Quantification of benefits of geosynthetic reinforced flexible pavements

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ABSTRACT: Construction of road pavements in soft clays acting as subgrade presents difficulty due to their high compressibility and inadequate support for the overlying pavement layers. This results in premature failure of such roads as they experience vehicular loadings that are comprised of static and dynamic loading. In this study, reinforcement geosynthetics (geogrids and geotextiles) were used as reinforcement inclusions within a granular base overlying a soft clay subgrade. Bench scale static and dynamic plate load tests were conducted to study the benefits from the reinforcement within the pavement structure. The resulting benefits were quantified in terms of base course reduction factor (BCR) and the traffic benefit ratio (TBR). The BCR and TBR were included in the AASHTO design equations and equivalent pavements designed for. TBR consideration in design for reinforced cases resulted in up to double the unreinforced design equivalent standard axles (ESALs) with more than 10% increment in the structural number. For the BCR, there was an increase in the reinforced pavements ESALs by up to 8 times the unreinforced ESALs and a reduction in the equivalent base thickness of up to 40%.

Keywords: Geogrid, Geotextiles, Infrastructure, Paved roads, BCR, TBR

1 INTRODUCTION

The wide spread of problematic soils in South Africa (Paige-Green, 2004) have required the construction of pavements over soft clay subgrade soils which is often associated with design and construction difficulties because of the compressible and low mechanical properties of such soils. During construction, placing an aggregate base on top of the soft subgrade will result in significant aggregate loss caused by intrusion which is triggered by construction traffic loads. Moreover, roadways constructed over subgrades with significant fines experience migration of fines into the aggregate base. The contamination of the base by subgrade fines and the aggregate loss into the subgrade causes localized failures hence leading to increased maintenance costs and shortened life cycle. Yoder & Witczcak (1975) determined that about 20% by weight of the subgrade soil when mixed into the aggregate will reduce significantly the bearing capacity of the base layer. The American Association of State Highway and Transportation Officials (AASHTO) noted that approximately 20% of pavement failure is due to insufficient structural strength (Pokharel, 1997; Tencate, 2014).

The traditional approaches such as replacing the top of the subgrade soils with better quality fill, increasing the thickness of the pavement layers and treating/stabilizing the subgrade with a binder such as cement or lime have been used to create a working platform by improving the engineering properties of the subgrade. However, all these methods have a scope of applicability but are disadvantaged because of being either expensive, time consuming or both. The inclusion of geosynthetics such as geotextile and geogrids within the pavement structure can be used to address this problem. This is because these materials are characterized by better qualities comparatively, through their reinforcement and separation functions that enhances pavement performance.

The adequacy of a road pavement is based on its ability to support heavy traffic loads and its resilience to the repeated and dynamic traffic loads without failure. Unbound aggregates forming the base are normally subjected to repeated application of stress with each wheel pass. The moving wheel loads are dynamic whose repetitions results in permanent deformation of the surface. In addition, sufficient bearing capacity is an important characteristic of a pavement and it is even more critical when the structure is expected to carry heavy traffic loads.

2 EXPERIMENTAL STUDY

A study was conducted to determine the benefits accruing from the use of geogrids and geotextiles as reinforcement inclusions within a pavement structure. A test tank of 1 m3 was used as a road model that comprised of a soft subgrade laid at a California Bearing ratio (CBR) of 2% and a granular base placed at 90% of the modified AASHTO. The soft subgrade was prepared using Kaolin clay. The kaolin had a standard proctor maximum dry density of 1520 kg/m^3 and optimum moisture content of 25.5%. The base was a G7 material according to South African Standards TRH 14. It is classified as SC Clayey sand and A-6 according to the unified soil classification system (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) classification systems respectively. The base material had a maximum dry density of 2000 Kg/m3 and an optimum moisture content of 13%. (Modified AASHTO).

Two types of geosynthetics were used in this study as reinforcement inclusions within the structure namely, woven geotextile and an extruded geogrid. The geogrid and the geotextile were each separately placed at the interface of the base and subgrade for the initial series of tests, which was then followed by placement of the geotextile at the interface and geogrid at the mid depth of the base. The geogrid was a biaxial geogrid with a square grid of 38 mm x 38 mm. The geotextile had a characteristic aperture (equivalent opening size) of 300 Microns. Table 1 presents a summary of the properties of the reinforcement material.

Table 1. Material properties (Maccaferri SA)

	Woven Geotextile (WGx) *Mactex W1 5S*	Extruded Geogrid (EG) *Macgrid EG 20S*
Tensile Strength MD* kN/m	50	20
Tensile Strength CMD* kN/m	50	20
Strain at maximum strength MD*	20	13
Strain CMD*	13	10
Tensile strength at 2% strain, Longitudinal kN/m	-	7
Tensile strength at 5% strain, Longitudinal kN/m	-	14
Tensile strength at 2% strain, Transverse kN/m	-	7
Tensile strength at 5% strain, Transverse kN/m	-	14

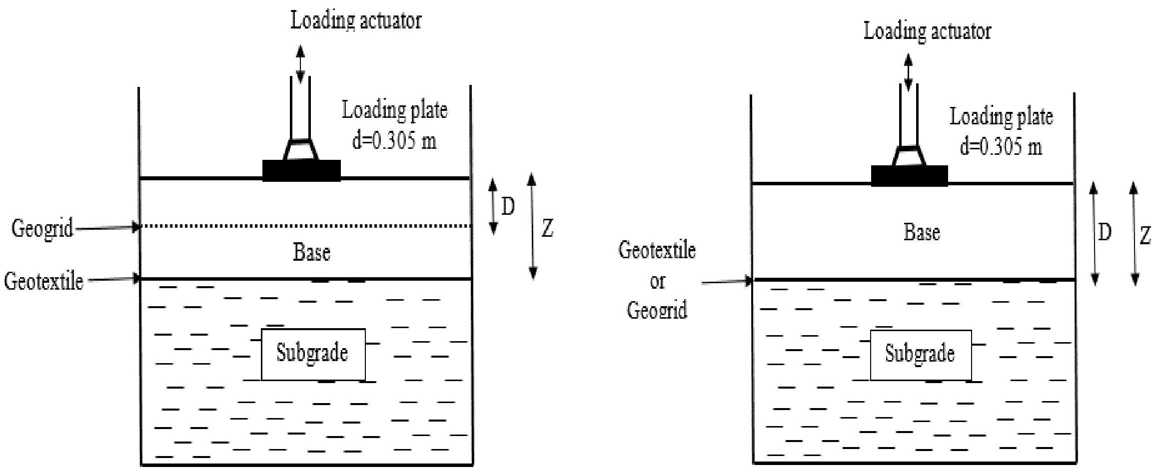

Figure 1: Schematic of the road model

Static plate load tests (Kiptoo et al., 2015) and cyclic plate load tests (Kiptoo et al., 2016b) were performed on the prepared road model through a 0.305 m steel plate to replicate the effects of a moving wheel load on a road pavement (Figure 1). Graphs of deformation against bearing pressure and deformation against number of cycles were drawn from the tests (Kiptoo, 2016a). Failure of the composite system was measured for a deformation of 75 mm as defined for unpaved roads (AASHTO, 1993; Giroud & Han, 2004). Additionally, the improvement from the use of reinforcement geosynthetic was measured against the unreinforced test as a reference point.

3 RESULTS

The resulting benefits were presented as the Bearing Capacity Ratio (BCR) and Traffic Benefit Ratio (TBR) obtained from static and cyclic plate load tests respectively at a deformation of 75 mm (Table 2).

Table 2. Bearing Capacity Ratio (Kiptoo et al., 2015) and Traffic Benefit Ratio (Kiptoo et al., 2016)

Pavement	Bearing Capacity Ratio (BCR)	Traffic Benefit Ratio (TBR)
Unreinforced	1	1
Geotextile	1.29	1.29
Geogrid	1.21	1.21
Geotextile & Geogrid	1.63	2.14

4 AASHTO DESIGN

The AASHTO design guide is one of the most widely used design criterion for flexible pavement design. This method considers a pavement as a multilayer elastic system with an overall structural number (SN). The structural number (SN) gives an indication of the combined structural capacity of all the pavement layers overlying the subgrade and it reflects the total pavement thickness and its resilience to repeated traffic loading (Gupta, 2010). Zornberg, (2011) has incorporated the resulting benefits of a geosynthetic in form of bearing capacity ratio (BCR) and traffic benefit ratio (TBR) to factor the structural number in unreinforced case.

The structural number (SN) is selected such that anticipated traffic loads will be supported without a loss in serviceability no greater than that allowed based on the requirements of the pavement. The SN is determined from a nomograph that solves the Equation 1.

$$\mathrm{Log}\,W_{18} = Z_R \,\mathrm{x}\, S_o + 9.36 \,\mathrm{x} \log(SN+1) - 0.2 + \frac{\log \frac{\Delta PSI}{2.7}}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \log M_R - 8.07 \qquad (1)$$

where W_{18} = the anticipated cumulative 80kN Equivalent Single-Axle Loads (ESALs) over the design life of the pavements, Z_R = the standard normal deviate for reliability level, S_O = the overall standard deviation, ΔPSI = the allowable loss in serviceability, and M_R = the resilient modulus (stiffness) of the underlying subgrade.

The structural number determines the total number of ESALs (Equivalent Single Axle Loads) that a particular pavement can support. From Equation 1, the structural number can be determined and the individual pavement layers can be designed through a series of iterations.

$$SN = (a_1 D_1)_{HMA} + (a_2 D_2 M_2)_{Base} + \cdots \qquad (2)$$

where a_i = ith layer coefficients, D_i = i^{th} layer thickness (in inches), and M_i = i^{th} drainage coefficients

In this design, ESALS selected was 30,000 which corresponded to road category D with a recommended design period of 10 years according to TRH4, (1996). The design pavement comprised of a base as a structural unit and a thin surfacing (HMA) protective layer. Using AASHTO flexible design excel spread sheet, by inputting the different components in Equation 1 as summarized in Table 3, an overall structure number of 2.19 was obtained for the pavement.

Table 3. Summary of Design parameters for unreinforced pavement (TBR and BCR =1)

Parameter	Symbol	Value
Predicted future traffic	W18	30000 ESALs
Reliability	R	50%
Overall standard deviation	So	0.3
Subgrade resilient modulus	MR	3000 psi
Initial serviceability	Po	4.5
Terminal serviceability	Pt	2.5
Layer coefficient	ai HMA	0.44
	ai Base	0.1
Drainage coefficient	mi (base)	0.9

4.1 *Unreinforced pavement design*

An unreinforced pavement was adopted with an equivalent standard axle loads (ESALs) of 30000, an asphalt surfacing of 50 mm and a base of 380 mm which yielded a safe design. The overall structural number that ensued was 2.23 which is greater than the design structural number of 2.19, hence sufficient (Table 3).

Table 4. Unreinforced pavement structural number

layer	Material Type	Thickness (mm)	Layer coefficient a^i	Drainage coefficient M^i	Structural number
1	Surfacing	50	0.44	1	0.87
2	Base	380	0.1	0.9	1.35
			Overall structural number		2.23
			Design structural number		2.19

4.2 *Geosynthetic Reinforced pavement design*

Two main benefits of the geosynthetic reinforcement have been considered in design: extended life of the pavement (i.e., additional vehicle passes), and reduced base aggregate thickness (i.e., reduced undercut, aggregate quantities and initial construction cost) as also determined by Holtz et al. (2008).

4.2.1 *Extended life of pavement*

The contribution of TBR in pavement design is factored into the design equivalent standard axle loads (ESALs) as shown in Table 4. The design ESALs in unreinforced case used was 30000. After factoring for a reinforced pavement, the computed ESALs were designed for an equivalent unreinforced bases. This was to express the benefits of geosynthetics inclusion in terms of an equivalent unreinforced base and structural number increment.

$$W_{18}\ (reinforced) = TBR\ x\ W_{18}\ (unreinforced) \tag{3}$$

Table 4. Pavement design using the Traffic Benefit Ratio (TBR)

	TBR from model testing	TBR factored ESALs	Structural Number	HMA Surfacing (mm)	Equivalent unreinforced Base Thickness (mm)
Unreinforced	1	30000	2.23	50	380
Geotextile	1.29	38400	2.32	50	400
Geogrid	1.21	36300	2.29	50	400
Geotextile & Geogrid	2.14	64200	2.50	50	460

The calculated traffic for the unreinforced section is 30000 ESALs. Factoring in the TBR, the calculated traffic for the geosynthetic reinforced pavements is 38400 ESALs for geogrid, 36300 for geotextile and 64200 for geotextile-geogrid reinforced pavements. It is evident that for a pavement with the same thickness, the inclusion of reinforcement geosynthetics results in a superior pavement that is able to withstand higher loading repetitions. The double reinforcement of geotextile at the interface and geogrid within the base carries more than twice the equivalent standard axles for the unreinforced pavements. Moreover, when the loading repetitions are designed for, there is an increase in the structural number greater than the unreinforced road. The equivalent unreinforced thickness increases with inclusion of a geosynthetics conveying that a higher unreinforced base thickness are required to match the increased structural number as a result of a inclusion of a geogrid and geotextile.

4.2.2 *Reduced base aggregate thickness*

Base course reduction factor is a modifier that is applied to the structural number (SN) of the pavement. For an equivalent standard axles (ESALs) of 30,000, the required design structural number of unreinforced pavement is 2.19

$$SN = (a \ x \ d)_{hma} + BCR.(a \ x \ d \ x \ m)_{base} \tag{4}$$

The BCR was factored in the base structural number and a new overall structural number for reinforced pavements determined. The eventual structural number was input in Equation 1 to calculate the resulting equivalent standard axles (ESALs). To show the benefit of reinforcement geosynthetic in the pavement, an equivalent unreiforced base thickness for the corrected structural number was obtained.

The reduced depth of base course can be computed by inputting the BCR when designing the pavement as follows:

$$d_{Base,(R)} = \frac{SN_u - (a \ x \ d)_{hma}}{BCR.(a \ x \ m)_{base}} \tag{5}$$

where $d_{base,\,(R)}$ is the reduced base course thickness due to reinforcement and SN_u is the structural number corresponding to the equivalent W18 for the unreinforced pavement.

Table 5. Pavement design using the Base Course Reduction (BCR)

	BCR from model testing	Factored SN	Equivalent ESALs	HMA surfacing (mm)	Equivalent unreinforced Base (mm)	Reduction in Base thickness (mm)
Unreinforced	1	2.19	30000	50	380	-
Geotextile	1.29	2.62	88000	50	500	120
Geogrid	1.21	2.50	66000	50	460	80
Geotextile & Geogrid	1.63	3.08	245000	50	630	250

The unreinforced thickness of 300 mm, on the inclusion of reinforcement geosynthetic, resulted in reduced base thickness by 31%, 18% and 65% for the geotextile, geogrid and geotextile-geogrid reinforced pavements respectively. In addition, computing the resulting equivalent standard axles (ESALs) from the factored structural number (SN), showed an increase in the ESALs of up to 8 times the unreinforced ESALs. Furthermore, the corresponding equivalent unreinforced thickness is up to 1.5 times more with the inclusion of geosynthetic reinforcements (Table 5).

The performance of the geotextile-geogrid reinforcement was better than the singly reinforced pavement with either geogrid or geotextile. The geotextile reinforced pavement sustained more ESALs than the geogrid reinforced pavement. This is attributed to the strength of the geotextile used being more than twice the strength of the geogrid.

4.3 *Cost savings analysis*

The cost saving was calculated from the obtained improvements which were considered in the AASHTO design for reinforced and unreinforced pavements. The economy is obtained from the reduction in the thickness of the base. The width of the road pavement was assumed to be 7 m and the cost savings were computed over 1 km length. The cost of materials is as shown in Table 6.

Table 6. Cost of materials

	Material Types	Cost
Granular base	G7 material	300 Rands/m^3
Geogrid	Macgrid EG 20S	15 Rand/m^2
Geotextile	Mactex W1 5S	19 Rand/m^2

Cost saving from the use of geotextile and geogrid reinforcement will vary from project to project depending on the subgrade conditions and the base material properties used. From the design adopted, it was determined that there was a reduction in the thickness of the granular base. The advantages of increasing base thickness was considered vis-à-vis the cost of use of geotextile and geogrid within the pavement as shown in Table 7. The outcome showed that there was savings from the cost of the reinforcement geosynthetics versus the additional base materials. This was represented as percentage saving in cost of base materials of 47%, 38% and 55% for the geotextile, geogrid and geotextile-geogrid pavements respectively.

Table 7. Cost of materials

Pavement	Equivalent unreinforced Base (m)	Reduced Base thickness (mm)	Cost of geosynthetics over 1 km (Rands)	Savings in base thickness reduction (Rands)	Percentage saving in cost
Unreinforced	380	-	-	-	-
Geotextile	500	120	133000	252000	47%
Geogrid	460	80	105000	168000	38%
Geotextile & Geogrid	630	250	238000	525000	55%

5 CONCLUSION

The results from static plate load tests and dynamic plate demonstrated clear benefits of geotextile and geogrid reinforcement that were represented as the Base Course Reduction (BCR) and Traffic Benefit Ratio (TBR). On inclusion of the improvements to the AASHTO design method, the results showed that:

- The design of a reinforced pavements showed that it was capable of supporting more than twice the Equivalent Standard Axles (ESALs) of an unreinforced pavement. Also, there was a reduction of the thickness of the base layer owing to from the inclusion of reinforcement geosynthetics by up to 40% of the unreinforced base thickness.
- There are cost savings attributed to use of the reinforcement geosynthetics of up to 55%, this was based on the cost of the geosynthetic materials relative to additional thickness of the base layer.

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