrete showing almost same surface temperature as the normal gravel road. But compared to normal gravel road, mud concrete roads have even, smooth surfaces, strength, resistance to erosion and minimum dust generation. Thus, Mud concrete have more advantages than normal gravel surfaces.

1.12. Heat and user comfort

Temperature increase in dark, non-reflective surface materials used in usual road construction causes pedestrian movement slightly uncomfortable. Material commonly used such as asphalt tend to absorb sun warmth and radiates them. This effect generates the “heat island” effect which causes the temperature near surface of such roads to be a few degrees higher than the surrounding surfaces. Hence using asphalt for low volume rural roads which are majorly used by pedestrians can cause them discomfort during daytime plus being the most expensive mode of them, it is not a very practice option. In such situations, far more cost effective, environmentally viable, maintainable and affordable methods are more ideal.

(Ministry of Higher Education and Highways Sri Lanka, 2017)

1.13. Long term behavior

After been operated under normal situation for nearly one year, there was a crack occurred at one of the wheel path of the constructed test section. Other than this slight failure due to differential settlement there were no thermal cracks on the surface was observed. No weathering of surface occurred due to abrasion. No erosion occurred though it faced some seasonal storms. Neither potholes nor surface layer removals were observed. There was no moss accumulated on the surface or any vegetation growth visible. No maintenance was done throughout this period and the surface behaved like that of concrete pavement.

Figure 33-Condition of Mud Concrete surface after 6 months of casting

Chapter 5

1.14. Cost Comparison

A cost comparison was done for each of the material used. The detailed analysis of cost calculation is annexed (see Annex 02)

HSR (Highway Schedule of Rates) 2017 for Southern Province was used as the reference for Labour/ machinery/ material rates. The rate breakdowns were prepared following the HSR ANALYSIS and compared as followed.

Construction details

Each section 2.0 m x 3.0 m surface

Mud Concrete and Concrete sections are 0.15 m in thickness

Asphalt and Primed sections are comprised with 0.15 m thick compacted ABC layer and (Tack coat+ 50 mm Asphalt layer) and Prime coat respectively

Cost for constructing each section is tabularized below

RDA Standard methods for constructing road strips (not more than 1.2 m wide) were followed while constructing each section.

Transportation Distances

Aggregate	25 km	Asphalt/premix	100 km
Sand	25 km	Bitumen	160 km
ABC	25 km	Interlocking blocks	15 km

Table 6- Cost for constructing each section

Description	Qty	Unit	Rate (Rs.)	Sub Total (Rs.)	Total Amount (Rs.)
Mud Concrete					
Sieving and Piling soil	0.9	m^3	1,661.83	1,495.64	
Mixing and laying Mud Concrete	0.9	m^3	6,501.29	5,851.16	**7,346.81**
Cement Concrete					
Mixing and laying concrete 1:2:4 (19mm)	0.9	m^3	13,659.54	12,293.59	
Transport Aggregate (25km)	0.81	m^3	600.29	486.23	
Transport Sand (25km)	0.54	m^3	600.29	324.16	**13,103.98**
Asphalt Concrete					
ABC laying, compacting	1.278	m^3	3,152.99	4,029.52	
Transport ABC (25km)	1.278	m^3	600.29	767.17	
Tack coat (@ 0.5 l/m^2)	3.0	m^2	41.32	123.96	
Transport Bitumen(160km)	0.003	m^3	1066.35	3.20	
Asphalt laying, compaction	0.3	m^3	7,647.29	2,294.19	
Transport premix (100 km)	0.3	m^3	3,709.30	1,112.79	**8,360.83**
Prime Surfaced					
ABC laying, compacting	1.278	m^3	3,152.99	4,029.52	
Transport ABC (25km)	1.278	m^3	600.29	767.17	
Prime coat (@ 1.0 l/m^2) incl sand sealing	6.0	m^2	90.47	542.79	

Transport Bitumen(160km)	0.006	m^3	1066.35	6.4	
Transport Sand (25km)	0.024	m^3	600.29	14.41	**5,487.56**
Interlocking Block paving					
Blocks	248	No	34.00	8,432.00	
5% wastage	12	No	34.00	408.00	
Transport Blocks (15 km)	260	block/km	0.12	468.00	
Paving and sand bedding	6.0	m^2	435.34	2,612.04	
Transport Sand (25km)	0.3	m^3	600.29	180.09	**12,100.13**

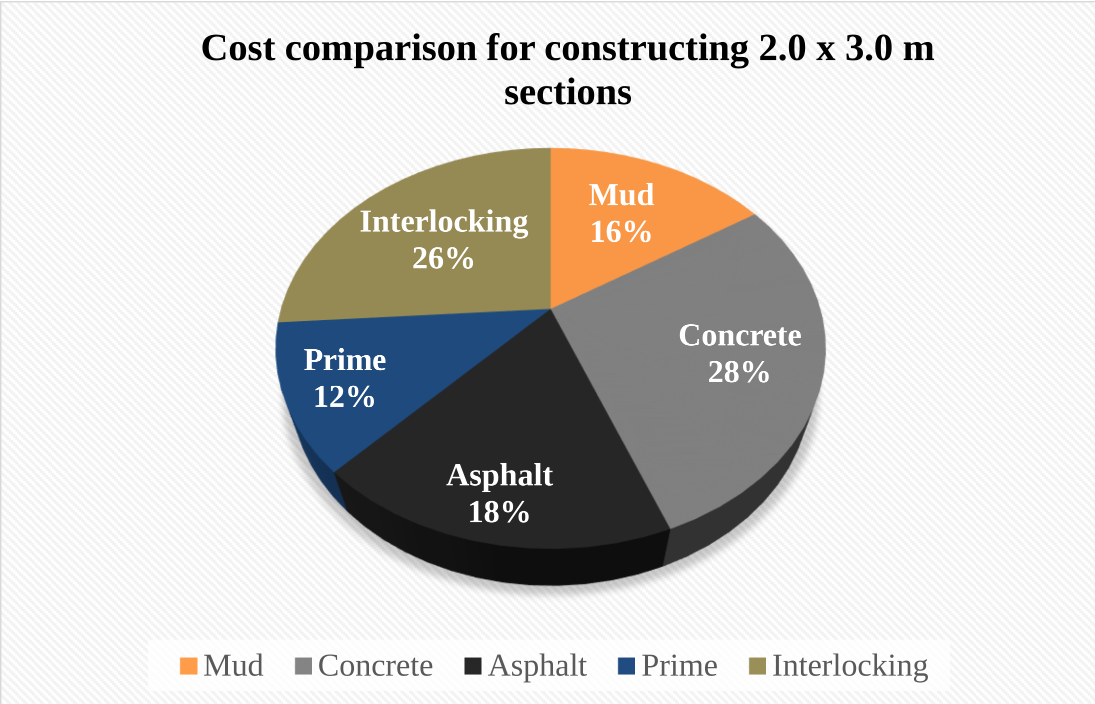

Figure 34-Cost comparison

Comparatively Primed section has the lowest cost with Mud Concrete coming close second. Asphalt, Concrete and Interlocking sections costs are comparatively high. But considering the difficulty in finding bitumen and ABC in rural areas, Mud Concrete can be considered less expensive then all the other paving methods. For above calculations, labour and machinery needed for smaller strips (to do manually) are incorporated. But In actual scenarios, much more complex machinery and labour force is required for Asphalting/Priming and Concreting. Hence, the cost for major processes can be higher than the above calculated values.

1.15. User Feedback

The road section used for testing provide accessibility for 6 families who used light weight vehicle range from bicycles to double cabs on a regular basis. The residents constantly use this road as pedestrians. The road is entirely exposed to sun rays all throughout daytime and situated in the wet zone coastal area.

After face to face interviews with the residents (above 15 years of age) and some of the frequent users of the same road, the feedback/opinion on the new material was evaluated. The structure of the questionnaire followed was attached in Annex 3.

20 number of permanent residents (13 females and 7 males) and 10 number of frequent users (5 females and 5 males) of the road were interviewed after allowing them to use the road for 6 months as usual. 93% of the responders were, within the age limit of 30-50 years and frequently used the roads mostly on mornings (5.00 a.m. to 9.00 a.m.) and evenings (3.00 p.m. to 6.00 p.m.). All of them, mentioned that they use the road as pedestrians at one time or other and frequency of using the road is higher during weekends. The male responders (18 no's) stated that they use both bicycles and light vehicles (10 no's) daily and due to a construction work at one house, heavy vehicles such as tippers and tractors access the roads occasionally as well. There were hardly any people used the road at night due to lack of street lighting.

The responders were not satisfied with the prevailing condition of the gravel road. 90% of the responders were highly unsatisfied with the smoothness of the existing gravel road. 47% are neither satisfied nor unsatisfied with the thermal comfort during daytime while 53% are unsatisfied and majority of them being of aged over 50 years. 15 numbers of responders including all 15-30-year olds stated they are not satisfied with the dust generation during daytime. 93% of the responders they are not satisfied with having to use the road at night and only 2 numbers of people said they use the road at night. Responders illustrate the inconvenience caused to them by the muddy pits form after rains with 90% of them agreeing. The vegetation growth within the vehicle path required frequent clearing and responders agreed 100% the condition with weeding and fungi on road surface is highly unsatisfying. Hence, using road during night should be done with cautious.

Since the responders were given a period to experience the Mud Concrete surface, all of them responded positively to the material. When interviewed about the Mud Concrete surface, responders 93% are satisfied with smoothness of the improved section with 83 % (majority of the pedestrians) saying the thermal comfort is satisfying compared to previous state. Majority of the residents said the dust generation is at a satisfying level for the Mud concrete section. 97% agreed that road can be used at night compared to the previous condition while 90% are content with condition of the section during rainy days and storm water surface drainage. 100% are either satisfied or highly satisfying with maintenance frequency and surface condition with fungi and weeds. 87% of responders are pleased with the strength of and durability of the Mud Concrete section while 13% who are mostly aged over 50 years are neither agreeing nor disagreeing. All the responders are either content or highly content about the cost aesthetical appearance/surface colour of the section (mentioned in the remark section that they are pleased with the natural mud colour surface stating that it is aseptically comfortable to eyes during daytime than other dark coloured surfaces and concrete). None showed any disliking to the disturbance during construction.

Responders much preferred Asphalted or Primed surface but some (2 numbers) even preferred concreting as a paving material to be used in improving. 1 responder (over 50-year male) preferred Interlocking blocks. 2 responders (15-30-year males) said they would prefer Mud Concrete as well. While majority of the male responders were much open to the new experimental materials all the female responders showed tendency to go with more familiar materials. Over 50-year-old responders preferred methods such as Concreting and Interlocking over Asphalting what they believed to be much cheaper. But all the responders agreed (in remarks) that the exiting condition should be improved with any kind of overlaying.

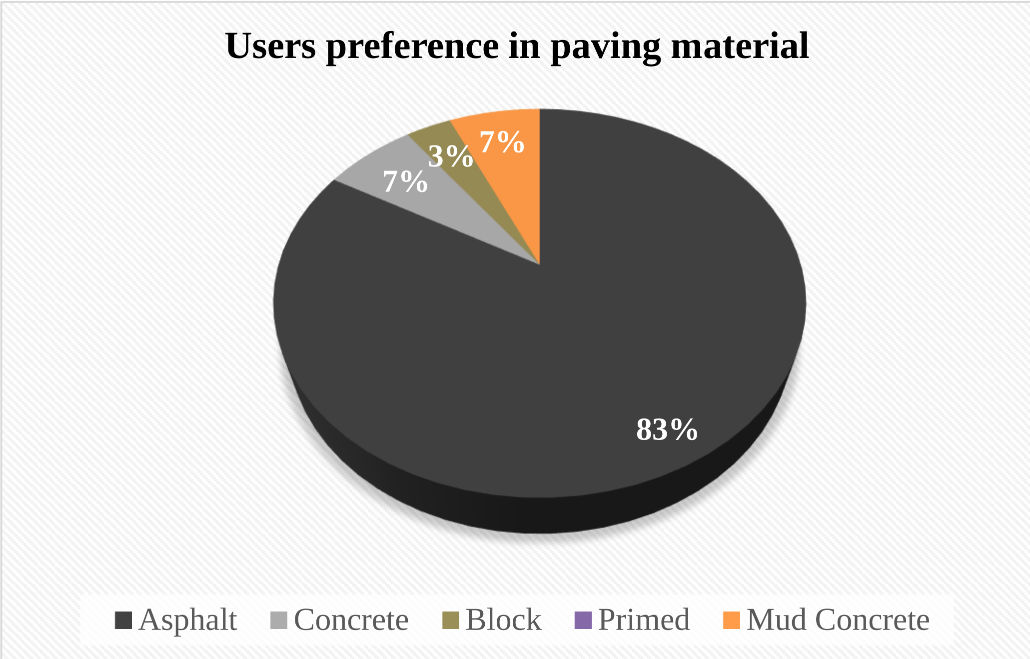

Figure 35- User preference in Paving Material

97% of the responders recommended the Mud Concrete to be tried as a paving material for such low volume access roads with remarks of suggesting that same method should be tested at parking spaces as well. Only one responded disagreed stating uncertainty of its durability and usability as a paving material.

1.16. Summary

The previous research (Galabada, 2016) on which this study was based on manufactured Mud Concrete blocks. Following the result found, the exact mix design was incorporated for this Mud Concrete pavement trial.

(Galabada, 2016) states that, a soil sample consist of 5 % Fine particles (particle size <0.425 mm), 60% Sand particles (0.425 mm <x<4.75 mm) and 35% gravel particles (>4.75mm) can be used without any improvement and with 18% cement will give a maximum compressive strength of 12.5 N/mm^2 for 18% cement and within 14%-15% water content.

Thus, for this experiment a specimen of 2 m long was casted manually on an actual low volume road and with above proportions. Prior to casting, laboratory experiments were conducted to test consistency of soil sample and casted test cubes for the selected mix design.

In-situ test cubes were also casted from the sample mixed at site and tested for 28 days which obtained a mean compressive strength of 14.2 N/mm^2.

In order to compare, identical sections of other different paving materials were casted at the same location exposed to similar conditions. Surfaces are created recreating the actual road surface conditions. Other paving materials used for testing were Concrete, Asphalt, Primed, Concrete Blocks and Gravel.

Surface temperature on each surface was measured in continuous 24-hour intervals in different days, recorded, sorted and plotted to be compared. The results illustrate that dark colour surfaces i.e. Asphalt and Primed sections give max temperature rises during daytime and spikes between 1.00 p.m to 3.00 p.m.

Compared to other materials Mud concrete and Gravel surfaces give least temperature rises during daytime. During nighttime all the surfaces maintains an almost same constant temperature. No visible thermal cracks occurred during the period of six months.

With the feedback given by the road users given after a certain period (about six months), they were curious about using low cost a new material that gives them almost same characteristic of a normal concrete road. Responders were satisfied with its surface colour and responded positively to the low- heat generation of the Mud concrete. Users were eager to have a surface that made them less uncomfortable during daytime and were satisfied with its quality after a period without any maintenance.

Mud concrete section was loaded with heavy machinery after 28 days and 3 months to observe its behavior under occasional sudden load. It withstood such loads in similar manner that of Concrete.

The only defect occurred along the wheel path due to a differential settlement of the base used.

The section was able to avoid erosion due to heavy rains and even without providing any proper drainages.

Chapter 6

1.17. Conclusion and Recommendation

This study tried to introduce a low-cost paving material to be used on rural roads as a wearing layer. Mud Concrete which has previously studied only as a unit of block was further experimented. While doing this research a firsthand experience was gained on the pros and cons of this new material. The new materials performances are presented bellow and users' reactions and feedback to this new material are portrayed here as well.

1.18. Performance of Mud Concrete Roads

Following previous similar studies, the same proportions used to manufacture Mud Concrete Blocks are used as the basic mix design of this study. Therefore, a laterite soil used should consist of around 5% fine particles, 60% sand particles and 35% gravel particles. One of the advantages of this method is the ability to use locally available material. This laterite soil that is ideal for mixing with cement are extensively found in tropical countries. (Arandara, Jayasinghe, & Jayasinghe, 2010). In Sri Lanka, a country where major portion of ground area consists of laterite soil, there is no shortages of extracting suitable material. The available material at site can be tested and used with or without improvement. When the required proportions are not met, either by adding quarry dust or chips accordingly, the desirable percentages can be achieved. Because of the use of locally available material mostly, the waste generation at construction can be kept at minimum and disposal after life cycle does not affect environment.

For the natural soil of around consistency, 18% cement is added by weight. Water was added to achieve a workable mix and prepared manually at site. Procedure like constructing a normal concrete road was followed but using readily available material. The surface is of light natural ground colours which helps to withstand excess surface heat generation. After continues observation of the behavior of Mud Concrete on natural environment, there is a high possibility that it can be developed into more advanced material once its drawbacks are addressed.

1.19. Recommendation

One of the drawbacks we experienced is the crack caused due to differential settlement. It is recommended to find methods to rectify such failures easily. Further experiments can be done to study its suitability in steeper slopes and hilly terrain. Thought this sample road section showed higher tolerance to erosion and extreme weather conditions, it is more appropriate to investigate how they behave in heavy surface runoffs on steep slopes.

It is also recommended to how surface texture (smooth or rough etc) can affect temperature factors and tractive forces of traffic.

The construction method can be further improved by trying out more convenient method for mixing at site.

1.20. Limitations

The experiment specimen was only tested on flat terrain with only light weight vehicle moving occasionally. The feedback of users' perspective was limited to a considerably small set. No precise super elevation was provided. No frequent heavy machinery movement was anticipated.

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ANNEX 01 – Surface Temperature Data

Day 01

Start time 8/8/2018 8:43:20

End time 8/9/2018 17:40:24

Number	Time	Mud Concrete	Primed	Gravel	Block	Asphalt	Concrete
1	8.45	27.3	28.15	27.35	27.25	28.2	27.4
2	9.15	27.15	28.2	26.8	26.2	28.1	27.3
3	9.45	26.45	28.2	26.7	26.8	28.45	27.5
4	10.15	25.6	26.8	25.35	25.75	26.65	26.65
5	10.45	26	27.2	25.8	26	27.15	26.45
6	11.15	26.05	27.5	26.25	26.15	27.4	26.65
7	11.45	26.85	28.8	27.15	26.95	28.45	27.65
8	12.15	31.75	36.85	29.3	30.75	36.15	32.6
9	12.45	28.95	33	28.6	29.8	31.4	30.55
10	13.15	29.5	33.4	29.1	29.7	32.65	30.9
11	13.45	29.65	34.7	29.75	31.45	34.35	32.35
12	14.15	32.35	38	30.8	34.7	40.65	37.1
13	14.45	34.55	40.85	31.4	38.15	43.75	39.15
14	15.15	32.35	41.3	31.05	38.75	44.85	37.75
15	15.45	30.45	36.2	29.15	35.65	36.85	33.7
16	16.15	29.15	33.3	28.8	31.75	34	32.25
17	16.45	28.85	32.75	28.5	31.55	33.5	31.9

18	17.15	27.85	30.6	27.85	30.05	31.25	30.7
19	17.45	26.9	28.6	26.7	27.6	29.9	29.35
20	18.15	25.3	26.95	25.85	27.5	27.9	27.95
21	18.45	25.15	27.4	25.9	27.35	28.05	27.85
22	19.15	25.3	27.25	25.4	26.95	27.85	27.9
23	19.45	24.95	27.05	25.35	26.6	27.65	27.6
24	20.15	24.75	26.7	25.1	26.3	27.35	27.35
25	20.45	24.95	26.85	25.3	26.35	27.3	27.25
26	21.15	24.9	26.6	25.25	26.2	27.05	26.9
27	21.45	24.25	25.7	24.75	25.3	26.4	26.4
28	22.15	24.45	25.45	25.1	25.1	25.95	25.75
29	22.45	24.65	25.45	25.05	25.25	26	25.9
30	23.15	24.2	25.35	24.65	25	25.8	25.85
31	23.45	24.5	25.4	25.05	25.1	25.95	25.85
32	0.15	24.4	25.45	24.7	24.9	26	25.95
33	0.45	24.35	25.1	24.8	24.65	25.65	25.45
34	1.15	24.45	25.3	24.8	24.8	25.75	25.5
35	1.45	24.35	25.45	24.4	24.95	25.7	25.6
36	2.15	23.8	25.05	24.2	24.6	25.35	25.25
37	2.45	24.05	25.05	24.45	24.65	25.3	25.05
38	3.15	23.85	24.9	24.25	24.5	25.15	24.9
39	3.45	24.1	25.2	24.35	24.6	25.2	24.85
40	4.15	23.5	24	24	23.85	24.4	24.25
41	4.45	23.55	24.15	23.95	23.95	24.4	24.3
42	5.15	23.25	24.05	23.7	23.85	24.2	24.1
43	5.45	23.45	24.1	23.9	24	24.35	24.1

44	6.15	23.5	24.3	23.8	23.95	24.45	24.2
45	6.45	23.95	24.85	24.2	24.25	25.05	24.5
46	7.15	24.5	25.45	24.75	24.8	25.55	24.95
47	7.45	25.3	26.25	25.6	25.4	26.25	25.45
48	8.15	25.85	27.05	26	26.1	27.15	26
49	8.45	26.45	27.35	26.5	26.4	27.4	26.35
50	9.15	27.75	28.7	27.45	27.35	28.6	27.3
51	9.45	27.85	28.85	27.35	27.65	28.9	27.65
52	10.15	28.75	29.9	28.25	28.45	29.65	28.5
53	10.45	29.2	32.55	28.65	29.5	32.05	30.15
54	11.15	29.4	31.5	28.45	29.5	31.3	30.2
55	11.45	28.65	30.25	28.15	29	30	29.6
56	12.15	30.45	33.15	29.45	30.95	32.8	31.85
57	12.45	30.4	34	29.85	32.15	33.7	32.35
58	13.15	31.15	34.2	30.5	33.1	36.1	33.05
59	13.45	31.5	35.35	30.7	33.8	37.05	33.8
60	14.15	31.7	38.05	31.1	35.75	39.7	35.2
61	14.45	30	34.2	29.45	32.7	35.5	33.15
62	15.15	30.05	34.05	29.35	32.4	35.1	32.5
63	15.45	29.25	33	28.9	31.55	33.65	31.85
64	16.15	28.65	31.55	28.4	30.9	31.9	30.9
65	16.45	28.45	31.55	28.3	30.55	32.05	30.8
66	17.15	28.15	30.5	27.95	29.85	31	30.15
67	17.45	27.35	28.85	27.05	28.6	29.4	29.1

Day 02

Start time 8/10/2018 7:41:32

End time 8/11/2018 10:11:32

Number	Time	Mud concrete	Primed	Gravel	Block	Asphalt	Concrete
1	7:45	27.25	27.50	27.00	26.90	28.00	27.60
2	8:15	27.70	28.40	27.45	27.35	28.70	28.10
3	8:45	28.05	28.85	27.65	27.75	29.10	28.30
4	9:15	28.45	29.50	27.90	27.90	29.85	28.75
5	9:45	29.15	30.10	28.20	28.50	30.50	29.25
6	10:15	29.70	31.85	28.95	29.35	32.25	30.05
7	10:45	30.15	32.50	29.05	29.65	32.70	30.50
8	11:15	30.55	32.55	29.25	29.75	32.40	30.40
9	11:45	30.90	36.35	30.45	31.45	37.15	33.20
10	12:15	32.45	38.15	29.95	32.95	38.65	33.70
11	12:45	30.95	37.55	30.40	32.90	36.90	33.35
12	13:15	30.95	35.65	30.50	31.70	36.10	32.05
13	13:45	32.25	38.70	33.05	34.35	40.45	34.20
14	14:15	31.20	35.90	31.10	32.95	36.95	33.70
15	14:45	31.70	32.95	30.40	32.30	32.80	32.35
16	15:15	31.70	35.25	32.10	35.05	35.30	34.75
17	15:45	30.95	33.65	30.65	33.60	33.05	32.85
18	16:15	30.25	32.00	30.25	32.50	32.10	31.95
19	16:45	29.55	31.25	29.35	31.65	31.25	31.45

20	17:15	28.90	30.15	28.70	30.65	30.60	30.85
21	17:45	28.55	29.80	28.35	30.00	30.05	30.35
22	18:15	28.05	28.80	27.75	29.50	29.20	29.65
23	18:45	27.75	28.35	27.65	29.00	28.65	29.00
24	19:15	27.40	28.05	27.20	28.55	28.35	29.00
25	19:45	27.20	27.80	26.95	28.40	28.15	28.60
26	20:15	27.35	27.85	26.95	28.10	28.00	28.40
27	20:45	27.15	27.65	26.90	27.95	27.85	28.35
28	21:15	27.10	27.70	26.85	27.75	27.90	28.30
29	21:45	26.95	27.55	26.80	27.60	27.80	28.15
30	22:15	26.85	27.30	26.75	27.50	27.65	27.95
31	22:45	26.75	27.25	26.70	27.40	27.45	27.95
32	23:15	26.80	27.20	26.55	27.25	27.35	27.70
33	23:45	26.80	27.30	26.60	27.35	27.40	27.95
34	0:15	26.80	27.45	26.70	27.30	27.65	28.00
35	0:45	26.70	27.15	26.40	27.10	27.25	27.70
36	1:15	26.60	27.00	26.30	27.10	27.20	27.70
37	1:45	26.45	27.00	26.55	27.15	27.25	27.70
38	2:15	26.25	26.60	26.15	26.70	26.80	27.15
39	2:45	26.30	26.45	26.05	26.55	26.70	27.10
40	3:15	26.30	26.50	26.00	26.50	26.70	27.10
41	3:45	26.30	26.80	26.00	26.60	26.95	27.20
42	4:15	26.30	26.65	26.10	26.50	26.80	27.05
43	4:45	26.15	25.90	26.20	26.60	26.80	27.10

44	5:15	26.20	26.10	26.10	26.35	26.45	26.80
45	5:45	26.30	26.35	26.25	26.35	26.50	26.75
46	6:15	26.50	26.55	26.35	26.45	26.65	26.90
47	6:45	26.75	26.90	26.55	26.55	27.00	27.10
48	7:15	27.15	27.35	26.95	26.95	27.45	27.45
49	7:45	27.80	27.70	27.20	27.15	27.75	27.70
50	8:15	28.20	28.50	27.85	27.70	28.40	28.40
51	8:45	28.75	28.85	28.25	28.15	28.85	28.70
52	9:15	29.20	29.95	28.80	28.90	29.85	29.55
53	9:45	29.65	29.95	29.05	29.20	30.05	29.65
54	10:15	14.80	30.70	29.55	29.75	30.55	30.45

Day 03

Start time 8/12/2018 7:55:00

End time 8/13/2018 10:25:12

Number	Time	Mud concrete	Primed	Gravel	Block	Asphalt	Concrete
1	8:00	25.75	25.6	25.5	26.1	25.7	26.45
2	8:30	26.6	26.3	26.65	26.1	26.75	26.9
3	9:00	27.45	27.65	27.75	27.2	27.85	27.55
4	9:30	27.7	28.35	28	27.45	28.35	27.95
5	10:00	27.8	28.6	28.4	27.9	28.75	27.55
6	10:30	28.05	30.9	28.95	28.5	30.95	28.3
7	11:00	29.15	34.75	29.65	29.8	35	31.6
8	11:30	29.75	34.2	30	31.1	34.6	32.5
9	12:00	32	37.75	30.6	34.25	36.9	36.4
10	12:30	33.6	40.85	32.35	42.25	39.95	39.2
11	13:00	35.35	41.35	36.75	40.05	39.1	41.45
12	13:30	32.35	36.75	34.15	39.2	37.75	38.7
13	14:00	33.95	38.9	34.9	39	37.45	37.25
14	14:30	36.6	40.55	39.3	42	40.65	39.6
15	15:00	32.55	34.75	31.45	35.55	34.45	35.3
16	15:30	32.3	33.9	30.85	34.95	33.9	34
17	16:00	31.2	32.1	30.35	34.3	32.8	33.5
18	16:30	32.1	32.75	31.1	34.2	33.05	33.7
19	17:00	30.95	31.2	30.05	33.1	32.4	33.05
20	17:30	30.25	30.25	29.15	32.05	31.05	31.9
21	18:00	29.6	29.45	28.6	31.35	30.55	31.3
22	18:30	29.8	29.7	28.55	31.1	30.45	31.25

23	19:00	29.05	29.05	27.95	30.3	29.85	30.25
24	19:30	28.7	28.9	27.8	29.95	29.45	30.35
25	20:00	28.5	28.4	27.6	29.5	29.2	29.85
26	20:30	28.35	28	27.3	29.2	28.85	29.55
27	21:00	28.15	28.1	27.2	28.9	28.85	29.3
28	21:30	28.05	28.05	27.2	28.75	28.65	29.15
29	22:00	28.15	28.2	27.2	28.7	28.8	29.2
30	22:30	27.8	27.7	27.05	28.4	28.35	28.8
31	23:00	27.75	27.55	27.1	28.25	28.35	28.85
32	23:30	27.8	27.75	27.15	28.25	28.35	28.7
33	0:00	27.8	27.75	27.05	28.2	28.25	28.6
34	0:30	27.7	27.6	27.05	28	28.15	28.6
35	1:00	27.5	27.4	26.9	27.85	28	28.4
36	1:30	27.5	27.35	26.85	27.85	27.9	28.45
37	2:00	27.45	27.25	26.75	27.65	27.75	28.15
38	2:30	27.45	27.45	26.75	27.7	27.95	28.15
39	3:00	27.35	27.25	26.65	27.6	27.75	28.3
40	3:30	27.3	27.25	26.6	27.45	27.65	28
41	4:00	27.35	27.35	26.6	27.5	27.75	27.95
42	4:30	26.1	26.2	25.55	26.35	26.55	27.25
43	5:00	26.3	26.1	25.55	26.25	26.5	26.9
44	5:30	26.25	25.8	25.9	26.15	26.5	26.85
45	6:00	26.2	25.95	26	26.15	26.5	26.7
46	6:30	26.25	26.1	26.25	25.95	26.65	26.45
47	7:00	26.4	26.55	26.5	26.4	26.85	26.65
48	7:30	27	25.95	26.5	26.45	27.1	27.1

ANNEX 2- Cost Breakdown

Cost per each type of paving material is calculated below. HSR- 2017 Southern Province (Highway Schedule Rate) is based when calculating the rates. Since the procedures recommended by RDA were followed during actual experiment (except for Mud Concrete), Rates calculated using the HSR could be compared. For mud Concrete, actual material quantities were measured.

Cost Breakdown for Mud Concrete

For sample calculation

Weight of the Soil = 20 kg

Weight of the Cement = 18% x 20 kg

= 3.6 kg

Total weight of the mix = 23.6 kg

Volume of the compacted mix = 0.02025 m^3

Code	Description	Qty	Unit	Rate	Amount (Rs.)
	Sieving and Piling Soil				
	Labour (S/Sk)	4	Days	1,555.06	6,220.24
	Labour (U/Sk)	1	Days	1,516.60	1,516.60
	Allow2.5% for labour for tools			193.42	193.42
	Rate per 2.83 m^3				7,930.26
	Rate per 1 m^3				**2,802.21**

	Mixing and Laying Mud Concrete (Manually) volume batching				
Labour	Data for 2.83 m^3				
	Mason (Sk/A)	0.75	Days	1,627.40	1,220.55
	Lobour (S/Sk)	4	Days	1,555.06	6,220.24
	Lobour (U/Sk)	1	Days	1,516.60	1,516.60
	Allow 2.5% on lobour for tools				223.93
Material	Cement	11	50 kg	816.80	8,984.80
	Soil	2.83	m^3	Locally available	
	Allow for water	2.83	Item	21.50	60.85
	Basket (2/3)	0.67	No	256.25	171.69
					18.398.66
	Cost per 2.83 m^3				18.398.66
	Cost per 1 m^3				**6,501.29**

Cost Breakdown for Concrete

Code	Description	Qty	Unit	Rate	Amount (Rs.)
ST1-046	Mixing and Laying Cement Concrete 1:2;4 (19mm) (Manually) volume batching using crusher run aggregate				
Labour	Data for 2.83 m^3				
	Mason (Sk/A)	0.75	Days	1,627.40	1,220.55
	Lobour (S/Sk)	6	Days	1,555.06	9,330.36
	Lobour (U/Sk)	1	Days	1,516.60	1,516.60
	Allow 2.5% on lobour for tools				301.69
Material	Cement	16	50 kg	816.80	13,068.80
	Aggregate (19 mm) less piling	2.55	m^3	1,959.20	4,995.96
	Sand	1.70	m^3	4,700.00	7,990.00
	Allow for water	2.83	Item	21.50	60.85
	Basket (2/3)	0.67	No	256.25	171.69
					38.656.50
	Cost per 2.83 m^3				38,656.50
	Cost per 1 m^3				**13,659.54**
T1-006	Transporting Material (25 km)				
	Aggregate	1	m^3	600.29	**600.29**
	Sand	1	m^3	600.29	**600.29**

Cost Breakdown for Asphalt Concreting surface

Code	Description	Qty	Unit	Rate	Amount (Rs.)
M1-013	Base-Dense graded aggregate base (ABC) spreading, watering and compacting graded 37.5 mm aggregate (loose volume)				
Labour	Data for 232 m^2 brushing, cleaning and moistening road surface (manual)				
	Mason (S/Sk) spreading	5.5	Days	1,555.06	8,552.83
	Lobour (S/Sk) blinding	0.5	Days	1,555.06	777.53
	Allow 2.5% on lobour for tools				233.26
Material	DGA 37.5mm (loose)	19.82	m^3	1,908.33	37,823.10
Machinery	Roller charges (8-10 Ton)	1.24	Days	10,931.84	13,555.48
	Tractor/Trailer Hire	0.22	Days	5,963.27	1,311.92
	Water tank and pump	0.22	Days	1,082.72	238.20
					62,492.32
	Cost per 2.83 m^3				62.492.32
	Cost per 1 m^3				**3,152.99**
T1-006	Transporting Material (25 km)				
	ABC	1	m^3	600.29	**600.29**

S1-015	Tack coat with emulsion /cold bitumen (CSS-1) @ rate 0.5 l/m2 including brushing and cleaning (manual)				
	Data for 232 m^2 brushing				
	Labour (U/Sk)	0.75	Days	1,516.60	1,137.45
	Allow 2.5% on lobour for tools				28.44
					1,165.89
	Cost per 232 m^2				1,165.89
	Cost per 1 m^2				5.03
Labour	Data for 372 m^2 tack coat				
	Labour (U/Sk)	0.75	Days	1,516.60	1,137.45
	Allow 2.5% on lobour for tools				28.44
Material	Emulsion (CSS-1)	186	l	55.45	10,313.70
					13,501.57
	Cost per 372 m^2				13,501.57
	Cost per 1 m^2				36.29
	Total rate 1 m^2				**41.32**
S1-031	Supply, lay and compact Aspahlt concrete (19mm 60/70 binder) dense (plant made) in wearing surface				
Labour	Data for 10 MT				
	Lobour (A/Sk)	1	Days	1,627.40	1,627.40
	Lobour (S/Sk)	4	Days	1,555.06	6,220.24
	Lobour (U/Sk)	2	Days	1,516.60	3,033.20
	Allow 2.5% on lobour for tools				272.02

Material	Aspahlt premix Concrete	10	MT	5,570.00	55,700.00
Machinery	Roller charges (7 hrs)	0.88	Days	10,931.84	9,620.02
					76,472.88
	Cost per 10MT				76,472.88
	Cost per 1 MT				**7,647.29**
T1-009	Transporting Asphalt premix in bulk incl loading at plant for 100 km				
	Premix	2.45	MT	1,515.00	**3,709.30**
	**Aspahlt 2.45 MT per* m^3				

Cost Breakdown for Priming surface

Code	Description	Qty	Unit	Rate	Amount (Rs.)
M1-013	Base-Dense graded aggregate base (ABC) spreading, watering and compacting graded 37.5 mm aggregate (loose volume)				
Labour	Data for 232 m^2 brushing, cleaning and moistening road surface (manual)				
	Mason (S/Sk) spreading	5.5	Days	1,555.06	8,552.83
	Lobour (S/Sk) blinding	0.5	Days	1,555.06	777.53
	Allow 2.5% on lobour for tools				233.26
Material	DGA 37.5mm (loose)	19.82	m^3	1,908.33	37,823.10
Machinery	Roller charges (8-10 Ton)	1.24	Days	10,931.84	13,555.48
	Tractor/Trailer Hire	0.22	Days	5,963.27	1,311.92
	Water tank and pump	0.22	Days	1,082.72	238.20
					62,492.32
	Cost per 2.83 m^3				62.492.32
	Cost per 1 m^3				**3,152.99**
T1-006	Transporting Material (25 km)				
	ABC	1	m^3	600.29	**600.29**
S1-022	Prime coat with emulsion /cold bitumen (CSS-1) @ rate 1 l/m2 including blindning with and @ a rate 250 m^2/m^3 brushing and cleaning (manual)				
	Data for 232 m^2 brushing, cleaning and moistening surface				
	Labour (U/Sk)	0.75	Days	1,516.60	1,137.45

	Allow 2.5% on lobour for tools				28.44
	Allow for water	1	Item	64.65	64.65
					1,230.54
	Cost per 232 m^2				1,230.54
	Cost per 1 m^2				5.30
Labour	Data for 372 m^2 tack coat				
	Labour (S/Sk)	2	Days	1,555.06	3,110.12
	Labour (U/Sk)	0.5	Days	1,516.60	758.30
	Allow 2.5% on lobour for tools				96.71
Material	Emulsion (CSS-1)	372	l	55.45	20,627.40
	Sand	1.49	m^3	4,700.00	7,003.00
	Basket (2/3)	0.33	Item	256.25	84.56
	Cost per 372 m^2				13,680.09
	Cost per 1 m^2				85.16
	Total rate 1 m^2				**90.47**
T1-006	Transporting Material (25 km)				
	Sand	1	m^3	600.29	**600.29**
T1-010-012	Transporting Barrels of Bitumen (160 km)				
	Bitumen	1	m^3	1,066.35	**1,066.35**

Cost Breakdown for Paving Interlocking blocks

Transport distance	=	25 km
No of blocks per load	=	2750
Dimension of a block	=	220 x 110 x 80 mm
Volume of load	=	5.32 m^3
Avg. weight of a block	=	4.65 kg
Weight per trip	=	12,788.00 kg
Assumed avg speed of lorry	=	20 km/hr
Distance transported (2 way)	=	50 km

Code	Description	Qty	Unit	Rate	Amount (Rs.)
	Transportation				
Anx1 Tb2	Lorry	50	km	96.07	4,803.50
Anx1 Tb2	Loading/unloading idling	2	hr	1,252.57	2,505.14
Labour	Labour (U/sk) (4 nos for 1 hr)	0.5	Days	1,516.60	758.30
	Total transportation Cost per Load for 25 km				8,066.94
	Cost per block per km				**0.12**

Material	Paving Blocks	1	no	34.00	**34.00**
	Paving of concrete blocks and preparation of sand bedding				
	Data for 93 m^2 output area per day confined between 3m kerbs				
Material	Sand	4.65	m^3	4,700.00	21,855.00
	Add 10% for bulking and filling	0.46	m^3	4,700.00	2,209.00
Labour					
	Labour (A/Sk)	1	Days	1,627.40	1,627.40
	Labour (B/Sk)	1	Days	1,579.33	1,579.33
	Labour (U/Sk)	4	Days	1,516.60	6,066.40
	Add 2.5% of lobour for tools				231.83
Machinery	Plater Vibrtor	1	Days	3,620.05	3,620.05
	Cost per 93 m^2 for paving interlocks				37,189.01
	Cost per 1 m^2				399.88
	Cost cutting end blocks per 1 m^3				35.46
	Total rate 1 m^2 paving interlocking and cutting side kerbs excluding cost of side curbs				**435.34**
T1-006	Transporting Material (25 km)				
	Sand	1	m^3	600.29	**600.29**

Rates based on HSR-2017

Code	Description	Unit	Price (Rs)
Labour			
BO-001	Skilled A (Mason)	Days	1,627.40
BO-002	Skilled B	Days	1,579.33
BO-003	Semi-Skilled	Days	1,555.06
BO-004	Un Skilled	Days	1,516.60
Machinery			
BO-102	Concrete/Asphalt Mixer	Days	6,699.87
BO-103	Bitumen sprayer	Days	92.24
BO-104	Water tank	Days	1,082.72
BO-107	Plate Compactor (90 kg)	Days	3,620.05
BO-108	Vibrator rammer (60 kg)	Days	3,403.35
BO-111	Roller 8-10 T	Days	10,931.84
BO-117	Tractor/ trailer 3 T	Days	5,963.27
BO-138	Emulsion Sprayer (handcraft)	Hr	765.99
Material			
BO-308A	19 mm aggregate (Plant produced)	m^3	2,100.00
BO-313	37.5 mm DGABC	m^3	1908.33
BO-331	Sand (Surfacing)	m^3	4,700.00
BO-332	Sand (Concreting)	m^3	4,700.00
BO-352	Emulsion CSS-1	l	55.45
BO-353	Emulsion CRS-1	l	52.35
BO-361A	Asphalt Binder 60/70	MT	5,470.00
BO-401	Cement	50 kg	816.80
BO-461	G25 Paving blocks	No	34.00
BO-631	Basket	No	256.25
BO-786	Water (for moistening)	Item	64.65
BO-787	Water	Item	21.50

Piling			
A1-018	Available Aggregate	m^3	140.80
Transportation			
T1-006	Aggregate/Sand/ABC		
	Less than 3 km	m^3	71.10
	3km-10km	m^3/km	23.70
	More than 10 km	m^3/km	21.35
T1-009	Premix		
	Incl loading at plant	MT/km	15.14
T1-010	Barrels of Bitumen		
	Less than 1 km	no	37.45
	1km-8km	no/km	9.10
	More than 8 km	no/km	6.35
	16 barrels have approx. 2.1 m^3		

ANNEX 3- Questionnaire

**Following questionnaire structure was followed while interviewing the road users. Please note that the responses were recorded by the interviewer herself*

Feedback/ opinion on the new material (Mud Concrete) used for the experimental road section

Part 1- General Information

1. Age group

15-30	31-50	50 or Older

2. Gender
    - Male ☐
    - Female ☐

3. Responder is
    - A permanent resident of the road ☐
    - A frequent user ☐
    - Other ☐

4. Responder use the road more as a
    - Driver ☐
    - Pedestrian ☐
    - Cyclist ☐
    - Other ☐

5. Responder normally use the road between
    - Morning 5.00 a.m to 9.00 a.m ☐
    - Midday 9.00 a.m to 12.00 noon ☐
    - Afternoon 12.00 noon to 3.00 p.m. ☐
    - Evening 3.00 p.m. to 6.00 p.m. ☐
    - Nighttime 6.00.p.m. to 5.00 a.m ☐

Part 2- Opinion Survey

From question 5-26 please √ your preference

1 – Highly unsatisfying

2- Unsatisfying

3- Neither satisfying nor unsatisfying

4- Satisfying

5- Highly satisfying

Condition of existing road	**1**	**2**	**3**	**4**	**5**
6. Smoothness on the existing gravel road					
7. Thermal comfort during daytime/ reflection of sunlight					
8. Dust generation during daytime					
9. Using road at night (lighting/ safety concerns due to insect attacks etc)					
10. Using road during rainy days (water puddles/ potholes/water retaining on surface/ time taking for infiltration of rainwater etc)					
11. Surface slipperiness					
12. Frequency of maintenance/weeding/ fungi generation etc					
13. Comfort for pedestrian					
14. Comfort for vehicle movement					

Opinion on Mud Concrete	**1**	**2**	**3**	**4**	**5**
15. Smoothness of the mud concrete surface					
16. Thermal comfort during daytime/ reflection of sunlight					
17. Dust generation during daytime					
18. Using road at night (lighting/ safety concerns due to insect attacks etc)					
19. Using road during rainy days (water puddles/ potholes/water retaining on surface/ time taking for infiltration of rainwater etc)					
20. Surface slipperiness					
21. Frequency of maintenance/weeding/ fungi generation etc					
22. Comfort for pedestrian					
23. Comfort for vehicle movement					
24. Durability					
25. Strength					
26. Cost					
27. Aesthetical appearance / Surface colour					
28. Disturbance during construction period					

29. Mark √ your preference in a paving material

- Asphalt ☐
- Concrete ☐
- Concrete Block paving ☐
- Primed ☐
- Mud Concrete ☐
- Other ☐

30. Would you recommend using the new material (mud concrete) as a new paving material in future?

- Yes, I recommend ☐
- No, I do not recommend ☐

31. Any other remark

………………………………………………………..