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Designing a Paved Road Using Geogrids to Reduce the Thickness of the Pavement Layers

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Abstract

Performance and durability of road pavements are significantly dependent on the strength and stability of the underlying soil layers, most especially the subgrade pavement layer. Currently, in Uganda most roads are constructed through low lying areas characterized by soft, hence weak, clay soils. The main practice, of improving the strength of such subgrade layers, has been to import stronger lateritic soils and dump them in layers over the weaker soils in thicknesses of more than 1.0 m. This is expensive, especially in terms of the haulage costs, and not environmentally friendly. Additionally, the lateritic soils are also getting depleted. Hence the need to utilize alternative means of increasing the strength of weak subgrades. This study focused on the application of Geogrids in pavement layers to reduce their overall thickness and life cycle costs of the road. A low-lying section on the Bajjo road, a bypass connecting Mukono to Seeta, was used as a case study. According to the AASHTO classification system of subgrade materials, the subgrade soils fell under the soil ranges of A-7, A-7-6, and A-6 group, therefore a poor subgrade material requiring stabilization. The average CBR was determined as 19%. The inclusion of the Geogrid reduced the overall layer works thickness by 25% and it’s cost effective by 42% over the whole lifecycle of the road.

Keywords: *Subgrade, Geogrids, Lateritic soils, Pavement thickness, Life cycle cost*

1 Introduction

Low volume roads, both paved and unpaved, usually serve as entrance or access roads to rural areas, towns and cities. They play an important role in rural economy, resource industries (forest, mining) and transportation to agricultural production areas. Constructing these roads on poor subgrade soils, usually leads to large deformations, which increase maintenance cost and interruption of traffic services. Leng (2002) states that, in general deterioration of unpaved and paved roads is faster than road replacement. Nonetheless, the increasing material, construction and maintenance costs make it important to explore alternative construction methods with longer service life, but at the same time remaining cost effective. Use of

Geosynthetics has been found to be a cost-effective alternative to improve poor sub-soils in adverse locations, especially in situations where there may be non-uniform quality or non-availability of desired soils with applications in almost all geotechnical engineering projects such as airport and highway pavements (Koerner, 2005). This study focused on utilizing biaxial Geogrids as reinforcement in pavement layer works.

2 Materials and Methods

2.1 Clay Soil

Samples of clay soil were obtained from Bajjo road, the project site, at depths between 0.5 m and 1.5 m. It was grey in color. Various laboratory classification and strength tests were carried out on clay specimens in accordance to BS1377, 1990. The results of these tests are shown in Table 1.

Table 1. Clay soil properties.

Soil property	Result
Color	Dark greyish
Liquid Limit (%)	33.3
Plastic Limit (%)	19.2
Plastic index (%)	14.1
Optimum Moisture Content (%)	14.2
Linear shrinkage (%)	7.1
Maximum Dry Density (g/cm^2)	1.699
California Bearing Ratio at 95% MDD (%)	19
Gravels (%)	0.5
Sand (%)	6
Fines (%)	93.5

The clay soil was classified as a fine grained lean clay of medium plasticity (CL) based on the Unified Soil Classification System. According to AASHTO classification system of subgrade materials (ASTM D 3282, 2004), the soil fell under the soil range A-7, A-7-6 and A-6 group hence a poor subgrade material that required stabilization. This was because the liquid limit and plastic limit exceeded the minimum values of 41% and 11% respectively. According to ETL1110-1-189 (2002, 2003), Geogrids can be applied to soils with CBR of 19% for reinforcing the base.

2.2 Lateritic Soil

Samples of lateritic soils were obtained from the Uganda Christian University borrow pit. It was reddish brown in color. Various laboratory classification and strength tests were carried out on lateritic soil specimens in accordance to BS1377, 1990. The results of these tests are shown in Table 2.

Table 2. Lateritic soil properties.

Soil property	Result
Color	Reddish brown
Liquid Limit (%)	37.5
Plastic Limit (%)	24.3
Plastic index (%)	13.2
Optimum Moisture Content (%)	14.3
Linear shrinkage (%)	6.4
Maximum Dry Density (g/cm^2)	1.994
California Bearing Ratio at 98% MDD (%)	61

The CBR value was found to be 61% satisfying the minimum base course CBR requirements according to TM 5-822-5 of 50%.

2.3 Geogrids

The specifications for the Geogrids were obtained from ETL 1110-1-189 (2003). It outlines the common engineering Geogrid properties with lower limits below which the Geogrids should not be used.

2.4 Traffic counts

Traffic counts, along Bajjo road, were carried out for seven consecutive days starting at 7:00 am to 10:00 pm at an interval of 15 minutes. The traffic was assembled into groups 1, 2, 3 from the lightest to the heaviest respectively according to TM 5-822-5. The traffic was projected for 25 years at a growth rate of 7% in accordance with UNRA (2008) and the design hourly volume (DHV) estimated, according to TM 5-822-2. Table 3 shows the obtained Average Daily Traffic (ADT).

Table 3. Average daily traffic.

Traffic Category	ADT
Boda	1087
Passenger cars	761
Mini buses	115
Small trucks	107
Medium buses	53
Coasters	24
Larger buses	10
Heavy trucks (2 axles)	16
Heavy trucks (3 axles)	2
Total	2175

The traffic was of category II and group 1 with 14.31% two-axle trucks in accordance to TM-5-822-5. An expression for projecting the traffic was obtained as shown in Equation 1.

$$DT = T * \frac{(1+0.07)^{25}-1}{0.07} = 63.249T \quad (1)$$

Table 4 indicates the projected traffic. The percentage of the heavy traffic was acquired from the projected values so that the design hourly volume could be obtained. Bajjo road is located in a flat terrain and open area. Total percentage of heavy traffic was 7.33%, with a total daily heavy traffic count of 5059. The design hourly volume (DHV) for roads can be estimated to be 15% of vehicles from ADT, (TM 5-822-2).

$$DHV = \frac{15*5059}{100*24} = 32 \tag{2}$$

Hence a road class of E as obtained from Table 5. In accordance with TM 5-822-2, for traffic category II and road class E the design index was 2, determined from Table 6.

Table 4. Traffic projections

Type of traffic	Current traffic	Unidirectional traffic (T)	DT = 63.249T	Group according to TM	% of total DT
Boda	1087	544	34408	1	49.91
Passenger cars	761	381	24098	1	34.95
Mini buses	115	58	3668	1	5.32
Small trucks	107	54	3415	2	4.95
Medium buses	53	27	1708	1	2.48
Coasters	24	12	759	2	1.10
Larger buses	10	5	316	2	0.46
Heavy trucks (2 axles)	16	8	506	3	0.73
Heavy trucks (3 axles)	2	1	63	3	0.09
Total	2175	1090	68941		100

Table 5. DHVs for different road classes (TM 5-822-2)

Class	Road	Street
A	>=900	>=1200
B	720-899	1000-1199
C	450-719	750-999
D	150-449	250-749
E	10-149	25-249
F	<10	<25

Table 6. Pavement Design Index (ETL 1110-1-189, 2003)

Traffic Category	**Pavement Design Index by Road/Street Class**					
	A	**B**	**C**	**D**	**E**	**F**
I	2	2	2	1	1	1
II	3	2	2	2	2	1
III	4	4	4	3	3	2
IV	5	5	5	4	4	3
IVA	6	6	6	5	5	4
V(60-kip tracked vehicles or 15-kip forklifts)	7	7	7	7	7	-
500/day	6	6	6	6	6	-
200/day	6	6	6	6	6	-
100/day	6	6	6	6	6	6
40/day	6	6	6	5	5	5
10/day	5	5	5	5	5	5
4/day	5	5	5	5	4	4
1/day	5	5	5	4	4	4
VI (90-kip tracked vehicles or 25-kip forklifts)						
200/day	9	9	9	9	9	-
100/day	8	8	8	8	8	8
40/day	7	7	7	7	7	7
10/day	6	6	6	6	6	6
4/day	6	6	6	6	6	6
1/day	5	5	5	5	5	5
1/week	5	5	5	4	4	4
VII (120-kip tracked vehicles)						
100/day	10	10	10	10	10	10
40/day	9	9	9	9	9	9
10/day	8	8	8	8	8	8
44/day	7	7	7	7	7	7
1/day	6	6	6	6	6	6
1/week	5	5	5	5	5	5

2.5 Design procedure

The following procedure was utilised in the design of the pavement layers:

- The California Bearing Ratio (CBR) value for the subgrade was determined and noted down. This was used to obtain the subgrade class.
- From the traffic counts Average Daily Traffic and Daily Hourly Vehicle values were calculated to get the traffic class.
- Figure 1 was used to get the thickness of the pavement.
- Table 7 was utilised to determine the minimum asphalt concrete (AC) thickness values for the surface. Final pavement structure is dependent on the minimum AC values.
- The geogrid-reinforced aggregate thickness (base) was taken from the equivalency chart, Figure 2. The reinforced aggregate thickness was determined by subtracting the minimum AC thickness from the equivalent reinforced aggregate thickness in the pavement design. Hence forming the reduced thickness and reinforced pavement layers.

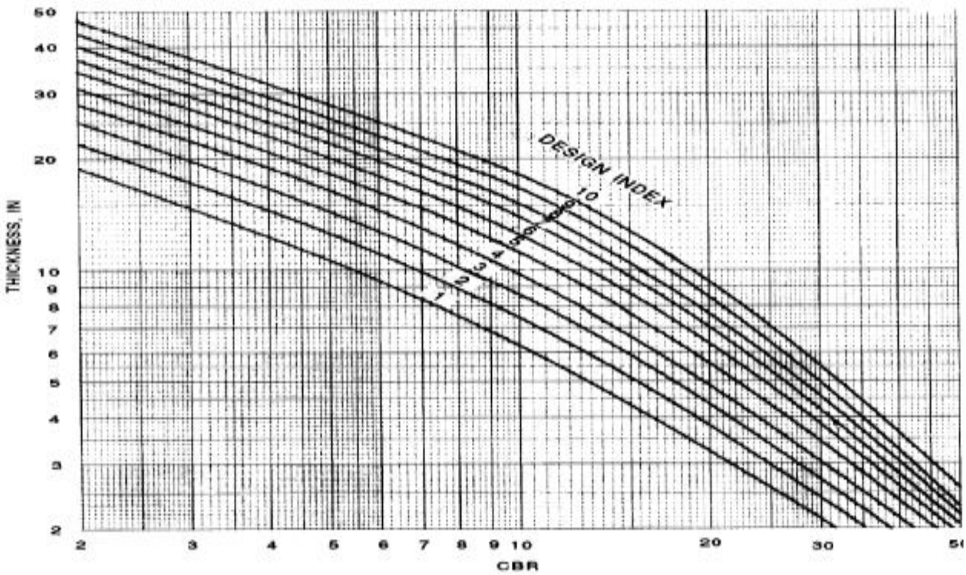

Figure 1. Flexible pavement design curves for roads and streets (TM 5-822-5).

2.6 Cost comparison

This was done by first assuming unreinforced pavement road and comparing it to the reinforced road with the Geogrid designed using the same materials covering same dimensions of both roads. Then the total materials cost used for the two roads were compared by way of estimating the volumes for the material used and the area of Geogrid used to cover the materials that fit in the dimensions and multiplying with unit costs of materials, to ascertain the cost effectiveness of the design. The service life was projected to 25 years. Maintenance cost was taken as a percentage of the initial cost.

Table 7. Minimum pavement layer thickness (TM 5-822-5/AFM 88-7)

Minimum Thickness of Pavement Layers (extracted from Table 6-1 of TM 5-822-5)[1]

	Minimum Base Course CBR								
	100			80			50[2]		
Design Index	Pavement (in.)	Base (in.)	Total (in.)	Pavement (in.)	Base (in.)	Total (in.)	Pavement (in.)	Base (in.)	Total (in.)
1	ST[3]	4	4.5[5]	MST[4]	4	4.5[5]	2	4	6
2	MST[4]	4	5[5]	1.5	4	5.5[5]	2.5	4	6.5
3	1.5	4	5.5[5]	1.5	4	5.5[5]	2.5	4	6.5
4	1.5	4	5.5[5]	2	4	6	3	4	7
5	2	4	6	2.5	4	6.5	3.5	4	7.5
6	2.5	4	6.5	3	4	7	4	4	8
7	2.5	4	6.5	3	4	7	4	4	8
8	3	4	7	3.5	4	7.5	4.5	4	8.5
9	3	4	7	3.5	4	7.5	4.5	4	8.5
10	3.5	4	7.5	4	4	8	5	4	9

[1] Table 6-1 extracted from TM 5-822-5, Chapter 6.
[2] In general, 50 CBR Base Courses are only used for road classes E and F.
[3] Bituminous surface treatment (spray application).
[4] Multiple bituminous surface treatments.
[5] Minimum total pavement thickness for road classes A through D is 6 inches.

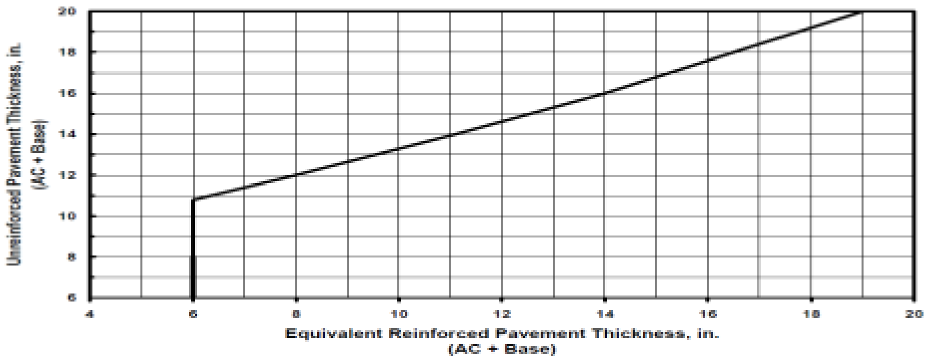

Figure 2. Webster's reinforced pavement thickness equivalency chart.
(ETL 1110-1-189, 2003)

3 Design of Pavement Layers

For the design subgrade CBR of 19 and the Design Index (DI) of 2, the total required pavement thickness was determined as 4in (101.6mm), Figure 1.

According to Table 7, for DI 2 and a road class E the minimum pavement thickness is 2.5in (63.5mm) and a base thickness of 4in (101.6mm). The minimum total thickness was taken to be 6.5in.

Additionally, the design index of 2 requires that a minimum thickness be 8in (203.2mm) at the CBR value of 95% MDD as indicated in Table 8. Consequently, the minimum total thickness was taken to be 8in.

Table 8. Depth of compaction for selected materials and subgrade.

Design index	Depth of compaction* for percent compaction shown, in.									
	Cohesive soils PI > 5; LL > 25					Cohesionless soils PI ≤ 5; LL ≤ 25				
	100	95	90	85	80	100	95	90	85	80
1	3	7	10	14	17	7	13	19	26	33
2	4	8	12	16	20	8	15	22	29	38
3	4	9	14	18	23	9	17	25	33	42
4	5	11	16	21	26	11	20	28	37	48
5	6	12	18	23	28	12	22	31	40	53
6	7	14	19	25	31	14	24	35	44	58
7	7	15	21	28	34	15	26	38	48	63
8	8	16	23	30	37	16	29	41	52	68
9	9	18	25	32	40	18	31	44	56	74
10	10	20	28	35	43	20	34	47	59	77

* Depth of compaction is measured from pavement surface.

From the Webster's design chart Figure 2, the minimum unreinforced thickness of 8in. gives an equivalent reinforced thickness of 6in (base plus AC) therefore the minimum AC thickness should be 4in. (101.6mm) and the aggregate thickness should be 2in. (50.8mm) Minimum, Figure 3.

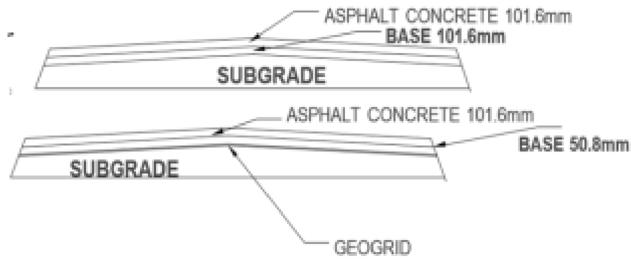

Figure 3. The geometric design of the pavement layers for both reinforced and unreinforced.

The camber used for the cross falls was 2.5%. This helps in attaining good drainage on the road surface. All other thicknesses remained the same apart from the reinforced base layer. The Geogrid is placed between the subgrade and the base interface for base thicknesses less than 14 inches and in the middle of the base layer for aggregate thicknesses greater than 14 inches.

4 Cost Comparison

The addition of Geogrids reduced the thickness of pavement by 2in, which is from 4in to 2in of the base material. This comparison was based on the difference in cost of the 2in. aggregate layer and the Geogrids. Both the reinforced and unreinforced pavements had 4in thickness of asphalt concrete layer. The comparison was done based on a 1km long, 6m wide and 2in (50.8mm) thick road.

The cost of lateritic soil per truck was determined at 40,000 Ugandan shillings (/=) of Tipping truck of 3.5m length x 2.0m wide x 0.5m deep, and cost of Geogrid as US \$0.50/m^2

4.1 Unreinforced road

Take a 1km section of a 6m wide road, 4in thick section without Geogrids.

$$V = L * W * H$$
$$V_{un} = 1000x6x4x2.54x10^{-2} = 609.6m^3 \quad (3)$$

Where: V_{un} is the volume of the unreinforced pavement considering the base only

Volume of 1 truck is equal to

$$V_t = 3.5x2x0.5 = 3.5m^3 \quad (4)$$

Where: V_t is the volume of a truck

So cost of $1m^3$ is equal to:

Cost = 40000/3.5 = 1429/= (5)

Therefore: 609.6m3 cost (initial construction cost)
= 609.6x11429 = 6,967,118/= (6)

4.2 Reinforced road

Take a 1km section of a 6m wide road, 2in thick section with Geogrids between the base and subgrade.

$V_r = 1000x6x2x2.54x10^{-2} = 304.8m^3$ (7)

Where V_r is the volume of the reinforced road.

So using $V_t = 10.404m^3$ and cost of a truck 40,000/=
Cost of $1m^3$ = 11429/=
Therefore initial cost of $304.8m^3$ will be
= 304.8x11429 = 3,483,559/= (8)

Then add the cost of the Geogrids
$1m^2$ = \$0.5 (https://www.alibaba.com)
1\$ = 3,500/= from (http://www.xe.com)
So $1m^2$ = 0.5x3500 = 1750/=
Required Geogrid area
= 1000x6 = $6000m^2$
Considering an overlap of 1ft = 0.3048m for CBR >4% (ETL 1110-1-189 2003)
= $0.3048x1000m^2 = 304.8m^2$
Giving a total of $6304.8m^2$
Total cost of required Geogrid is
= 6,304.8x1750 =11,033,400/=
The estimated (shipping + transportation cost) = 5,000,000/= (9)

Therefore total initial construction cost
= 5000000+11,033,400+3483559 =19,516,959/= (10)

This shows clearly that initial construction cost using the Geogrid layer was higher than constructing without, after deducting the 2in thickness of the aggregate layer. Initial percentage cost increase due to reinforcement

$$= \frac{19{,}516{,}959 - 6967118}{6967118} * 100$$
$$= \mathbf{180\%} \quad (11)$$

4.3 Maintenance comparison

Geogrids are said to outlast the life of the road, (Meyer & Elias, 1999), implying that the Geogrids, if not intentionally damaged will always perform their functions for as long as the road exists. This reduces the need for frequent maintenance and rehabilitation activities. On the other hand, maintenance operations for the unreinforced road must be more frequent to avoid quick degeneration of the road. Therefore refilling and resurfacing will cost more on the unreinforced road.

Unreinforced road
Total initial cost was 6,967,118/=
Maintenance cost was said to be 50% of the initial cost after every three year. (UNRA, 2008)

$$= \frac{50}{100} * 6{,}967{,}118 = 3{,}483{,}559/= \quad (12)$$

The life cycle of the road was projected to 25years minus the year of commissioning or opening the road. So total maintenance cost will be:

$$= 3483559\text{x } (25/3) = 29{,}029{,}658/= \quad (13)$$

Total cost after 25 years

$$= 29{,}029{,}658+6{,}967{,}118 = 35{,}996{,}776/= \quad (14)$$

Reinforced road
Total initial cost was equal to 1,171,956/=)
Maintenance cost was said to be 5% of the initial cost after every three years.

$$= 5/100\text{x}3483559 = 174178/= \quad (15)$$

The life cycle of the road was projected to 25years minus the year of commissioning or opening the road. So total maintenance cost will be:

$$= 174178\text{x}25/3 = 1{,}451{,}483/= \quad (16)$$

Total cost after the 25years for the reinforced pavement was

$$= 1{,}451{,}483+19{,}516{,}959 = 20{,}968{,}442/= \quad (17)$$

The total percentage reduction in cost of reinforced over unreinforced after the 25years.

$$= \frac{35{,}996{,}776-20{,}968{,}442}{35{,}996{,}776} * 100$$
$$\underline{= \mathbf{42\%}} \quad (18)$$

Therefore, the initial cost of constructing with Geogrids for reinforcement was greater by 180% and the reinforced design is more cost effective over the unreinforced by 42% over the 25years.

5 Conclusion

From the cost analysis comparisons, it was found out that reinforcing the road reduces the total cost over the life of the road. Reinforcing using Geogrid was cost effective by 42% over the unreinforced pavement. However, the initial cost of reinforcing using Geogrids was greater by 180%.

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