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Application of Geosynthetics in Pavement Design

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Abstract - *Geosynthetics have been widely used in recent thirty years for separation, reinforcement, filtration, drainage, and containment functions of the pavement design. The use and sales of geosynthetics materials are increasing 10% to 20% per year. This paper reviews research into the application of geosynthetic materials such as geogrids, geotextiles, geocomposites, geonets, geomembranes, geosynthetic clay liners, geofoam, and geocells in pavement design by focusing on the literature review, basic useful characteristics and basic information collection of geosynthetics. Among them the study focuses on the reduction of base course thickness by using the geogrid material in the base course layer without changing load carrying capacity and performance of the pavement. Modified AASHTO design result shows that about 20% to 40% base course reduction is possible using geogrid in pavement design, with greater percentage reduction for stronger subgrade materials.*

Key Words: Geosynthetics, geogrids, geotextiles, geocomposites, geonets, geomembranes, geosynthetic clay liners, geofoam, and geocells.

1.INTRODUCTION

In recent decades, traffic loads on the pavement have been increasingly heavy, and there is no end in sight. As per 2014 data, there are 797 motor vehicles per 1000 population in the USA [1]. The Number of freight traffic is increasing too due to rapid expansion of the online shopping. Due to disproportionality between number of repetition of heavy traffic loads and structural strength of pavement, pavement deformation or distress is increasing. Because people rely on pavement, more care should be taken for the structural capacity of the pavement.

Geosynthetics with reinforcement function can play a vital role as they not only improve the load bearing capacity but at the same time reduce deformation [2]. A geogrid reinforced aggregate surfaced pavements can carry about 3.5 times more traffic repetitions. For subgrade CBR strengths of 1.5 to 5.0 than equivalent nonreinforced pavements before a 1.5-in. rut depth was reached. Studies show that Geogrid-reinforced pavement sections can carry three times the number of loads as conventional unreinforced pavements, and allowed up to 50% reduction in the base course thickness (Webster, 1993). For flexible pavement design, geogrid reinforcement provides a cost-effective solution (Montanelli, Zhao, & Rimoldi, 1997).

The soil-geosynthetic-aggregate (SGA) provide some benefits such as: the reduction of shear stress on the subgrade, improvement of load distribution on the subgrade layer, reduction of permanent lateral displacement of granular material, increasing of stiffness and confinement of base material.

Geosynthetic reinforcement in pavement design was based on the empirical method until 1980. In 1985 FHWA published the Geotextile Engineering Manual [3]. Acceptable design guidelines for designing geosynthetic-reinforced pavements, identification of properties governing performance the geosynthetic pavement performance, quantification of the reinforcement mechanisms are unavailable [4]. However, this study aims to discuss a better understanding of geosynthetics reinforcement design guideline, mechanisms of geosynthetic reinforcement as well as the use of geosynthetic in pavement design by reviewing literatures.

2. Problem Statement

High volume traffic pavements transfer their traffic load typically on asphalt or concrete treated surface over a base course layer & distribute the load on subgrade. When the subgrade soil is weak or unable to support adequate traffic loads for long time duration due to either traffic or environmental loads, there will permanent deformation in the pavement. Improvement of load carrying capacity of the conventional unreinforced pavements is costly. Some smart materials can offer low life-cycle cost by improving structural capacity as well as reducing of deformation and thickness of pavement that are construction cost efficient, eco-friendly, beneficial for the community, and useful for engineering purpose

3. Methodology

The design methodology is based on the literature review [4]. The steps for geogrid pavement design are:
Step-1: Soil Sample collection
Step-2: Laboratory testing: Soil Particle-Size Distribution, Soil Atterberg Limits (liquid limit, plastic limit, shrinkage limit), Specific gravity, Proctor compaction test, determination of the moisture content of the soil, California Bearing Ratio (CBR)
Step-3: Traffic load count and pavement modeling

The methodology to solve the problem is based on the incorporation of geosynthetic reinforcements into AASHTO (1993) design. The method considers the pavement as a multi-layer elastic system having an overall structural number (SN), which can be determined from nomograph that solves the following equation:

$$\log W_{18} = Z_R \times S_O + 9.36 \times \log(SN+1) - 0.2 + \frac{\log\frac{\Delta PSI}{2.7}}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \log M_R - 8.07$$

In the equation, the variables are:

W18 = anticipated cumulative 18-kip ESALs over the design life of the pavements

ZR = standard normal deviate for reliability level

SO = overall standard deviation

ΔPSI = allowable loss in serviceability

MR = resilient modulus (stiffness) of the underlying subgrade, MR = 2555*CBR0.64.

After determining the overall SN, the individual layers can be designed from the equation:

SN = (a*d)hma + (a*d*m)base + (a*d*m)subbase

Where, a = Structural layer coefficient can be found from Fig. 1, d = each layer thickness in the inch and m = modifier accounting for moisture characteristics of the pavement.

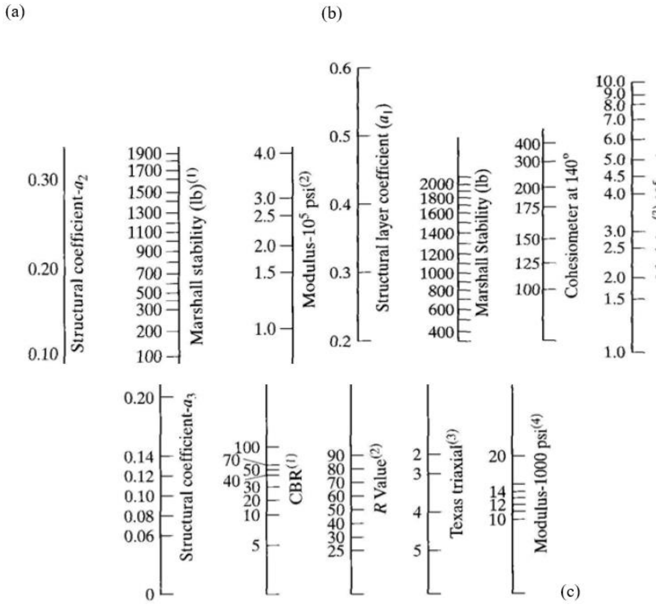

Fig-1: Correlation chart for estimating layer coefficient of (a) HMA Surface, (b) subbase, and (c) bituminous treated base [5]

The above equations are used in geosynthetic reinforcement pavement by modifying. The improvement of the addition of geosynthetic reinforcement in flexible pavement is expressed in terms of the Traffic Benefit Ratio (TBR) and the Base Course Reduction (BCR).

TBR= Nr/Nu , W18 (reinforced) = TBR * W18 (unreinforced)

Where, Nr = number of load cycles on a reinforced section, and

Nu = number of load cycles on an unreinforced section. TBR value for geogrid is range from 1.5 to 70 and for geotextiles is range from 1.5 to 10 depending on the type of geogrid, its location on the road, and the testing scenario [4]. TBR can also find from Fig. 2.

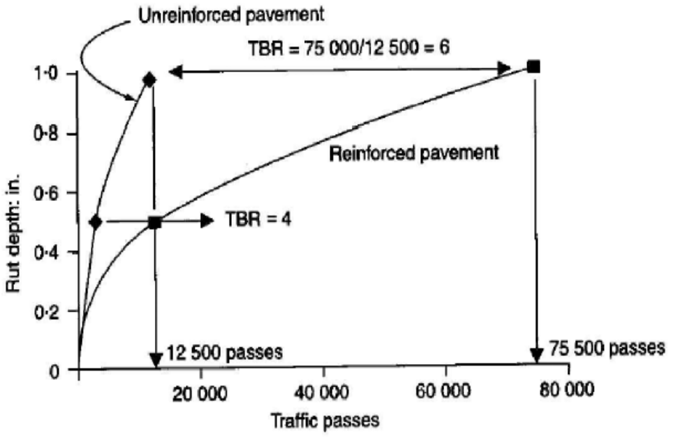

Fig-2: Typical TBR value of reinforced and unreinforced pavement [4]

BCR= Tr/Tu

Where, Tr = % reduction in the base-course thickness due to an addition of geosynthetic reinforcement,

Tu = thickness of the flexible pavement with the same materials but without reinforcement

A modifier has been applied to the SN equation:

SN = (a*d) hma + BCR*(a*d*m)base + (a*d*m)subbase

The reduced base course thickness (d base,(R)) due to reinforcement is

$$d_{base,(R)} = \frac{SN_u - (a \times d)_{hma} - (a \times d \times m)_{subbase}}{BCR.(a \times m)_{base}}$$

SNu = the structural number corresponding to the equivalent W18 for the unreinforced pavement.

BCR ranges from ranges from 20% to 40%, with greater percentage reduction for stronger subgrade materials.

Step-4: Geogrid selection and placement

Aperture size is 25mm*21mm. Round or square stiff aperture shape is better. Placement of geogrid layer at the upper one-third of the base aggregate layer perform better than geogrid at the base-subbase interface or in the middle of the base layer. For better interlocking geogrid should place a 2in. thick in compacted state of loose limestone aggregate layer and then sandwich it another layer of loose limestone aggregate (4in. thick in compacted state) and then compacting both layers together. Before the placement of geogrid, an application of prime coat on the compacted support soil can help to improve geogrid-base interaction (Abu-Farsakh & Chen, 2011). Rigid sheet-type geogrid (SS-2) can choose for the design (Webster, 1993).

3. Literature Review

Geosynthetics material are polymeric products that are used in roads, airfields, railroads, embankments, retaining structures, reservoirs, canals, dams, erosion control, sediment control, landfill liners, landfill covers, mining, aquaculture and agriculture for separation, reinforcement, filtration, drainage, and containment. There are eight types of Geosynthetics: geogrids, geotextiles, geocomposites, geonets, geomembranes, geosynthetic clay liners, geofoam, and geocells. In this chapter, much effort has been made to discuss the use of geosynthetics in pavement design.

3.1 Geogrids

A geogrid is a regular open network (called apertures) of integrally connected tensile elements which is used to reinforce base or subbase materials, earth retailing wall, embankment etc. [6]. It is manufactured from high-density polyethylene (HOPE), polypropylene, or high tenacity polyester. Biaxial geogrids are used for base reinforcement applications.

3.1.1 Types of Geogrids

Based on the manufacturing process, there are three types of geogrids—Extruded Geogrid, Woven Geogrid, and Bonded Geogrid. Based on which direction the stretching is done during manufacture, geogrids are classified as Uniaxial geogrids and Biaxial Geogrids [7] as shown in Fig. 3.

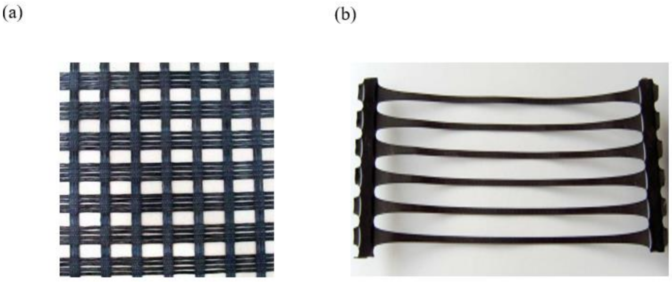

Fig-3: (a) Biaxial woven geogrid and (b) Uniaxial geogrid

3.1.2 Geogrid reinforcement mechanisms

There are two geogrid reinforcement mechanisms that reduce permanent deformation- (i) confinement and interlocking with the base layer aggregate that reduce permanent lateral displacement of granular material and (ii) "slab" effect of base layer and geogrid that improve in load distribution on the subgrade layer [8]. Fig. 4 shows the relative load distribution scenario between with or without geogrid reinforcement. Geogrid reinforcement helps to improve the performance of the pavement by attributing three mechanisms (i) lateral confinement, (ii) improved bearing capacity, and (iii) tensioned membrane effect [4] as shown in Fig. 5.

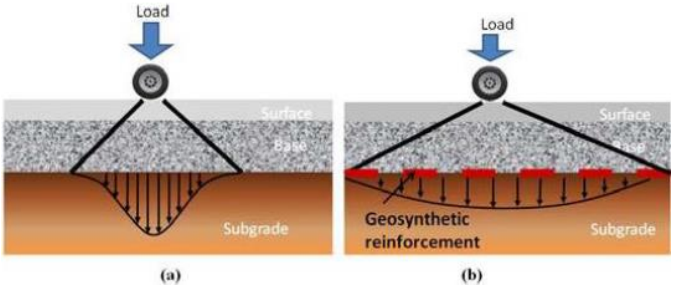

Fig-4: Relative load distribution at subgrade layer of flexible pavement for (a) without reinforcement (b) with reinforcement [9]

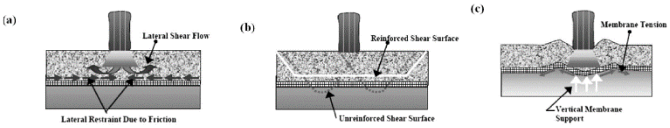

Fig-5: Geogrid reinforcement mechanisms (a) lateral confinement, (b) increasing bearing capacity, and (c) tension membrane effect [10].

The geogrid apertures and base soil particles restrained aggregate lateral movement by transferring share load from the base layer to a tensile load in the geogrid. It increases shear strength & limit lateral strains in the base layer by using frictional and interlocking characteristics at the interface between the soil and the geogrid as shown in Fig. 3(a). Presence of a geogrid in the pavement imposes the development of an alternate failure surface that provides a higher bearing capacity and vertical confinement outside the loaded area as illustrated in Fig. 3(b). It is assumed that geogrid can act as a tensioned membrane. Using this tensioned membrane effect, geogrid contributes to support wheel loads & reduces vertical stress on the subgrade [4]. Only in case of subgrade CBR below 3 this reinforcement mechanism is being reported [11].

6.1.3 Use of geogrids in road construction

Geogrids enhances structural capacity & reduces potential distress. It can effectively reduce horizontal deformation of the aggregate base course layer with 203mm to 457mm thickness in the traffic direction. For the thinner aggregate layer, the optimal location of geogrid at the unbound aggregate-subgrade interface whereas the location is the upper third of the layer for thicker base layer [12]. It can improve the performance of low CBR pavement section shown in the Table 1.

Table 1: Comparison of thickness & displacement with & without Geogrid in pavement section [13]

Reinforcement Type	AVG Applied Pressure/cycle (KPa)	Subgrade CBR (%)	HMA Thickness (cm)	Base Thickness (cm)	Displace in HMA (cm)	Displace in Base Layer (cm)	Displace in Subgrade (cm)
None	543	4.4	7.6	14.8	0.4	1.2	1.3
Geogrid	525	5.7	7.3	14.5	0.8	0.3	1.3

Another study showed that for an unpaved road where .075m or 0.15m displacement is acceptable, 10% reduction in pavement thickness (from unreinforced thickness) is possible due to the membrane effect of the geogrid. In clay subgrade due to subgrade confinement, approximately half of the thickness reduction resulting from geogrid reinforcement [14].

An experiment showed that geogrid use interlocking effect instead of membrane surface tension effect to reduce nonuniform settlement in a soft clay subgrade pavement by placing it in a convex shape. By placing it in a concave shape, it uses membrane surface tension effect to suppress nonuniform settlement. The experiment also showed that the long-term effect of geogrid as a reinforcement is comparable to that of a 10cm thick base materials [15].

An accelerated testing of unpaved road showed that a 15cm thick sand base and a 7cm thick aggregate cover unpaved road could not support an 80kN traffic axle load for one pass without the geocell. With the geocell in the same base course layer, the test demonstrated that after 5000 wheel passes a 4.8cm rut depth developed, which is comparable to the performance of a 22cm thick higher-quality aggregate base course on the same subgrade [16].

A 40kN cyclic plate loading testing showed that when geogrid layer placed at the upper one-third of the base aggregate layer, better performance could be found and at a rut depth 19.1mm TBR can be increased up to 15.3 [17].

Haas et al (1988) indicated that a geogrid should be placed at the base-subgrade interface of thin base sections and near the midpoint of thicker base layers for getting better performance and for optimum grid reinforcement, it should be in a zone of moderate elastic tensile strain (i.e., 0.05%.0.2%) beneath the load center, and allowable permanent strain in the grid during its design life is 1% to 2% depending on the rut depth failure criteria [18]. When geogrid is placed at the bottom and middle of the base layer, there is 40% and 70% reduction in vertical deformation respectively.

3.2 Geotextile

A geotextile reduces subgrade deformation when it uses at the top of the subgrade and it performs better than a geogrid as a separator between subgrade and base [19] as shown in Fig. 7. Under dynamic traffic loading, the pore water pressure in the subgrade soil develop and when the pore pressure is greater than the total stress of the soil, a soil slurry is formed. This soil slurry and the fines from subgrade tends to migrate into the base course aggregate and affect the drainage capacity and structural capacity of the pavement system. To achieve the proper filtration mechanism, incorporation of geotextiles prevents the generation of pore water pressure as well as not allowing fine material into the base course from subgrade soil [3]. The largest amount of subgrade strengthening comes from proving double layer geotextile fabric and the effectiveness of fabric increase by increasing deformation [20]. Under dynamic traffic loading, a good frictional capability geotextile can provide tensional resistance to lateral movement of aggregate [4]. Fig. 6 show a typical placement of geocell geotextile for road construction. By using woven Geojute, the thickness of base course can be reduced by 32%, while for non-woven is 20%. Improvement of bearing capacity is as low as 7% and as high as 123%, in different bed condition and reinforcement layers [21].

Fig-6: Geocell geotextile for road construction [22]

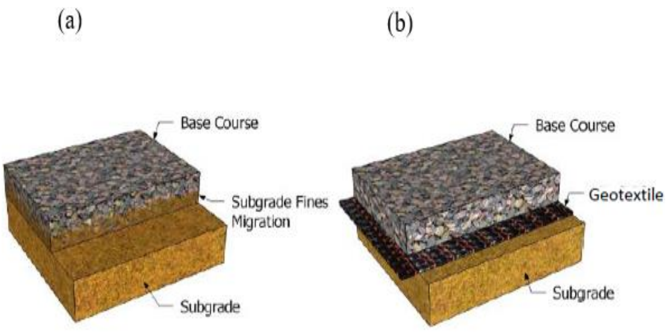

Fig-7: Geotextile as a separator (a) unreinforced pavement and (b) reinforced pavement [23]

3.3 Geocomposites

Geocomposites are the combination of two or more different geosynthetics to obtain the best features of each material in an optimal manner and cost efficiently shown in Fig. 8(a). These materials provide the hybrid facilities such as reinforcement, filtration, separation, containment, and drainage. The still nonperforated polyethylene Geoweb showed the greatest performance improvement of all geocomposite reinforcement.

A study showed that the load-deformation response of 200mm gravel base rut depth and 150mm thick Geoweb mattress is equivalent to 300mm unreinforced gravel rut depth material. For 300mm thick Geoweb, composites are equivalent to 500mm to 600mm thick unreinforced gravel bases. The unreinforced gravel bases show the twice the thickness of Geoweb reinforced gravel bases (Bathurst & Jarrett, 1988).

In late 1970, the U.S. Army Corps of Engineers at the Waterways Experiment Station (WES) used plastic tubes in a 300mm three-dimensional mattress prototype with a CBR 1.0 and the cellular mattress was infilled with sand. Under the repeated passes of track load, it was observed that the prototype generate wheel ruts under cumulative axle loads equivalent to the performance of 500mm thick unreinforced sand bases (40% savings in granular fill) (Webster & Watkins, 1977). Instead of the plastic tube, WES used cellular grid fabricated from slotted aluminum sheeting in another study and got significant cost savings (Webster & Alford, 1978).

3.4 Geonet

It is a mesh structure with overlapping threads (diameter 3mm to 15mm) and permanent angle 60̊ - 90̊. Main application of geonets are (i) reinforced existing, constructive new road surface, (ii) reinforced joints of rigid pavement, patch work, preventing cracking when extending road and so on [24] shown in Fig. 8(b). Geonet can also use for reinforcing soft clay subgrade [25].

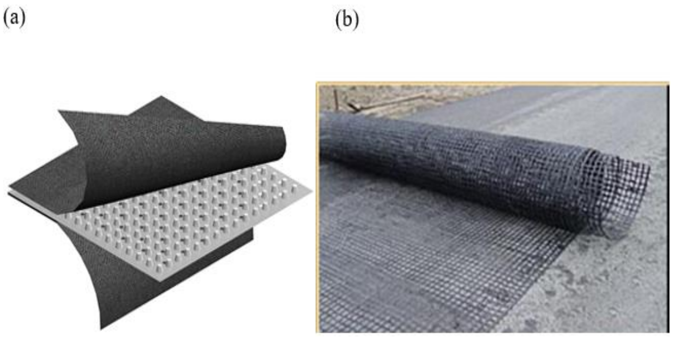

Fig-8: (a) SITEDRAIN DS-180 Geocomposite and (b) placement of geonet on the road.

3.5 Geomembrane

Geomembranes are relatively thin, flexible polymeric materials that are primarily used for containment of liquid or vapor barrier or both. Oklahoma DOT used Geomembrane for undulation problem in I-35 due to the expansion of clay beneath the road surface shown in Fig. 9. Due to increase in the moisture content the clay tends to swell and causes a non-homogenous expansion and contraction. These causes a detrimental effect on pavement. By using geomembrane, significant moisture changes in the pavement subgrade would minimize. It also provides several facilities such as strength properties, lighter weight, portability, cost-savings, and so on [26].

Fig-9: More than 630,000 sq. ft. of geomembrane was installed over expansive clay in Ardmore, Oklahoma to stabilize Interstate 35 [26].

3.6 Geotube

The Geotube system are a very large tubular geotextile fabric containers having an oval cross section of approximately 12ft with local sand and sediment-filled to hold unstable banks in place [27]. Geotube contain the heavy mineral and other contaminates from pyretic rock unearth during I-99 in Pennsylvania road construction. This prevented acid runoff problems.

3.7 Geofoam

Some studies showed that Geofoam can be used as lightweight fill material in subbase or subgrade, and it can simplify design and construction activities [28]. On the other hand, John S. Horvath (1999) reported that using geofoam raised some problems in road construction such as fires during construction in Euro road E6 in Vestby, Norway, premature pavement failure due to block shifting under traffic, street reconstruction project in Rotterdam, the Netherlands, Geofoam damage due to insect infestation, differential icing of pavement surface, failure of insulated pavement systems, water absorption problem, and so on [29].

3.8 Geosynthetic clay liners

Geosynthetic clay liners (GCL) have advantages such as rapid installation/less skilled labor/low cost, very low hydraulic conductivity to water. If properly installed GCL can withstand large differential settlement and has excellent self-healing characteristics. It is not dependent on the availability of local soils. It is easy to repair resistance to the effects of freeze/thaw cycles and more airspace resulting from the smaller thickness. Field hydraulic conductivity testing is not required. Hydrated GCL is an effective gas barrier and reduces overburden stress on the compressible substratum (MSW) [30]. It is also used to prevent the uncertainty of sinkhole formation underneath the pavement [31].

4. Conclusions and Recommendation

The available literature involving field, laboratory and numerical study results demonstrate that Geosynthetics materials can use separation, reinforcement, filtration, drainage, and containment functions of the pavement. Pavement performance can be improved by placing geosynthetics at the upper one-third of the base course-layer. Geogrids helps in less accumulated permanent deformation in the subgrade layer by redistributing the traffic load over a wide area on the subgrade. Approximately half of the thickness reduction resulting from geogrid reinforcement is possible in clay subgrade by interlocking effect when it is placed in a convex shape. Modified AASHTO design results that about 20% to 40% base course reduction is possible using geogrid in pavement design, with greater percentage reduction for stronger subgrade materials. Future research works are needed for designing the geogrid reinforcement pavement by Mechanistic-Empirical design method and efforts are needed to establish the guideline for placement of geogrid in the pavement.

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