DYNAMIC BEHAVIOR STUDY OF A PASSENGER CAR DURING HANDLING MANEUVERING

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Abstract. The objective of the present research is the comprehension of the real and physical phenomena associated with the dynamic behavior of a moving passenger vehicle, its effects on handling qualities, data acquisition and analysis of car mobility data, the practical training with instrumentation. A tendency analysis of the handling behavior on a ride test, based on a modification of the mechanical characteristics of suspension component is also a relevant part of this study. In order to make it feasible, this study was divided into three parts; a theoretical study phase, data acquisition, and analysis of handling. First, the theoretical study was based on a literature review concerning suspension, steering systems, and tires. During the experimental work, the characteristics of springs, anti-roll bars (stabilizer), and shock absorber were changed. The individual response of changing parts was analyzed to reach the final objective. The outcome analysis is highlights to importance of reducing the development time on the final ride and handling tests, and it also shows the main points that must be changed to obtain the best dynamic performance on handling maneuvers.

Keywords. *passenger car, dynamic behavior, handling maneuvering.*

1. Introduction

According to Gillespie (1992), handling is the vehicle response to the driver commands and its controllability in lateral maneuvers. During the tests and vehicle behavior adjusts phase, all the suspension component characteristics may be changed (e.g.: springs, dampers, tire and suspension angles, gear speeds, etc.). The handling vehicle tests are strongly linked to passenger comfort and internal noise and vibration. The objective is to obtain describe/find/ establish a relation between comfort and security, taking into account the vehicle application, i.e., a passenger car, a truck, etc. The vehicle suspension should guarantee the adequate contact between tires and road, absolving vibrations and providing the vehicle stability. Fast response to any maneuver would also be assured.

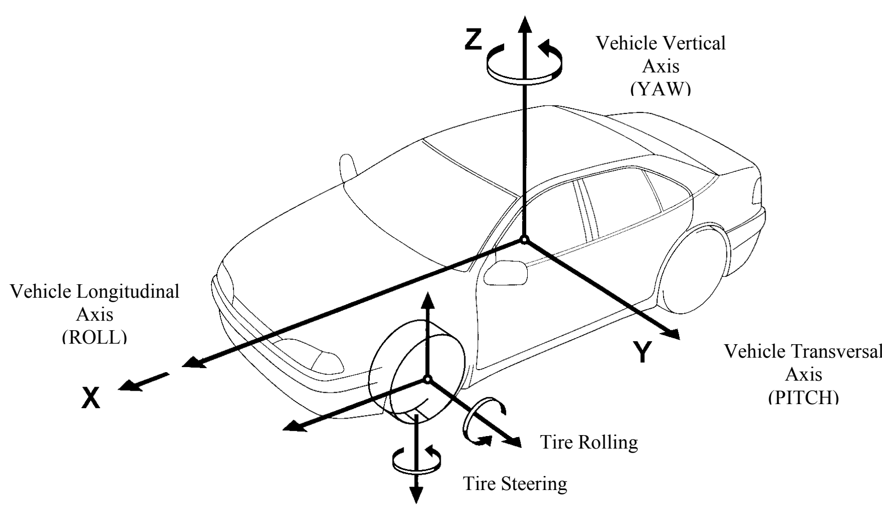


Figure 1. Vehicle Coordinate System according to ISO 4130 and DIN 70000 standards.

Reimpell (1996) considers vibrations between 1 and 80 Hz the most critical for the vehicle comfort behavior. Usually comfort is divided into 2 categories for road harshness: 1 to 4 Hz is the wide for ride comfort and up to 4 Hz, road comfort. Humans are able to hear vibrations from 20 to 20,000 Hz. Most passenger cars have their critical frequency up to 25 Hz. Trying to reduce the prejudicial effects of accelerations in humans is possible through the use of softer suspensions, where less rigid springs and dumpers are employed. Nevertheless, more suspension flexibility may cause bigger chassis movement amplitudes. These bigger amplitudes, as well as in roll and pitch axis, compromises the handling behavior and the car stability in curves and rough roads.

Based on SAE (1976) data concerning human vibration and noise tolerances, it is possible to affirm that human body is more sensible to vertical vibrations of frequencies between 4 and 8 Hz. It happens due to the abdominal cavity resonance. This behavior changes when the vibration frequency is close to 1 Hz. This is the most comfortable scene because this frequency is the human walk natural frequency. Due to that, most passenger vehicles have their natural frequencies between 1 and 1.5 Hz (Bastow and Howard, 1997). When it comes to longitudinal vibrations, according to the literature, the most critic frequency is 2 Hz. Handling vehicle tests have the difficult task of combining all these possible behaviors and find a close relation between comfort and handling behaviors, trying to provide the driver and passengers' security.

2. Experimental Methodology

The main objective of this work is to study the vehicle dynamic behavior during handling maneuvers in passenger cars. This study has been carried out using an instrumented passenger car which suspension characteristics were changed to check its handling sensibility. The changing line maneuver at constant speed was used as handling maneuvers. All experimental data were acquired and processed at FIAT Automóveis S.A.

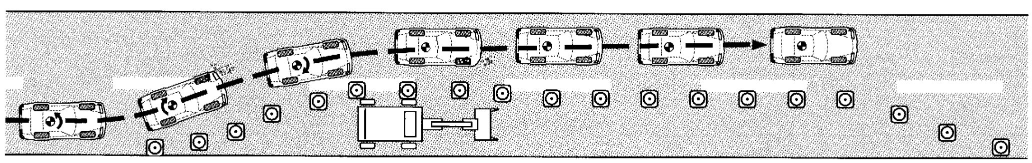


Figure 2. Changing line maneuver.

The passenger car characteristics are as follows:

Table 1. Test vehicle general characteristics.

Data	Axis	Left	Right
Vehicle Weight [Kg]	Front	295	318
	Rear	195	194
Tire Radius [mm]	Front	264	266
	Rear	273	274
Bumper Height [mm]	Front	647	646
	Rear	648	648
Tire Pressure [bar]	Front	1.9	
	Rear	1.9	

Table 2. Test vehicle suspension characteristics.

Suspension Geometry		**Front**		**Rear**	
		Left	**Right**	**Left**	**Right**
Caster Angle	Real Value	2° 06'	2° 03'	-	-
	Designed Value	2° 20' ± 30'		-	
Camber Angle	Real Value	-47'	-52'	-8'	-28'
	Designed Value	-30' ± 30'		-30' ± 30'	
Convergence [mm]	Real Value	-1.2		+0.15	+0.42
	Designed Value	-1 ± 1 (total)		1.5 ±1.5 (total)	

The control and output parameters were defined as follows:

2.1 Control Parameters

These parameters are used to check the test repeatability. This procedure is necessary because a test pilot carries out the handling tests.

- Steering wheel angle;
- Steering wheel angular speed;
- Vertical acceleration, and
- Vehicle longitudinal speed.

2.2 Output Parameters

These parameters are used to verify the vehicle behavior during the handling maneuvers. These parameters are:

- Lateral acceleration (Y axis);
- Vehicle roll angle;
- Vehicle pitch angle;
- Vehicle roll speed;
- Vehicle pitch speed, and
- Vehicle transversal speed.

2.3 Sensors

The following sensors were applied to carry out the handling experimental tests:

- Correvit V1 Sensor: an optical sensor assembled in vehicle back used to measure vehicle longitudinal and lateral speed (Figure 2-a);
- Dynamometric wheel sensor: this sensor is used to measure steering wheel torque, steering angles, and steering wheel angular velocity (Figure 2-b);
- Accelerometers: assembled in vehicle mass center and used to measure lateral and vertical accelerations;
- Transducers: assembled in vehicle lateral and used to measure the vehicle roll movement (figures 2-c and d)

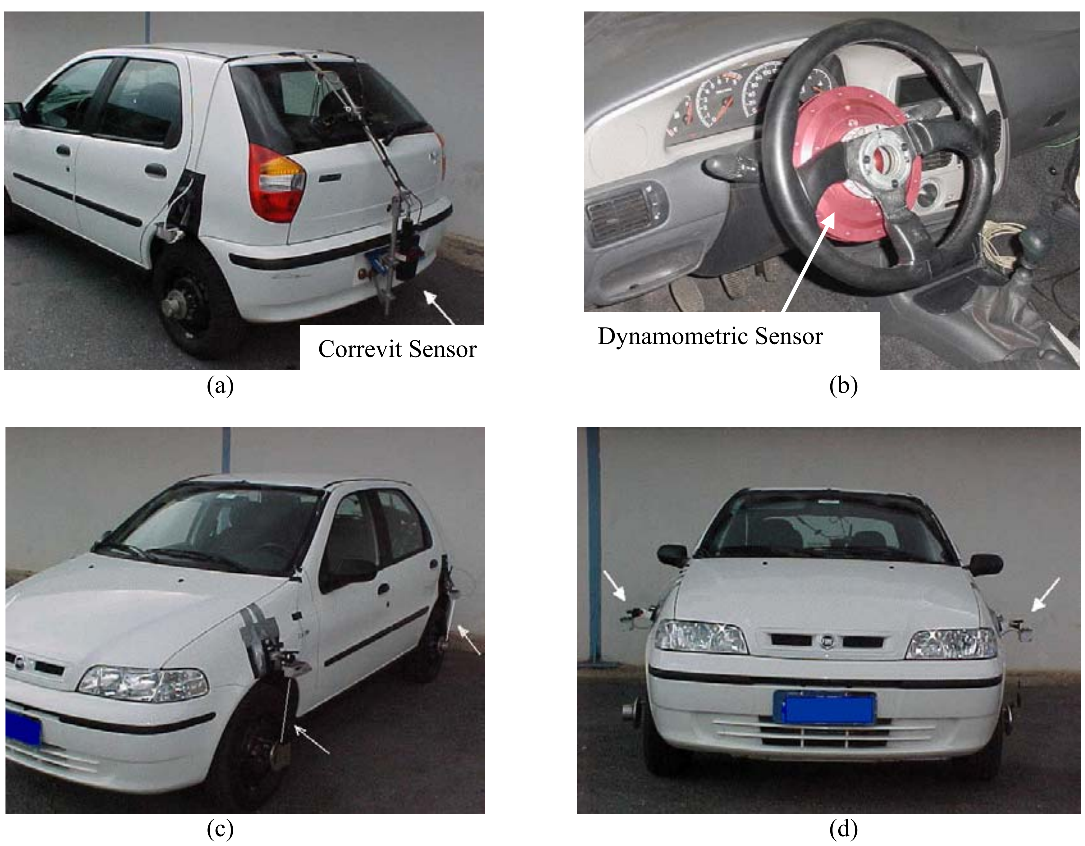


Figure 2. Sensor Correvit installed in vehicle back (a). Details of the dynamometric wheel sensor installed in the vehicle steering wheel (b) and the transducers (c and d).

All sensor data were acquired and stored by Spider 8 from HBM, an acquisition data system witch has 8 channels, printer and PC interfaces.

Table 3. Correvit sensor data.

Model	DATRON V1
Speed Range (long. and transv.)	0.25 to 310 Km/h
Error	< ± 0.5%
Output signal	
Frequency (3 channels)	0 – 40 KHz
Analogical (2 channels)	0 – 10V
Signal Sensibility	± 80 mV / V
Linear Deviation	< ± 0.2 %
Sensor Weight	1.2 Kg
CPU Weight	0.8 Kg
Temperature Range	–25°C to + 80°C

Table 4. Data Acquisition System data.

Model	Spider 8
Frequency measure range	0.1; 1;10;100;1,000 KHz
Tension	± 10 V
Counters measure range	25,000; 2,500,000
Linear deviation	± 0.05 %
Temperature range	–20°C a + 60°C
Weight	2.75 Kg
Dimensions	300 x 75 x 270 mm
Data acquisition frequency	1.2 Hz

Table 5. Dynamometer wheel sensor data.

Model	DATRON
Measure Range	± 50 N.m
Tolerance	± 0.15%
Resolution	± 0.1°
Linear Deviation	± 0.5 %
Angular range	± 1250°

Table 6. Accelerometer sensor data.

Model	B12/200
Natural frequency	200 Hz
Measure Range	0 – 100 Hz
Acceleration Range	± 200 m/s^2
Output signal sensibility	± 80 mV / V
Linear Deviation	< ± 0.2 %
Weight	17 g
Dimensions	ϕ 12.6 mm x 40 mm

Table 7. Transducer sensor data.

Model	ASM WS10
Maximum Range	500 mm
Resolution	± 0,3 mm
Linear Deviation	± 0.05 %
Weight	0.8 Kg
Impact Absorption Capacity	Up to 50 g / 6 ms
Vibration Absorption Capacity	Up to 10 g

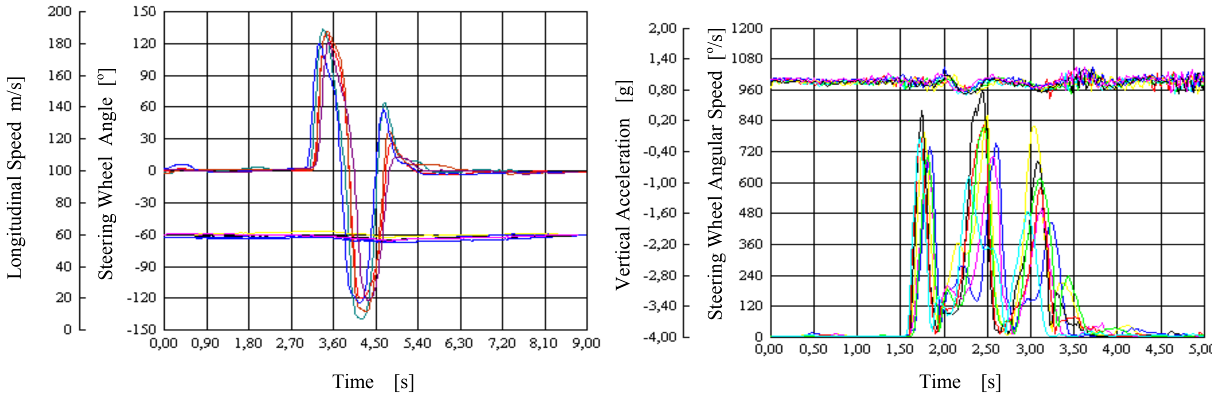
3. Experimental Tests

Some suspension characteristics were changes to verify their influences in the vehicle handling behavior to proceed the experimental tests. Table 8 shows all tested suspension configuration.

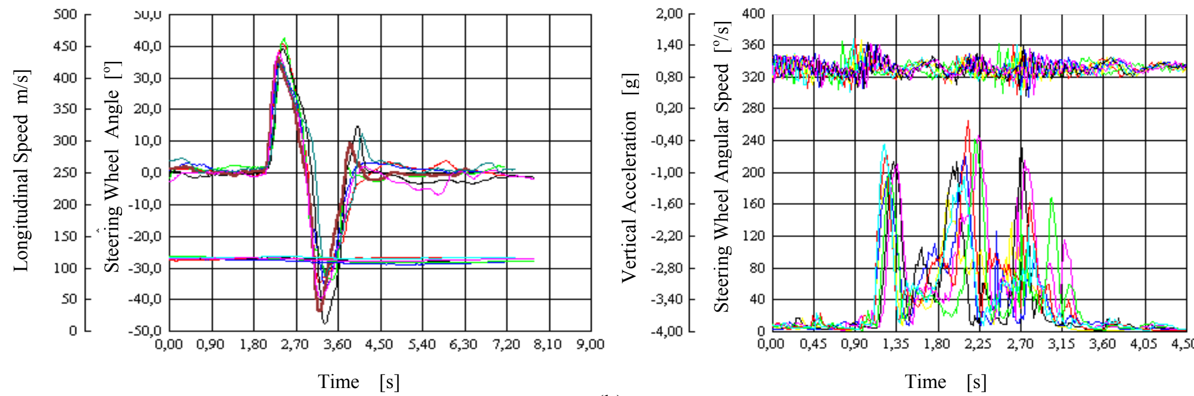
Table 8. Tested suspension configurations.

Configuration	**Front Spring** [mm/daN]	**Rear Spring** [mm/daN]	**Front bar** [mm]	**Rear bar** [mm]	**Front Dumper** [plot]	**Rear Dumper** [plot]
Standard	**0.57**	**0.32 / 0.20**	**20**	**16**	**AD-1**	**AT-1**
Test # 1	0.49	0.32 / 0.20	20	16	AD-1	AT-1
Test # 2	0.57	0.30 / 0.18	20	16	AD-1	AT-1
Test # 3	0.49	0.30 / 0.18	20	16	AD-1	AT-1
Test # 4	0.57	0.32 / 0.20	22	16	AD-1	AT-1
Test # 5	0.57	0.32 / 0.20	none	16	AD-1	AT-1
Test # 6	0.57	0.32 / 0.20	20	18	AD-1	AT-1
Test # 7	0.57	0.32 / 0.20	20	none	AD-1	AT-1
Test # 8	0.57	0.32 / 0.20	20	16	AD-2	AT-1
Test # 9	0.57	0.32 / 0.20	20	16	AD-1	AT-2

Plot 1 shows the steering wheel angle and steering wheel angular speed at 60 Km/h (a) and 120 Km/h (b) for all experimental tests. Plots 2 to 5 show the influence of spring's characteristics on vehicle rolling angle, response time, pitch angle and lateral acceleration. Plots 6 to 9 show the influence of anti-rolling bar diameter and plots 10 to 13, the influence of damper characteristics.

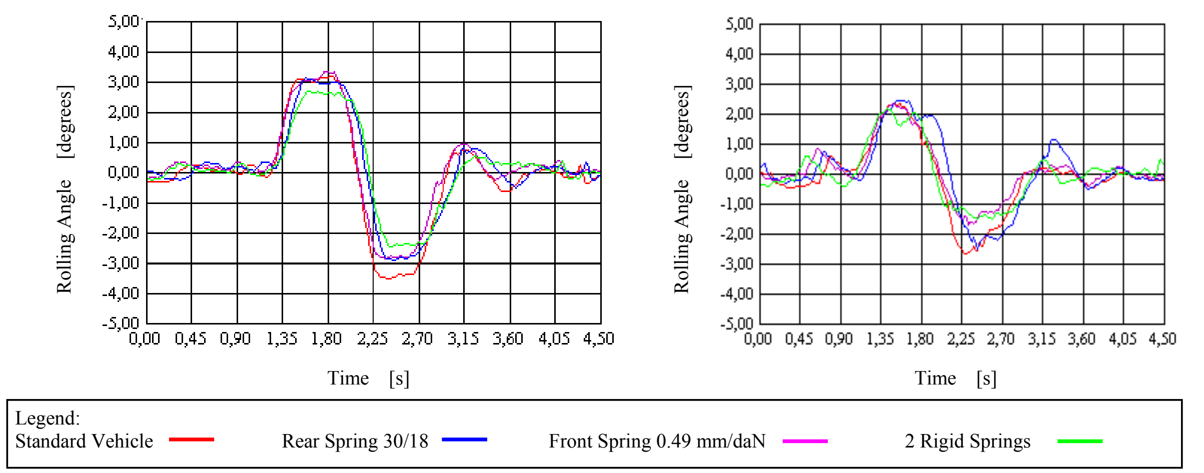


(a)



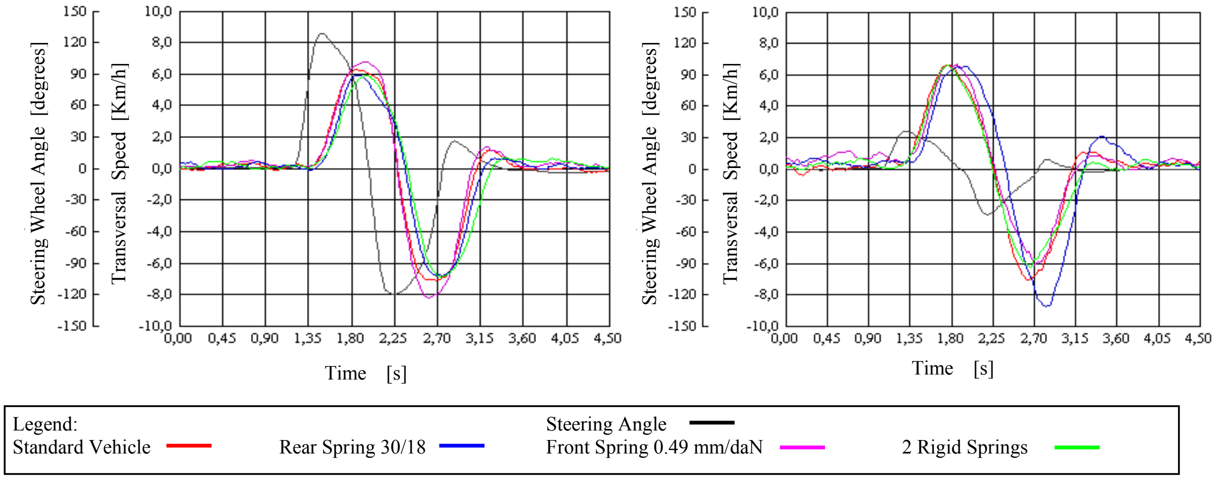
(b)

Plot 1. Steering Wheel Angle and Steering Wheel Angular Speed Control: vehicle at 60 Km/h (a) and 120 Km/h (b).



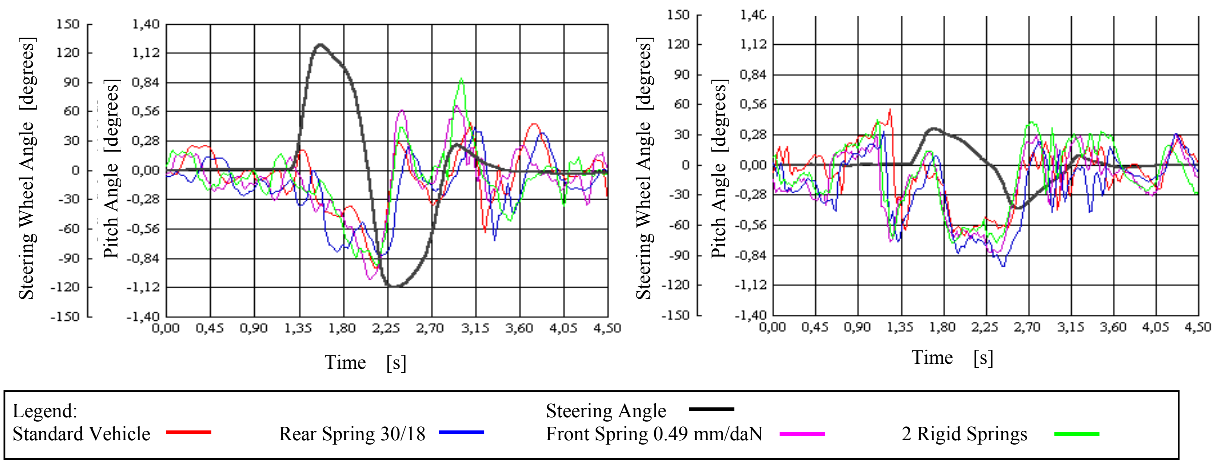
(a) (b)

Plot 2. The influence of spring's characteristics on Rolling Angle behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).



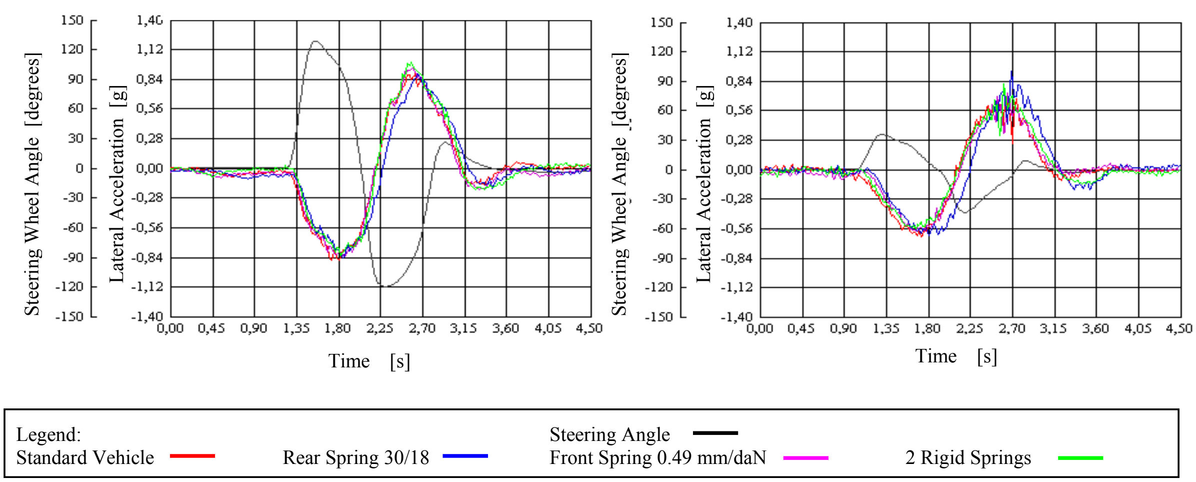
(a) (b)

Plot 3. The influence of spring's characteristics on Response Time behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).



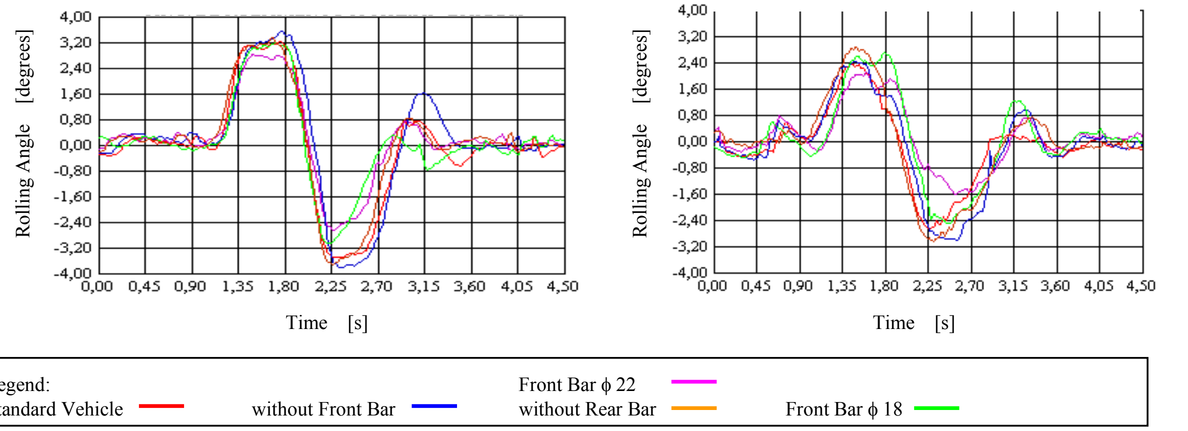
(a) (b)

Plot 4. The influence of spring's characteristics on Pitch Angle behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).



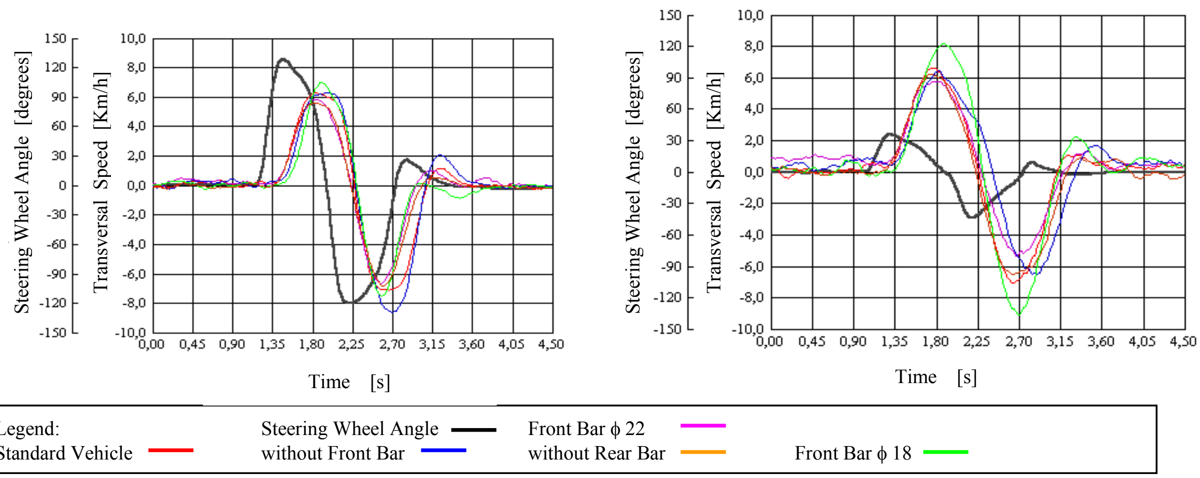
(a) (b)

Plot 5. The influence of spring's characteristics on Lateral Acceleration behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).



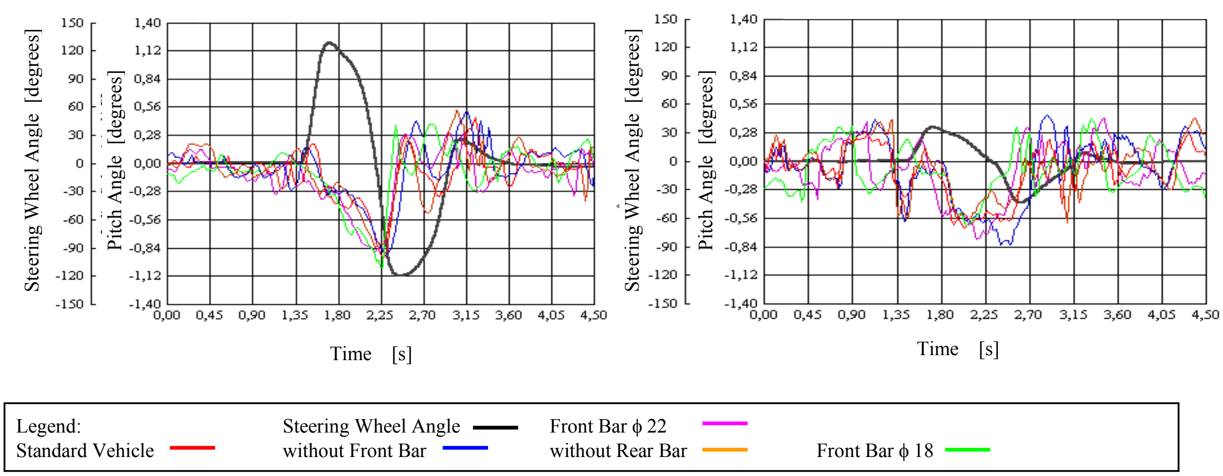
(a) (b)

Plot 6. The influence of anti-rolling bar diameter on vehicle rolling angle behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).



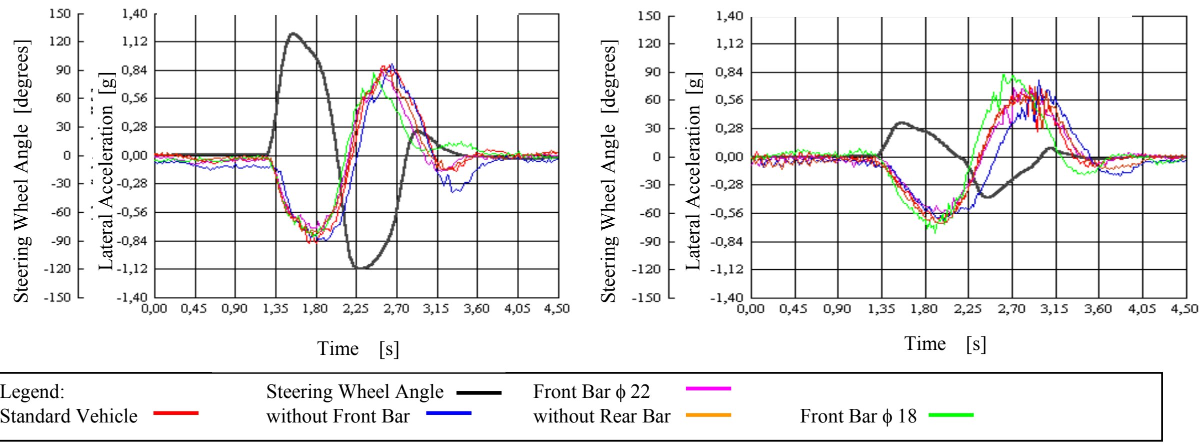
(a) (b)

Plot 7. The influence of anti-rolling bar diameter on vehicle rolling angle behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).



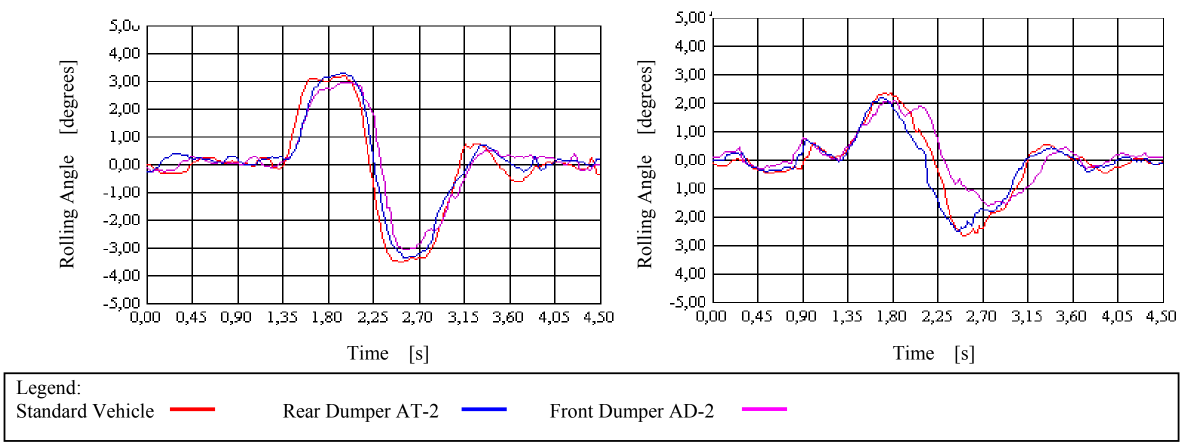
(a) (b)

Plot 8. The influence of anti-rolling bar diameter on vehicle pitch angle behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).



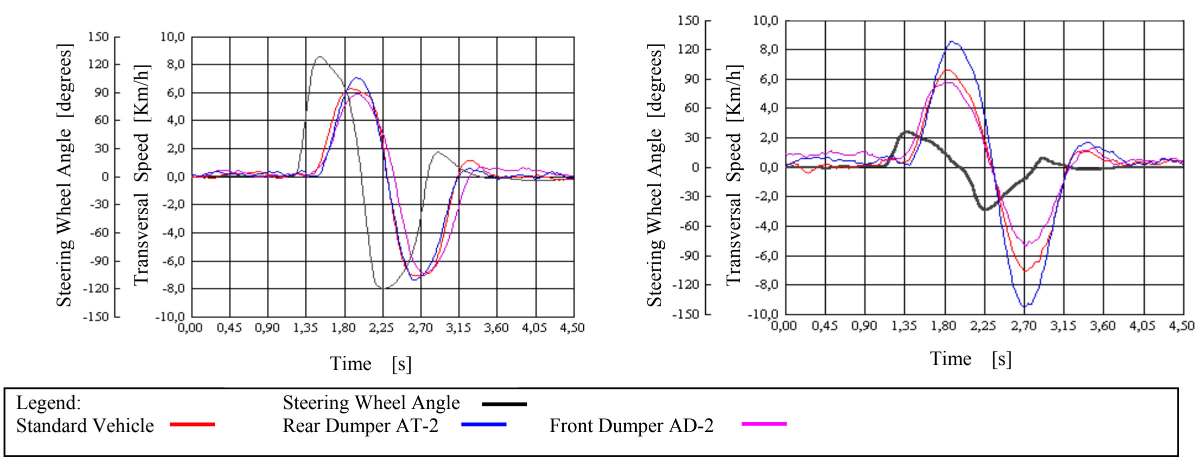
(a) (b)

Plot 9. The influence of anti-rolling bar diameter on vehicle lateral acceleration behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).



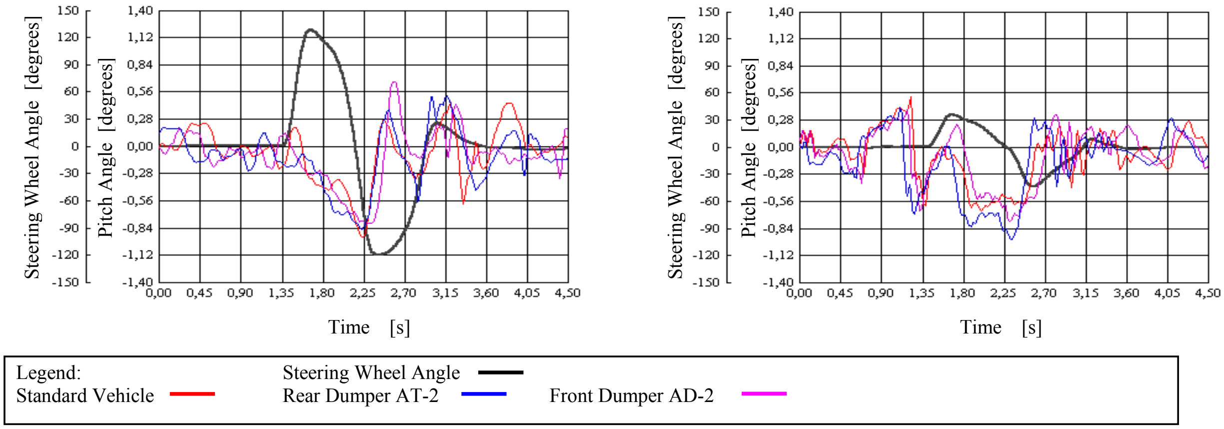
(a) (b)

Plot 10. The influence of dumper characteristics on vehicle rolling angle behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).



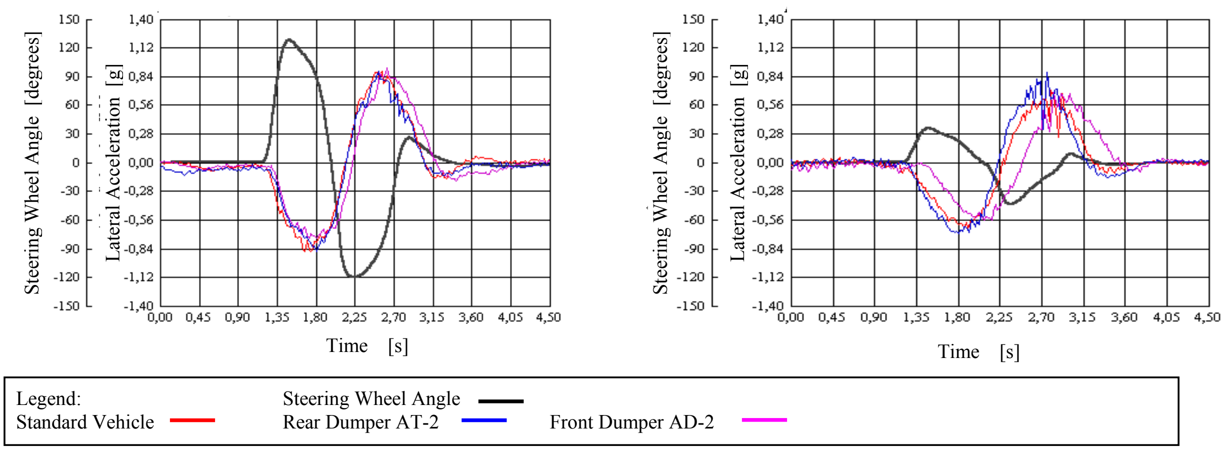
(a) (b)

Plot 11. The influence of dumper characteristics on vehicle transversal speed behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).



(a) (b)

Plot 12. The influence of dumper characteristics on vehicle pitch angle behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).



(a) (b)

Plot 13. The influence of dumper characteristics on vehicle lateral acceleration behavior: vehicle at 60 Km/h (a) and 120 Km/h (b).

4. Conclusions

A methodology to measure the vehicle behavior during maneuvers is essential to understand the well-known subjective phenomena that occur during handling tests. It also gives indications of which suspension components should be changed, and how they should, to obtain a better relation between comfort and handling behaviors. Today the automotive makers are applying some multi-body dynamics software for simulations, like ADAMS, to optimize chassis and suspension components, obtaining promising results. Nevertheless, firstly it is necessary to obtain a large quantity of experimental data to valid and refine computational models of vehicles.

The rolling angle results for the various tests were according to literature. The more they decreased the more rigid the components became. The experimental tests showed that the standard vehicle was well adjusted concerning comfort and handling requirements. The obtained values were closer to European references values than the American ones.

The suspension non-dumped natural frequencies values calculated, respectively 1.21 and 1.64 for front and rear vehicle suspension in the standard configuration. During tests at 120 Km/h, the rear suspension showed a rigid behavior, compromising the comfort. But, due the design limitations (over and under steer behavior, esthetic, etc.), the suspension characteristics cannot be changed. This rear axis rigid behavior can be observed in it's pitch behavior (see Plots). The anti-roll bar, spring and dumpers rigid incensement caused a pitch angle incensement. So, the front axis rigidity should be increased as well to prevent vehicle instabilities. This would decrease the passenger comfort.

The use of anti-roll bar with an excessive diameter incensement and the rough road cause a large lateral vibration transmission. In these cases, it is recommended the use of more rigid springs and dumpers. The suspension characteristics changes did not affect the vehicle time response. This is due to the fact that this parameter considerably depends on dependent of suspension geometry and tire characteristics. The rough road considerably affected the handling tests at 120 Km/h. This roughness caused large vehicle vertical accelerations.

The resulting procedures of this study will be applied further in data acquisition for the development of vehicle mathematical models. These models will drastically reduce the experimental costs during the vehicle development phase.

5. Acknowledgement

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