Structural Health Monitoring, Round Robin Tests

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Public presentation of results

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INTRODUCTION

- Deliverables for the 4 project phases:

► Phase 1: Improving interpretation of monitoring methods for an accurate pavement diagnostic

Authors: Benoit Picoux - GC2D Laboratory, Rémi Tautou - University of Limoges

► Phase 3: High-speed deflection measurements

Author: Pascal Trottier – PAVEXPERT

► Phase 4: Round robin tests

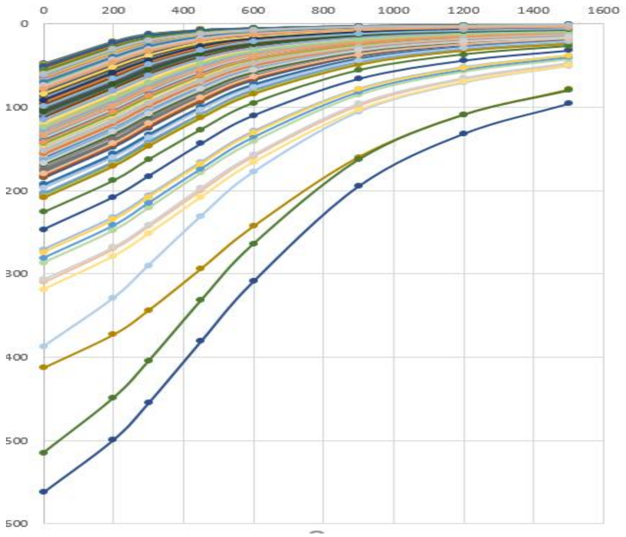
Authors: Alain Hebting – Cerema, Pascal Trottier - Pavexpert

► Improving interpretation of monitoring methods for an accurate pavement diagnostic based on impact methods

- Existing methodology in accordance with equipment (Dynaplaque, Deflectograph, FWD)
- Structural indicators (SCI, radius of curvature, etc.)
- Overview of backcalculation software
- Physical and mechanical variables
  - Temperature, Load, Water content, Layer thickness, Interface, Viscoelasticity



NEW EQUIPMENT

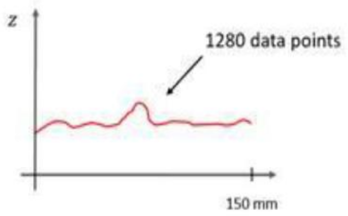




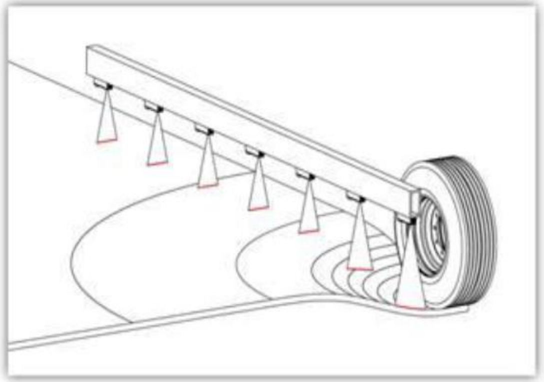
Deflection measurement principles used

Raptor

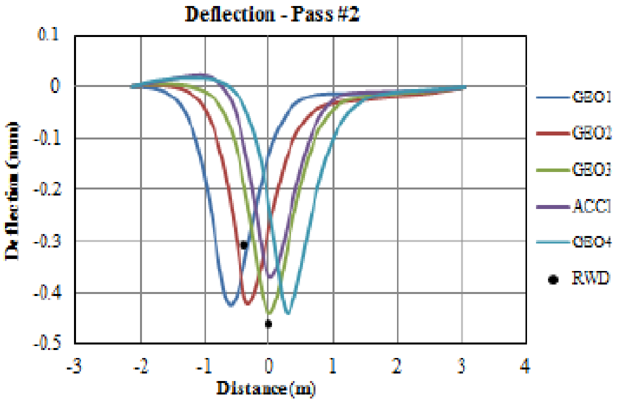
Line scans at 4000 Hz from several line laser profilers

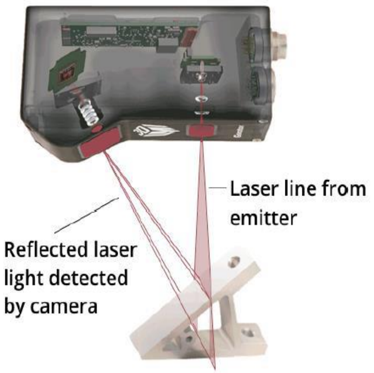


z = *distance from laser to surface*

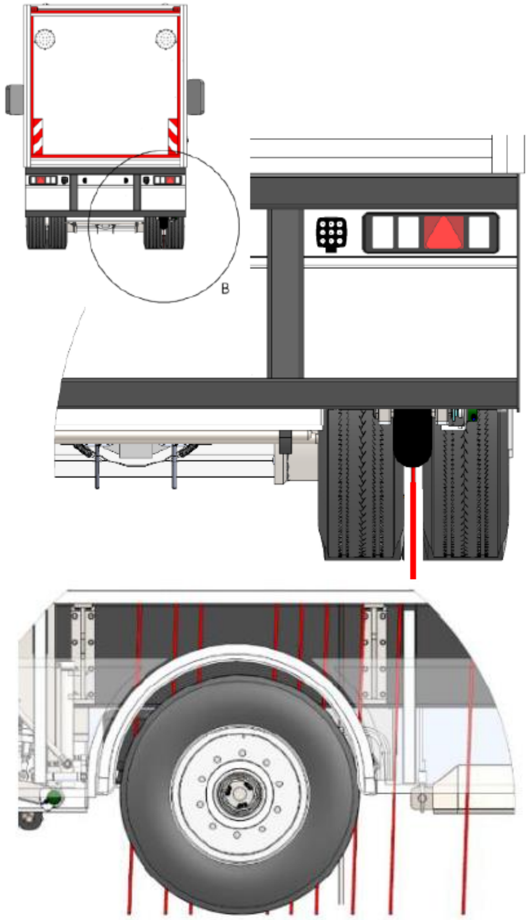


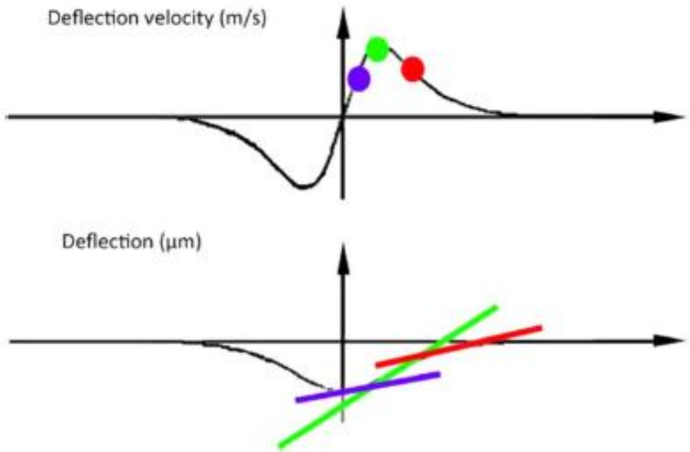
Raptor measuring setup. Laser line profilers scan a road surface deflected by a heavy wheel load.

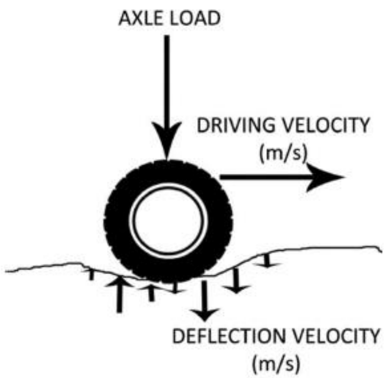




TSD

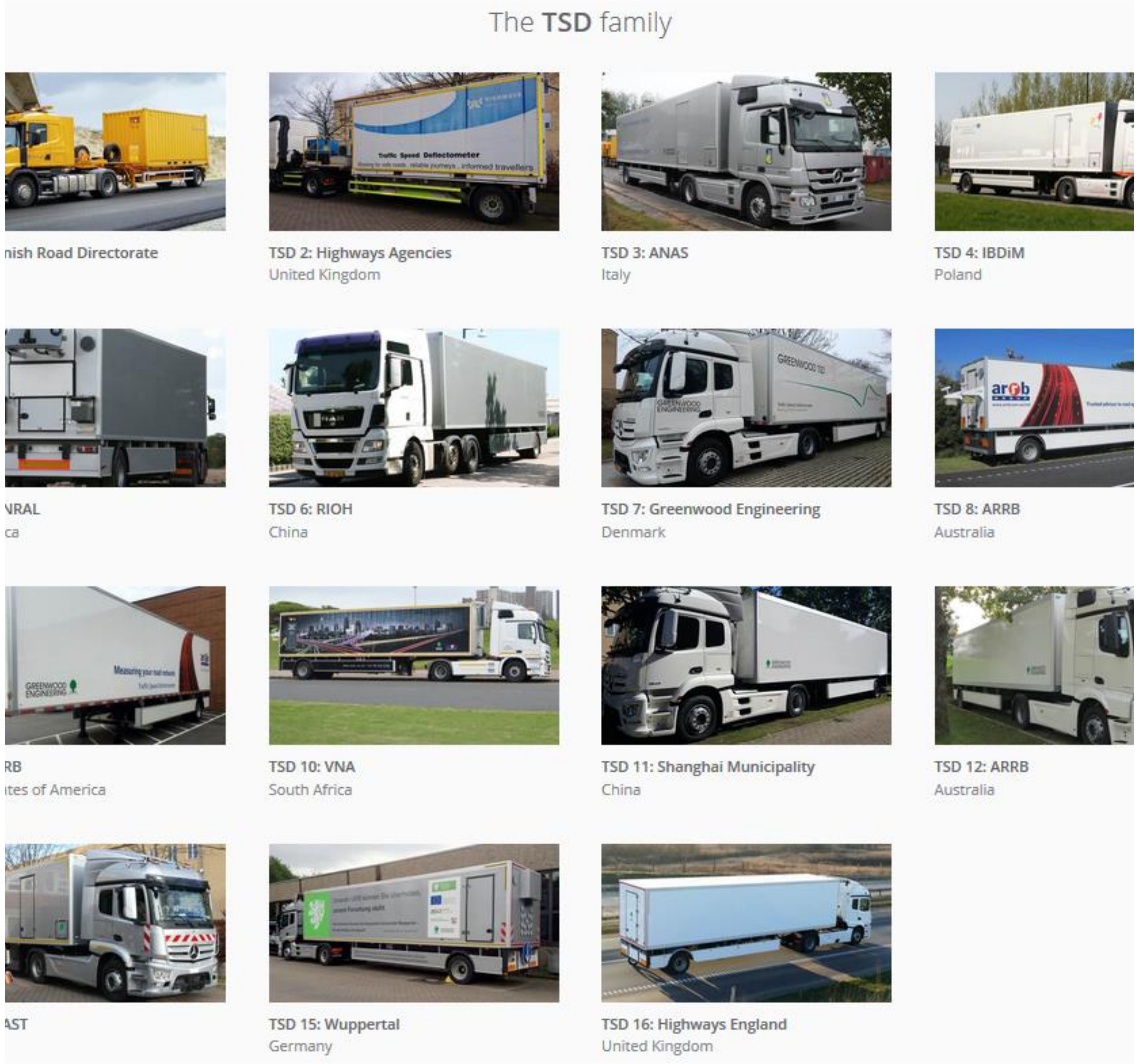






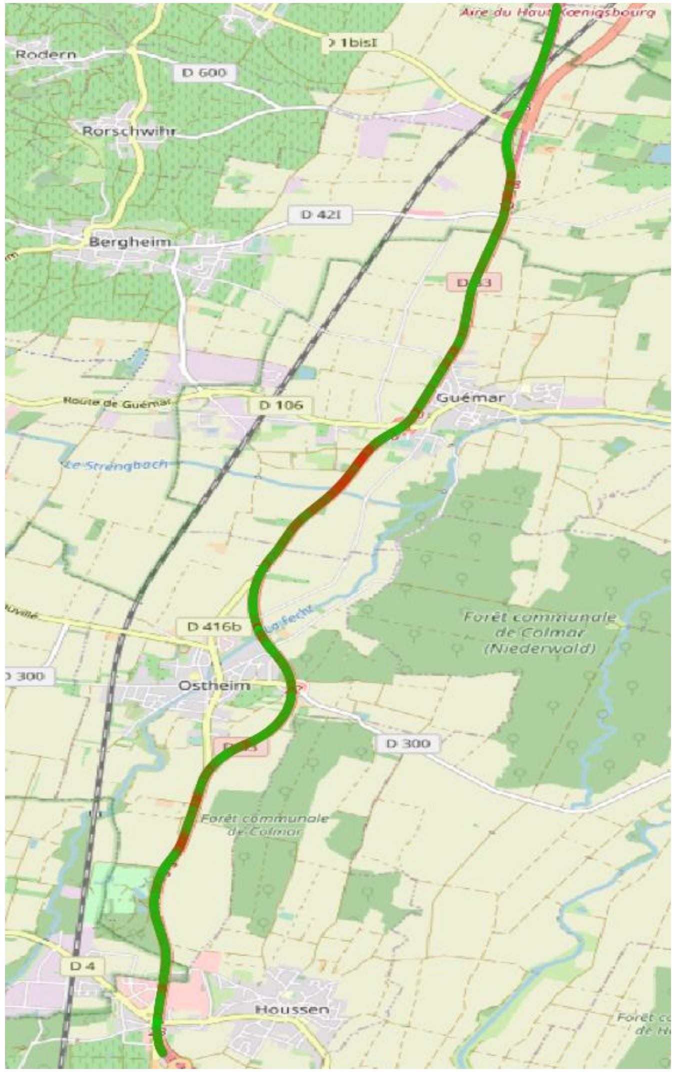


EQUIPMENT THAT HAS EVOLVED OVER TIME



Example: TSD 2 operated by TRL in England 	**Generation 1** - TSD 1 and TSD 2. Both still in operation - Built on a standard container - Equipped with 4 Doppler lasers located at the front on the rear loading axle.
Example: TSD 8 operated by ARRB in Australia - equipped with LCMS lasers 	**Generation 2** - TSD 3 - TSD 12. - Built on an insulated trailer. - Equipped with 7 Doppler lasers located on the centre line between the dual wheels and at the front of the rear axle.
Example: TSD 15 operated by BASt in Germany - equipped with georadar and Fraunhofer laser scanner 	**Generation 3** - TSD 14 – TSD 15 - Built on an insulated trailer. - Equipped with 10-11 Doppler lasers located on the centre line between the dual wheels. 7-8 lasers are located in front of the rear axle and 3 are located behind the axle.
Exemple: TSD 16 operated by TRL in UK - equipped with Doppler lasers to measure deflections on left and right treads 	**Generation 4** - TSD 7 + TSD 16 and newer. - Built on an insulated trailer. Equipped with 10-11 high-frequency Doppler lasers located on the centre line between the dual wheels. 7-8 lasers are located at the front of the rear axle and 3 are located behind the axle.





- Measurements in traffic flow, up to 80 km/h
  - No inconvenience to users
  - No specific operating constraints (measurements in the daytime, no protection needed)
  - BUT measurement in dry weather
- Network management
  - Identification of weak areas on where to focus the precise diagnostic work
  - Prioritisation of work
  - Monitoring over time
  - Estimation of residual service life (using a model)

► International indicators (based on FWD)

Index	Formula	Parameters	Unit
Surface Curvature Index (SCI)	$SCIr = D0 - Dr$	D0 = Deflection 0 inches from the load Dr = Deflection r inches from the load	mil
Deflection Slope Index (DSI)	$DSIr0{-}r = Dr0 - Dr$	Dr0 = Deflection r0 inches from the load Dr = Deflection r inches from the load	mil
Tangent Slope (TS)	$TS_r = \frac{dD}{dr}$	dD = Difference in deflections Dr = Difference in distance	mil/inches
Radius of curvature (R1)	$R1_r = \frac{r^2}{[2D_0\left(1 - {}^{D_r}/_{D_0}\right)]}$	r = Distance from load D0 = Deflection under load Dr = Deflection at distance r from the load	inches
Radius of curvature (R2)	$R2_r = \frac{r^2}{[2D_0\left({}^{D_0}/_{D_r} - 1\right)]}$	r = C6 D0 = Deflection under load Dr = Deflection at distance r from the load	inches
Deflection basin area (A)	$A = 6[1 + 2\left(\frac{D_{12}}{D_0}\right) + 2\left(\frac{D_{24}}{D_0}\right) + \frac{D_{36}}{D_0}]$	Dr = Deflection r inches from the load	-

Index	Formula	Parameters	Unit
Shape Factor F1	$F_1 = \frac{D_0 - D_{24}}{D_{12}}$	Dr = Deflection r inches from the load	-
Shape Factor F2	$F_2 = \frac{D_{12} - D_{36}}{D_{24}}$	Dr = Deflection r inches from the load	-
Base Curvature Index (BCI)	$BCI = D24 - D36$	Dr = Deflection r inches from the load	mil
Base damage index	$BDI = D12 - D24$	Dr = Deflection r inches from the load	mil
Slope of Deflection (SD)	$SD_r = \frac{tan^{-1}(D_0 - D_r)}{r}$	Dr = Deflection r inches from the load	-
Area Under Pavement Profile (AUPP)	$AUPP = \frac{5D_0 - 2D_{12} - 2D_{24} - D_{36}}{2}$	Dr = Deflection r inches from the load r = Distance from load	mil



Evaluation of tensile stress at the base of the asphalt mix

$\varepsilon = a(DSI)b$ $\varepsilon = a'(SCI300)b'$ Rada (2016)

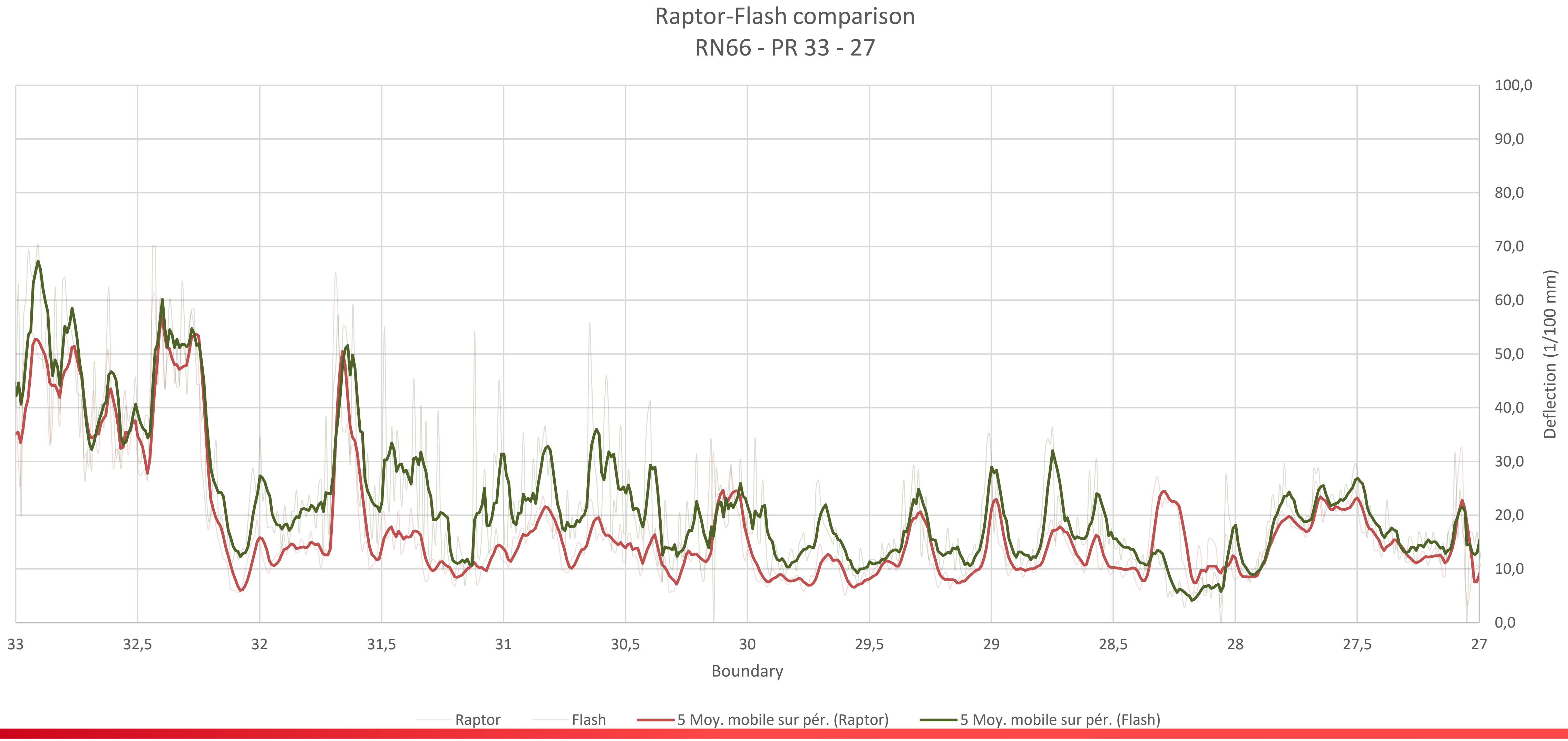
With the following parameters:

As a reminder (1 inch = 2.54 cm)

AC Layer Thickness	Parameter	
	a	b
3-4 inches	66.96	0.9351
4-5 inches	62.567	1.0174
5-6 inches	64.660	1.0379
6-7 inches	71.646	1.0005
7-8 inches	74.381	0.9757
8-9 inches	76.458	0.9427
9-10 inches	77.802	0.9107
10-11 inches	77.868	0.8674
11-12 inches	76.861	0.8395
12-13 inches	75.154	0.8149
13-14 inches	72.194	0.778
14-15 inches	70.196	0.7824
15-16 inches	66.402	0.7525
3-6 inches (Thin)	69.100	0.9348
6-9 inches (Medium)	75.100	0.9532
9-16 inches (Thick)	75.170	0.8579

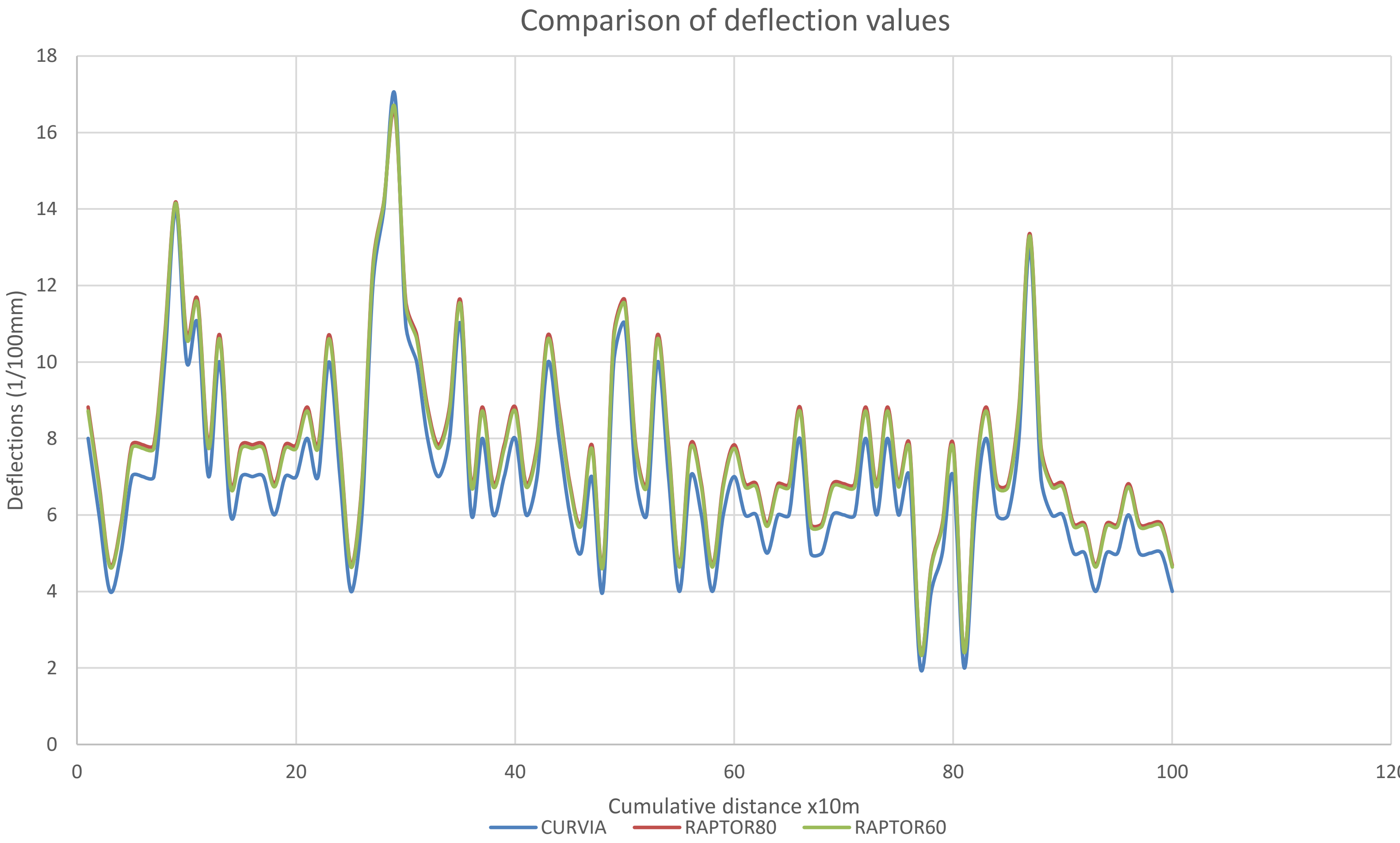
AC Layer Thickness	Parameter	
	a'	b'
3-4 inches	52.438	0.9620
4-5 inches	50.814	1.0200
5-6 inches	53.725	1.0240
6-7 inches	59.704	0.9870
7-8 inches	62.539	0.9520
8-9 inches	64.595	0.9120
9-10 inches	65.645	0.8820
10-11 inches	65.656	0.8373
11-12 inches	64.639	0.8103
12-13 inches	63.058	0.7895
13-14 inches	60.592	0.7479
14-15 inches	58.494	0.7594
15-16 inches	55.386	0.7285
3-6 inches (Thin)	57.818	0.9270
6-9 inches (Medium)	63.202	0.9350
9-16 inches (Thick)	62.538	0.8412




Raptor-Flash comparison
RN66 - PR 33 - 27
100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
Deflection (1/100 mm)
33
32,5
32
31,5
31
30,5
30
29,5
29
28,5
28
27,5
27
Boundary
Raptor
Flash
5 Moy. mobile sur pér. (Raptor)
5 Moy. mobile sur pér. (Flash)



▶ Direction 1 - Thick asphalt structure



▶ Comparison of values over 13 km - Direction 1

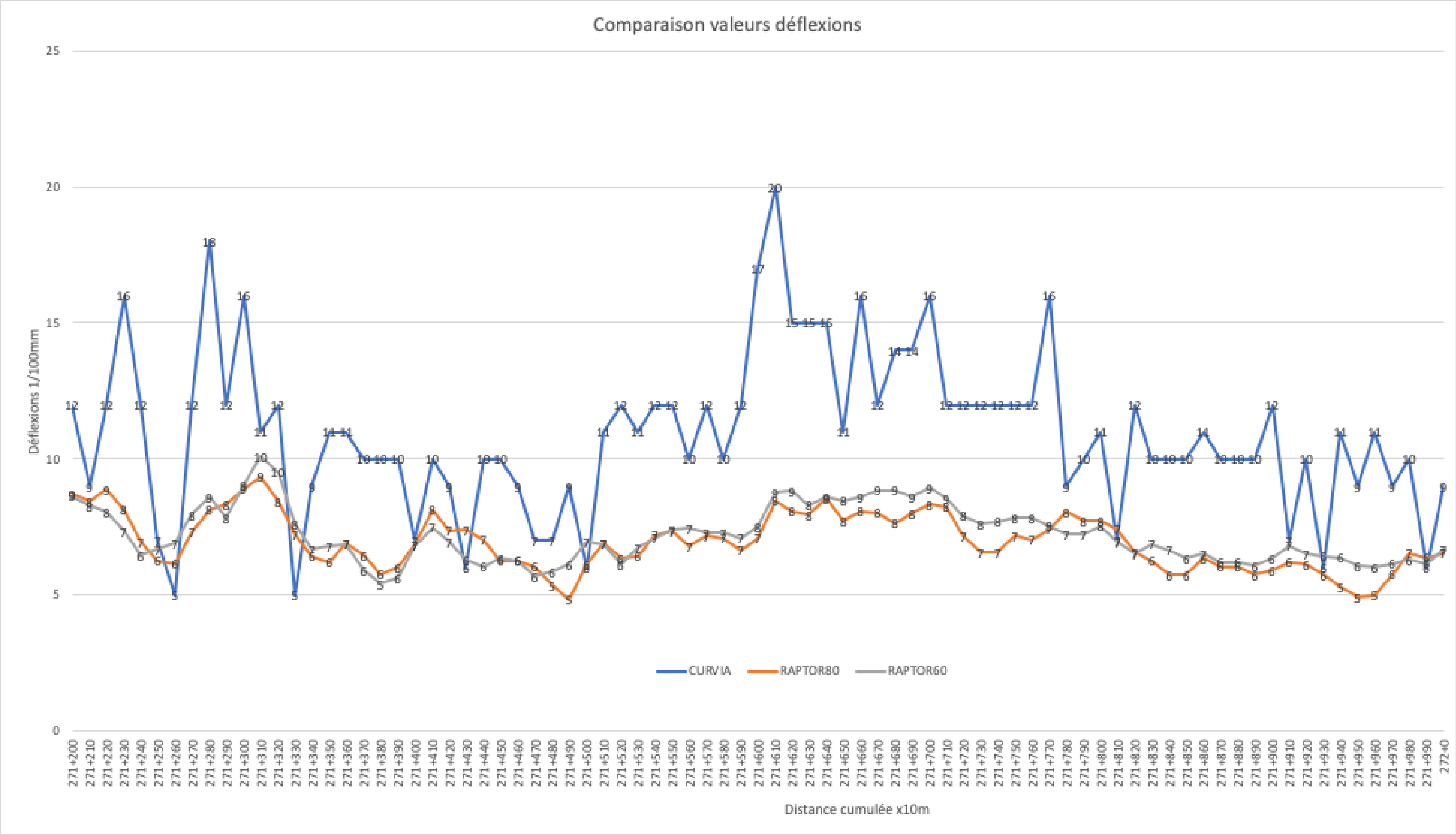
- Mean difference:
  - 0.747
- Standard deviation:
  - 0.12
- Mean squared error:
  - 0.60

▶ If values with weighting + 0.75

- Mean squared error:
  - 0.04
- Mean difference:
  - 0.0025
- Standard deviation:
  - 0.12



► Direction 2 - Thick asphalt structure





▶ Comparison of values over 13 km - Direction 2

- Mean difference Curviameter/Raptor 80km/h
  - 1.56
- Standard deviation:
  - 2.29

- Mean difference Curviameter/Raptor 80km/h
  - 1.33
- Standard deviation:
  - 2.31



Flash Deflectograph

	0	1	2	3	4	5	6	7	8	9	10
1er passage											
2ème passage											
3ème passage											
4ème passage											
5ème passage											
6ème passage											

TSDDs

FWD

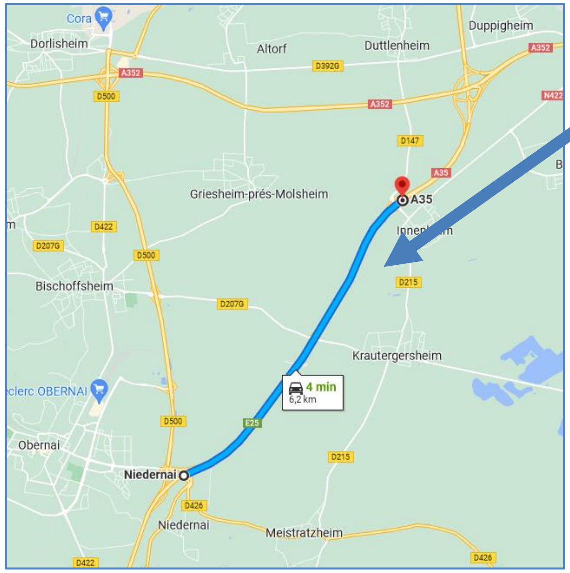
Aigle3D

CereMap3D

Radar3D

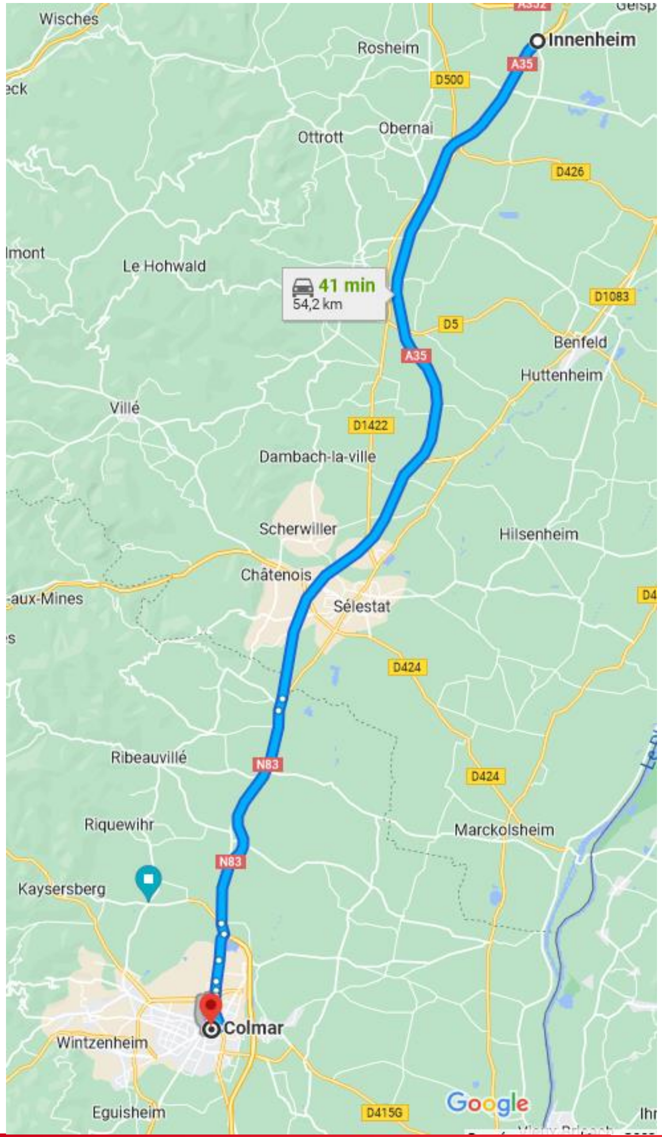
▶ DVDC project sections

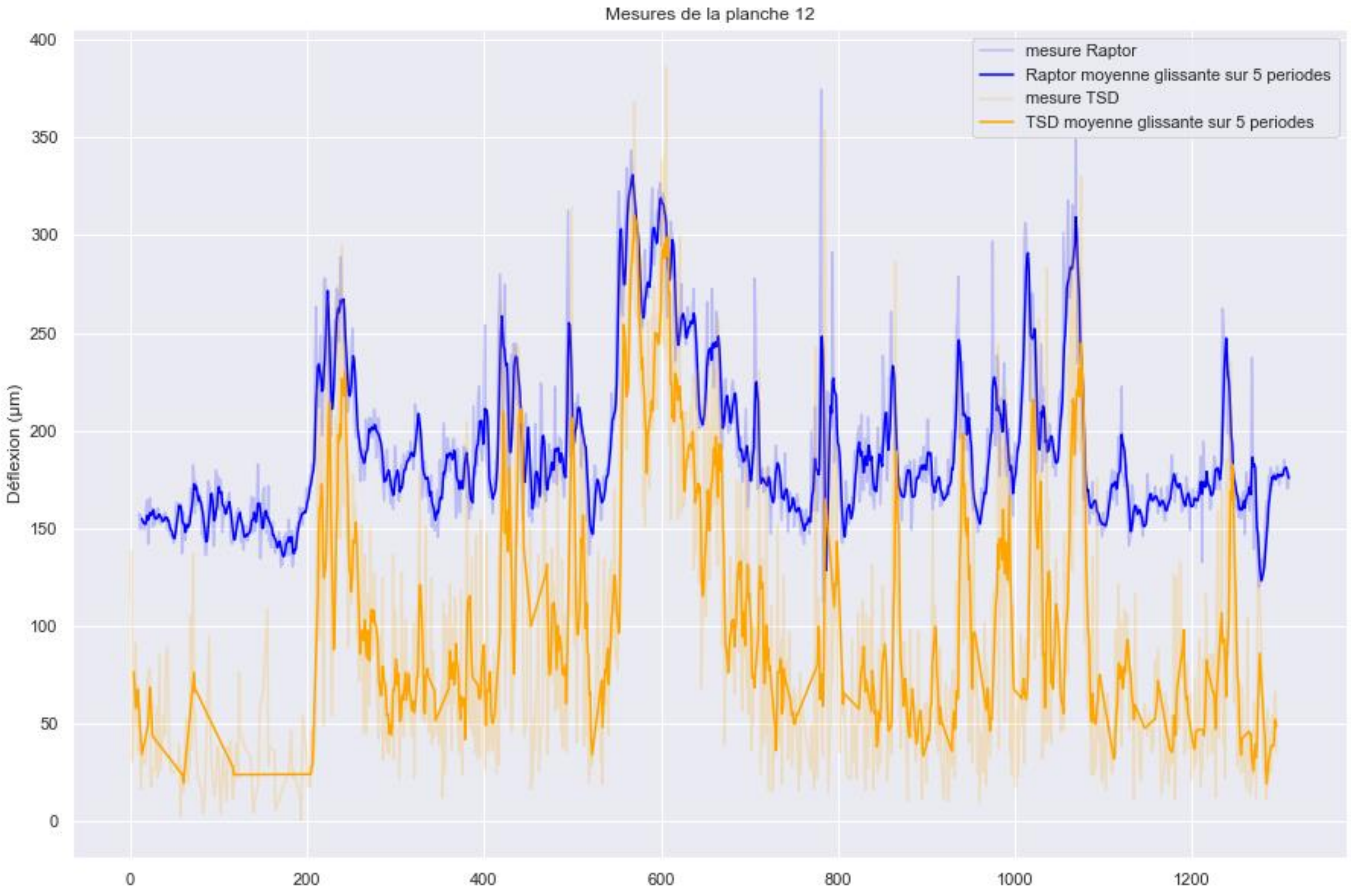
Section for repeatability



- ▶ Entire route (168 km)
- ▶ **A35:**
  - Bituminous and hydraulic
- ▶ **RN83:**
  - Bituminous and hydraulic
- ▶ **RD422:**
  - Flexible
- ▶ **RD500:**
  - High modulus asphalt
- ▶ **RD1422:**
  - Reinforced with geogrid
- ▶ **RN4:**
  - Historical route
- ▶ **A351:**
  - New, bituminous

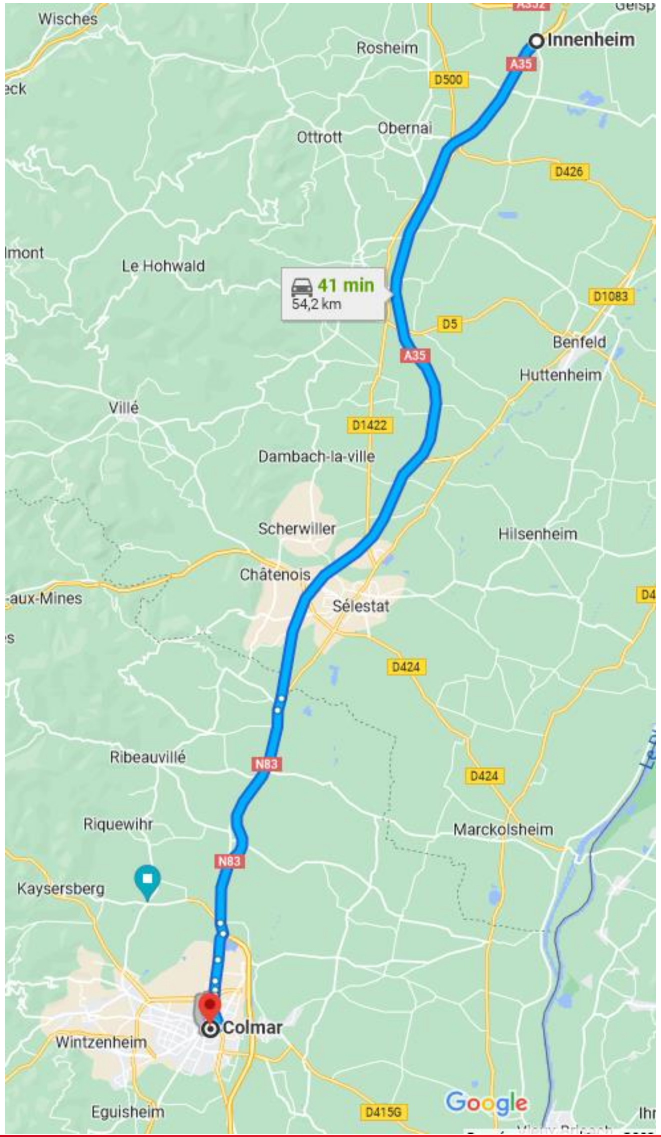
DEFLECTION RESULTS – SECTION 12

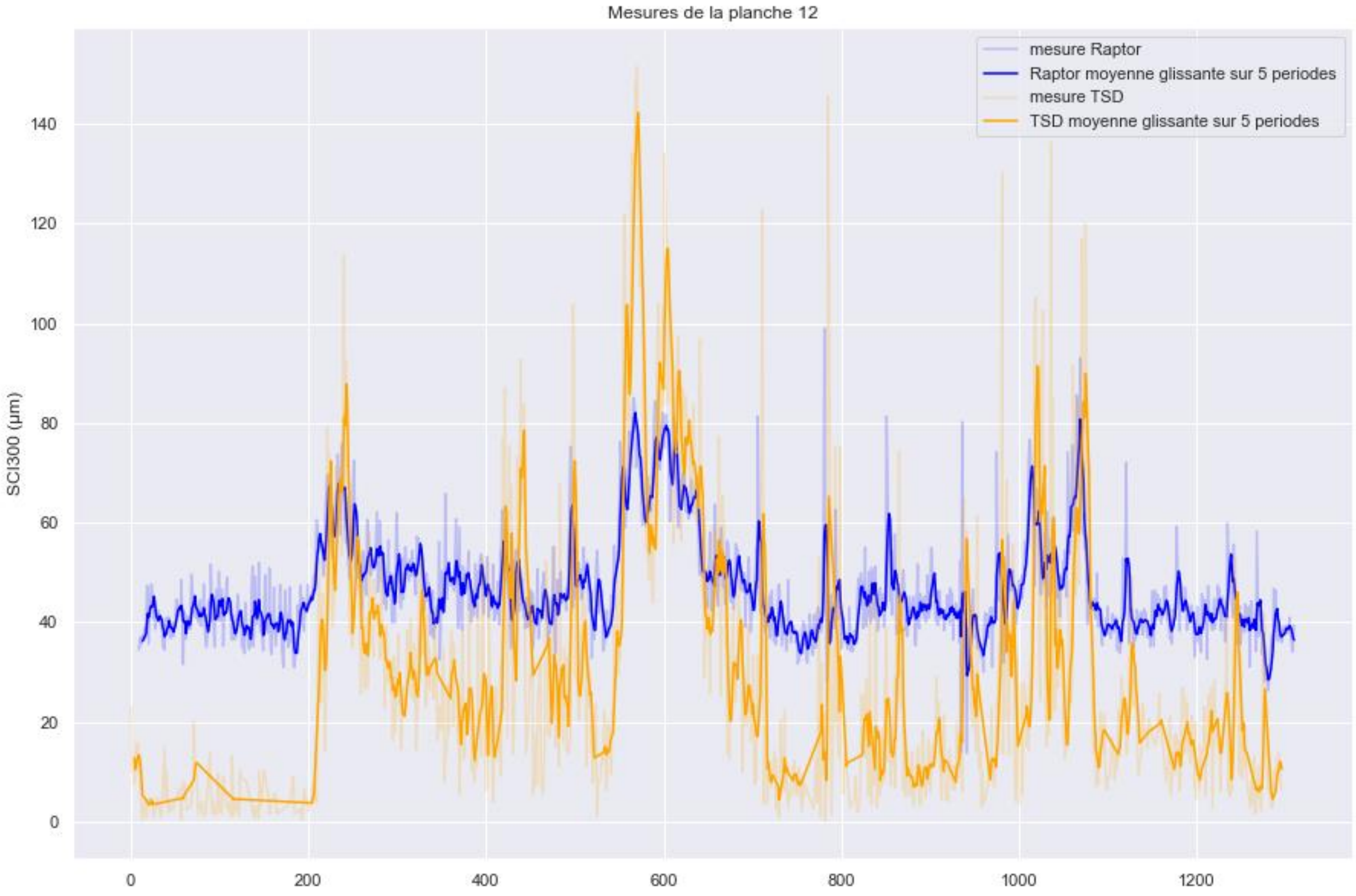


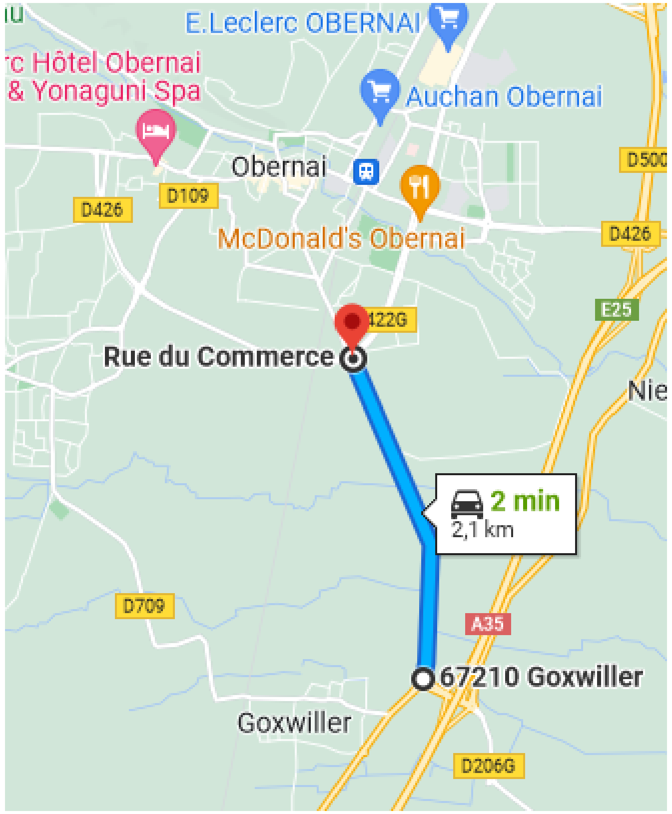


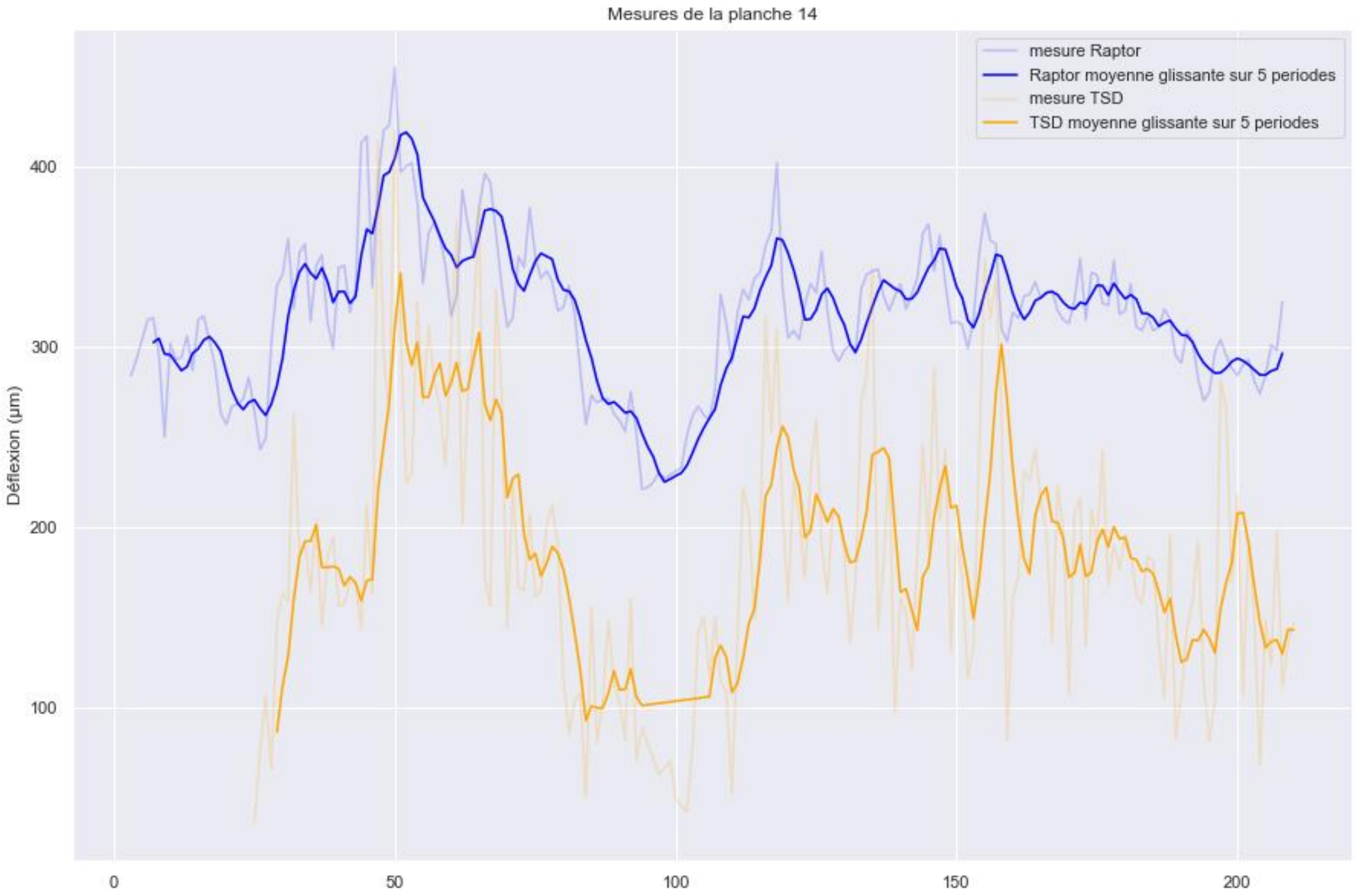


SCI300 RESULTS – SECTION 12



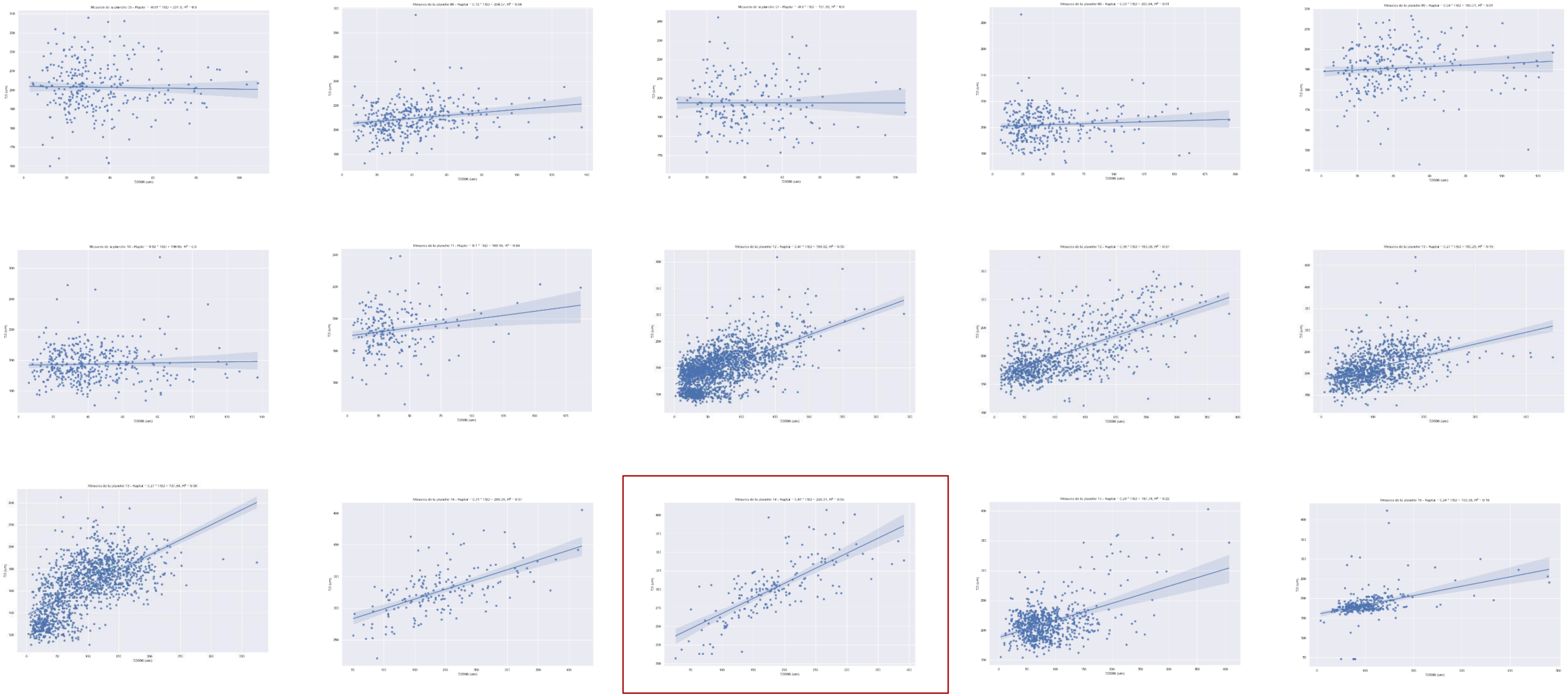



E.Leclerc OBERNAI
Hôtel Obernai
& Yonaguni Spa
Auchan Obernai
Obernai
D500
D426
D109
McDonald's Obernai
D426
E25
Rue du Commerce
Nie
2 min
2,1 km
D709
A35
67210 Goxwiller
Goxwiller
D206G

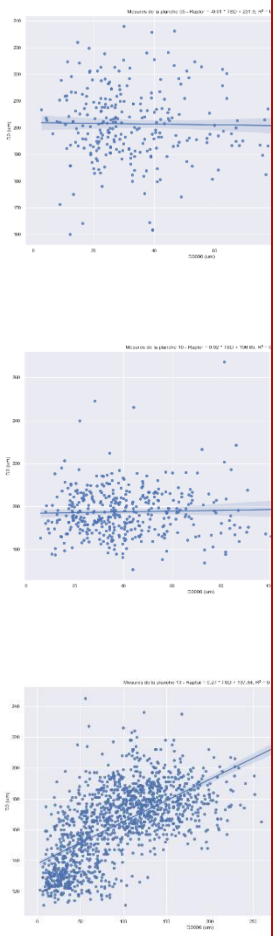

Mesures de la planche 14
mesure Raptor
Raptor moyenne glissante sur 5 periodes
mesure TSD
TSD moyenne glissante sur 5 periodes
Déflexion (µm)
400
300
200
100
0
50
100
150
200

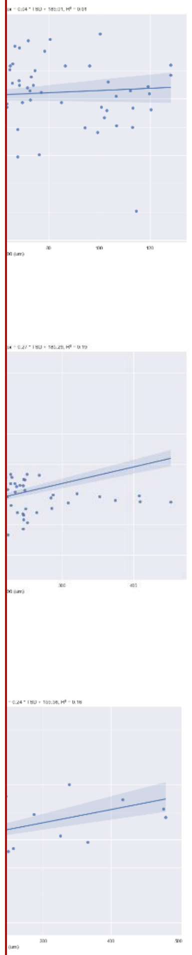


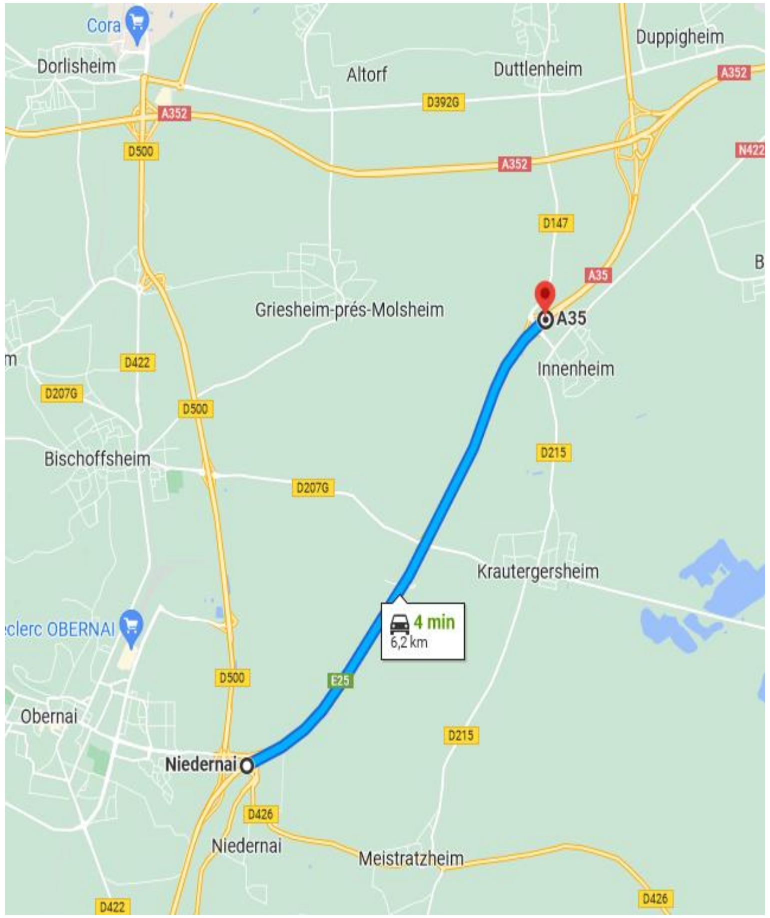
Correlations – Raptor = F (TSD) – $R^2 \leq 0.55$

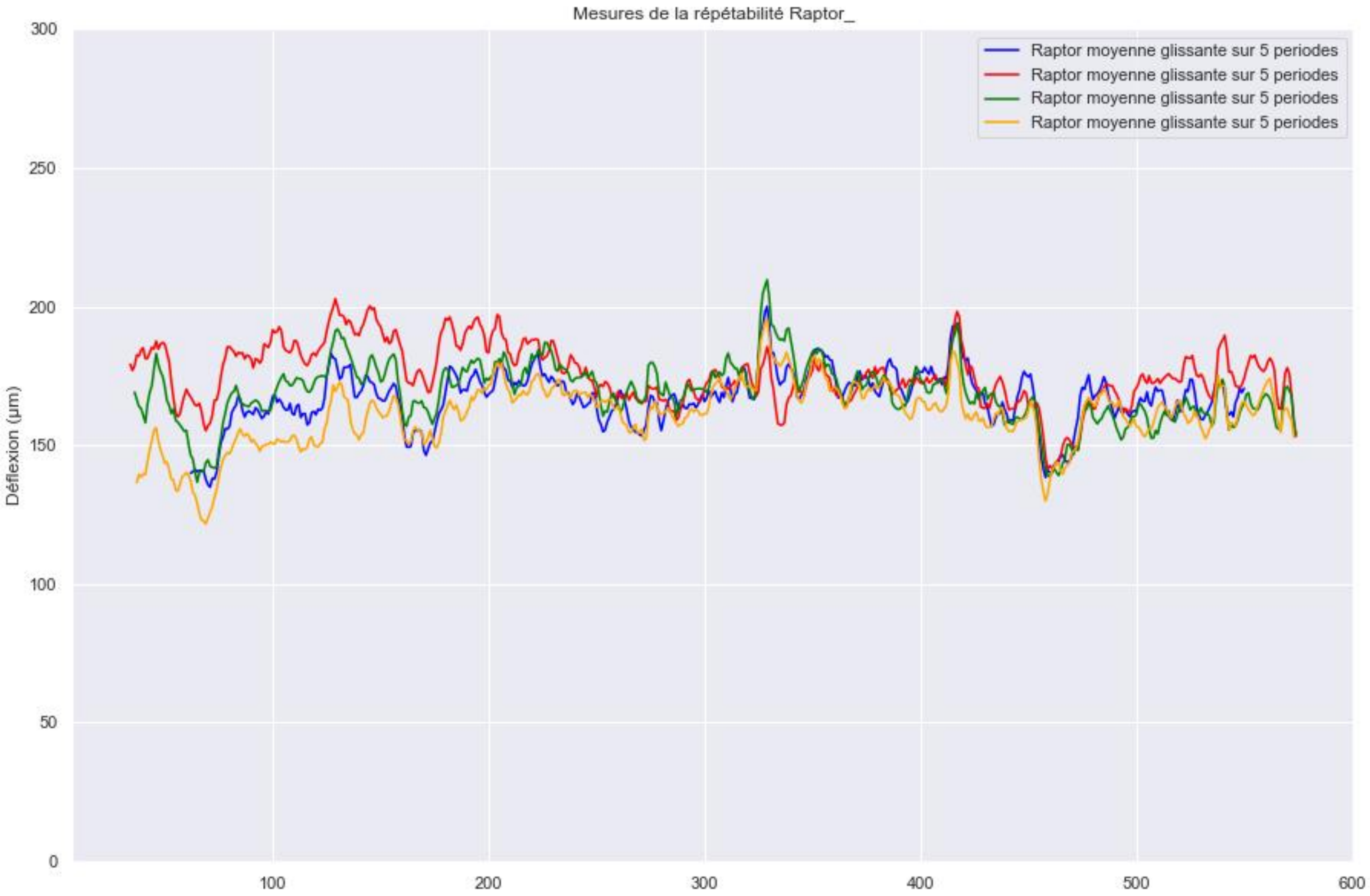


CORRELATIONS – RAPTOR = F (TSD) – $R^2 \leq 0.55$

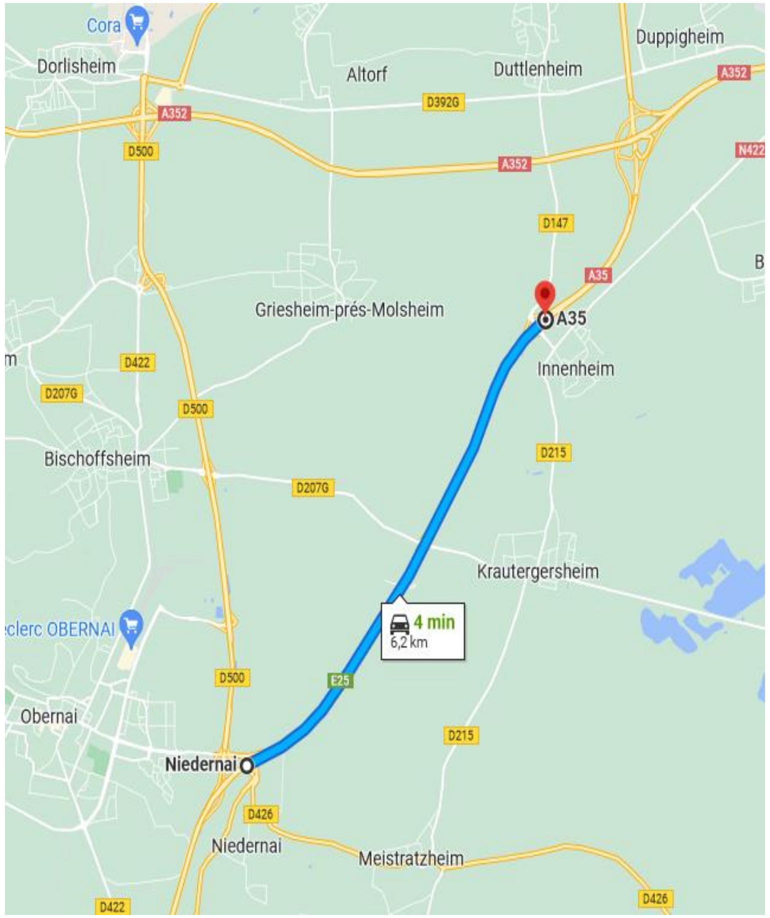


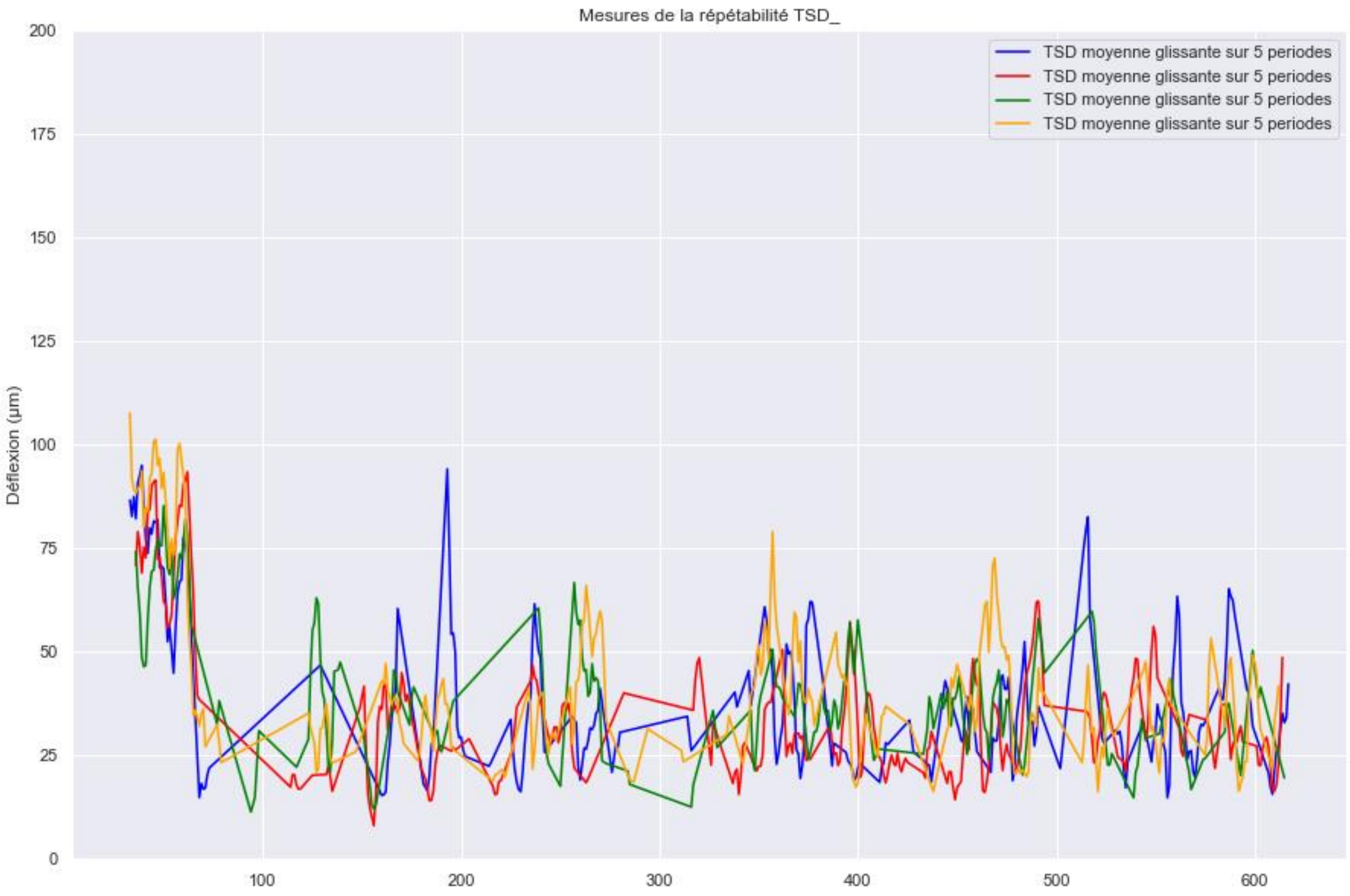



Cora
Dorlisheim
Altorf
Duttlenheim
Duppigheim
A352
D392G
D500
N422
D147
A35
Griesheim-près-Molsheim
Innenheim
D422
D207G
Bischoffsheim
D215
Krautergersheim
4 min
6,2 km
E25
Obernai
Niedernai
D426
Meistratzheim


Mesures de la répétabilité Raptor_
Raptor moyenne glissante sur 5 periodes
Raptor moyenne glissante sur 5 periodes
Raptor moyenne glissante sur 5 periodes
Raptor moyenne glissante sur 5 periodes
Déflexion (µm)
0
50
100
150
200
250
300
100
200
300
400
500
600




Cora
Dorlisheim
Altorf
Duttlenheim
Duppigheim
Griesheim-près-Molsheim
A35
Innenheim
Bischoffsheim
Krautergersheim
4 min
6,2 km
Obernai
Niedernai
Meistratzheim


Mesures de la répétabilité TSD_
TSD moyenne glissante sur 5 periodes
TSD moyenne glissante sur 5 periodes
TSD moyenne glissante sur 5 periodes
TSD moyenne glissante sur 5 periodes
Déflexion (µm)
0
25
50
75
100
125
150
175
200
100
200
300
400
500
600

› Field of application

- Possible to make comparisons between the two devices:
  - Network-wide monitoring.
  - Homogeneous areas

- Attention must be paid to the geolocation variable for repeatability/reproducibility.

- Deviation of the deflection value itself and, therefore, of the characteristic deflection according to the structure in place.
  - The greater the deflection value, and thus the more flexible the structure, the less significant the difference between the devices;
  - Both devices have been tested by their respective manufacturers on rather flexible pavements, and use an FWD as a reference;
  - Further testing is needed to assess this effect.

THANK YOU FOR YOUR ATTENTION

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