JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

GEOTECHNICAL ENGINEERING STREAM

Effects of geogrid on reduction of reflection cracking in asphalt overlays

A thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Geotechnical Engineering

By: Samuel Teklebrhan

Adviser: Dr. Yoseph Birru

Co-Adviser: Mr. Mamuye Busier

January, 2016

Jimma, Ethoipia

Declaration

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Samuel Teklebrhan	____________________	________________
Name	Signature	Date

This thesis has been submitted for examination with my approval to University supervisors

____________________	____________________	________________
Main Advisor	Signature	Date
____________________	____________________	________________
Co-Advisor	Signature	Date
____________________	____________________	________________
External Examiner	Signature	Date
____________________	____________________	________________
Internal Examiner	Signature	Date
____________________	____________________	________________
Chairman	Signature	Date

Acknowledgement

My deepest gratitude goes to my advisor Dr. Yoseph Birru, for originating the idea of making a research towards geogrid reinforcement of asphalt overlays, for his guidance throughout the research and for his support through the Construction Project Management Institute of Ethiopia (CPMIE) starting from facilitating the arrival of the Hatelit C40/17 from Germany up to the installation of the geogrid material at all the sites.

My co-adviser Mr. Mamuye Busier and Mr. Tadesse Abebe also deserve my sincere gratitude for their constructive comments and suggestions.

I would like to take this opportunity to thank the CPMIE staff members who were tirelessly engaged in the clearing of customs for receiving the geogrid material, participate during the overlay reinforcement at all the sites and for arranging a workshop that I believe has enhanced the awareness of local contractors on the advantages of geogrid materials in the construction industry.

I also whole heartedly thank the HUESKER Synthetic GmbH Company for providing the 100 mx3 m Hatelit C40/17 Geogrid material through the assistance of Mr. Peter Assinder.

ABSTRACT

During this experimental study, a biaxial geogrid material, Hatelit C40/17, having a tensile strength of 50 kN/m^2 in both directions and having dimensions of 3 m (width) X 100 m (length) was used as asphalt reinforcement during an overlay construction in Addis Ababa. Three sites, designated in this research as National Theatre 1, National Theatre 2 and Gandhi Hospital were selected for conducting the research. The geogrid material was laid at the bottom of the overlay sandwiched between two layers of tack coats on 07/04/2015 at the National Theatre sites and on 08/05/2015 at Gandhi Hospital site. Longitudinal and transverse directions of reinforcement were carried out to study the effect of direction of installation. A control section was left unreinforced to observe the difference in performance between reinforced and unreinforced sections of the pavement.

The National Theatre 1 and 2 sites were characterized by the wide reflection cracks and high traffic volume they accommodate. However the Gandhi Hospital site was mainly a demonstration site on how to install the Geogrid material during an overlay construction.

A manual traffic volume count was also conducted to estimate the number of Equivalent Single Axle Loads (ESALs) the road sections were subjected to during the 8 months of study period. The information collected from the traffic volume count reveals that the National Theatre 1 site was subjected to 4.1 Million ESALs and the National Theater 2 site was subjected to 3.1 Million ESALs during the study period.

As the main purpose of this experiment was to study how effective geogrid materials are in mitigating reflection cracks in Asphalt Overlays in Ethiopia, the difference in performance between the reinforced and control sections of the sample roads was evaluated. After duration of 8 months marked difference was observed at the National Theatre 1 site. The width of a major crack was compared with the original width of cracks (prior to geogrid reinforcement) and with the control section. At the National Theatre 1 site, 33.3% of the original crack width was reflected to the surface at the control section whereas 0% of the original crack width appeared to the surface at the reinforced section during the study period of 8 months. The National Theatre 2 site was used to experiment the effect of direction of installation. A transverse direction of installation resulted in 41.2% of the original crack width to appear on both the control and reinforced parts of the road. At the end of the study period, it was found that the longitudinal direction of installation could efficiently mitigate reflection cracking *from appearing to the surface whereas the transverse direction of installation did not contribute in arresting reflection cracks.*

As the other purpose of the research is to introduce the use of geogrid material in asphalt overlay works, a presentation on Geogrids and their applications in the construction industry was held at Gihon Hotel, Addis Ababa. A demonstration on how to install Geogrid material during an overlay construction was also conducted at Gandhi Hospital site as part of the workshop organized by The Construction Project Management Institute of Ethiopia and Ministry of Science and Technology.

Contents

List of Figures

List of Tables

Acronyms:

AC: Asphalt Cement

AADT: Annual Average Daily Traffic

ADT: Average Daily Traffic

ASCE: American Society of Civil Engineers

CMHB: Coarse Matrix High Binder.

EPS: Expanded Polystyrene

ERA: Ethiopian Road Authority

ESALs: Equivalent Single Axle Loads

HMA: Hot Mix Asphalt

LEFs: Load Equivalency Factors

PCC: Portland cement Concrete

TxDOT : Texas Department Of Transportation

XPS: Extruded polystyrene

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Even though Geogrid materials have been applied in various construction projects around the world, little is known about their applications and advantages in Ethiopia. There are only a few sites where geosynthetic materials have been applied. To mention some of the sites geosynthetic materials were used:

- A geomembrane was used at Addis Ababa ring road to stabilize the moisture content variation of a black cotton soil,
- A geomembrane at Jimma oxidation pond as an impervious lining.
- A geosynthetic material at Sebeta (for drainage purposes)

According to a report from ERA, a geogrid material has never been applied in asphalt reinforcements in Ethiopia. Moreover, continuous overlay construction could not solve asphalt distresses that originate due to problems at subgrade, base or sub base level [1]. This repeated overlay construction has led to spending of resources on problems that will keep reappearing.

As this research specifically studies the effect of geogrid reinforcement in mitigating reflection cracking in asphalt overlays, a geogrid material and a road section under severe reflection cracking problem were identified. A 100 m X 3 m roll of Hatelit C40/17 was provided by a HUESKER Gmbh Company from Germany. Hatelit C40/17 is particularly manufactured for reinforcing asphalt pavements.

1.1.1. Research Sites (selection criteria and location).

Out of six sites which were under consideration to be a potential research sites, three road sections were selected. The most defining criteria during the site selection process were:

- Whether the asphalt road contains reflection cracks or not.

Reflection cracks are asphalt distresses that appear to the surface due to a problem at the lower layers (sub-base, base or subgrade). If a road section has been maintained so many times during its life time and if cracks repeatedly appear to the surface, it is most probably suffering from reflection cracking.

- Whether it is a high or low traffic volume road.

The higher the road sections are exposed to repeated cyclic loads the more quickly the effect of geogrid reinforcement is observed.

- Should be under the ACCRA annual maintenance program.

As the ACCRA has its own annual maintenance program, the road sections need to be under this program to get the necessary budget for maintenance.

Based on the above criterion, three road sections in Addis Ababa were selected, namely: National Theatre 1, National Theatre 2, and Gandhi Hospital.

Table 1.1: Coordinates of road sections under study.

Site location		Northing	Easting	Elevation
National Theatre 1	Starting point	09˚01’022”	038˚45’148”	2361
	End point	09˚01’019”	038˚45’138”	2361
National Theatre 2	Starting point	09˚01’033”	038˚45’146”	2361
	End point	09˚01’037”	038˚45’135”	2361
Gandhi Hospital	Starting point	09˚00’937”	038˚45’272”	2348
	End point	09˚00’943”	038˚45’305”	2348

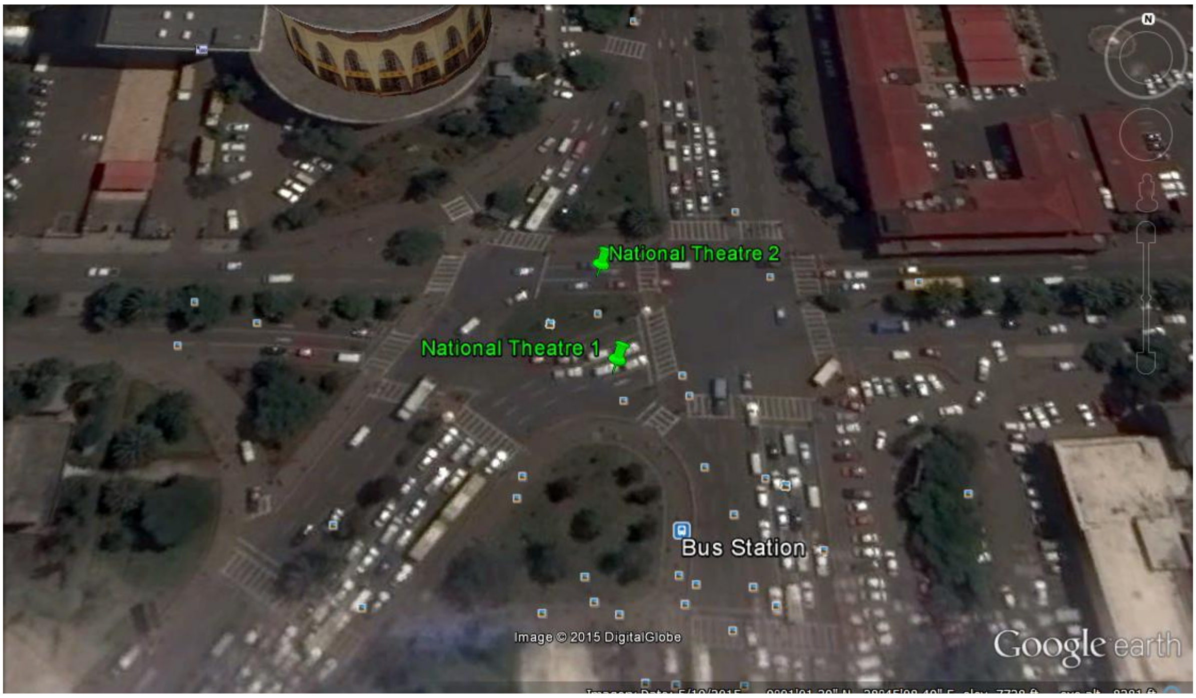

Figure1.3: Google Earth Image of National Theatre 1 and National Theatre 2 sites

Figure1.4: Google Earth Image of Gandhi Hospital Site.

After the sites were selected, the geogrid material was inserted at the bottom of the overlay during a maintenance work by ACCRA.

1.2. Statement of the problem

Pavement maintenance treatments are often ineffective and short lived due to their inability to both treat the cause of the problems and renew the existing pavement condition [1]. In Ethiopia, specifically in Addis Ababa overlays are added repeatedly to cover reflection cracking as the previous layer fails to serve the purpose. Under favorable conditions, some geogrid products can delay reflection cracking in an asphalt overlay by about four times longer than a similar overlay without a geogrid [2]. However, since no previous attempt was made to reinforce asphalt overlays in Ethiopia, little is known if geogrid reinforcement of asphalt overlays can bring about positive effect in mitigating reflection cracks.

According to a report from ERA overall asphalt overlay work costs around 270,000 Birr per kilometer (information collected in 2014). As overlay construction does not solve inherent asphalt distresses like reflection cracking, a road section should go through a repeated maintenance to lengthen its service time. Such an approach is not viable given the economy of the country. However, overlays are still the only viable option for extending the life of distressed pavements in Ethiopia, at times even in the case of reflective cracking. As a matter of fact, the thicker the overlay the longer it will last but thick overlays are expensive as are special asphalt mixes. The other extreme alternative option is reconstruction. Depending on the cause of the problem, this can involve removing layers of pavement, improving subgrades, and repaving. Given the economy of the country, this is even more expensive and time consuming.

In addition to the above mentioned problems, serious drainage problems also occur in asphalt roads as overlay thickness exceeds or levels with the curbstones in many places like the Megenagna-Hayat, Arat Killo- Piasa, Piasa-Addisu Gebeya, in front of Ambassador Hotel and many other locations.

Fig. 1.5: Photo, Repeated overlay construction making asphalt overall thickness higher than the curbstones and creating drainage problems in front of the Ambassador Hotel.

1.3. Objectives of the study

Thus the general and specific objectives of the study were drawn to address the above mentioned problems.

General objective of the study:

- to study the effectiveness of inserting a geogrid material during an overlay construction for mitigating reflection cracking in asphalt pavements in Addis Ababa.

Specific objectives of the study:

- to compare and contrast the extent of the reflection cracks that appear to the surface with and without using a geogrid material in asphalt overlays.
- to study whether direction of installation of the geogrid under the overlay affects the results or not.
- to introduce the use of geogrid material in road maintenance works in Ethiopia particularly on overlay construction.

1.4. Significance of the Study

As mentioned on the statement of the problem, no attempt was done before to study how effective is geogrid reinforcement of asphalt overlays in delaying reflection cracking in Ethiopia. Thus, this research provides information on the effect of asphalt reinforcement with a geogrid material in Addis Ababa.

It also studies if those positive results of geogrid reinforcement can be achieved with the current methods of the ACCRA asphalt overlay construction procedures and materials.

This research introduces geogrid reinforcement of asphalt overlays in Ethiopia which would be an eye-opener to most professionals in field. It also demonstrates the step by step procedures on how to install a geogrid during an overlay construction.

1.5. Scope of the study

As geogrid has versatile reinforcement applications, this research tries to specifically study the effect of geogrid reinforcement of an asphalt overlay.

Moreover, despite the existence of many types of asphalt distresses; this thesis particularly considers reflection cracking on three selected sites: The National Theatre 1, National Theatre 2 and the Gandhi Hospital sites.

In addition, due to time constraint on submitting thesis report, only the effect of the geogrid reinforcement for a period of eight months starting from the installation of the geogrid is studied and documented.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Background

2.1.1. Definition of terms [3]

“Geosynthetics” are defined herein as fabrics, grids, composites, or membranes. Grids and composites are newer generation materials developed for specific purposes by manufacturers.

Fabrics or geotextiles may be woven or nonwoven and are typically composed of thermoplastics such as polypropylene or polyester but may also contain nylon, other polymers, natural organic materials, or fiberglass. Filaments in nonwoven fabrics are typically bonded together mechanically (needle-punched) or by adhesion (spun-bonded, using heat or chemicals). Grids may be woven or knitted from glass fibers or polymeric filaments, or they may be cut or pressed from plastic sheets and then post tensioned to

maximize strength and stiffness. Grids typically have rectangular openings from 6.5 mm to 51 mm wide. Grids are designed to exhibit high modulus at low strain levels such that their reinforcing benefits begin before the protected pavement layer fails in tension. Composites generally consist of a laminate of fabric onto a grid. For the composite, the fabric provides absorbency (primarily to hold asphalt) and a continuous sheet to permit adequate adhesion of the composite onto a pavement surface; whereas, the grid provides high strength and stiffness.

A heavy-duty membrane is a composite system, usually consisting of a fabric mesh laminated on one or both sides with an impermeable rubber-asphalt membrane. They are typically placed in strips over joints in concrete pavements or used for repair of localized pavement failures.

2.1.2. Application of Geogrids

Geogrid is one of the various types of geosynthetics in which its primary application is invariably reinforcement. Generally Geosynthetic materials have the following five major functions:

- Separation
- Reinforcement
- Moisture Barrier/Containment
- Filter
- Drainage

The use of geogrid to retard and minimize reflective cracking within old pavements from propagating through newly placed overlays is of interest in the current study.

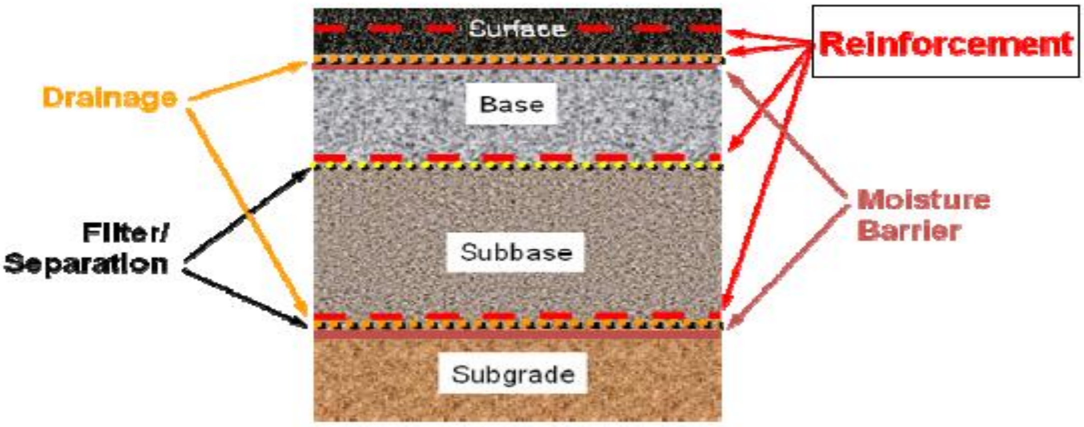

Fig.1.1 Potential applications of geosynthetics in a layered pavement system.

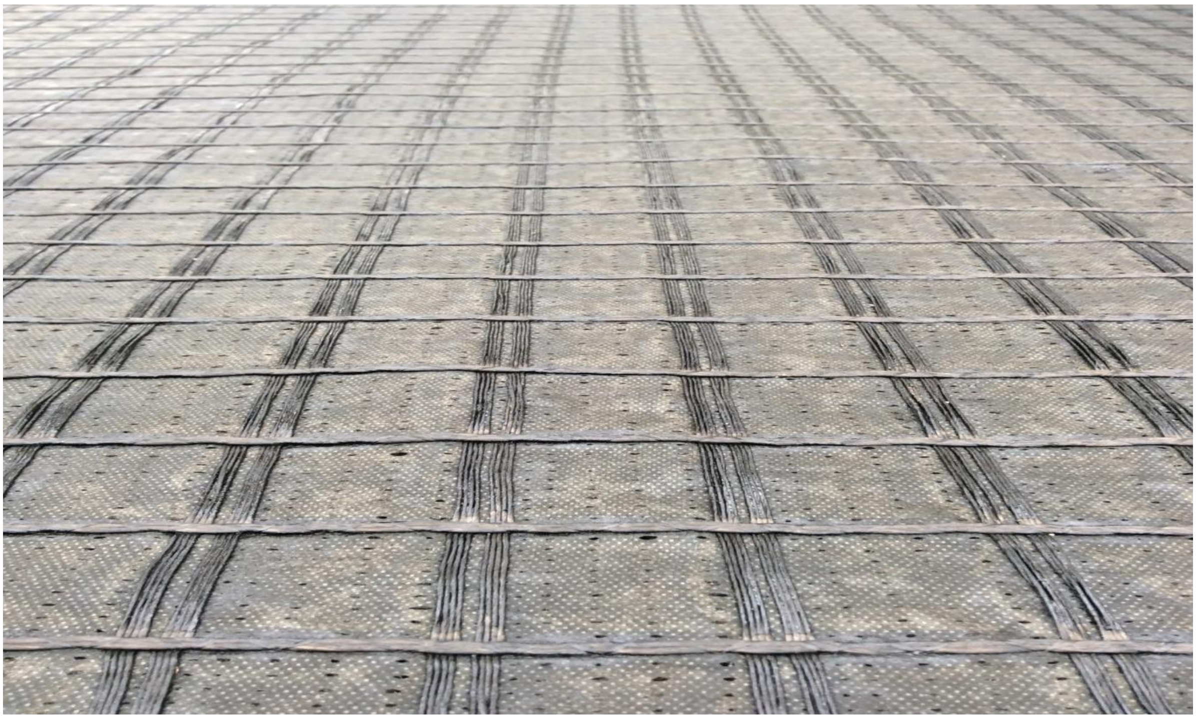

Fig1.2 Photo: Hatelit C40/17 Biaxial Geogrid, shipped from HUESKER Synthetic Gmbh Company, Germany.

As this research specifically concentrates on the effect of geogrid reinforcement in mitigating reflection cracks, road sections under severe reflection cracking were selected.

During the past decades many researchers have proposed solutions to retard reflection cracking based on field, laboratory and numerical investigation [1, 4, and 9]. After a number of service years, pavement defect cracking appear at the surface due to repeated traffic loading, local environment distress moisture and temperature induced, and aging. The traditional flexible-pavement rehabilitation using the overlay method is expensive and rarely provides a durable solution as the cracks rapidly propagate through the new asphalt layer forming so-called "reflective cracks". In contrast, an interlayer of geogrids can be placed over the distressed pavement or within the overlay to create an overlay system. The geogrid interlayer contributes to the life of the overlay via stress relief and/or reinforcement and by providing a pavement moisture barrier [11].

Because reflective cracking has a variety of contributing causes, including current pavement condition, traffic, crack spacing, temperature and moisture changes in the base course and subgrade, presence or absence of voids beneath the pavement surface, overlay thickness, geogrid type and position, tack coat application rate, and correct installation of geogrids, each of these field conditions affects the rate at which the reflective crack propagates through the overlay [10].

There are situations when even the most elaborate system for combating reflective cracking will be ineffective. Then, reconstruction is the only option. Depending upon the cause of the problem, this can involve removing layers of pavement, improving/stabilizing base course/subgrade, and repaving. This option is extraordinarily expensive and time consuming. In early1990s, field studies made on geogrid- reinforced asphalt overlay proved that the glass fiber grid placed at the bottom of overlay was effective in limiting cracks near the interface and increasing of bending strength by 42% and of fatigue life by 80%[14]. Another study conducted with a field test showed that thick asphalt overlay reinforced with geogrid did decrease surface deflection and two layers of geogrid are even more effective than single layer [27].

Kim et al. conducted lab test to study reflection cracking in asphalt overlay with polymer modified asphalt mixture and glass grid or polypropylene film. To simulate an asphalt pavement overlaid on top of a crack in concrete pavement, an asphalt mixture specimen was placed on top of two discontinuous concrete. Their result showed that when modified asphalt mixture was reinforced with the glass grid at the bottom of the asphalt layer, its fatigue life increased by a factor of 16.7 [11].

Brown et al. placed asphalt beam specimens on two pieces of plywood that had a 10 mm gap at center to simulate an existing joint or crack underneath the overlay, with the whole system placed on a rubber base representing the soil foundation [31]. Reddy et al. [14] studied the propagation of reflection cracks by placing asphalt beam specimens on small concrete blocks (at different gap intervals) simulating the broken PCC resting on an elastic foundation prepared with compression springs. Goulias and Ishai [15] used a wheel-tracking device to test an overlay with a pre-sawn crack or notch underneath the specimens. Castell et al. [16] predicted crack growth rate with maximum strains and found bottom-up cracking is more likely to be found than top-down cracking. Thick overlay was once considered to prevent bottom up reflective cracks. Yet, Uhlmeyer et al. [17] investigated thick overlay and found cracks starting at surface and propagate downward. Sha [18] also noticed top-down reflection cracking happened for thick overlay according to field observation in China. Castell et al. [16] Goulias and Ishai [15] further used the ABAQUS finite element program to model geogrid-reinforced asphalt overlay on the old PCC pavement with joint/crack. They concluded that placing the geogrid at one third depth of asphalt overlay thickness from bottom had the minimum tensile strain.

In a recent study, a laboratory experiment program and detailed analysis were employed. The primary objective of the experimental phase was to study the effects of placement of geogrid in overlay under the condition of mode I (bending) on the growth and propagation of reflection crack over different existing pavement (asphalt or concrete).In the experiment, a geogrid reinforcement resulted in an overall boost on tensile strength of the overlay.[18]

Another geogrid application in roadways is to place the geogrid or geocomposite at the bottom or within the base course to provide reinforcement through lateral confinement of the aggregate layer. Lateral confinement arises from the development of interface shear stresses between the aggregate and the reinforcement and occurs during placement, compaction, and traffic loading. A small residual restraint remains after each load application, thus increasing the lateral confinement of the aggregate with increasing load applications. Base reinforcement thus improves the long-term structural support for the base materials and reduces permanent deformation in the roadway section and has been found under certain conditions to provide significant improvement in pavement performance. Increases in traffic volume up to a factor of 10 to reach the same distress level (1 inch or 25-mm rutting) have been observed for reinforced sections versus unreinforced sections of the same design asphalt and base thickness [19].

For pavements constructed on compressible soils, the inclusion of geotextiles or geogrids can lead to less deformation of the pavement and can reduce the thicknesses of base materials needed. In many cases, this can be cost effective, as the savings in importing base material and in repairs to the pavement can offset the cost of the reinforcement.

Miura et al.[21] investigated the mechanism by which a geogrid could Suppress non uniform settlement of a pavement constructed on a soft clay subgrade. They showed in preliminary experimental tests that the mechanism by which a reinforced pavement base improved performance was mainly the interlocking effect rather than the membrane tension effect. They placed the geogrid in a slightly convex shape. After applying vertical load to the surface of the model pavement, compressive strains were developed in every part of the geogrid, yet the grid still worked as a reinforcement even though it was not in tension. This showed that the contribution to reinforcement could only have been due to interlocking. To develop the membrane effect of a grid it was recommended that the geogrid be placed in a concave shape. Miura et al. [21] also mentioned that the long-term effect of a one-layer geogrid as a reinforcement in a pavement is comparable to that of base material about 10 cm thick.

Chan et al. [22] conducted large-scale experiments in order to investigate the aggregate base reinforcement potential of geogrids and geotextiles in surface pavements. Their experimental tests included multiple and single-track tests. Their results indicated that the inclusion of a geogrid, despite its lower stiffness, resulted in better performance than that of a geotextile, because geotextiles required a much higher deformation, which is not desirable in paved roads, in order to produce the same effect as the geogrid. This showed that strengthening was due to restraint or some local reinforcement effect rather than a membrane effect. Their investigation showed, however, that a geotextile performs better than a geogrid as a separator between the subgrade and base. Reduction in deformation of the subgrade was evident when a geofabric was placed directly on top of the subgrade, particularly when it was prerutted. Prerutting of a geogrid might result in increasing its membrane effect. The investigation of Chan et al. [22] also indicated that overall resilient behavior of the pavement was not significantly influenced by a geogrid. They recommended pre rutting to improve resistance to permanent deformation and to lessen surface rutting; however, they did not recommend it for weak granular materials.

Hass et al. [22] indicated that for low deformation systems interlock and confining action is required, while for high deformation systems, a tension membrane action is more effective. They also concluded that, for better performance, a geogrid should be placed at the base-subgrade interface of thin base sections and near the midpoint of thicker base layers. For optimum grid reinforcement they proposed placing the grid in a zone of moderate elastic tensile strain (i.e., 0.05% - 0.2%) beneath the load center, and stated that maximum permanent strain in the grid during its design life should not exceed 1% - 2% depending on the rut depth failure criteria.

In designing and maintaining transportation facilities, designers attempt to provide facilities that will meet users' current needs without rapidly becoming obsolete that will be safe, and that will be economical to construct and maintain. In the past, one or more of these objectives often had to be sacrificed. Geogrids have enabled innovative designs that can better meet all of these objectives [24]. There has been much discussion of the notion that standardization reduces opportunities for innovation. Another way of viewing the relationship between the two is to say that innovation, or the state of the art, must precede the adoption of technology, or its standardization (state of the practice). Quite often, however, the move from state-of-the-art technologies to the state of practice within transportation agencies lags behind that in other engineering communities. Some of this is due to economics; innovation tends to be costly until the technology becomes the standard of practice. Other factors, such as governmental conservatism, also play a role. With regard to geogrids, designers must become more willing to use these new materials in such applications as geogrid-reinforced earth structures. Doing so will allow the state of the art to become the state of practice, which in turn will lead to reduced project costs [25].

2.2. Causes of Reflection Cracking

One of the more serious problems associated with the use of thin overlays is reflective cracking. This phenomenon is commonly defined as the propagation of cracks from the movement of the underlying pavement or base course into and through the new overlay as a result of load induced and/or temperature-induced stresses [38].

1. The reflection crack has two major driving forces:

The external wheel load; this contributes to high stress and strain levels in the overlay above the existing crack. The discontinuity in the existing pavement reduces the bending stiffness of the rehabilitated pavement section and creates a stress concentration. When conditions are such that the stress state exceeds the fracture resistance of the overlay, a reflective crack can be initiated and / or propagated. A combination of mode I (opening) and mode II (shearing) stress leads to crack propagation through the overlay [38].

2. Daily temperature variations;

The contraction of the discontinuous underlying pavement leads to additional concentrated tensile stresses in the overlay above the existing crack or joint. This phenomenon is almost exclusively linked to the pure mode I crack opening mechanism [39].

Because of a number of variables involved in the nature of reflection cracking no solution for completely preventing of these cracks propagation has been suggested yet. Only retardation of crack progress is the best solution strategy adopted so far. Inclusion of geosynthetic interlayer may enhance the resistance to reflection cracking either by a stress-relief or a reinforcement mechanism, or by a combination of both.

2.3. State of practice

Certain geogrid materials are used routinely by some state transportation departments and local road authorities. These materials and their applications include geotextiles roadway pavement separators, blankets and mats for erosion control, geotextile barrier asphalt overlays, geogrid composite drains, geotextile filters, and geotextile or geogrid reinforcement of embankments over soft foundations. The widespread use of geotextile separators between soft, wet subgrade and base course layers is expected to continue. The use of geogrids and synthetic-natural composites for erosion control is likely to increase in the future with stricter environmental regulations and enforcement [26]. However, the use of geogrids material in Ethiopia is very low. Most of the local construction companies do not even fully understand the advantages of implementing geogrid materials.

Impregnated geotextile barriers are used routinely in asphalt overlays, but only in certain areas of the country and typically by local road authorities. Use of these barriers in asphalt overlays is expected to be limited in the future. Geogrid composites are widely used for pavement edge drains [26]. Expanded use of these drains will likely occur as design and installation procedures continue to be refined, but their application can be significantly increased if more definitive economic benefits are demonstrated. The use of geotextile filters in drainage systems and of geogrid reinforcement beneath embankments over weak foundations should continue in the future [27].

The future use of geogrids in all of these applications, particularly asphalt overlays can be enhanced with better documentation of immediate and life-cycle cost and benefits as compared with alternative methods. Use of geotextile separators over relatively firm subgrade could become routine if the economics and mechanisms of pavement improvement were better defined.

2.4. Materials used in overlay reinforcement

2.4.1. Geogrids:

Grids may be woven or knitted from glass fibers or polymeric (polypropylene or polyester) filaments, or they may be cut or pressed from plastic sheets and then post tensioned to maximize strength and modulus. Grids typically have rectangular openings from 1/4 inch (1.2 cm) to 2 inches (5 cm) wide. A grid may have a thin membrane laminated onto it that assists in construction (i.e., attaches to the asphalt tack coat) but is designed to melt and thus disappear when the hot HMA overlay is applied. Additionally, some grids have thin, permanent fiber strands partially filling the openings that adhere the grid to the tack coat without forming a waterproof barrier. Grids are designed to exhibit high modulus at low strain levels such that their reinforcing benefits begin before the protected pavement layer fails in tension [28].

2.4.2. Geocomposites:

Composites generally consist of a laminate of fabric onto a grid. For the composite, the fabric provides absorbency (primarily to hold asphalt) and a continuous sheet to permit adequate adhesion of the composite onto a pavement surface; whereas, the grid provides high strength and stiffness. Manufacturers custom design these third-generation products, based on laboratory and field research, to meet the needs of asphalt retention and high initial tangent modulus (i.e., high modulus at low strain levels) [30].

Currently, geogrids and geotextiles are being used to a very limited extent to reinforce the pavement base course and to enhance performance over a soft subgrade of flexible Pavement structures.

However, better definition of mechanistic design procedures, life-cycle costs, key material properties, and specifications is needed for geogrid pavement reinforcement to become the state of the practice within transportation agencies. Spurring this expected growth is the challenge of extending the pavement analysis period (i.e., design life) to 30 to 50 years and the growing cost of base course materials.

Another application that should increase is the use of geogrids to reinforce fill embankment edges. Reinforcement enhances soil compaction and soil shear strength, thus decreasing future maintenance costs associated with reinstating sloughing-type failures [31].

As the effect of geogrid reinforcement in mitigating reflection cracks in asphalt overlays is being studied by this research, base reinforcements with a geogrid should also be locally experimented to minimize the options of replacing problematic soils with selected materials during pavements construction works in Ethiopia.

2.5. Effect of position (depth) of reinforcement

According to the study conducted by Hass et al. [22], cracks occurred first between geogrid and overlay AC. Then cracks developed from bottom of overlay and propagated to the surface. Yet, unreinforced specimen had wider cracks than reinforced specimens. As shown in Fig 2.1 the best location of geogrid for reflection crack was found to be one- third depth from bottom of overlay that had a fatigue life 6.7 times greater than unreinforced specimen. The studies showed that if the geosynthetic is embedded at middle of overlay it will provide a fatigue life greater than embedded in bottom. It should be noted that they did not make a reinforced specimen in one-third depth from bottom. Samples with geogrid embedded at middle or one-third sustained more than 1.4 times the deformation of unreinforced specimens. However they withstood over 5.8 times the number of cycles before terminal cracking [22].

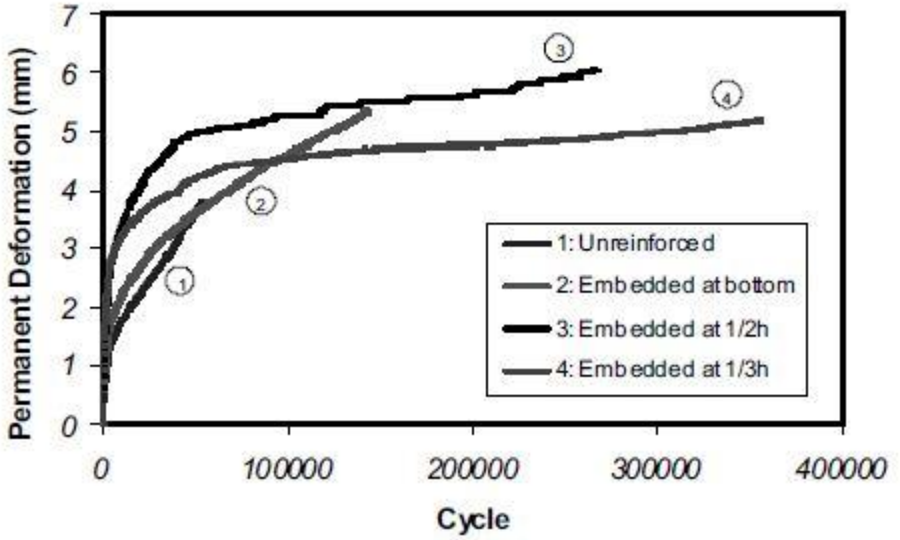

Fig 2.1. Permanent deformation over fatigue life for overlays with asphalt block base and 10 mm gap at 20 °C

2.6. The effect of width of joint/crack in old pavement in geogrid application

Based on the laboratory studies conducted by Hass et al.[22] the best location for geosynthetic in overlay with old asphalt or concrete block that had 10 mm gap interval was one third depth from bottom of overlay, the other reinforced samples with reinforcement in one-third depth with different gap interval were made to compare with unreinforced samples with different gaps in block. Three crack/ joint widths were selected, 10 mm to simulate cracks developed in asphalt pavement and 15 or 20 mm to simulate a joint opening in an existing concrete pavement to be overlaid by asphaltic mixes. As shown in Fig. 2.2, reinforced overlay on concrete block with 20 mm gap interval had 66% of fatigue life of reinforced overlay on PCC with 10 mm joint/crack. However, specimen with geogrid embedded in one- third depth of overlay over a concrete block with 20 mm joint had service life 8.7 times and approximately same permanent deformation before terminal cracking of that of unreinforced specimen with 20 mm gap. Also Samples over an asphalt block base with 15-20 mm gap had a greater crack growth rate and deformation in fatigue life and lower service life and dynamic stability when compared with those placed over a 10 mm gap asphalt block base (Fig. 2.3). The results in general indicate that the effect of reinforcing geogrid in overlay with increasing joint/ crack in existing pavement was almost constant. Service life for all various conditions is shown in Fig. 2.4. From this figure, the most and least effective geogrid position in asphalt overlay in relation to resistance to reflection cracking can be easily distinguished.

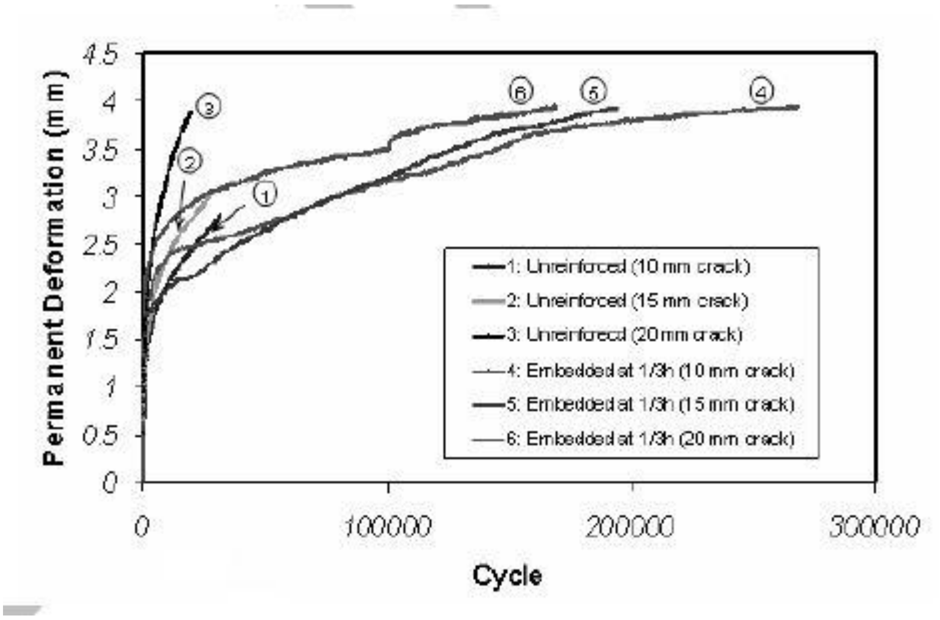

Fig. 2.2 Permanent deformation for unreinforced and reinforced overlays in one -third depth with concrete block base at 20 °C [22]

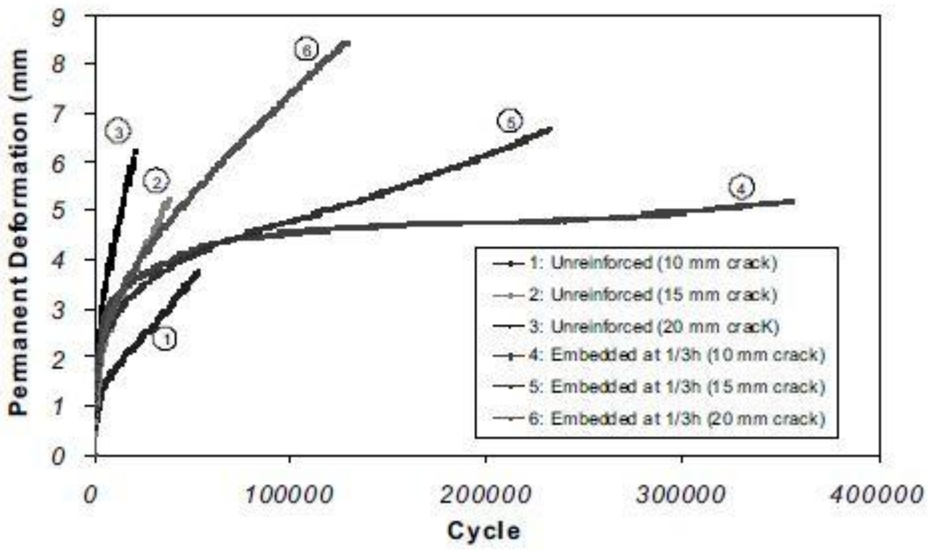

Fig. 2.3 Permanent deformation for unreinforced and reinforced overlays in one-third depth with asphalt block base at 20 °C [22]

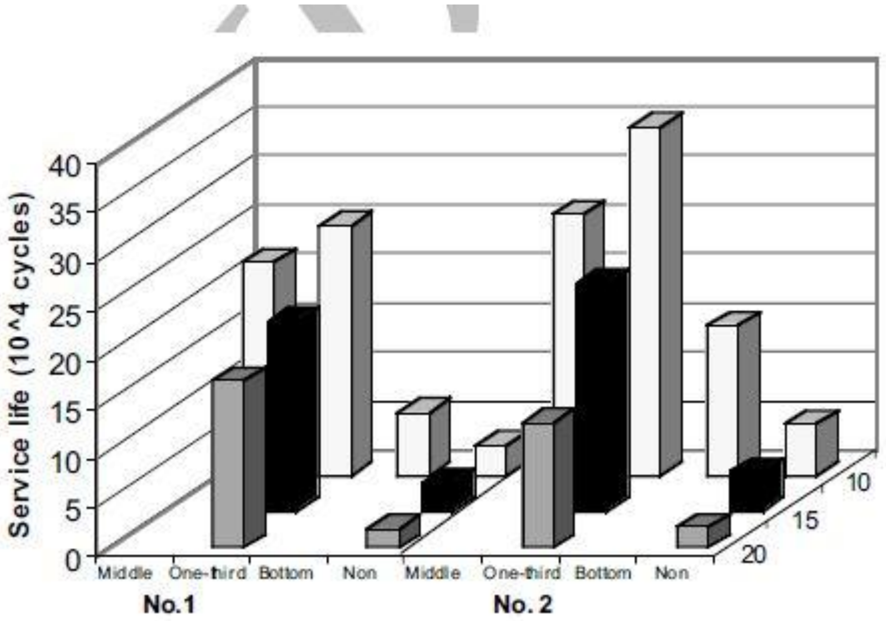

Fig.2.4 Comparison of service life for various conditions Note: No.1 and No. 2 represent overlay with old concrete block and asphalt concrete block respectively, 10, 15 and 20 corresponds to the width of crack in old block in mm [22].

2.7. Reduction in overall cost of construction due to reinforcement

The in-place costs of geogrids and other methods to address reflection cracking are influenced by: (a) the specific product used, (b) the quantity to be placed, (c) tack coat requirements, (d) local experience with its installation, (e) local labor costs, and (f) the general condition of the market place. The in-place cost of fabrics has fallen significantly since the early 1980s, apparently due to stiff competition and, perhaps, improved contractor experience and acceptance of geogrids [19]. The in-place cost of a full-width paving fabric is roughly equivalent to the cost of about 0.5 inch to 0.6 inch (1.27 cm-1.53 cm) of asphalt concrete. Under favorable conditions (many of which are described herein), some geogrid products can delay reflection cracking in an asphalt overlay about two to four years longer than a similar overlay without a geogrid. Reflection cracks are usually sealed through a maintenance program [20].

Such maintenance costs and any delays by a geogrid are reasonably easy to quantify and should be considered when the cost of different design alternatives is analyzed. An estimate of the probability of success should be included in all economic analyses. Under favorable conditions, the probability of success of a paving fabric will be about 60 to 65 percent [20]. The use of geogrids and other techniques should, at a minimum, be compared with the cost of using an overlay of similar thickness with a crack-sealing program. Thicker overlays can also be used as a basis for comparison. One should obtain realistic cost data for the particular situation and estimate a reasonable probability of success. A simple approach is to determine or estimate the performance equivalency between two alternatives and directly compare their costs. California DOT indicated a paving fabric interlayer may be equivalent to about 1.2 inches (3cm) of HMA in retarding reflective cracking. Using typical in-place costs, a fabric interlayer is about 50 percent of the cost of 1.2 inches (3 cm) of HMA and this assumes a 100 percent success rate. Considering a 65 percent probability of success, the economic advantage of using paving fabrics appears to be somewhat less unless the potential benefits of reduced water infiltration and resultant improved ride quality are considered. Determination of cost effectiveness of products in pavements typically requires several years. As a result, information on cost effectiveness of the newer grids and composites is not currently available in the literature [33].

2.7.1. Overlay Thickness

Overlay thickness for both flexible and rigid pavements should be determined as if the geogrid interlayer is not present. Generally, overlay thickness should not be reduced from that determined by standard structural design methods when using a geogrid. When overlay thickness is reduced based on contributions of the geogrid, it should not be reduced to less than four times the size of the largest aggregate in the HMA overlay neither mixture nor less than 1.5 inches (3.8 cm) [33].

Avoid the use of thin (< 2 inches (5 cm)) or inadequately compacted overlays with fabric, particularly on high traffic volume facilities. Stage construction is not recommended. That is, a thin overlay should not be constructed with plans for placing another thin overlay in a few years. Data and experience suggest that a minimum overlay thickness of 2 inches (5 cm) should be used with or without paving fabrics [34].

Overlays less than 0.5 inch (1.3 cm) thick cool rapidly and, thus, are difficult to compact to the required density. A poorly compacted overlay may exhibit high permeability and allow water to become trapped on top of a fabric interlayer. Trapped water can lead to distress due to stripping and freeze-thaw damage in the overlay, which will appear prematurely as cracks in the wheel paths and will deteriorate rapidly [34].

2.7.2. Overlay Type

Normally, only dense-graded, well-compacted, low permeability HMA mixtures should be used as overlays over fabrics or composites. Beneath permeable HMA mixtures, any water-proof layer must be placed at a drainable grade so that surface water drains out of the overlay. For milled inlays, proper drainage must be provided. Permeable overlays, such as poorly compacted mixtures with interconnected voids, should not be permitted, particularly in inlays. CMHB mixtures have shown significant permeability when first placed and, therefore, should not be used over a waterproofing fabric or composite [35].

2.8. Things to consider while designing for flexible pavement overlays involving geogrids

The recommended steps in developing an overlay design for flexible pavements where a geogrid is a potential candidate are given below. Details have been modified to accommodate TxDOT (Texas Department Of Transportation) circumstances [32].

a. Evaluate Pavement Condition

A general pavement condition survey is valuable in establishing the type, severity, and extent of pavement distress. Such information is needed to develop required repair strategies and the overlay design strategy. Candidate pavements should be divided into segments. Non-destructive surveys, including visual distress, ground penetrating radar (GPR), deflection (FWD), or seismic (SPA), are possible tools to establish where these divisions should be made. For each segment, determine extent and severity of cracking (longitudinal, transverse, alligator, block, random), rutting, patching, potholes, flushing, raveling, etc. Crack widths should be measured. TxDOT has existing systems for rating pavement condition.

A tentative conclusion should then be drawn as to whether a geogrid is a suitable candidate in the rehabilitation scheme. If a formal pavement condition survey is not performed, at a minimum, the type, extent, and level of cracking should be established [36].

b. Evaluate Structural Strength

Overall structural strength of the pavement should be evaluated, along its length, using the falling weight deflectometer /(FWD). The pavement should have a remaining life of greater than 5 years [32].

c. Identify base/subgrade failures

Areas that have experienced base or subgrade failures should be identified. There should be no evidence of severe load associated distress (e.g., alligator cracking > 5 percent, deep ruts, or failures). When nondestructive testing devices are not available, proof loading of the pavement with a loaded truck has also been used to identify structurally weak areas. Reflection cracking will not be significantly delayed by geogrids in areas that have base/subgrade failures; however, a waterproof geogrid product can be used on affected areas to help keep surface water out of the base.[38]

d. Develop remedial pavement treatment

Results of the pavement condition survey and deflection measurements should be used to develop a pavement repair strategy for each segment.

e. Select Overlay Design

An adequate overlay thickness must be selected to ensure a reasonable overlay life. Using geogrids with thin, under designed overlays, which lead to significant reflection cracking in three to five years or less, will not justify the use of a geogrid. In other words, overlay thicknesses play a great role in delaying reflection cracks and should be designed to the adequate thickness even when being reinforced with geogrids.

f. Monitor Performance

To develop a data bank of performance histories with geogrids, performance monitoring during construction and service of the overlay is highly desirable. Constructing a control section without the geogrid, with all other items equal, will provide valuable comparative data for future decisions. Without a control section, a so-called test pavement has no value.

2.9. Step By Step Procedures While Installing a Geogrid For Asphalt Reinforcement.

a. Preparing the Surface [6]

These recommendations are designed to ensure that the geogrid or level-up course will have continuous firm support, which will assist in proper compaction of the overlay and allow continuous tack coat application to uniformly saturate the geogrid product.

1. Before application of a geogrid, thoroughly clean the existing pavement using a broom and/or compressed air.
2. Confirm that the existing pavement is dry.
3. Fill cracks exceeding $^1/8$ inch (3.2 mm) wide with appropriate crack sealant.

4. Fill cracks exceeding 1 inch (2.50 cm) wide with a fine-grained bituminous mixture.
5. Level faulted cracks or joints with vertical deformation greater than ½ inch (1.3 cm); use a fine-grained bituminous mixture or other suitable material.
6. Properly repair potholes even with the existing pavement surface.
7. Allow crack filler and patching materials to cure prior to placement of the geogrid.

b. Importance of a Leveling Course

Apply a leveling course to uneven, rutted, or extremely rough surfaces. For best results, place a level-up course (0.75 inch to 1 inch) (19 mm-25.4 mm thick), whenever possible, before placing the geogrid. This will maximize performance of the geogrid by reducing reflective cracking. Both observation and analysis have shown that it is important to place a leveling course before placing a geogrid to further retard the appearance of reflection cracks. The leveling course does several important things to promote success of the overlay including providing a smooth surface on which to place a geogrid and a fresh, un oxidized surface to which the geogrid or new overlay can bond. The leveling course can also establish a drainable grade, when necessary, on which to place the geogrid [33].

Placing a geogrid (and particularly a fabric) directly on an old or even a milled surface can cause wrinkles, which can themselves reflect a crack upward to the surface of the overlay. Grids also benefit from being placed on a level-up course because the smooth surface:

- makes the installation much easier,
- provides maximum adhesion,
- allows the reinforcing strands to be placed flat to mobilize their strength and stiffness at small deformations, and
- provides new material both above and below the grid so that compaction will press aggregates down through the grid apertures to lock the grid in place.

Theory and practice indicate that the life of an overlay can be shortened by placing a grid directly on the old pavement surface, whether it is milled or not, and then placing the overlay on top of it. Typically, the life of the overlay is shortened if the overlay thickness is between 2 inches (5 cm) and 5 inches (12.5 cm) thick and no leveling course is used beneath the grid. In such cases, analysis shows that, in this range of total thickness of overlay, the use of a leveling course can provide an overlay reflection cracking life that is 20 to 100 times longer than it would be if a grid were placed directly on the old pavement surface [35].

Because the movement at cracks and joints in jointed concrete pavements is relatively large, a level-up course is highly recommended.

c. Tack Coat Selection and Application

Selection of proper tack material and application rate is one of the most important aspects in construction and performance of certain geogrid inter layers. One should consult the particular geogrid manufacturer's installation manual. Hot asphalt cement (AC) is usually recommended as tack for geogrids. Tack coat should be applied uniformly at the specified rate using a calibrated asphalt distributor truck. The tack coat should be sprayed approximately 4 inches (10cm) wider than the geogrid. Common field problems with tack coat applications include proper temperature control, clogged or leaking spray bars or nozzles, application of too much or too little material, and non uniform distribution[27].

d. Temperature Control

Tack application temperatures are generally about 290°F (144°C) to a maximum of 325°F (163°C). Temperature of the tack when the geogrid is placed can be critical. Although emulsified asphalts have been successfully used as tack for fabrics, they develop bond strength more slowly than asphalt cement, and debonding on windy days has been re- ported. Cutback asphalts should never be used for fabric tack, because the solvent can remain for extended periods and weaken the polymer.

Tack coats for fabric application are relatively heavy and should be applied uniformly with a calibrated distributor truck. Insufficient or excessive asphalt tack applied for fabric adhesion can result in overlay failures due to slippage at the fabric interface, especially in areas of high shear forces during periods of hot weather. Excessive tack can cause slippage of the paving machine or subsequently migrate to the pavement surface and appear as flushing in the wheel paths. Low-viscosity asphalts are more susceptible to this bleeding than higher viscosity materials.

Tack coat should be applied using relatively long shot lengths. Start-stop operations less than a few hundred feet yield highly variable asphalt application rates. Shot lengths equal to fabric roll lengths (about 300 feet) are convenient for some operations. Greater lengths are encouraged provided the freshly sprayed asphalt does not become contaminated with dust or other foreign material. Starting and stopping on paper will reduce the buildup of asphalt at the overlapping sites [28].

e. Tack Coats and Grids

Grids or mesh products often do not have enough continuous surface area to adhere tenaciously to an asphalt tack coat. Some grids are fastened to the existing pavement by methods other than asphalt tack. Some grid products have a self-adhesive backing. Therefore, tack may or may not be necessary to fasten a grid to the existing pavement. Generally, one should follow the manufacturer's recommendations for tacking grids. However, keep in mind that the interface between the existing pavement and the new overlay often needs tack to prevent delamination and thus slippage due to vertical and horizontal traffic loads. Placement of a light tack coat onto the mesh after installation should minimize potential slippage and/or debonding but may cause construction problems [27].

Placing a thin overlay without tack (particularly on a high-traffic facility) invites slippage and/or debonding problems. When placing a self- adhesive grid product for use with an overlay on an old pavement surface (i.e., not a new level-up course), a tack coat should be applied on top of the grid (i.e., after grid application) to ensure adequate adhesion at the interface. The appropriate quantity of tack is that normally used without a grid or slightly more. Type of tack should be hot-applied asphalt cement (not emulsion) of the same grade as that determined for the HMA overlay. If the grid is placed on a new level-up course, the tack coat may not be necessary [35].

f. Tack Coats and Composites

Typically, the tack coat selection and application guidelines for fabrics apply to composites.

g. Tack Coats and Membranes

Membranes may or may not require tack coat. If a tack is required, it may be a proprietary product.

h. Placement of Geogrids

An experienced crew using a small tractor rigged for handling geogrid rolls should be specified for geogrid placement. Such a crew can move much faster than the paving train. To avoid placing traffic on the geogrid, no more geogrid should be placed than can be overlaid the same day. Manual placement should be disallowed except in small areas where equipment may have difficulty maneuvering [35].

i. Aligning and Smoothing

As the geogrid is spread onto the asphalt tack coat, it must be aligned and smoothed to remove wrinkles and folds. Some wrinkling of geogrids during installation is unavoidable due to curves and undulations in the pavement surface. Folds that result in a triple thickness must be slit with a knife and overlapped in a double thickness. Wrinkles can be a source of premature cracking in the overlay due to compaction without firm support or possibly due to shrinkage (polypropylene products) [34].

j. Handling Overlaps

A 4-inch to 6-inch (10 cm-15 cm) overlap is suggested at all longitudinal and transverse joints. Transverse overlaps should be in the direction of paving to avoid fabric pick-up by sticky tires. It is necessary to apply additional asphalt tack at these locations to ensure proper saturation and bonding. For this purpose, emulsified asphalt can be applied using a hand sprayer, brush, or compressed air [35].

k. Controlling Traffic

Traffic will damage geogrids and may cause delamination from the pavement surface prior to overlay placement. Geogrids significantly reduce pavement surface friction and can present a skid- ding hazard, particularly during wet weather. Significant traffic should never be allowed on geogrids. If trafficking is necessary, speed should be strictly controlled to 25 mph. If significant trafficking is necessary, an alternative to geogrids should be considered [26].

l. Handling Equipment

To avoid displacement or damage to geogrids while turning construction equipment, turning should be gradual and kept to a minimum. Parking of construction equipment on a completed geogrid/ asphalt tack interlayer, even for short periods, should be avoided [27].

m. Dealing with Rain

Geogrids should not be placed during rainfall or when rain is expected. Rainfall before, during, or after placement can result in severe debonding and even loss of the geogrid. On highly textured surfaces (e.g., a milled surface), geogrids are more subject to damage by rainfall and traffic [28].

n. Highly Textured Surfaces

Geogrids can be successfully employed on highly textured surfaces such as freshly milled pavement. Milled surfaces may require additional tack coat; this can be accomplished by pre tacking any milled surfaces (e.g., next to curbs). In urban areas subject to high shear forces (e.g., at intersections), a highly textured surface may help decrease the probability of slippage [29]

o. Placement of Fabrics

The bonded or glazed side of a fabric is better to drive on than the fuzzy side (i.e., less damage).The fuzzy side should be placed next to the tack coat. This practice will provide the highest bond strength and best slippage resistance [29].

When fabric is applied on hot days (>90 °F) (>32 °C), pavement surface temperatures near

160°F/72°C may prevail. These temperatures can be sufficiently high to keep the viscosity of asphalt tack, low enough to partially saturate the fabric during placement and fully saturate the fabric in the wheel paths of construction vehicles [26].

Tires of HMA haul trucks can become coated with asphalt and will often pick up the fabric. The amount of asphalt tack coat should not be reduced to solve this problem [26].

1. First, allow the tack to cool longer before placing fabric.
2. Alternatively, hand spread a small amount of HMA mix on top of the fabric in the wheel path of the haul vehicles.
3. Application of sand is the least desirable choice, as sand will absorb some of the asphalt and defeat its purpose. If sand is used, the quantity should be minimized and the grading should be coarse.
4. Change to a “heavier” grade of asphalt cement for the tack coat material.
5. Shorten the distance between fabric placement and the paving machine.
6. Minimize the number of vehicles on the fabric.

Cool weather construction may require the use of a lightweight rubber tired roller to properly attach the fabric to the tack coat. Rolling is preferred over a short shot length to solve the cool weather fabric adhesion problem. Excessive rolling should be avoided [27].

High winds can be problematic during application of fabrics particularly on a highly textured milled surface. Limited pneumatic rolling of a fabric immediately after application will maximize adhesive strength and minimize its disruption by wind and construction traffic [27].

Pneumatic rolling on a steep grade or cross slope can result in slippage at the pavement fabric interface if the asphalt tack is still hot.

Construction joints in fabrics should generally follow the manufacturer’s instructions. Additional tack hand-applied on transverse fabric overlaps or applied by distributor on longitudinal overlaps can reduce disruption by wind and construction traffic. Emulsified asphalt is suitable for securing fabric overlaps at construction joints [27].

p. Placement of Grids and Composites

Placement of grids and composites are generally similar to placement of fabrics. They should be tensioned during placement using a specially equipped tractor or laid flat to maximize their reinforcement effects [27].

q. Placement of HMA Overlay [6]

An HMA overlay can be placed immediately after placement of a geogrid using conventional equipment and techniques. No cure time is necessary. The HMA mixture should not be less than 250 °F (121 °C) nor greater than 325 °F (163 °C) as it exits the paving machine. The minimum temperature is required to obtain adequate density of the overlay and pull the binder up through the geogrid. The maximum temperature is required to avoid damage to geogrids containing polypropylene.

On hot days, premature saturation of the geogrid may occur. Therefore, it may be necessary to broadcast a thin layer of HMA mix in front of the paving machine in the wheel paths of haul trucks and the paving machine to prevent geogrid “pick-up. [35]”

If the installed geogrid should get wet due to rainfall, the overlay should not be placed until all free water is removed. The geo- synthetic surface may be slightly damp but one should not be able to squeegee any free water out of the geogrid. If an overlay is placed over excess moisture, the resultant steam will not permit adequate bond of the interlayer system and could lead to overlay problems [6].

A minimum compacted overlay thickness of 1.5 inches (3.5 cm) is required as the first lift over a geogrid. If the thickness of the overlay is tapered toward the edges, at the thinnest point, it should not be less than 1.5 inches (3.5 cm). Thinner overlays will not generate enough heat to draw the asphalt up into the paving geogrid to produce a well-bonded interlayer. [35]

2.10. Potential Construction Problems

In hot weather (pavement temperatures > 120 °F/ 49 °C), asphalt tack may bleed through fabrics. Vehicles can splash asphalt onto their painted surfaces. Construction traffic can become sticky and pick up fabric and in severe cases wrap the fabric around the tires or axles. Bleeding can be exacerbated by excessive pressure applied by the brush on the fabric application tractor. Incomplete fabric saturation can occur due to insufficient tack application rate, overlay temperature, and/or overlay compaction [35].

If wet fabric is applied or if fabric is applied on damp pavement, blistering can occur due to vaporization of moisture underneath the asphalt-impregnated fabric. Pavement that has recently received rainfall but has a dry surface can retain enough moisture to cause blistering.

If blisters appear, workers should eliminate them by using a lightweight rubber-tired roller before overlaying [25].

2.11. Performance Monitoring

Performance monitoring during the construction period and service life of the overlay is highly desirable. This will allow development of a data bank of geogrid project performance histories. The primary areas of interest are reflective cracking and road roughness. Clearly, the most meaningful results will come from a special monitoring study where cracks in the old pavement are carefully mapped rather than depending on routine PMIS data. Constructing a control section without the geogrid, with all other items equal, will provide valuable comparative data to assist future decisions.

2.12. Milling/Recycling Pavements Containing Geogrids

A few problems have been reported when recycling pavements containing a geogrid interlayer. Hot milling and, particularly, heater scarification can cause problems when a geogrid is present; however, cold milling does not usually present problems. [25].

2.13. Design of Geogrid Reinforced Asphalt Pavements.

Many studies typically indicate that a reinforcement function is provided to the pavement system by the geogrid, by a rather complex set of mechanisms. Some possible contributors include the following: increasing initial stiffness, decreasing long term vertical deformation, decreasing long term horizontal deformation, increasing tensile strength, reducing cracking, improving cyclic fatigue behavior, and simply holding the system together [38]. This leads to difficulties as far as a specific design methodology is concerned. We could use a geogrid effectiveness factor and divide it in to the design traffic number to determine a modified value and design accordingly, that is

$$DTN_R = \frac{DTN_N}{GEF} \quad (1)$$

Where: DTN_R= Design Traffic Number for geogrid reinforced case.

DTN_N= Design Traffic Number under standard (non reinforced conditions).

GEF: Geogrid Effectiveness Factor. (≈ 3.0 for the unitized, homogenous geogrid evaluated)

Carrol et al. have further refined the technique using the same experimental data to calculate the structural number as per AASHTO [40].

Using the concept of structural number, the non reinforced (control section) is:

$$SN= 25\ a_1 d_n + 25 a_2 d_2 \qquad (2)$$

Where SN= Structural Number

a_i= layer coefficients (0.4 for asphalt and 0.14 for granular stone base)

d_i= thickness (mm) of each layer.

The use of geogrids to retard and minimize reflective cracking within old pavements from propagating through newly placed asphalt overlays is a topic of great interest. Results of laboratory testing by Molenaar and Nods Suggest the use of a power law to calculate the rate of crack propagation through the new overlay thickness [39].

$$\frac{dc}{dN} = AK^n \qquad (3)$$

$\frac{dc}{dN} = Crack\ propagation\ rate\ per\ number\ of\ load\ cycles$

K = Stress Intensity Factor.

A,n = Experimentally obtained constants.

The use of “standard” geogrids may result in uneconomical or unsafe designs. Thus, this research paper selected a particular type of geogrid that can mitigate a reflection cracking effectively. The Huesker Gmbh Company was instrumental in selecting the right type of Geogrid material after an information on the type of asphalt distress was assessed based on site visits and photos sent to the company.

In Africa, geogrid reinforcement in overlays has been practiced for quite some time now. A HaTelit® C17/40 was installed in Uganda, Kampala-Jinja road by the Huesker Company to mitigate reflection cracking [36]. Another Example is a Polyester nonwoven geogrid paving fabric installed to hold the crack propagation in the upper layer of asphalt pavement that had block cracked on overlay work in South Africa in 1980 [25].

CHAPTER THREE

3. MATERIALS AND METHODOLOGY

3.1. Experimental Details

This research was mainly an experimental program to study the improvement in delaying reflection cracking due to the introduction of a geogrid material. The study was carried out during an actual asphalt overlay work at the selected sites in Addis Ababa. The road sections under study, specifically the National Theatre 1 and National Theatre 2 sites were high traffic volume roads. This exposure to high cyclic load from traffic has led to the reflecting of the cracks to the surface. The size of the cracks before the application of the overlay was measured. The size of the cracks that appeared to the surface at the road section with and without the geogrid reinforcement is recorded and compared with the original size.

According to the recommendation proposed by the Huesker Synthetic GmbH Company, the following procedures were followed to ensure the correct and successful installation of the Geogrid material

3.1.1. General evaluation of the asphalt distresses.

The road section under consideration contains wide reflection cracks that kept reappearing even after multiple maintenance works. The cracks are wide and run for a considerable length uninterrupted across the road sections. According to the information from ACCRA the National Theatre 1 and National Theatre 2 sites have been maintained several times previously and yet the cracks repeatedly reflect to the surface. The width of the cracks at various points along its length was measured. The width of the major crack at the National theatre1 site varies from 6 mm to 17 mm and the Major Crack at the National theatre 2 site varies from 15 mm to 19 mm. Those measurements were taken using a roll meter before the overlay construction.

Fig. 3.1: Photos, Reflection cracks at the National Theatre 1 and National Theatre 2

3.1.2. Preparation of the surface.

The surface was prepared prior to the application of the overlay to ensure that the geogrid or level-up course will have continuous firm support. This assisted in proper compaction of the overlay and allowed continuous tack coat application to uniformly saturate the geogrid product.

Before application of a geogrid, the existing pavement was thoroughly cleaned using a compressed air.

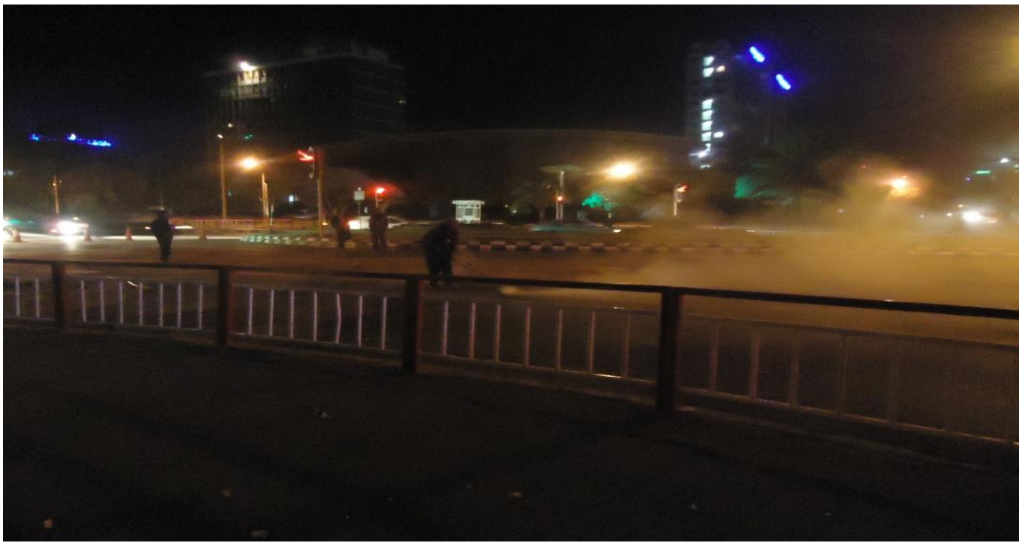

Fig. 3.2: Photo taken during cleaning the surface using compressed air (during the night).

Fortunately, there was no rain during the overlay construction around the National Theatre.

However the Gandhi Hospital road section had to be dried with a compressed air prior to the application of tack coat.

Fig. 3.3: Photo, Drying of the surface after a rainfall at Gandhi Hospital road section:

Moreover, cracks exceeding 1 inch (2.54cm) wide were filled with a fine-grained bituminous mixture. Faulted cracks or joints with vertical deformation greater than ½ inch (1.25 cm) were treated by using a fine-grained bituminous mixture. Potholes were properly repaired to make them even with the existing pavement surface. And finally crack filler and patching materials were allowed to cure prior to placement of the geogrid.

Fig. 3.4: Photo: Application of leveling course to treat potholes and other road defects.

Fig.3.5: Photo: Leveling and compacting of treated areas using a roller compacter

However, since this thesis was aimed at studying the improvement due to overlay reinforcement with a geogrid material, some of the cracks at the National Theatre road section were not treated with a crack sealant prior to the placement of the tack coat. This was done to observe the effect of the Geogrid reinforcement as quickly as possible. Since a similar procedure was followed on the control section, a comparison could still be made between the reinforced and unreinforced section of the road. The surface and the cracks were cleaned using a broom.

Fig.3.6: Photo: Image showing an untreated major crack running through both the reinforced and unreinforced sections of the road at National Theatre 1 site.

3.1.3. Taking measurements.

Measurements on the width of the cracks before and after the application of the overlay were crucial for the validity of this study. Hence, major cracks were identified, labeled and their widths measured. After the placing of the overlay, periodic site visit was conducted to observe and record differences observed between reinforced and unreinforced sections. The width of the major crack at the National theatre1 site varies from 6 mm to 17 mm and the Major Crack at the National theatre 2 site varies from 15 mm to 19 mm.

Fig.3.7: Photo: Taking of measurements at the National Theatre site

3.1.4. Placement of tack coat.

Hot asphalt cement (AC) is usually recommended as tack for geogrids. In this experiment, the usual tack coat material that the ACCRA uses during overlay works AC70 was sprayed over the existing pavement and over the geogrid material to create a bond between the old pavement surface and the geogrid, and between the geogrid and the new overlay as well. This sandwiching of geogrid material in between two tack coat layers prevents delamination and thus slippage due to vertical and horizontal traffic loads. Moreover, the tack coat was sprayed approximately 10 cm wider than the geogrid. Tack application temperatures were generally about 143 °c to a maximum of 163 °c. Optimum temperature for embedment of fabric is 82.2 °c to 121 °c. Geogrid was installed while asphalt was still tacky.

Fig. 3.8: Photo application of tack coat before laying of geogrid at the Gandhi Hospital and National Theatre sites.

3.1.5. Placement of Geogrids.

The HaTelit® C40/17 was installed at the National Theatre 1 and National theatre 2 sites on 07/04/2015. And at the Gandhi Hospital site on 08/05/2015. The Geogrid was laid at the bottom of the overlay on all of the road sections. Most of the installation was in the longitudinal direction which is along the course of the road. However a transverse direction of installation was experimented on the National theatre 2 site to study the effect of direction of installation.

100 m x 3 m roll of Biaxial Geogrid was received from Huesker Gmbh Company and out of this 45 m was laid at National Theatre 1 site, 30 m at National Theatre 2 site and the remaining 25 m was installed one month later at the Gandhi hospital road section.

Fig: 3.9 Photo: Longitudinal laying of Geogrid at National Theatre 1 site:

Fig. 3.10, Photo: Longitudinal laying of Geogrid at the Gandhi Hospital site

Fig. 3.11, Photo: Transverse direction of Geogrid installation at National Theatre 2 site

3.1.6. Placement of the overlay:

Referring to the Literature review, it is possible to reduce the thickness of an overlay if geogrid reinforcement is adopted. However, since this research aims to compare the performance of the reinforced and the control sections in their crack arresting capability, the overlay thickness needs to be uniform in both the sections. Thus an overlay thickness of 40 mm was constructed and well compacted with a roller compactor.

Fig 3.12 Photo: Placement of 40mm overlay at the Gandhi Hospital Site

3.1.7. Loading

The section was open to traffic starting from the next day on 08/04/2015 at the National Theatre sites (overlay construction completed during the night) and on 08/05/2015 at the Gandhi Hospital Site.

As the size of reflection cracks that appear to the surface depend on the wheel loads from the traffic road sections (both the control and reinforced), information on the amount of Equivalent Single Axle Loads was collected.

Generally speaking, traffic volume studies are conducted to determine the number, movements, and classifications of roadway vehicles at a given location. These data can help identify critical flow time periods, determine the influence of large vehicles or pedestrians on vehicular traffic flow, or document traffic volume trends. The length of the sampling period depends on the type of count being taken and the intended use of the data recorded. For example, an intersection count may be conducted during the peak flow period. If so, manual count with 15-minute intervals could be used to obtain the traffic volume data. The most usual type of survey is a classified count in which, as vehicles pass the observation point, an observer records each vehicle on a survey form according to the vehicle type [24].

The size of the data collection team depends on the length of the counting period, the type of count being performed, the number of lanes or crosswalks being observed, and the volume level of traffic [34]. The number of personnel needed also depends on the study data needed. For example, one observer can record certain types of vehicles while another counts total volumes. Observers conducting manual traffic counts must be trained on the study purpose. To avoid fatigue, observers must be relieved periodically. Every 2 hours observers should take a 10 to 15 minute break [34].

Determining Load Equivalency Factors (LEFs) is critical in pavement design and Rehabilitation. The LEF represents the ratio of the number of repetitions of any axle load and axle configuration (single, tandem, tridem) necessary to cause the same reduction in the present serviceability index (PSI) as one application of an 80 kN (18-kip) single-axle load.

LEFs are needed to represent mixed-axle loads in terms of a single-design axle load. LEFs multiplied by the number of axle loads within a given weight category and axle configuration (single, dual, tridem) give the number of 80 kN single-axle load applications that will have an equivalent effect on the performance of the pavement structures. The

obtained number of 80 kN single-axle load applications for all weight categories and axle types is used in the design procedure. Current LEFs are listed in Appendix D of the *AASHTO Guide for Design of Pavement Structures.*

When no Weight in Motion (WIM) or vehicle classification data are available to determine actual Equivalent Single Axle Loads (ESAL) Factors, use the following values:

Table 3.1 : AASHTO Equivalent Single Load Factors

	Total Axle Load in kN	Equivalent Damage in ESALs
Single Axle	62.3	0.36
	80.0	1
	98	2.18
Tandem Axle	133.5	0.66
	151.3	1.09
	169.1	1.70
	195.8	3.00

The count was conducted at different times of the day to minimize errors while determining an average number of vehicles per day. All the vehicles crossing both the National Theatre 1 and National Theatre 2 sites were counted and categorized according to their size (number of axle).

The manual count was conducted during peak and off peak hours. Number of vehicles during the night (10 pm to 6 AM) was taken to be 20% of the day time traffic count (6 am to 10 pm).

Table 3.2 Traffic Volume Data at the National Theatre 1 and National Theatre 2 sites.

NATIONAL THEATRE 1 SITE TRAFFIC COUNT DATA							
TYPE OF VEHICLE	PEAK HOURS			OFF-PEAK HOURS			
	7AM-9AM	12AM-2PM	5PM-8PM	6AM-7AM	9AM-12AM	2PM-5PM	8PM-10PM
1b cars	6345	6634	6570	4300	4504	3902	4600
1c small buses	57	43	36	24	36	34	27
1d light trucks	19	23	24	13	17	23	25
2a large buses	13	16	17	10	8	15	15
2b Medium trucks	NON	NON	NON	NON	NON	NON	NON
2c Heavy trucks	NON	NON	NON	NON	NON	NON	NON
SUB TOTAL	6434	6716	6647	4347	4565	3974	4667
GRAND TOTAL	**44820**						

NATIONAL THEATRE 2 SITE TRAFFIC COUNT DATA							
TYPE OF VEHICLE	PEAK HOURS			OFF-PEAK HOURS			
	7AM-9AM	12AM-2PM	5PM-8PM	6AM-7AM	9AM-12AM	2PM-5PM	8PM-10PM
1b cars	4759	4976	4928	3225	3378	2927	3450
1c small buses	43	32	27	18	27	26	20
1d light trucks	14	17	18	10	13	17	19
2a large buses	10	12	13	8	6	11	11
2b Medium trucks	NON	NON	NON	NON	NON	NON	NON
2c Heavy trucks	NON	NON	NON	NON	NON	NON	NON
SUB TOTAL	4826	5037	4986	3261	3424	2981	3501
GRAND TOTAL	**33615**						

Thus the Equivalent Single axle loads applied for 8 months on the National Theatre 1 and National Theatre 2 can be calculated as follows:

(veh/day for a particular category) x (No of days in 8 months) x (Equivalent Damage in ESALs)

National Theatre 1: Equivalent Single Axle Loads for a duration of 8 months:

- ESALs for Category 1b Cars:

  44325 *240 * 0.36 = 3.83 Million ESALs

- ESALs for Category 1c Small Buses, 1d Light Trucks, 2a Large Buses :

  495 *240 * 2.18 = 0.26 Million ESALs

  The total number of ESALs from all types of vehicles on the National Theatre 1 site is 4.1 Million axle loads

National Theatre 2: Equivalent Single Axle Loads for a duration of 8 months:

- ESALs for Category 1b Cars:

  33243 *240 * 0.36 = 2.87 Million ESALs

- ESALs for Category 1c Small Buses, 1d Light Trucks, 2a Large Buses :

  372 *240 * 2.18 = 0.2 Million ESALs

  The total number of ESALs from all types of vehicles on the National Theatre 2 site is 3.1 Million axle loads

Fig. 3.13 Photo 4: Manual counting being carried out by observers (researcher and an assistant) situated at an observation point at the side of the road at the National Theatre 1 and National Theatre 2 sites

3.1.8. Taking readings (Measurement of crack width).

The size of the cracks before and after the overlay construction was measured and recorded. Readings were taken every two months as it was difficult to notice differences in performance between the control section and the reinforced sections of the site in matter of days.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

After the geogrids were inserted at the bottom of the overlay, frequent site visits were conducted and readings on the width of the cracks that appeared to the surface were taken every two months for a total study period of 8 months.

The size of the cracks that appeared to the surface depends on:

1. Amount of cyclic loads applied,
2. The original width of the cracks prior to overlay construction,
3. Whether the section is reinforced with a geogrid or not
4. And on the direction of installation of the geogrid.

The cracks at the National Theatre 1 and National Theatre 2 were originally wide reflection cracks which made the two sites preferable for observing the effect of the geogrid reinforcement over the Gandhi Hospital site. Two major reflection cracks were selected from each road section, their original widths recorded and compared with their size at the end of each period.

The Gandhi hospital site was characterized by potholes and it was chosen mainly to demonstrate the installation process to local contractors and to people involved in the construction industry in various sectors.

4.1 Analysis of results for the National Theatre 1 site

The width of the major crack before overlay construction at the National theatre 1 site varies from 6 mm to 17 mm. However, about 70% of the length had a width of 15 mm. Hence, taking 15 mm as the original width before the application of the overlay better represents the crack width than taking the average width. Moreover, the comparison between crack widths before and after overlay was conducted with reference to the 15 mm crack width.

Fig. 4.1 Photo: Major Crack at the National theatre 1 site (before application of the overlay)

To observe progress of the crack widening, the study period was divided in to four periods of each two months duration.

The size of the cracks was measured every two months starting from the installation of the geogrid material.

Table 4.1: Width of cracks at the National Theatre 1 site before and after overlay construction

	NATIONAL THEATRE 1 SITE (WIDTH OF CRACKS IN mm AFTER THE INSTALLATION OF THE GEOGRID)			
	AFTER 2 MONTHS (1.03 MILLION ESALs)	AFTER 4 MONTHS (2.06 MILLION ESALs)	AFTER 6 MONTHS (3.09 MILLION ESALs)	AFTER 8 MONTHS (4.1 MILLION ESALs)
CONTROL SECTION	NONE	HAIRLINE CRACKS	<2 mm	5 mm
REIFORCED SECTION	NONE	NONE	NONE	NONE

Fig.4.2 Photo: National Theatre 1 site: after 8 months of asphalt reinforcement. The Black heavy line represents the boundary between the control section and the reinforced section.

Fig.4.3 Photo: National Theatre 1 site: Measuring of crack size after the installation of the geogrid material

As one can see from Table 4.1, there was no any visible difference between the control section and the reinforced road segments for the first 4 months apart from some hairline cracks started appearing at the control section towards the end of the first 4 months.

However, after 6 months visible differences were observed as cracks of around 2 mm wide emerged at the control section while the reinforced section remained intact. Even after 8 months, no crack appeared to the surface on the reinforced section whereas the control section entertained a crack width of 5 mm.

As both the control and the reinforced road sections are subjected to the same traffic volume, the introduction of the Geogrid material as overlay reinforcement was the only reason for the arrest of the reflection cracks at the reinforced part of the road.

Moreover Load repetitions along with the environment, damage pavement over time. Each individual load inflicts a certain amount of unrecoverable damage. This damage is cumulative over the life of the pavement and when it reaches some maximum value the pavement is considered to have reached the end of its useful service life.

In our case, the reinforced section of the road could withstand a traffic load of 3.83 Million ESALs without permitting the reflection crack to appear to the surface. Referring to the Literature Review section, other researches had shown the advantages of geogrid reinforcement in mitigating reflection cracks however no attempt was conducted locally to prove this fact or to check if the current ERA/ACCRA overlay construction procedures can in fact produce better results with the introduction of geogrids in the system. This result thus adds to the previous studies that concluded geogrid reinforcement of asphalt overlays delays reflection cracks by a factor of 4 times [23] even though further tests on deflection due to traffic loads and longer study periods are required to substantiate the findings.

4.2 Analysis of results for the National Theatre 2 site:

The width of the reflection cracks at the National Theatre 2 site was measured and it varies from 19 mm to 15 mm. In this case an average crack width of 17 mm can be taken. The crack widths after the end of each period is recorded and presented in tabular form.

Fig. 4.4: Photo: National Theatre 2 site: Crack before the installation of the Geogrid.

From the traffic volume count data, a total of 3.1 Million ESALs was applied to this section (both the control and reinforced part).

The positive effect of geogrid reinforcement in delaying reflection cracks was clearly observed at the National Theatre 1 site. The effect of direction of installation was studied at The National Theatre 2 as a transverse direction of installation was attempted.

Fig.4.4: Photo: Transverse direction laying of Geogrid at National Theatre 2 site:

Table 4.2: Width of cracks at the National Theatre 2 site before and after overlay construction

	NATIONAL THEATRE 2 SITE (WIDTH OF CRACKS IN MM AFTER THE INSTALLATION OF THE GEOGRID)			
	AFTER 2 MONTHS (0.78 MILLION ESALs)	AFTER 4 MONTHS (1.55 MILLION ESALs)	AFTER 6 MONTHS (2.34 MILLION ESALs)	AFTER 8 MONTHS (3.1 MILLION ESALs)
CONTROL SECTION	NONE	HAIRLINE CRACKS	<3 mm	Around 7 mm
REINFORCED SECTION	NONE	HAIRLINE CRACKS	<3 mm	Around 7 mm

Even though the Hatelit C40/17 geogrid is designed to withstand tension from both directions, the transverse direction of installation exposes the geogrid to wrinkles and ripping off due to the wheels of the paving truck. This wrinkling and overlap of the geogrid material created a gap in the transfer of the load from the cracks to the geogrid. In other words, the tension was carried by the asphalt overlay only as the geogrid was not fully stretched during installation. This led to a poor performance of the geogrid reinforcement as the cracks appeared almost equally to the surface both on the control and reinforced sections of the road.

Fig.4.5: Photo: National Theatre 2 site: after 8 months of geogrid reinforcement.

From the National Theatre 2 transverse direction of installation, we can come up with a recommendation not to install geogrids in other directions other than the longitudinal direction or the geogrid should be fixed to the ground (old pavement) firmly prior to the rolling over of the Paving truck.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The following conclusions can be drawn based on the differences observed between the reinforced and control sections in mitigating the reflection cracking.

- ✓ From the National Theatre 1 site, it can be observed that the reinforced section of the road can delay reflection cracking by 100% for a study period of 8 months. However, the unreinforced section reflected 33.33% of the original crack width to the surface with in the same duration of 8 months. Hence it can be concluded that even with the current ACCRA/ERA overlay construction methods, geogrid reinforcement of asphalt overlay can remarkably mitigate reflection cracks.
- ✓ From the National Theatre 2 site, it can be concluded that direction of installation of the geogrid can hugely affect the end results. Geogrids should be installed longitudinally and should not be installed in the transverse direction.
- ✓ A presentation on Geogrids in the construction industry in general and geogrid reinforcement of Asphalt overlay in particular was conducted during the workshop organized by the CPMIE and Ministry of Science and Technology at Gihon Hotel, Addis Ababa from 02/08/2015 to 04/08/2015. From this workshop, it can be concluded that the level of awareness towards geogrids among local contractors is very low.

5.2 RECOMMENDATIONS

- ➢ As the amount of cyclic loads increases with the length of the study period, continuous assessment of the site shall be conducted to observe differences in performance between the control section and the reinforced part of the study area.
- ➢ One of the advantages of geogrid reinforcement of asphalt overlays is that we can reduce the overlay thickness from the usual thickness when no geogrid is involved. Hence, it is recommended that further studies to be made on how much we can reduce our overlay thickness when we apply geogrid reinforcement.

REFERENCES:

[1] Buttlar, W.G. Kim, J., (2010), "Analysis of reflective crack control system involving reinforcing grid over based-isolating interlayer mixture", Journal of Transportation Engineering, Vol.150, No.5, July/August, pp. 375-384

[2] Jingkui Chi, (2009), "History, development, and future prospects for geogrids industries in China**,** Geogrids"

[3] The Geogrid Materials Association (GMA), (2002), "Hand book of geogrids" Memphis, 6467, USA.

[4] G Venkatapa Rao and PK Banerjee, (1997), "recent developments- geogrids, Indian institute of technology", Haus Khas, New Delhi, 110 016, India.

[5] Geogrid material association (2005) "handbook of geotechnical engineering" Melbourne, 196 453, Australia

[6] HUESKER, (2012), "Installation Guidelines HateLit" Germany.

[7] Joe W. Button, P.E. and Robert L. Lytton, P.E.,(2006), "Guidelines For Using Geogrids With Hot Mix Asphalt Overlays To Reduce Reflective Cracking" TRB 2007 Annual Meeting

[8] J. P. Giroud, M.ASCE,1 and Jie Han, M.ASCE2,(2004), "Design Method for Geogrid-Reinforced Unpaved Roads. I. Development of Design Method", J. Geotech. Geoenviron.

[9] De Bondt, A.H., (1998), "Anti-reflective cracking design of (reinforced) asphalt Overlays " PhD Thesis, Dept. of Civil Engineering, Delft Univ. of Technology, Delft, The Netherlands

[10] A. Khodaii1,*, Sh. Fallah2, (2009), "Effects of Geogrid Reinforcement on the Propagation of Reflection Cracking in Asphalt Overlays", International Journal of Civil Engineering. Vol. 7, No. 2,

[11] Kim, K.W., Doh, Y.S. and Lim, S., (1999), "Geosynthetics Engineering", ASCE, Vol.126, No.4,

[12] M. T. Mukhtar B. J. Dempsey,(2006), "Interlayer Stress Absorbing Composite (ISAC) For Mitigating Reflection Cracking In Asphalt Concrete Overlays", Transportation Engineering Series No. 94 Illinois Cooperative Highway and Transportation Series No. 260

[13] Jayawickrama, P.W. and Lytton, R.L., (1987), "Methodology for Predicting Asphalt Concrete Overlay Life Against Reflective Cracking", Proceedings, 6th International Conference on the Structural Design of Asphalt Pavements, Vol. 1 9.

[14] Fujio Yuge, Masahiko Ishitani, Atsushi Kasahara, and Hiroshi Kubo,(1993), "Prevention of Reflection Cracking in Asphalt Overlay on Concrete Pavement with Glass Grids"

,Proceedings, Paving in Cold Area Workshop, Vol 5.

[15] Daniel Yeh, (2009), “Quantifying the Benefits of Geogrids for More Durable Pavements” WisDOT Research and Communication Services.

[16] Uhlmeyer, J.S, Pierce, L.M, Willoughby, K. and Mahoney, J.P.,(2000), “Top-Down Cracking in Washington State Asphalt Concrete Wearing Courses”, presented in 79thAnnual Meeting of Transportation Research Board, Washington D.C.

[17] Sha, Qing-Lin., (1993), “Two kinds of Mechanism of Reflective Cracking, Reflective Cracking in Pavements: State of the Art and Design Recommendations” Proceedings of the Second International RILEM Conference, Liege,

[18] Barry R. Christopher, Ph.D., P.E., (2010), “geogrids in roadway and pavement systems” transportation engineering series no. 45 Tennessee cooperative highway and transportation series no. 208.

[19] Giroud, J.P., (2008) “The Geogrids Discipline: Achievements and Challenges”, Opening Address, Proceedings of the First Pan American Geogrids Conference, Cancun, Mexico

[20] Miura, T.K.,Barksdale, R.D., Brown, S.F and Chan, F (1989), “Potential Benefits of Geogrids in Flexible Pavement Systems”, NCHRP Report – 315, TRB.

[21] Chan, F.H (2010), “Foundations on Expansive Soils”, Elsevier Publishing Co.,Amsterdam.

[22] Hass, U.J, Chang, D. J. J., Ho, N.H., Chang, H.Y and Yeh, H.S (2009), “Laboratory and Case Study for Geogrid Reinforced Flexible Pavement overlay”, Transportation Research Record No. 1687

[23] Skelton Grange Rd, Stourton, (2009), Durability of Geofabrics, GEOfabrics Limited.

[24] Brorsson, I and Irikson, L (1986), “Long Term Properties of Geotextiles and their Function as a Separator in Road Construction”, Proc. of 3rd International on Geotextiles, Vienna, Austria, pp 93-98.

[25] Button, J.W (1989), “Overlay Construction and Performance Using Geotextiles”, Transportation Research Record No.1248, Transportation Research Board, pp 24.

[26] Cancelli A, Rimoldi P, Togni A (1992). “Frictional characteristics of geogrids by means of direct shear and pull-out tests”, Proc. of ISKyushu 92 Int. Symposium on Earth Reinforcement Practice,Fukuoka, Japan,

[27] Collin, J. G., Kinney, T. C., and Fu, X.(2006). ‘‘Full scale highway load test of flexible pavement systems with geogrid reinforced base courses.’’ *Geosynthet. Int.*

[28] Fannin, R.J. and Sigurdson, O. (2011), "Field observations on stabilisation of unpaved roads with Geogrids", Journal of Geotechnical Engineering, A.S.C.E, 122(7),541-

552

[29] Ghosal, A and Som, N (1999), "Use of Geogrids in India: Experiences and Potential", CBIP Report, New Delhi, pp 321-334.

[30] Giroud, J. P., and Noiray, L. (1981). ''Geotextile-reinforced unpaved road design.'' *J. Geotech. Eng.*, 107~9!, 1233–1254.

[31] Barksdale, R.D., Brown, S.F and Chan, F (1989), "Potential Benefits of Geogrids in Flexible Pavement Systems", NCHRP Report – 315, TRB.

[32] Holtz, R.D., Christopher, B.R. and Berg, R.R., (1998). "Geogrid Design and Construction Guidelines", U.S. Department of Transportation, Federal Highway Administration, Washington, DC, FHWAHI-98-038, 460 p.

[33] Killeavy. M and Anderson. P (1989) " Geotextiles and Geogrids : Cost effective altenative materials for pavement design and construction." Proceedings of the conference Geosysthetics. '89 San Diego, California USA, Vol.2.

[34] Kinney, T.C., Stone, D.K and Schuler, J (1998), "Using Geogrid For Base Reinforcement as Measured by Falling Weight Deflectometer in Full Scale Laboratory Study, ", Transportation Research Record No.1611, TRB, pp 70-77.

[35] Koerner, R.M (1986), "Designing With Geogrids", Prentice–Hall,Eaglewood Cliffs, New Jersey.

[36] Dipl. -Wirt. -Ing. Laurent Sakou, (2014),"Site Report Uganda Use of HaTelit® asphalt reinforcement within the rehabilitation of the Kampala-Jinja road."

[37] Button, J.W (1970), "Overlay Construction and Performance Using Geotextiles", Transportation Research Record No.1445, Transportation Research Board, pp 56.

[38] Brown, S.F., Brodrick, B.V., and Hughes, D.A.B. (2004), " Tensar Reinforcement of Asphalt : Laboratory Studies, " Proceedings of the Symposium on Polymer Grid Reinforcement in Civil Engineering. Institution of Civil Engineers, 1984, pp.158-165.

[39] Molenaar, A.A.A. and Nods, M., (2010)" Design Method for Plain and Geogrid Reinforced overlays on cracked Pavements, " proceedings of the 3rd International RILEM Conference, edited by L.Francken, E. Beuving, and A.A.A. Molenaar. E and FN Spon., 1996, pp.311-320.

[40] Kennephol, G.J.A. and Kamel, N. I.(2013), " Construction of Tensar Reinforced Asphalt Pavements, "Proceedings of the Symposium on Polymer Grid Reinforced in Civil Enginnering. Institution of Civil Engineers, 1984, pp. 171-175.