DESIGN OF LONG LIFE PAVEMENTS BASED ON THIN HIGH STRENGTH CEMENT BOUND BASES. M7/M8 PORTLAOISE MOTORWAY EXPERIENCE (IRELAND)

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ABSTRACT

A long life pavement could be defined as that capable of withstanding the traffic loadings with no need to carry out a structural strengthening, being exclusively object of surfacing interventions during 40 years design life period approximately.

Based on this Philosophy, both foundation and pavement have been designed in one of the major areas that conform the Irish Motorway network, the M7/M8 Portlaoise to Cullahill / Castletown PPP Motorway Scheme sections, which add up to 41 km length.

The long life pavement designed is a flexible composite one that includes the innovations as follows:

- Use of low noise surface course in order to achieve 3 dB(A) traffic noise reduction
- Use of thin (150 mm thickness) high strength cement bound bases (above 20 MPa) in order to increase the pavement durability, achieve a water infiltration reduction through the upper asphalt layers caused by possible leaks, and reduce the pavement construction costs.
- Pre-cracking on the cement bound granular base at one meter spacing, in order to delay the down-up transversal cracking reflection caused by thermal retraction, throughout the design period.
- Design of high strength foundation, achieving equivalent stiffness modulus above 400 Mpa, based on the use of a multi-layered system formed by two cement bound layers, that perform as non-deformable leans and provide a lower susceptibility to water infiltration, instead of using the traditional foundation formed by capping and granular sub-base.

1. FOUNDATION DESIGN

Foundation is one of the main factors to take into consideration for addressing long-life pavement designs.
The choice of the foundation class resistance is conditioned by the Surface Modulus Design, measured on the top of foundation.
Table 1 shows the different types of foundation class susceptible to be designed taking as reference the U.K. Standards. [1]

Table 1- Top of Foundation Surface Modulus Requirements

Quantity	**Surface Modulus (MPa)**			
	Class 1	**Class 2**	**Class 3**	**Class 4**
Foundation Class (Stiffness Modulus used in Design)	**50**	**100**	**200**	**400**

1.1. Basis of Foundation Design: Performance design

A detailed study for both likely scenarios found on site and available materials, were neccessary to address the foundation design. The basis adopted for the analytical calculation turned out to be that of Figure 1. [1]

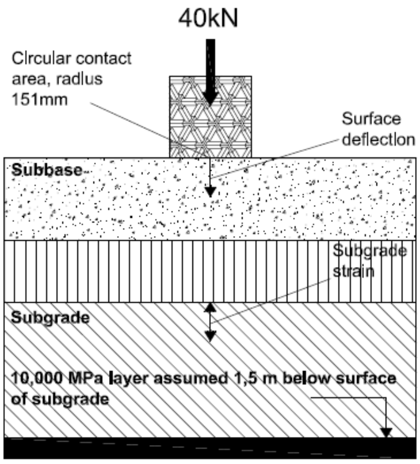

Figure 1- Basis of Foundation Designs

As it can be observed on Figure 1 the basis of the calculation uses a multi-layered linear elastic model of the foundation to determine permissible levels of vertical compressive strain at top of the sub-grade, induced by a standard wheel load (F= 40 KN and r= 151 mm)

It is worth noting that Great Britain uses 80KN standard axles in terms of cumulative traffic loadings for analytical designs.

The available materials from cuttings or close quarries used on site were the following: Cl. 804 (well-graded granular material), 6E (selected granular material), 7F (selected silty cohesive material), 1C (coarse granular material) and 2C (stony cohesive material). [2]

Based on such materials and the intention of designing a long-life pavement, a foundation Class 4 was chosen and two different scenarios were determined on the whole road layout:

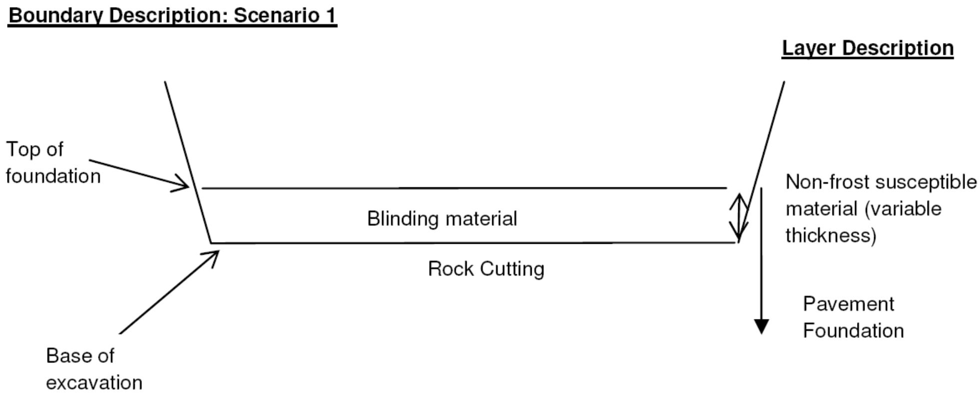

Figure 2- Scenario 1: Rock cutting

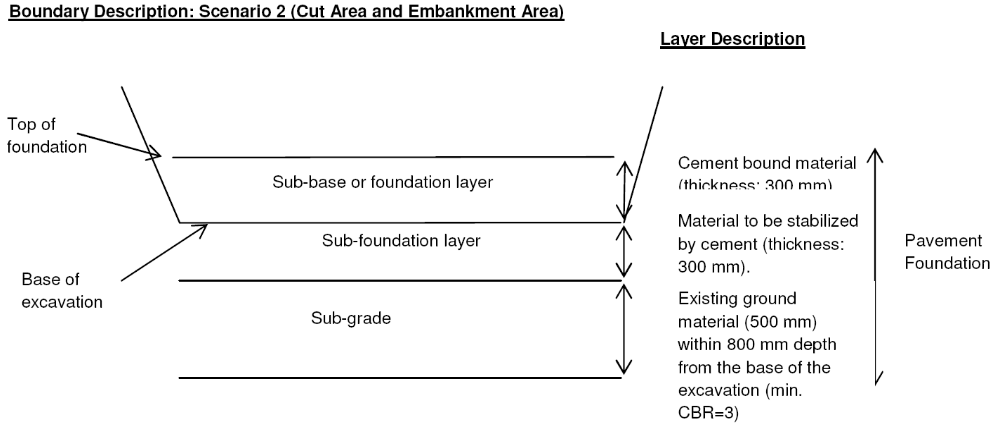

Figure 3- Scenario 2: Embankments and cuttings

Once carried out the analytical models corresponding to each scenario, the following matters were reviewed:

a) Design Stage

- The vertical compressive strain at the top of the sub-grade was checked to be less than that permitted as per the sub-grade CBR value previously determined. (See Figure 4). [1]

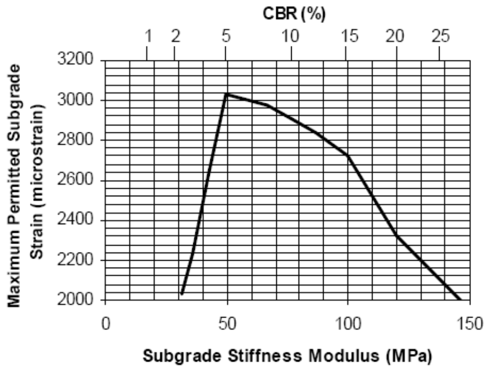

Figure 4- Sub-grade strain limits

- The deflection derived by analytical models was checked to be less than the maximum permitted for a foundation Class 4, in accordance with table 2. [1]

Table 2- Maximum deflection permitted for each Foundation Class under a standard wheel load

Class 1 – 2.96mm
Class 2 – 1.48mm
Class 3 – 0.74mm
Class 4 – 0.37mm

b) Construction Stage

- The stiffness modules of a number of layers within the foundation (sub-grade, sub-foundation and foundation layer), were verified on site to check the confidence level with the analytical model designed, by means of tests. The Surface Modulus, which value defines the Foundation Class as per Table 3, was also tested assuming the slow curing option, as it was going to be used GGBS on the cement bound mixture to produce the foundation layer. [2]

Table 3- Top of Foundation Surface Modulus Requirement

Quantity	Surface Modulus (MPa)			
	Class 1	**Class 2**	**Class 3**	**Class 4**
Foundation Class (Stiffness Modulus used in Design)	**50**	**100**	**200**	**400**
Target	Unbound: **40** Bound: **50**	Unbound: **80** Bound: **100**	Fast Curing: **300** Slow Curing: **150**	Fast Curing: **600** Slow Curing: **300**
Minimum	**25**	**50**	Fast Curing: **150** Slow Curing: **75**	Fast Curing: **300** Slow Curing: **150**

Surface modulus is measured using both static (Plate Bearing Tests-PBT) or dynamic plate test (Falling Weight Deflectometer-FWD). The results from these tests could be different from the long-term design value. The results are also expected to contain significant scatter due to sub-grade variability and because foundation layer materials generally have not been through the same level of production control as plant mixed bound materials used in the pavement layers. Table 3 takes both effects into account by defining a Target value and an absolute Minimum value. The Target value in the short term, for bound materials tends to be higher than the design value because of the deterioration expected during the life of the pavement.

1.2. Measuring non-frost susceptible pavement thickness

Being aware of the Irish climate constraints to build the motorways and the adverse effects on pavements because of the frost cycles, the designers were required to measure the non-frost susceptible pavement thickness. This was obtained based on the frost index (I), which is defined as the product of the number of days of continuous freezing and the average amount of frost (in degrees Celsius) on those days. It is related to the depth of frost penetration (H). [3]

$$H = 4 \sqrt{I} \quad [3]$$

1.3. Demonstration areas. Correlations

The measurement of the surface modulus (or equivalent modulus) related to foundation, as well as the sub-foundation and sub-grade layer was tested on site by means of PBT or FWD. [1]

Several demonstration areas associated to different scenarios and material types were carried out in order to verify the confidence level of the analytical foundation design.

In this respect it is worth noting that the surface modulus has an adjust factor depending on the structural capacity of the layer below the foundation. To make the adjustment that allows for a higher actual sub-grade CBR (or stiffness modulus) at the demonstration area than that used as a basis for the design, the required foundation stiffness modulus (both target and minimum) is multiplied by the following factor:

$$\text{Factor} = 1 + k \times \text{Ln (Sub-grade Ratio)} \quad [1]$$

K = 0.28 when working with CBR ; K= 0.43 when working with stiffness modulus

On the other side, and once reviewed the results from those tests (PBT and FWD), it was observed how different those as per the standard used were. That was the reason why the designer requested to establish a correlation between both tests in order to ensure the goodness and reproducibility with the basis of the design.

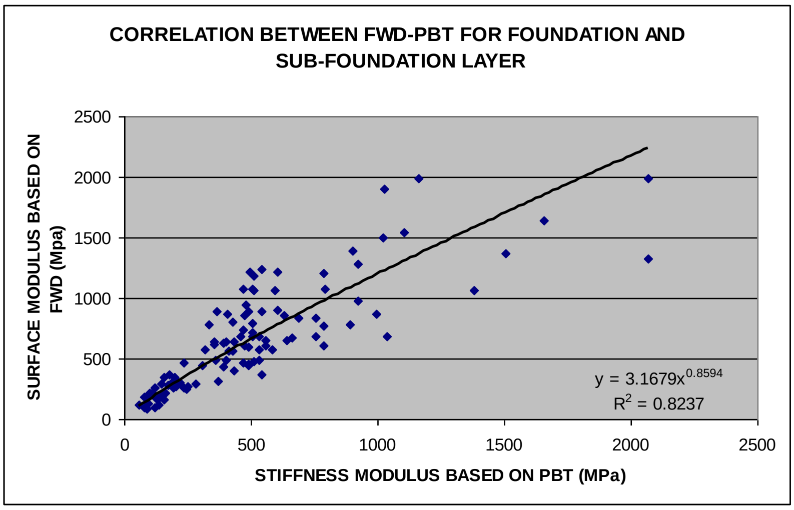

Figure 5- Plate Bearing Test (PBT) and Falling Weight Deflectometer (FWD) Correlation

Figure 6, as an example, shows the test results of one of the demonstration areas where it can be observed the frequency of testing, the adjusting factors, the compaction levels and the stiffness modulus for each layer. In this case the surface modulus was tested by FWD.

Chainage	22600	22610	22620	22630	22640	22650	22660	22670	22680	22690	22700	22710	22720	22730	22740	22750	22760	22770	22780	22790	22800
Cut / Fill / Transistion	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb	Emb
Westbound																					
Subgrade Material	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow
Subgrade CBR / Stiffness	26/03/09					26/03/09					26/03/09					26/03/09					26/03/09
Lane 1	33.3										53.6										43.3
Lane 2						56										47.9					
Subgrade Density	26/03/09					26/03/09					26/03/09					26/03/09					26/03/09
Lane 1	**96**										**97**										**97**
Lane 2						**97**										**98**					
Subfoundation Material	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow	C1 H.Dow
Subfoundation Stiffness	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09	15/05/09
Hard Shoulder	172		373		230		102		357		494		306		396		249		174		222
Lane 1		298		396		294		250		424		965		509		382		214		490	
Lane 2	342		269		313		246		384		343		340		287		287		255		542
Subfoundation Density																					
Lane 1			**96**						**96**						**100**						
Lane 2						**103**						**96**						**96**			
Foundation Material	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E	Lisduff 6E
Foundation Stiffness	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09	29/05/09
Hard Shoulder	700		636		954		1544		982		1365		597		689		768		929		1985
Lane 1		825		1418		844		1045		1072		1066		678		569		546		953	
Lane 2	534		690		706		428		374		1137		774		796		804		624		1288
MEAN	**617**	**825**	**663**	**1418**	**830**	**844**	**986**	**1045**	**678**	**1072**	**1251**	**1066**	**686**	**678**	**743**	**569**	**786**	**546**	**777**	**953**	**1637**
Foundation Density	19/05/09		19/05/09		19/05/09		19/05/09		19/05/09		19/05/09		20/05/09		20/05/09		20/05/09		20/05/09		20/05/09
Hard Shoulder					**96.5**						**102.3**				**96.4**						**99.7**
Lane 1			**96.3**						**98.9**				**99.2**						**99.7**		
Lane 2	**98.5**						**96**										**98.7**				
Rolling avg						**866**	**928**	**964**	**967**	**909**	**979**	**1016**	**966**	**905**	**916**	**832**	**755**	**668**	**683**	**729**	**878**
Factor	1.38	1.44	1.48	1.57	1.40	1.44	1.21	1.37	1.54	1.60	1.59	1.95	1.48	1.67	1.50	1.55	1.40	1.30	1.30	1.66	1.55
Upper E_{Target} adjusted (1)	414	433	443	470	421	432	364	411	461	479	477	585	444	502	451	465	420	391	391	497	465
Lower E_{Target} adjusted (2)	207	217	221	235	211	216	182	205	231	239	239	292	222	251	225	233	210	195	195	249	233
average (1)	446																				
desviation (1)	51																				
percentil 85% (1)	**479**	**Adjusted target Value**																			
average (2)	223																				
desviation (2)	26																				
percentil 85% (2)	**240**	**Adjusted Minimum Value**																			
STATUS	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok

Figure 6- Demonstration area located in embankment with sub-grade based on 1C material

From a statistic point of view and in order to review the trend, it has been taken the running mean of the last six results of the surface modulus. All results overcome widely the minimum requirements to form a foundation class 4, once applied the adjusting factors: The adjusted surface modulus to achieve, characterized by 85th percentile, would be 479 MPa, meanwhile those obtained on site vary between 668 and 1016 MPa, or between 506 and 824 Mpa when applying the correlation provided in Figure 5.

Finally, thank to the demonstration areas, the analytical model designed was be able to be verified on site and consequently implemented during the main works.

2. PAVEMENT DESIGN

The pavement design was based on analytical models developed by the designer, though the Pavement UK (HD26/06) and NRA (HD26/01) Standards and some UK Technical Reports produced by Transport Research Laboratory (TRL 615 y TRL 1132) were also taken as a reference. [4] [9]

Two permitted pavement options were studied for the design but the conclusion, after doing a multi-parametrical study to achieve the most efficient solution, was to carry out a flexible composite pavement (semi-rigid), except in those locations were soft grounds were punctually encountered. In such cases the best option was to design a fully flexible pavement to minimize the adverse effects of likely differential settlements caused during the concession period.

Technically the traffic design was associated to a 20 year period. However, the pavement was designed and built to withstand the traffic loadings for a period time over 35 years, which means a long life pavement.

Table 4- Traffic design in million standard axles (msa – 80 KN)

Section	Traffic loadings (msa). Standard Design	
	Design Life Period	
	20-year life (2010-2029)	35-year life (2010-2044)
M7 Motorway (East), from existing Portlaoise Bypass to M7/M8 Interchange	37.5	83.3
M7 Motorway (West), from M7/M8 Interchange to Borris-in-Ossory Grade separated junction.	14.2	32.4
M8 Motorway (West), from M7/M8 Interchange to Rathdowney Grade separated junction.	24.5	56.6
M8 Motorway (South), from Rathdowney Grade separated junction to Oldtown Roundabout.	23.5	54.3

Regarding the hardshoulders and since they are non-trafficked ‘lanes’ except in case of emergencies, it was considered a reduced pavement section but based on a semi-rigid solution as well.

2.1. Pavement design (Lane and hardstrip)

Despite of the bases of design were the analytical models, the pavement sections derived by this methodology were also compared to those from the UK (HD26/06) and NRA (HD26/01) Standards and to the flexible composite design criterion of UK TRL 615 (Transport Research Laboratory). (See Figures 10 y 11) [4]

For the semi-rigid pavement analytical designs two different scenarios were studied as per the compressive strength of the cement bound granular material (CBGM) adopted (CBGM C12/15 ó CBGM C16/20). The pavement performance sensivity concerning likely CBGM thickness varying during construction was analyzed in both scenarios. (See Figure 7 and 8)
The bases of design in both cases were the following:

- This expression was used as fatigue law for the CBGM:

$$\sigma_r / Rf,lp = 1 - 0,080 \times \log N \quad [5], \quad \text{being}$$

σ_r = tensile stress at the bottom of the CBGM thickness (MPa)
$R_{f,lp}$ = flexural strength in long term (MPa)
N = million standard axels (80 KN)
In the application of such expression the loading transfer between slabs was taken into consideration to ensure a suitable pavement performance. Additionally it was taken into account the pre-cracking spacing over the CBGM (1 meter), along with the use of a safety factor to minimize the flexural strength so as to be on the safe side (5-10%).

- The determination of the CBGM stiffness modulus was based on the compressive strength values for each material (CBGM C12/15 or CBGM C16/20), and supported by previous experiences and specialized references. [4] [6] [7] [8] [9] [10]
- The black top was formed with the use of Asphalt Concrete, i.e., AC 32 base 35/50 (HDM50 base) and AC 22 binder 35/50 (HDM50 binder), being the wearing course a thin reducer-noise semi-drainer asphalt layer, named Thin Surface Course System (TSCS). [11]

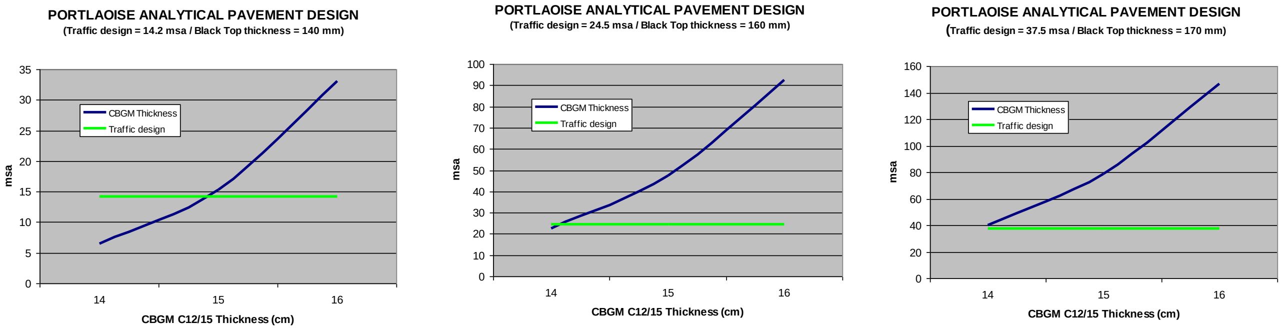

Figure 7- Sensitivity analysis, varying the CBGM C 12/15 thicknesses concerning the pavement durability

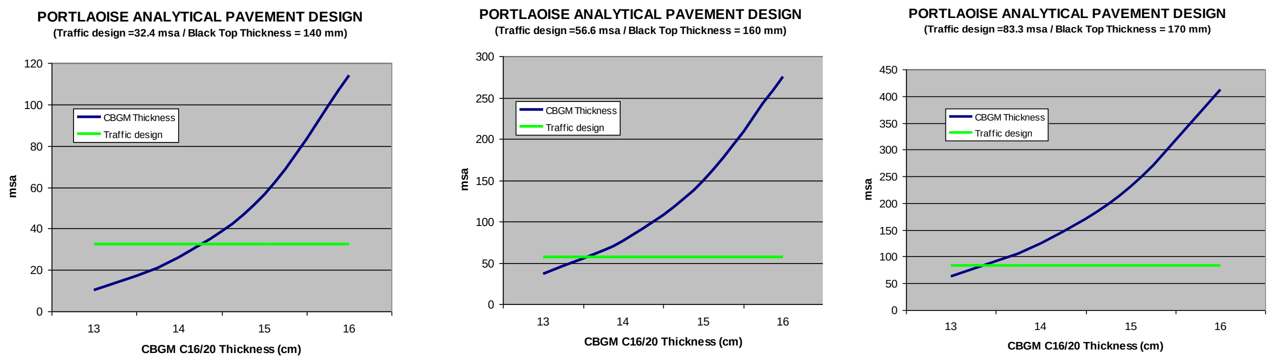

Figure 8- Sensitivity analysis, varying the CBGM C 16/20 thicknesses concerning the pavement durability

From the sensistivity analysis carried out (see Figures 7 and 8) it can be concluded that the optimum CBGM thickness in all cases is 15 cm, as it is the one that shows the most representative design index (k).
The Figure 9 below puts together all the analysis done highlighting the influence of the pavement durability as per the CBGM class resistance used as well as its thickness associated.
This graphic shows how using a 15 cm thick CBGM C12/15 base can achieve 20 years design period. However, increasing slightly the cost of such base (derived by adding some more cement) to achieve a 15 cm thick CBGM C16/20 base it gets produced a quality leap on the pavement performance that turn it into a long life pavement.
That was the reason why this high resistence material was eventually used on site.

Table 5- Comparison of sections (relationship between CBGM thicknesses and safety factor)

Black Top Thickness (cm)	CBGM C12/15 Thickness (cm)	Traffic design (msa)	Traffic calculated (msa)	k (safety factor)
14	14	14.2	7	0.71
14	15	14.2	15	1.03
14	16	14.2	33	1.32

Black Top Thickness (cm)	CBGM C12/15 Thickness (cm)	Traffic design (msa)	Traffic calculated (msa)	k (safety factor)
16	14	24.5	23	0.98
16	15	24.5	47	1.21
16	16	24.5	92	1.41

Black Top Thickness (cm)	CBGM C12/15 Thickness (cm)	Traffic design (msa)	Traffic calculated (msa)	k (safety factor)
17	14	37.5	40	1.02
17	15	37.5	79	1.20
17	16	37.5	147	1.38

Black Top Thickness (cm)	CBGM C16/20 Thickness (cm)	Traffic design (msa)	Traffic calculated (msa)	k (safety factor)
14	13	32.4	10	0.67
14	14	32.4	26	0.94
14	15	32.4	56	1.16
14	16	32.4	114	1.36

Black Top Thickness (cm)	CBGM C16/20 Thickness (cm)	Traffic design (msa)	Traffic calculated (msa)	k (safety factor)
16	13	56.6	36	0.89
16	14	56.6	76	1.07
16	15	56.6	149	1.24
16	16	56.6	275	1.39

Black Top Thickness (cm)	CBGM C16/20 Thickness (cm)	Traffic design (msa)	Traffic calculated (msa)	k (safety factor)
17	13	83.3	62	0.93
17	14	83.3	124	1.09
17	15	83.3	231	1.23
17	16	83.3	413	1.36

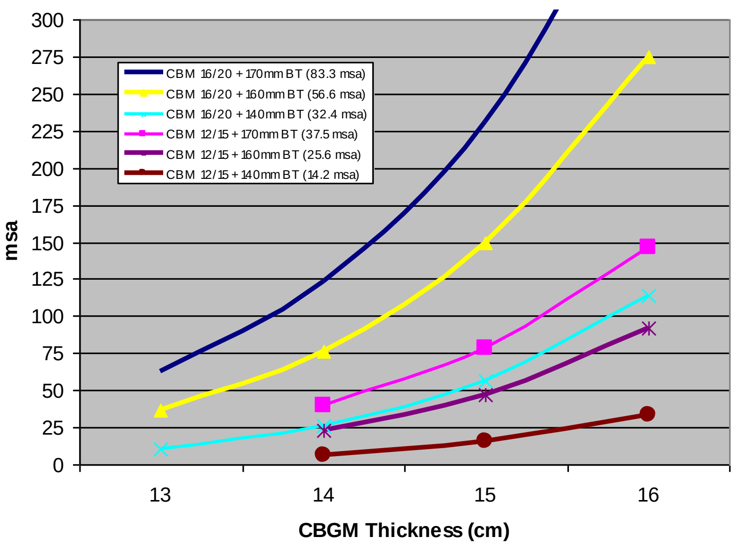

Figure 9- Influence on durability, as per the CBGM class resistence, and the CBGM and black top thicknesses.

Similar conclusions can be made from the comparison analysis carried out among the different Standards (UK, Irish, TRL) based on the traffic design and the CBGM class resistance. Figures 10 and 11 show some examples of such conclusions.

Traffic Design	83.3 msa

CBGM 16/20

	THICKNESSES (mm)				
References	CBGM thickness (mm)	AC 32 base thickness (mm)	AC 22 bin (mm)	TSCS thickness (mm)	Total (mm)
NRA HD26/01	180.00	90.00	65.00	35.00	370.00
UK HD26/06	150.00	80.00	65.00	35.00	330.00
TRL 615	150.00	80.00	65.00	35.00	330.00
Analytical Design	150.00	65.00	50.00	35.00	300.00

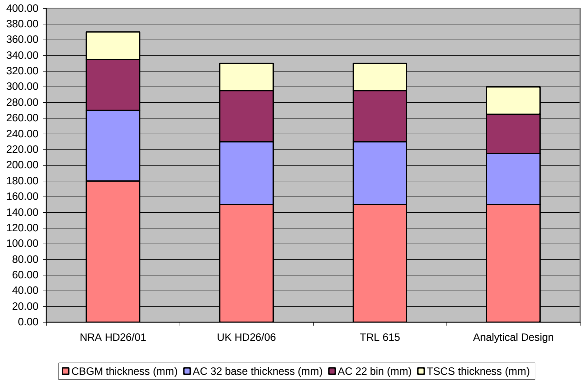

Figure 10- Comparison of pavement sections, based on 83.3 msa design traffic and CBGM C16/20.

Traffic Design	37.5 msa

CBGM 12/15

	THICKNESSES (mm)				
Methodology	CBGM thickness (mm)	AC 32 base thickness (mm)	AC 22 bin (mm)	TSCS thickness (mm)	Total (mm)
NRA HD26/01	180.00	90.00	65.00	35.00	370.00
UK HD26/06	150.00	70.00	65.00	35.00	320.00
TRL 615	150.00	65.00	65.00	35.00	315.00
Analytical Design	150.00	60.00	65.00	35.00	310.00

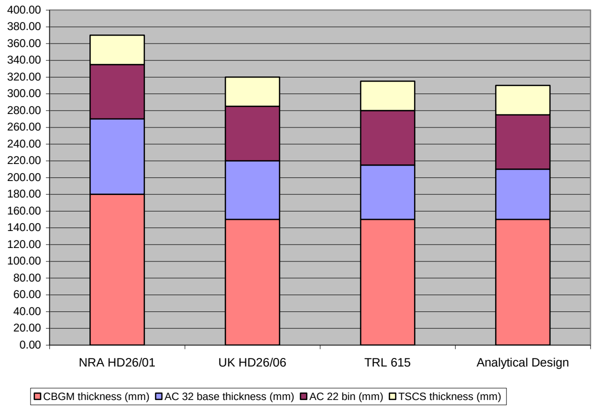

Figure 11- Comparison of pavement sections, based on 37.5 msa design traffic and CBGM C12/15.

Finally, the permitted pavement option chosen, i.e., for mainline and hardstrips, was that designed by analytical methods and using a CBGM 16/20 base, as it shows the following advantages:

- Cost reduction in comparison with the current Standards
- Greater durability (long life pavement)
- Cost reduction in O&M stage as no structural pavement treatments will be necessary. Only surface interventions.
- More environmentally-friendly pavement, as it shows a reduced consumption of materials during construction, which reduces the transport costs, the green house effects, makes the best use of local materials and avoids the exploitation of further natural sources.

2.2. Hardshoulder design

The only requirement from the contract for the hardshouder design was the capability of withstand 3 msa traffic loading. This constraint allowed the design of a reduced section, which is highly interesting from an economical point of view.
Taking this requirement into consideration and trying to avoid high stiffness differences between mainline and the hardshoulder in the same cross section, the designer decided to adopt a similar pavement type in both but reducing the CBGM class resistance to C8/10. The wearing and binder courses designed for the mainline were prolonged up to complete the spreading of the whole wide carriageway. The material, therefore, below the binder course in the hardshoulder would be formed by CBGM C8/10 up to reach the foundation level. [5]

It is worth noting how important was the design of the locations for the construction (longitudinal) joints within the pavement in order to avoid placing them in the wheel paths or nearside lanes or to avoid water being able to travel through several layers without being impeded. [12]

3. REQUIREMENTS FOR THE CBGM

The CBGM is the most important layer in the flexible composite pavements as it is the one that has the goal of withstand in a high percent the traffic loadings caused by the heavy vehicles

The use of CBGM in pavements provides lots of advantages in comparison with unbound materials as long as it is well constructed, as otherwise these advantages (some of them are shown in item 2.1) would turn into disadvantages.

The most frequently failures produced in this type of pavements, that can give rise to dramatic adverse effects concerning pavement durability, are as follows:

- CBGM thickness below the design minimum
- Poor compaction in the CBGM
- Scattering moisture content in the granular material susceptible to be mixed with cement
- Failures in Job Mixture regarding cement content.
- Poor mixed CBGM
- Absence or bad use of additives under adverse meteorological conditions

Being, therefore, aware of the risks associated when constructing this kind of layers, the designer produced a requirement package based on its experience, which was not included in any Standard, though the UK Specification for Highway Works was taken as reference. [2]

These CBGM C16/20 requirements were:

- Compressive strength to be 3.2 N/mm2 and 4 N/mm2 (C16/20) when tested as a ratio 2 cylinder or cube sample, respectively, as minimum requirement before being overlaid by HDM 50 layer
- Compressive strength to be 10.50 N/mm2 and 13.00 N/mm2 (C16/20) when tested as a ratio 2 cylinder or cube sample, respectively, as minimum requirement before being trafficked, though either way it is recommendable never within 7 days of mixing in plant.
- Aggregate Grading to be achieved:

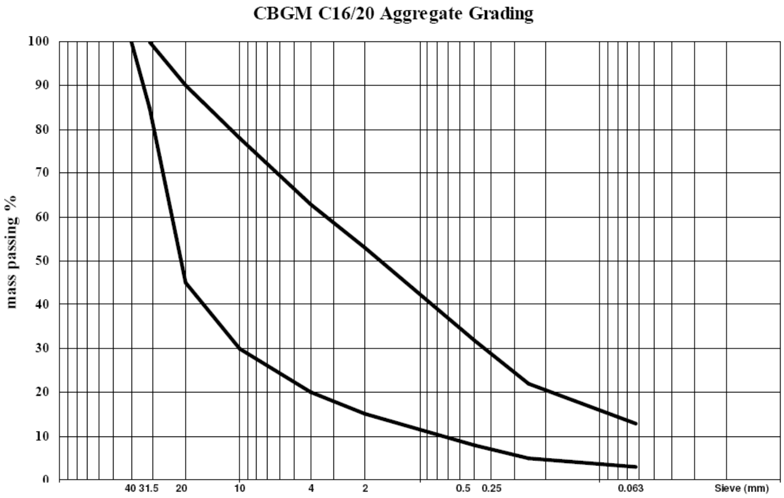

Figure 12- Aggregate grading for CBGM C 16/20.

- Compaction: The full depth of the layer shall be compacted to an average wet density of not less than 98% of the average wet density of the strength specimens made in accordance with Clause 870.[2]
- Pre-cracking induced with max. 1 metre of spacing
- Longitudinal cracks inducement will be carried out for all those carriageway widths greater than 5 m, and where the applied stresses are lowest, avoiding the wheel paths.

CBGM C8/10 requirements were similar to C16/20, except this one:

- Compressive strength to be 6.40 N/mm2 and 8.00 N/mm2 (C8/10) when tested as a ratio 2 cylinder or cube sample, respectively, as minimum requirement before being trafficked, though either way it is recommendable never within 7 days of mixing in plant.
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Figure 13 shows some examples of the compressive strength values achieved at the age of 7 and 28 days concerning CBGM C16/20:

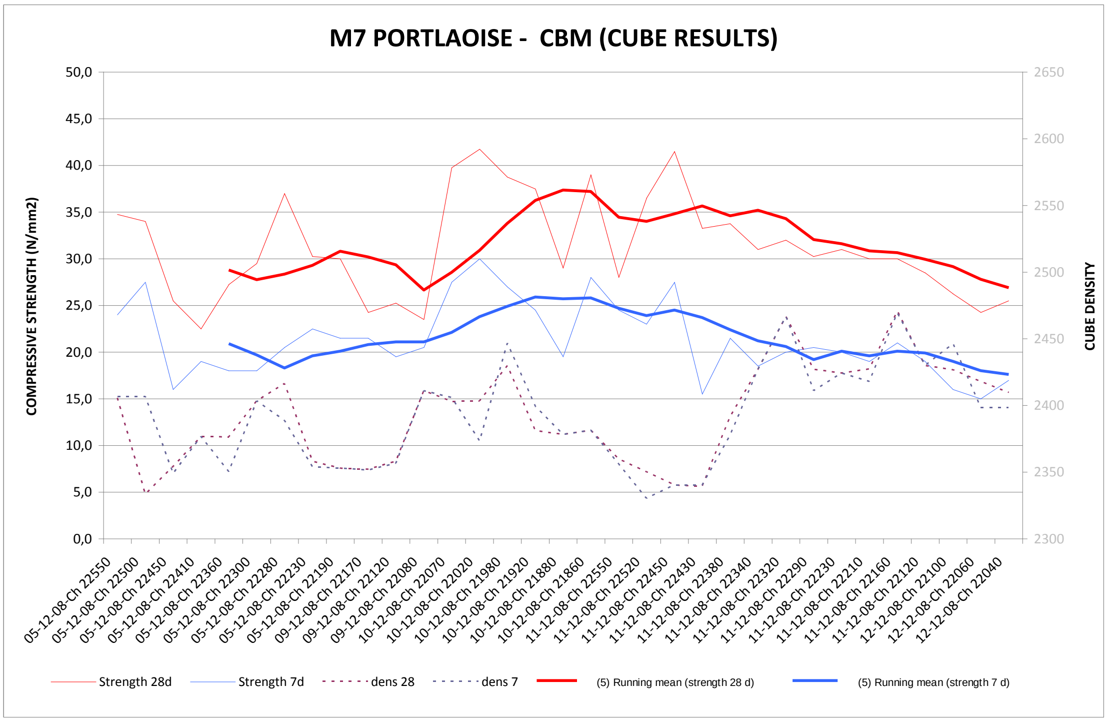


Figure 13- Examples of compressive strength values obtained on site for CBGM C 16/20.

4. CHOSING THE PRE-CRACKING SPACING

Flexible composite pavements possess generally more advantages than the flexible from a structural and economical point of view, depending on the traffic, the ground types, etc, but also show disadvantages as the transversal cracking reflexion that is produced on the surface course.
The most effective method to face and minimize this problem as the experience shows to date is pre-cracking.
The pre-cracking spacing chosen was based on an experimental study carried out in the mid 90´s by a Consortium formed by the Transport Research laboratory (U.K.) and the Danish Road Institute over the A-30 Motorway in Cornwall (U.K.), which was highly trafficked. [8]

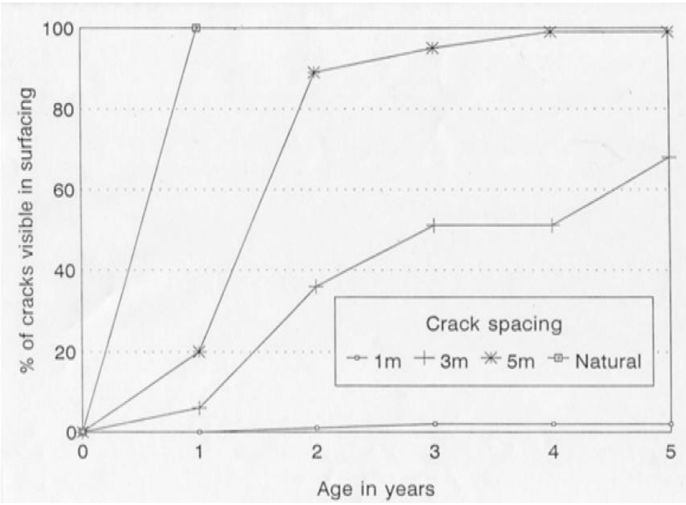


Figure 14- Evolution of cracks visible in surfacing as per the pre-cracking spacing and the age

For such study a rigid pavement surfaced by 65 mm thick black top was designed, which was leaned over a high structural capacity foundation, based on 150mm thick unbound material (Cl. 804). The rigid layer was formed by 235 mm thick unreinforced concrete with C60 class resistance. Over this layer pre-crackings were carried out with 5, 3, 1 meter spacing and with no pre-cracking in order to check the cracking performance along the time. Five years after the opening the wearing course of the Motorway showed the results of Figure 14. [8]

Figures 15 and 16 show the relationship between the crack width and the load transfer level as per the pre-cracking spacing. The less pre-cracking spacing carried out, the more load transfer the slabs will get and the more durable the pavement will be.

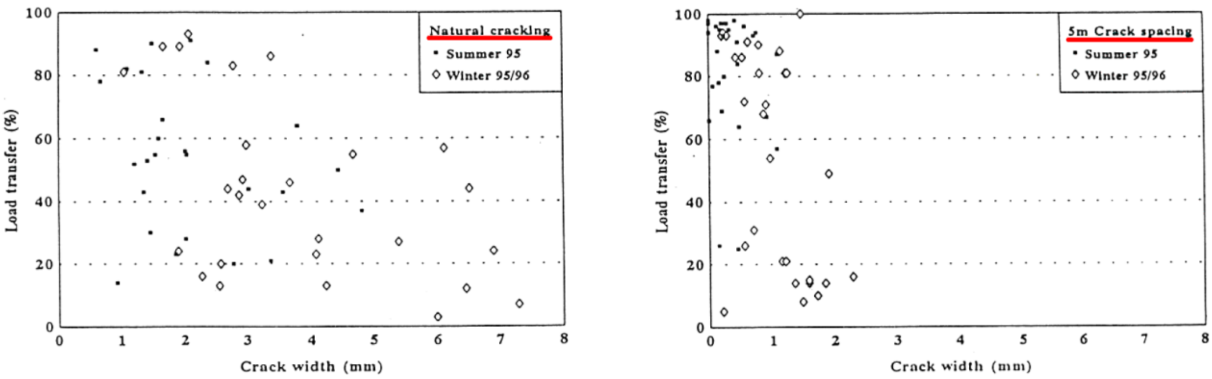
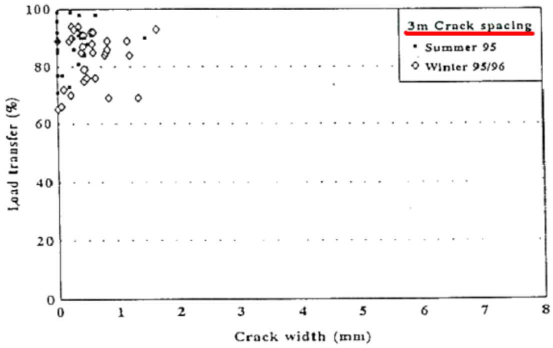


Figure 15- Relationship between the crack width and the load transfer level as per the pre-cracking spacing: no pre-cracking (left); 5 m pre-cracking spacing (right)



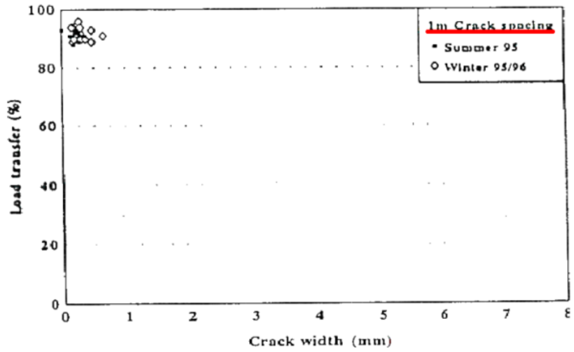


Figure 16- Relationship between the crack width and the load transfer level as per the pre-cracking spacing: 3 m pre-cracking spacing (left); 1 m pre-cracking spacing (right)

To the light of the conclusions from that study and focusing on both goals, minimization of percentage of visible crackings in surfacing and the design of a long life pavement, the designer chose to establish a one meter pre-cracking spacing.
The pre-cracking machine used on site was formed by high efficiency equipment that carried out the cutting operation which was filled by bitumen emulsion.

5. CHOSING THE SURFACE COURSE

The election of a pavement surface course is subject to the analysis of several aspects such as comfortability, safety, durability, and is also based on a reduced environmental impact.
Taking the locations and the constraints associated to this Project into consideration it was adopted a wearing course with drainage properties, high resistance to abrasive traffic loadings, high macrotexture, high deformation resistance, high skid resistance and a low noised impact in comparison to the conventional surfaces such as Hot Rolled Asphalt.
That is the reason why this type of wearing course, Thin Surface Course System (TSCS), has been selected as the only one that gathers all these properties.
The minimum requirements to comply, for both materials and final product are as follows: [13]

a) Materials

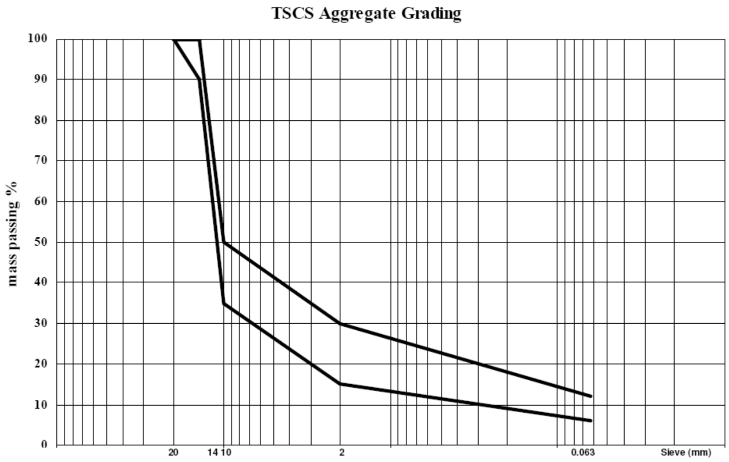


Figure 17- TSCS aggregate grading

PROPERTIES	TEST METHOD	SPECIFIELD VALUE
Penetración at 25ºC 0.1mm	IS EN 1426	65-105
Softenig Point, ºC	IS EN 1427	>60
Fraass Brittle Point, ºC	IP 80	<-15
Storage Stability, ºC difference in softening point, top-bottom, alter four days at 160ºC	Clause 941	<5
Resistance to hardening (Rolling thin-film Test) Mass Change, (percent) Retained Penetration (Percent) Softening point increase ºC Softening point decrease ºC	ASTM D2872	<1.0 >60 <8 <2

PROPERTY	CATEGORY
Polished Stone Value (PSV)	PSV 60 $_{declared}$
Resistance to Fragmentation (Los Angeles Test)	LA $_{25}$
Aggregate Abrassion Value (AAV)	AAV_{10}
Flakiness Index	FI_{15}

*Unless otherwise stated in table 3.1 of HD36 (NRA DMRB 7.5.1)

Figure 18- Properties of TSC Polymer Modified Binder (left) and coarse aggregate properties (right)

b) Final product

Classification	Test Temperature	Maximum wheel Tracking values	
Road Category		Rut rate (mm/hr)	Rut depth (mm)
Very heavily stressed sites Requiring high rut resistance	60ºC	5.0	7.0
Moderately stressed sites requiring high rut resistance	45ºC	2.0	4.0

Mean sfc (Initial)	Not more than 15% Below	Minimun sfc (After 3 Years)
>0.55	0.55	0.50

Where maximum Vehicle speed is:	≤ 50 Km/h		> 50 Km/h	
Nominal stone size of mix (mm)	10	14	10	14
Initial, after laying				
Average for each Lane Km or Surfaced length if less than 1 Km.	≥1.2 mm	≥1.2 mm	≥1.5 mm	≥1.5 mm
Average of each set of ten measurements	≥1.0 mm	≥1.0 mm	≥1.2 mm	≥1.2 mm
After 3 years				
Average for each Lane Km or Surfaced length if less than 1 Km.	≥1.0 mm	≥1.0 mm	≥1.3 mm	≥1.3 mm
Average of each set of ten measurements	-	-	≥1.0 mm	≥1.0 mm

Figure 19- Wheel tracking requirements for site classifications (upper left), requirements for macrotexture (right) and requirements for skid resistance (lower left)

A tack coat based on polymer modified emulsion was laid prior to installing the surface course (TSCS). The bitumen used to produce the mixture was polymer modified as well.

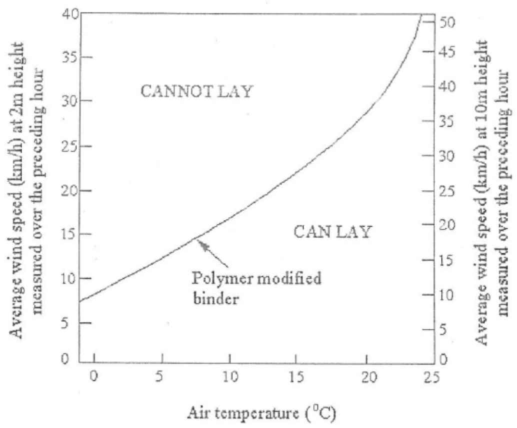


Figure 20- Limiting weather conditions for laying Thin Surfacing Materials

6. CONCLUSIONS

A high structural capacity foundation and a flexible composite pavement, formed by a thin high strength cement bound base and by a reduced black top thickness, have been design based on analytical studies. Such features provide these pavement types with so many advantages in comparison to the traditional:

- Cost reduction at D&C stage if compared with the resulting from current Standards, as allows thickness optimizations in terms of base and black top materials.
- Greater durability, as it is a long life pavement
- Cost reduction at O&M stage as no structural pavement treatments are necessary. Only surface interventions.
- More environmentally-friendly pavement, as it features a reduced consumption of materials during construction, which reduces the transport costs, the green house effects, makes the best use of local materials and avoids the exploitation of further natural sources.
- Due to the pre-cracking spacing carried out (1 meter) in the base layer, a high load transfer between slabs is achieved as well as a high transversal cracking reduction caused by CBGM thermal expansion, and reflected on the surface course.
- High noise reduction on surface course (3 dB(A)), with respect to traditional surfaces, which also shows a certain drainage capacity, due to its discontinuous grading, and a high skid resistance that turns it into a comfortable, safe and mostly so much durable highway.

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