



# PIARC International Seminar

## Technical Committee 4.1 Pavements

### Use of Recycled Materials in Pavements

Cold in-place recycling with cement – Rehabilitation Works in National Road 4 (EN4)

Eugénia Correia, Pedro Carvalho, Anabela Martins, Helder Lourenço

PIARC / Infraestruturas de Portugal

Argentina – Virtual Mode

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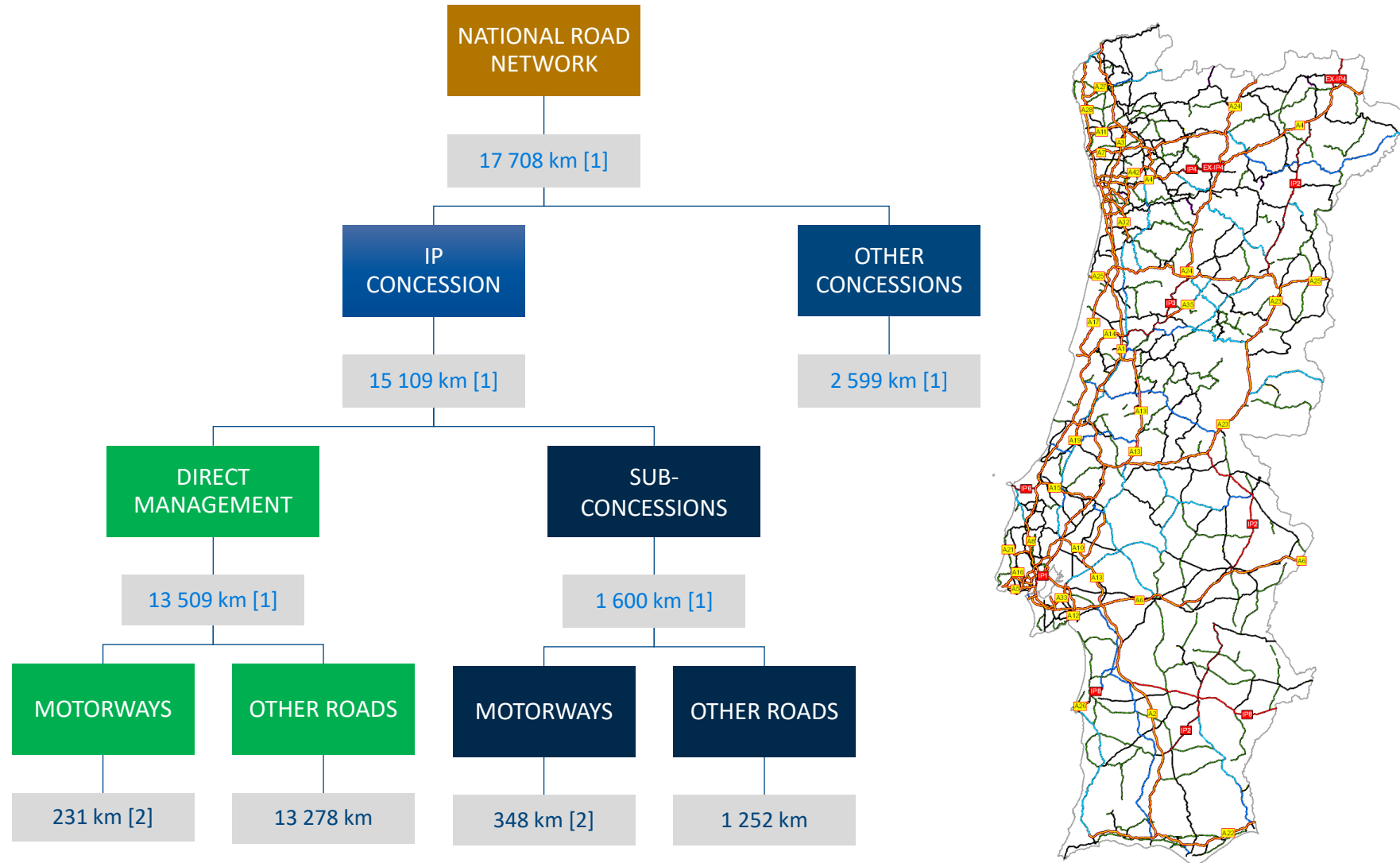
# INFRAESTRUTURAS DE PORTUGAL

## About us

- **INFRAESTRUTURAS DE PORTUGAL** results from the merger between two Portuguese public institutes **REFER** - National Railway Network and **EP - Estradas de Portugal** – National Road Network.
- The merger was celebrated on June, 1<sup>st</sup> 2015, following the Law Decree No. 91/2015 of May, 29<sup>th</sup>



# Portuguese National Road Network



Source: [1] Rede Rodoviária Nacional – Extensão das vias – January 2017, IP ; [2] DCO, IP

# COLD IN-PLACE RECYCLING WITH CEMENT – REHABILITATION WORKS IN NATIONAL ROAD 4 (EN4) - INTERSECTION WITH EN 118 MONTIJO (KM 18+750) AND INTERSECTION WITH EN10 PEGÕES (KM 44+257)

## Portuguese Rehabilitation Strategy Framework

- After decades of investment in the construction of new road sections, and with the implementation of a large part of the Portuguese National Road Plan 2000 (PRN2000) concluded; the priority for the Portuguese National Road Administration is to direct the financial resources available mostly, to the Rehabilitation / Maintenance and Improvement of the existing National Road Network.
- To create strategies, of pavement rehabilitation solutions with a view to a better use of the available resources, either economically, either existing materials. One of the best solutions for good technical, economic and environmentally sustainable management of material resources and inserted in a perspective of circular economy is the use of recycled materials in pavements.
- The "circular economy" is presented as a production/consumption model that promotes the use of resources, presenting itself as an alternative to the so-called "linear economy". One of the key ideas to "circular economy" is the idea of a closed loop, with zero waste, where materials required for production are, in almost its entirety, derived from the recycling of materials and not extraction.



# COLD IN-PLACE RECYCLING WITH CEMENT – REHABILITATION WORKS IN NATIONAL ROAD 4 (EN4) - INTERSECTION WITH EN 118 MONTIJO (KM 18+750) AND INTERSECTION WITH EN10 PEGÕES (KM 44+257)

## Case Study: Rehabilitation of EN 4: 25,5 KM

- Rehabilitation of the National Road EN 4 between the Intersection with National Road EN 118 near Montijo (km 18 + 750) and the intersection with EN10 near Pegões (km 44 + 257), in a total length of 25,5 km.
- The recommended strategy for this project was to study solutions with a high rate of reuse of existing materials and at the same time guarantee a lower cost for intervention.
- In this case study, the technical, economic and environmental advantages / disadvantages are evaluated by implementing the in place recycling solution versus a traditional solution (removing pavement and implementing new paving structures), as well as the importance of laboratory control on site, in the success of the solution.



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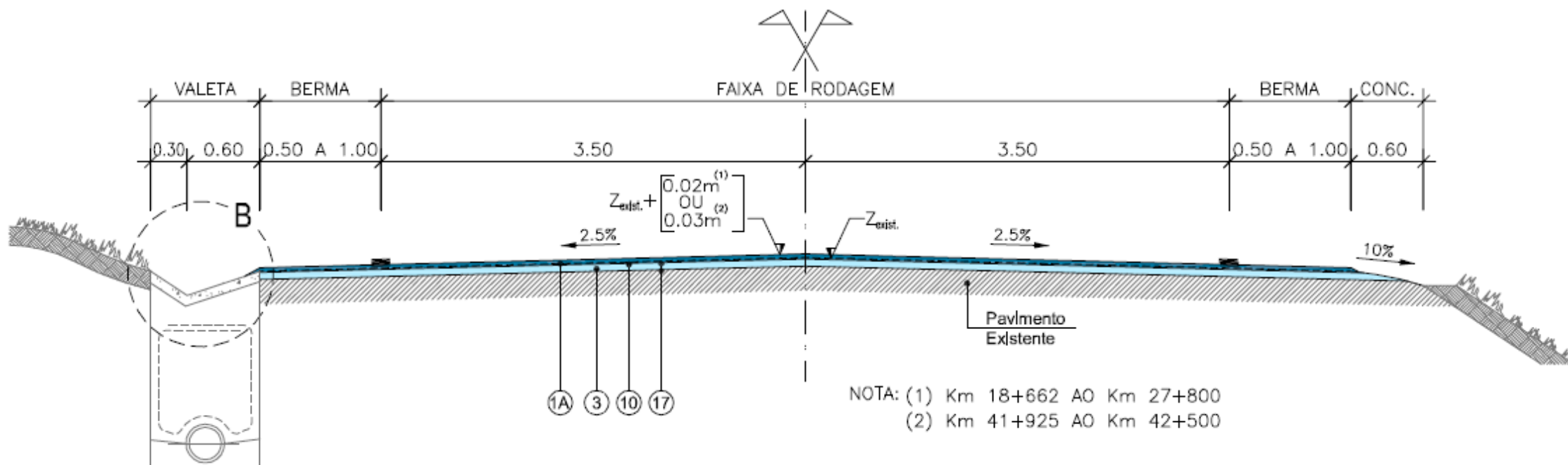
## Case Study: Rehabilitation of EN 4: 25,5 KM

- **District:** Setúbal
- **Municipalities:** Montijo, Alcochete, Palmela
- **Road Characteristics and Pavement:**
  - Cross-section profile type (1x2);
  - Lane of 7.00m wide ;
  - Shoulders of variable width (0.50m to 1.00m), with or without paving structures;
  - It was possible to divide the extension in two sections with different traffic demands. The average annual daily heavy vehicle traffic for the opening year were 269 and 527, per each section, per direction. It was considered a design period of 20 years to compare the solutions. The existing pavement was a flexible pavement





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Cross-Section Profile

# **COLD IN-PLACE RECYCLING WITH CEMENT – REHABILITATION WORKS IN NATIONAL ROAD 4 (EN4) - INTERSECTION WITH EN 118 MONTIJO (KM 18+750) AND INTERSECTION WITH EN10 PEGÕES (KM 44+257)**

## **Preliminary investigations**

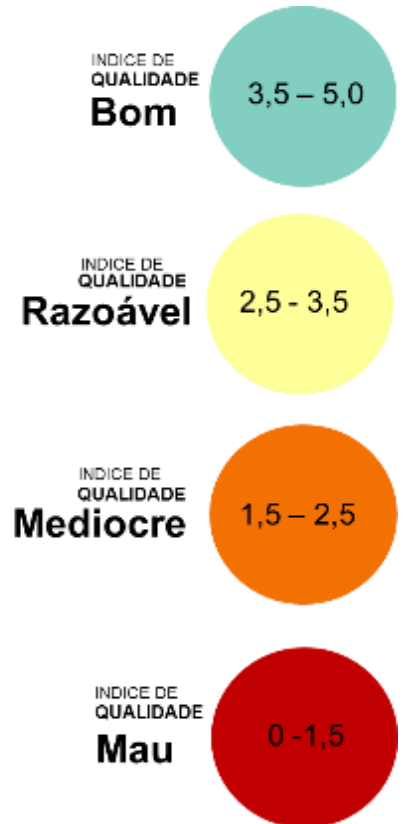
- It was consulted the historical data from the pavement management system (PMS), it was conducted a Falling Weight Deflectometer (FWD) campaign to assess the stiffness deflection, an IRI campaign (longitudinal unevenness). It was made an extensive visual inspection to detect and classify the existing pathologies.
- It was also conducted field work with the extraction of 23 cores and the execution of 13 test pits. The collected material was characterized in laboratory.
- The laboratory tests on scrambled samples, granular materials and subgrade soil, collected from prospecting pits were : granulometric analysis; Atterberg consistency limits (liquidity and plasticity); sand equivalent; heavy compaction (modified proctor); determination of the CBR (for the optimal conditions of foundation and for the "in situ" conditions of foundation. The laboratory tests the bituminous mixtures extracted were bitumen penetration at 25°C; bitumen softening temperature by ring and ball method; maximum technical barity of bituminous mixture by the pycnometer method; percentage of bitumen of the bituminous mixture; apparent barity of bituminous mixture and granulometric analysis of aggregate mixture in the bituminous mixture.



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## Preliminary investigations

- It was verified that the central lane presents bituminous hot mixtures ranging from 5cm to 20cm, cold open bituminous mixtures an average thickness of 9 cm and hydraulic macdame ranging from 18cm to 30cm. In the widening zones of the lane, an average thickness of hot bituminous mixtures of 20cm and granular material was observed, in crushed aggregate of extensive granulometry and selected soils, with 30cm thickness. The section in question was the object of several interventions, from the construction phase to the present moment, namely maintenance / conservation actions, structural rehabilitation and even requalification of the road with widening of the carriageway.
- From the visual inspection carried out it was concluded that the existing extension to rehabilitated presented a severe degradation, in some cases in full ruin and punctually had reasonable and good sections, classified in its entirety with a Quality Index from Mediocre (Poor) to Bad. The degradations observed were, among others, cracking (crocodile skin, transverse and longitudinal fissures), wheel wand deformation. The laboratory tests confirm the previous elements, great heterogeneity of materials, aging of them, at the end of their life cycle, and in some specific areas' bad foundation soils. It was possible to conclude that more than 60% of the extension presented serious pathologies, without enough structural capacity for the requests and requiring robust rehabilitation solutions.



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Besides each individual condition parameter, a global quality index is used.

## PAVEMENT QUALITY INDEX

$$IQ = f \left( \begin{array}{c} \text{automatic evaluation} \\ \text{longitudinal unevenness, transverse unevenness} \end{array} \text{ and } \begin{array}{c} \text{automatic evaluation} \\ \text{cracking} \end{array} \text{ and } \begin{array}{c} \text{assessed by} \\ \text{the operator} \\ \text{and cracking} \end{array} \right)$$

$$IQ_t = 5 \times e^{-0.0002030 \times IRI_t} - 0.002139 \times R_t^2 - 0.03 \times (C_t)^{0.5}$$

## PAVEMENT QUALITY RANK

Good:  $IQ > 3.5$

Fair:  $2.5 < IQ < 3.5$

Poor:  $1.5 < IQ < 2.5$

Bad:  $IQ < 1.5$

NON-STRUCTURAL MAINTENANCE



STRUCTURAL MAINTENANCE

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## Pavement solutions analyzed: Linear Economy versus Circular Economy models

For the length of the road without structural capacity, it was made a comparison between a “linear economy” approach and a “circular economy” one.

Based on the deflection values obtained in the tests, the recycled mixture layer was designed with a thickness of 0,30 m and cement as the hydraulic binder used in the recycling. The process used was FDR, with the existing granular and bituminous materials to be recycled.

Solution	Pavement Structure analysed	
Reconstruction of a new pavement with the replacement of all pavement structure and Foundation	0,03m	AC10 surf (mBBr)
	0,04m	AC14 bin 35/50 (MB)
	0,09m	AC20 base 35/50 (MB)
	0,09m	AC20 base 35/50 (MB)
	0,20m	ABGE – extensive grading crushed aggregate

Solution	Pavement Structure analysed	
Full depth Reclamation of existing granular material and existing bituminous mixtures in a depth of 0, 30 m, and execution of new binder and surface asphalt layers	0,04m	SMA11 surf PMB 45/80-65
	0,04m	MBR-BBA
	Full depth reclamation with cement	
	0,30m	



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## Pavement solutions analyzed: Recycled layer characteristics

It was defined as a design criteria, that the mix design study, to be carried out in the construction phase, would define the type and composition of the recycled mixture, whose minimum percentage in cement, in relation to the total dry mass of the material to be recycled, would be obtained from laboratory formulation studies, so that the following minimum characteristics would be obtained:

Parameter	Design minimum value	Value obtained in construction
Cement percentage in relation to the total dry mass of materials to be recycled, minimum	3,0 %	3,0 %
Simple compressive strength at 7 days, minimum	3.0 MPa	4,1 MPa-4,8 MPa
Simple compressive strength at 28 days, minimum	5.0 MPa	5,0 MPa -5,9 MPa
Tensile strength at 28 days, in a diametrical compression test, minimum	0,6 MPa	1,7 MPa
Simple compressive strength at 90 days, minimum	8.0 MPa	7,9 MPa-9,0 MPa
Tensile strength at 90 days, in a diametrical compression test, minimum	0.8 MPa	2,4 MPa
Quotient between resistance to simple compression with immersion at 14 days (Ri) and resistance to simple compression at 28 days (Rc), $R_i / R_c$ , equal to or greater than	$\geq 0,75$	Generally complies

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## Pavement solutions analyzed: Recycled layer characteristics

- The mixture, after compacting, should reach a modulus greater than 3000 MPa at 28 days, and 5000 MPa at 90 days, determined “in place” through load tests with impact deflectometer in the first trial section.
- The pavement design was elaborated considering the Shell Method, its associated fatigue equations (transfer equations), and the software Bisar 3.0.

$$\textbf{Stabilized (with cement) layers: } \frac{\sigma_t}{\sigma_r} = 1 - \alpha \times \log N_{adm}$$

- $\sigma_t$  – Maximum admissible flexural stress at the base of the stabilized layer;
  - $\alpha$  – Constant, usually between 0,06 and 0,1 (was considered 0,07, depending on the composition and properties of the mixture);
  - $N_{adm}$  – Number of ESAL (Equivalent Standard Axle - 130 kN);
  - $\sigma_r$  – Flexural strength of the material.
- One of the concerns when recommending mixtures with high rigidity as the recycled mixture with cement, with the combined effect of the temperature variations and the traffic actions is the appearance of cracking by thermal retraction. In order to avoid such a phenomenon, in addition to the specifications required in the construction specifications, with the execution of a transversal pre-cracking, it was also recommended the application of a layer with special flexibility characteristics to avoid the propagation of cracks in the wear layer: rough bituminous mixture with rubber modified bitumen

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## Recycled Layer: Equipment and construction data

- The recycling equipment was a Wirtgen WR2500 with a WM1000 (cement/water slurry mixer);
- Recycling depth of 30 cm;





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## Recycled Layer: Equipment and construction data

- Minimum cement content (by mass) of 3%;
- “In situ” density above 97%;



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## Recycled Layer: Equipment and construction data

- Minimum compressive strengths:
  - 3,0 MPa (7 days)
  - 5,0 MPa (28 days)
  - 8,0 MPa (90 days)



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## **Quality control of the recycled layer**

- Some of the aspects related to the execution of the recycled layer are related, namely the working formula, stabilization, working time and thermal retraction cracking.
- One of the most worrying aspects was the variability of thicknesses found in the pavement, which made it difficult to determine the working formula, requiring, in certain areas, previous milling work of bituminous mixtures that were not incorporated into the recycled layer. With the previous milling it was possible to create a single formula for the whole project, where the particle size analysis, water content and cement percentage were in line with the project specifications. Regarding the percentage of cement in the formulation of the mixture points to the minimum value defined in the project: 3%.
- The trial section was performed, on the left road (November 2017), attesting to the formulation of the mixture prepared in the laboratory and the following data were verified: simple compressive strength at 7 days in the order of 4.1 MPa to 4.8 MPa, much higher than that specified in the project (>3MPa), at 14 days and 28 days reaches values like that stipulated in the project (in the order of 5 MPa). Regarding tensile strength, both at 7 days and 28 days, the values obtained are significantly higher than those stipulated in the project, with 1.7 MPa and 2.4MPa when 0.4MPa and 0.6MPa is required, respectively for the different time periods.



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## **Quality control of the recycled layer**

- In the first days of production, in December 2017, there were better results of the obtained in the trial section. These results were reflected in all parameters at 7 days and 14 days. In most situations, resistance gain occurs in the first days (up to 7 days) and at the end of 14 days and 28 days the values point to values closer to those stipulated in the project.
- Regarding the compaction control, in the experimental section, final values of 98.1% were obtained well above the 97% required in the CETO (constructions prescriptions). The values obtained are considered ideal for recycled structures, because with lower densities, even if little significant, they can lead to significant reductions in resistance. At the same time, it was necessary to ensure that, in the pre-compaction, the values were lower in order to avoid moisture losses and ensure that the bottom of the recycled is compacted.
- Throughout the recycling work, and due to the heterogeneity of the existing paving structures there was a need to adjust, in certain sections, the working formula but in a not significant way.

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## **Quality control of the recycled layer**

- As shown previously quality control throughout the work points to the following results:
  - The resistance to simple compression on the 1st day, at 7 days, at 14 days, at 28 days and 90 days point to values equal to or higher than those defined in the implementation designed, except in three situations where the value of 90 days of Cr did not reach 8MPa for 7.9MPa;
  - Tensile strength at 7 days, at 14 days, at 28 days and at 90 days, in diametric compression test, always presents values higher than those required in the design;
  - The quotient between simple compressive strength with immersion at 14 days (Ri) and simple compression resistance at 28 days (Rc) presents values that generally comply with the predicted design values.
- Finally, it is added that the curing time of the recycled layer was quite variable over the several months of work but never reached the theoretical time defined in the project: 7 days, which required reformulations to the planning of the works.

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## Conclusions

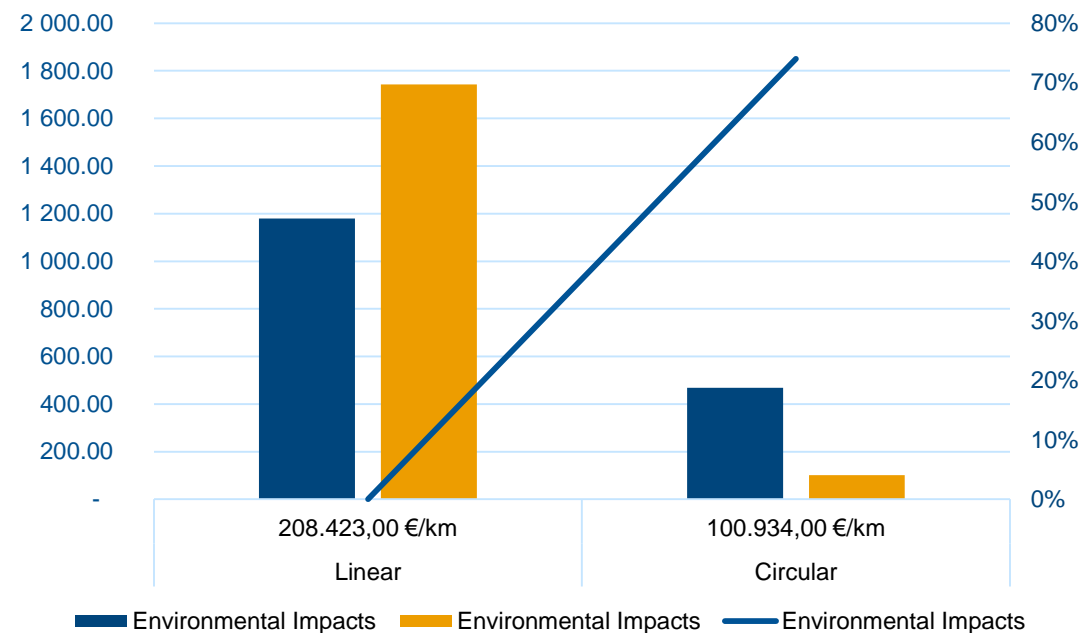
- The decision, in the design phase, to follow a "circular economy" model needs validation after its implementation, because in addition to the advantages that are exposed throughout this case study and present in all existing documentation on this subject, the need to evaluate the two solutions in the design phase is urgent, in the economic, environmental and technical aspects, considering the implications of the implementation on the recycling solution. The following table highlights the aspects that are considered most important and conditioning in decision-making, in the design phase:

Parameter	Linear Economy Solution	Circular Economy Solution
Costs	208 423,00€/km	100 934,00€/km
New bituminous mixtures	117907 t	46892 t
Milling + Remotion	174291 t	10067 t
% of reused materials	0	74%
Equipments	Tradicional paving equipments	Specific equipment for recyglyng
Construction Process	Conventional	Complex
Performance	532t/day/ team 2913 m²- 5989m²/day	1626m²/day/team
Curing time	0 days	7 days
Quality control	Traditional	More demanding



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## Conclusions

The main aspects considered in the decision-making, in the design phase, when comparing both solutions, concluded that the use of recycled materials:

- Was the most economical rehabilitation solution;
- Presented environmental advantages, which highlight the use of aged pavement materials, elimination and reduction of waste products to lead to flow and reduction of energy consumption and reduction of emissions of harmful gases;
- Had more specific and technical requirements;
- Presented more demanding construction methods and more effective quality control in order to ensure good pavement performance.



# Thank you for your attention!



**Eugenia Correia / Pedro Carvalho**

**TC 4.1 – Pavements Member**

**[eugenia.correia@infraestruturasdeportugal.pt](mailto:eugenia.correia@infraestruturasdeportugal.pt)**

**[pedro.fcarvalho@infraestruturasdeportugal.pt](mailto:pedro.fcarvalho@infraestruturasdeportugal.pt)**

World Road Association (PIARC)  
Grande Arche – Paroi Sud – 5<sup>e</sup> étage  
92055 – La Défense Cedex – France



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