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Evaluation of Electric Road Systems using APT tests

Université Gustave Eiffel

Introduction

To limit global warming France's objective is to be carbon neutral by 2050.
For transport, this means **complete decarbonization of land transport by 2050**.

In France, the sector of transport is responsible for **31 % of CO_2 emissions**

94 % of transport emissions come from road transport
The road represents 85 % of transport in volume

It is clear that the road will remain, in France, the main mode of transport for both passengers and goods. Therefore to reduce $C0_2$ emissions, it is **vital to decarbonize road transport**

For **heavy-duty vehicles (HGVs),** solutions for decarbonization are biofuels, battery electric, hydrogen or **Electric Road Systems (ERS).**

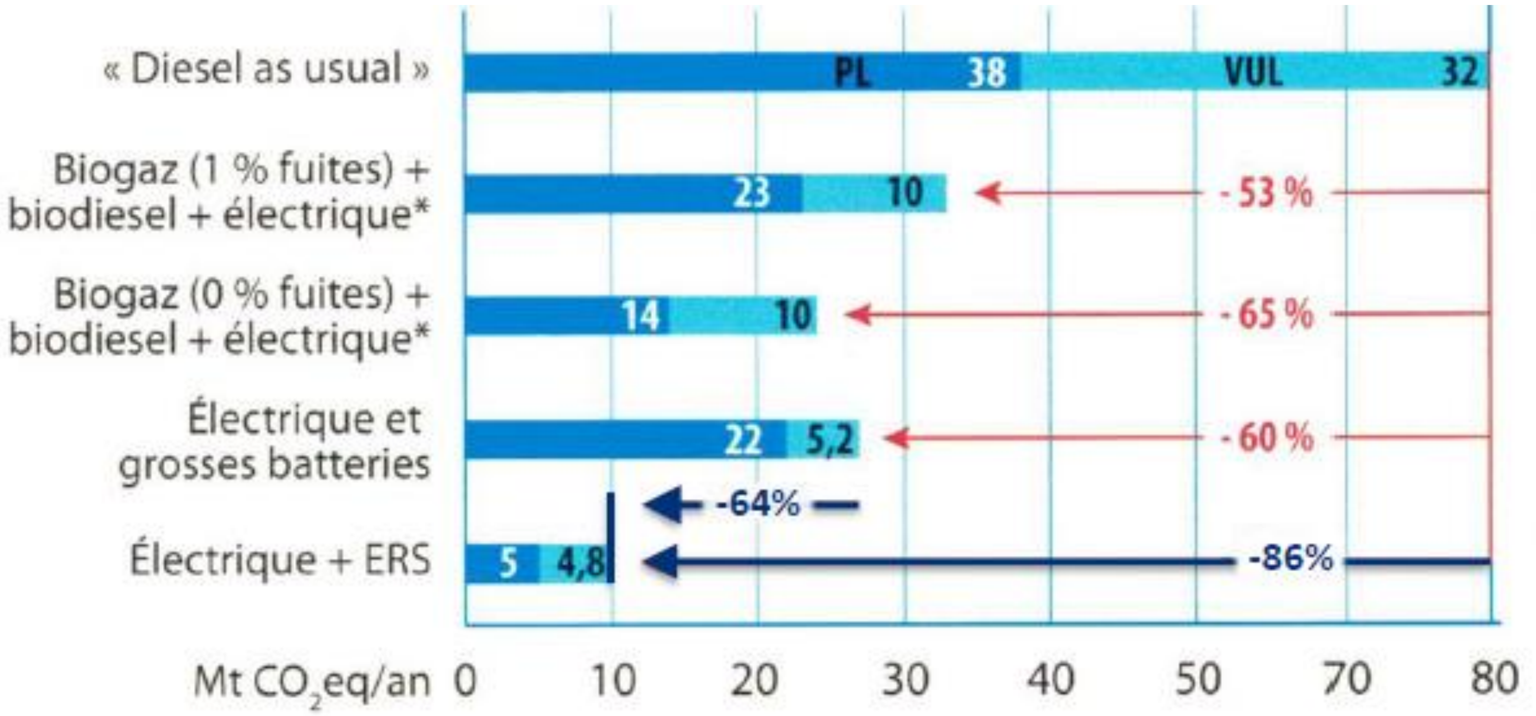
ERS consist in supplying electricity continuously to vehicles on the road, to improve the range of the vehicles without the need of very heavy and expensive batteries

Electric Road technologies

3 ERS technologies		Advantages	Limitations
Conductive charging by catenaries		- High charging power - Compatible with different pantographs - Large experience in the rail sector	- Non interoperable - Cable height - Risk of fall of cables - Need of regular cable maintenance - Visual impact
Conductive charging by rails		- High charging power - Interoperable between different vehicle types - No visual impact	- **Less mature technology** - Robustness of the current collector - **Road safety** - Need to clean the rails - Winter maintenance
Inductive charging		- Interoperability - Electrical safety - Low maintenance cost - No visual impact	- **Lower charging power** - Electromagnetic field exposure - Distance and alignment between primary and secondary coils - Heat dissipation - **Greater complexity**

Potential impact of electric roads in France

Potential of ERS for heavy vehicles : reduction of CO_2 emissions by 86 % compared with the scenario « Diesel as usual » , and 64 %, compared with the scenario « Electric with large batteries »



Other benefits : Estimated reduction of consumption of 1,7 Million tons of raw materials (lithium, Nickel, Cobalt …) over 20 years, compared with use of large batteries, minimizing environmental impacts and use of natural resources.

Reduction of energy dependence compared with diesel

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French strategy for electric roads

- **Focus on heavy goods vehicles**
- Power requirements : 350 to 400 kW per Heavy Goods Vehicle (40 tons)
- This leads to a power capacity of about 3 to 4 MW per km on motorways
- Equipment of 80% of roadway length, avoiding certain critical sections (bridges, tunnels, interchange areas, etc.).

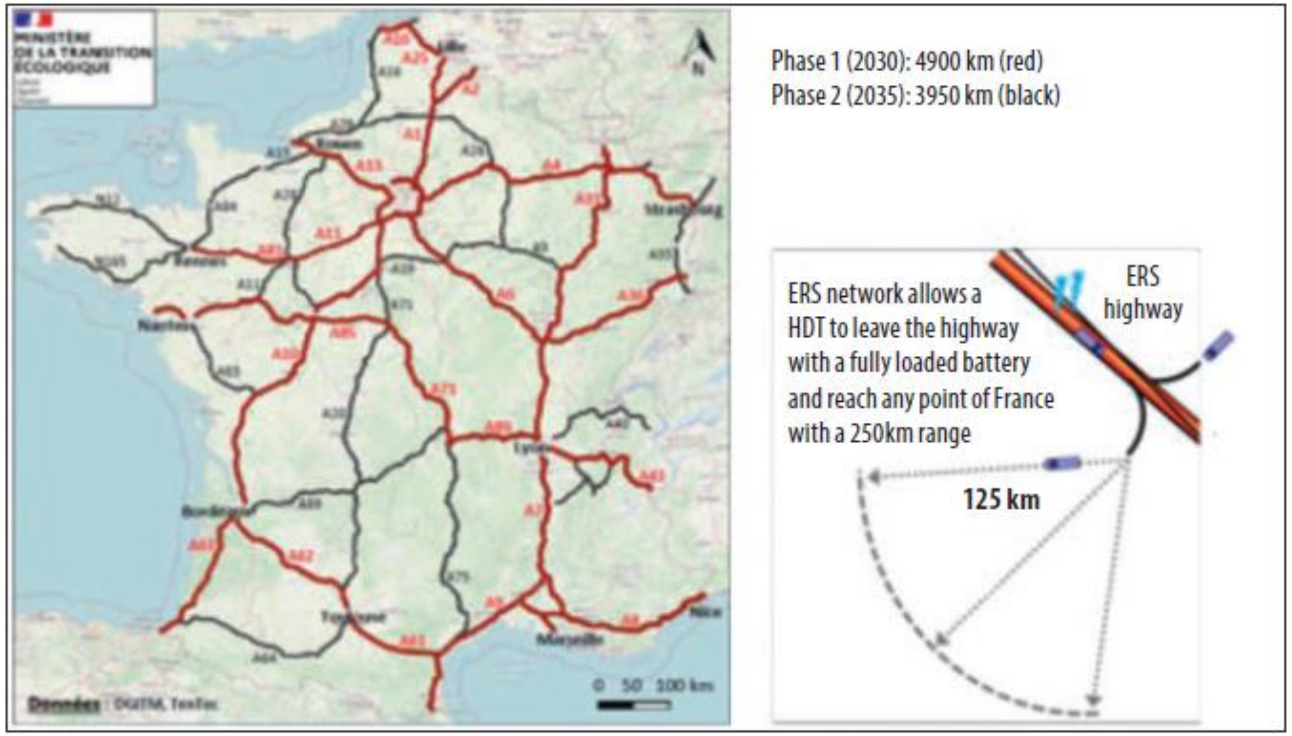
Objective :

- To develop in a first phase a network of 4,900 km of ERS by 2030, on motorways

Estimated total cost : 30 to 40 billion euros !

Enormous challenge for the transport industry !

Proposed deployment of ERS in France.



⇨ Large research calls launched in France and Europe to develop these technologies

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Road integration of electric vehicle charging systems

Next important challenge : demonstrating feasibility of road deployment.

Integration issues

Road construction method

Effects of temperature and water

Resistance to trafic

Resistance to temperature and compaction

Maintenance

Winter Maintenance

Road safety
For rails

Road integration of electric vehicle charging systems

Two large demonstration projects launched in France :

- **Charge as you Drive (2023 – 2026) :** Demonstration of two charging technologies, by **induction and conduction**, for heavy vehicles

- **e.Road Mont Blanc (2023-2027)** : demonstration of charging by **conductive rails**, for heavy vehicles

Focus of the presentation on **APT tests,** used to validate these ERS solutions.

APT tests were essential to validate the road integration methods and durability under traffic of these solutions, before deployment on real heavy traffic roads.

e.Road Mont Blanc project

e.Road Mont Blanc project (2023 – 2027)

Partners : ATMB, Alstom, Université Gustave Eiffel, Greenmot, Pronergy

Charging by conductive rails – system developed by ALSTOM - Maximum charging power 500 kW

Challenges

- Demonstrate the technology **in real conditions on a motorway** open to traffic
- Demonstrate interoperability with 3 categories of vehicles : heavy truck, bus and light utility vehicle
- High speed operation (90 km/h)
- Ensure road safety (skid resistance, road profile) and reliability of the current collector

.

2023 – 2024 : Laboratory testing of components and design improvements
APT tests with the FABAC traffic simulator

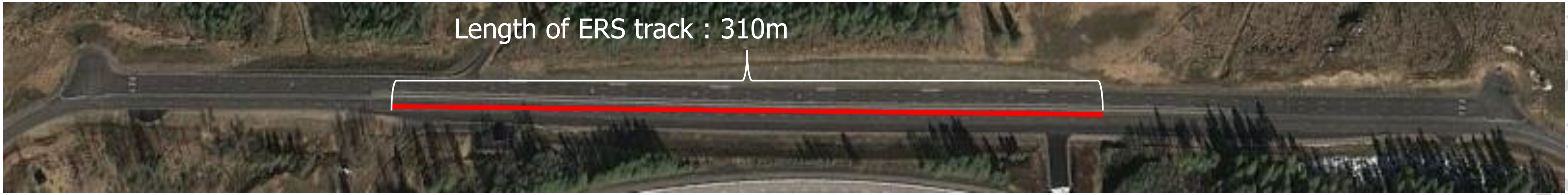
2024-2025 : Construction of 400 long demonstrator on a closed track, at Transpolis
Performance tests with 3 vehicle types - **validation of the solution**

2026 : Construction of 2 km long demonstrator on the access road of the Mont Blanc Tunnel (National Road RN 205)

Alstom conductive charging technology

Charging by conductive rails : Solution derived from the APS system, developed for electric supply of tramways by the ground

- First demonstration performed in Sweden, with Volvo trucks, in 2017 (Slide-In project)
- Construction of a 310 m long track. Demonstration of feasibility of charging at speeds between 60 and 90 km/h, with an efficiency of 97 %



e.Road Mont Blanc project

Laboratory testing – Objectives :

- Validation of skid resistance of track surface
- Proposal of method for installing and sealing the conductive rails in asphalt pavement structures

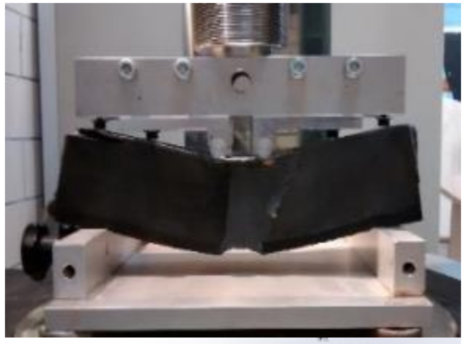
Proposed rail installation method :

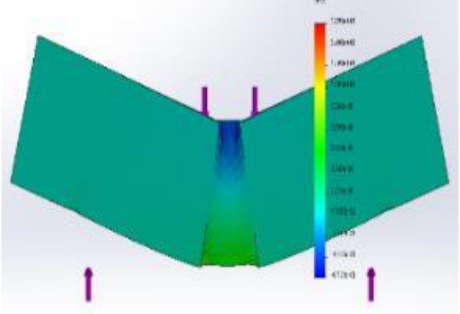
- Milling of 6 cm deep trench in the middle of the road lane
- Positioning of the EPDM rubber support of the rails in the trench an sealing with a resin
- Screwing of the metallic rails on the EPDM support
- Need to select appropriate resins for sealing the EPDM elements in the trench

Laboratory testing

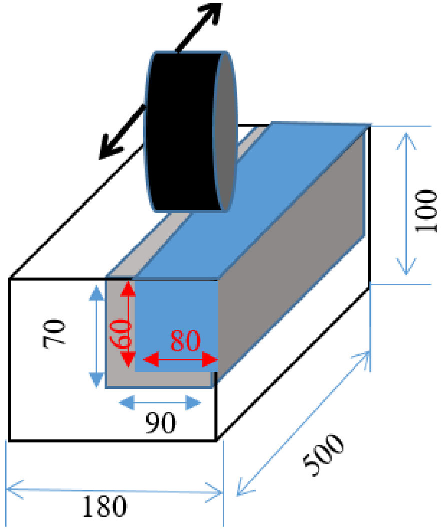
Proposed mechanical performance tests for selecting resins for bonding of EPDM support with asphalt layers :

4 point bending tests
⇨ tensile strength of bond

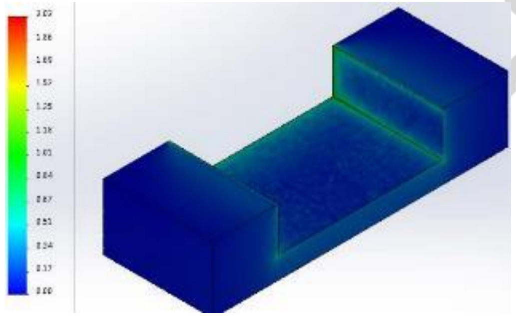




Wheel tracking tests at 20, 40 and 60 °C
⇨ Rutting resistance



Temperature cycles
⇨ Thermal cracking



⇨ Selection of two suitable resins for the sealing of the EPDM elements

e.Road Mont Blanc project – Accelerated pavement testing

Objective : validation of conductive rail behavior under heavy vehicle loads, before deployment on a real road

FABAC Machines

Characteristics of the mobile FABAC traffic simulators :

- Circulated length : 2 m
- Loads : 4 axles with single or dual wheels (30 to 75 kN)
- Loading speed : 3 to 7 km/h
- Maximum loading capacity: 1 million loads / month

1 machine can be equipped with a temperature control system (10°C to 60 °C)

Test program

Testing of 3 pavement sections :

- Two sections with different solutions for sealing the conductive rails using different resins (A and B),
- One section designed to test a maintenance procedure

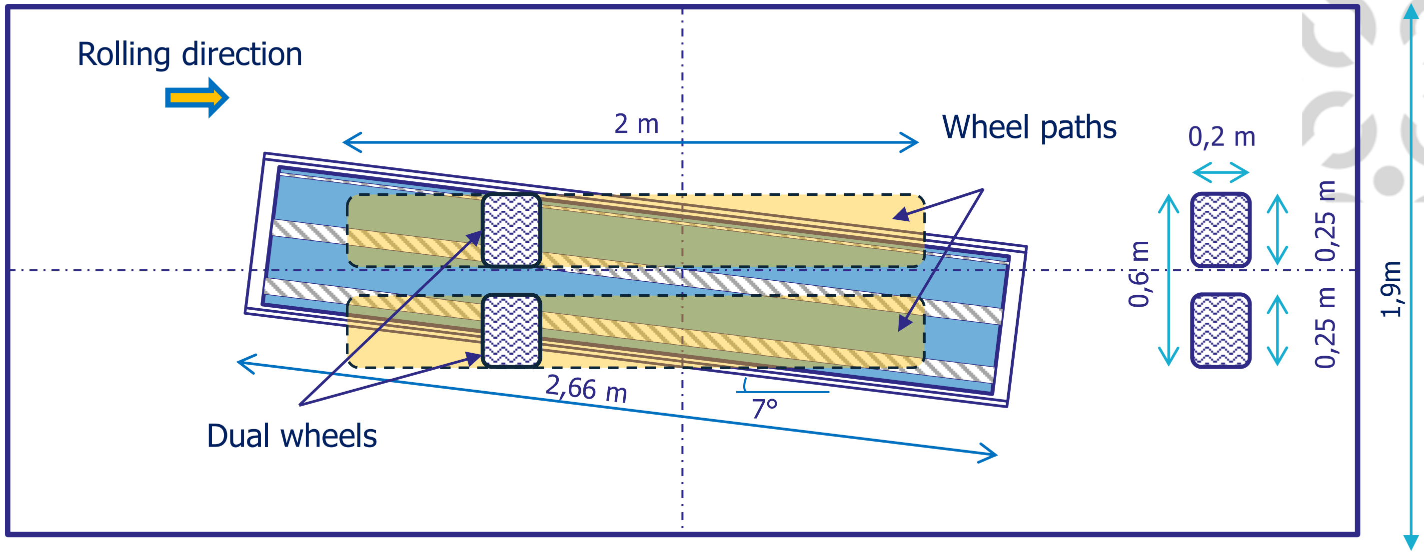
Loadings :

- 200 000 load cycles at ambient temperature
  + 40000 cycles at 35°C
  + 10000 cycles at 50 °C)
- loads : dual wheels, loaded at 65 kN - speed 3 km /h

Pavement monitoring :

- Deflection measurements
- Transverse profile measurements
- Visual inspection (distress surveys)

Test Layout



Installation of the conductive rails – Validation of construction procedure



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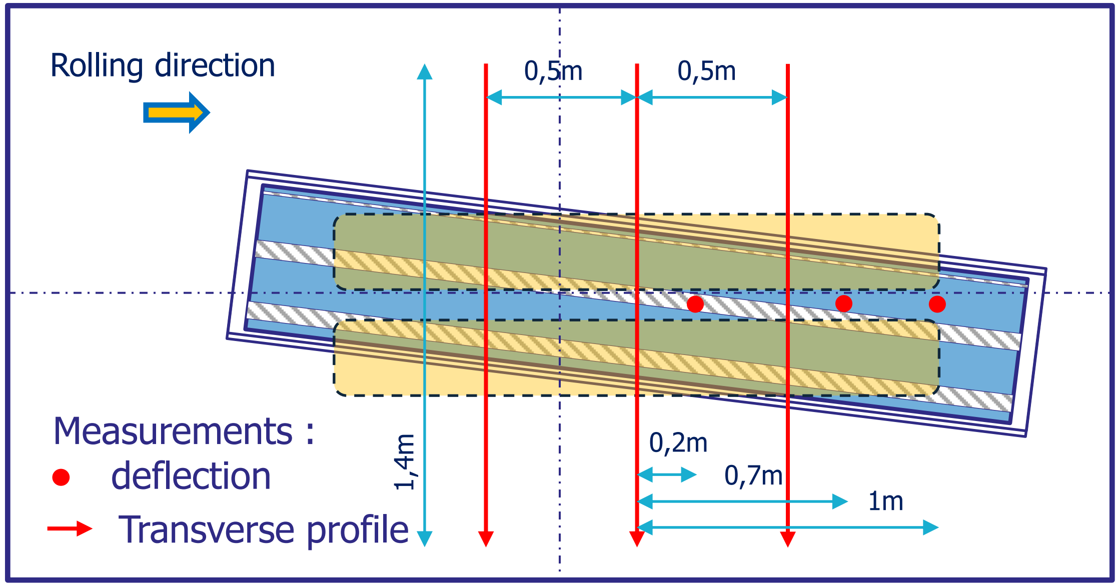
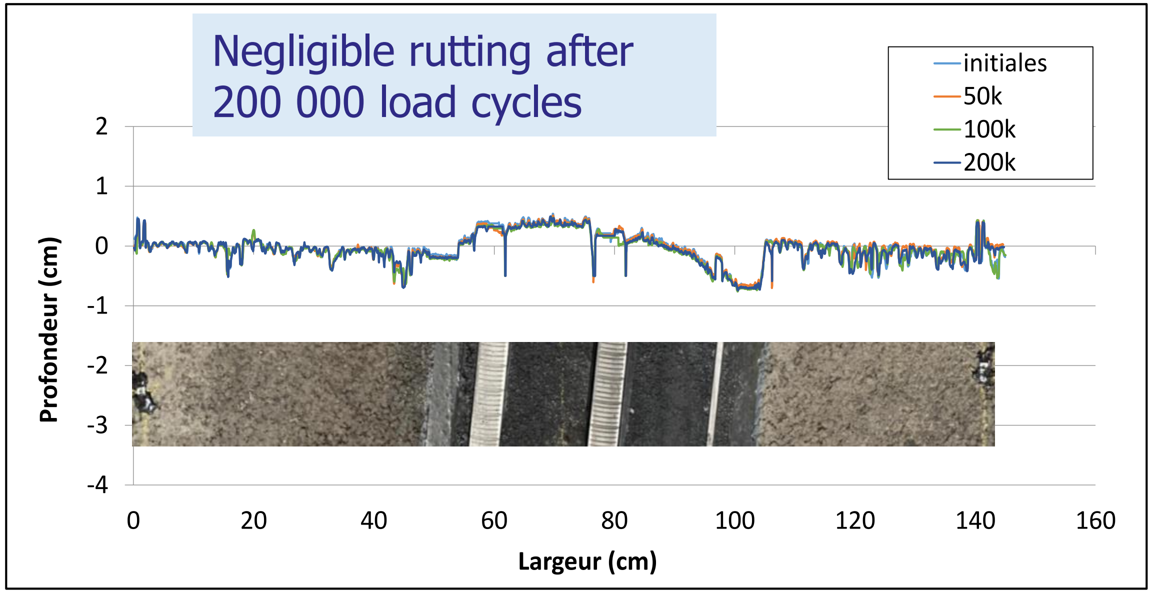
Results of FABAC test 1 (resin A)





No visible deterioration after 200 000 load cycles

⇨ Good resistance to trafic of the conductive rail sealed with resin A

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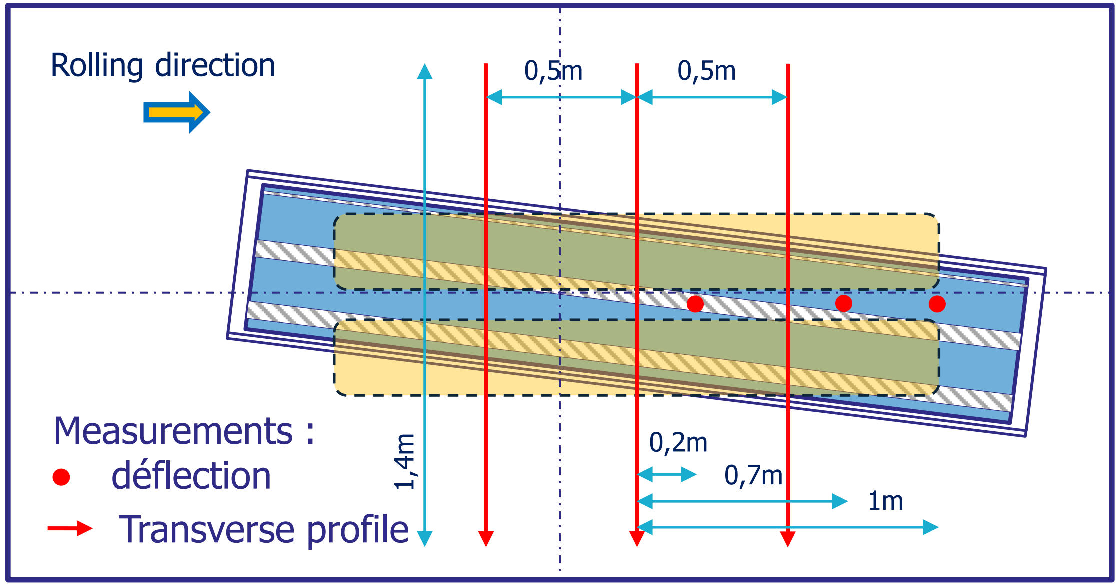
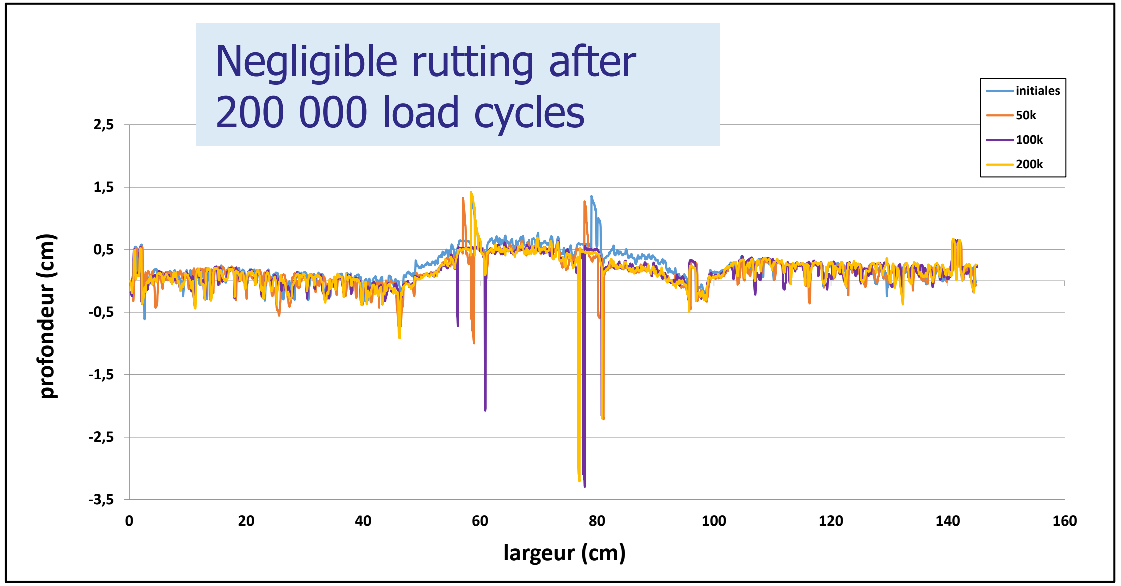
Results of FABAC test 2 (resin B)





No visible deterioration after 200 000 load cycles

⇨ Good resistance to trafic of the conductive rail sealed with resin B

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Conclusions

- Development of specific laboratory mechanical tests
  ⇨ validation of resins for rail sealing (and of skid resistance of rail surface)
- APT tests with FABAC simulator

  validation of construction procedure

  validation of resistance to traffic (200 000 load cycles – 65 kN loads)

Next steps :

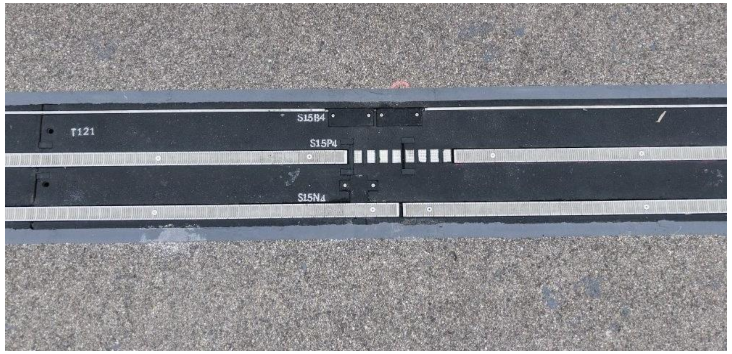
- Modeling of the mechanical and thermal behaviour
- **Construction of 400 m long demonstrator** in 2025 on closed track (at Transpolis)

  Tests with vehicles (road safety – charging efficiency)
- If tests are successfull, construction of a 2 km long demonstator on the access road of the Mont-Blanc Tunnel in 2026.

Closed track demonstrator

400 m long demonstrator installed in spring 2025 on the Transpolis test site

Charging power : 300 kW - Tests with vehicles will start soon



Charge as you Drive project

Project Charge as You Drive (CAYD) (2023 – 2026)

Partners : Vinci, Université Gustave Eiffel, Electreon, Elonroad, Hutchinson

Two technologies :

- Charging by induction (Electreon System) - Maximum charging power : 200 kW
- Charging by conductive rails (Elonroad system) - Maximum charging power 300 kW

Challenges

- Demonstrate the two technologies **in real conditions on a motorway**, with 3 categories of vehicles : heavy truck, bus and light utility vehicle
- High speed operation (90 km/h)
- Induction : increase of charging power to 200 kW (using 3 coils)
- Conduction : ensure road safety (skid resistance, road profile) and reliability of current collector

2023 – 2024 : Laboratory testing of components and design improvements

Large APT test on the Nantes carrousel on inductive solution

2025 : construction of 1.5 km long demonstrator of **inductive solution** on motorway A10 near Paris

2025-2026 : APT test and construction of demonstrator of conductive solution

Inductive charging technology

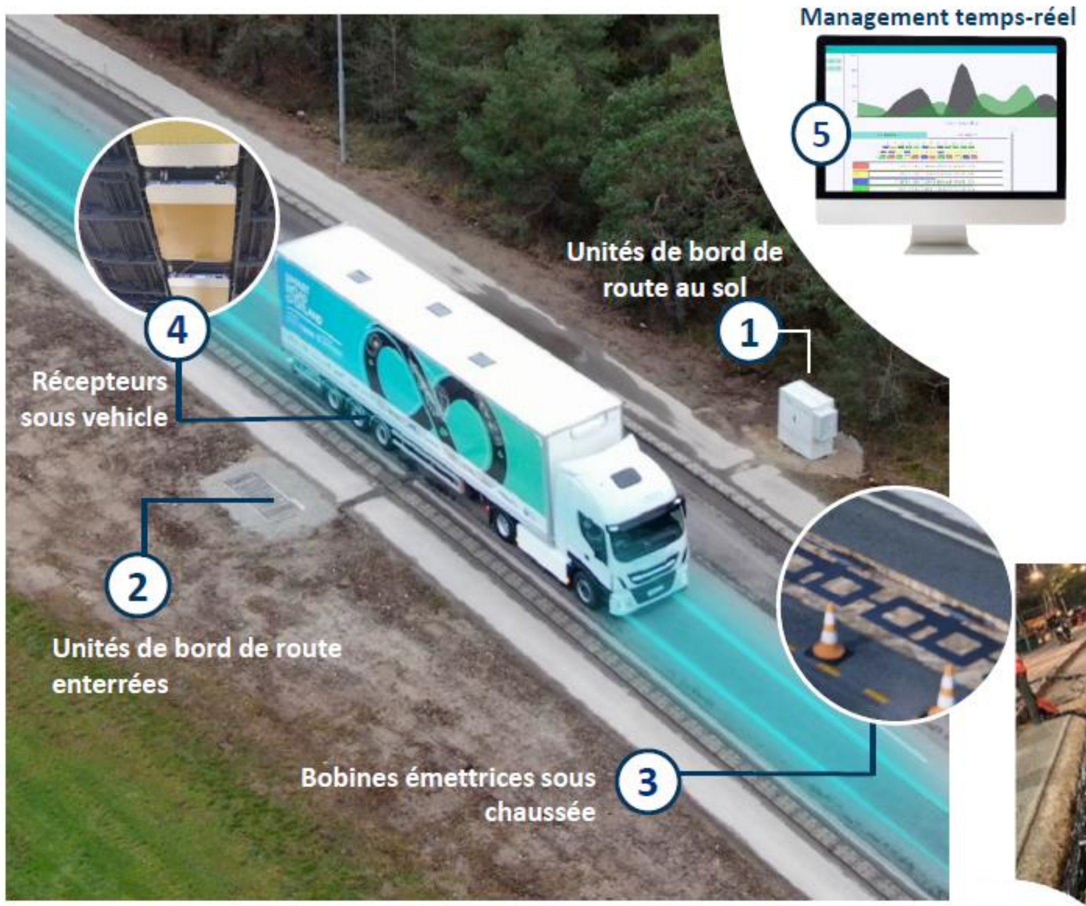
electreon & HUTCHINSON

1 & 2 Road side units
Power supply and inverters

3 Primary transmitter coils embedded in the pavement
Power 70 kW

4 Secondary receiver coils placed under the vehicle

5 Real time management of vehicle charging (cloud application)



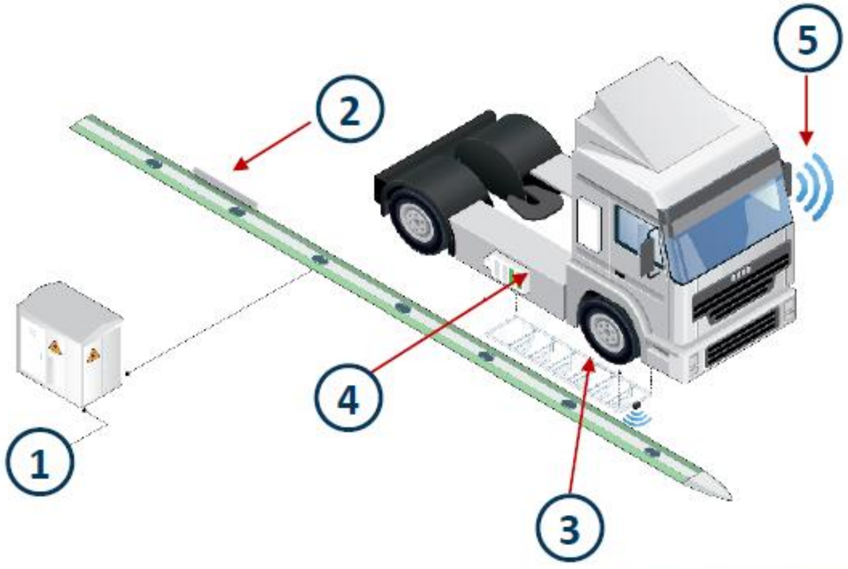
Conductive charging technology

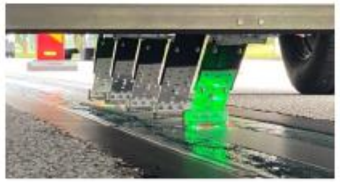
ELONROAD

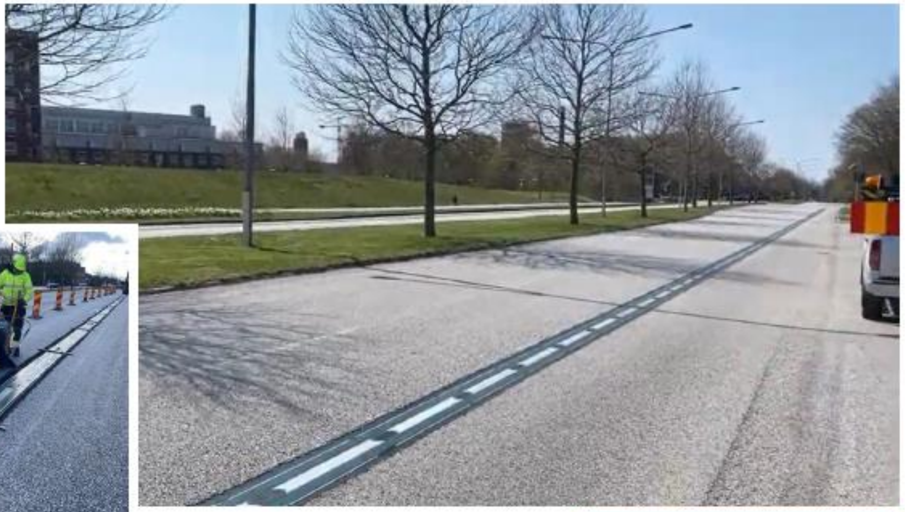
1. Road side units : 3 MW transformers every 1,5 km
2. Conductive rails
   10 m long, 1m long charging sections
   DC charging

3 & 4 Current collectors :
3 to 6 collectors depending on vehicle size

5. Real time management of vehicle charging (cloud application)







CAYD project – Accelerated pavement testing on inductive technology

Need to validate road intergration before deployment on a real road

APT facility of Université Gustave Eiffel

Outdoor circular facility

- 40 m diameter (120 m long track)
- 4 loading arms
- Maximum load per arm : 150 kN
- Maximum loading speed 100 km/h
- Lateral wandering (11 positions)
- Maximum loading capacity ≈ 500 000 loads / month
- 3 test tracks – mobile machine

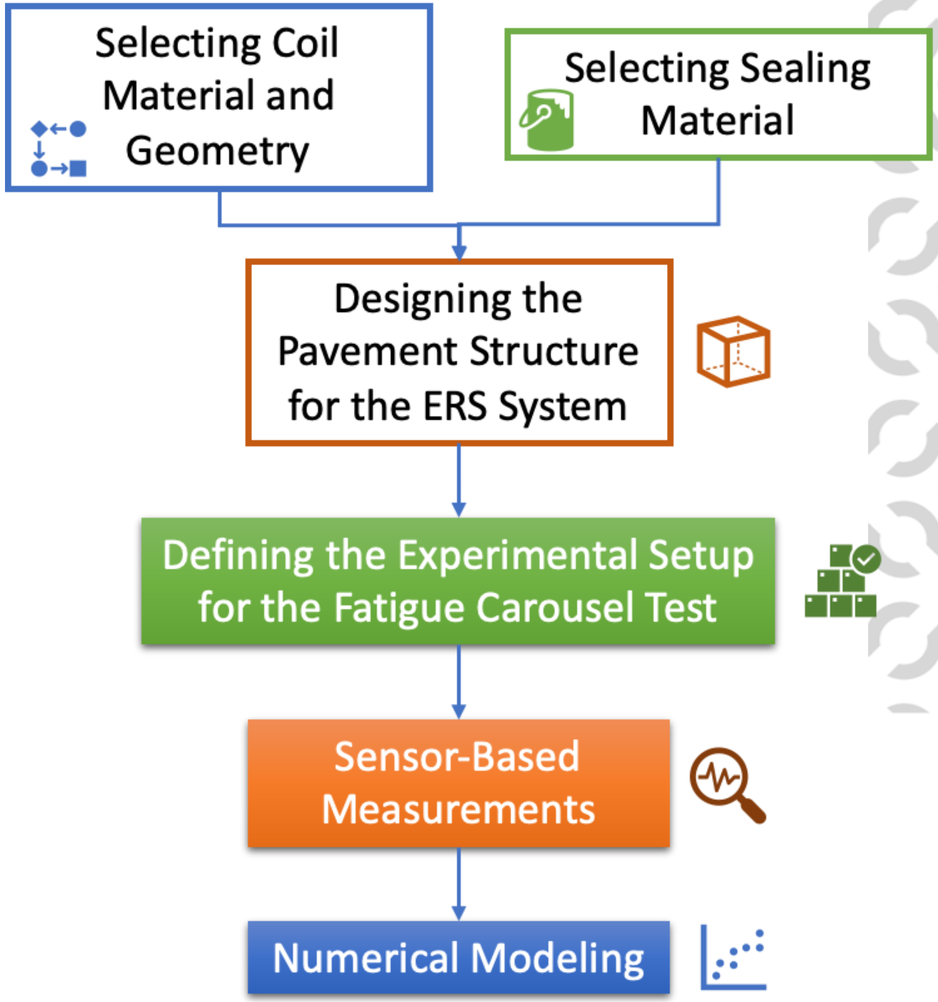
Objectives of the study

- **Laboratory testing**
  - Define materials for encapsulating and protecting the inductive coils
  - Selecting resins for sealing the coils in the pavement layers.

- **APT testing**
  - Defining pavement integration solutions
  - APT testing – 7 different test sections
  - Comparison of the mechanical response of the different sections

- **Numerical Calculation** with Viscoroute©2.0 pavement analysis software

Work plan



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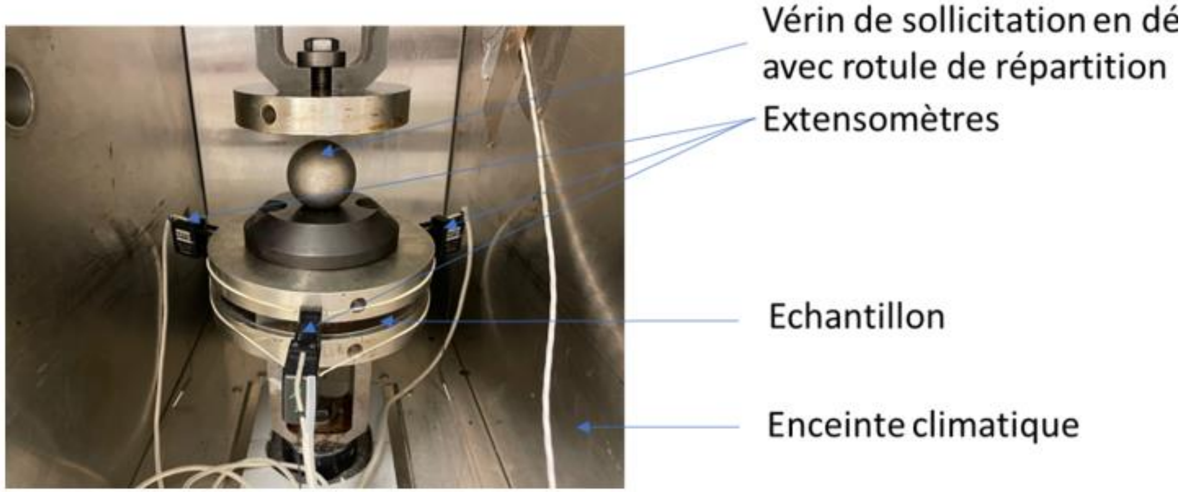
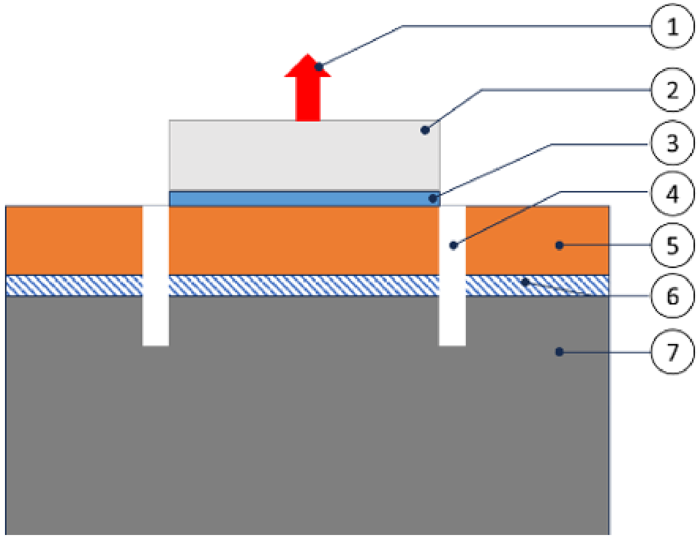
Laboratory testing

Testing of 3 coil materials

Dynamic modulus tests at different temperatures



Testing of bond strength between coil / resin and asphalt



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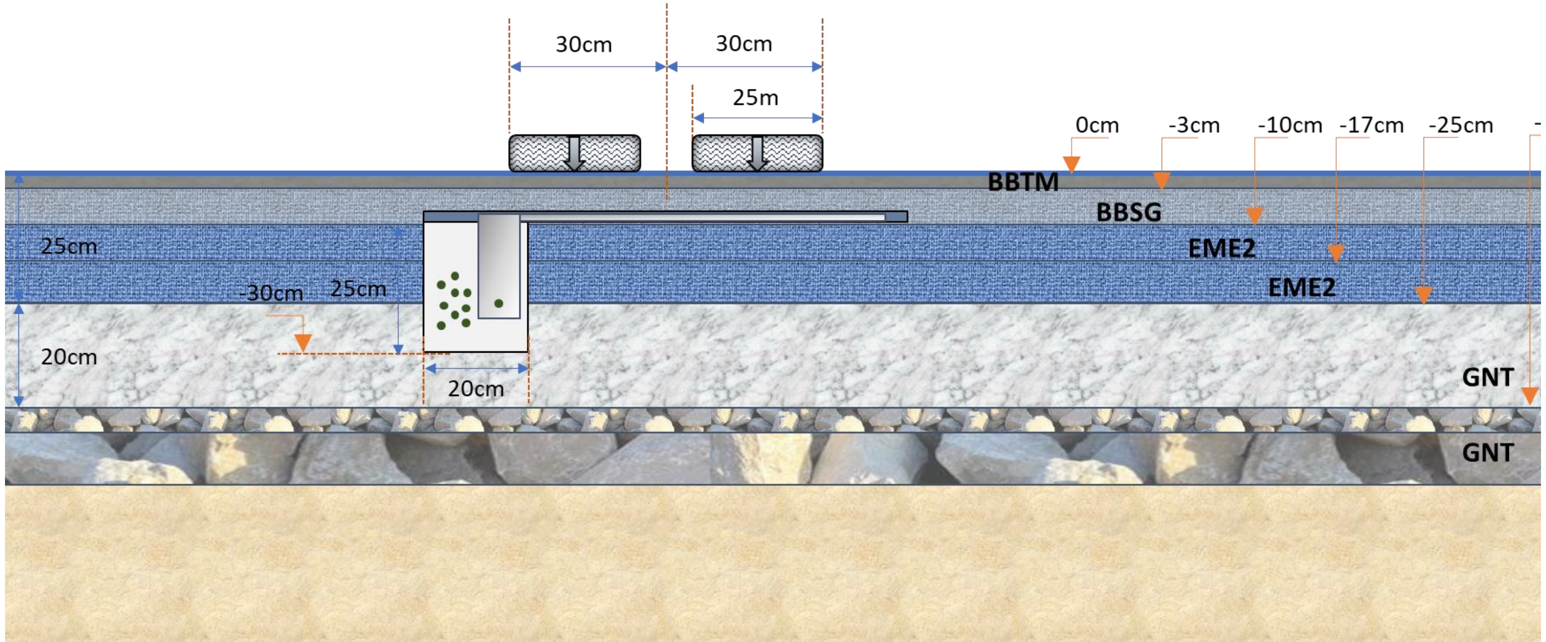
CAYD project – APT testing of inductive technology



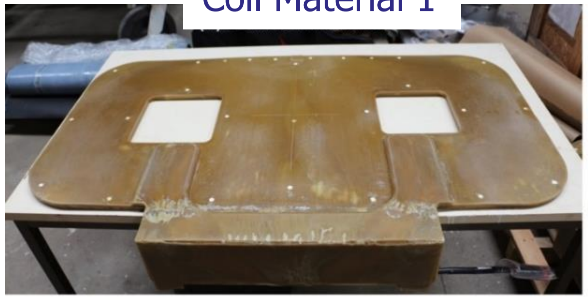
Motorway asphalt Pavement structure

25 cm of asphalt materials over granular subbase

Coils placed at 10 cm depth, between base course and binder course, sealed with appropriate resin

Testing of 3 coil designs + 3 bonding solutions : Resins A and B, and bitumen emulsion

Coil Material 1



Coil Material 2

Coil Material 3

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Layout of the 7 test sections

Total pavement length : 62 m

Test sections

0 - Reference section without coils

1 (10m) – Material 1 – Resin A

2 (16m) – Material 2 – Resin A

3 (22m) – Material 3 – Resin B

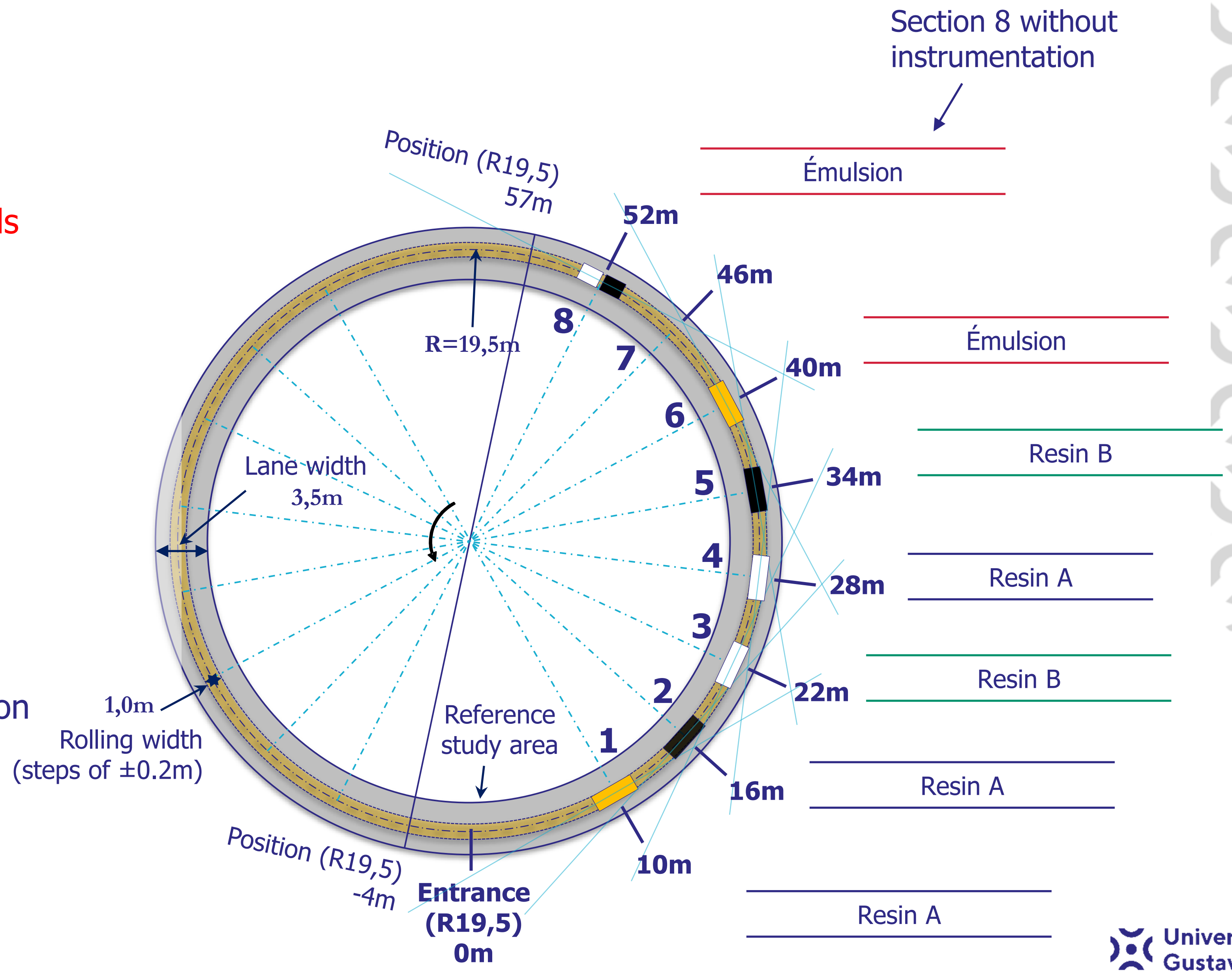
4 (28m) – Material 3 – Resin A

5 (34m) – Material 2 – Resin B

6 (40m) – Material 1 – Emulsion

7 (46m) – No Coils

8 (52m) – Material 2/Material 3 - Emulsion



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Test program

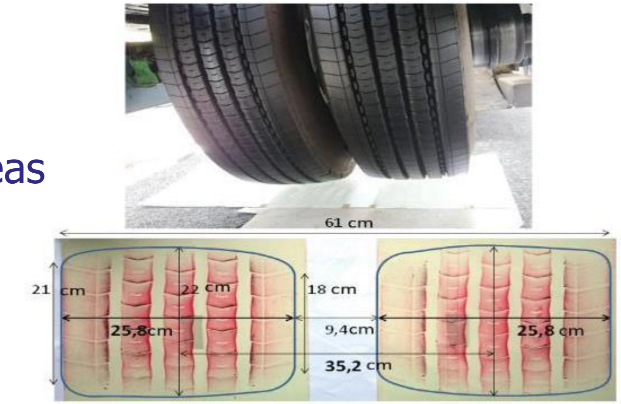
Application of 200 000 load cycles, in July – August 2024

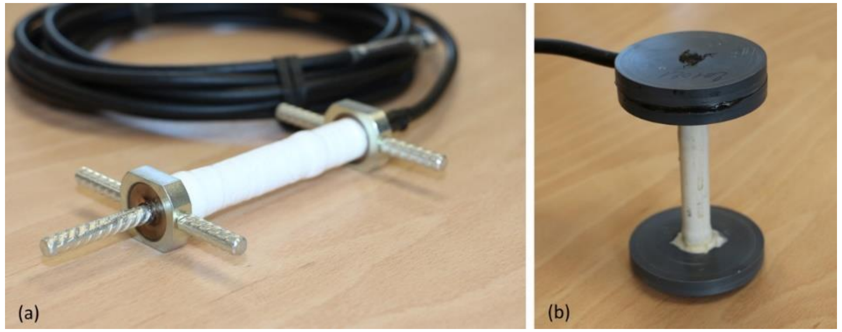
Dual wheels with 65 kN loads (French reference axle load)

Loading speed : 70 km / h

Lateral wandering : 5 lateral positions, by steps of 10 cm

Wheel contact areas





Pavement monitoring

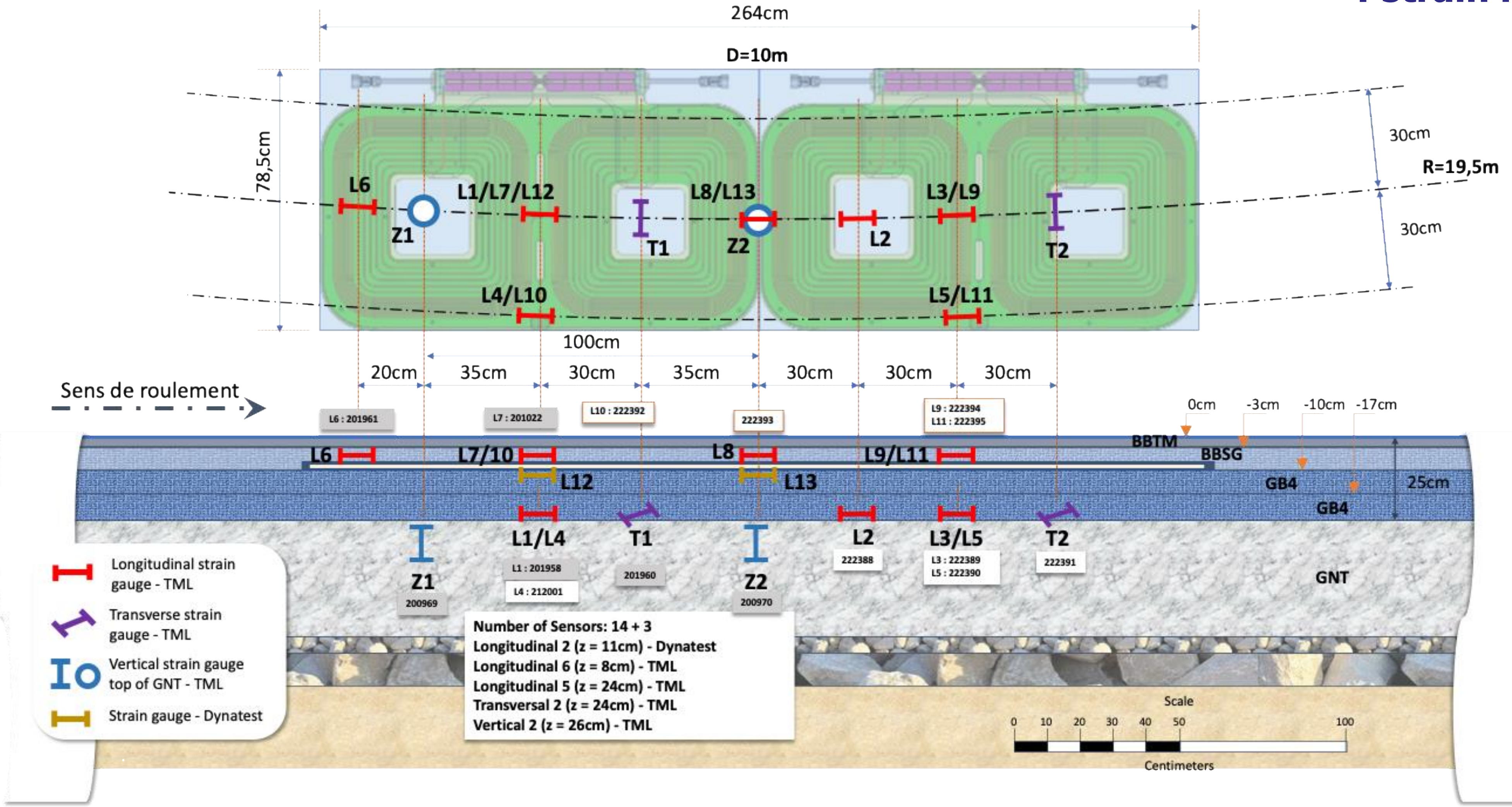
Strain and temperature measurements (sensors)

Deflection measurements (FWD)

Transverse profile measurements (laser profiler)

Visual distress surveys

Example of Pavement Instrumentation



4 strain measurements levels:

- Longitudinal strains above the coils
- Longitudinal strains below the coils, only on sections 1 and 2
- Longitudinal and Transversal strains at the bottom of Asphalt base
- Vertical strains in granular layer

Total instrumentation of the 6 sections : 74 strain gauges – 6 temperature probes

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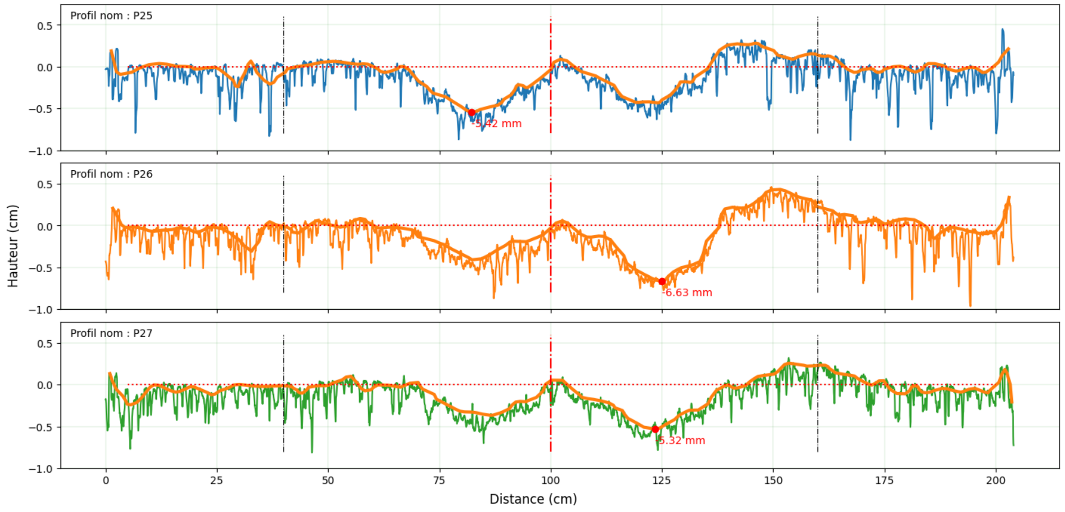
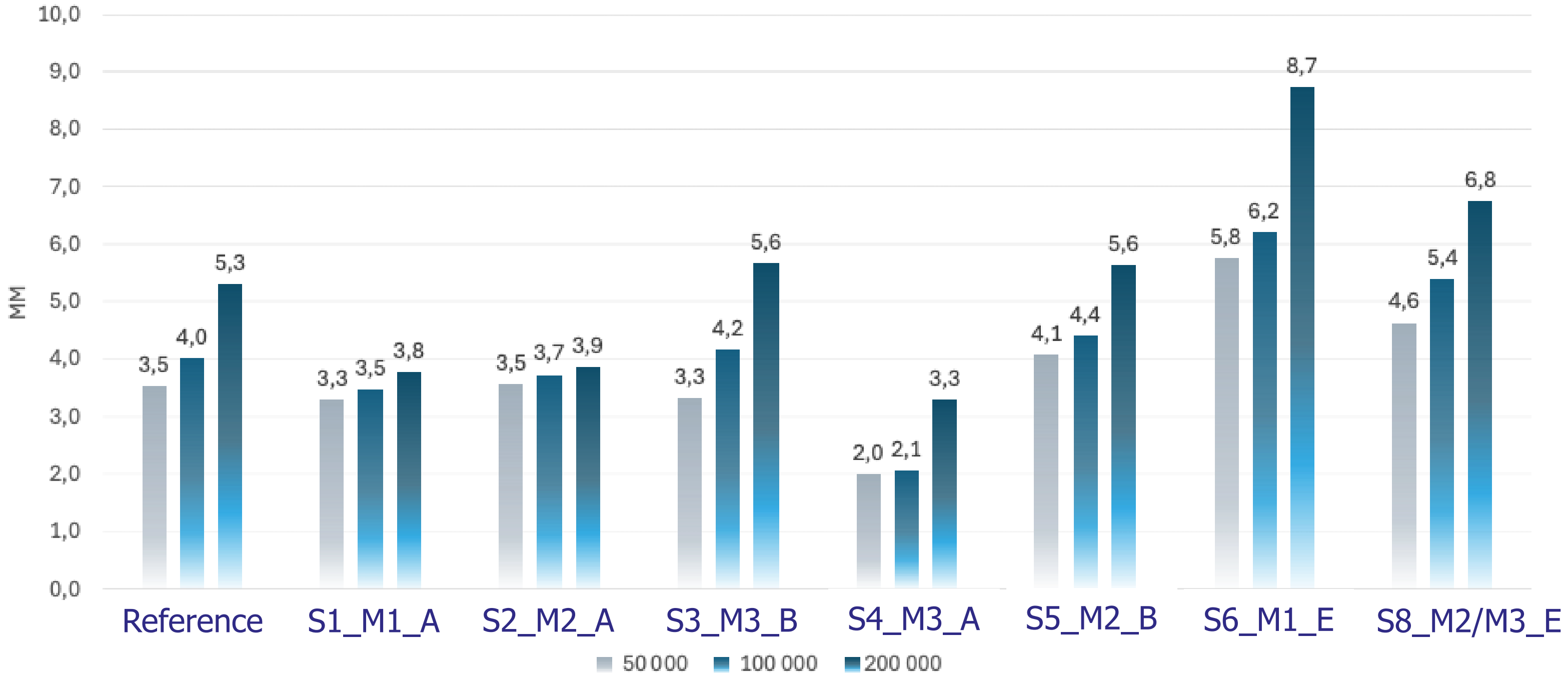
Permanent deformation measurements

Example of permanent deformation profiles after 200 000 cycles on section 8
Maximum rut depth : 6,8 mm

Transverse profiles – section 8



Maximum rut depths on the different test sections



Moderate permanent deformations, similar to reference without coil, on sections 1,2,3,4, 5

Higher permanent deformations on sections 6 and 8, **with bitumen emulsion**

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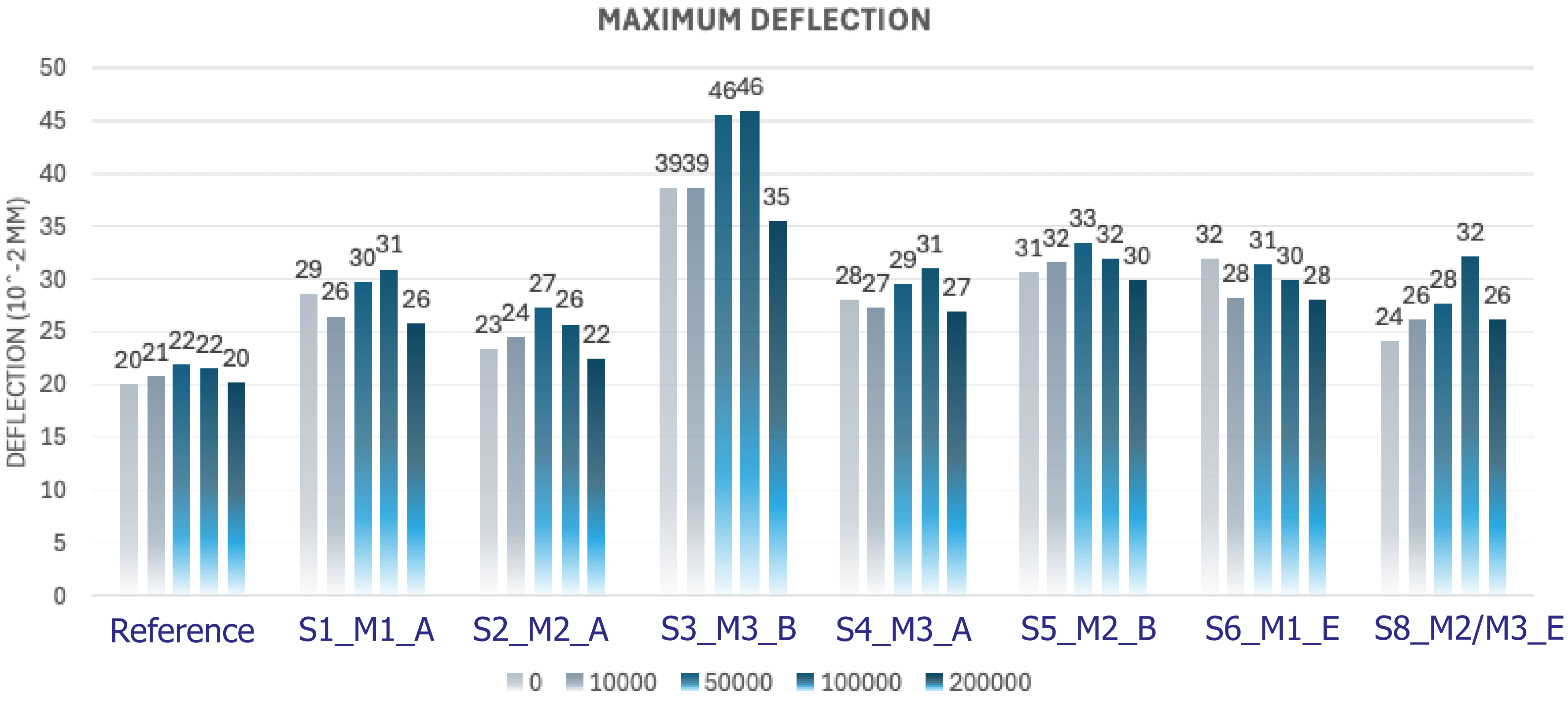
Deflection Measurements (FWD) – 65 kN load pulse

Comparison of maximum deflections (at 20 °C) on all sections at different numbers of load cycles



- Deflections increase on all sections with coils
- Deflections are similar on all sections except section **3 with soft coil material** which presents higher deflections
- No significant increase of deflections with traffic level ⇨ No significant pavement damage

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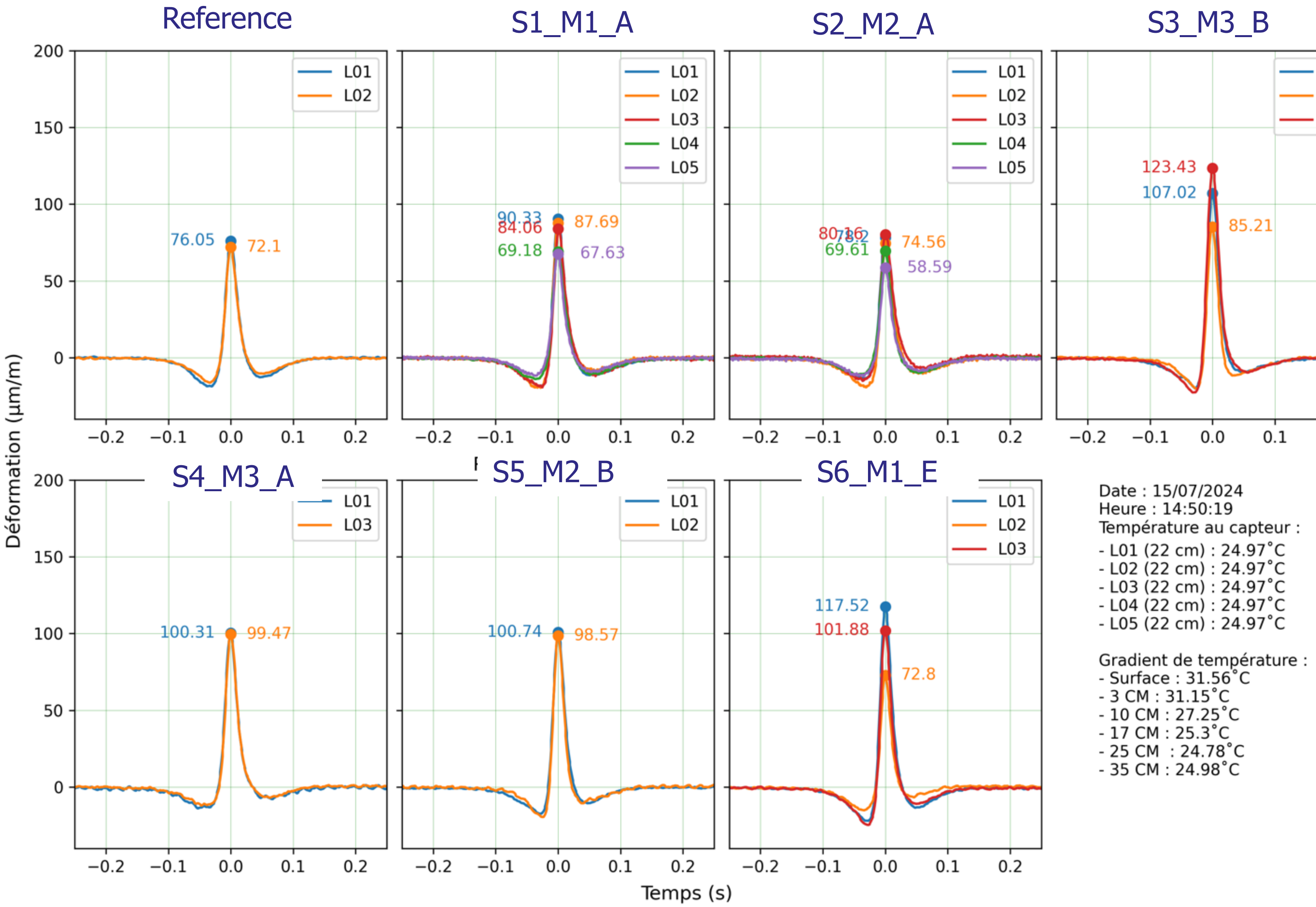
Strain measurements

Longitudinal strain signals at the bottom of the bituminous base layers (beginning of APT test)



Loading conditions :

- 65 kN load
- 59 km/h

Positive strains = Extension on all sections

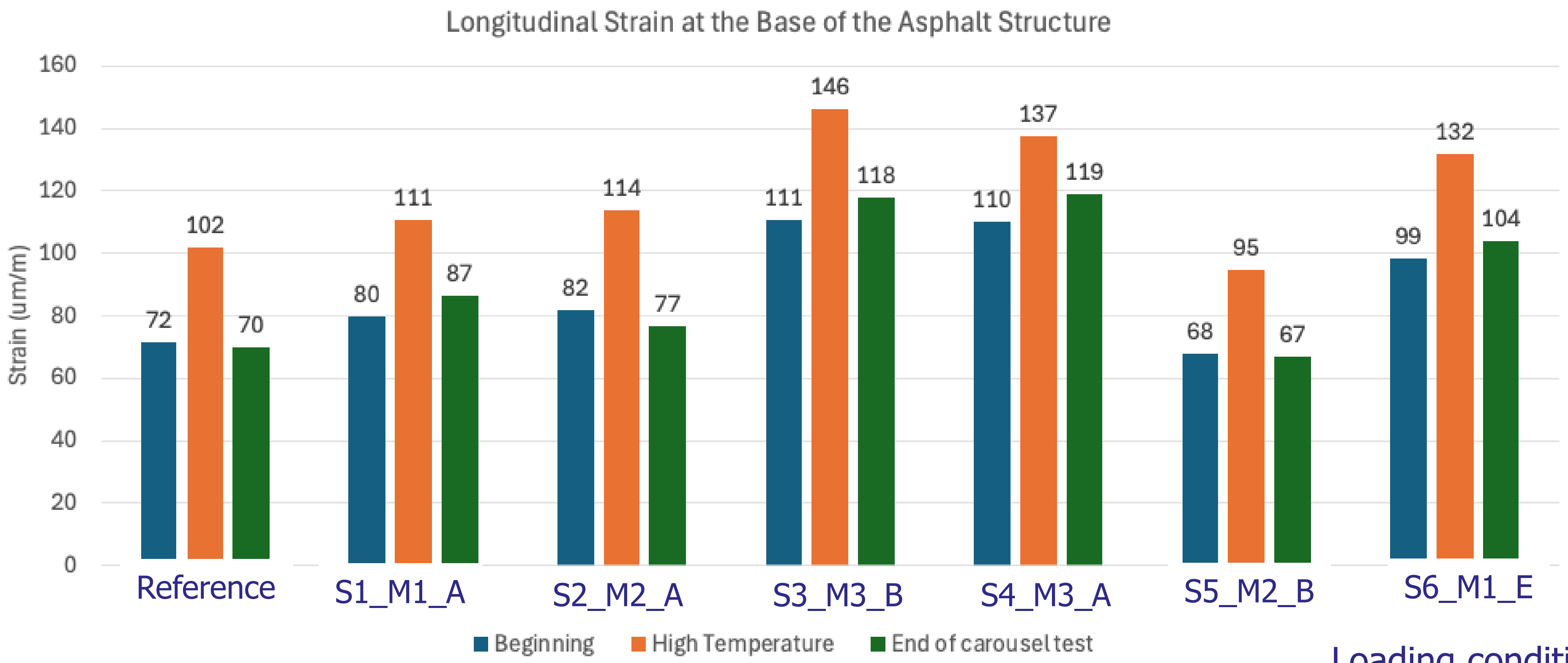
Good repeatability of measurements

Strains on sections 1 and 2 similar to the reference

Higher strains on sections 3, 4, 5, 6

Strain measurements

Maximum longitudinal tensile strains at the bottom of asphalt base layers in all sections for different conditions : beginning of the test, highest temperature, end of the test.



Loading conditions:
- 65 kN
- 59 km/h

- Significant strain increase at high temperature (48 °C on surface)
- No significant strain evolution with traffic at 25 °C (No damage)
- Higher tensile strains on sections 3, 4 and 6, but no “critical” values

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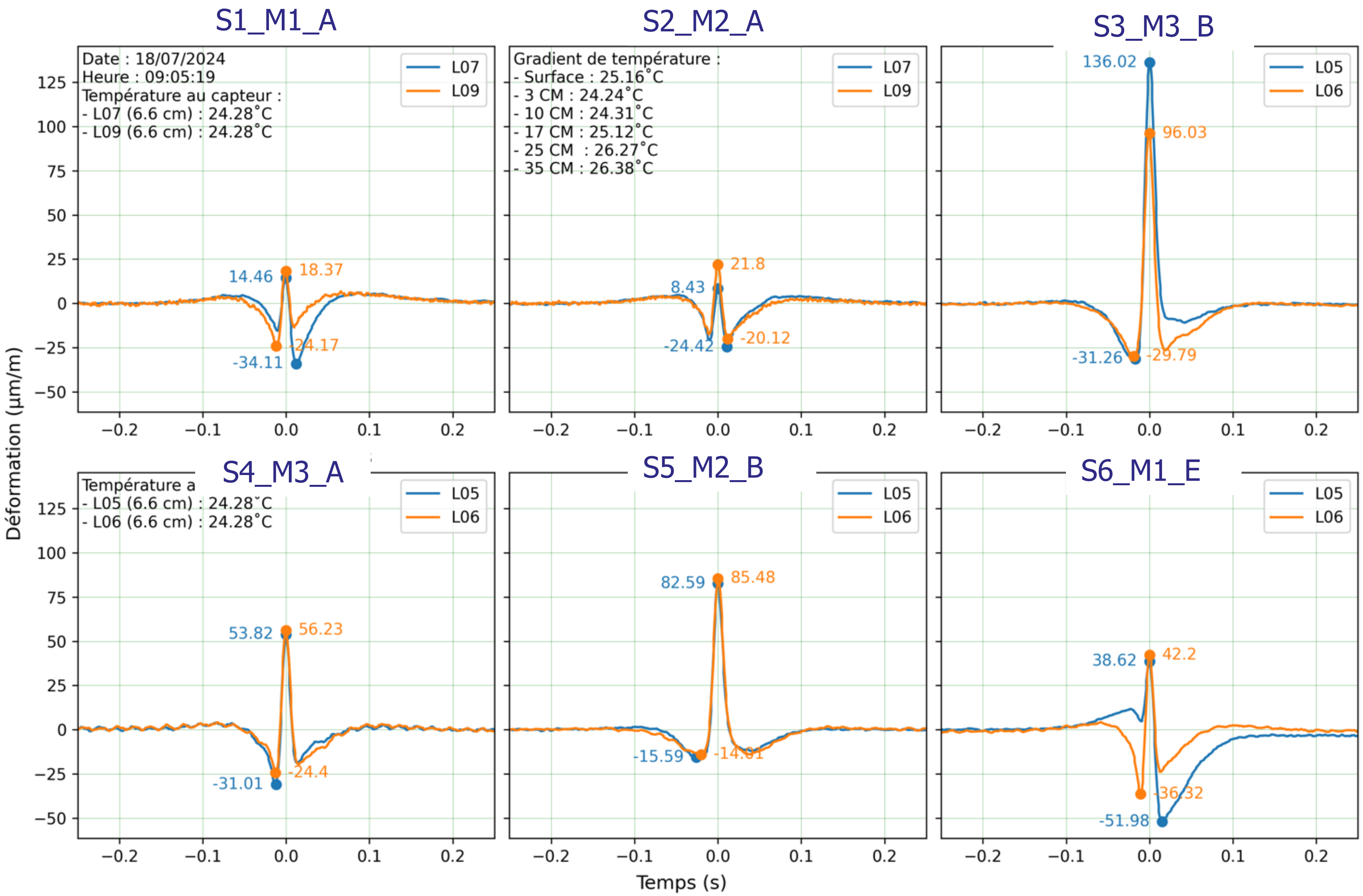
Strain measurements

Longitudinal strain signals above the coils (beginning of APT test)



Loading condition:

- 65 kN
- 59 km/h

Good repeatability of measurements

Much higher strains in extension on sections 3,4,5
⇒ Probable debonding

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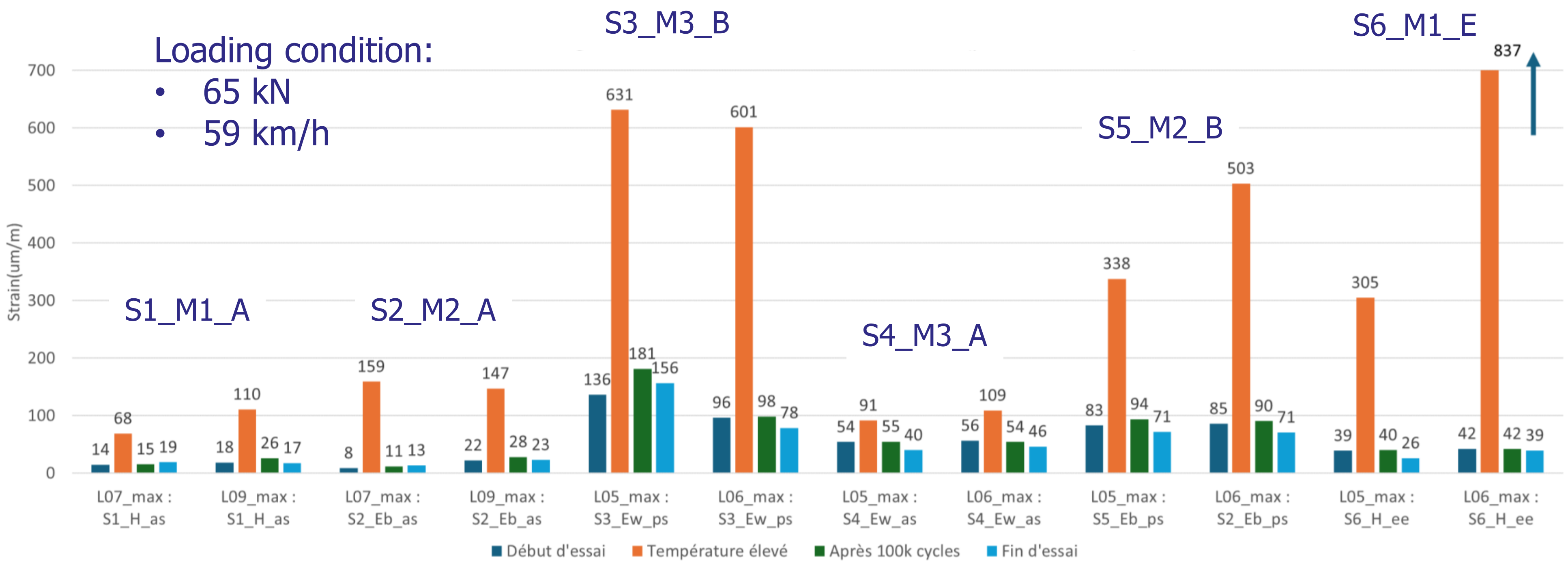
Strain measurements

- Maximum longitudinal strains in extension above the coils on all sections



- Very large (critical) strains in extension at high temperature (48 °C on surface) on sections 3, 5, 6 ⇒ poor performance of resin B and emulsion (**probable debonding of the coils**)
- The strains above the coils present the largest differences between sections
- No significant strain evolution with traffic at 25 °C

CAYD project – Summary of APT test results

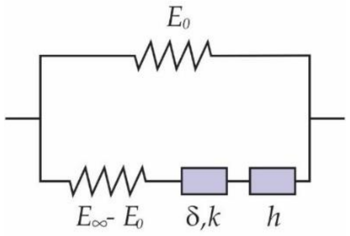
Tentative comparison of the performance of the different sections

Criteria	Reference	S1_M1_A	S2_M2_A	S3_M3_B	S4_M3_A	S5_M2_B	S6_M1_E	S8_M2/M3_E
Permanent Deformation - 200k	5,3	3,8	3,9	5,6	3,3	5,6	8,7	6,8
Deflection - Highest values (~100k)	22	31	27	46	31	33	32	32
E_vertical granular layer - 200k (compresive strain)	172	202	214	269	192	242	240	-
E_long. bottom base - 24°C - 200k (tensile strain)	67	83	72	108	102	93	96	-
E_long. bottom base - 29°C (tensile strain)	102	111	114	146	137	141	132	-
E_long. top coil - 24°C - 200k (tensile strain)	-	18	18	117	43	71	32	-
E_long. top coil - 42°C (tensile strain)	-	89	153	616	100	420	571	-

- Most relevant performance criteria : permanent deformation, deflection, and strains above the coils
- Sections with emulsion present larger permanent deformations
- Sections with resin B and emulsion present large (critical) tensile strains above the coils, especially at high temperature (debonding ?)
- Resin A provides by far the best bonding
- **Sections S1 and S2 (materials 1 and 2 with resin A) present the best overall performance**

First Numerical simulations and comparison with experimental measurements

First modelling with ViscoRoute©2.0



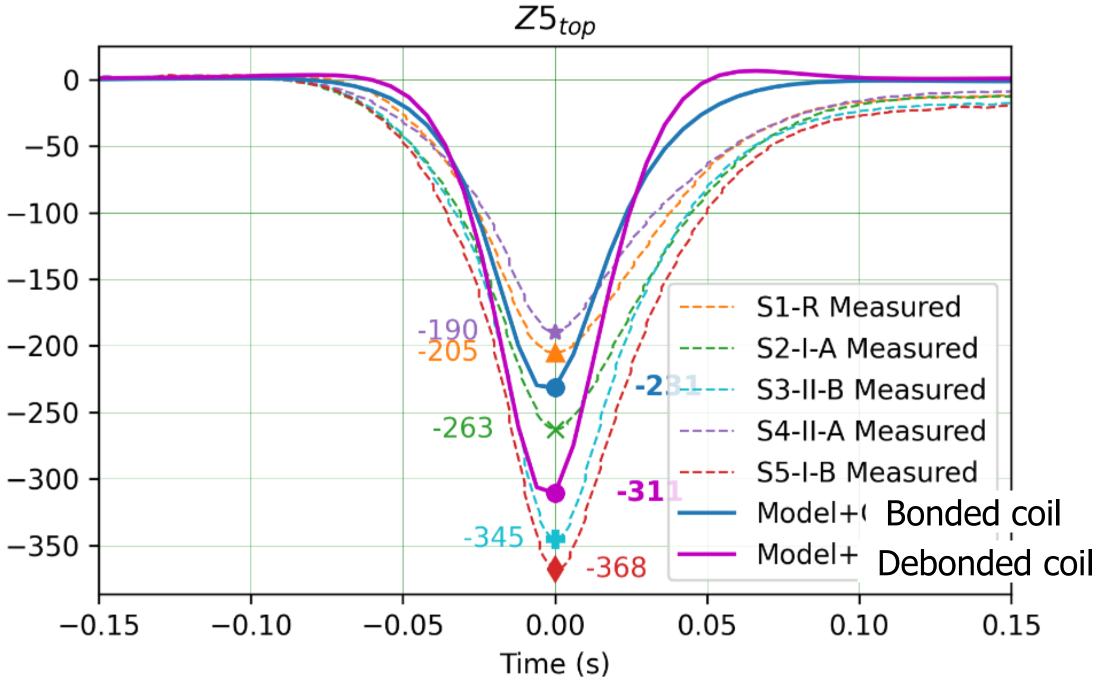
$$E^*(i\omega\tau) = E_0 + \frac{E_\infty - E_0}{1 + \delta\left(i\omega\tau(\theta)\right)^{-k} + \left(i\omega\tau(\theta)\right)^{-h}}$$

Rheological model proposed by Huet-Sayegh

- **Properties of pavement materials**
  - BBTM – Viscoelastic
  - BBSG – Viscoelastic
  - Coil – Elastic
  - GB4 – Viscoelastic
  - Subgrade – Elastic

Two modelling assumptions : Bonded coil interface and debonded coil interface

Comparions of measured and predicted vertical strains at top of subgrade



- Model with bonded coil predicts well strains on **Sections 2 and 4 with resin A**

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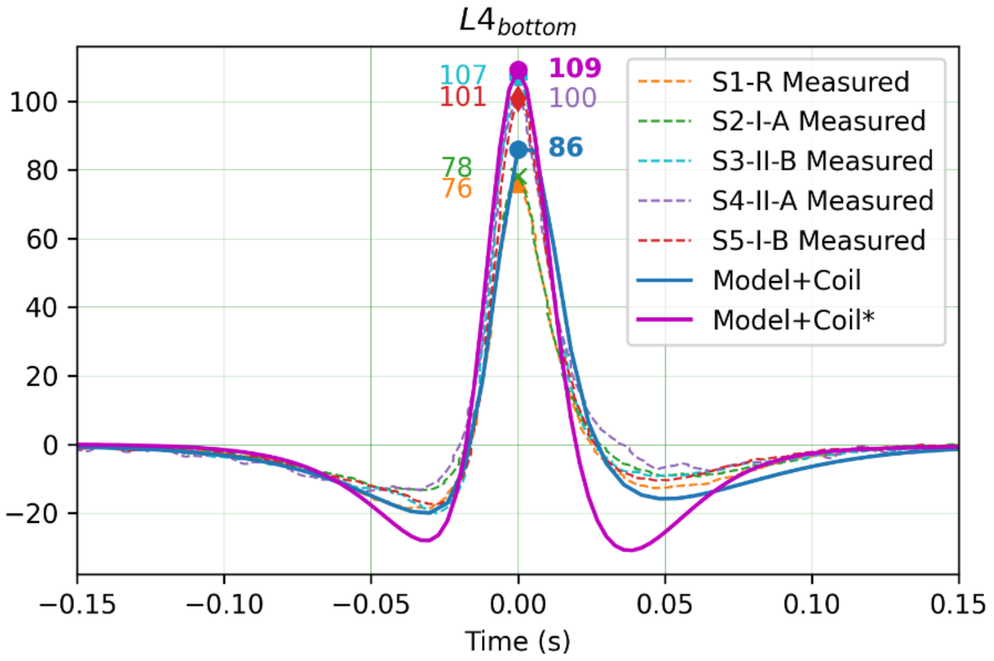
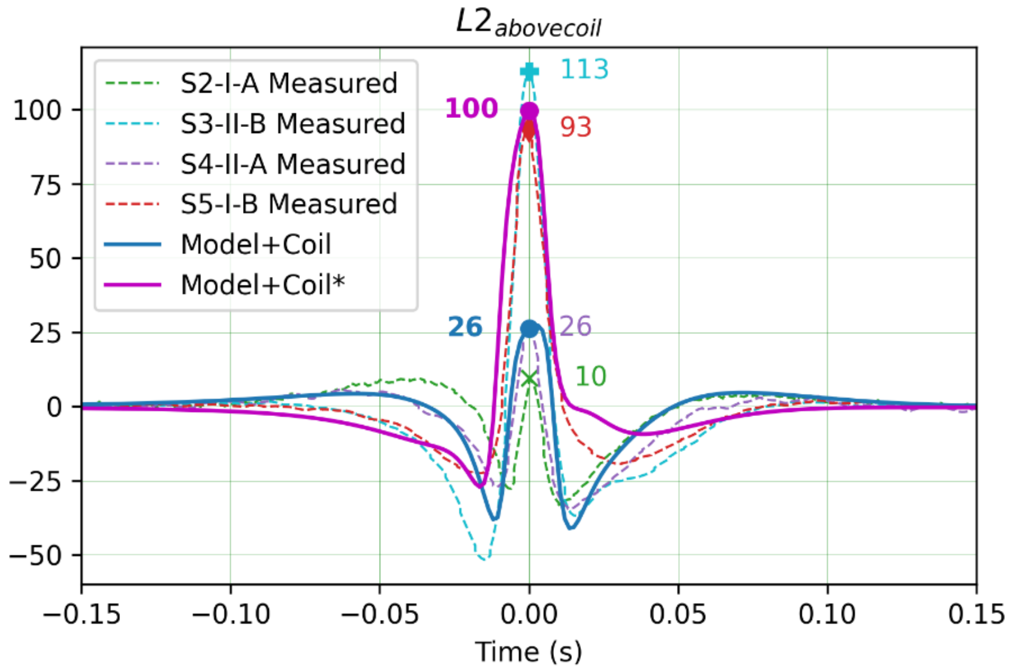
First Numerical simulations and comparison with experimental measurements

Two modelling assumptions : Bonded coil interface and debonded coil interface

Comparions of measured and predicted tensile strains at bottom of asphalt layers



Comparions of measured and predicted tensile strains above the coils



Temperature at sensor depth:
- Z5_top: 24.8˚C
- L4_bottom: 24.97˚C
- L2_above coil: 29.14˚C

- Model with bonded coil predicts well strains on **sections 2 and 4 with resin A**
- Model with debonded coil predicts strains on **sections 3 and 5 with resin B**

o Model+Coil with Coil in bonded condition
o Model+Coil* with debonded Coil/GB4 interface

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CAYD project – Conclusions and next steps

Conclusions of APT tests :

- **Validation of pavement integration solutions with materials 1 and 2 and resin** A
  No significant pavement deterioration except moderate permanent deformations after 200 000 load cycles and no excessive tensile strains
- Effect of all coils on pavement response : increase of deflections and strains compared to the reference pavement – in particular at high temperature
- Limited effect of coils on tensile strains at bottom of asphalt base
  Much higher effect on tensile strains above the coils (risk of debonding).
- Strong influence of coil bonding on pavement response ⇨ good performance with resin A poor performance with resin B and emulsion

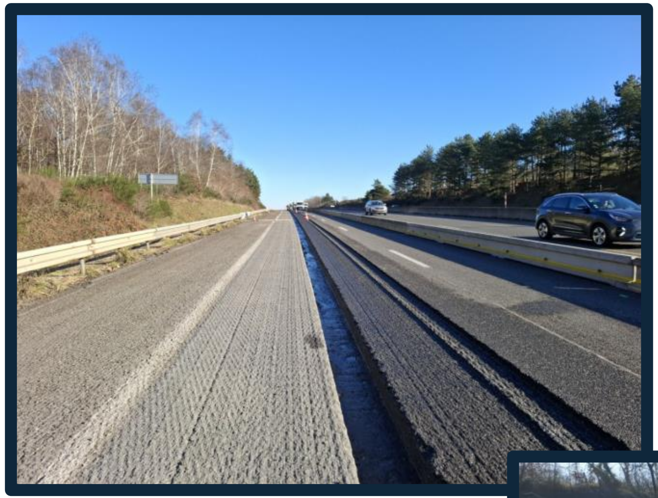
Next steps :

- Detailed modeling of the mechanical and thermal behaviour
- Measurement of electromagnetic emissions
- Construction of 1500 m long demonstrator on motorway A10 – tests with vehicles

1500 m long demonstrator built on Motorway A10 west of Paris in spring 2025

Installation of 900 coils and 38 roadside units for electric supply.

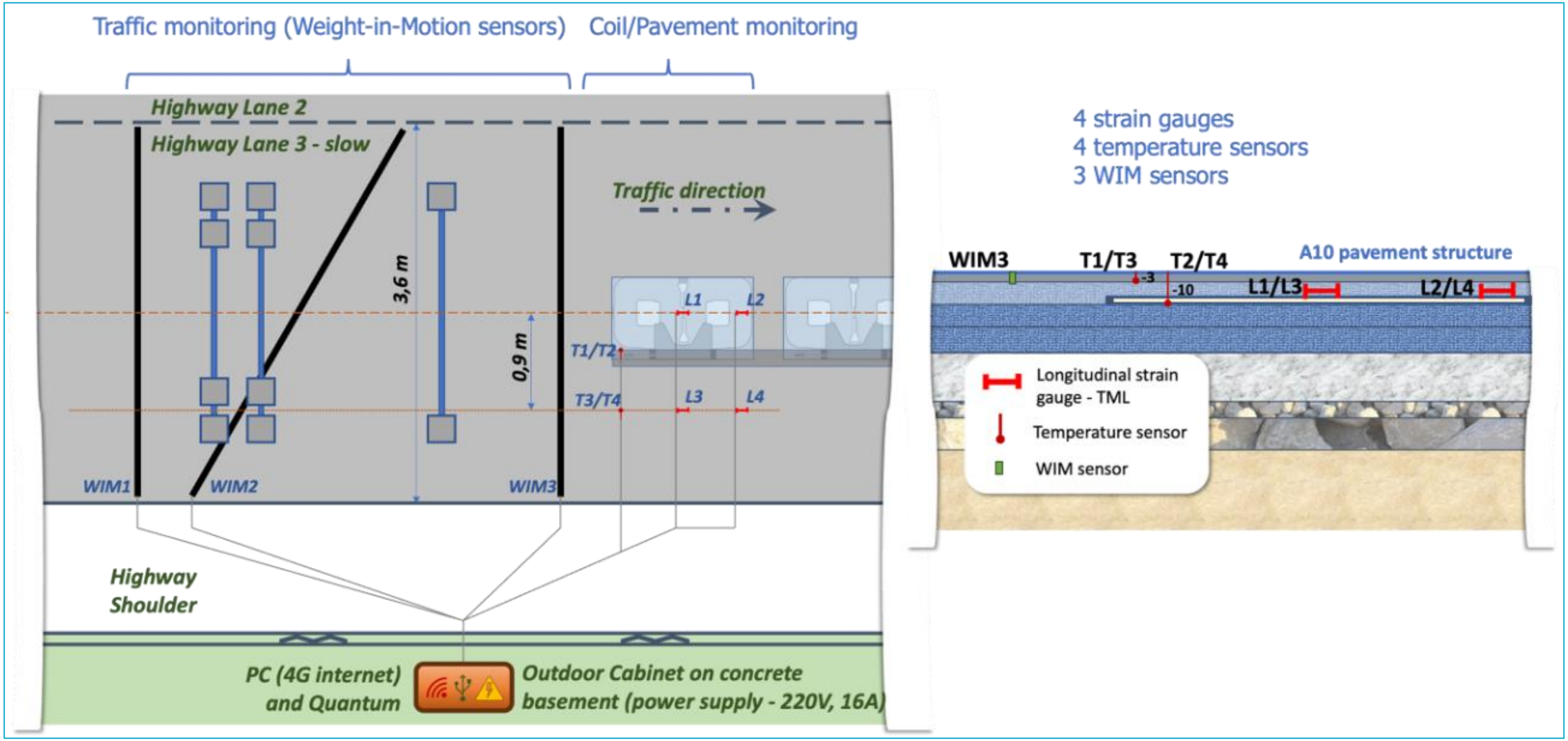
Charging power : 70 kW / coil - Installation rate : 100 coils / day



1500 m long demonstrator built on Motorway A10 in spring 2025

Tests with 4 vehicles will start soon : heavy truck, bus, light utility vehicle, passenger car
+ monitoring of deflections and instrumentation with strain gauges and temperature sensors

Instrumentation of the demonstrator



Thank you for your attention

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