Geo-synthetics in Road Pavement: An Overview

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Abstract: Geo-synthetics have been adopted in the reinforcement of the flexible pavements since last three decades. However, the performance of the road pavements can still be improved by characterization of different types of geo-synthetic used. Still, the performance of the roads they are used in, can still be increased with characterization of these materials. Geo-synthetics have been in practice due to the specific functional characteristics. They can modify stress distribution in road pavements effectively. This paper thus focuses on the advantage of using geo-synthetics in flexile pavements compared with the conventional methods. Different field tests, road tests, laboratory and numerical tests carried on geo-synthetics are also discussed. In this review paper comparison is made among geo-membrane, geo-grid, geo-cell, etc. in terms of their use. Suitability of different geo-synthetics is then discussed in terms of their use in bitumen, concrete and also in low traffic roads.

Keywords: geo-synthetics, flexible pavement, bitumen roads, concrete roads, low traffic roads.

Introduction

Geo-synthetics now days are a part of construction of flexible road pavement. They mark their presence in construction industry from at least 3 decades. Different classes of geo-synthetic used in road pavement are geo-membrane, geo-grid, geo-cell, woven and non- woven geotextiles, etc. They basically act as a lateral restraint in the roads to prevent their excessive deformation. The soil reinforcement provided by these products increase the bearing capacity of underlying layers of road. Geo-grids can be used as a tensional membrane to support the wheel loads acting on the surface of the roads. The development of ruts on the surface of high traffic volume roads can be controlled in this way. Performance analysis of the different geo-synthetics can be done by filed scale test, laboratory test and numerical simulation. Full – scale test includes accelerated pavement test that simulate actual pavement behavior. However, laboratory tests are cheaper and can be carried out in more controlled conditions. Numerical studies have been used to simulate both the field and laboratory tests. Use of different forms of geo-synthetics in pavement design can be characterized based upon their performance in different exposure conditions and case studies around the world. Economy can be achieved by making use of specialized techniques in low volume road pavements with the help of geo-synthetics.

A brief theoretical background explaining the design of a road pavement and the problems associated with them. The elimination of these problems is discussed in subsequent sections. A typical cross section of flexible pavement includes surface course, followed by base course and sub base course and the bottom most layer is sub grade course.

Roads allow distribution of the generated stresses through its structure to underlying layers. As the pavement becomes more flexible the distribution of stresses comes over wider area. Attention during the design of pavements is on two features:

(1) The horizontal strain at the bottom of asphalt layer, which should be minimized to prevent fatigue cracking and

(2) Vertical stresses on top of subgrade, which should be minimized to reduce the permanent deformation.

A typical flexible pavement experiences two types of failure loads – (1) Structural failure and (2) Functional failure. Structural failure results in collapse of pavement, and it makes the pavement incapable of sustaining the surface loads. On the other hand, functional failure makes the pavement incapable of carrying out its function, which ultimately results in uncomfortable situations to the passengers. Pavement distress may occur either due to traffic load or environmental load. Construction practice also may lead to distress in road structure. Ultimately, the durability of road depends on the construction practices and maintenance followed (Zomberg et al., 2010).

Typical functions of Geo-synthetics used in the construction of roadways include reinforcement, separation, filtration, lateral drainage and sealing. Geo-synthetics used for separation minimize intrusion of subgrade soil into the aggregate base or sub-base. The potential for the mixing of soil layers occurs when the base course is compacted over the subgrade during construction and also during operation of traffic. Additionally, a geo-synthetic can perform a filtration function by restricting the movement of soil particles while allowing water to move from the subgrade soil to the coarser adjacent base. In addition, the in-plane drainage function of a geo-synthetic can provide lateral movement of water within the plane of the geo-synthetic. Finally, geo-synthetics can be used to mitigate the propagation of cracks by sealing the asphalt layer when used in the overlay of the pavement. This paper focuses on the reinforcement function of geo-synthetics in flexible pavements. The improved performance of the pavement due to geo-synthetic reinforcement has been attributed to three main mechanisms, as follows: (1) Lateral Restraint, (2) increased bearing capacity, and (3) the tensioned membrane effect. Each of this mechanism is illustrated in Figure 2 and discussed as follows:

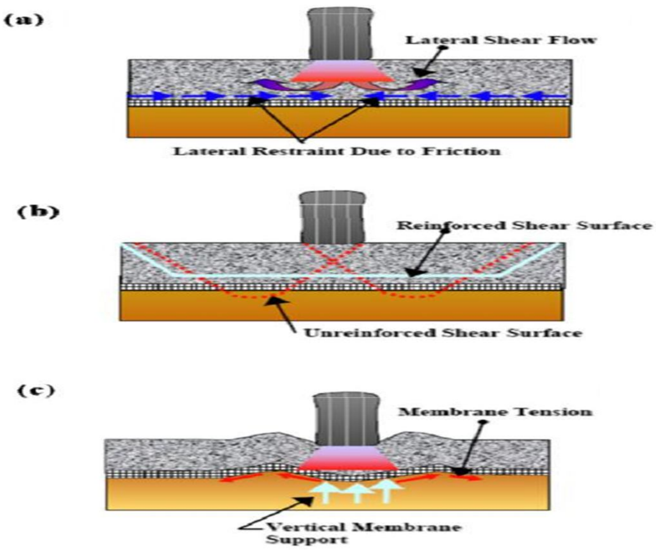

Fig. 2: Reinforcement mechanisms induced by geo-synthetics: (a) Lateral restraint; (b) In-creased bearing capacity; and (c) Membrane support

Lateral Restraint : The basic function associated with geo-synthetics as reinforcement (Fig. 2a) is lateral restraint which is more actually shear – resisting interface. Aggregate is subjected to lateral displacement under the traffic loads unless prevented so by subgrade or geo-synthetic reinforcement. As, a geo-synthetic is stiff in tension, it limits the lateral displacement in base layer itself. A geo-synthetic layer confines the base course layer eventually increasing its mean stress and leads to an increase in shear strength. Both frictional and interlocking characteristics at the interface between the soil and the geo-synthetic contribute to this mechanism. For a geo-grid, this implies that the geo-grid apertures and base soil particles must be properly sized and a geotextile with good frictional capabilities can be a better choice.

Increased Bearing Capacity: Bearing capacity is the safe ultimate load or stress the soil sub-layer can sustain which can be effectively increased by geo-synthetics which act as an alternated surface of failure. This new alternate plane provides a higher bearing capacity (illustrated in Fig. 2b). The bearing failure mode of the subgrade is expected to change from punching failure without reinforcement to general failure with reinforcement.

Tensioned membrane effect: A geo-synthetic can also act as a tension membrane. This membrane supports the load coming onto the surface by wheels (Fig.2c). Reinforcement provides a vertical reaction component to the applied wheel load and thus reduces the vertical stress on the subgrade. An overview of literature focusing on performance analysis of Geosynthetics for flexible pavements is discussed in next section.

Literature Review

The properties of different geo-synthetics used in transportation industry have mostly remained unorganized, because these geo-synthetics were used in different parts of the world for different on field conditions prevailed. However, classification of these forms should be made for an effective use by comparing the more likely field conditions. The literature review has been thus confined to full scale/ field scale tests, laboratory tests and numerical studies followed by review of literature pertaining to variety of geosynthetic adopted for a particular type of pavement for better understanding of the theme of this paper.

Full/Field scale studies

Zomberg et al., 2010, analyzed the performance of pavements by conducting field scale tests, laboratory tests, and numerical simulations. These tests differ widely from each other and the interpretation of the data collected by different test is also different on large. Full scale tests include field studies and modern pavement tests that simulate actual pavement behavior. But the cost of data gathering is high and, the numbers of tests that can be conducted are limited. Thus, the preferred way is to go for small scale laboratory studies or numerical simulations. Laboratory tests are cheaper than field tests and can be performed under controlled conditions. However, it has been always difficult to replicate the actual behavior of the pavement system under loads on field in laboratory tests. Finally, numerical studies have been conducted to take care of both field and laboratory tests and important for studying the parameters. Full-scale field tests have been performed on both public roadways and in-service roads. Useful data has also been generated using accelerated pavement testing (APT). APT facilities consist of test tracks located either in-door or outdoor as shown in Fig. 3.

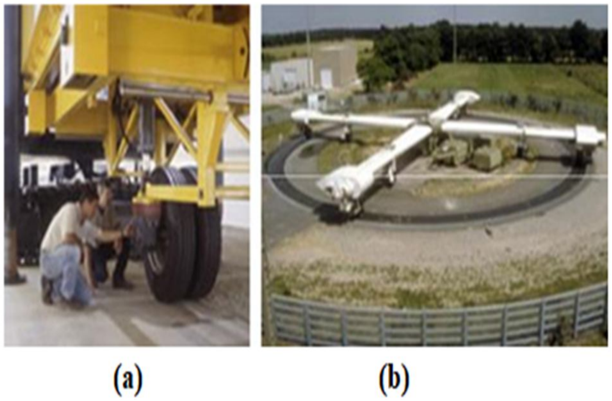

Fig. 3: APT test facilities (a) ATLAS at the Illinois Center for Transportation, USA; (b) pavement fatigue carousel at LCPC, France

As depicted in Fig.3, the test involves the use of automated, single wheel loads that repeatedly run over the test track surface. APT may provide a good simulation of the performance of in-service pavements and can be particularly useful to provide rapid indication of pavement performance under severe conditions. In pavements, the two most common testing criteria are surface deflection and cracking. Surface deflection is the most common performance criterion for both reinforced and unreinforced pavements. Distress has been evaluated using: (1) Measurement of existing surface deflections in terms of rutting depth, and (2) Measurement of surface deflections in response to an applied load to determine its structural capacity.

Rutting occurs because of the development of permanent deformations in any of the pavement layers or in the subgrade. Rutting is generally measured in square meters of surface area for a given severity level. Measurements of rutting depth are comparatively easy to obtain, as they are taken at the pavement surface, and provide a simple method of comparing pavement performance among multiple test sections. Deflection measurements have also been made using non-destructive testing (NDT) devices and the device most widely used to measure pavement deflections is the Falling Weight Deflectometer (FWD) as described in fig.4.

Fig. 4: Non-destructive testing methods used in pavement evaluation (a) Falling Weight Deflectometer and; (b) Rolling Dynamic Deflectometer

Fig. 4 shows non – destructive tests used in pavement evaluation. Studies have shown that, geo-synthetic reinforced test sections led to less rutting depth than the unreinforced sections. The improved performance has been attributed to the ability of the geo-synthetics to control lateral spreading of the base layer.

Moving wheel tests (Jai Han, Jitendra K. Thakur 2014) were conducted on five geo-cell-reinforced and two unreinforced RAP (Recycled Asphalt Pavement) bases over weak subgrade (target CBR = 3%) to evaluate the effect of geo-cell reinforcement on rut depth and stress distribution angle at a certain number of passes of the wheel load. Two types of recycled asphalt materials, named RAP and FRAP (fractioned RAP or RAP with finer gradation) were used in this study. The following base sections were prepared and tested:

(1) 300 mm thick unreinforced RAP.
(2) 150 mm thick geo-cell reinforced RAP with a 20 mm thick RAP cover.
(3) 100 mm thick geo-cell-reinforced RAP with a 70 mm thick RAP cover.
(4) Double layered geo-cell-reinforced RAP with a 30 mm thick RAP cover above a 100 mm thick bottom geo-cell layer and a 70 mm thick RAP cover above a 100 mm thick top geo-cell layer.
(5) 250 mm thick unreinforced FRAP.
(6) 100 mm thick geo-cell-reinforced FRAP over a 100 mm thick unreinforced FRAP base course with a 50 mm thick FRAP cover.
(7) 75 mm thick geo-cell-reinforced FRAP over a 100 mm thick unreinforced FRAP base course with a 75 mm thick FRAP cover.

It is observed that the geo-cell improved the life of unpaved sections by a factor of 1.3 using one layer of 75 mm high geo-cell and 1.8 using one layer of 100 mm high geo-cell at a rut depth of 75 mm. It is concluded that the geo-cell reinforcement reduced the rut depth and vertical stresses transferred to the subgrade by distributing the load over a wider area at the same number of passes. The vertical stresses at the interface of subgrade and FRAP base versus the number of passes are shown in Fig. 5.

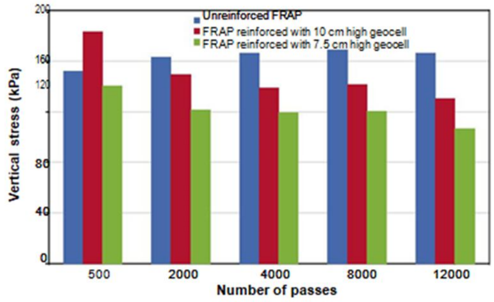

Fig. 5: Vertical stress at the interface of base and subgrade versus number of passes

Figure 5 indicates the performance of unreinforced FRAP by considering vertical stress (kPa) over number of passes. The measured vertical stresses at the interface of subgrade and base were much lower than the tire pressure of 552 kPa applied on the road surface for each section. The vertical stress increased or remained constant with the number of passes for unreinforced sections but decreased with the number of passes for reinforced sections.

Large-scale cyclic plate loading tests were also done on one unreinforced RAP base (300 mm thick) and three geo-cell-reinforced RAP bases (150, 230, and 300 mm thick) over weak subgrade (target CBR = 2%) to evaluate the performance of unreinforced and geo-cell-reinforced RAP bases over weak sub-grade. The permanent deformation, the resilient deformation, the vertical stress at the interface of subgrade and base, and the strains in the geo-cell wall were measured during the cyclic plate loading tests. Fig. 6 shows the permanent deformations of the unrein-forced and reinforced bases over weak subgrade at the center of the loading plate versus the number of loading cycles (Jai Han, Jitendra K. Thakur 2014).

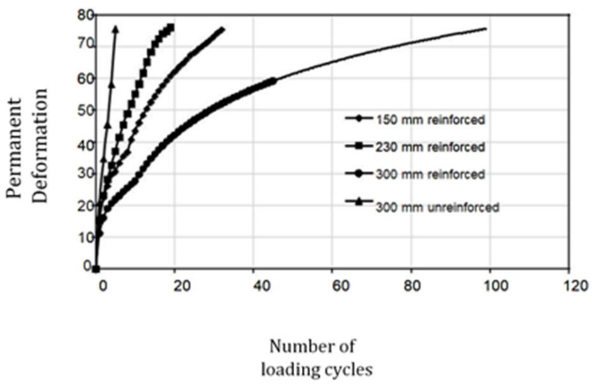

Fig. 6: Permanent deformations at the center versus the number of loading cycles for RAP bases over weak subgrade (Thakur et al., 2012)

It can be noted from Figure 6, that the permanent deformation increased with the number of loading cycles. The rate of increase in the permanent deformation decreased with the number of loading cycles. On the weak subgrade, the geo-cell reinforced RAP bases (150, 230, and 300 mm thick) improved the performance (i.e., the number of cycles) by a factor of 6.4, 3.6, and 19.4 as compared with the 300 mm thick unreinforced RAP base, respectively, at 75 mm permanent deformation. The 230 mm thick geo-cell-reinforced base had a lower improvement factor than the 150 mm thick geo-cell reinforced base because of the lower CBR values of the base and subgrade in the 230 mm thick base as compared with those in the 150 mm thick base. It is concluded that geo-cell-reinforced RAP bases provided a sustainable solution for roadway construction technology by improving the performance of RAP bases. In addition to reducing the permanent deformation of bases, geo-cell reinforcement reduced the vertical stresses transferred to the subgrade and increased the percentage of resilient deformation of RAP bases.

Laboratory Test

The primary objective of laboratory tests has been to quantify the soil geo-synthetic interaction mechanisms in flexible pavement systems either by measuring the geo-synthetic index properties or by replicating the field conditions. Depending on the adopted approach, the tests reported in the literature can be grouped into two main categories: unconfined and confined tests. In unconfined tests, Geo-synthetic properties are measured in-air, while in confined tests they are measured within confinement of soil. The various advantages as well as disadvantages of laboratory tests are discussed in next section.

Unconfined Tests: Unconfined tests are conducted using geo-synthetic specimens in isolation. Advantages of these tests include expedience, simplicity, and cost effectiveness. They can be run in short periods of time using conventional devices. However, correlations are required between the index property obtained from these tests and the field performance of the geo-synthetic reinforced pavements. The tensile strength of Geo-synthetic materials has of-ten been deemed as the most important property for projects involving reinforcement applications. The current state of practice for measuring the tensile properties of a Geo-synthetic involves placing the material within a set of clamps, positioning this assembly in a load frame, and tensioning the Geo-synthetic until failure occurs. The test is generally performed at a constant strain rate. Currently, two ASTM standards are available for tensile tests. The grab tensile test (D4632) is used for manufacturing quality control. Instead, the wide-width tensile test (D4595) has been used in design applications. The load frame for a wide-width tensile test conducted using roller grips shown in Fig. 7.

Fig. 7: Wide-width tensile test conducted with roller grips at the University of Texas at Austin

As shown in Figure 7, the tensile test provides the tensile stiffness at different strain values (1%, 2%, and 5%), as well as the ultimate tensile strength. Methods used for unpaved road design have included the tensile stiffness at 5% in product specifications. Based on full scale model studies for the paved roads, Berg et al. (2000) reported accumulated in-service tensile strain of 2% in Geo-synthetics and thus recommended the tensile stiffness at this strain level for design.

However, the actual strain level representative of field conditions is certainly smaller for the case of pavement applications. The stress and strain conditions in wide-width tensile tests are investigated. It is concluded that strains vary across the specimen from a plane-strain, biaxial condition near the grips, to a uniaxial condition near the center of the specimen. Thus, there may be a misconception that the test measures Geo-synthetic behavior under the 1-D condition that is representative of field applications.

Confined tests: Geo-synthetics are used for base reinforcement under the confinement of soil and subjected to dynamic loading (traffic). These conditions cannot be created by unconfined tests. Geo-synthetic soil confinement depends not only on the macro-structure and properties of geo-synthetics but also on the properties of soil and, most importantly, on the interaction between geo-synthetics and soil particles (Han et al. 2008) also, the interaction between soil and geo-synthetics under confinement, specifically the confined stress-strain research. So, in this case one should go for confined tests. Recently, a number of confined tests have been proposed, out of which six tests have focused on characterizing the behavior of Geo-synthetics used to reinforce flexible pavements. These tests include the cyclic plate load test, cyclic tri-axial test, cyclic pullout test, bending stiffness test, modified pavement analyzer test, and the pullout stiffness test. The cyclic plate load test has generally involved large scale laboratory experiments on reinforced and unreinforced pavement sections (Zornberg, J.G., Gupta, R., 2010).

The test setup designed by Perkins consisted of a 2 m wide and 1.5 m high reinforced concrete tank. The model pavement section was constructed with a geo-synthetic at the interface of the base course and sub-grade layers. The load was applied by a pneumatic actuator in the form of a trapezoidal wave pulse, which generated a maximum surface pressure of 550 kPa on the pavement. The force and displacement responses were measured using a load cell and eight surface LVDTs. TBRs ranging from 1 to 70 and BCRs ranging from 20% to 50% were obtained using cyclic plate load tests in sections involving geo-textile and geo-grid reinforcements. These tests were reported to have successfully demonstrated the effect of soil confinement and dynamic loading. However, facilities in which cyclic plate loading can be conducted are not readily available, thus restricting the application of this test to re-search studies. In addition, the cyclic plate loading test was considered to have important drawbacks associated with the testing procedures, time demands, and appropriate simulation of rolling wheel loads (Han et al. 2008).

Numerical Studies

The different field and laboratory tests above mentioned may not be able to predict the actual on field performance of the pavement because of the inability of available analytical tools to predict the time-dependent behavior of pavements under actual traffic loads. However, numerical methods can be used to provide insight into the mechanics of pavement systems.

Finite elements have been used in several studies to simulate the behavior of Geo-synthetics used to rein-force flexible pavements. Results from the finite element studies have been generally reported in the form of surface deformation of the given system under the applied load. Comparisons were generally made between the magnitudes of surface deformation for unreinforced and reinforced pavements. Finite element modeling of flexible pavements was conducted by Perkins using representative sections such as that shown in Fig. 9.

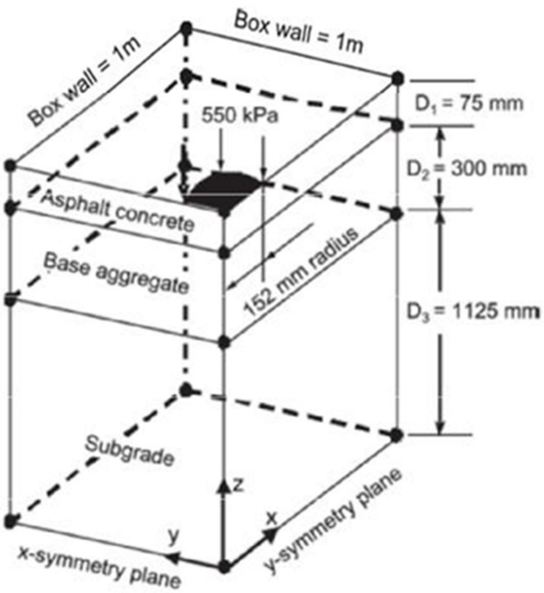

Fig. 9: Flexible pavement - Finite element model

Figure 9 depicts the basic model considered for analysis. The numerical results indicated a reduction in lateral strain at the bottom of the base and a reduction in shear at the top of the sub-grade due to the presence of the reinforcement (Zornberg, J.G., Gupta, R., 2010).

Geo-grid reinforcement in asphalt pavement

All three types of biaxial geo-grids were placed into three groups of pavement structure. Calculation of strength of three groups of pavement structure had done with and without geo-grid reinforcement. The first group of pavement structure was for base reinforcement, geo-grid was placed between subgrade and crushed stone base course. The second group of pavement structure was for asphalt concrete layer reinforcement. In this group of pavement structure geo-grid was placed between asphalt concrete layers and crushed stone base course. The third group was for asphalt concrete layer reinforcement, which was placed between two asphalt layers. The researching field's observation was done three times at Section A (Table 1).

Table 1 Road sections of field investigations

Facilities	Section 1	Section 2	Section 3	Section 4	Section 5
Position	In front of Mungun Zavya shopping center	At the intersection of Tsetsegtuy	Right side of Selbe river	At the Ulaan Culuutger district	At Nisekh apartment district
Section length (m)	60	50	160	80	65
Geo-grid type	TGSG 30-30	Pet 20-20	TGSG 30-30	TGSG 30-30	TGSG 50-50
Pavement structure type	B Type	C type	A type	A type	B type
Work implemented time	August 2009	September 2009	October 2009	August 2010	October 2011

The above mentioned table shows the locations of the pavement structure where all the 3 geo-grid reinforcements were tested. The other specific details like section lengths followed by type of geo0-grid, pavement structure type and at the end work implemented time are also shown. The observations period was also specific. The field observations of pavement performance at Section 3 which is located right side of "SELBE" river have done three times from April, 2010 until September, 2012. In April 2010, visual observation was done at section A cracks were not occurred.

1) In May 2012, visual observation. There were occurred transverse cracks every 4-6m.
2) In September 2012, there had been measured length and width of transverse cracks and rutting.

The average distance of each transverse cracks was 6m at north side, 14m at south side of bridge. These cracks were occurred similar for every reinforced and non-reinforced pavement structure. So here it can be concluded that the type of geo-grid used here was not suitable for cracking control. The maximum depth of rutting was occurred 10mm on reinforced, 13mm on non-reinforced pavement at north side and 10 mm on reinforced, 9 mm on non-reinforced pavement at south side of bridge. On the part of cost, the following conclusions were made, (1) Construction cost of reinforced pavement structure reduced 5% by using geo-grid under base course and, (2) Maintenance cost of reinforced pavement structure reduced 8% by placing geo-grid under base course. Thus it can be stated that, geo-grid helps in improving the durability of road.

Geosynthetic in concrete pavement

Tests were carried out on geo-synthetic overlay asphalt concrete pavement in China (Yazhen Sun, Minjiang Zhang, Junfeng Shi, 2011). A mechanical model test was run for the study of reflective crack on concrete pavement by making use of Finite Element Method (FEM). The effects of normal and tension stresses were related with vertical deflection on the surface of geo synthetic were observed. Conclusions have indicated that the normal stress is reduced with elastic modulus of geo-synthetics increased. This result shows that geo-synthetics overlay really can retard the propagation of the crack and normal stress is decreased with distance from crack tip increased. The elastic modulus influence on change extent is analyzed, and, we obtain that stress concentration is decreased with elastic modulus increased, then, stress distribution is changed. It has been observed that the elastic modulus of optimum geo-synthetics overlay is 1000 MPa and the change extent of maximum vertical deflection is not obvious with modulus of geo-synthetics (Yazhen Sun, Minjiang Zhang, Junfeng Shi, 2011).

Geosynthetics in Low volume roads

Low-volume roads are roads with an average annual daily traffic (AADT) of 1000 to 400 or less vehicles per day. Low volume roads make up roughly two thirds of all the roads worldwide, or roughly 30 million kilometers of roads, yet they do not receive the attention and appropriate technologies deserving of such a major amount of infrastructure. Limited or no use of geo-synthetics is found on many low-volume road projects. A high strength – low elongation paving geotextile can be placed for improved properties of low volume roads prior to asphalt overlay (Gordon R. Keller, 2016).

Geo-cell and geo-membrane in asphalt pavement

Jitendra K. Thakur, Jie Han studied the performance analysis of geo-cell and geo-membrane in recycled asphalt pavement (RAP). The thickness of RAP cover over the geo-cell was 50-80 mm and the thickness of RAP between two layers of geo-cell was 30 mm. Three large scale cyclic plate load tests were conducted on geo-cell reinforced RAP bases with thicknesses of 0.15, 0.23 and 0.30 m over a weak subgrade of with a CBR value of approximately 2%. For a comparison purpose large scale cyclic plate load test was also conducted on unreinforced RAP bases. The major conclusions from this study indicates that 100% recycled asphalt pavement (RAP) can be used as a base course material with geo-cell confinement as a sustainable roadway construction technology and the geo-cell improved the performance of RAP bases over weak subgrade as compared with the unreinforced base section. Also it has been observed that the geo-cell significantly increased the percentage of resilient deformation of the RAP base and the geo-cell reinforcement reduced the vertical stresses transferred to the subgrade by distributing the load over a wider area.

Summary and future scope

Based on theoretical background and literature review, the key inferences drawn in this study are as follows:

1) Sustainable construction techniques using geo synthetics for bitumen road with reduced cost will certainly achieve the economy of road projects undertaken by the government of India.
2) The main problem observed in the case of bitumen roads is the cracking and rutting on the surface. This problem can be eliminated by making use of geo-grids and geo-nets.
3) Geo-synthetics with higher values of modulus of elasticity increase the stress distribution area of vertical load coming onto the road due to wheel loads
4) Lateral displacement of the sub-layer is one of the commonly observed phenomenon. Placing geo-membranes as a separator between the layers of pavement can be proved a smart solution for this constraint.
5) Geo grid is found to be most desirable in road construction. Geo-grids has been observed to improve the seepage properties of pavements, thereby increasing their durability.
6) A nonwoven geotextile can be placed between the subgrade and the geo-cell reinforced RAP.
7) Use of geo-cell reduces the magnitude of shear and tensile stress in concrete roads.

It is anticipated that, further research for the development of geo synthetics for high volume roads can be done, as these roads are continuously being subjected to wearing. The current state of research for low volume road appears to be useful for the projects like ‘Pradhanmantri Gram Sadak Yojna’.

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