12 UTILISING BITUMEN STABILIZED MATERIAL AND A TRIAXIAL GEOGRID IN THE REHABILITATION OF A BUSY URBAN ARTERIAL

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ABSTRACT

The rehabilitation of a 1.5 km length of dual carriageway in McGregor Street in Bloemfontein was carried out by incorporating a triaxial geogrid beneath a bitumen stabilized base (BSM). The existing pavement was severely distressed requiring strengthening of the existing pavement layers. The traditional pavement design solution would require a layerworks depth of 700 mm and thereby relocation of the numerous existing services located at a shallower depth. The road is located in a built-up area with the existing drainage system, sidewalks and levels of the accesses to adjacent private properties fixed. This meant that the pavement could also not be strengthened by raising the road surface level. There was also a need to minimize traffic disruptions as Macgregor Street is a busy arterial carrying approximately 10 000 vehicles per day.

A shallow pavement design was required that would be quick to construct and yet provide the required pavement strength. An investigation was made into a technology that uses a triangular aperture geogrid that significantly reduces the pavement thickness required to provide equivalent performance. Typically, the existing pavement is excavated to a shallow depth to install the Geogrid, followed by a granular stabilized or unstabilised base and surfacing.

The materials design for the BSM layer was to also take cognizance of the reuse of all the materials from the existing upper pavement layers which reduced the cost of importing new construction materials. The upper pavement layers were selectively milled to a depth of 250 mm and stockpiled separately. The optimum mix proportion for the BSM layer was determined through laboratory tests for varying proportions of material from each stockpile together with imported crushed stone material which was limited to only 10%.

INTRODUCTION

Historical Development

A geogrid is defined as a polymeric (i.e., geosynthetic) material consisting of connected parallel sets of ribs with apertures of sufficient size to allow the passing through of well graded granular material. Their primary functions are mechanical stabilization and separation. Mechanical stabilization refers to the mechanism by which the engineering properties of the composite soil/aggregate are mechanically improved. Separation refers to the physical isolation of dissimilar materials - say, dump rock and granular fill material - such that they do not mix.

Historically speaking, in the 1950's Dr Brian Mercer (1927-1998) developed the Netlon® process in which plastics are extruded into a net-like process in a single stage. Based on Dr Mercer's further innovative research and development work on extruded net technology, some polymer straps and strips were formed into grid-like products during the 1970's, but the first integral geogrids were developed in the late 1970's and first employed in various applications in the early 1980's. In the early stages of the development of geogrid several universities in the UK, namely Leeds, Nottingham, Oxford, Sheffield and Strathclyde, were heavily involved in a comprehensive program of research that examined the polymer technology.

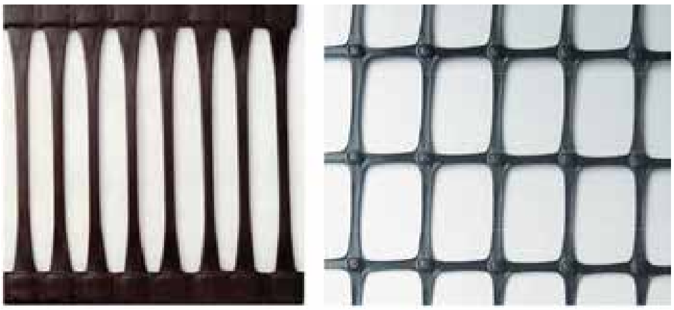

FIGURE 1. Extruded uniaxial (left) and biaxial geogrid (right)

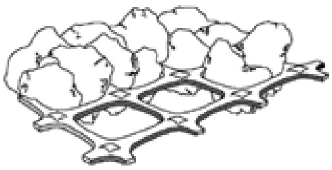

FIGURE 2. Interlock mechanism

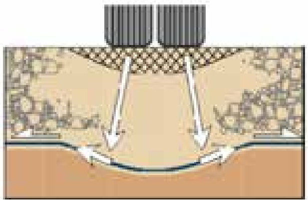

FIGURE 3. Tensioned membrane mechanism

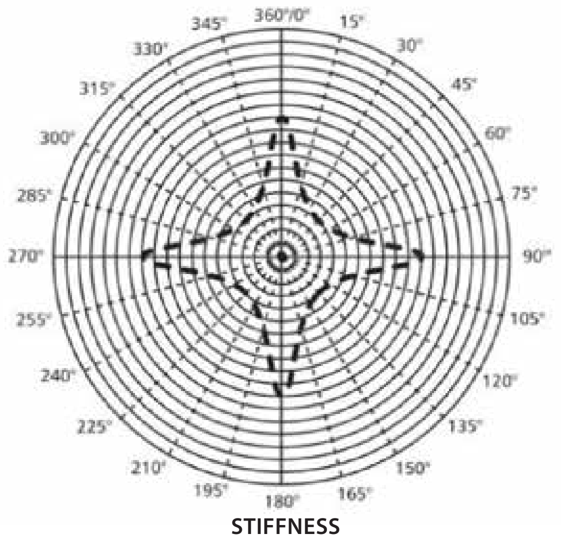

FIGURE 4. Polar diagram showing the stiffness footprint of a biaxial geogrid.

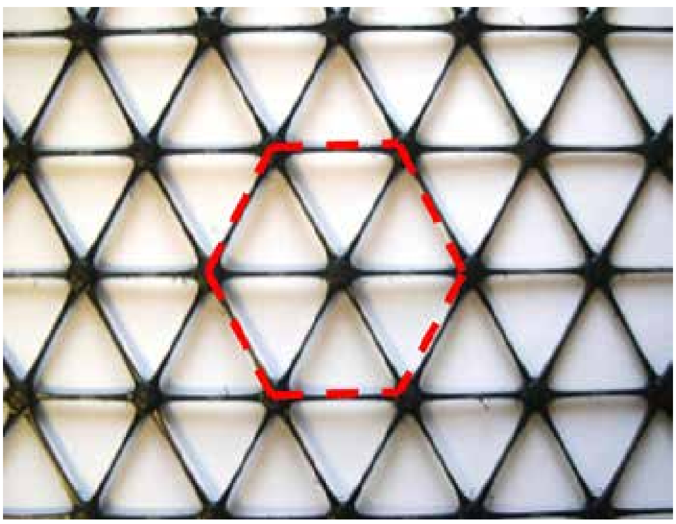

FIGURE 5. A geogrid with triangular apertures

The initial extruded geogrids were of two types - Uniaxial and Biaxial (Figure 1). They were formed using a thick sheet of polyethylene or polypropylene that was punched and drawn to create apertures to enhance engineering properties of the resulting ribs and nodes. Uniaxial extruded geogrids were manufactured by stretching a punched sheet of high-density polyethylene in only one direction. This process resulted in a product with high one-directional tensile strength and modulus. Biaxial geogrids were manufactured by stretching the punched sheet of polypropylene in two orthogonal directions. This process resulted in a product with monolithic rigid junctions and stiff deep ribs in two perpendicular directions. The resulting grid apertures were either square or rectangular.

Mechanical interlock is vital for the performance of any geogrid in mechanical stabilization. It is a typical property of geogrids, occurring when well graded granular material is compacted on top of a geogrid, letting the coarser particles to partially project through the geogrid's apertures to lock them into place (Figure 2). The mechanical interlock and the resulting lateral restraint of the granular layer assembly explains the performance provided by extruded geogrids compared to geotextiles and other geogrids. On the interlock between the geogrid and aggregate particles, the study by Jewell et al. (1984) identified early on the important mechanisms of soil and geogrid interactions through the use of large shear box testing. The research findings of Jewell et al. therefore laid down the foundation for understanding the fundamental mechanisms by which geogrids improve pavement systems by entertaining the idea of choosing the type of geogrid for the intended aggregate particle sizes and gradation.

The other mechanism which has been considered is the tensioned membrane where the geosynthetic material is deformed by channelized traffic so that it develops its tensile strength to act as a membrane supporting the aggregate layer. If the traffic is channelized and the material is anchored to each side of the loaded path then this mechanism could be mobilized for reinforcement but it requires large deformations to develop the necessary strength and resistance (Figure 3). Hence, interlock is the critical mechanism for efficient stabilisation.

Recent Innovations

For some 25 years, this form of geogrid, characterised by a monolithic structure, (i.e. made from a single sheet) with integral junctions and molecularly oriented ribs developed only marginally. The stiffness of the geogrid was organised around the orthogonal longitudinal and transverse directions. A polar diagram of the tensile stiffness at low strain for a biaxial geogrid, Figure 4, shows how the stiffness is strongly aligned along the rib directions.

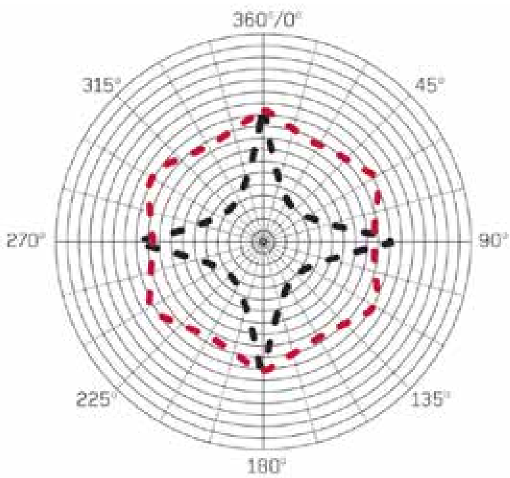

FIGURE 6. Polar plot for a triangular monolithic geogrid

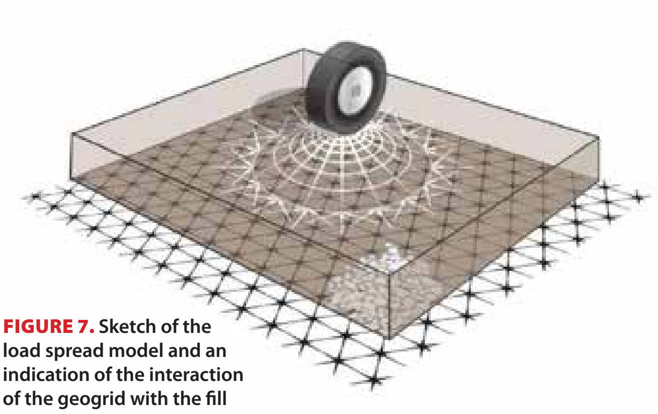

FIGURE 7. Sketch of the load spread model and an indication of the interaction of the geogrid with the fill

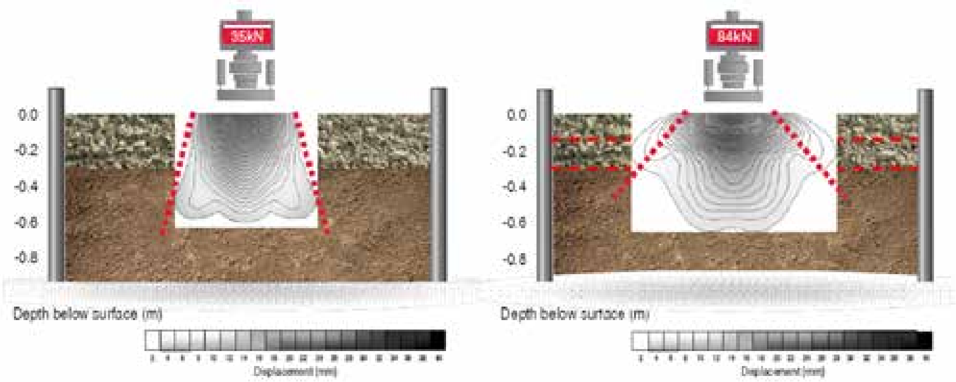

FIGURE 8. Load distribution:
Left - unstabilised fill, Right – mechanically stabilised fill with two layers of geogrid

The logical conclusion from this cruciform shape is that the biaxial form of geogrid is some way short of the more circular optimum polar shape. This propelled research into a geogrid of such a form that the performance is similar in all directions of travel and the orientation of the geogrid placement is independent of traffic. With a geogrid that has an aperture shape of a triangle, Figure 5, rather than a rectangle, there was a prospect that performance under trafficking could be improved. Adjacent triangles form hexagons which overlap to track the rolling wheel loads applied to the road surface. The resulting polar plot, Figure 6, provided an improvement in the trafficking characteristics.

Performance Testing

The geogrid form with triangular apertures offered an improved performance under the rolling wheel of traffic loading. The instantaneous loading will have the appearance as sketched in Figure 7 radiating out from the contact point.

The radial load spread is being counter-acted by a multitude of geogrid rib directions at the bottom of the layer. Therefore, this loading 'snapshot' was investigated at the Building Research Establishment (UK), Watts & Jenner (2008). With the use of pressure cells in the foundation soil and deflection monitors, it was possible to create the 'load distribution' model, Figure 8. Contour lines of equal vertical displacement have been plotted through the fill (mechanically stabilized or unstabilised base) and into the foundation soil (subgrade), thereby indicating the pressure distribution from the load plate, to the base of the fill and then into the foundation soil.

The left diagram shows the relatively narrow angle, to the vertical, of the load distribution and the potential for a punching type of bearing capacity failure. The right diagram shows a significantly increased load spread from a fill with its two geogrid layers. The displacement contours in the mechanically stabilised fill is much concentrated in the fill layer, indicating that the structural performance is more concentrated in the mechanically stabilised fill and, accordingly, the foundation soil is contributing less to the support of the load. Scanning across the geogrid level, the distribution of displacement is plotted, Figure 9. The implication is that this plot is also representative of a pressure distribution from an elastic response.

Deductions that can be made from this plot of vertical displacement against the distance from the centre of load are:

- The pressure under the centre of the load was reduced by approximately 60% due to the conversion of the fill layer to a more stiff mechanically stabilised layer
- A similar effect was seen at the edge of the plate
- The influence of load increased the spread from a 600 mm diameter footprint to approximately 900 mm

The quality of interlock is a variable and the geogrid geometry is one of the defining features. There is an optimal relationship between aperture size; rib depth and the granular particle size. When addressing extension of pavement life, it is necessary to consider the Traffic Benefit Ratio (TBR). TBR is defined as the ratio of load repetitions-to-failure in a geogrid stabilised section compared with an unstabilised section of the same thickness. As indicated in independent, full-scale testing conducted by a number of research entities, the TBR varies significantly with different geogrids. Once the TBR has been determined for a specific geogrid, it can be multiplied by the design Equivalent Single Axle Load's (ESAL's) for an unstabilised pavement section to determine the performance of that section when a geogrid is included. Alternatively, geogrids can reduce the base thickness required to support a specified amount of ESAL's. The reduction in base thickness also varies significantly with different geogrids and material properties from 25% to 100%.

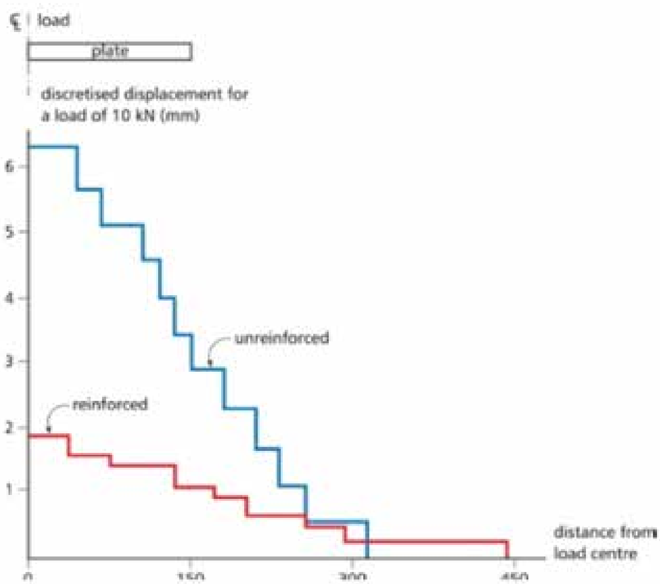

FIGURE 9. Interpretation of load distribution for stabilised and unstabilised fill

FIGURE 10. Dual Carriageway

FIGURE 11. Distressed Pavement

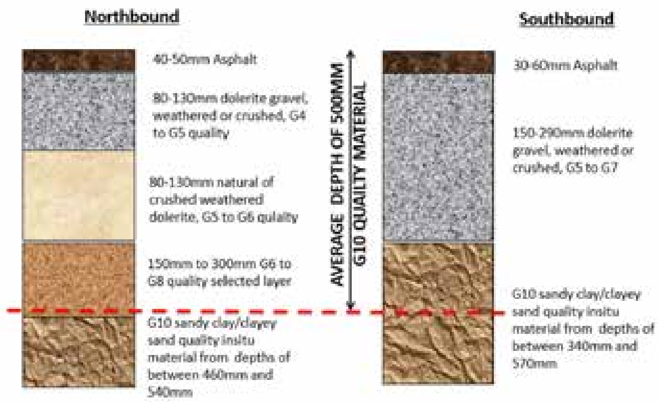

FIGURE 12. Summarized test pit profiles

MCGREGOR STREET REHABILIATION DESIGN

Project Information

McGregor Street, in Bloemfontein, was showing signs of severe pavement distress (Figure 11). In December 2013, the Manguang Metropolitan Municipality undertook a programme to examine and propose rehabilitation options for McGregor Street.

McGregor Street extends north from the intersection with Dr Belcher Road to the National Road N8. It is a dual carriageway urban arterial, 2 lanes in each direction, with asphalt surfacing and a median island which consists of block paving (Figure 10).

The length of McGregor Street is 1.5 km and the project includes slip lanes onto the N8 and Dr Belcher Road, as well as at the intersection of McGregor Street with McKenzie Street. Shallow services and utilities were located under the existing asphalt pavement which would need to be relocated or protected when using a traditional pavement design solution. The existing kerb levels and accesses to properties were fixed so the proposed rehabilitation solution also needed to maintain the existing finished road level. The road is also located in a built-up and highly populated city centre and thereby a need to minimise traffic and pedestrian disruption and environmental hazards such as noise, dust, construction traffic and emissions.

Non-Intrusive Investigations

Non-intrusive testing was carried out on McGregor Street which included visual assessments, profile measurements, deflection measurements and DCP probes as outlined in TRH12. A summary of the results are tabulated in Tables 1, 2 and 3.

Intrusive Investigations

Twelve (12) test pits were excavated to a depth of 1 m over the length of the carriageways and slip lanes. The test pit profiles are summarized and annotated in Figure 12.

TABLE 1. Summary of Rut Depth Measurements

Carriageway	Lane	Sound <10 mm	Warning 10-20 mm	Severe >20 mm
Northbound	Fast		14.2	
	Slow			21.0
Southbound	Fast		11.5	
	Slow			26.2

TABLE 2. Summary of Deflection Parameter Ratings

Data	90th Percentile (microns)		Structural Condition Rating		
	Northbound C/way	Southbound C/way	Sound	Warning	Severe
Y Max	1055	775	<200	200 - 400	>400
BLI	460	380	<100	100 - 300	>300
MLI	375	280	<50	50 - 100	>100
LLI	115	97	<40	40 - 80	>80

TABLE 3. Summary of IRI Measurements

Carriageway	Lane	Sound <3.5	Warning 3.5-4.2	Severe >4.2
Northbound	Fast			6.7
	Slow			6.6
Southbound	Fast			5.8
	Slow			6.0

TABLE 4. Station 1 - McKenzie St to N8 (Northern Section)

Northbound C/way		Estimated E80s for a 20 yr design life			
		E80/Heavy	1.0	1.8	2.5
ADT = 8353 ADTT = 707 (8.5%)	Growth Rate (%)	2	6 422 642	11 560 755	16 056 605
		4	8 025 725	14 446 305	20 064 313
		6	10 105 036	18 189 065	25 262 591
Southbound C/way					
		E80/Heavy	1.0	1.8	2.5
ADT = 9629 ADTT = 866 (9%)	Growth Rate (%)	2	7 839 277	14 110 698	19 598 192
		4	9 795 950	17 632 710	24 489 876
		6	12 333 893	22 201 007	30 834 732

TABLE 5. Station 2 - Dr Belcher Street to McKenzie Street (Southern Section)

Northbound C/way		Estimated E80s for a 20 yr design life			
		E80/Heavy	1.0	1.8	2.5
ADT = 10112 ADTT = 419 (4.1%)	Growth Rate (%)	2	3 750 362	6 750 652	9 375 906
		4	4 686 448	8 435 606	11 716 120
		6	5 900 616	10 621 110	14 751 541
Southbound C/way					
		E80/Heavy	1.0	1.8	2.5
ADT = 10204 ADTT = 351 (3.4%)	Growth Rate (%)	2	3 138 352	5 649 034	7 845 880
		4	3 921 681	7 059 025	9 804 202
		6	4 937 713	8 887 883	12 344 282

Residual Life of the Existing Pavement

The existing pavement structure was evaluated in terms of the South African Mechanistic Design Method using deflections and typical test pit data. The various models used in this analysis all show that the existing pavement on both carriageways has a very short life of between 0.2 million E80s and 0.7 million E80s. This equates to approximately 1 to 2¼ years.

Selection of an Appropriate Pavement

Five (5) traditional rehabilitation alternatives were considered. Each of these alternatives were tested against the site conditions and reported in Table 6. From Table 6 it is noted that none of the alternatives are able to satisfy all the site conditions.

A. Deep insitu recycling & cement stabilization followed by a new base and surfacing
B. Recycling of the surfacing and base & stabilization with bitumen (BSM) followed by a new surfacing
C. Continuously Reinforced Concrete Pavement (CRCP)
D. Reconstruct the pavement using the existing pavement as a subgrade
E. Reconstruct the pavement by removing all the existing layerworks

Traffic Estimation

Traffic counts were carried out on each carriageway in March 2014, using count stations at two locations. A sensitivity analysis was carried out using the ADT (average daily traffic) and considering the ADTT (average daily truck traffic) in each direction, for each counting station. The analysis was done for a 20 year design period. The data in Table 4 (Station 1) and Table 5 (Station 2) summarises the outcomes of the sensitivity analysis.

As would be expected from the difference in the percentage of heavies found in the counts from the two traffic count stations, the sensitivity analysis also shows a shift in the design traffic. The Design traffic between the N8 and McKenzie Street falls into the ES30 Traffic Class, while the Design Traffic between McKenzie Street and Dr Belcher Street falls within the ES10 Traffic Class. Taking into account that the length of McGregor Street between McKenzie Street and Dr Belcher Road is only 600 m, it was prudent to use an ES30 pavement design (17 million E80s) based on TRH 4 recommendation for the full length of McGregor Street.

Alternative Pavement Design: Mechanically Stabilized Layer (MSL)

An investigation was made into a technology that uses a geogrid that significantly reduces the pavement thickness. Typically the existing pavement is excavated to a shallow depth to install the geogrid, followed by a granular base and surfacing. Recent innovations in geogrids pointed towards using a triaxial geogrid. The numerous turning movements anticipated at the intersections and accesses to business necessitated a geogrid where the performance is similar in all directions of travel or the orientation of geogrid placement was independent of traffic.

Furthermore, the supplier of the triaxial geogrid has undertaken extensive trafficking trials to gather knowledge about how geogrids perform. Material properties for the MSL for a matrix of different material types and geogrid aperture size and rib depths have been derived from rigorous analysis and interpretation of a large body of performance data that has been obtained from large scale testing validated against 25 years of real project performance.

TABLE 6. Traditional Rehabilitation Alternatives

Conditions to Satisfy	Alternatives				
	A	B	C	D	E
ES30 Design traffic	✓	×	✓	✓	✓
Poor quality materials (G10) located on average 500 mm below existing surface level	×	✓	✓	✓	✓
Lane closures must be minimized for as short a time as possible	×	✓	×	✓	×
On street parking, sidewalks and adjacent private properties levels to be maintained	✓	✓	✓	×	✓
Numerous utility services located 600 - 1 000 mm below existing surface level	×	✓	×	✓	×

FIGURE 13. TRL Performance testing

The properties of the MSL have been determined by back analysis of the data obtained from test sections using the AASHTO Flexible Pavement Structural Design (1993) predictive model. These properties have been incorporated into the supplier's pavement design software used for the design of the mechanical stabilized layer (MSL). The software retains the use of the AASHTO 93 Method or STRUCTURAL NUMBER METHOD. This research and design methodology has been independently reviewed and validated.

Structural Number Method

This empirical pavement design method was developed in the USA in the 1960s. Initially for one site; but gradually improved to accommodate other conditions through the publications of AASHTO 72; 86 and 93 resulting in the formula below

$$\log_{10}(W_{18}) = Z_R S_o + 9.36\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40+\frac{1094}{(SN+1)^{5.19}}} + 2.32\log_{10} M_R - 8.07$$

The SN = Structural Number is indicative of the individual layer materials, thickness and drainage conditions.

$$SN = a_1 D_1 + a_2 D_2 M_2 + a_3 D_3 M_3$$

Where,

a = layer coefficient that depends on the material type (i.e. crushed stone; asphalt; BSM; etc)

D = layer thickness

M = drainage coefficient

1, 2 and 3 denote the Surfacing, Base and Subbase layers respectively;

This formula has been modified for Mechanically Stabilized Layers by incorporating a Layer Coefficient Ratio (LCR).

$$SN = a_1 D_1 + LCR\, a_2 D_2 m_2 + a_3 D_3 m_3$$

LCRs are dynamic factors that vary depending on AC thickness; aggregate thickness; aggregate quality; subgrade resilient modulus; moisture, traffic, etc. These factors were derived from the full scale trafficking trials and are embedded in the supplier's pavement design software.

Pavement Design Incorporating the MSL

The design criteria for the Mechanically Stabilized Layer are shown in Table 7.

TABLE 7. Requirements for MSL

Maximum thickness	200 mm - 300 mm (say 250 mm)
Design traffic	17 million E80s
Insitu subgrade	G7 quality located at 250 mm below the existing road level

The base materials considered for mechanical stabilization are shown in Table 8 with the associated pros and cons. A bitumen stabilized base (BSM) appears to be the only alternative that meets the design criteria.

TABLE 8. Alternative Base Material

Asphalt	HMA cannot be placed directly on the geogrid
Cement Treated base	Risk of reflective cracking
Crushed stone	Unlikely to meet strength required
Bituminous stabilized base (BSM)	Most appropriate

The pavement was analysed using the supplier's software and the following pavement structure was recommended for the rehabilitation of McGregor Street:

- 40 mm asphalt surfacing with modified binder
- 250 mm thick BSM
- Triaxial Geogrid
- Insitu G7 roadbed material

Materials Design

The materials design for the BSM layer also takes cognizance of the reuse of all the materials from the existing upper pavement layers which reduces the cost of importing new construction materials. The upper pavement layers were selectively milled to a depth of 250 mm and stockpiled separately. The optimum mix proportion for the BSM layer was determined through laboratory tests for varying proportions of material from each stockpile together with imported crushed stone material which was limited to only 10%.

Since geogrids are installed on the subgrade with the base placed over it, construction of the BSM layer through in-situ recycling and stabilization was not possible. The BSM layer would have to be mixed in-plant and then paver laid over the geogrid. Under these circumstances, BSM-Foam was most appropriate due to the availability of a high quality mobile mixing plant and the fact that BSM-Foam can also be left in stockpile for up to 3-5 days before placing.

Due to the heavy traffic loading a BSM 1 was specified with mixing proportions as below:

- Reclaimed asphalt surfacing 30%
- Milled crushed stone base 20%
- Milled gravel subbase 40%
- Imported crushed stone 10%
- Cement 1%
- Bitumen (50/70 pen) 2.2%

Construction Sequence

The rehabilitation of McGregor Street was completed over a construction period of approximately 3 months thereby minimizing disruption to traffic. Figures 14 to 20 annotate the construction sequencing for McGregor Street rehabilitation. After one year of trafficking the surfacing is showing no signs of distress (Figure 21).

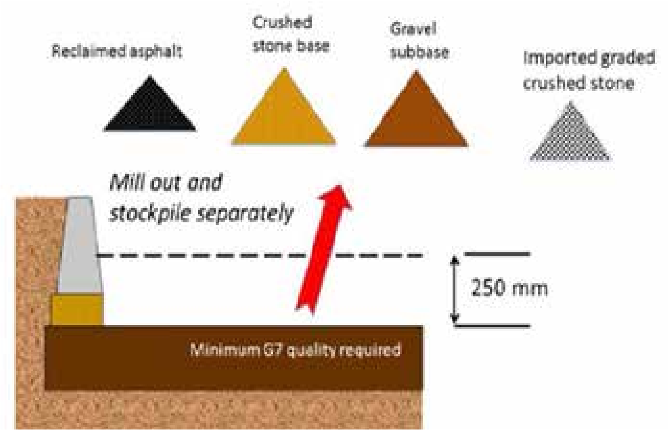

FIGURE 14. Milling

FIGURE 15. Stockpiling

FIGURE 16. In Plant Recycling of the BSM

FIGURE 17. Installation of the Triaxial Geogrid

FIGURE 18. Paving of the BSM

FIGURE 19. Compaction of the BSM

FIGURE 20. Surfacing on Completion (2016)

FIGURE 21. Riding quality after one (1) year (2017)

CONCLUSIONS

This paper provides a brief historical background of the development of geogrids over the last 30 years. It also explains the mechanism by which the engineering properties of the composite soil/aggregate are mechanically improved by the installation of a geogrid beneath a base or subbase layer. Of significance is that the quality of interlock is a variable and the geogrid geometry is one of the defining features. There is an optimal relationship between aperture size; rib depth and the fill size.

The paper further examines the research and performance testing required to develop the Traffic Benefit Ratio (TBR) to quantify the extended pavement life and the Layer Coefficient Ratio (LCR) to quantify the reduction in pavement layer thickness for any given base type and geogrid aperture shape, aperture size and rib depth.

The rehabilitation of McGregor Street in Bloemfontein is a case study which successfully demonstrates the benefit of using a triaxial geogrid to mitigate against relocation of services or a change to the final road surface level without compromising the pavement strength. This resulted in an extremely short construction period with minimal disruption to traffic. This case study also establishes that the use of geogrids will not compromise recent trends in road construction that take cognizance of the reuse of all the materials from the existing upper pavement layers which reduces the cost of importing new construction materials.

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