2.1 GENERAL

In this chapter a review of literature presented on importance of subgrade in pavement design, swelling mechanism of expansive soils, subgrade treatment methods for expansive and non expansive soils. The usage of geotextiles and geogrids in pavement construction has also been discussed.

2.2 IMPORTANCE OF SUBGRADE ON PAVEMENTS

Coarse grained soils serve as good subgrades for supporting pavements where as fine grained soils, particularly clayey soils pose problems to pavements (Yoder and Witczac, 1975). Pavement failure occurs due to two mechanisms, one is due to the combination of densification and repetitive shear and the second is due to the deformation of pavement component layers with more contribution from subgrade, particularly in clayey soils.
Generally flexible pavements are done using CBR method. The Rate of loading, size of piston and compaction energy is certain limitations on CBR value (Yoder and Witczac, 1975). The subgrade soil at the edge regions of pavement is not properly reflected in CBR test as the sample is not confined in vertical direction. The risk of shear of subgrade soil is not considered in the methods group index, McLeod and AASHTO.

Similar to a shallow foundation, the soil-bearing capacity of the subgrade plays a large role in supporting a road pavement and transferring the vehicle loads. It is necessary that no shear failure occurs within the subgrade. In the method of plate-load testing Das (2006) gave a field based test to check soil-bearing capacity. Satyanarayana Reddy and Rama Moorthy (2005) reviewed existing flexible pavement building technology to conclude that the safety against subgrade bearing capacity failure does not seem to be a consideration in modern pavement design methods. Natarajan and Shanmakhra Rao (1979) and Steinberg (1985) report that the most apparent location of these failures occurs in the extremity of pavements where moisture changes are common. The potential that a particular subgrade and/or pavement material has for densification directly affects the likelihood of permanent deformation occurring, which can be visible on the surface. This deformation typically occurs along the wheel paths, and is worse in the outer path (i.e. closer to the shoulder or kerb and channel).

The properties of subgrade soil are very important in the design of flexible pavements (Haas and Hudson, 1978). The subgrade influence is the main cause for pavement failure and ruts in the flexible pavements (Reddy et. al. 1981; Saxena, 1989; Livenah & Ishai, 1987). The shear failure in subgrade soil is not properly accounted in the designing methodology of pavements.

2.3 IMPACT OF EXPANSIVE SUBGRADE ON PAVEMENTS

The phenomenon of swelling soils in the country is recently being slowly recognized and more often when this has manifested itself in the form of extensive damage to the pavements. Swelling soils are widely distributed in areas of volcanic deposition or origin with tropical climate and also in arid and/or semi desert climates. In tropical volcanic
settings, alumina rich volcanic ash gets deposited in general over a large area. Some get concentrated in depressions or low areas which are fully saturated with water. This regular inundation tends to leach the alumina and concentrate these at the bottom 1.0 meter to 2.0 meters generally and sometimes deeper depending on the leaching effects.

In expansive clayey subgrade due to cyclic shrinkage and swelling phenomenon there is seasonal moisture fluctuation and more over they also lose strength due to softening after swelling which might lead subgrade intrusion into overlying layers and penetration of sub base material into it. (Holtz, 1959; Stevens et al, 1986; Deshpande et al, 1990; Steinberg, 1985).

The damage caused by expansive soils to various civil engineering structures is enormous due to their cyclic swell and shrink behaviour. Expansive soils have been listed as one among the six major hazards (Earthquakes, Landslides, Expansive soils, Hurricanes, Tornado and Floods) related to building losses from national hazards by National Science Foundation in 1981 (Chen, 1988). Most of the civil engineering structures built on expansive soils, highways and street roads receive major damage which amounts to several thousand millions of dollars per annum (Jones and Holtz, 1973; Steinberg, 1992). The problems of roads in expansive clayey soils (black cotton soils) is major as nearly 20 percent of area in India is covered by expansive soils and carry several thousand kilometers of road length (Patel and Qureshi, 1979). The design pavement thickness is high due to very low strengths of expansive soils in wet condition and hence pavement construction becomes very costly (Sharma, 1988; Deshpande et al, 1990).

Apart from high initial cost of construction, pavements over expansive clay soil incur high maintenance cost during and after every rainy season. Pavements over expansive soil subgrades exhibit cracks due to alternate heave and settlement that lead to ultimate failure of pavements (Sen and Chakraborty, 1977). Swelling of expansive soil during rainy season results in intrusion of subsoil into overlying structural layers of flexible pavements and it is reported from Indian Roads Congress road test track project at Peravali, A.P that even the stone soling, sand cushioning at subgrade level could not check subgrade intrusion into overlying layers (Natarajan and Shanmukha Rao, 1979). Further, the contamination of upper layers of pavements by subgrade soil reduces the
pavement thickness over a period of time that leads to progressive pavement failure (Hicks et al, 1986). It is observed that a base contamination of 10 percent subgrade fines can destroy structural strength of base layer.

The expansive soil subgrades soften after swelling and as a result rutting with longitudinal cracks takes place along wheel tracks and lead to wavy appearance of pavement surface (Gokhale, 1977; Agarwal and Saran, 1983; Livenah and Ishai, 1987; Evans and Mc Manus, 1999). The longitudinal cracks later became source of moisture entry into cross section of pavement and causes problem of raveling due to loss of bond between aggregate and bitumen.

Noticeably major portion of road length over expansive soils in India is of single lane and serious damages are found in rainy season due to off tracking of vehicles during overtaking (Natarajan and Shanmukha Rao, 1979). As shoulders are not generally designed for carrying loads, the subgrade soil is found to fail in shear at the shoulder and edges. Even railway tracks supported on expansive soils are facing such failures (Ma-Ji, 1987).

2.4. SWELLING MECHANISM IN EXPANSIVE SOILS

The crystal structure of swelling clays (smectites) consists of one Al-OH (or Fe-OH or Mg-OH) octahedral layer sandwiched by two Si-O tetrahedral layers. The deficiency in positive charges of structural layers due to cation substitution, and interlayer cations are required to balance the negative layer charge. Interlayer cations are exchangeable and this exchange is reversible for simple cations. When the water molecules enter the space between the structural layers, the distance between two structure layers increases and volume of the clay expand. This is called clay swelling. The magnitude of swelling depends on the nature (type) of the exchangeable cations, composition of the solution, and the clay compositions. This is very severe in fresh water. The potential of clay swelling decreases with increase in salinity. With salinity being the same, the potential of clay swelling is largely influenced by the nature of the exchangeable cations. Among the monovalent cations, swelling potential decreases in the order Li⁺<Na⁺<K⁺⁺<Cs⁺. Due to
this KCl and ammonium salts are often used in completion fluids. Generally smectites with divalent cations swell less than those with monovalent cations.

2.5 METHODS OF SUBGRADE TREATMENT

Petry and Little (2002) believe that the majority of treatment methods currently used in the field have been around since 1960, including various forms of chemical or mechanical modification. The following methods are the popular treatment methods in use.

2.5.1 Replacement

Das (2004) expresses that the first precaution of foundation construction on swelling clays as replacement of the expansive soil with a less expansive material. This is an interesting point since majority of researchers rates replacement as a last option. Ipswich City Council has found this appears to be the case in established urban areas where service pipes and conduits (such as telecommunications, water, sewerage, gas and oil) are often within the roadway and under the pavements that needs reconstruction or rehabilitation. However, current practice shows that if ample depth is available, the preference is still to remove the weak clay soil and replace it with a less expansive material (usually profiling from the old surface).

2.5.2 Controlled Compaction

West (1995) states that the bearing capacity of a subgrade soil can be improved by densification or compaction of the soil. Consequently the soil displays a decreased tendency to volume change (swell). Das (2006) states that if clay is compacted at less than optimum, inter-particle repulsion is minimized and the double layer surrounding the particle will be suppressed, leading to a random particle orientation. This clarifies that the soil tends to swell as there is space for water molecules to occupy, however, a greater strength is achieved than those soils compacted greater than OMC. When the soil is on the wet side of optimum moisture content, the particles align producing less voids but a slight reduction in strength. In addition to moisture, the degree of compaction effort plays a major role in the final outcome.

Low compaction effort leads to greater compression when the moisture is slightly greater than optimum. However, higher compaction effort requires moisture slightly below
OMC to achieve the same degree of compaction. In contrast to Das, Petry and Little (2002) comment that during construction the moisture content should be maintained 3-5% above the OMC till the final compaction.

2.5.3 Pre-wetting

Petry and Little (2002) state pre-wetting had become a proven method by the end of the 1970’s. McKinney, Kelly and McDowell (1974), Steinberg (1977) and Poor (1978) believe that ponding water on a foundation reduces the future swell initial, often controlled by moisture barrier installation. The idea of deliberately ponding water on the subgrade before the construction of a pavement may seem a little unusual, however, Das (2004) discusses the benefit of inducing heave. Water injection is yet another method of achieving moisture stabilization of foundations/subgrades. A moistened soil can be immediately covered with a plastic barrier to keep moist or constructed upon immediately (Petry and Little 2002). The clear disadvantages of working on moist clays include an inability to support the construction equipment and machinery and the process can be time consuming. Das (2004) further commented on the option of lime stabilization at this point to create a working platform.

2.5.4 Stabilization of Subgrade

Generally, there are three types of chemical stabilisers – traditional, by-product (kiln dust) and non-traditional (such as sulphonated oils, polymers, enzymes etc). Petry and Little (2002) make the comment that lime and portland cement are the most commonly used chemical stabilizers, however, moisture stabilization (as previously described) is still the most widely used method.

After conducting various tests Chen (1988) reported that among stabilizers including calcium lime, portland cement and lime/cement mixtures, lime shows the greatest improvement to compressibility, CBR and swelling. In the field it is extremely difficult to properly mix the clay and lime due to natural moisture content. Eades, Nichols and Grim (1963) gave the relationship between variable quantities of lime and different mineral properties of clays. Still common today, lime quantities are being incorrectly mentioned and as such many engineers do not consider the outcome effective. Harrison
(2005) after study of dynamic cone penetrometer (DCP) test results concluded lime stabilisation improves the strength of black clay soils.

Ramanujam and Jones (2007) explain that the main disadvantage of subgrade cement stabilization is the high stiffness and a tendency for the overlying pavement to crack. Over recent years road makers have moved to an alternative slow setting cement that contains additives in order to improve workability, however, this has proven to cause greater stiffness than the original cement stabilization process leading to more cracking problems. In Australia, Europe and the USA, alternative mixtures such as pozzolans have gain popularity to enhance strength. Some clay types require special assistance to undergo the desired lime reaction.

Osinubi (2000) explains about the use of cement and pulversied coal bottom ash (PCBA) as an admixture for stabilization of black clay in Nigeria. The reaction of the PCBA with the clay produces cementing agents which produce an initial high strength followed by a pozzolanic reaction leading to longer-term strength. PCBA is very similar to Portland cement. For economical solution Osinubi (2000) recommended 5% by weight of dry soil pulverized PCBA mixed with 8% cement stabilised CL soil to improve subgrade soils.

Petry and Little (2002) recommended for future research, stabilization should include the establishment of protocols that allow the designer to determine the option best suited for a particular scenario. In addition the issues of sulphate heave, understanding of the mechanisms of stabilisation and assessment of various field properties from laboratory results need to be refined.

2.5.5 Moisture Barriers

As the title here suggests, moisture barriers around a foundation or pavement can assist in controlling the movement of water causing differential heave. This may include a geosynthetic material or plastic layer that lines the pavement box to contain the pavement materials. Of all the research carried out for this review, there was little mention of the use of moisture barriers and no elaboration on successful methods.
2.5.6 Geosynthetics

Geosynthetics include a large variety of products composed of polymers and are designed to enhance geotechnical and transportation projects. Geosynthetics perform at least one of five functions: separation, reinforcement, filtration, drainage, and containment.

Das (2006) believes that geosynthetics (including geofabrics, geotextiles, geomembranes and the like) play a role in separation of materials, reinforcing, filtering, draining and moisture barrier. By keeping a clay subgrade and sub-base material separate, increasing load bearing capacity, protection of fine-grained soils from transportation and channeling undesirable water away. This is supported by Zornberg and Gupta (2009) who state that geosynthetics reinforce the subgrade or base materials by providing lateral restraint (minimizing spread), tensile membrane support and increasing the bearing capacity. Zornberg and Gupta (2009) conclude that in the absence of geofabric incorporation in design manuals it appears that due to a lack of understanding and actual testing on the contribution that these fabrics are delivering to improved pavement performance. Tutumluer and Kwon (2005) gave cost benefit analyses have not yet been realised and an adequate design procedure is unavailable.

In 2008, Zornberg et al. (2008) reported their findings after field evaluation of 35 projects over expansive clays in the USA (Forth Worth to Dallas) which were experiencing cracking. They found that out of the 26 projects had been constructed using geosynthetics (with bi-axial grids the preference) with no well defined design procedures. Further investigations explained by Zornberg and Gupta (2009) proved to have significant outcomes, as follows:

1. Geosynthetic reinforcement helps in preventing the development of longitudinal cracks, whereas the control section with no geogrid developed cracks within a few months of construction.

2. Geosynthetic reinforcements will relocate cracks beyond the reinforced area; it was reported that a trial section was not constructed as directed and the area in the road shoulder where the geogrid did not cover cracked before the road was even opened to traffic.
3. Lack of understanding of geosynthetic specifications – tensile properties of geogrids will vary among manufacturers. Trials have shown that the junction efficiency (i.e. within the bonded portion of the longitudinal and transverse ribs) plays a major role in the performance of the grid. In comparison the polyester geogrid failed and the polypropylene grid performed well.

Geosynthetics have been also used in rehabilitation of pavements, particularly for preventing the reflection cracking of overlay constructions. Geosynthetics reinforced asphalt overlays are used to control pavement failure due to propagation of cracks from expansive subgrades (Button, 1989; Saxena, 1989; Wolfe, 1993; Pradeep Kumar, 1995; Chang et al., 1999). Usage of geosynthetics is also reported in the layers of flexible pavement system laid over different soils for improved performance (Haas et al., 1978; Barksdale et al., 1989; Al Quadi et al., 1997; Perkins and Ismeik, 1997; Kinney et al., 1998). Though reinforcement placement in layers help by distributing load spreading in base layer and improves life of pavements by preventing crack propagation to the surface of overlay, attempts have been made by researchers to try natural reinforcing material like bamboo, coir mats as reinforcing materials in overlays to cut down the heavy cost resulting from geosynthetics (Fang, 1979; Prasada Raju, 2001). Geotextiles and Geogrids are popular geosynthetics used in pavements for improved performance.

2.5.6.1 Geotextiles in Pavements

It has been reported by Hicks et al (1986) that a base contamination of about 10 percent subgrade soil fines can destroy structural strength of base layer. The problem of contamination can be solved by placement of geotextiles at subgrade level (Guram et al, 1994; Brorsson et al, 1986; Fannin and Sigurdsson, 1996). Further by placing geotextile as a separator between base course and subgrade soil permits water to drain off quickly through and along the plane of the fabric. As a result the surface remains clear, dry and intact (Srivastav et al, 1995). Due to multi functions like separation, reinforcement, filtration and drainage, geotextiles are extensively used in unpaved roads (Bender And Barenberg, 1978, Fannin and Sigurdsson, 1996).
The performance and service life can be improved by incorporating a geo textile in pavement design (Guram et al., 1994). All roadways derive their strength and stability from subgrade. The pavements lose their designed thickness over a period of time due to intrusion of soft subgrade material into aggregate base and penetration of base material into subgrade. When the pavement thickness is reduced, it leads to progressive failure mechanism resulting in need for continuous road maintenance.

The reinforcing action of fabrics on unpaved road structure has been interpreted by Hausmann, 1990 as follows:

- By placing geotextiles over weak subgrades at subgrade level a general shear failure takes place, where local or punching shear failure occurs otherwise. Thus the bearing capacity factor of soil may be taken to increase from $N_c = 3$ to 5 or more.

- By placing geotextile at interface fabric restrains the aggregate base layer and subgrade. The restraint provided enables to account for load spreading by considering slab action.

- Subsidence associated with wheel path rutting develops tension in the fabric. Reinforcing action of fabric within the subgrade is less because of necessary displacement of soil prior to placement and low soil-fabric friction. Placement of fabric at the interface of subgrade and sub base layer has the advantage of all fabric functions.

Evaluation study on non-woven needle punched geotextile Supac 8NP (tensile strength of 35 kN/m at elongation of 50%) with 610 mm of lime stabilised subgrade was carried out on state highway SH-131 in Atoka county, Oklahoma (Guram et al., 1994). It has been reported that non-woven geotextile showed performance equivalent to that of lime treated layer. Even after 9 years the fabric did not loose any strength. Significant savings in both construction and maintenance are realised due to placement of geotextiles.
USDA forest service (Powell and Mohney, 1994) used geotextiles in the year 1976 in test sections of flexible pavements over subgrade soils of high organic clays and silts with CBR values less than 1. The tensile strengths of fabrics used were 10 kN/m and 20 kN/m. The fabrics were laid at subgrade level and 0.5 to 1m thick shot rock fill was dumped. The rock fill was surfaced by 0.2 to 0.3m of glacial pit run gravels. The constructed pavement is tested to 36000 kg gross vehicle load. Geotextiles are found to function as per the design. It is found that tensile strength decreased by about 10 to 40% owing to construction damage and thereafter during service the strength loss was only 2 to 12%. It is also reported that stresses from traffic did not cause damage to the geotextiles.

Cancelli et al. (1992) showed that a woven, flexible geogrid and a high-modulus geotextile-reinforced section performed marginally better than the control section, where as stiff geogrids and a multilayer geogrid have proved significant improvement. For very soft subgrades, two layers of a relatively weak geogrid were found to be more effective than placing one layer of a very stiff geogrid. Geogrids were effective in allowing for reduced base course layer thicknesses and in extending the service life of a section for a given thickness. Geogrid benefits generally increases with decrease in subgrade strength and increase in allowable rut.

Killeavy and Anderson (1989) tested three sections with different base course thicknesses that were designed to perform identically. The results of the study indicate that all the sections performed the same. Therefore, the geotextile – reinforced base layer thickness could be reduced from 450 to 350 mm, while the geogrid- and geotextile-reinforced section thickness could be reduced from 450 to 200 mm.

Public works department in Maharashtra state used non-woven geotextiles and bi-oriented geogrids in the state highways for strengthening the pavements over black cotton soils in 1997 (Rao and Banerjee, 1999). Based on limited Indian experiences, Ministry of Surface Transport (Roads wing) has included geosynthetics for use in subsurface drains, highway pavements, slope protection works and reinforced soil structures in their 1995 version of specifications for road and bridge work.
Of the design approaches proposed, the empirical methods of Penner et al. (1985), Montanelli et al. (1997), and Webster (1992) are limited to the experimental study. The design methods do not appear capable of accounting for the influence of wide variations in variables such as geosynthetic type, load magnitude, asphalt concrete and base layer thickness, and subgrade type. The analytical method proposed by Davies and Bridle (1990) does not account for movement in the base layer soil, which appears to largely control the development of rut depth for properly designed sections and must be calibrated from actual pavement loading experiments.

The analytical approach of Sellmeijer (1990) appears promising due to its ability to account for the effect of increased confinement on the base course layer as a result of interaction with the geosynthetic. Varying degrees of success have been reported in developing a finite element model to predict the response of reinforced flexible pavements. Barksdale et al. (1989) and Miura et al. (1990) incorporated certain laboratory/field tests into their design models. Perhaps the most significant limitation of all of the models developed to date is the inability to predict pavement section response over a number of repeated load cycles. All of the models were developed to predict response of pavement under a single load application.

Membrane Action of Geotextiles

Geotextile reinforcement contributes not only to load distribution but also it supports load through a mechanism called “Tensioned membrane effect” (Groud J.P. 2008). The tensioned membrane effect consists in decreasing the load induced in the subgrade soil under the wheels, by transferring part of this load to lateral zones (i.e. away from the wheels). Due to the traffic loads the geosynthetic is deformed and is therefore, under tension. Under the wheels, due to rutting, the geo synthetic has concave shape. The resultants (which are oriented upward) of the geosynthetic tensions on each side of the concave shape contribute to wheel support. These resultants are balanced by downward resultants associated with the convex shape of the geosynthetic away from the wheels.

2.5.6.2 Geogrids in Pavements

According to Koerner (1986) geogrid is defined as a geosynthetic material consisting of connected parallel sets of tensile ribs with apertures of sufficient size to allow strike-
through of surrounding soil, stone, or other geotechnical material. Existing commercial geogrid products include extruded geogrid (Geogrid – Tenax LBO 330 SAMP), woven geogrids, welded geogrids, and geogrid composites. Most geogrids are made of polymers, but some products have been manufactured from natural fibres, glass, and metal strips.

Geogrids used within a pavement system perform the primary functions of geosynthetics: separation and reinforcement. Due to their large aperture size associated with geogrids are typically not used for achieving separation of dissimilar materials. The ability of a geogrid to separate two materials is a function of the gradations of the two materials and is generally outside the specifications for typical pavement materials. However, geogrids can theoretically provide some measure of separation, but limited. For this reason, separation is a secondary function of geogrids used in pavements. The primary function of geogrids used in pavements is reinforcement, in which the geogrid mechanically improves the engineering properties of the pavement system.

The three primary uses of a geogrid in a pavement system are to serve as a construction aid over weak subgrades, to improve or extend the pavement’s projected service life and to reduce the structural cross section for a given service life. Geogrids have been successfully used to provide a construction platform over weak subgrades (Cancelli et al. 1996, Haas et al. 1978, Halliday and Potter 1984, and Santoni et al. 2001). In this application, the geogrid improves the ability to obtain compaction in overlying aggregates, while reducing the amount of material required is to be removed and replaced. Numerous research programs have also reported the extended service lives for pavement sections with geogrids compared to similar sections without geogrids (Al-Qadi et al. 1997, Barksdale et al. 1989, Cancelli et al. 1996, Collin et al. 1996, Haas et al. 1988, Miura et al. 1990, Perkins et al. 1997a/b, and Webster 1993). Finally, research has shown that the required base course thickness for a given design may be reduced by using geogrid in pavements.

For mechanical subgrade stabilization and base reinforcement applications the geogrid should be placed at the bottom of the base for aggregate layers less than 14 inches. If a geotextile is to be used for separation of the subgrade and base materials, the geotextile should be placed directly on the top of the subgrade. The reinforcement geogrid is then placed directly on top of the separation geotextile for aggregate layers less than 14 inches. For pavements with a design base thickness greater than or equal to 14 inches,
the geogrid should be placed in the middle of the base course layer (Webster 1993). However, Collin et al. (1996) and Haas et al. (1988) recommend to place the geogrid in the middle of the base course layer for layers more than 10 inches, otherwise placement should occur at the layer interface. Regardless of the placement location of the geogrid, the separation geotextile is always placed at the subgrade base interface.

Tests by Watts et al. (1996) interpreted by Giroud & Han (2006) show that geogrid strains under dual wheels are still very small (i.e. between 0.1 and 1.2%) after full development of ruts at the end of the test. Like other geosynthetic fabrics used in any application, a geogrid is sufficiently robust to withstand the rigors of transportation, handling, installation, placement of materials in contact, and other construction activities. Also, the geogrid is capable of maintaining the integrity of its structure and properties throughout its service life. The geogrid material is not degradable for long periods in any way in a soil environment.

Al-Qadi et al. (1997) and Smith et al. (2004) after studying three test track concluded that the improvement mechanisms associated with geogrids and geotextiles were different. Mixing of the subgrade and base course material was observed in the control and geogrid-reinforced sections, whereas contamination was not observed in the geotextile-reinforced sections.

Killeavy M and Anderson (1989) performed FWD tests on field test sections that were designed to yield equivalent performance. The test results indicated that similar subgrade deformations were observed in each section, and reduced asphalt strain and better load distribution occurred in the geogrid-reinforced sections. Back-calculation techniques showed that the geogrid section had the largest base layer modulus (560 MPa), followed by the geotextile section (400 MPa) and the control section (170 MPa). Visual observation of the sections after a one year and a ten year monitoring period indicated little difference between the surface rut characteristics of the three sections. Barker (1987) compared a test section reinforced with Geogrid, where the reinforcement was placed in the middle of the 150 mm thick base, to an identical unreinforced test section. In terms of rut depth development, the reinforced section performed worse than the control section for rut depths less than 18 mm. For instance, for 10 traffic passes, the reinforced section showed 4 mm of displacement while the control section showed less than 1 mm. For rut depths greater than 18 mm, the performance of the reinforced section, as compared to the control section, continued to increase.
Barksdale et al. (1989) noted that a geogrid with less stiffness than a geotextile is exhibiting better performance. This improved performance was attributed due to interlocking ability of the geogrid and its role in preventing lateral spreading of the base layer soil. The test results suggested that the geotextile required significantly higher deformation in order to mobilize the same reinforcing potential as the geogrid. The geotextile was superior than geogrid in preventing mixing of the subgrade with the base course soil.

Collin et al. (1996) showed that test section performance improved due to geogrid reinforcement and increased with increasing the base thickness up to a base thickness of 255 mm, and then decreased with continued increasing base thickness, when the geogrid was placed at the bottom of the base. The number of wheel loads carried by the reinforced sections exceeded the control section by a factor as great as 10 for a 25 mm rut depth. Geogrid reinforcement controlled initial pavement deformations that occur during the first several hundred load cycles before the section stiffens. The reinforcement caused the deflection versus load cycle curves to flatten and become approximately linear. Similar to the study by Brown et al. (1982), Halliday and Potter (1984) demonstrated no improvement in the rate of development of rut depth or vertical strain in the subgrade with the use of strong woven geotextile for reinforcement. The presence of the geotextile appeared to have no influence on the structural quality of the roadway but helps in the construction process through the mechanism of separation. It was estimated that the penetration of sub base soil into the soft subgrade by a depth of 70mm in the control section where a geotextile was not present. Collin et al. (1996) showed that increase in geogrid modulus was insignificant in improving performance when the geogrid was placed at the bottom of the base and when the base layer was either thin (< 175 mm) or thick (> 275 mm).

Haas et al. (1988) after performing laboratory experiments concluded that the importance of variables such as geogrid placement position, base course thickness, and subgrade strength. It was stated that reinforced sections carried three times the number of load cycles as compared to a similar control section, and that reinforcement allowed up to a 50% reduction in base course thickness.

The optimum geogrid location was at the bottom of thin bases and at the midpoint for base thicknesses in excess of 250 mm. For very soft subgrades, optimum performance occurred with two layers of geogrid, where in excess of three times the number of load
cycles could be carried. Strain measurements on the geogrid showed that tensile strains in excess of 1% was observed under the load center and that these strains diminish to zero at a radius of 1.5 times the radius of the load plate, indicating that long anchorage lengths were not required in such situations.

The laboratory test results reported by Miura et al. (1990) demonstrated that geogrids of increased stiffness provided for improved performance. Improvement was closely related to the magnitude of strain measured in the geogrid while loading. The performance of the field sections also improved by using the stiff geogrids, but not to the same level as that demonstrated in the laboratory tests.

Tensile properties of geogrids can vary among manufacturers. Trials have shown that the junction efficiency (i.e. within the bonded portion of the longitudinal and transverse ribs) plays a major role in the performance of the grid. In this case the polyester geogrid failed and the polypropylene grid performed well. Moghaddas-Nejad and Small (1996) demonstrated that placing of geogrid at the bottom of a thin base results in a 40% decrease in rut depth for single-track wheel passes and a relatively light load, whereas geogrid placement in the middle of the base results in a 70% decrease. These values correspond to 5000 wheel passes. For multiple-track loading, both placement positions resulted in a 50% decrease in rut depth. The deflection basins below the reinforced sections were wider and shallower than those of the unreinforced section, suggesting that the reinforcement improved the pressure distribution on the subgrade. Studies on measurements of vertical deformation at the level of the geogrid showed that there was substantial improvement when load-induced vertical deformations of the geogrid were less than several millimeters. This suggests that improved performance was not due to a tensioned membrane effect, but was due to lateral restraint of the base soil.

Webster (1993) showed that flexible geogrids were not as effective as stiff geogrids for base layer reinforcement in flexible pavements. The torsional rigidity of the geogrid, which is governed in part by the characteristics of the junctions, was the most important factor to determine the suitability of the geogrid product. Sections reinforced with a stiff geogrid are efficient in carrying as much as 21 times the number of traffic loads as an unreinforced section. The value of this factor depended on the position of placing the geogrid, the thickness of the base layer, and the strength of the subgrade soil.

Barker (1987) tested by constructing a one-layer, reinforced test section containing a geogrid placed in the middle of a 150 mm thick base resting on a strong sub base-
subgrade system. The traffic load applied to the section was heavy in comparison to the majority of the other studies. The reinforced section performed worse than the control section up to a 18 mm rut depth; for greater rut depths improvement was observed.

2.6. REVIEW OF DESIGN PRACTICES OF REINFORCED FLEXIBLE PAVEMENT

To determine the aggregate pavement thickness a number of design procedures has been proposed by Giroud & noiray, Sellmeijer et al., Koerner and Barenberg etc. Among these Giroud& Noiry and BarenBerg are popular.

2.6.1 Giroud and Noiray Method

They proposed a design methodology taking into consideration the membrane effect of geotextile and allowance to traffic. In his analysis he equated the maximum pressure on subgrade to ultimate bearing capacity. The pressure on subgrade is given by,

\[ q_u = P - P_g \]  --- (1)

where,

\( q_u \) is ultimate bearing capacity of subgrade soil = 5.14 \( C_u + \gamma h \)

\( P = \) pressure on subgrade due to surcharge

\( P_g = \) Reduction of pressure due to membrane effect

Pressure \( P \) is calculated using load spread angle \( \alpha \) through aggregate layer as

\[ P = \frac{P}{2(B + 2h\tan\alpha)(L + 2h\tan\alpha) + \gamma H} \]  --- (2)

Where, \( P \) is the Axle load

\( \gamma \) is unit weight of aggregate

Dual wheels are assumed with each set of tires covering an area \( B \times L \). For a tyre pressure \( p_c \), the dimensions are as follows.

On Highway Trucks

Off Highway Trucks
\[ B = \frac{P}{\sqrt{p_c}} \]

\[ B = \frac{p_{B}}{\sqrt{p_c}} \]

\[ L = \frac{B}{\sqrt{2}} \]

The methodology uses a value of \( \alpha = 0.6 \) in reinforced case conservatively that exists in unreinforced case.

The \( P_g \) value is determined by assuring that the shape of deformed geotextiles represents a section of parabolas and the volume of central heaved area is related to soil displaced by settlement. The fabric strain is calculated as

\[ \varepsilon = \frac{b + b'}{a + a} - 1 \quad \text{for} \ a' > a \]

\[ = \frac{b}{a} - 1 \quad \text{for} \ a > a' \]

Where, \( b \) and \( b' \) represent the half chord lengths of parabolas \( p \) and \( p' \)

The widths \( a \) and \( a' \) are obtained from the relationships.

\[ 2a = B + 2h \tan \alpha \]

\[ 2a' = e - B - 2h \tan \alpha \]

Where, \( 'e' \) is track width.

Chord lengths \( b \) and \( b' \) are calculated from the following equations

\[ \frac{b}{a} - 1 = \frac{1}{2} \left[ \sqrt{1 + \left( \frac{2s}{a} \right)^2} + a \ln \left( \frac{2s}{a} + \sqrt{1 + \left( \frac{2s}{a} \right)^2} \right) - 2 \right] \]

\[ \frac{b'}{a} - 1 = \frac{1}{2} \left[ \sqrt{1 + \left( \frac{2(r-s)}{a} \right)^2} + a \ln \left( \frac{2(r-s)}{a} + \sqrt{1 + \left( \frac{2(r-s)}{a} \right)^2} \right) - 2 \right] \]

Finally the fabric tension is determined from the relation,

\[ T = \varepsilon E_f \]

and membrane support as,
where, \( E_f \) is elastic modulus of the fabric.

**Figure 2.1 Shape of Deformed Fabric According to Giroud and Noiray**

Using equation 1 for the cohesion \( C_u \), a relationship can be established between \( C_u \) and required aggregate height for a given geometry, load, configuration and fabric modulus. The analysis is referred to as quasi-static as it does not take into account traffic numbers.

The effect of traffic is considered to impose the same effect on reinforced pavements with regard to increase in design pavement thickness. The unreinforced aggregate depth, \( h_o \), is given by

\[
h_o = \frac{1.6193 \log N + 6.3964 \log P - 3.7892r - 11.8887}{C_u^{0.63}} \quad N>20 \ & \ N<10,000
\]

where \( P = \) axle load

\( C_u = 30 \) CBR (kPa)

\( r = \) rut depth (m)
for N< 20, it is proposed to use a quasi-static analysis based on a bearing failure, at $q_u = \pi C_u + \gamma h_0$ and the pressure at the aggregate-subgrade interface can be calculated according to equation 2 with $h_0$ instead of $h$.

The theory does not account for the velocity of vehicles, loads and suits only to unpaved roads. The design methodology is based on a total vertical stress of $q_u$ at subgrade level, which leads to higher settlements in soft clays. So the theory should not be used in paved roads where surface settlement should not exceed 40mm or less.

### 2.6.2 Koerner Method

Koerner proposed a laboratory method modeling the field situation to arrive at the influence of a geotextile (Koerner, 1986). The method involves conducting CBR test on CBR specimen with soil and aggregates half filled. The test is to be done up to 5 cm penetration level. CBR test is also done on specimen with geotextile held in position at interface of soil and aggregate. The reinforcement ratios, defined as load resisted by unreinforced and unreinforced specimen are calculated at different penetration levels. Modified CBR value is determined as Maximum reinforcement ratio x actual CBR value of soil. The design thickness of reinforced flexible pavement is determined using modified US army Corps of Engineers Formula given below.

$$t = \left[0.447 \log c + 0.305 \left( \frac{P}{3.6045 \times CBR} - \frac{A}{6.45 \pi} \right)^{0.5} \right]$$

where,

- $t =$ Thickness of pavement in cm
- $c =$ Anticipated number of vehicle passes
- $P =$ ESWL in kg
- $A =$ Contact area of tyres in cm$^2$

However, the design is based on small scale load penetration test and needs verification in the field.

Geotextile fabrics were suggested to be used over soft clay subgrades based on analytical report to economise pavement thickness and reduce rutting (Natarajan et al., 1989). The fabric deformed shape at subgrade has been treated as combination of two inclined
straights. Geotextiles, woven and non-woven types have been recommended to be used unhesitatingly for filtration and drainage functions. The use of geotextiles has been proven to be cost effective when sand or other good quality sub base materials are not available within economic leads or when CBR of subgrade is less than 3 and/ when roads are waterlogged (Natarajan and Murthy, 1989). The tentative specifications have been given to satisfy filtration and drainage requirements.

Based on load deformation characteristics observed from tests conducted in CBR moulds on geotextile reinforced CI and CH group soils, it is reported that woven geotextiles were observed to give higher percentage improvement against deformation as well as economy in terms of thickness of pavement (Shroff, 1989). It is also suggested that geotextile should be placed at optimum depths below surface of weak subgrade or placing small layer of subgrade material on laid geotextile over subgrade and then placing aggregate above it. The reinforced pavement thickness determined from Giroud and Noiray approach and Koerner method over different soil subgrades using geotextiles has revealed that the reinforcing fabrics significantly reduced pavement thickness over soils of CBR less than 1 and reduction in pavement thickness was insignificant for CBR values of about 15 (Rao et al., 1999).

2.6.3 Bender and Barenberg Method

Based on laboratory model studies on aggregate - soft subsoil with non-woven geotextile for temporary roads on soft subgrades, Bender and Barenberg have postulated that allowable stress on subgrade can be related to ultimate bearing capacity without significant rutting (less than 5 cm). Design curves have been developed using elastic stress distribution theory for rut depth of 10 cm and low traffic volume (N<100) using low and moderate modulus fabrics for different wheel loads (22 – 89 kN) and contact pressures of 345 to 552 kPa (Bender and Barenberg, 1978). These curves can not be directly used for Indian roads as allowable rut depth is less than 10 cm as assumed (Venkatappa Rao, 1998).
2.7 DEFICIENCIES IN THE EXISTING LITERATURE

The following deficiencies have been noticed from the literature that has been reviewed above.

- There is no established procedure for design of reinforced flexible pavement over clay subgrade in general and expansive soil in particular.
- The concept of membrane action of geotextile reinforcement and geo grid reinforcement over soft subgrade requires further study.
- Usage of geotextile for swell control was not given much attention.
- None of the papers reported reinforced mattress approach of geogrids.
- Less work was done on performance study of laid test tracks with geosynthetic reinforcement in expansive soils.

2.8 SPECIFIC SCOPE OF THE PROPOSED RESEARCH

- In the present work, a design methodology was formulated for reinforced flexible pavement design over non expansive and expansive clay subgrades ensuring safety against swell, shear failure and settlement failure risks.
- The performance of CH soil in CBR method is compared and a reinforced method through test track studies is proposed.
- The reinforced soil mattress concept applied to stiffen the sub base layer using geogrid reinforcement in flexible pavement design over a clay subgrade of intermediate compressibility is also studied.
- The test track is laid using geogrid and is being monitored under traffic and varied seasonal effects.

2.9 SUMMARY

In literature review existing practices for design of reinforced flexible pavement and deficiencies are noticed. After defining specific scope from literature review the research methodology has been developed and presented in next chapter.