GIGSA GeoAfrica 2009 Conference
Cape Town 2 - 5 September 2009

Geosynthetic Reinforcement for the Rehabilitation Works of Airport Taxiways and Parking Areas

D.P. Lange. Technical Department, Maccaferri Southern Africa, des.lange@maccaferri.co.za
M. Vicari. Research and Development, Maccaferri Head Office, Italy, marco.vicari@maccaferri.com
R. Rambinintsoa. Madagascar Branch, Maccaferri Southern Africa, maccaferri@moov.mg

ABSTRACT
The design and construction of pavements for roads and airfields over relatively soft soil foundations produce interesting engineering challenges. Experience by Maccaferri using geosynthetic reinforcement in the pavement, has shown that the extensive concentrated loads on the surface are more readily restrained by this method and the overall thickness of the structure is also significantly reduced. These concepts are demonstrated on a project on the Ivato International Airport in Madagascar, where a new parking area and taxiways were required. A conventional design produced a pavement structure with a total depth of 1200 mm which included a 100 mm thick asphaltic wearing course. An alternative design by Maccaferri was accepted which reduced the overall thickness of the pavement to 880 mm. This paper presents details of the main technical aspects relevant to this design.

1. INTRODUCTION

1.1 The Wearing Course as a Primary Component of a Flexible Pavement

The primary component of a flexible pavement constructed for use as a road, highway or airport runway is the asphaltic concrete or hot mix asphalt (HMA) wearing course. The asphalt consisting mainly of bituminous bound fine stone aggregate and sand filler. This, the most critical layer in the pavement structure, can vary from 25 mm to 150 mm in thickness depending on the application and the wheel or traffic loads to be carried. In the case of rehabilitation of an existing pavement or planned preventative maintenance, it is sometimes necessary only to prepare the surface and place a thin HMA overlay of 25 to 50 mm in order to extend the working life of the structure. New pavements or existing ones requiring more extensive repairs will be treated with HMA layers of greater thickness. The thickness and quality of this layer are major driving forces in the overall cost of the pavement. As a result of this fact, solutions using thin surface layers for the design of new pavements or the repair of existing ones are the most desirable.

The primary functions taken into account for the design and construction of the wearing course are: protection of the existing surface against water intrusion, reduction of roughness on the riding surface, restoration of skid resistance, increase of the structural capacity, and improvement of the overall ride quality.

1.2 Problems Associated with the use of Thin Overlays

One of the more serious problems associated with the use of thin overlays is reflective cracking. This phenomenon is commonly defined as the propagation of cracks from the movement of the underlying pavement or base course into and through the new overlay as a result of load-induced and/or temperature induced stresses. Increasing traffic loads, soft foundation soil, inclement weather, and insufficient maintenance funding compound this problem and inhibit the serviceable life of these pavements in most cases. (Cleveland et al., 2002)

1.3 The Need to Search for Less Costly Alternatives

The bituminous binder used in the asphalt overlay is produced during the refining process of crude oil. As the world demand for oil continues to increase (USDOE, 2000) the costs associated with constructing and maintaining flexible pavements will also undoubtedly continue to increase. These factors decrease the useful life of HMA overlays and/or increase the need for cost-effective preventive maintenance techniques.

1.4 The Role of Other Layers in the Pavement

The main purpose in the design of the thickness and strength of both the base and sub base layers, which are situated between the wearing course, and the subgrade, or foundation layer, is to intercept and evenly distribute the stresses induced by the wheel loads on the surface. Figure 1 below provides an illustration of this mechanism.

In the process of carrying out the structural design of the pavement beginning with the HMA layer at the surface, the thickness of each layer in the pavement is adjusted to find the optimal cross section in terms of a balanced and cost-effective solution. The ideal design will produce a cross section which requires the thinnest HMA layer possible, but often necessitating a relatively thick base and sub base.

Due to its flexible nature the pavement structure deflects under the repetitive wheel loading during its design life. The lower layers, which are the least resilient, may eventually go into a state of permanent deformation, especially in situations where the subgrade is weak or subsurface water is permitted to infiltrate the structural layers, either from above or below. Cavities form beneath the wearing course thus reducing the required support for this layer. Lytton (1989) defined a system of stress pulses which led to cracking first at the underside of the HMA which eventually propogated upwards towards the top of the pavement structure, leading to the formation of reflective cracking clearly visible at the surface.

McLaughlin (1979) carried out a study to determine the minimum thickness of surface overlays for airport pavements to avoid the development of reflective cracking.

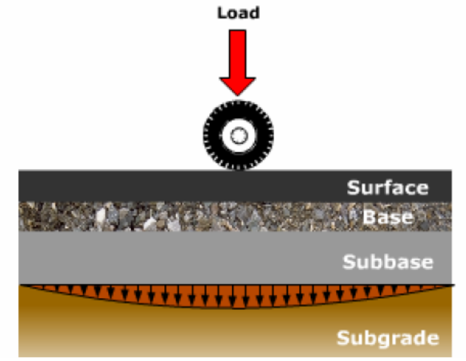


Figure 1. Flexible Pavement Load Distribution

2. GEOSYNTHETIC MATERIALS IN FLEXIBLE PAVEMENTS

The previous section illustrates how traditional pavement design and construction practices require high quality materials and carefully designed layer thicknesses, in order to achieve appropriate construction standards. High quality materials required for these designs are becoming increasingly scarce. Pavement design engineers are hence forced to seek alternative designs using substandard materials, viable construction aids, and innovative design practices.

2.1 The Primary Functions of Geosynthetics in Pavement Design

One category of construction aids that has proved to be successful is the inclusion of geosynthetic materials in the pavement layers. Geosynthetics include a large variety of products composed of polymers which are designed to enhance the integrity of engineering works in the wide range of geotechnical, hydraulic, erosion control and transportation technologies. In their role as engineering products geosynthetics perform at least one of five functions in specific applications as follows: separation, reinforcement, filtration, drainage, or containment. Geogrids and geotextiles used within a pavement system perform two of these primary functions, which are: separation and reinforcement.

2.2 Geogrids used for Reinforcement Applications

Due to the relatively large aperture sizes associated with most geogrid products, geogrids are typically used for reinforcement as they contribute to the mechanical improvement of the engineering properties of the pavement system. Grids or geogrids are typically constructed of high-modulus filaments of glass fibers or drawn polymers such as polyester or polypropylene. This material generally has moduli which are much higher than that of the asphalt premix in the HMA at normal service temperatures. These grids are designed to decrease stresses in the new overlay so that reflective cracking will be reduced and caused to develop more slowly. Kennepohl et al., (1985) recommended that appropriate design principles would allow the mobilization of the tensile strength characteristics of the grid in order to limit the deformation of the pavement.

2.3 The Use of Geocomposites

In certain applications where a geogrid is used in conjunction with a bituminous material, a composite material is formed as the geogrid becomes integrated with the bituminous layer. In these cases, the term geocomposite is often used. The materials used to form these geocomposite solutions helped overcome the earlier problems caused by stiffer grids which buckled during application of the overlay construction, thus allowing portions of the grid to protrude through the surface of the overlay and in some cases, come into contact with the underside of the paving machine.

Modern geocomposites have been designed to meet the needs of asphalt retention and high initial tangent modulus, often referred to as high modulus at low strain.

2.4 Geotextiles used for the Separation Function

Geotextiles, on the other hand, are mainly used to separate two different unbound materials, and are often installed lower down in the pavement between the base and sub base layers. The primary function served here is for the provision of additional reinforcement and also as a separation medium to control the contamination of the base course by fines migrating from the subgrade and sub base.

The presence of a geotextile separator under a paved road eventually reduces the damage to the sub base and subgrade from the loads imposed by the continuous application of axle passes, and also makes allowance for the reduction in the required thickness of the unbound base and sub base layers for the same design life. See figure 2 below.

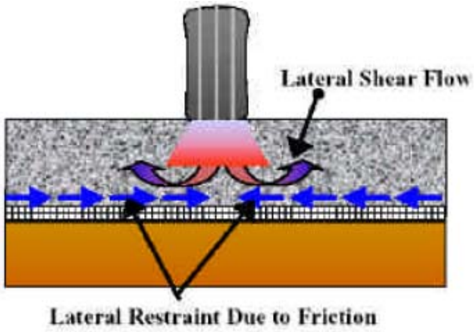


Figure 2. Diagrammatic view of Geotextiles serving as reinforcement in the pavement.

One other common application has been control of the infiltration of water into the pavement. Experience has shown that unacceptably high moisture content in the sub base and base course layers are frequently the main source of deterioration and resulting damage to a pavement. The geotextile consists normally of a polypropylene woven fabric of low permeability and fine pore size characteristics enabling it to serve the purpose of limiting flow of water into the pavement layers.

2.5 Research Findings on the Use of Geosynthetics in Pavement Design and Construction

There are many examples of research projects which have shown that the required overall thickness for a pavement structure over a given design life may be considerably reduced when a geogrid and/or geotextile is included within the layers as part of the design.

2.5.1 HMA Fatigue Test Beams

Research has consistently revealed the fact that geosynthetics solutions are more effective than those based on conventional methods. For example, Saraf et al. (1996) found in a laboratory study of HMA fatigue test beams that beams reinforced with composite materials performed significantly better than beams containing paving fabric alone, and beams reinforced with fabric performed better than unreinforced control beams.

2.5.2 Linear Elastic Crack Fatigue Model

Following the premise that design of reinforced pavements can be based on an empirical mechanistic process, the UK highways agency commissioned a research programme at Nottingham University where use was made of a linear elastic crack fatigue model. Experiments were carried out to demonstrate the behaviour of reinforced pavements under wheel load traffic conditions. The thickness of the asphalt in each case was designed to generate a level of strain under wheel loading which would result in cracks developing relatively quickly. Two principal tests were conducted, comparing glass fibre, polymer and steel grids with an unreinforced control sample. The Semi-continuously supported beam test replicated the distribution of stress cracking through pavements. Results showed that reinforcement can significantly enhance the resistance of asphalt to crack propagation, offering a life enhancement factor of up to 3.

2.6 Computer Programmes for the Design of Reinforced Overlays

The work carried out at Nottingham University resulted in the development of a computer programme for the design of reinforced overlays: OLCRACK. A spreadsheet-based predictive programme which is suitable for use in overlay design which has been taken through extensive sets of trials. The programme is capable of replicating test results from both semi-continuously supported beam tests and the pavement test facility. It was found that the outputs were of the same order as those produced using the CAPA finite element programme developed at Delft University. CAPA offers the flexibility required to cope with the highly complex problems posed by reflective cracking and the effectiveness of reinforced asphalt in extending the life of the pavement.

The design Inputs required for OLCRACK are:

- a definition of the elastic moduli of the layers in the existing pavements and also in the overlay
- details of the traffic loading.

The output provides details on the fatigue life for both the unreinforced and reinforced pavements. It is important to note that this empirical model is mechanistic and based on specific reinforced asphalt research data, and therefore will not generate the same fatigue life results calculated by using other linear elastic empirical models. Vicari and Scotto (2008) showed that if the life of the critical layer was calculated by other means, then that life could be treated as equivalent to the unreinforced fatigue life value calculated by their model, and the benefit achieved due to the effects of the reinforcement, would be the use of the same improvement factor value.

2.7 Precautions in the Use of Geosynthetics in Pavement Construction

Experience has shown that particular problems must be considered in the process of the design and construction of pavements which incorporate geosynthetic applications. Hence, pavement engineers considering fabric or composite in their overlay design should be aware of these potential problems and take appropriate action. Some of the more important precautions are listed below:

- Predoehl (1990) indicates that placing overlays with or without fabric less than 50 mm thick is essentially guaranteeing premature cracking and thus may be very inefficient.
- Thicker fabrics result in lower stresses at the tip of a reflection crack. To improve this property it is recommended that the fabric is first saturated in asphalt to its full thickness before the HMA is placed. This fact illustrates the importance of the asphalt retention rate of the fabric. Button (1989) has shown that a thicker fabric with a greater asphalt retention rate may delay cracking longer than a thinner fabric.
- Correct positioning and proper installation of grid is crucial to good performance. The more flexible, self-adhesive fiberglass grids make correct positioning and proper installation easier to execute. Kennephol and Kamel (1984).
- Harmelink (1993) recommends that a light tack coat is placed on top of a self-adhesive grid to ensure adequate bond between the old pavement and new layer during rehabilitation. This approach is also recommended between the base course and the premix layer in a new structure.
- During placing, extra precaution should be taken to prevent a fiberglass grid from buckling under the wheel loads of the paving plant leading to protrusion through the surface of the premix or overlay. Special care is also necessary to ensure that the grid does not catch onto the underside of the paving machine.
- Marienfeld and Baker (1999) recommend that the geotextile fabric should be saturated with sufficient asphalt to provide a continuous moisture barrier where this is required. Further findings showed that insufficient tack coat will diminish the waterproofing effect.
- Discretion must be used when incorporating a moisture barrier under a new overlay, especially where the overlay is permeable or insufficiently compacted. Surface water will enter the permeable overlay and become trapped by the geosynthetic moisture barrier. Subsequent kneading and scouring action by traffic in the presence of the water will cause rapid failure of the overlay. Experience has shown that good compaction of dense-graded HMA is always important for achieving proper density and minimum permeability, particularly when an impermeable underseal is used. Roads and Bridges, 2000.
- A number of engineers are convinced that water vapor rising from below due to solar heating and subsequent evapo-transpiration, can accumulate just under a moisture barrier (seal coat, asphalt impregnated fabric, etc.), condense during the cooler nights, and cause significant damage, if the HMA mixture in the affected pavement layer is susceptible to water damage. Distress will develop first in the wheel paths due to repetitive loading by traffic on the weakened pavement layer and then will progress rapidly to other parts of the structure.
- It is essential, especially when working with a geogrid between the base course and surface layers, to ensure that the finished surface of the base course is as level and smooth as possible before laying the grid. In this process it may be necessary to fill cracks and remove irregularities greater than 5mm. This can be done by patching or, if the surface is badly out of shape, by applying a regulating course. Before placing the grid it is advisable to sweep the surface clean of loose material and then spray on a tack coat.
- In order to inhibit the growth of classical fatigue cracking in the main asphalt layer of a pavement, the geogrid reinforcement layer should be placed near the bottom of the layer where the tensile stress and strain is a maximum That is, at the base of the asphalt wearing course.
- The standard specifications must be adhered to in order to ensure that the overlaps between adjacent sides and ends of grids and geosynthetic sheets are correct. Furthermore, adequate bond lengths must be provided along the edges of the structure.
- It stands to reason that the upper section of the subgrade layer must be well compacted and leveled according to the design specification before construction of the pavement can commence.

3. DESIGN FOR THE PARKING AREA AND TAXIWAYS AT IVATO AIRPORT

3.1 Original Design Details

The originally design for the pavement structure required a global thickness of 1200 mm consisting of:

- The HMA wearing course of 100 mm thick
- A base course 350 mm thick consisting of an untreated crushed rock gravel
- A sub base of 750 mm thick consisting of a mixture of the gravel in the base course and river sand.

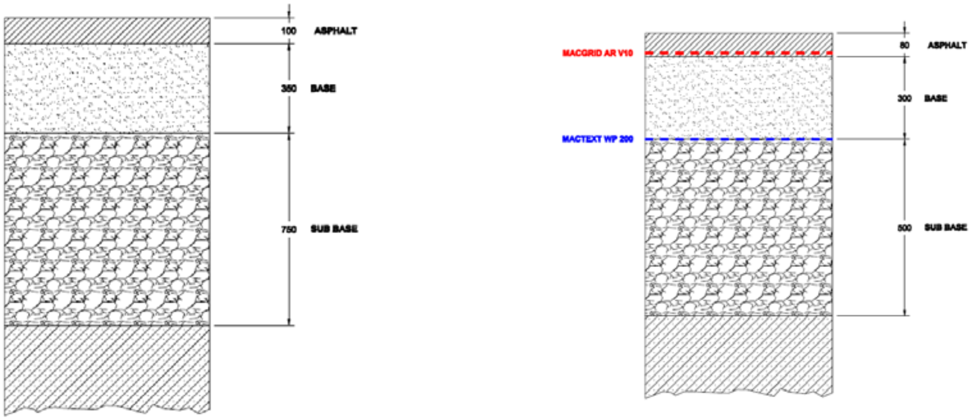
This is illustrated in figure 3(a) below.

3.2 Design Solution using Geosynthetics

The solution proposed was based on the use of both a geotextile separator and a geogrid reinforcement layer. The main objective was to reduce the structural cross section originally proposed without affecting the service life. Figure 3(b) below provides an illustration.

This solution was based on the following:

- The HMA layer of 80 mm
- A single layer of Macgrid AR V10 (glass fibre geogrid)
- The base course of 300 mm thickness (material as per original design)
- A single layer of Mactex WP 200 (geotextile separator)
- The sub base of 500 mm (material as per original design).



a) original design

b) design utilizing Geosynthetics

Figure 3. Cross sections showing the designs for the Ivato Pavement

3.2.1 Properties of the Macgrid

For this application, the reinforcing geogrid selected was required to be most effective in terms of both dynamic and thermal fatigue resistance. Hence a material characterised by a high tensile strength and a high stiffness was needed. A glass fibre geogrid with very high mechanical properties, having a tensile strength of 100 kN/m in both directions, and elongation at rupture of less than 4%, was selected. Figure 4(a) below illustrates a sample of this product.

a) MacGrid AR V b) Mactex WP

Figure 4. Samples of the Geosynthetics used.

3.2.2 Properties of the Mactex

The geotextile selected for the separator layer between the base course and sub base layers was a polypropylene woven fabric with a tensile strength in both the main and cross directions of 40 kN/m, and at an elongation of 18% and 12% respectively in these directions. The Mactex WP 200 has a water permeability of 20 l/m²/sec with a pore size of 0.23 mm. See figure 4(b) above.

3.3 Design Principles used

The design was carried out in two separate stages. First, an analysis was carried out to determine the effect of the MacGrid on the HMA layer and then steps were taken to accommodate the Mactex separation layer between the base and sub base.

3.3.1 Wheel Loads

The design calculations incorporated a standard equivalent axle load of 80 kN, with an equivalent tyre pressure of 850 kPa, which is commonly adopted to modern heavy vehicle tyres, and also using a radius of 150 mm at the contact area with the surface.

3.3.2 Elastic Moduli of the materials

The design method requires an indication of the Resilient Modulus (M_R) which is a measure of the material stiffness or amount of resistance that the underlying layers can provide in order to support the applied loads. This property is generally related to the subgrade. Hence the term subgrade modulus is sometimes used. A material's resilient modulus is actually an estimate of its Modulus of Elasticity (E) which is based on a constant ratio of stress versus strain during the elastic range for the soil under a compressive load. Powell et al., (1984) determined the following relationship between E and the California Bearing Ratio (CBR) of the subgrade material:

$$E = 17.6\,(CBR)^{0.64} \qquad [1]$$

In the case of Ivato, tests on the subgrade produced a CBR ≥ 20. This value was used to determine E for the design.

3.3.3 Determining the Thickness of the Asphalt Layer

The OLCRACK programme was used to run a crack reflection analysis using both the unreinforced HMA layer and then the proposed layer reinforced with the Macgrid. This method made it possible to determine the required thickness of the grid reinforced layer which would provide an equivalent design life to that of the un-reinforced layer.

The output received showed the following result:

An 80 mm thick asphalt layer reinforced at its base with one layer of Macgrid AR V10 was equivalent to the 100 mm thick unreinforced asphalt layer.

3.3.4 Incorporating the Geotextile Reinforcement/Separator Between the Base and Sub base Layers.

Giroud and Noiray (1981) and Sellmeijer (1990) have quantified the benefit of a geotextile separator under a paved road by applying a method similar to the one adopted for unpaved roads. Thus, when a geotextile separator is provided beneath a paved road, and the loading is expressed in terms of passes (N') of an axle load (P') other than the standard axle load (P), the loading can be converted into an equivalent number of standard axle passes (N) using the Sellmeijer equation:

$$N/N' = (P/P')^{6.2} \qquad [2]$$

On the other hand, if no geotextile separator is used, the equivalent number of standard axle passes is given by the Giroud and Noiray equation:

$$N/N' = (P/P')^{3.95} \qquad [3]$$

Combining these equations with the well known Giroud equation used to determine the aggregate depth, it can be determined that:

$$h'_0 = [125 \log N - 294(r - 0.0075)]/c_u^{0.63} \qquad [4]$$

where,

N	is the number of passes of a standard 80 kN axle
r	is the rut depth in m
c_u	is the undrained soil cohesion in N/m^2
h'_0	is the aggregate depth in m

It is possible therefore to obtain a saving in the unbound layer thickness due to the geotextile separator.

Depending upon the actual c_u (or CBR) value of the subgrade, here assumed to be equal to 20, the reduction of the aggregate layer provided by the insertion of a geotextile separator, for the same design life of the pavement, is approximately 30 %. Therefore this will be the value assumed for the reduction in thickness of the unbound layers. Thus it will be possible to reduce the thickness in the original design from 1100 mm to 770, say 800 mm. In order to provide a conservative solution this reduction is distributed in such a way that the lower section, or sub base, receives the greater portion, as follows:

- 300 mm of untreated crushed rock gravel (instead of 350 mm)
- 500 mm of gravel – river sand mix (instead of 750 mm)

To provide an effective separation and reinforcement effect, the geotextile is required to have adequate mechanical (tensile strength, puncture resistance, penetration resistance), and filtering (pore size, permeability) characteristics. A woven, 100% polypropylene, bi-axial geotextile with a tensile strength of 40 x 40 kN/m would be required and installed at the interface between the sub base and base course layers.

4. CONCLUSION

There are many examples, both good and not so good, of pavements which have been designed to incorporate geosynthetics as a reinforcing element. The recommended design methods are based on sound engineering principles and are relatively straightforward in their application.

Experience which has been developed in the use of reinforcing materials in the form of geogrids, geocomposites and geotextiles has provided potential users with adequate information which can readily be adapted to most situations where this technology is needed. Design engineers and product specialists in the Maccaferri group have played an effective role with other leaders in this field in the process of developing standard methods and specifications that can be readily applied. Practical experience gained on projects such as the extensions to Ivato Airport Airport have enabled further development of the best techniques suited to this type of application for pavement construction. As knowledge improves and further advancements are made, opportunities for this type of solution will increase, reducing the costs of pavement construction and subsequent maintenance, resulting in better roads for the future.

REFERENCES

Button, J.W. (1989a), Overlay Construction and Performance Using Geotextiles. In Transportation Research Record 1248, TRB, National Research Council, Washington, D.C. pp. 24- 33.

Button, J.W.(1989b), Engineering Fabrics and Asphalt Overlay Performance. Report No. 187-17. Texas Transportation Institute, Texas A&M University, College Station, Texas.

Cleveland, G.S., Button, J.W. and Lytton, R.L. (2002), Geosynthetics in Flexible and Rigid Pavement Overlay Systems to Reduce Reflective Cracking.Report No. 1777-1, Project No. 0-17777. Texas Transportation Institute, College Station, Texas,

Giroud, J. P., and Noiray, L. (1981). “Geotextile Reinforced Unpaved Road Design,” Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT9, pp. 1233-1254.

Harmelink, D.S. (1993), Crack Reduction, Pavement Reinforcement, Glasgrid. Report No. CDOTDTD-R-93-6. Colorado Department of Transportation, Denver, Colorado.

Kennepohl, G.J.A. and N. Kamel. (1984), Construction of Tensar Reinforced Asphalt Pavements. In Proceedings, Science and Engineering Research Council, London, England.

Kennepohl, G.J.A., N. Kamel, J. Walls, and R.C.G. Haas. (1985), Geogrid Reinforcement of Flexible Pavements: Design Basis and Field Trials. In Proceedings, Association of Asphalt Paving Technologists, Volume 54.

Lytton, R.L. (1989), Use of Geotextiles for Reinforcement and Strain Relief in Asphaltic Concrete. Geotextiles and Geomembranes, Vol. 8, pp. 217-237.

Marienfeld, M.L. and T.L. Baker. (1999), Paving Fabric Interlayer System as a Pavement Moisture Barrier. In Transportation Research Circular Number E-C006, TRB, National Reseach Council, Washington, D.C.

McLaughlin, A.L. (1979), Reflection Cracking of Bituminous Overlays for Airport Pavements, A State of the Art. Report No. FAA-RD-79-57. Federal Aviation Administration.

Powell, W. D., Potter, J. F., Mayhew, H. C. and Nunn, M. E. “The structural design of bituminous roads”, TRRL Report LR 1132.

Predoehl, N.H. (1990), Evaluation of Paving Fabric Test Installations in California – Final Report. Report No. FHWA/CA/TL-90/02. California Department of Transportation, Sacramento, California.

Roads & Bridges, (2000), “The Waterproofing Debate,” Roads & Bridges, Scranton Gillette Communications, Inc., Des Plaines, Illinois, pp. 48-53.

Saraf, C.L., K. Majidzadeh, and W.O. Tribbett. (1996), Effect of Reinforcement on Fatigue Life of Asphalt Beams, In Transportation Research Record 1534, TRB, National Research Council, Washington, D.C.

Sellmeijer, J. B. (1990). “Design of Geotextile Reinforced Paved Roads and Parking Areas,” Proceedings of the Fourth International Conference on Geotextiles, Geomembranes, and Related Products, Balkema, Vol. 1, The Hague, Netherlands, pp. 177-182.

USDOE, (2000), United States Department of Energy web page, Annual Energy Outlook 2000, Energy Information Administration, Available: http://www.eia.doe.gov/.

Vicari M and Scotto M, (2008). “ Pavement Structure Reinforced with Macgrid AR V10 and Mactex WP 200,” Design Report, Ivato Airport, Madagascar. Technical Department, Officine Maccaferri, Bologna, pp. 4.