



## Road force sensor for vehicle grip estimation and road monitoring devices verification

Alex Coiret<sup>1</sup>, Pierre-Olivier Vandanjon<sup>2</sup>

Gustave Eiffel University, <sup>1</sup>SII and <sup>2</sup>SPLOTT laboratories, France.



- 1 Introduction
- 2 Experimental Set-Up
- 3 Road Sensor Validation
- 4 Results
- 5 Conclusion

## Road safety

- Related to tire to road grip: braking, turning
- Monitoring devices such as GripTesters: a small measuring wheel, with a speed 15% lower than the support wheels of a trailer

## Road sensor

- Specific vehicles (dynamometric wheels, trailers, skid resistance tester SRT): monitor grip resistance of a given road section, everywhere on road network
- Embedded road sensor: could assess mobilized grip for various vehicles, in a given place of the road network
- Interest: focus on grip issue for some vehicle classes, with road wear and road geometry (turns)

## In this research

- Validation of a road sensor facing a passenger car: laboratory test track, rolling and braking on a 40x40cm instrumented road portion.
- Comparison of road sensor measurements to measures of several GripTesters rolling on it

## Perspectives

- Laboratory sensor reference facing vehicles and grip devices
- On road system to statistically evaluate the mobilized grip of a distribution of vehicles (vehicle characteristics, driver behavior, road evolution with time)

- 1 Introduction
- 2 Experimental Set-Up**
- 3 Road Sensor Validation
- 4 Results
- 5 Conclusion

6D forces and moments sensor: up to 750 daN in road tangential directions, up to 2500 daN in the road normal direction.

Embedded in the road, with the original road section affixed to the upper plate.

Signal processing and conversion enable a measurement frequency of 2500 Hz.



Fig: Excavation in the roadway, sensor, and interface plate (asphalt layer of the wearing course not visible)

GripTester: device for measuring road grip, speed range 5 km/h - 130 km/h, attached to a trailer vehicle

Mass of 85 kg, approx. 1 m in length and width

Rear measuring wheel braked at a 15 % proportion to the support wheels speed.



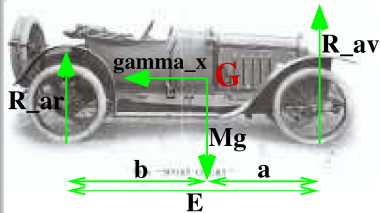
Fig: from left to right, rear measuring wheel, wetting system, two front support wheel (source: Tr. Scotland Ex. Agency, 2018)

- 1 Introduction
- 2 Experimental Set-Up
- 3 Road Sensor Validation**
- 4 Results
- 5 Conclusion



## preliminary validation of the road sensor

- Braking on sensor with passenger car
- Dedicated test track, initial speed of 20 m/h, dry surface
- Braking only with the front brakes (stability and model simplification)
- Application of the fundamental principle of dynamics



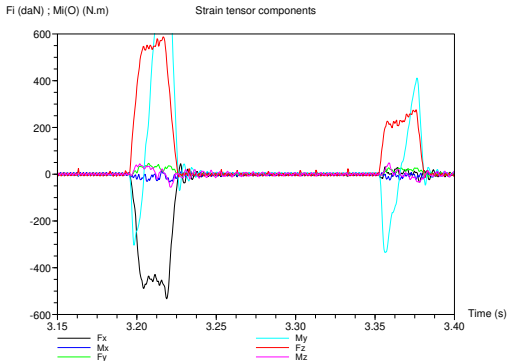
## Vertical force plotted in red

Front wheel: 590 daN vert. force

Rear wheel: 220 daN vert. force

Compared to their static values  
of 470 and 340 daN

⇒ 120 daN mass transfer from  
the rear axle to the front axle



## Braking force plotted in black

Front wheel: 450 daN (rear: 0) ⇒ longitudinal tire-to-road grip of 0.76

$M_x$  value remains almost null ⇒ good lateral wheel centering / road sensor

$M_y$  value increases for each wheel (negative to positive value) ⇒ tire  
longitudinal advancement / sensor

Static loading:  $R_f + R_r = Mg$

$M$  mass,  $g$  gravity acc.,  $R_f / R_r$  front / rear normal reaction forces

Balance of moments:

$$R_f \cdot a - R_r \cdot b = 0 \rightarrow R_f = \frac{Mgb}{E} \quad ; \quad R_r = \frac{Mga}{E} \quad (1)$$

While braking:

$$R_f \cdot a - R_r \cdot b = Mh\gamma_x \quad (2)$$

Mass transfer leads to:

$$R_f = \frac{Mg \cdot b}{E} + \frac{M \cdot h \cdot \gamma_x}{E} \quad \text{and} \quad R_r = \frac{Mg \cdot a}{E} - \frac{M \cdot h \cdot \gamma_x}{E} \quad (3)$$

Our experimental case,  $M = 1300 \text{ kg}$ ,  $h = 0.7 \text{ m}$ ,  $E = 2.6 \text{ m}$ , and  $\gamma_x = 7.9 \text{ m/s}^2$

⇒ Mass transfer of 138 daN / wheel. It aligns quite well with experimentally evaluated 120 daN mass transfer (considering instabilities in braking, aerodynamic forces, ...) ↪ Road sensor validation



- 1 Introduction
- 2 Experimental Set-Up
- 3 Road Sensor Validation
- 4 Results**
- 5 Conclusion

## Grip measurements

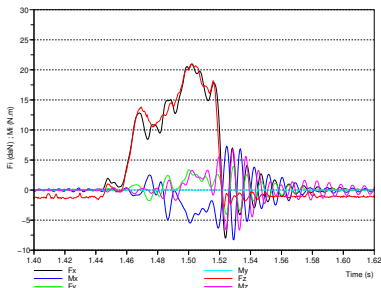
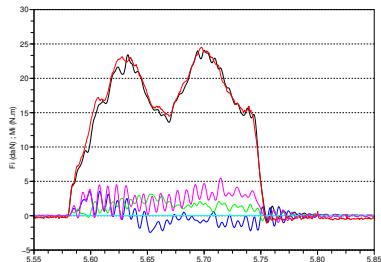
- 4 GripTesters
- On 3 different road surfaces, A, B, and C (lab. test tracks)
- 6 repetitions (test1 ... test6)
- One additional place on C surface: Road sensor
- Issue to achieve perfect centering on the road sensor (behind trailer)

## Road sensor

- On C surface
- Low level of GripTester applied forces (sensor measurement ranges of 750 and 2500 daN)

## Initial low speed tests (6 km/h, dry)

- $F_x$  and  $F_z$  (black and red): increase / tire enters the sensor surface and decrease at exit
- Signal oscillations: mechanical impacts and small use of the sensor's measuring range
- Moments have lower amplitudes: more impacted by signal noise
- The  $F_x / F_z$  ratio provides a grip evaluation of nearly 1, stable over the two trials (as expected for dry contact)



## Road sensor measurements

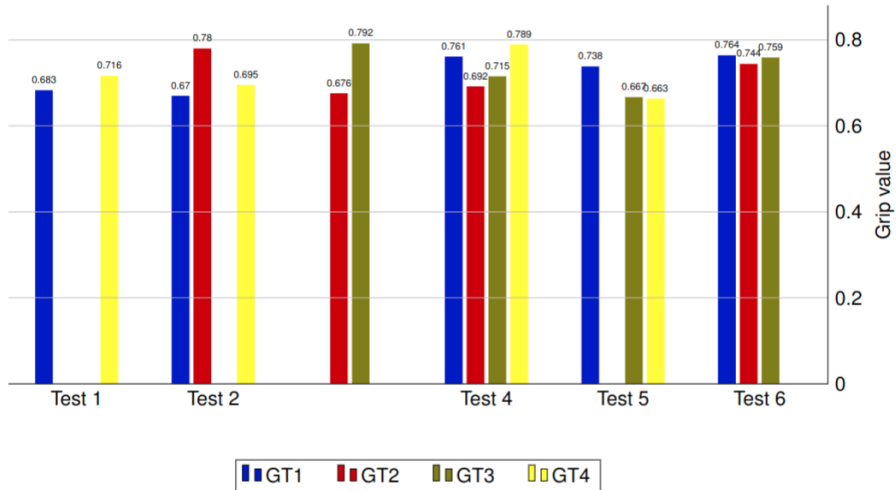
- 4 GripTesters passing on it
- GripTesters speed of 30 km/h, towed by vans
- With wetting systems
- 6 repetitions: test series 1 to 6 (1 and 2 given bellow)
- Some issues: no grip evaluation

(a) Test serie 1				
Device	$F_x$ (daN)	$F_z$ (daN)	Grip	Issue
GT1	14	20.5	0.683	
GT2				no wheel on sensor
GT3	9.7	11		wheel not centered
GT4	13.6	19	0.716	

(b) Test serie 2				
Device	$F_x$ (daN)	$F_z$ (daN)	Grip	Issue
GT1	12	17.9	0.67	
GT2	16	20.5	0.78	
GT3	4.5	9.5		wheel not centered
GT4	14.6	21	0.695	

Graphical representation:

→ 4 or 5 valid grip evaluations for each GripTester





## Road sensor: mean values

- Values from the 6 series allowed the determination of mean grip values and standard deviations for each GripTester
- Values are consistent across the 4 GripTesters, averaging either 0.72 or 0.73

Device	Mean grip value	Standard deviation
GT1	0.72	0.04
GT2	0.72	0.05
GT3	0.73	0.05
GT4	0.72	0.05

## GripTesters measurements

- GripTesters measurements on the 3 surfaces A, B and C (and standard deviations)
- Large variations between surfaces (textures are very different)
- For the C surface, GripTester values range between 0.72 and 0.748, which aligns closely with the estimates from the road sensor system, ranging between 0.72 and 0.73
- (the road sensor is on the C surface)

Device	surface A	surface B	surface C
GT1	0.478 (0.010)	0.478 (0.008)	0.733 (0.010)
GT2	0.536 (0.010)	0.497 (0.017)	0.720 (0.008)
GT3	0.532 (0.008)	0.550 (0.017)	0.734 (0.009)
GT4	0.545 (0.007)	0.576 (0.016)	0.748 (0.005)

- 1 Introduction
- 2 Experimental Set-Up
- 3 Road Sensor Validation
- 4 Results
- 5 Conclusion**

- Effectiveness of the developed road sensor in assessing the interaction between the tire and the road surface
- Ability to estimate the forces applied by a GripTester
- Challenges related to GripTester low levels of forces and need to properly center the tire on the sensor
- Results have demonstrated a good correlation between the measurements of the road sensor and the GripTester
- Potential of road sensors to contribute to:
  - the tire to road grip estimation, in a road safety context
  - road devices comparison