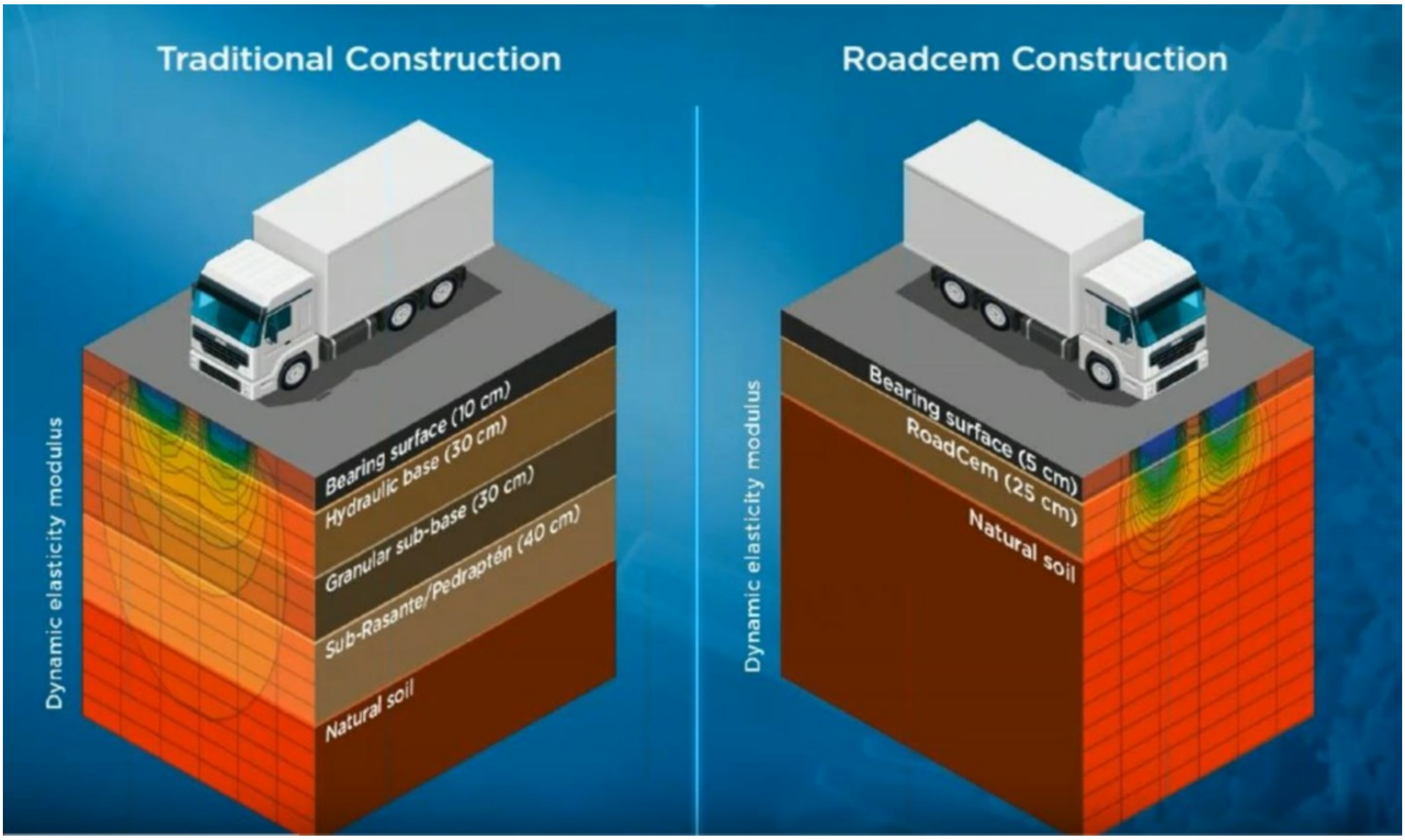
Highway SP-333 in Brazil Constructed using RoadCem Zeolite Soil Base, using just the in-situ site soils………

Design and Testing by ARCADIS BV
Traditional Construction Life Span 10.3 years
RoadCem Construction Life Span 30 + years









EVALUATION RESULTS RESEARCH TRADITIONAL AND ROADCEM CONSTRUCTION BRAZIL

RoadCem

29 JUNI 2018

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1 INTRODUCTION

1.1 General

PATRIA, is a concessionaire for highways in Brazil. The company Patria is therefore also investing in gathering new technologies and innovations, resulting in a durable, profitable and ecological solution for their constructions. PATRIA and the Dutch company RoadCem technology built a stretch in the highway SP 332 km. This project was partially subsidized by the Dutch government, aiming to promote the use of this Dutch technology. The subsidy was approved based on the successful performances in other countries, and the ecological advantages of this technology. According the NIBE report [1], the use of RoadCem has a large beneficial impact on the reduction of CO2, in road construction.

PATRIA has to fulfil the demands of the ARTESP, the Brazilian standards, and therefore PATRIA invested in extensive testing and simulation to compare the effects of the technology. PATRIA requested a study of two independent engineering companies. DYNATEST, who performed the simulation tests, and ARCADIS, to interpret the results and conclude the differences between a traditional pavement construction and a RoadCem construction. The results of DYNATEST are described in the report “Simulador de trafego” [2] In this report the results are presented, and then interpreted as described. Finally, a general conclusion is described.

The project location is Marilia, Brazil on highway SP 333, km. 322, two pavement sections were constructed, one with a traditional construction and the other with the RoadCem construction [3]. To be able to compare both constructions, it was built a stretch of 1 km, plus another 100 m length to run the simulator tests.

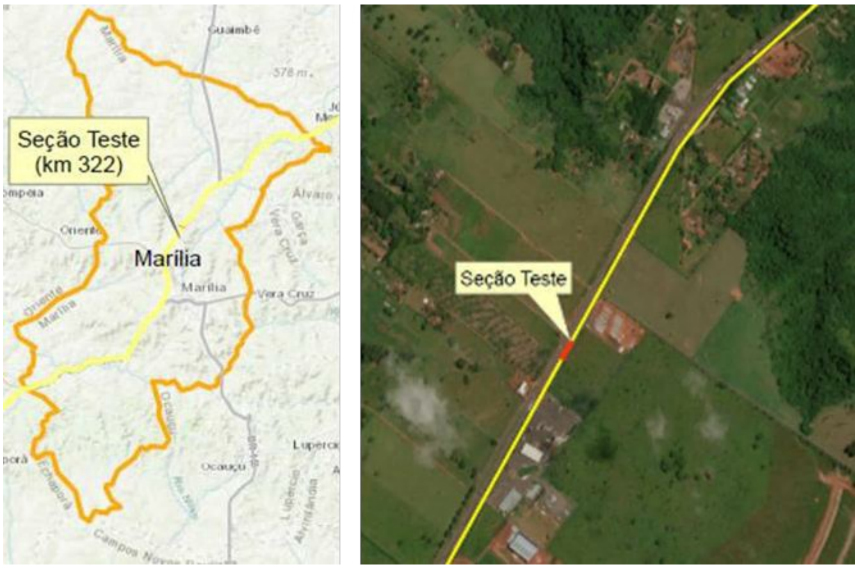

Figure 1. Location of the project

To analyze the construction, the functional lifetime and the structural lifetime are evaluated. The functional lifetime is examined, when is the first maintenance measurement required, with respect to the ARTSEP norms on the asphalt pavement. According to DYNATEST an estimation was based on the input of a test loading of 160 kN and not on the actual 80 kN. In this evaluation, the functional lifetime is also calculated in case the load would be 80 kN instead of 160 kN. The structural lifetime of the construction must be 10 years, however a longer structural lifetime is favourable, due to the reduction of costs at the end of this lifetime. In this report it is given an insight of all the information received from PATRIA. We analyze it and are providing an overview of the information, and finally we give our conclusion.

1.2 Index

In chapter 2 we describe the two used pavement construction: the traditional pavement construction, and the RoadCem pavement construction. In chapter 3 the research methods are presented as well the specific test result requirements. Chapter 4 describes the observations of the tests, resulting in graphs and test results. In Chapter 5 Interpretations of the results are described, the interpretation is supported by calculations programs, and design methodologies to support the interpretation. Finally in chapter 6 the conclusion is described.

2 CONSTRUCTIONS

2.1 Traditional constructions

The traditional construction is based on Brazilian standards and common practice. The 40 cm of natural soil is excavated. As foundation, 20 cm gravel and 17 cm sand with cement is applied. In the first five years the construction has a layer of 8 cm (2 layers 4 cm) asphalt (Figure 1) and after these five years 3 cm extra asphalt (Figure 2) is applied.

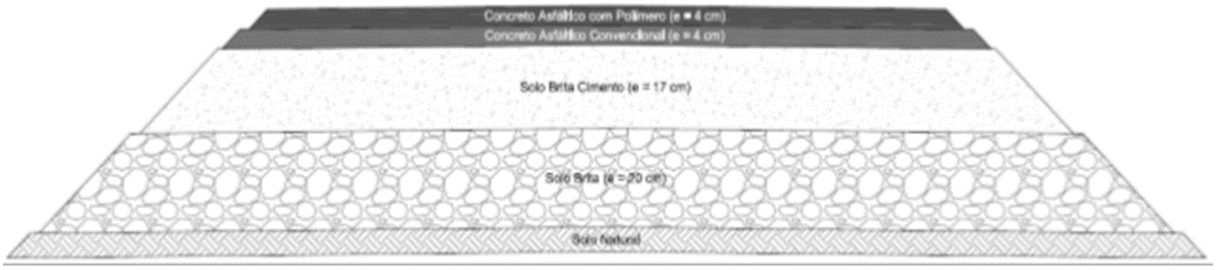

Figure 1 Traditional construction during the first five years

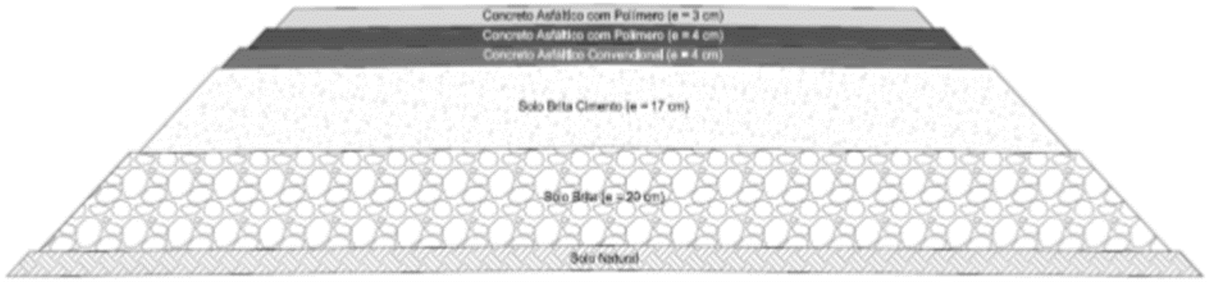

Figure 2 Traditional construction with 3 cm extra asphalt after 5 years

2.2 RoadCem construction

The RoadCem pavement construction is based on the design criteria, the expected material properties and the results of the strains, stresses and deformations calculated in BISAR, a linear visco-elastic multi-layer calculation program. The RoadCem construction is based on the design of PowerCem Technologies. As foundation, the natural soil is mixed with 1,2 kg/m3 RoadCem and 80 kg/m3 cement (Votoran). To determine the material properties of the in-situ treated material, laboratory tests were done in PowerCem Technologies laboratory. The thickness of the RoadCem foundation is calculated to be 31 cm, to fulfil the demands. Due to the fact that in-situ materials are stabilized, PowerCem Technologies respects the use of high safety factors to calculate the construction. The results are described in the technical report of PowerCem [3]. As wearing course, the simulator test was done during the first five years the construction has a layer of 7 cm asphalt (Figure 3) and after these five years 3 cm is milled out and a new surface of 5 cm of asphalt is applied (Figure 4). The reason the asphalt was replaced was due to rutting of more than 7 mm occurred on the RoadCem construction due to the high load of 160 kN during the simulation.

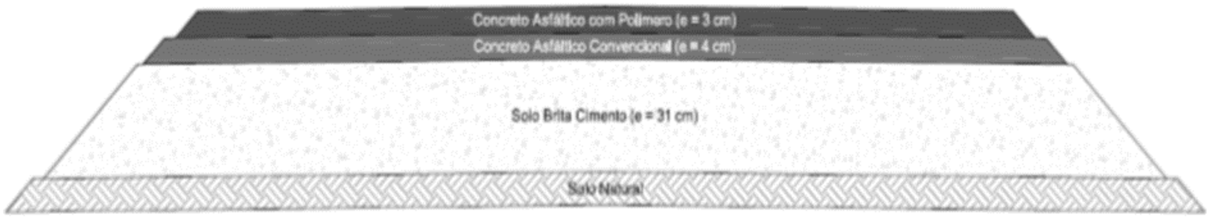

Figure 3 RoadCem construction during the first five years

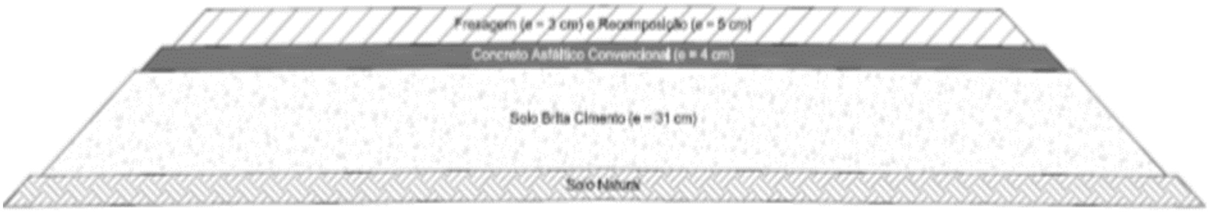

Figure 4 RoadCem construction after 5 years

3 RESEARCH METHODS

3.1 Simulation

DYNATEST used a Heavy Vehicle Simulator (Figure 5), to simulate the test of the construction during the functional and structural lifetime of 10 years. With this test a wheel load of 2*80 kN is driving over the pavement on a conditioned (temperature, moist) test track, in the asphalt the temperature is conditioned. In the DYNATEST report [2] this data is described for deformations and deflections.

Figure 5 Heavy Vehicle Simulator

3.2 Structural lifetime

To observe the structural lifetime, tests were done prior to any load was applied on the pavement and at the end of the simulation. Based on deflection measurements the reduction in strength can be measured. In the beginning the deflection will be low, in time the deflection will increase due to the loss of strength of the materials after a certain amount of loads.

3.2.1 Deflection

Several tests where done to evaluate the pavement constructions. For the structural performance, tests with the Benkelman beam (Figure 6) where done as well as Falling Weight Deflection (further FWD) tests (Figure 7).

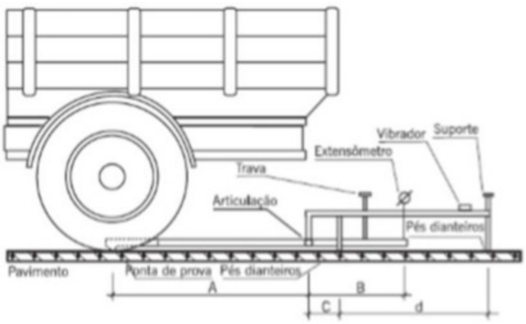

Figure 6 Benkelman beam test

Figure 7 Falling Weight Deflection test (FWD)

3.3 Functional lifetime

To determine the functional lifetime of the asphalt on the pavement constructions, the deformation at the surface, the micro texture and the macro texture are tested. The deformation is dependent of external factor such as: the load, the temperature on the surface of the asphalt support of the subsoil, internal factors: the asphalt mixture resulting is specific characteristics.

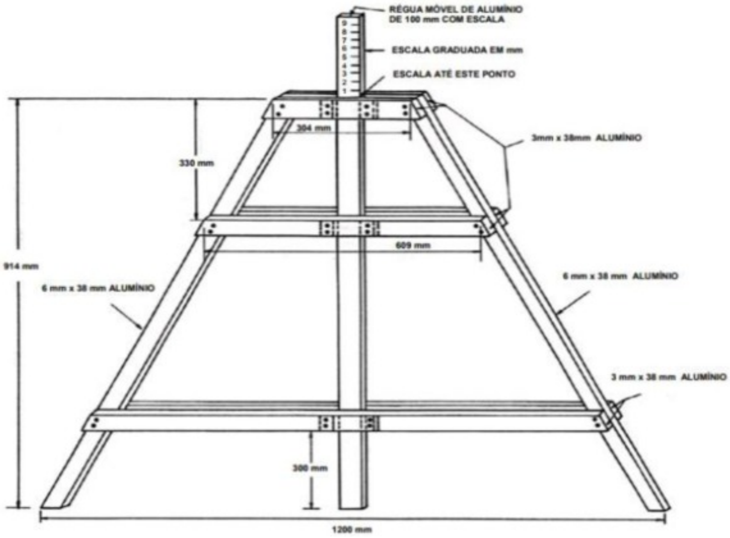

Figure 8 ATR measurement

Figure 9 Deformation measurement

4 OBSERVATIONS

4.1 General

During all phases:
- prior to the load,
- during the surface asphalt layer repair
- after the load, simulating a period of 10 years.

The deflections are measured by the Benkelman-beam and the FWD. The results are presented in graphs for having a good overview of the results allowing us to make conclusions based on the results of both constructions.

4.2 Structural behavior

4.2.1 Benkelman

The deflection of both constructions is measured and presented in Figure 10 and Figure 11.

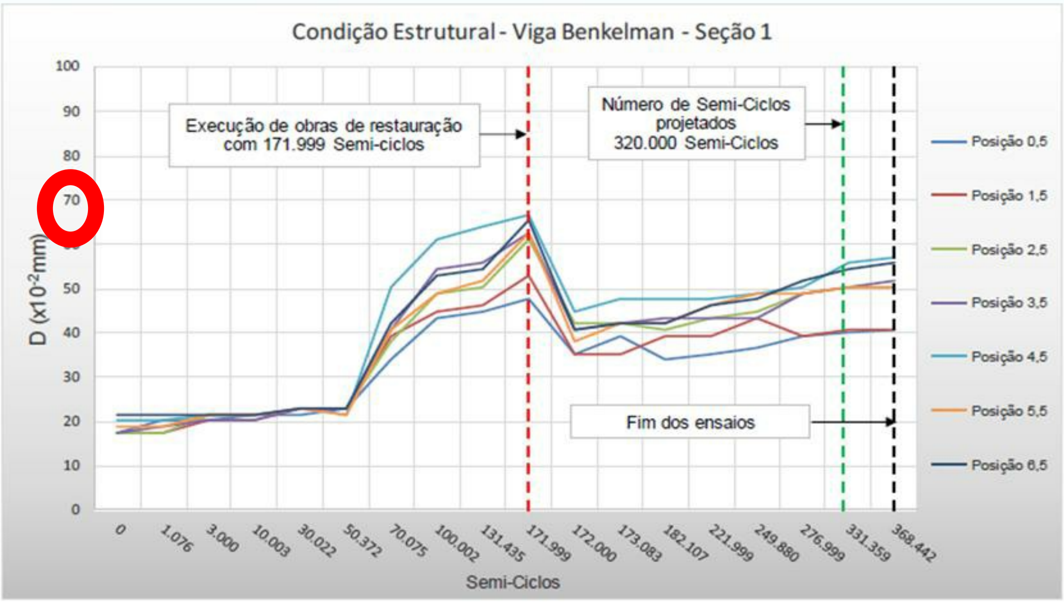

Figure 10 Deflection results for traditional construction, maximum deflection of 670 μm with Benkelman beam

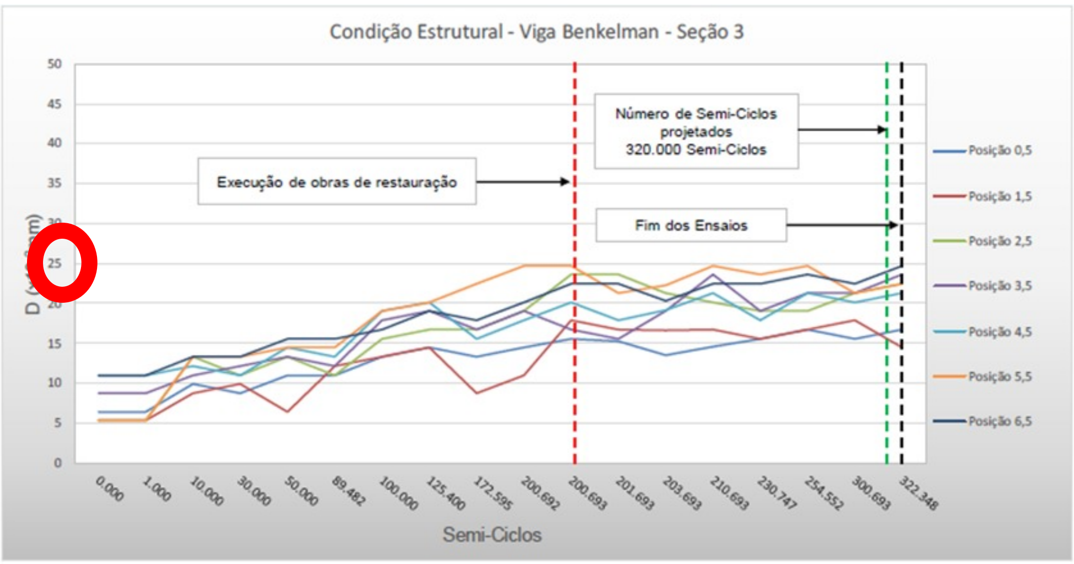

Figure 11 Deflection results for RoadCem, maximum deflection according 250 μm with Benkelman beam

We compare both figures,10 and 11.

Prior to the load

	Minimum	Maximum	Unit
Traditional (0 cycles)	17	22	10^{-2} mm
RoadCem (0 cycles)	5	11	10^{-2} mm

Table 1 Minimum and maximum values with the Benkelman method after 0 cycles

During the surface asphalt layer repair at the traditional construction (171.999, 160 kN axle load passes)

	Minimum	Maximum	Unit
Traditional (171.999 cycles)	47	68	10^{-2} mm
RoadCem (171.999 cycles)	9	22,5	10^{-2} mm

Table 2 Minimum and maximum values with the Benkelman method after 171.999 cycles of 160 kN

After the load, simulating a period of 10 years, after 320.000 cycles of 160 kN axle load passes).

	Minimum	Maximum	Unit
Traditional (320.000 cycles)	40	55	x 10^{-2} mm
RoadCem (320.000 cycles)	15	24	x 10^{-2} mm

Table 3 Minimum and maximum values with the Benkelman method after 320.000 cycles

4.2.2 FWD

The deflections of both constructions are measured before and after the Heavy Vehicle Simulator. They only measured the deflection at the center under the footplate of the FWD. The geophones at the beam were not connected, so we can not exactly calculate the stiffness of the different layers (asphalt, foundation, soil) in the constructions. The results are presented in Figure 12 FWD traditional construction and Figure 13 FWD RoadCem.

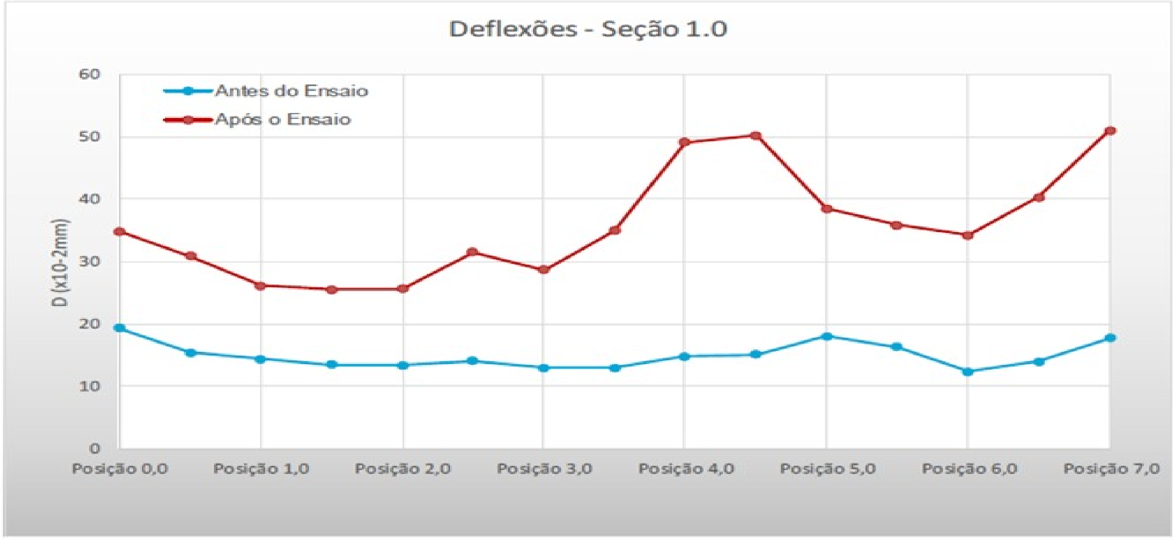

Figure 12 FWD traditional construction result (blue line prior to applying loads, red line after applying loads to simulate 10 years' lifetime)

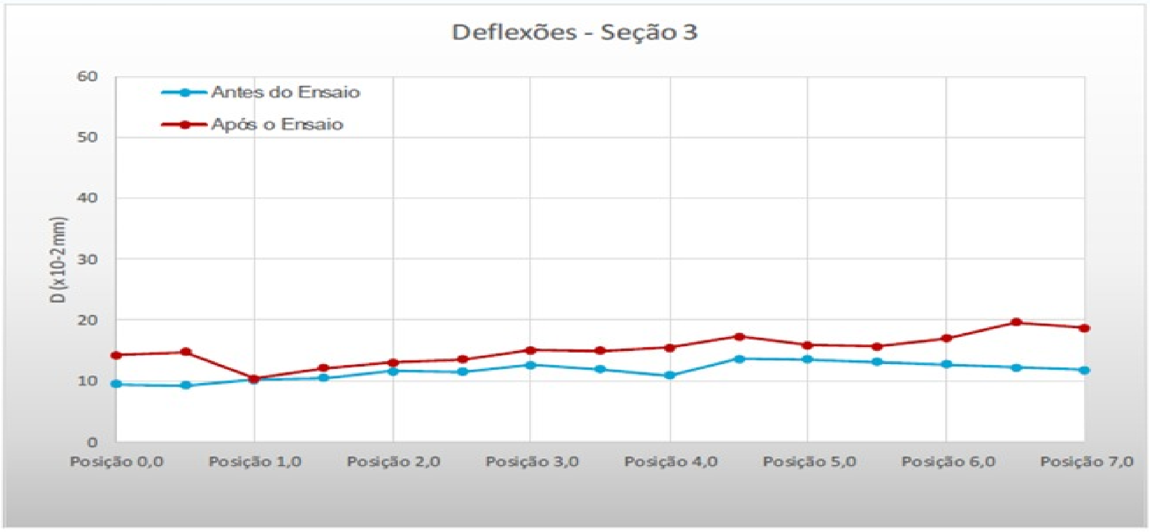

Figure 13 FWD RoadCem result (blue line prior to applying loads, red line after applying loads to simulate 10 years' lifetime)

	Minimum	Maximum	Unit	Standard deviation
Traditional (0 cycles)	12	20	x 10^{-2} mm	5,7
RoadCem (0 cycles)	8	14	x 10^{-2} mm	1,4

Table 4 Minimum and maximum values with the FWD after 0 cycles, including standard deviation.

	Minimum	Maximum	Unit	Standard deviation
Traditional (320.000 cycles)	26	51	x 10^{-2} mm	17,7
RoadCem (320.000 cycles)	10	18	x 10^{-2} mm	7,1

Table 2 Minimum and maximum values with the FWD after 320.000 cycles, including standard deviation

4.3 Functional behavior

4.3.1 Macro texture asphalt

The macro texture is measured in all phases during the heavy vehicle simulator. The traditional construction no longer meets the requirements by 171.999 cycles and the construction with RoadCem by 200.692 cycles. After the measurement values (Hs) have been exceeded, maintenance has been carried out on the asphalt construction. By passing 320.000 cycles, the values (Hs) of the standard construction meet the requirements. The values (Hs) of the construction with RoadCem are between 0,6 and 0,8 mm.

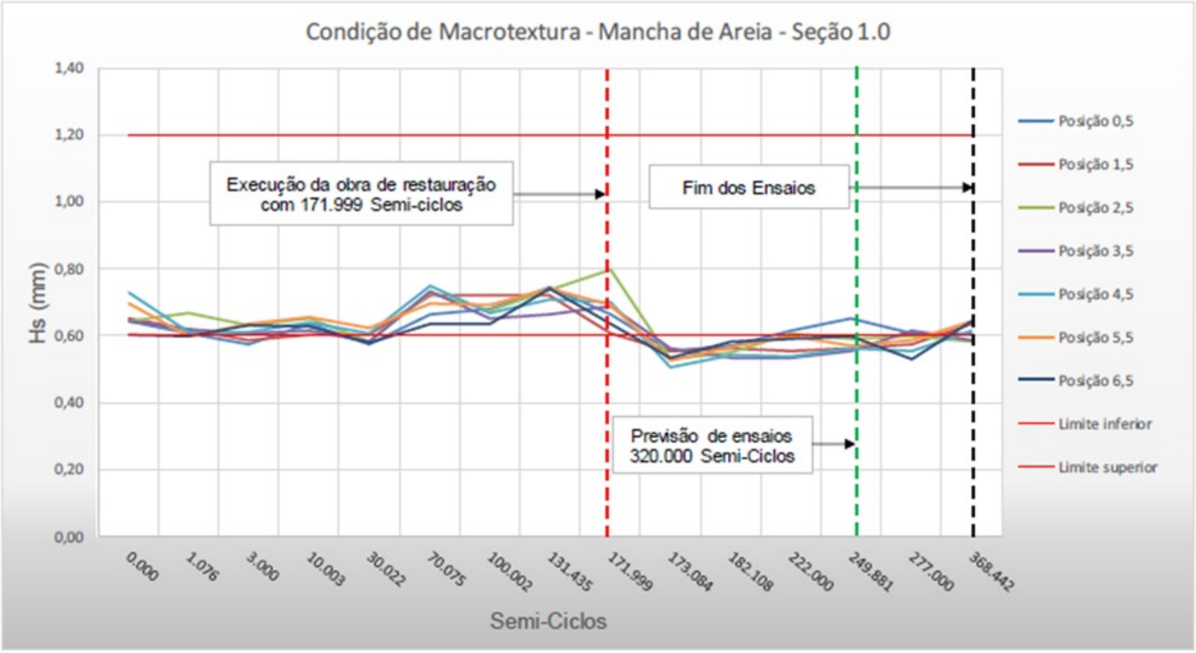

Figure 14 Macro texture traditional construction

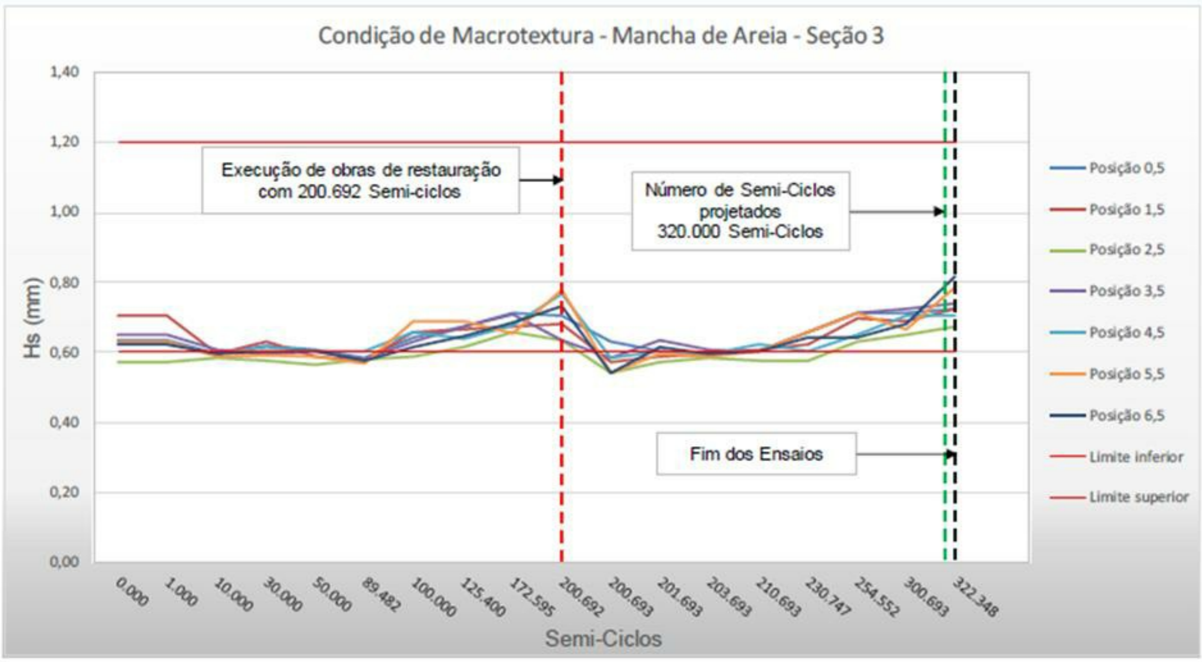

Figure 15 Macro texture RoadCem

	Minimum	Maximum	Unit
Traditional (0 cycles)	0,65	0,72	mm
RoadCem (0 cycles)	0,58	0,70	mm

Table 6 Macro texture minimum and maximum values after 0 cycles

	Minimum	Maximum	Unit
Traditional (171.999 cycles)	0,60	0,80	mm
RoadCem (171.999 cycles)	0,64	0,75	mm

Table 7 Macro texture minimum and maximum values after 171.999 cycles of 160 kN

	Minimum	Maximum	Unit
Traditional (320.000 cycles)	0,56	0,65	mm
RoadCem (320.000 cycles)	0,68	0,79	mm

Table 8 Macro texture minimum and maximum values at simulating 10 years.

4.3.2 Micro texture

The values of the micro texture meet the requirements (47 < VRD < 76) of both structures. Figure 16 and figure 17 shows the results of the micro texture.

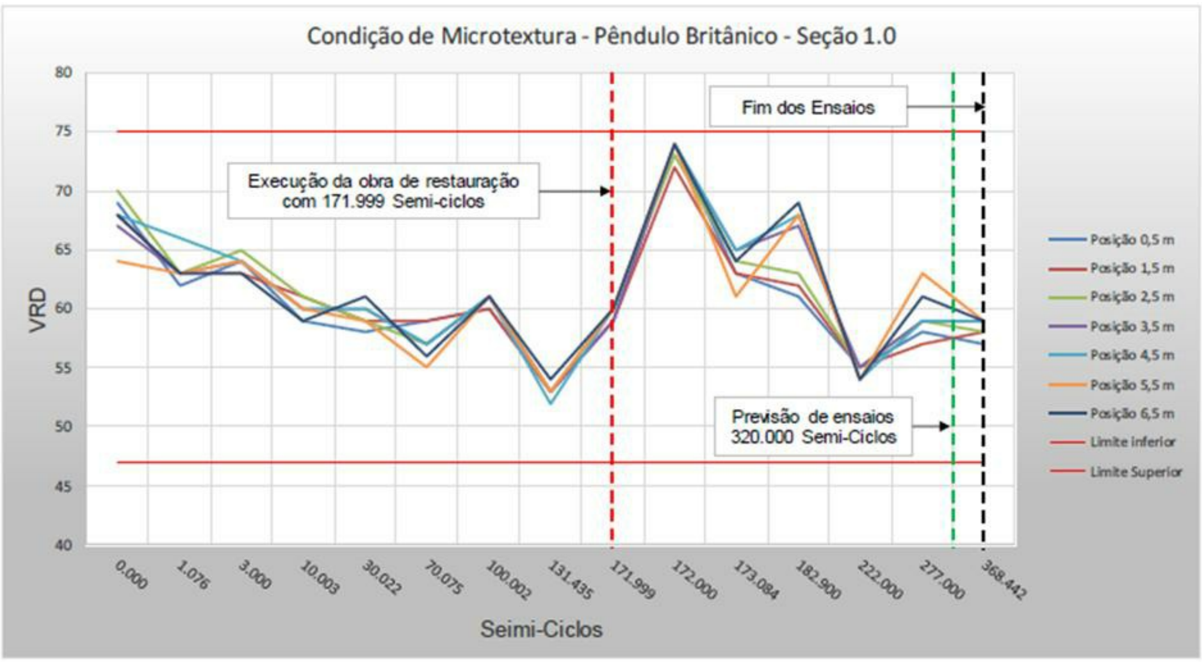

Figure 16 Micro texture traditional construction

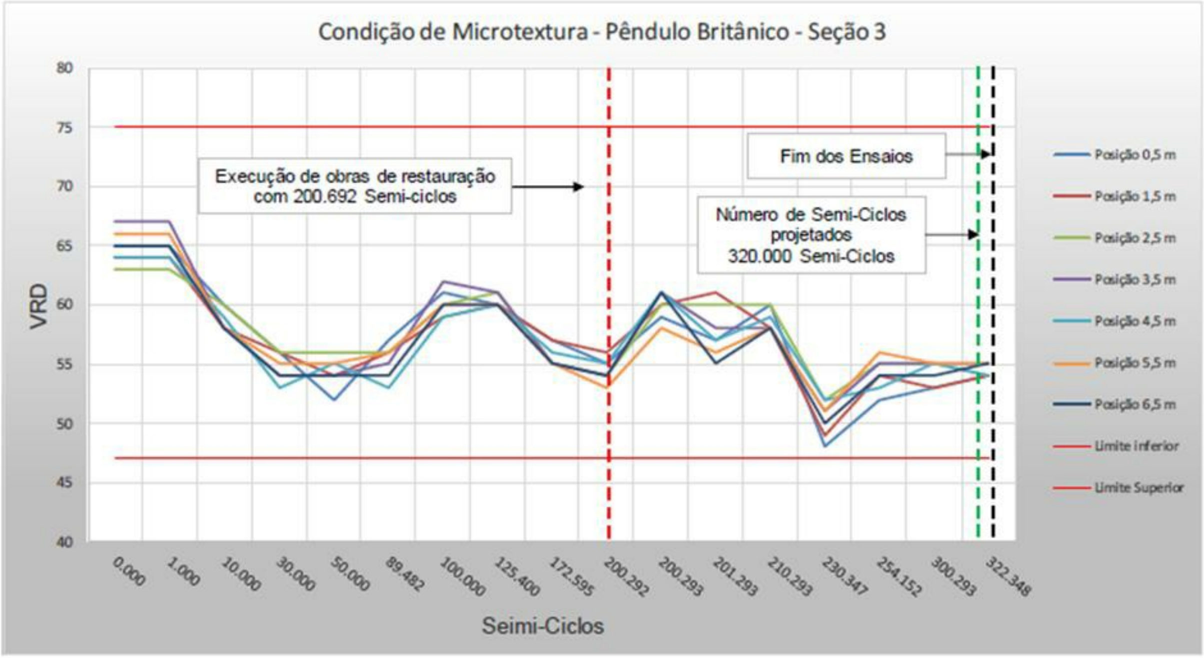

Figure 17 Micro texture RoadCem

	Minimum	Maximum	Unit
Traditional (0 cycles)	64	70	-
RoadCem (0 cycles)	63	67	-

Table 9 Micro texture minimum and maximum values after 0 cycles

	Minimum	Maximum	Unit
Traditional (171.999 cycles)	57	60	-
RoadCem (171.999 cycles)	54	57	-

Table 10 Micro texture minimum and maximum values after 171.999 cycles of 160 kN

	Minimum	Maximum	Unit
Traditional (320.000 cycles)	57	61	-
RoadCem (320.000 cycles)	54	55	-

Table 11 Micro texture minimum and maximum values after 320.000 cycles.

4.3.3 Deformation of the asphalt

During all phases of the Heavy vehicle simulator they measured the deformation of the asphalt.

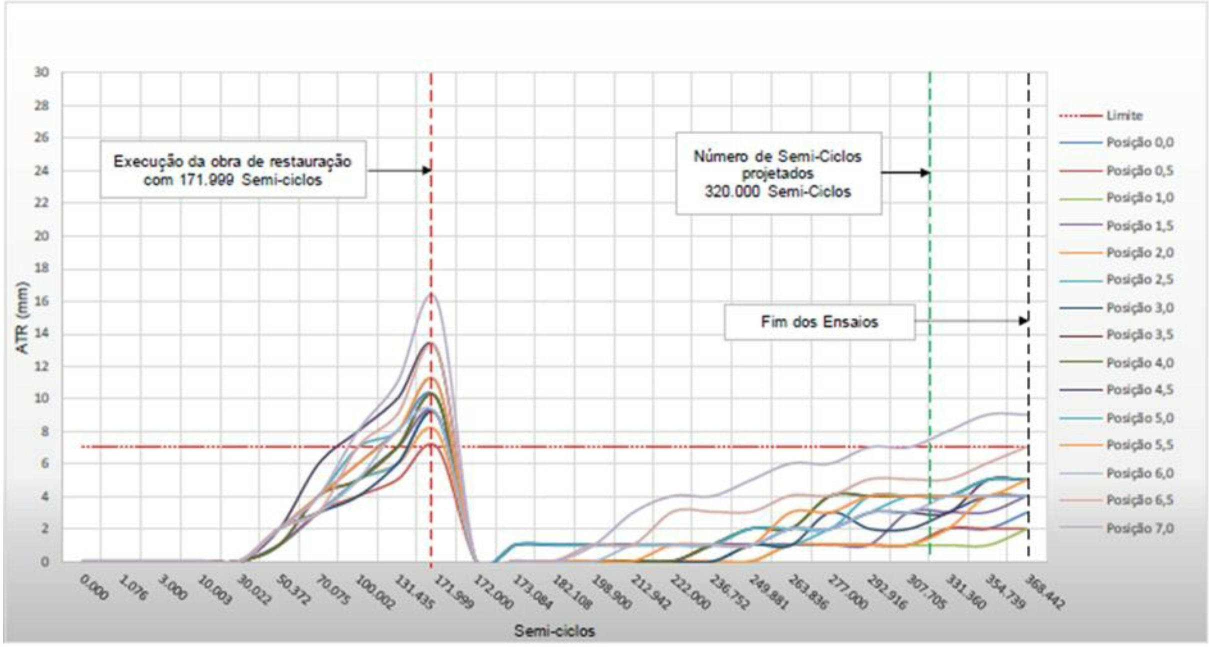

Figure 18 Traditional construction deformation

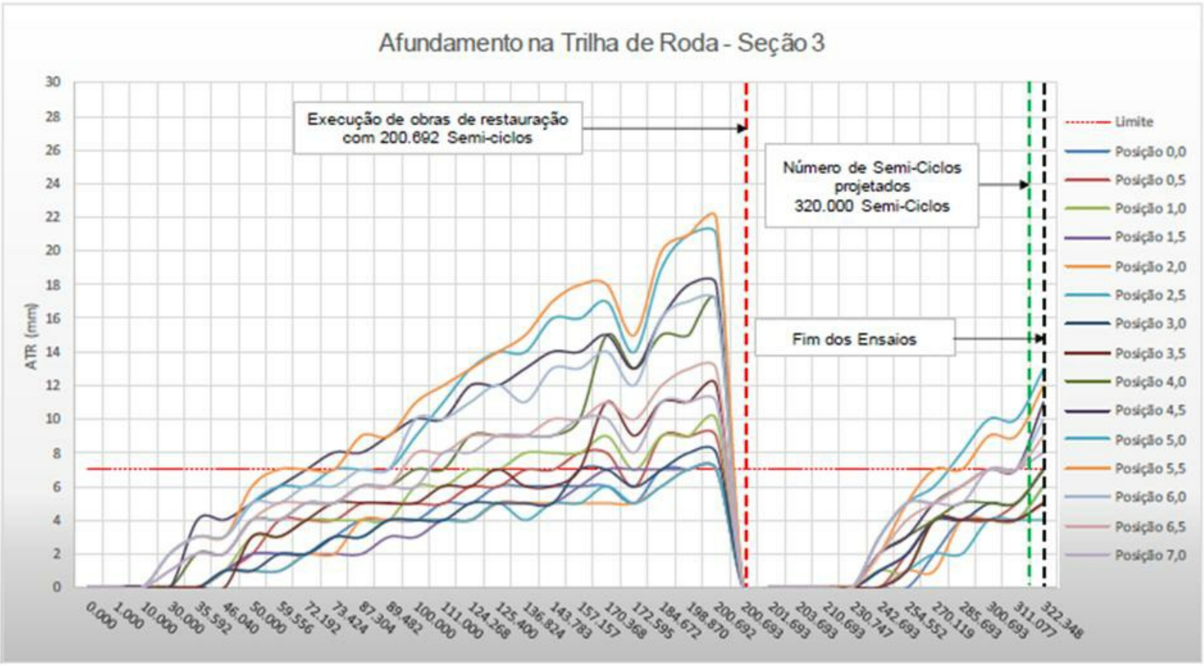

Figure 19 RoadCem construction deformation

4.3.4 Deformation of the asphalt

Traditional construction asphalt surface layer repair was required after 171.999, 160 kN axle load passes.

	Minimum	Maximum	Unit
Traditional (171.999 cycles)	7	16,5	mm
RoadCem (171.999 cycles)	5	15	mm

Table 12 Minimum and maximum values with the Benkelman method after 171.999 cycles of 160 kN

After the load, simulating a period of 10 years after 320.000 cycles of 160 kN axle load passes.

	Minimum	Maximum	Unit
Traditional (320.000 cycles)	1,0	7,5	mm
RoadCem (320.000 cycles)	4,0	11,2	mm

Table 13 Minimum and maximum values with the Benkelman method after 320.000 cycles

4.3.5 Visual

After the simulation there were no cracks in the asphalt construction visually observable. The deformation was under and nearby the track of the Heavy vehicle simulator.

5 INTERPRETATIONS RESULT

5.1 Structural behavior

5.1.1 General

Structural behaviour describes the behavior of the pavement structure prior to maintenance, analyzing if either the asphalt or the foundation needs to be reconstructed. Deflections are indicating the loss of strength clearly of a pavement structure. For the two constructions the structural remaining life time is determined.

To determine the remaining structural lifetime of construction, the following methodology is applied.

Step 1.

Determine and check material properties without subjected to traffic loads. This determination is done by interpolating the Stiffness of the pavement materials in relation with: respectively the applied load of the FWD, the different layer thickness of the asphalt and foundation material, the bearing capacity of the subsoil and the measured deflections under the falling weight. To determine the stiffness versus deflection relation a linear visco-elastic multi-layer program is used. To make a proper comparison the stiffness of the asphalt is fixed on both constructions, assuming that the asphalt has the same properties prior to the subjected loads.

Step 2.

Determine and check material properties after subjected to traffic loads (320.000 axle loads of 160 kN). This determination is done by interpolating the Stiffness of the pavement materials in relation with: respectively the applied load of the FWD, the different layer thickness of the asphalt and foundation material, the bearing capacity of the subsoil and the measured deflections under the falling weight, after the pavement was subjected to this amount of loads. To determine the stiffness versus deflection relation a linear visco-elastic multi-layer program is used.

Step 3.

Based on the calculated stiffness, after 10 years of loading the remaining lifetime can be determined. The stiffness after 10 years is used to calculate the strains at the bottom of the bounded materials, when an equivalent axle load of 80 kN will pass the pavement. For the traditional construction, this is the asphalt layer, for the RoadCem construction this is at the bottom of the RoadCem layer. For the asphalt the following fatigue formula is used:

$$N_{eff} = exp^{(0{,}33796\times\left(\ln\left(E_{dyn}\right)^2\right)-7{,}3642*(\ln\left(E_{dyn}\right)+77{,}142-5{,}2438\times\ln(\varepsilon))}$$

For the RoadCem the following fatigue formula is used:

$$N_{eff} = 10^{(22{,}9-8{,}561\times\log(\varepsilon))}$$

In the following paragraphs the analyses are made for the asphalt construction and the RoadCem construction.

5.1.2 Structural lifetime of the traditional asphalt construction

5.1.2.1 Prior to loading

Input parameters

- the bearing capacity of the subsoil (80 MPa)
- the layer thickness of the asphalt (8 cm)
- the layer thickness of the foundation (37 cm for the traditional construction)
- the load and pressure of the FWD (40 kN and 700 kPa)
- the measured average deflection occurring under the load (see figure 12, blue line), 16,9 * 10^{-2} mm, (169 µm/m)

Calculation interpolation of the initial stiffness

BISAR 3.0 - Block Report

brazilie traditional year 0

System 1: (untitled)

Structure

Layer Number	Thickness (m)	Modulus of Elasticity (MPa)	Poisson's Ratio
1	0,080	1,100E+04	0,35
2	0,370	5,000E+03	0,25
3		8,000E+01	0,35

Loads

Load Number	Vertical Load (kN)	Vertical Stress (MPa)	Horizontal (Shear) Load (kN)	Horizontal (Shear) Stress (MPa)	Radius (m)	X-Coord (m)	Y-Coord (m)	Shear Angle (Degrees)
1	4,000E+01	7,000E-01	0,000E+00	0,000E+00	1,349E-01	0,000E+00	0,000E+00	0,000E+00

Position Number	Layer Number	X-Coord (m)	Y-Coord (m)	Depth (m)	Stresses XX (MPa)	Stresses YY (MPa)	Stresses ZZ (MPa)	Strains XX µstrain	Strains YY µstrain	Strains ZZ µstrain	Displacements UX (µm)	Displacements UY (µm)	Displacements UZ (µm)
1	1	0,000E+00	0,000E+00	0,000E+00	-1,124E+00	-1,124E+00	-7,000E-01	-4,417E+01	-4,417E+01	7,921E+00	0,000E+00	0,000E+00	1,694E+02
2	1	0,000E+00	0,000E+00	8,000E-02	-7,392E-02	-7,392E-02	-5,407E-01	1,284E+01	1,284E+01	-4,445E+01	0,000E+00	0,000E+00	1,676E+02
3	2	0,000E+00	0,000E+00	4,500E-01	2,191E-01	2,191E-01	-8,322E-03	3,328E+01	3,328E+01	-2,357E+01	0,000E+00	0,000E+00	1,523E+02

Figure 20: Interpolation calculation to determine the stiffness of the asphalt and foundation layer corresponding with the deflection found with applying the FWD, prior to the load.

Results

Construction	Thickness	Stiffness
Asphalt	8 cm	11.000 N/mm^2
Base	37 cm	5.000 N/mm^2
Subsoil	-	80 N/mm^2

Table 14 Initial material properties asphalt pavement construction prior to any load

5.1.4.1 After 320.000 load cycles (10 years)

Input parameters

- the bearing capacity of the subsoil (80 MPa)
- the layer thickness of the asphalt (11 cm), after maintenance 3 cm extra asphalt is applied!
- the layer thickness of the foundation (37 cm for the traditional construction)
- the load and pressure of the FWD (40 kN and 700 kPa)
- the measured average deflection occurring under the load (see figure 12, red line), 37,5 * 10^{-2} mm, (375 μm/m)

Calculation interpolation of the stiffness after 10 years

BISAR 3.0 - Block Report

Brazil traditional construction year 10

System 1: (untitled)

Structure

Layer Number	Thickness (m)	Modulus of Elasticity (MPa)	Poisson's Ratio
1	0,110	3,000E+03	0,35
2	0,370	5,250E+02	0,25
3		8,000E+01	0,35

Loads

Load Number	Vertical Load (kN)	Vertical Stress (MPa)	Horizontal (Shear) Load (kN)	Horizontal (Shear) Stress (MPa)	Radius (m)	X-Coord (m)	Y-Coord (m)	Shear Angle (Degrees)
1	4,000E+01	7,000E-01	0,000E+00	0,000E+00	1,349E-01	0,000E+00	0,000E+00	0,000E+00

Position Number	Layer Number	X-Coord (m)	Y-Coord (m)	Depth (m)	Stresses XX (MPa)	Stresses YY (MPa)	Stresses ZZ (MPa)	Strains XX µstrain	Strains YY µstrain	Strains ZZ µstrain	Displacements UX (µm)	Displacements UY (µm)	Displacements UZ (µm)
1	1	0,000E+00	0,000E+00	0,000E+00	-1,343E+00	-1,343E+00	-7,000E-01	-2,092E+02	-2,092E+02	7,995E+01	0,000E+00	0,000E+00	3,766E+02
2	1	0,000E+00	0,000E+00	1,100E-01	6,098E-01	6,098E-01	-3,341E-01	1,711E+02	1,711E+02	-2,537E+02	0,000E+00	0,000E+00	3,652E+02
3	2	0,000E+00	0,000E+00	4,800E-01	8,262E-02	8,262E-02	-2,561E-02	1,302E+02	1,302E+02	-1,275E+02	0,000E+00	0,000E+00	2,672E+02

Figure 21: Interpolation calculation to determine the stiffness of the asphalt and foundation layer corresponding with the deflection found applying the FWD, after 320.000 axle load repetitions of 160 kN.

Results

Construction	Thickness	Stiffness
Asphalt	11 cm	3.000 N/mm^2
Base	37 cm	525 N/mm^2
Subsoil	-	80 N/mm^2

Table 15 Material stiffness asphalt pavement construction after 320.000 cycles of 160 kN.

Conclusion

The asphalt strength and the foundation strength are reduced drastically, after 320.000 cycles of 160 kN.

Construction	Stiffness asphalt prior to load	Stiffness asphalt after 10 year	Reduction	Stiffness foundation prior to load	Stiffness foundation after 10 year	Reduction
Traditional	11000 N/mm^2	3000 N/mm^2	-72,72%	3500 N/mm^2	525 N/mm^2	**-85%**

Table 16 Material stiffness reduction in the asphalt pavement construction after 320.000 cycles of 160 kN.

5.1.4.2 Calculation of remaining lifetime:

Input parameters

- the bearing capacity of the subsoil (80 MPa)
- the layer thickness of the asphalt (11 cm), with a stiffness of 3000 N/mm^2
- the layer thickness of the foundation (37 cm for the traditional construction) with a stiffness of 525 N/mm^2
- the load and pressure of the standard axle truck, 80 kN (4 tires of 20 kN), tire pressure of 577 kPa.
- Fatigue formula for asphalt is applied as mentioned on page 18.

BISAR 3.0 - Block Report

Brazil traditional construction rest life time

System 1: (untitled)

Structure

Layer Number	Thickness (m)	Modulus of Elasticity (MPa)	Poisson's Ratio
1	0,110	3,000E+03	0,35
2	0,370	5,250E+02	0,25
3		8,000E+01	0,35

Loads

Load Number	Vertical Load (kN)	Vertical Stress (MPa)	Horizontal (Shear) Load (kN)	Horizontal (Shear) Stress (MPa)	Radius (m)	X-Coord (m)	Y-Coord (m)	Shear Angle (Degrees)
1	2,000E+01	5,774E-01	0,000E+00	0,000E+00	1,050E-01	0,000E+00	-1,575E-01	0,000E+00
2	2,000E+01	5,774E-01	0,000E+00	0,000E+00	1,050E-01	0,000E+00	1,575E-01	0,000E+00

Position Number	Layer Number	X-Coord (m)	Y-Coord (m)	Depth (m)	Stresses XX (MPa)	Stresses YY (MPa)	Stresses ZZ (MPa)	Strains XX µstrain	Strains YY µstrain	Strains ZZ µstrain	Displacements UX (µm)	Displacements UY (µm)	Displacements UZ (µm)
1	1	0,000E+00	0,000E+00	1,100E-01	2,754E-01	-8,265E-02	-1,401E-01	1,178E+02	-4,334E+01	-6,919E+01	0,000E+00	0,000E+00	3,178E+02
2	1	0,000E+00	-1,575E-01	1,100E-01	4,474E-01	3,563E-01	-2,205E-01	1,333E+02	9,229E+01	-1,673E+02	0,000E+00	-4,251E+00	3,167E+02
3	2	0,000E+00	0,000E+00	4,800E-01	7,501E-02	6,602E-02	-2,280E-02	1,223E+02	1,009E+02	-1,106E+02	0,000E+00	0,000E+00	2,583E+02
4	2	0,000E+00	-1,575E-01	4,800E-01	6,982E-02	5,835E-02	-2,118E-02	1,153E+02	8,797E+01	-1,014E+02	0,000E+00	-1,522E+01	2,513E+02
5	3	0,000E+00	0,000E+00	4,800E-01	2,091E-03	8,232E-04	-2,280E-02	1,223E+02	1,009E+02	-2,978E+02	0,000E+00	0,000E+00	2,583E+02
6	3	0,000E+00	-1,575E-01	4,800E-01	1,913E-03	2,945E-04	-2,118E-02	1,153E+02	8,797E+01	-2,744E+02	0,000E+00	-1,522E+01	2,513E+02

Figure 22: Determine remaining lifetime of the asphalt construction based on the rest strength of the materials in the asphalt pavement structure.

Result

Based on the dynamic elastic modulus and calculated strain at the bottom of the asphalt pavement the life time is determined.

Construction	Stiffness (E_{dyn})	Strain value	Fatigue formula	Amount of admissible N_{eq}
Asphalt	3000 N/mm^2	133 μm/m	$N_{eff} = \exp^{(0,33796*(\ln(E))^2-7,3642*\ln(E)+77,142-5,2438*\ln(\varepsilon))}$	$1,46*10^6$

Table 17 Calculation amount of Standard equivalent axle load of 80 kN (N_{eq}), prior to structural damage (expected sever cracks and rutting)

During a 10 year lifetime the amount equivalent standard axle load repetitions is expected to be $4,65*10^7$. This means that with, $1,46*10^6$ admissible axle load repetitions (N_{eq}) the remaining lifetime is **<u>0,3 years</u>**.

5.1.5 Structural lifetime of the RoadCem pavement construction

5.1.5.1 Prior to loading

Input parameters

- the bearing capacity of the subsoil (80 MPa)
- the layer thickness of the asphalt (7 cm)
- the layer thickness of the foundation (31 cm for the RoadCem construction)
- the load and pressure of the FWD (40 kN and 700 kPa)
- the measured average deflection occurring under the load (see figure 13, blue line), 12,9 * 10^{-2} mm, (129 μm/m)

Calculation interpolation of the initial stiffness

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brazilie roadcem year 0

System 1: (untitled)

Structure

Layer Number	Thickness (m)	Modulus of Elasticity (MPa)	Poisson's Ratio
1	0,070	1,100E+04	0,35
2	0,310	2,600E+04	0,25
3		8,000E+01	0,35

Loads

Load Number	Vertical Load (kN)	Vertical Stress (MPa)	Horizontal (Shear) Load (kN)	Horizontal (Shear) Stress (MPa)	Radius (m)	X-Coord (m)	Y-Coord (m)	Shear Angle (Degrees)
1	4,000E+01	7,000E-01	0,000E+00	0,000E+00	1,349E-01	0,000E+00	0,000E+00	0,000E+00

Position Number	Layer Number	X-Coord (m)	Y-Coord (m)	Depth (m)	Stresses XX (MPa)	Stresses YY (MPa)	Stresses ZZ (MPa)	Strains XX μstrain	Strains YY μstrain	Strains ZZ μstrain	Displacements UX (μm)	Displacements UY (μm)	Displacements UZ (μm)
1	1	0,000E+00	0,000E+00	0,000E+00	-6,536E-01	-6,536E-01	-7,000E-01	-1,635E+01	-1,635E+01	-2,205E+01	0,000E+00	0,000E+00	1,297E+02
2	1	0,000E+00	0,000E+00	7,000E-02	-4,603E-01	-4,603E-01	-6,410E-01	-6,806E+00	-6,806E+00	-2,898E+01	0,000E+00	0,000E+00	1,280E+02
3	2	0,000E+00	0,000E+00	7,000E-02	-4,496E-01	-4,496E-01	-6,410E-01	-6,806E+00	-6,806E+00	-1,601E+01	0,000E+00	0,000E+00	1,277E+02
4	2	0,000E+00	0,000E+00	3,800E-01	4,897E-01	4,897E-01	-5,110E-03	1,418E+01	1,418E+01	-9,614E+00	0,000E+00	0,000E+00	1,245E+02
5	3	0,000E+00	0,000E+00	3,800E-01	-1,007E-03	-1,007E-03	-5,110E-03	1,418E+01	1,418E+01	-5,507E+01	0,000E+00	0,000E+00	1,245E+02

Figure 23: Interpolation calculation to determine the stiffness of the asphalt and RoadCem layer corresponding with the deflection found when applying the FWD, prior to the load.

Results

Construction	Thickness	Stiffness
Asphalt	7 cm	11.000 N/mm^2
Base	31 cm	26.000 N/mm^2
Subsoil	-	80 N/mm^2

Table 18 Initial material properties RoadCem pavement construction prior to any load

5.1.5.2 After 320.000 load cycles (10 years)

Input parameters

- the bearing capacity of the subsoil (80 MPa)
- the layer thickness of the asphalt (9 cm),
- the layer thickness of the foundation (31 cm)
- the load and pressure of the FWD (40 kN and 700 kPa)
- the measured average deflection occurring under the load (see figure 13, red line), 14,9 * 10^{-2} mm, (149 μm/m)

Calculation interpolation of the stiffness after 10 years

BISAR 3.0 - Block Report

brazilie roadcem year 10

System 1: (untitled)

Structure

Layer Number	Thickness (m)	Modulus of Elasticity (MPa)	Poisson's Ratio
1	0,090	3,000E+03	0,35
2	0,310	2,600E+04	0,25
3		8,000E+01	0,35

Loads

Load Number	Vertical Load (kN)	Vertical Stress (MPa)	Horizontal (Shear) Load (kN)	Horizontal (Shear) Stress (MPa)	Radius (m)	X-Coord (m)	Y-Coord (m)	Shear Angle (Degrees)
1	4,000E+01	7,000E-01	0,000E+00	0,000E+00	1,349E-01	0,000E+00	0,000E+00	0,000E+00

Position Number	Layer Number	X-Coord (m)	Y-Coord (m)	Depth (m)	Stresses XX (MPa)	Stresses YY (MPa)	Stresses ZZ (MPa)	Strains XX µstrain	Strains YY µstrain	Strains ZZ µstrain	Displacements UX (µm)	Displacements UY (µm)	Displacements UZ (µm)
1	1	0,000E+00	0,000E+00	0,000E+00	-4,146E-01	-4,146E-01	-7,000E-01	-8,152E+00	-8,156E+00	-1,366E+02	0,000E+00	0,000E+00	1,482E+02
2	1	0,000E+00	0,000E+00	9,000E-02	-3,888E-01	-3,888E-01	-6,445E-01	-9,049E+00	-9,049E+00	-1,241E+02	0,000E+00	0,000E+00	1,351E+02
3	2	0,000E+00	0,000E+00	9,000E-02	-5,286E-01	-5,286E-01	-6,445E-01	-9,049E+00	-9,049E+00	-1,463E+01	0,000E+00	0,000E+00	1,351E+02
4	2	0,000E+00	0,000E+00	4,000E-01	5,184E-01	5,184E-01	-5,595E-03	1,501E+01	1,501E+01	-1,018E+01	0,000E+00	0,000E+00	1,320E+02
5	3	0,000E+00	0,000E+00	4,000E-01	-1,166E-03	-1,166E-03	-5,595E-03	1,501E+01	1,501E+01	-5,974E+01	0,000E+00	0,000E+00	1,320E+02

Figure 24: Interpolation calculation to determine the stiffness of the asphalt and RoadCem layer corresponding with the deflection found applying the FWD, after 320.000 axle load repetitions of 160 kN.

Results

Construction	Thickness	Stiffness
Asphalt	9 cm	3.000 N/mm^2
Base	31 cm	26.000 N/mm^2
Subsoil	-	80 N/mm^2

Table 19 Material stiffness RoadCem pavement construction after 320.000 cycles of 160 kN.

Conclusion

After 320.000 cycles of 160 Kn, the asphalt strength is reduced, however the RoadCem strength is not reduced

Construction	Stiffness asphalt prior to load	Stiffness asphalt after 10 year	Reduction	Stiffness foundation prior to load	Stiffness foundation after 10 year	Reduction
RoadCem	11000 N/mm^2	3000 N/mm^2	-72,72%	26000 N/mm^2	26000 N/mm^2	**0%**

Table 20 Material stiffness reduction in the asphalt pavement construction after 320.000 cycles of 160 kN.

5.1.5.3 Calculation of remaining lifetime:

Input parameters

- the bearing capacity of the subsoil (80 MPa)
- the layer thickness of the asphalt (9 cm), with a stiffness of 3.000 N/mm^2
- the layer thickness of the RoadCem foundation (31 cm for the RoadCem construction), with a stiffness of 26.000 N/mm^2.
- the load and pressure of the standard axle truck, 80 kN (4 tires of 20 kN) , tire pressure of 577 kPa.
- Fatigue formula for asphalt is applied as mentioned on page 18.

BISAR 3.0 - Block Report

Brazil roadcem construction rest life time

System 1: (untitled)

Structure

Layer Number	Thickness (m)	Modulus of Elasticity (MPa)	Poisson's Ratio
1	0,090	3,000E+03	0,35
2	0,310	2,600E+04	0,25
3		8,000E+01	0,35

Loads

Load Number	Vertical Load (kN)	Vertical Stress (MPa)	Horizontal (Shear) Load (kN)	Horizontal (Shear) Stress (MPa)	Radius (m)	X-Coord (m)	Y-Coord (m)	Shear Angle (Degrees)
1	2,000E+01	5,774E-01	0,000E+00	0,000E+00	1,050E-01	0,000E+00	-1,575E-01	0,000E+00
2	2,000E+01	5,774E-01	0,000E+00	0,000E+00	1,050E-01	0,000E+00	1,575E-01	0,000E+00

Position Number	Layer Number	X-Coord (m)	Y-Coord (m)	Depth (m)	Stresses XX (MPa)	Stresses YY (MPa)	Stresses ZZ (MPa)	Strains XX µstrain	Strains YY µstrain	Strains ZZ µstrain	Displacements UX (µm)	Displacements UY (µm)	Displacements UZ (µm)
1	1	0,000E+00	0,000E+00	9,000E-02	-1,020E-01	-1,100E-01	-1,007E-01	-9,424E+00	-1,304E+01	-8,812E+00	0,000E+00	0,000E+00	1,319E+02
2	2	0,000E+00	0,000E+00	9,000E-02	-3,853E-01	-4,604E-01	-1,007E-01	-9,424E+00	-1,304E+01	4,260E+00	0,000E+00	0,000E+00	1,319E+02
3	1	0,000E+00	-1,575E-01	9,000E-02	-3,020E-01	-2,991E-01	-4,954E-01	-7,970E+00	-6,682E+00	-9,500E+01	0,000E+00	1,499E+00	1,319E+02
4	2	0,000E+00	-1,575E-01	9,000E-02	-4,325E-01	-4,057E-01	-4,954E-01	-7,970E+00	-6,681E+00	-1,099E+01	0,000E+00	1,499E+00	1,319E+02
5	2	0,000E+00	0,000E+00	4,000E-01	4,714E-01	4,225E-01	-5,251E-03	1,412E+01	1,177E+01	-8,797E+00	0,000E+00	0,000E+00	1,309E+02
6	3	0,000E+00	0,000E+00	4,000E-01	-1,165E-03	-1,304E-03	-5,251E-03	1,412E+01	1,177E+01	-5,484E+01	0,000E+00	0,000E+00	1,309E+02
7	2	0,000E+00	-1,575E-01	4,000E-01	4,500E-01	3,987E-01	-5,100E-03	1,352E+01	1,106E+01	-8,356E+00	0,000E+00	-1,823E+00	1,298E+02
8	3	0,000E+00	-1,575E-01	4,000E-01	-1,163E-03	-1,308E-03	-5,100E-03	1,350E+01	1,106E+01	-5,294E+01	0,000E+00	-1,823E+00	1,298E+02

Figure 25: Determine remaining lifetime of the asphalt construction based on the rest strength of the materials in the RoadCem pavement structure.

Result
Based on the dynamic elastic modulus and calculated strain at the bottom of the asphalt pavement the life time is determined.

Construction	Stiffness (E_{dyn})	Strain value	Fatigue formula	Amount of admissible N_{eq}
RoadCem	26.000 N/mm^2	14,2 μm/m	$N_{eff} = 10^{(22,9-8,561*\log(\varepsilon))}$	> 10^{10}

Table 17 Calculation amount of Standard equivalent axle load of 80 kN (N_{eq}), prior to structural damage

During a 10 year lifetime the amount equivalent standard axle load repetitions is expected to be 4,65*10^7.
This means that with, 10*10^{10} admissible axle load repetitions (N_{eq}) the remaining lifetime is an additional **20 years above the 10 years the RoadCem construction was designed for**.

5.2 Functional behavior

5.2.1 General

For the functional behavior several tests were made. However, the effect of the load will have a larger deviating effect than can be expected for the road structure. For example, the load of 160 kN is not representative compared with 80 kN. The reason for this is that inside the construction, stresses and strains will behave completely different through the several layers. The asphalt mix will be more subjected to damage process which will not occur when a load of 80 kN is load. For example, when a certain value of stress or strains in the asphalt mix is crossed, stones can start crushing, bitumen's are squeezed out, etc, which would never occur if these values are not crossed.

However, to make a comparison between the asphalt behaviour on the Traditional construction and the RoadCem construction, extensive calculations are made [4].

5.2.2 Macro-texture asphalt

Regarding the macro-texture asphalt, no maintenance is required during the lifetime for the Traditional pavement construction as well as for the RoadCem construction.

5.2.3 Micro-texture asphalt

Regarding the micro-texture asphalt, no maintenance is required during the lifetime for the Traditional pavement construction as well as for the RoadCem construction.

5.2.4 Deformation of the asphalt

Based on figure 18 and 19 that with a traditional construction, prior to the RoadCem construction, maintenance, for the functionality would be required due to rutting. This is required on the traditional construction after 171.999 cycles and for RoadCem it is required after more than 200.000 cycles based on a standard axle load of 160 kN.

By analyzing the increase of the occurrence of the deformation, 4 sections can be noted regarding the measured deformations in the traditional construction (table 18), and on the RoadCem construction (table 19):

Construction	$0\text{-}3\times10^4$ cycles asphalt 8 cm	$3\times10^4\text{-}17\times10^4$ cycles asphalt 8 cm	$17\times10^4\text{-}23\times10^4$ cycles asphalt 11 cm	$23\times10^4\text{-}36\times10^4$ cycles asphalt 11 cm
Traditional	0	$7{,}8*10^{-5}$	$1*10^{-5}$	$2{,}7*10^{-5}$

Table 18: Analyses increases of deformation on the traditional construction with standard axle load of 160 kN

Construction	$0\text{-}1\times10^4$ cycles asphalt 7 cm	$1\times10^4\text{-}20\times10^4$ cycles asphalt 7 cm	$20\times10^4\text{-}23\times10^4$ cycles asphalt 11 cm	$23\times10^4\text{-}32\times10^4$ cycles asphalt 11 cm
RoadCem	0	$6{,}3*10^{-5}$	0	$7{,}6*10^{-5}$

Table 19: Analyses increases of deformation on the RoadCem construction with standard axle load of 160 kN

As can be noticed in table 18, during the first 10.000 cycles of 160 kN no rutting at all occurred with an asphalt layer thickness of 7 cm, and between 10.000 cycles and 200.000 cycles there was a relatively low increase of the rutting in the wheel track. This increase is less than with a traditional construction. So the asphalt on top of the RoadCem construction is less affected by heavy loads than the traditional construction.

The rutting is the result of the Heavy Vehicle Simulator. The shape of the rutting explains the rout cause. Asphalt is a viscous elastic material that can deform plastically in case of overload. As a result, the material can start to flow, resulting in rutting (Figure 26). When a material is locally loaded to close to collapse, up that spot plastically deform the material. In this process, redistribution of tensions must occur. This is a part of the tensions transferred to the adjacent material. As the material for this purpose state creates a stable situation, if that is not possible the material flows away.

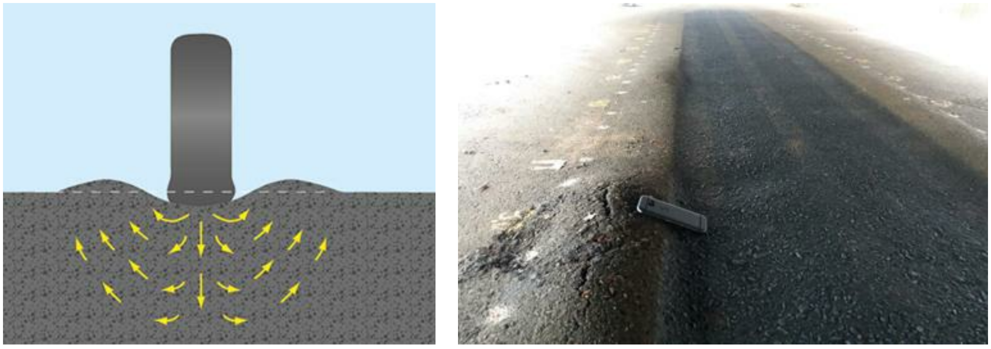

Figure 26 Rutting process caused by shift in tensions due to decrease of stiffness in the pavement materials.

To analyze the results of the test, on the functional behaviour, it is important to know two important factors in the simulating machine.
- The load is 160 kN under controlled temperature.
- The heavy loads are occurring every few seconds, so the occurrence of healing of the asphalt cannot occur during the tests. Healing is an important factor in visco-elastic materials. After a heavy load passed the visco-elastic material had the capability to heal itself.

A model was made to compare the differences between a RoadCem stabilization with an asphalt thickness of 7 cm, when the load would be 80 kN, where the asphalt mix designs are based on! and the overload of 160 kN applied on top of the asphalt [4]. As can be noticed in figure 27 and 28 with a RoadCem construction the deformation will be less than with a traditional construction at 7 cm thickness.

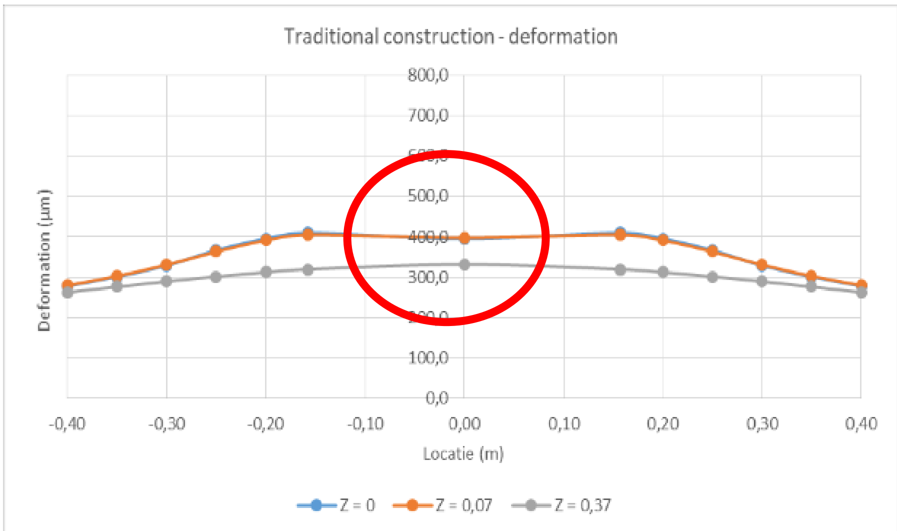

Figure 27 deformation after 1 load on the traditional construction

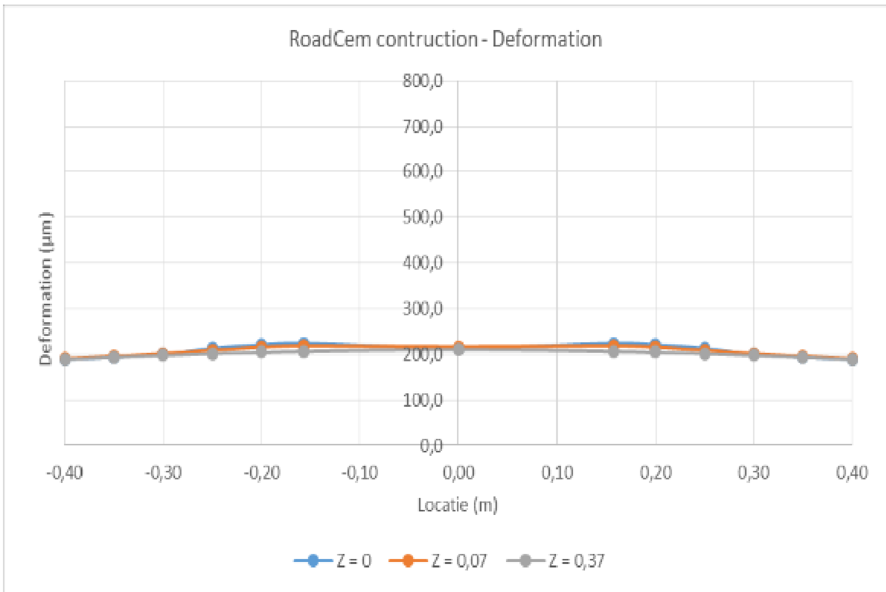

Figure 28 deformation after 1 load on the RoadCem construction

Based on the outcome of the model [4] the deflection in the wheel track would be reduced with 50%. Leading towards a decrease of stresses and strains in the asphalt.
Due to the fact that the stiffness of asphalt will not decrease that fast during the actual loading of 80 kN, healing effect, lower temperature also will occur, the chance of rutting during the first 10 years is not to be expected, with a thickness of 7 cm of asphalt.

In figure 29 it can be clearly noticed that during the tests with the simulation of 160 kN the horizontal stress in the traditional construction (red curve) is higher on every part in the asphalt construction compared with a RoadCem construction. This resulted in faster maintenance due to rutting on the traditional construction (figure 18).

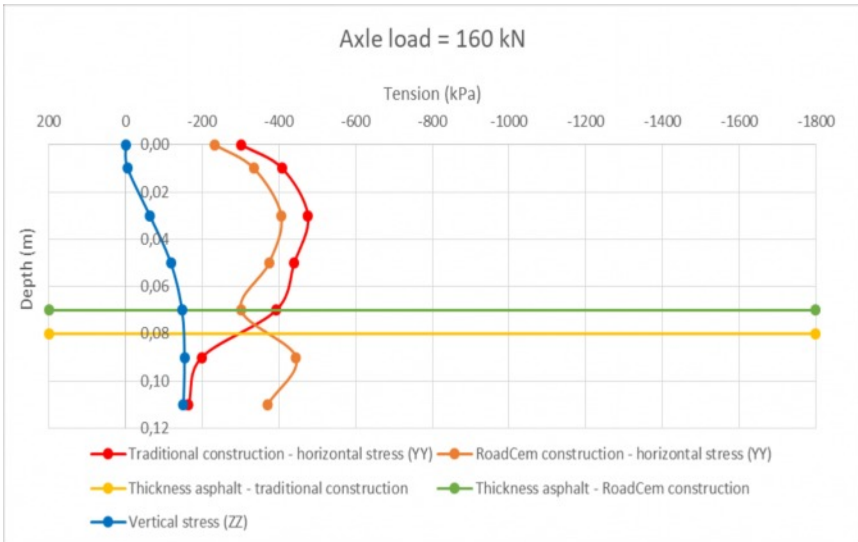

Figure 29 Horizontal stress in traditional construction (red line), with 8 cm of asphalt and RoadCem construction (orange line) with 7 cm of asphalt.

After a lifetime simulation of 5 years, the asphalt layer was made thicker (+ 3 cm) in the traditional construction (new asphalt thickness =11 cm), and on the RoadCem construction the surface layer was removed (-3 cm) and a new surface layer of asphalt (+ 5 cm) was laid over the asphalt under layer, resulting in a total asphalt thickness of 9 cm. The rutting occurred on top of the RoadCem layer (figure 19) according the measurements. The calculation model shows that in the traditional construction the horizontal stress occurred high in the new surface layer, and then reduced in the older layer. However due to the fact that it is a new layer, it is able to bear the horizontal stresses. With RoadCem the new asphalt that is laid on the roadcem layer is 5 cm thicker, this results in possible faster rutting behavior due to the fact of an unstable asphalt mix on top.

Figure 30 Horizontal stress in traditional construction (red line), with 3 cm of new asphalt and RoadCem construction (orange line) with 5 cm of new asphalt.

However the most important question is to predict if rutting would occur in the asphalt layers (total thickness 7 cm) on top of the RoadCem layer, in graph 31, the horizontal stress relation shows that the horizontal stress in the RoadCem construction is less through the whole asphalt thickness compared with a traditional construction. Also compared with a load of 160 kN it shows a reduction of 50% for the calculated maximum horizontal stress. So deformation is not expected with the maximum axle load for highways of 80 kN.

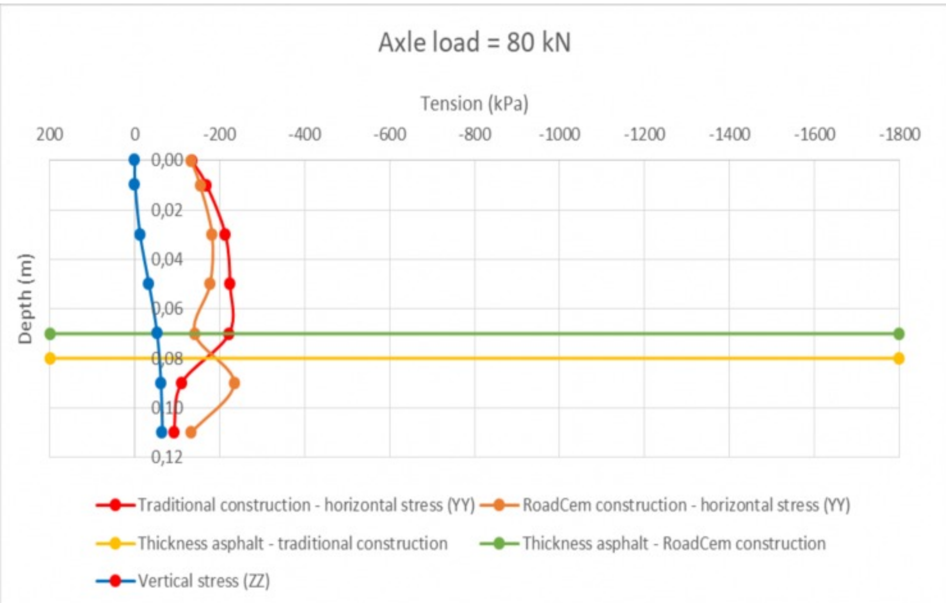

Figure 31 Horizontal stress in the traditional construction (red line) is higher in comparison to the asphalt on top of the RoadCem construction (orange line) with a load of 80 kN.

6 CONCLUSION

Hereby, we provide our conclusion which is based on the results of the research conducted, historical input, and our interpretations of all the information disclosed in the Dynatest report. In the conclusion, a comparison is presented between the functional lifetime, leading towards reduced maintenance, lower costs, and longer structural lifetime.

Functional lifetime

1. The functional lifetime on RoadCem stabilization is longer than a traditional asphalt construction, in cases where the asphalt thickness (8 cm in two layers) is the same. In the traditional construction, rutting occurred at an earlier stage than with the RoadCem stabilization. The test results demonstrated a rutting value higher than 7 mm over all the measurement points once the traditional construction reached over 171.999 axle load repetitions of 160 kN while in the RoadCem construction, it only reached over 200.692 axle load repetitions of 160 kN. This results in approximately 15% longer functional lifetime on the RoadCem construction.

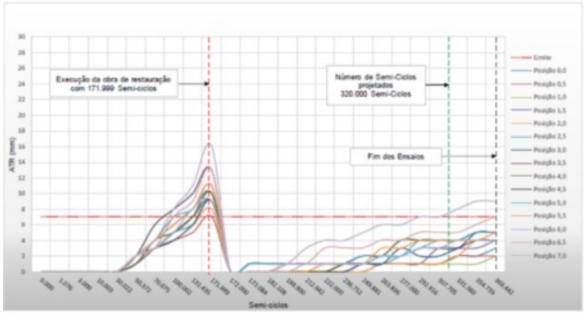

Figure 29 Traditional construction deformation

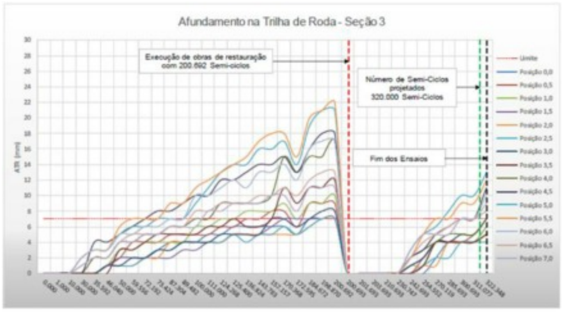

Figure 8 RoadCem construction

2. After the intervention, the traditional construction has an asphalt thickness of 11 cm and the RoadCem construction of 9 cm, the functional lifetime of the traditional asphalt pavement is extended due to this asphalt overlay of 2 cm.
3. The rutting in the asphalt is externally influenced by the load, temperature, and supporting material of the asphalt layer, along with the material characteristics of the asphalt. PowerCem Technologies engineers used the BISAR calculation system to simulate the differences in performance of deflection with one axe load of 80 kN with an asphalt that has the same characteristics on the traditional, as well as on the stronger RoadCem base. Based on the calculations, more rutting can be expected in a traditional construction, as confirmed in the tests (1). In case the load is 80 kN the deformation will be reduced to ca. 50% on a RoadCem construction compared with a traditional construction, resulting in a decrease of stresses and strains, in the construction materials. By decreasing the stresses and strain in the asphalt, rutting in a 7 cm asphalt thickness on top of the RoadCem will be significantly reduced, compared with loads of 160 kN, with high temperatures on the asphalt and the reduce of healing. In fact the lifetime of the 7 cm asphalt could reach 10 years without over exceeding rutting values. However the asphalt mix need to be well designed and less variance should occur in the outcome of the performances of the asphalt.

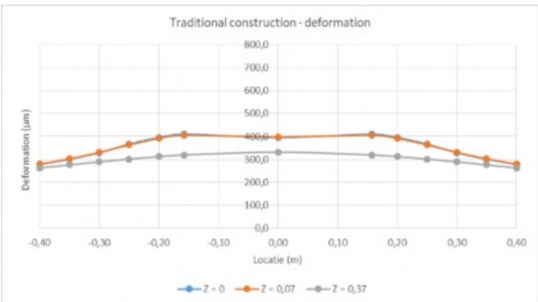

Figure 31 Traditional construction deformation

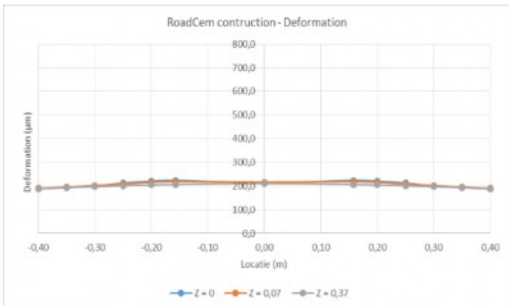

Figure 32 RoadCem construction deformation

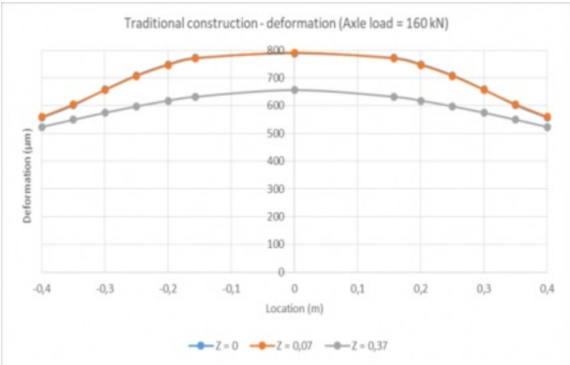

Figure 33 Traditional construction deformation (160kN) with 9 cm asphalt

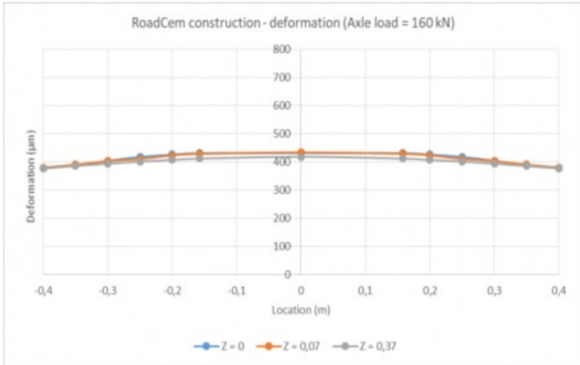

Figure 34 RoadCem construction deformation (160kN) with 7 cm of asphalt

4. The maintenance intervention value on the asphalt is unpredictable, based on the fact of the large variance in data. This will have a higher impact on the maintenance management. However, the calculation results demonstrate that with every load the rutting with the RoadCem construction is lower, with an extended functional lifetime.

Structural lifetime

The structural performance is based on deflection measurements of the FWD test. The tests were performed prior to any load of 40 kN (stress of 700 kPa) and after the simulation of 10 years, with a load of 160 kN. The results are presented in figure 22-23. Based on the deformation, it is evident the difference with and without loading, in the traditional construction the deflections are significantly increased (table 8).

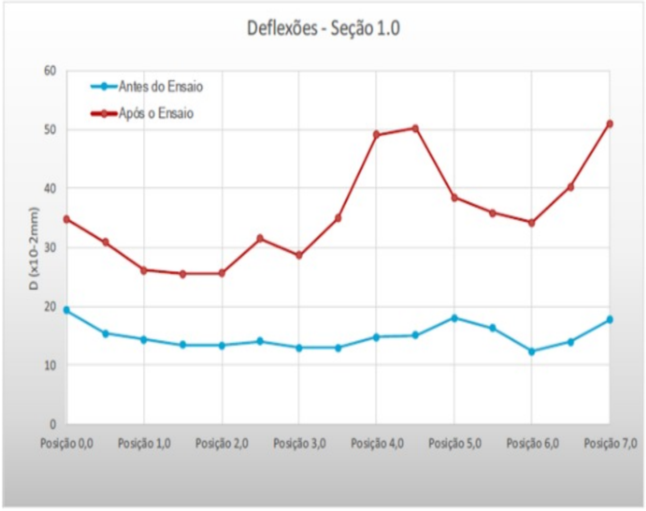

Figure 33 Traditional construction deflection

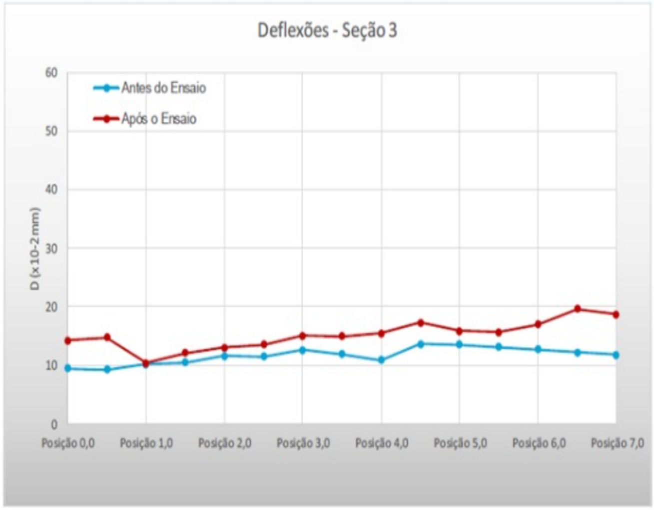

Figure 34 RoadCem construction deflection

The construction with RoadCem behaves in a more consistent manner compared to the traditional construction. This conclusion is based on the results of the FWD (Chapter 4; figure 11). This means there is more variance on the structural behaviour of a traditional construction which results in a less profitable road maintenance management system.

Based on a BISAR calculation the measurement is simulated. Based on the tension and load of the falling weight, the average measured deflection, the stiffness of the base, and the measured pavement thickness, the elastic modulus of the overall pavement construction are determined. This calculation is done before and after the loading. It is assumed that the effective height is the same as the full thickness of the pavement construction.

Construction	Average deflection prior to load	Average deflection after loads (10 years)
Traditional	16,9*10^{-2} mm	37,5 *10^{-2} mm
RoadCem	12,9*10^{-2} mm	14,9 *10^{-2} mm

Table 20 Measured deflection before and after loading the test track.

Construction	Stiffness asphalt prior to load	Stiffness asphalt after 10 year	Reduction	Stiffness foundation prior to load	Stiffness foundation after 10 year	Reduction
Traditional	11000 N/mm^2	3000 N/mm^2	-72,72%	3500 N/mm^2	525 N/mm^2	-85%
RoadCem	11000 N/mm^2	3000 N/mm^2	-72,72%	26000 N/mm^2	26000 N/mm^2	0%

Table 21 Reduction structural performance of the materials

On the RoadCem pavement, the difference is relatively smaller before and after the load, at some point there is not even an increased deflection after loading (position=1 m), what seems to be the perpetual pavement behaviour.

Based on the calculated elastic modulus after 10 years, a BISAR calculation was made to evaluate the structural lifetime for loads at 80 kN.

Construction	Strain value	Fatigue formula	Rest lifetime
Traditional	133 μm/m	$N_{eff} = \exp^{(0,33796*(\ln(E))\wedge 2-7,3642*\ln(E) +77,142-5,2438*\ln(\varepsilon))}$	0,3 years
RoadCem	14 μm/m	$N_{eff} = 10^{(22,9-8,561*\log(\varepsilon))}$	> 20 years

Table 22 Indicative lifetime

RoadCem construction has a longer lifetime due to a large safety factor held in the design methodology, since in-situ materials are stabilized as shown in test procedures.

Overall performance and maintenance
Based on the tests performed with a load of 160 kN, the scattering in data of deformation in the asphalt is very diverse, and therefore not possible to determine the intervention moments. However, the intervention moments will be reduced by using RoadCem due to the effect of the stronger support on the asphalt applied on top of the base. Also, the results show that maintenance will be reduced when using RoadCem.

Based on the deflection tests, prior and after loads, an indicative estimation was calculated on the structural lifetime. By using RoadCem it is clear that the structural performance after 10 years will be extended for an additional 20-year lifetime when loads of 80 kN are applied. In comparison, the traditional construction needs to be fully reconstructed, resulting in higher costs once it reaches the 10 year lifetime.

Dutch project inspections
Projects constructed in the Netherlands were also visited and inspected prior to issue this report.
Such projects show no deformation occurred in the asphalt after 5 years over the RoadCem base. In the Netherlands, the allowed axle load is 100 kN, which we believe to be more than the limit axle load allowed in Brazil. Also, the long structural lifetime performance of stabilized material can be expected, especially in case low strains are occurring in the material.

Figure 35 Asphalt on top of a RoadCem stabilization on Dutch road network, inspected by ARCADIS. No deformations occurred with standard axle load 100 kN.

COLOFON

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