BASE STABILIZATION AND ASPHALT REINFORCEMENT FOR AIRPORT RUNWAY EXTENSION: DESIGN METHODOLOGY AND EXPERIENCE

Pietro Pezzano[1], Nicola Brusa[2], David Crowther[3],
[1] Pavement Technical Specialist, Officine Maccaferri Spa
[2] Regional Engineer, Southern England, Maccaferri Ltd, UK
[3] Technical Manager, Maccaferri Ltd, UK

Maccaferri UK Ltd,
7600 The Quorum, Oxford Business Park North
Garsington Road - Oxford OX4 2JZ
T: +44 (0) 1865 770555
F: +44 (0) 1865 774550
www.maccaferri.co.uk
oxford@uk.maccaferri.com

ABSTRACT

The airport expansion is a design challenge for every engineer involved in the various aspects of the project.
Pavement engineering are then faced with different methodology in order to design the runway and taxiway structures. The use of geosynthetics reinforcement, to increase the bearing capacity of the foundation layers and in asphalt reinforcement, is becoming a standard in the flexible pavements but no design method are today available for the airport design.
The most popular design methods and software for design airport structures are based on the dynamic modulus of the various layers but they does not take cares of the geosynthetics improvements.
The aim of this paper is therefore proposing a design method based on the road structures design where the design of the geosynthetics is already available. Starting from the design aircraft's gear a comparison with the passages of EALF standard axle load is provided. Once the load is defined the possibility to use the road software is open and we could demonstrate the improving of the geosynthetics into the design.
The paper will explore the difference between the axle load of a truck and the aircraft gear showing the calculation procedures and providing an innovative engineering design approach.

I. Introduction

The use of geosynthetics reinforcement is today a standard into the road structure design. A lot of codes of practice like AASHTO R 50-09 are already published and others are coming to give advice on the design methods for the geosynthetic products, for the stabilization and the reinforcement (particularly in the asphalt) functions in the road structure. According to this standards a lot of design tools had been prepared from university researchers, designers and companies involved in this business.

Unfortunately the key parameters to design the improvement of the geosynthetic reinforcement comes from researches done with APT and real scale tests or in laboratory by fatigue tests. So to define this parameters very long and expensive campaigns are request.
All of these were already developed for the flexible road structures, the scope of this paper is to explain how a designer could use the pavement design tools to evaluate the benefits of the geosynthetic reinforcement also in airport structures.

II. Design of the Aircraft Traffic Load

Traffic Load is the most important input parameter in pavement design. The consideration of traffic shall include both the loading magnitude and configuration and the number of load repetitions.
One of the primary functions of a pavement is load distribution, therefore, in order to adequately design a pavement, something must be known about the expected loads it will encounter. Loads, that is the vehicle forces exerted on the pavement (e.g., by trucks, heavy machinery, airplanes), can be characterized by the following parameters:

- Axle loads and tire pressures
- Axle and tire configurations
- Repetition of loads
- Distribution of traffic across the pavement
- Vehicle speed

Loads, along with the environment, damage pavement over time. The simplest pavement structural model considers that each individual load produces a certain amount of unrecoverable damage. This damage is cumulative over the life of the pavement and when it reaches some maximum value the pavement is considered to have reached the end of its useful service life.
Therefore, pavement structural design requires a quantification of all expected loads that a pavement will encounter over its design life.
In FAARFIELD software the Airplane window allows for the creation and modification of an airplane list for a selected section. FAARFIELD program currently provides approximately 200 different aircraft models. Each model is unique with respect to take off load, load distribution, wheel spacing and tire pressure.
For each gear is possible to evaluate the pass-to-coverage ratio (P/C). It is the ratio of the number of passes required to apply one full load application to a unit area of the pavement. One coverage is a repetition of maximum strain at the top of the subgrade layer.

The scope of the analysis is to define an equivalent axle load factor (EALF) between the standard axle load used for trucks 80 kN and the axle of the design aircraft.
The airplanes do not have aligned axles like trucks so to design we have to consider the most loaded section of the runway, the maximum load comes from the most loaded gear.
To explain step by step the procedure let’s take as example a Boeing 747-400 as design aircraft (see the gear in).

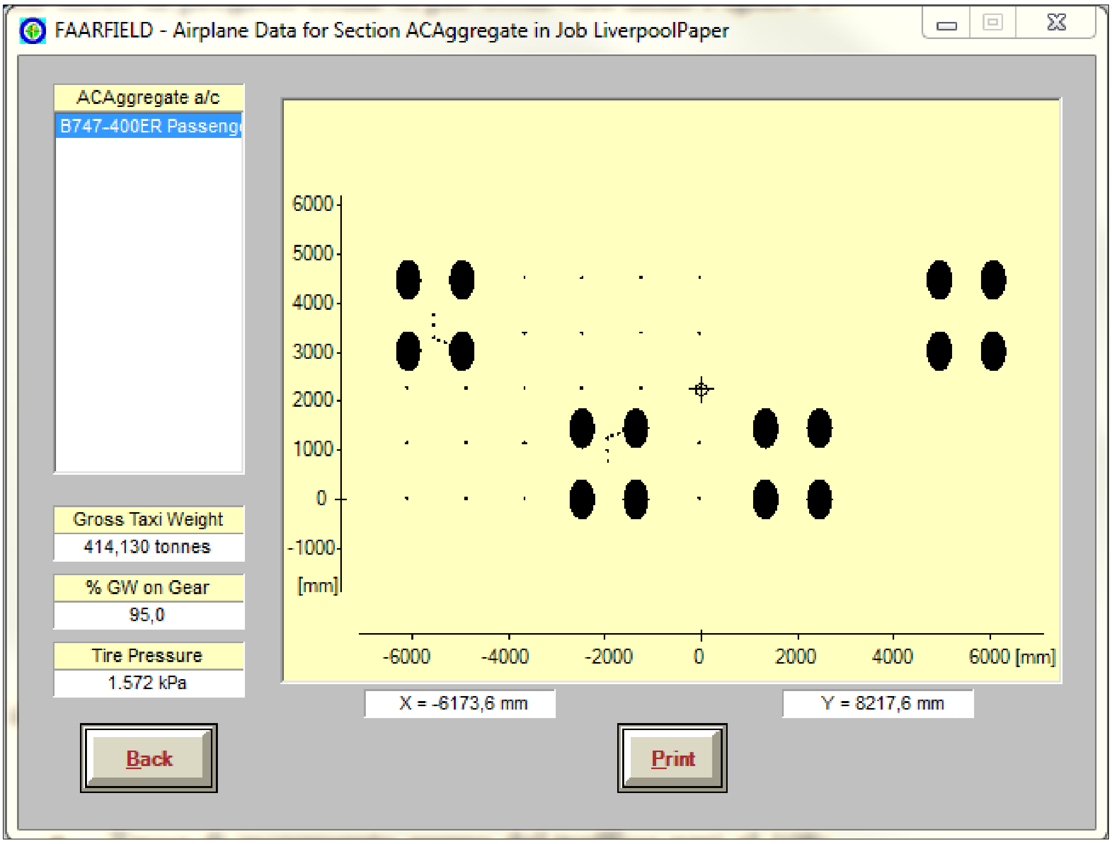

Figure 1 - Boeing 747-400 rear gear from FAARFIELD

The input data for traffic design in FAARFIELD software considered for the airport are reported in Table 1.

Table 1. Input data for traffic design with FAARFIELD software.

Airplane Name	Gross Taxi Weight (tns)	Annual Depart.	% Annual Growth	Total Departures
B747-400	414,130	1000	5%	30,000

To input the traffic load into the design software based on the AASHTO method we need to do a quantification of traffic loads done by the fixed standard vehicle.
Using the Equivalent single axle loads (ESALs) approach we convert wheel loads of various magnitudes and repetitions ("mixed traffic") to an equivalent number of "standard" or "equivalent" loads.
Practically the thickness of pavement is considered to be governed by the number of repetitions of a standard vehicle or axle load, usually the 18-kip (80 kN) single-axle load.
If the axle load is not 80 kN or if it consists of tandem or tridem axles, it must be converted to an 80 kN single-axle load by an Equivalent Axle Load Factor (EALF). The number of repetitions under each single or multiple axle loads must be multiplied by its EALF to obtain the equivalent effect based on an 80 kN single-axle load.

The sum of the equivalent effects of all axle loads during the design period results in an Equivalent Single-Axle Load (ESAL), which is the single traffic parameter for design purposes.

In this case our vehicle is the Boeing 747-400 and we have to consider that the most loaded section of the runway will be loaded only by one leg of the rear gear of the aircraft.

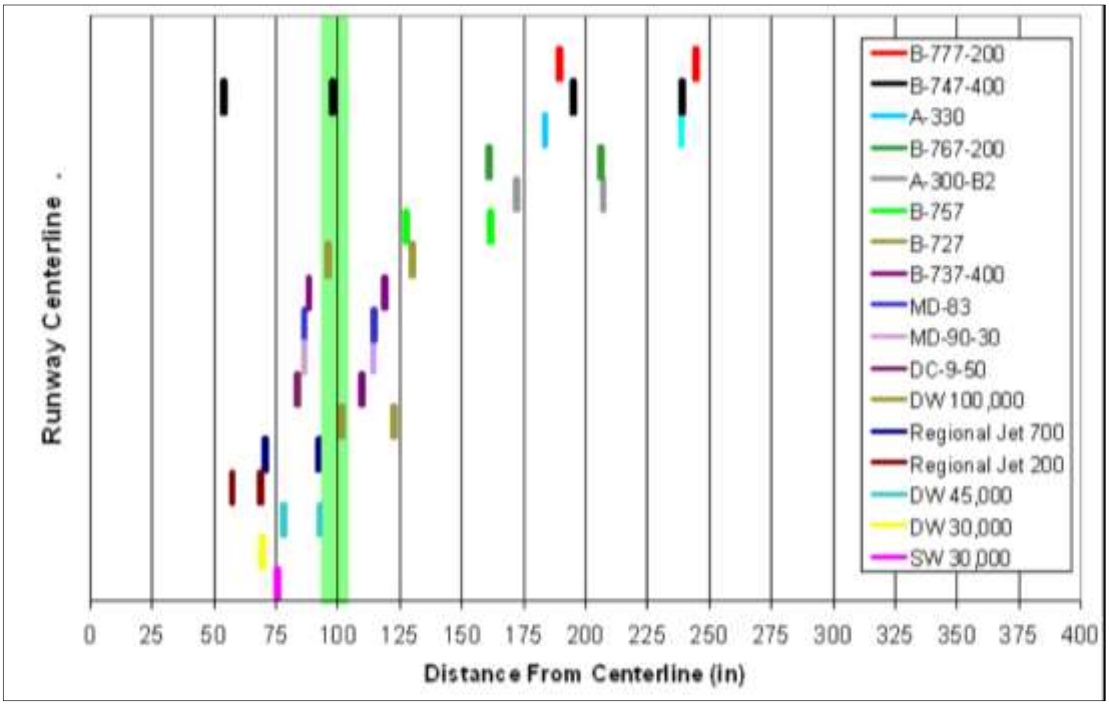

Figure 2 - Large aircraft traffic mix gear locations

The distribution of the load between the three gears of the aircraft has been calculated through the following formula:

$$Q_g = r \cdot \frac{0.825 + 0.025 \cdot N}{R} \cdot Q_t \tag{6}$$

where:
Q_t = total maximum weight of the aircraft (kN)
N = number of landing gears
R = total number of wheels of the main gear
r = number of wheels of the leg of the main gear under consideration.

Considering the main gear, with reference to Fig. 1, the load acting on each wheel of the main gear is:

$$Q_g = r\frac{0.825+0.025N}{R}Q_t = 4 * \frac{0.825+0.025*5}{16} * 4061 = 964{,}5 \text{ kN} \tag{7}$$

Therefore the load acting on the single wheel is:

$$Q_w = \frac{Q_g}{4} = 241{,}125 \text{ kN} \tag{8}$$

From Q_w is possible to find an equivalent axle load on the most loaded section:

$$Q_x = Q_w * 2 = 482{,}25\ kN \quad (9)$$

Characteristics of aircraft used in calibration				
Aircraft Model	Take-off mass (t)	Gear Configuration	Tyre pressure (MPa)	pass to coverage ratio
A380-800	560	Dual-tridem	1.50	1.42
		Dual-tandem	1.50	1.91
B747-400	398	Dual-tandem	1.38	1.73
B777-300	300	Dual-tridem	1.48	1.38
A340-300	276	Dual-tandem	1.42	1.90
A300-600	172	Dual-tandem	1.34	1.69
B767-200	144	Dual-tandem	1.31	1.98
B757-200	116	Dual-tandem	1.26	1.93
B737-800	79	Dual	1.41	3.53
A320-200	74	Dual	1.38	3.70

The gear is a tandem so to find the EAL we have to multiply the axle load by the P/C (pass to coverage) ratio 1,73:

$$Q_{eal} = Q_x * 1{,}73 = 834{,}29\ kN \quad (10)$$

So each passage of our design airplane is like a single passage of an axle of 834,29 kN.

Now an equivalent axle load factor (EALF) must be used to define the damage per pass to a pavement by the axle in question, relative to the damage per pass of the standard axle load, usually the 80 kN single-axle load.
Considering the difference between the axle and wheels of a truck and of an aircraft, the EALF for an aircraft shall be evaluated using one leg of the main gear as the axle: therefore the EALF shall be evaluated by comparing the load Q_{eal} = 834,29 kN with the standard axle load of 80 kN.
The EALF can be determined through the evaluation of the damaging effect following this equation:

No. of standard axles for same damage = (Load on axle / Standard axle load)^4 (11)

Hence from the equation:
- a single axle with Axle Load = 834,29 kN affords EALF = 11828;
Equivalent EALF per aircraft = 11828.

The pavement design is based on the total number of passes of the standard axle load during the design period, defined as the equivalent single-axle load (ESAL) and computed by:

$$ESAL = \sum_{i=1}^{m} F_i n_i \qquad (12)$$

where m = the number of axle load groups
F = the EALF for the i^{th}-axle load group
n_i = the number of passes of the i^{th}-axle load group during the design period

In this case there is one only type of airplane, hence the data for Eq. (12) are:
m = 1;
F = 11828;
n = 1000.

The resulting number of total ESALs in one year is then:

TOTAL ESAL * YEAR = 11828*1000 = 11828000 (ADT_i) (13)

In case of an airport the total volume of traffic during the analysis period is given by the equation:

$$w18 = \left(1 + \frac{b*L}{200}\right) * a * L \qquad (14)$$

where:
w18 = total volume of 18 kips loads during the analysis period
L = pavement design life = 20 years
a = ADT_i = 11828000
b = percent annual growth = 5%

Therefore:
w18 = 35,4840,000 (15)

Now the value of w18 must be divided for the equivalent EALF per aircraft to cross check that the number of aircraft total departures is the same calculated by FAARFIELD:

Aircraft total departures = 35,4840,000 / 11,828= 30,000 (16)

This value is equal to the value obtained with FAARFIELD software and reported in Table 2: hence the method above described for calculating the total ESALs of the AASHTO method is correct.
The same approach could be used for every different kind of aircraft and gear with particular attention to the load distribution on the section.

III. Flexible pavement design with the MacRead 2 software

The AASHTO method is commonly used worldwide for the design of flexible pavements.
Such method consists in defining a target thickness, called Structural Number SN, based on the expected traffic for the whole design life of the road and on the characteristics of subgrade; the thickness SN shall then be obtained by summing the

structural contributions of the asphalt layer, base course and subbase course, given by the product of their thickness D_i multiplied by their layer coefficients a_i:

$$SN = a1 \times D1 + a2 \times D2 \times m2 + a3\ D3\ m3 + \ ... \qquad (17)$$

When extruded geogrids like MacGrid EG are introduced for base and/or subbase reinforcement, their structural contribution to the flexible pavement system can be quantified by the increase in the layer coefficient of the aggregate base and subbase course. This modified AASHTO method has been implemented in the in-house Maccaferri Software MACREAD 2.0.

The AASHTO equation (17) is then modified as:

$$SN = a1 \times D1 + LCR \times a2 \times D2 \times m2 + LCR \times a3\ D3\ m3 + \ ... \qquad (18)$$

where LCR is the Layer Coefficient Ratio, with a value higher than one.

LCR value is determined based on the results from laboratory testing on flexible pavement systems with and without geogrid:

$$LCR = \frac{SN_r - \alpha_1 * D_1}{SN_u - \alpha_1 * D_1} \qquad (19)$$

where SN_r, structural number of the reinforced section, and SN_u, structural number of the unreinforced section, used in Equation (19), are both evaluated under the same pavement conditions, i.e. same base course depth, subgrade CBR, and rut depth.

Figure 3 shows the LCR values against the subgrade CBR applicable to extruded geogrid, obtained by interpolation of curves available in literature.

The reduction in aggregate base thickness can be evaluated by the use of extruded geogrid using Equation (17) (assuming no sub-base layer):

$$D_2 = \frac{SN - a_1 * D_1}{LCR * a_2 * m_2} \qquad (20)$$

or instead, the asphalt thickness can be reduced; the asphalt thickness can be calculated as follows:

$$D_1 = \frac{SN - LCR * a_2 * D_2 * m_2}{a_1} \qquad (21)$$

Note that the pavement contribution to the Structural Number is given by the term a1 x D1; in this way the wearing course contribution is neglected and only the binder contribution is taken into account.

When, due to local regulations or technical requirements, the wearing course shall be designed with a larger thickness than 1.0 inch (25.4 mm), its contribution to SN can be accounted for by putting:

$$a1 \times D1 = a_{\text{wearing course}} \times D_{\text{wearing course}} + a_{\text{binder}} \times D_{\text{binder}} \qquad (22)$$

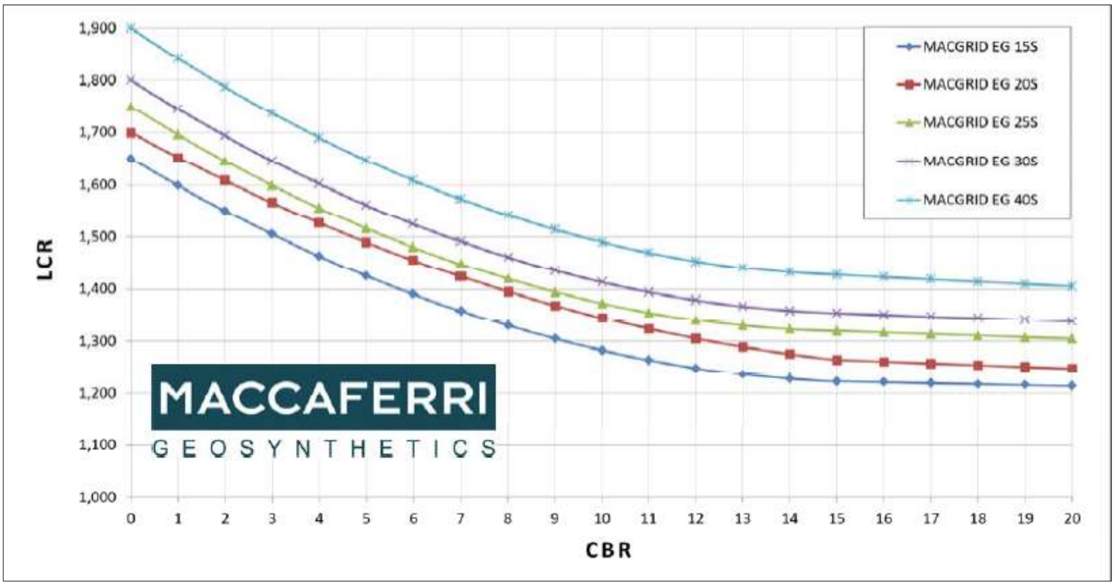

Figure 3 - Layer Coefficient Ratio for extruded geogrid vs Subgrade CBR

IV. Asphalt Overlay design with the OlCrack software

The design of the asphalt reinforcement products as RoadMesh and MacGrid AR is an empirical mechanistic process and is based on the research commissioned by the UK highways agency, which resulted in a design software for reinforced overlays and is currently used by Maccaferri's professional team.

OLCRACK is a spreadsheet-based predictive programme which is suitable for use in overlay design and which uses a linear elastic crack fatigue model derived from research and modelling at Nottingham University in the UK.

This programme has been extensively trialled and is capable of replicating test results from both semi-continuously supported beam tests and the pavement test facility. The resulting predications are of the same order as those from the CAPA finite element software, developed at Delft University. This software offers the flexibility required to cope with the highly complex problem posed by reflective cracking and the effectiveness of reinforced asphalt in extending the life of the pavement.

Two principle tests were conducted, comparing glass fiber, polymer and steel grids with an unreinforced control sample. The Semi-continuously supported beam test replicates the distribution of stress cracking through pavements. The results showed that reinforcement can significantly enhance the resistance of asphalt to crack propagation, with steel mesh being particularly effective, offering a life enhancement factor of up to 3.

The Nottingham Pavement Test Facility was used to demonstrate the behavior of reinforced pavements under wheel load traffic conditions: the thickness of the asphalt was designed to generate a level of strain under wheel loading which would result in

cracks developing relatively quickly. Various reinforcing grids were fixed within the asphalt according to specification.
The design input requires the definition of the elastic moduli of the layers in the existing pavements and in the overlay, and the traffic. The output is a fatigue life for 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. However, if the life of the critical layer is calculated by other means, then this life can be treated as equivalent to the unreinforced fatigue life value calculated by our model, and the benefit of the reinforcement applied using the same improvement factor value.

V. Conclusion

The design of a geosynthetic reinforced structure is based on the product behaviors of increase the bearing capacity and/or the fatigue performances of the reinforced layers. This approach achieve cost effective solutions to extend the service life of the structures and/or decreasing the thickness of the layers. Design a solution with the geosynthetic products is today possible not only with the rule of thumb but also with design criteria. Input data must be taken with care, especially the layers moduli (static vs dynamic) to avoid wrong evaluation of the structure bearing capacity. The best approach is to design the thickness of the airport structure with the standard methods and after evaluate the improvement of the geosynthetic reinforcement with an appropriate design software.

REFERENCES

AASHTO (1993). “AASHTO Guide for Design of Pavement Structures”, American Association of State Highway and Transportation Officials, Washington, D.C.

CANCELLI, A., MONTANELLI, F., RIMOLDI, P. AND ZHAO, A. (1996) “Full Scale Laboratory Testing on Geosynthetics Reinforced Paved Roads,” Proceedings of the International Symposium on Earth Reinforcement, Fukuoka/Kyushu, Japan, November, Balkema.

GEOSYNTHETIC MATERIALS ASSOCIATION (2000) - White Paper II— “Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures”.

THOM, N.H. (2000) – “A simplified computer model for grid reinforced asphalt overlays” - 4th International RILEM Conference – Reflective Cracking in Pavements. Ottawa, Canada.

BROWN, S. F., THOM, N. H. and SANDERS, P. J. (2001) - “A study of grid reinforced asphalt to combat reflection cracking” - J. Assoc. Paving Technologists. Vol.70.

CAFISO, S., DI GRAZIANO, A. (2003) - “Evaluation of flexible reinforced pavement performance by NDT” - 82nd Annual Transportation Research Board (TRB). National Research Council, Washington DC.

MOSTAFA, E., AL-QADI, I. (2004) – “Effectiveness of Steel Reinforcing Nettings in Combating Fatigue Cracking in New Pavement Systems” - 83rd Annual Transportation Research Board (TRB). National Research Council, Washington DC.

MONTEPARA, A., TEBALDI, G. and COSTA, A., (2005) – "Performance evaluation of a surface pavement steel reinforcement" - Proceedings of the 5th International Conference on Road & Airfield Pavement Technology (ICPT). Seoul, Korea.

FAA (2009) – "Airport Pavement Design and Evaluation" AC 150/5320-6E.

LANGE, D.P., VICARI, M., RAMBININTSOA, R. (2009) – "Geosynthetic Reinforcement for the Rehabilitation Works of Airport Taxiways and Parking Areas" - GIGSA GeoAfrica 2009 Conference – Cape Town, South Africa.

AASHTO (2010) – "Standard Practice for Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures" AASHTO Designation: R 50-09.

RIMOLDI, P., SCOTTO, M., GHOSHAL, D. (2012), "Design method for geogrid reinforcement of road bases". Proceedings Geosynthetics Asia 2012 Conference, Bangkok, Thailand.

RIMOLDI, P., PEZZANO, P., ZANNONI, E. (2013), "Design model for strength and position of geogrids for road base stabilization". Proceedings Geosynthetics Africa 2013 Conference, Accra, Ghana.

ZANNONI, E., PEZZANO, P. (2015) – "Asphalt reinforcement through geosynthetics" - 11th Conference on Asphalt Pavements for Southern Africa (CAPSA 2015). Sun City, South Africa.