RIDE QUALITY EVALUATION: 8 D.O.F. VEHICLE MODEL CALIBRATION

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ABSTRACT

All road authorities try to obtain a good ride quality in their network, particularly with respect to the vibrations induced in the vehicles by road roughness. ISO 2631 defines the criteria to evaluate human whole body vibration (WBV) experienced by passengers during the ride, starting from the time history of recorded vertical accelerations in the vehicle; ISO standard also establishes vibration limits for discomfort, various activities, safety and health.

The acceleration time histories also can be deduced by means of simulations of the motion, in which a vehicle model runs on measured pavement profiles. Simulations are useful to obtain global synthetic roughness indexes: for example, the I.R.I. (International Roughness Index) is the result of a simulation performed with a standard vehicle model, named *"quarter car"*.

Nevertheless, in order to obtain a better evaluation of the ride quality of pavements, it needs to use more complex models, corresponding to real vehicles, after a calibration process. This process essentially consists in the comparison of the recorded vertical accelerations, achieved in real tests, with the results of simulations, varying model parameters. Simulations and real tests must be referred to a real vehicle, a reference road section, and various speeds.

In this paper, the activities carried out to determine the parameters of a 8 D.O.F. vehicle model are presented; the result is a calibrated model, valid to obtain the time histories of vertical accelerations from the simulations, and to qualify the ride quality starting from geometric profiles of roads. Particularly, relating IRI and human WBV, simulations can be applied to plan the pavement management policies and to establish road roughness limits in various situations.

Keywords: pavement, roughness, ride comfort, whole body vibration

1. INTRODUCTION

The roughness of a road pavement is an expression of the surface irregularity, and includes both localized and diffuse unevenness. It causes vibration phenomena during the motion of vehicles and usually reduces the ride quality experimented by the users.

Also, roughness affects both the maintenance costs (in consequence of the rate of road deterioration) and the generalized-transportation costs (in consequence of the connected operating problems such as consumption of wheels, fuel wear, increase of travel time, etc.).

Analytical methodologies concerning relationship between road surface unevenness and vehicle vibrations can be developed to improve actions regarding road infrastructures. Various methods are actually available for these purposes: it is generally necessary to perform the measurement of real road surface conditions and/or to evaluate the connected ride quality expression.

2. RIDE QUALITY AND ROAD ROUGHNESS

As a property of a road surface, the roughness is defined as the vertical variation of the distance of real points of the pavement from an ideal reference plane. The pavement roughness is able to influence various functional and operational aspects of the road transportation system, because:
- it causes stresses and fatigue damages in the vehicle structures;
- it reduces the comfort experimented by the users (in other words, it reduces the "ride quality");
- it increases the dynamic loads applied on the pavement by vehicle wheels, so accelerating fatigue damage of the road structure;
- the user's discomfort and the reduction of road-vehicle load transmission effectiveness, regarding steering and braking actions, could increase the accident risk exposure and the users' weariness.

So, a quantitative knowledge of the road-vehicle interactions is important for all involved subjects:
- the *user* of the road system, who is interested in improving safety and comfort and in reducing costs;
- the *road administration* and the *road managing companies*, that are interested regarding the functional performances which the pavements can offer, and – in consequence – the rehabilitation actions and the maintenance programmes and costs;
- the *mechanical constructors*, interesting in ameliorating the comfort on board, changing the functional and structural responses of vehicles;
- the public agencies and administrations involved in the preservation of the people's safety and health.

2.1 Evaluating criteria

Various evaluating criteria can be adopted to quantify the functional properties of road pavements, related to roughness characteristics:

1. *direct methods*, based on the measurement of parameters which are directly related to some pavement performances (e.g.: on-board accelerations, loads applied by wheels on the pavement, noise, etc.) or on the statistic evaluation of the judgements of people driving along the road (*subjective panel ratings*);
2. *indirect methods*, based on the use of conventional equipped boogies or vehicles, whose dynamic behaviour observation allows to indirectly determine the functional performances related to the pavement roughness;
3. *simulation methods*, which consist of the determination of performance parameters by means of analytical processes, starting from the road profiles measured with suitable profiling devices.

The first two evaluating criteria significantly depend from the measuring equipment and from the evaluating methodology, which make difficult the repeatability and the reproducibility of results, in terms of examined parameters.

On the contrary, the third evaluating criterion, which starts from geometric measurement of the pavement profiles, is less sensitive respect to the operational process; actually, it is often preferred because it allows to carry out a back-calculation process of the effects induced by road unevenness on the vehicles and users, after the geometric survey of profiles.

3. LEVEL OF COMFORT DETERMINATION

The level of comfort experimented by a person (an human body) in a road vehicle, moving on an uneven road surface, depends on the perceived vibrations.

The undesired effects of vibrations related to the vehicle dynamics are generally classified as:

–   *ride comfort*, that is associated to mechanical vibrations characterized by frequencies included in an interval from 0.5 to 80 Hz;
–   *noise*, that expresses the acoustic discomfort inside the vehicle, which is related to a wider field of frequencies.

The comfort associated to a vehicle moving along a road is a complex problem, because its objective evaluation needs to establish a correlation between the passengers' perception and the real level of vibrations transmitted inside, as consequence of the dynamic actions. Many researches regarding human physiology have shown that the perception of vibrations is certainly proportional to the accelerations vehicle gives to the user. The human response, indeed – that is also called *the human sensitivity to the vibrations* – depends on various environmental and psychological aspects.

Among the parameters related to the human response to vibrations, it is possible to find both *extrinsic variables* (that are variables which express the state of the dynamic system or the evolution of phenomenon, like vibration amplitude and frequency, direction of the movement, exposure time, etc.) and *intrinsic variables* (referred to the human subject: age, gender, physical characteristics, health conditions, posture of the body, etc.).

On the basis of a standardized conventional quantification – by means of statistic methods – of the relations between human perception and levels of vibrations, it is possible to define some objective criteria for the ride comfort.

Various existing standards, referred to comfort and vibratory problems, are mainly directed to allow the comfort quantification, or to establish the level of discomfort caused to the user by vibrations. These evaluations generally consist in the calculation of comfort synthetic indexes, starting from the accelerations transmitted to the passengers, characterizing in this way the dynamic interactions between the vehicle and the uneven road pavement.

3.1   Vehicle seat vibration measurement

According to the most common methodologies and standards ([2], [13]), just vertical direction influences evaluation of seat vibration: all other components become considerable only if they equal absolute values of vertical one. In particular, vertical acceleration influences the estimation of comfort independently by time exposure; indeed, this last parameter influences, essentially, vibration effects on drivers' health.

3.1.1 The measurement chain

The European Standard ENV 28041 [12] classifies the evaluation of vehicle seat vibration as measurement of Whole-Body Vibration (WBV). The use of a proper measurement chain, consisting of transducers, preamplifiers, filters, detecting and analyzing instrumentation is evidently recommended.

The almost universally used transducer is the piezoelectric accelerometer: choosing the most suitable model for measurements to do, means selecting the right sensitivity (ratio between signal output and acceleration), mass and dynamic range (frequency range) of the instrument. A miniaturized triaxial type, having 100 mV/g sensitivity, weight under 2 g and frequency range from 0.1 to 2000 Hz inclusive is apt to evaluate vehicle seat vibration. On the other hand, the European Standard EN 30326-1 [11] explains the correct mounting position of the accelerometer. It must be housed in a semi - rigid nitrile rubber disc (hardness Shore – A 80÷90, diameter 250mm ± 50mm, height under 12 mm) and joint to a thin metal disc (diameter 75mm ± 5mm, height 1.5mm ± 0.2mm) Figure 1, 1. The so called "Seat Pad Accelerometer" can be usefully mounted on the seat or on the back as shown below (Figure 1, position S or B).
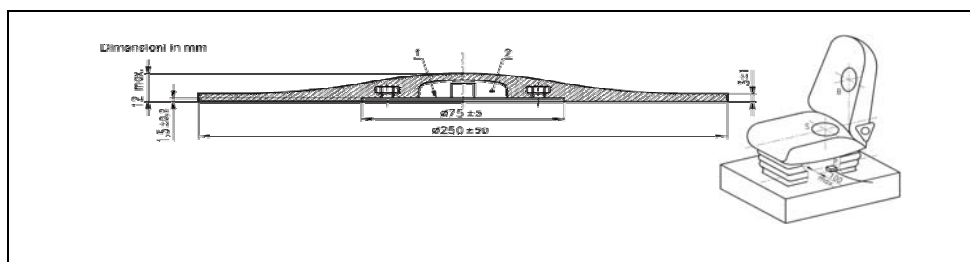
Figure 1– Seat Pad Accelerometer and correct mounting positions [11].

A preamplifier is functional for adjusting output signal accelerometer impedance to input measuring and analyzing instrument one. In the same way, a filters series (mechanical filter, filter bandwidth) limits the upper and lower frequency response to avoid interference from electrical noise or signals outside the linear portion of the accelerometer frequency range and lets all frequency components occurring within its

bandwidth pass, rejecting completely all others. After this treatment, the signal is received by a measuring amplifier, provided of calibrated variable gain to amplify and normalize input values, integrators to convert acceleration proportional accelerometer output to either velocity or displacement one, a digital output and remote control facilities so that it can be connected to a tape punch, computer, etc., to make fully automatic analysis systems [10].

3.2 Comfort evaluation according ISO standard

The part 1 of ISO 2631 [13] specifies how the evaluation of the effects of vibrations on the human comfort can be determined, starting from vertical accelerations. The standard requires using the frequency-weighted r.m.s. accelerations. This way, a synthetic index – called *vertical weighted r.m.s. acceleration*, a_{WZ} – can be calculated, starting from vertical accelerations express in the time domain, and making some operations, which can be resumed as follows:

- r.m.s. acceleration values on the user's body (a_{iz}^{RMS}) must be calculated, by means of the *power spectral density* (PSD), corresponding to each *i*-th octave thirds band;
- obtained a_{iz}^{RMS} values have to be multiplied by the weighting factor values W_K (because the human body has different vibration sensitivities, depending on the characteristic frequencies of vibrations) corresponding to these frequency bands;
- in the end, it is possible to determine the *vertical weighted r.m.s. acceleration*, a_{WZ}, extracting the square root of the sum of squares $(W_{k,i} \cdot a_{iz}^{RMS})^2$ computed in the point before:
$$a_{WZ} = \sqrt{\sum_{i=1}^{23} \left(W_{k,i} \cdot a_{iz}^{RMS} \right)^2} \qquad \text{(Eq. 1)}$$

Contrarily to the dated version of the ISO standard regarding *Evaluation of human exposure to whole-body vibration* (1985), the current standard does not contain vibration exposure limits, because many factors combine to determine the degree to which discomfort possibly will be noted or tolerated. In addition, interference with activities (e.g. reading, writing and drinking) due to vibration and many other factors (acoustic noise, temperature, etc.) could sometimes be considered as a cause of discomfort. For these reasons, only evaluation methods have been defined in the standard, so that they can be utilized as the basis for limits which may be prepared separately. In any case, the r.m.s. value of the frequency-weighted vertical acceleration in vehicle might be compared with the values in Table 1, giving approximate indications of likely reactions to various magnitudes of overall vibration total values in public transport.

Table 1 – Comfort Levels related to a_{WZ} threshold values [13]

intervals of a_{WZ} values	Comfort Level
less than 0.315 m/s^2	not uncomfortable
0.315 m/s^2 to 0.63 m/s^2	a little uncomfortable
0.5 m/s^2 to 1 m/s^2	fairly uncomfortable
0.8 m/s^2 to 1.6 m/s^2	Uncomfortable
1.25 m/s^2 to 2.5 m/s^2	very uncomfortable
greater than 2 m/s^2	extremely uncomfortable

Specifically for road transport, there are not in literature experimental studies which demonstrate validity of these limits, referred to human response to vibrations; in particular, until now, performed researches, in road transport field, had not jointly considered *intrinsic* and *extrinsic variables*, as defined in previous § 3.

For this reason, it seems very interesting a different approach, trying to understand existing correlations between a_{WZ} and other roughness indexes, like the IRI, in which comfort and ride quality are represented.

4. MODELLING AND SIMULATIONS

4.1 Characteristics of models

In modelling dynamic phenomena to study human WBV, first of all, it is necessary to assimilate the vehicle to a proper mechanical system. Complexity and accuracy of this theoretical model depend on examined nature of the problem and analysis objectives. If research regards, as in the present situation, the study of motion of different mechanical components of the system, a linked rigid bodies scheme is generally adequate. In this case, the linkage between various bodies is represented by means of elastic and/or dissipative (viscous) elements. These links usually are defined by linear equivalent models having time-constant coefficients.

The described theoretical model, after obtaining the laws which rule the dynamics of the system, allows to perform a motion simulation in order to analyze the response of a mechanical system, moving on uneven surface. As results, it is possible to get, by means of their expressions in the time domain, the most significant involved parameters: displacements, speeds, accelerations, forces, etc..

In some cases, developing these mechanical models, only a few "portions" of a real vehicle are considered; this way allows to obtain many simplifications of the problem, that are very advantageous to reduce the complexity of these analyses.

For example, this is the case of a very common model, the so called *"quarter car"*: it is a mechanical system with only 2 degrees of freedom (d.o.f.) representing the displacements of sprung and unsprung masses. It is also able to characterize the response of a road vehicle portion, corresponding to that weighing on a single wheel. In this model, displacements can occur just in vertical direction.

The *quarter car* is widely applied to calculate the IRI, that is probably the most common synthetic index expressing road roughness and ride quality; nevertheless, this model is totally conventional, because its dynamic characteristics are settled by the standard, and cannot be correlated to those of a real vehicle.

4.2 Full car 8 d.o.f. vehicle model

To better simulate real dynamic phenomena and also to examine other vibratory actions on a road vehicle, especially rolling and pitching (which are, respectively, rotation around the motion direction and rotation around a transversal axle), modelling process needs an increase of dynamic system accuracy, mainly in the number of d.o.f.,.

The authors of this paper already developed a 8 d.o.f. road vehicle model, named *"full car 8 d.o.f."* [4], which allows to perform many analytical calculations regarding the problems of users comfort and road ride quality [6]. In particular, starting from a

surveyed couple of road profiles, the model allows to calculate the accelerations on the driver's seat, also considering the rolling (α) and pitching (θ) motions of the vehicle, beyond vertical displacements of single system parts (Figure 2).
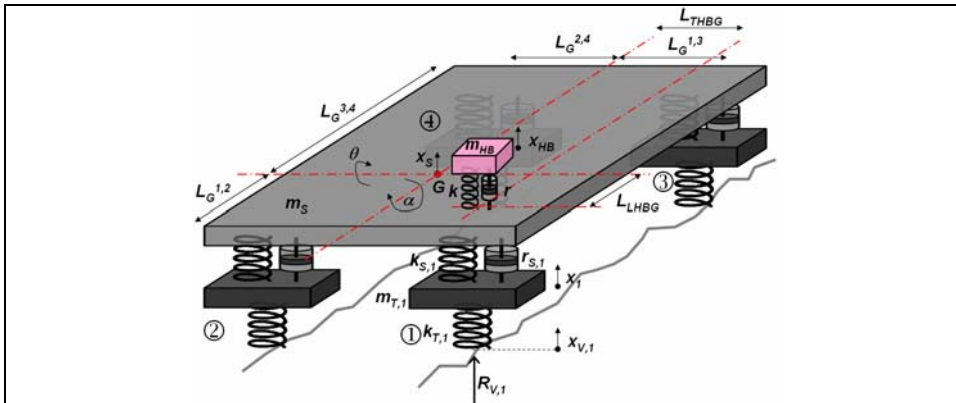
Figure 2– Scheme of the *"full car 8 d.o.f."* mechanical model used in simulations.

The complexity of the analytical problem greatly increases for this model, because in the description of its dynamic behaviour there are 12 independent variables, corresponding to the displacements of constraints ($x_{V,1}$, $x_{V,2}$, $x_{V,3}$, $x_{V,4}$) and the 8 d.o.f., that are the allowed vertical translation of sprung and unsprung masses (x_s, x_1, x_2, x_3, x_4), the allowed rotations (θ, α) and the vertical displacement of user's seat (x_{HB}).

$R_{V,1}$, $R_{V,2}$, $R_{V,3}$, $R_{V,4}$ represent the forces (reactions) exchanged between pavement and model in correspondence of contact points.

The *"full car 8 d.o.f."*, really, is a not-linear geometric model, but if the values of rolling (α) and pitching (θ) angles are little, it is allowed to assume $sen\,\theta \cong \theta$ and $sen\,\alpha \cong \alpha$ (in such a way as to eliminate its geometric not-linearity).

By means of the described model, it is possible to analyze the response of a vehicle on a road (as like as the case of *"quarter car"* model), and to obtain all information regarding the motion dynamics, especially vertical accelerations in various significant point of the vehicle.

These accelerations, achieved in form of time histories, as results of simulations conduced starting from geometric profiles of roads, are valid for ride quality determination procedures (§ 3.2).

5. FIELD TESTS FOR MODEL CALIBRATION

The 8 d.o.f. vehicle model, previously developed and adopted in this research, has been calibrated by means of experimental surveys on a real vehicle, passing on a known road uneven surface.

Field tests have been conducted using a proper instrumentation - in partial accordance with standard instructions described at § 3.1.1. (differences only concern the height of "Seat Pad Accelerometer") - and a defined commercially widespread vehicle, quite representative of european cars. The evaluation of seat vibration has been reached under different travel speeds, fixing a road section and particular pavement

irregularities, previously measured (road humps similar to "M3" type). These choices have been necessary to allow a correct running process for the model (it needed a surveyed couple of road profiles and a "typical" vehicle) but, in consequence, it needs to pay attention in generalizing the model usefulness. Especially, it would be necessary other future improvement, by means of calibration tests on diffuse rough surfaces and using various vehicles.

5.1   Description of measurement equipment [5]

A very common vehicle (Fiat Stilo 1.9 JTD, Figure 3), belonging to the most diffuse class of car in Europe, has been used to calibrate the simulation mechanical model.

Two identical accelerometers have been placed, respectively one on the passenger side seat, the other on vehicle level ground at passenger feet (in such a way as to correctly compare simulation model results). These monoaxial piezoelectric transducers (*PCB Piezotronics*, Model 393A03 ICP[®]) have sensibility 1000 mV/g, frequency range 0.5÷2000 Hz and needed a particular rubber disc to be housed in because of their vertical dimension. The accelerometer mounted on seat has been positioned in a triple layer disc manufactured with vulcanized Shore – A 70 rubber and joint to a metal disc on the base (Figure 3). A similar stand has been used for vehicle level ground transducer. Two different cables bring output signal from top electrical connection of accelerometers to relative preamplifier input (*PCB Piezotronics*) and two other analogous links allow to join detecting and recording instrumentation (positioned on back side seats of the car). This is a portable analogical tape recorder (*Teac* 16 Channel DAT Instrumentation Recorder, Model RD - 145T) able to receive output preamplifier signals and record on DAT[®] tape at the same time (Figure 3).

Every measurement has been successively downloaded on computer, thanks to an apposite data upgrade system, to obtain vertical accelerations on passenger seat and vehicle level ground (analyzing instrumentation). These values constitute the bases to perform the mechanical model calibration.

Figure 3 – Irregularity sample and equipment used in field tests [5].

5.2   Field tests [5]

First of all, it has been necessary to individuate a site in which a typical irregularity was there. The picked out rectilinear road has a series (symmetric in comparison with the middle of road planimetric axis development) of two identical 75 metres distanced humps and regular bituminous pavement. The hump sample has been measured using a wooden holed rectangular pole and a precision callipers as shown in Figure 3: its trapezoidal cross section 580mm in width is 43mm high.

The particular choice of the test site was due to the need of selecting a road section whose the geometric shape can be easily represented in the simulations. Also considering the vehicle trajectory variance, during test runs at various speeds, it was necessary to pick out a site having a longitudinal and transversal uniform geometry. The humps, that are localized irregularities, produce a shock to the vehicle, different from the case of diffuse unevenness. But the results were likewise useful to characterize the response of the car, due to its mechanics, and to calibrate the simulation model.

The second step has been deciding the test courses. As the humps are symmetrically central in comparison with the middle of the road, it has been easy to adopt a course 100m long, in which the humps series is preceded and continued by a distance of road 12.5m long, and a course of 185m long, identical to the first except the longer final distance (97.5m). This last solution has been useful to evaluate, in a better way, the damping phase successive to vehicle impact with the second hump. Both courses have been successively used as pavement sections during every simulation of model calibration process and have been covered during surveys with 8 different increasing speeds by the vehicle in such a way as to understand how seat vibration depends on this parameter (20, 25, 30, 35, 40, 50, 60, 70 km/h). Different sequences of tests have been completed with and without a person seated on Seat Pad Accelerometer, to evaluate the influence of passenger presence on measured vibration at the seat.

In short, the measurements are assembled in 4 different sequences, the first without seated passenger, the others three with passenger on Seat Pad Accelerometer. Two of these three sequences cover 100m long course, the last is done on 185 m long course. Every sequence is constituted by 8 surveys one for each speed (V): each one of them has completed with a constant speed as the scheme above explains (Table 2).

Table 2 – Measurement sequences and correspondences in simulation plan [5].

ID code	With Seated Passenger	Length (m)	Speed (km/h)	With Seat Pad Accelerometer	With accelerometer on vehicle level ground	Model Simulation
RC_1_100_V	yes	100	V	yes	yes	yes
RC_2_100_V	yes	100	V	yes	yes	yes
RC_3_185_V	yes	185	V	yes	yes	yes
RS_1_100_V	no	100	V	yes	yes	no
TOTAL = 32 FIELD TESTS, 24 SIMULATIONS						

In the end, all data recorded during field tests have been saved, organized and analyzed according to operations described at § 5.1. In particular, during download process on computer, a proper sampling frequency (250 Hz) has chosen to extract, in agreement with signal theory, values useful for comfort evaluation (Whole Body Vibration, frequency range 0.5÷80 Hz).

5.3   Analysis of results and model calibration [5]

The comparison between Series 1, 2, 3 and Series 4 confirms that human body, which has an own characteristic vibration frequency, completely interacts with road-vehicle-seat system taking up part of vibration generated by car transit on pavement irregularities. The absolute vertical acceleration values, checked during vehicle impact on humps, increase with speed rise of test series (both on seat, a_{HB} ([1]), and on vehicle level ground, a_s ([2])); the derived synthetic index a_{WZ} (§ 3.2) shows the same trend (Table 3), essentially because of the reason explained above, secondarily because of its inverse proportionality with time. It is necessary to highlight that this index has been used exclusively to evaluate calibration process results and not to establish ride quality during passages on road humps, because of their special characteristics (local irregularities).

Table 3 – a_{WZ} values in m/s^2 measured in field tests [5].

Speed (km/h)	RC_1_100	RC_2_100	RC_3_185
20	0,34	0,36	0,28
25	0,38	0,38	0,30
30	0,49	0,46	0,35
35	0,53	0,49	0,39
40	0,55	0,53	0,43
50	0,56	0,57	0,43
60	0,63	0,66	0,49
70	0,67	0,68	0,59

The calibration process is based on comparison between recorded accelerations in time domain, during field tests, and simulations performed by means of the mechanical model, constrained to move on a couple of pavement profiles similar to those measured in tests site. The software Matlab 7.0$^{®}$ [1] has allowed to calculate constant values of model parameter at every measurement speed by forcing simulation to obtain recorded acceleration first on vehicle level ground (a_S), then on the seat (a_{HB}). In particular, it was first necessary to set masses and dimensions of the car, the constant parameter of springs representing tires, the constant values of retarding time in Kelvin model used for vehicle suspension and seat, the pitching and rolling moments of inertia. The second step was the evaluation of car suspension damping at different speeds: successively, fixing this parameter every time, it has been possible to estimate the seat one. Every model parameter has evaluated taking into consideration that accelerations in time domain graphics, derived by simulation, had to be similar, in shape and absolute values, to those recorded during the field tests, in such a way as to permit an acceptable comparison between the synthetic index (a_{WZ}) obtained by simulations and measurements one. So, they can be considered constant until speed simulation of 50 km/h. It is necessary to increase them when velocity exceed this limit. The cause of this is the not-linear proportionality of model vehicle suspension with values of transmitted forces. All parameters are resumed, at different simulation speeds, in Table 4.

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[1] *HB* = Human Body.

[2] *S* = Structure (of vehicle).

Table 4 – Model parameters at different simulation speeds.

Model paramters		Dimension	Speed (km/h)		
			25-50	60	70
p	wheel base	m	2.59		
ms	sprung vehicle mass	kg	1300		
mhb	driver mass	kg	100		
$m1u$	front/left unsprung mass 1	kg	40		
$m2u$	front/right unsprung mass 2				
$m3u$	rear/left unsprung mass 3	kg	35		
$m4u$	rear/right unsprung mass 4				
$r1s$	damping constant suspension 1	Ns/m	1400	3100	3530
$r2s$	damping constant suspension 2	Ns/m	1400	3100	3530
$r3s$	damping constant suspension 3	Ns/m	1400	3100	3530
$r4s$	damping constant suspension 4	Ns/m	1400	3100	3530
r	damping constant seat	Ns/m	3000	2200	2600
$k1s$	spring constant suspension 1	N/m	38889	86111	98056
$k2s$	spring constant suspension 2	N/m	38889	86111	98056
$k3s$	spring constant suspension 3	N/m	35000	77500	88250
$k4s$	spring constant suspension 4	N/m	35000	77500	88250
$k1t$	spring constant tire 1	N/m	200000		
$k2t$	spring constant tire 2				
$k3t$	spring constant tire 3				
$k4t$	spring constant tire 4				
k	spring constant seat	N/m	87464	64140	75802
Jgb	sprung mass pitch moment of inertia	Nms^2	2700		
Jgr	sprung mass roll moment of inertia	Nms^2	400		
$LG13$	axle semiwidth (left)	m	0.8		
$LG24$	axle semiwidth (right)				
$LG12$	dist. between front-axle/c.o.g. G	m	1		
$LG34$	dist. between rear-axle/c.o.g. G	m	1.59		
$LLHBG$	dist. longit. between seat/c.o.g. G	m	0.2		
$LTHBG$	dist. transv. between seat/c.o.g. G	m	0.4		

6. CONCLUSIONS

Pavement unevenness can cause significant road-vehicle dynamic interactions and usually influences vehicles and road structure damage increase and ride quality decrease. The roughness of a road surface produces in fact dynamic loads on vehicles moving on it and induces stresses on structures and users' discomfort.

Comfort, in particular, is difficult to objectively evaluate, because it needs also to consider the perception which users have of dynamic effects – especially vibrations transmitted in the vehicle.

In consequence, also considering costs and safety reduction related to these problems, many efforts have been recently accomplished to study complex phenomena which correlate road surface roughness and ride quality, as expression of users' comfort.

Useful indications, for objective evaluation of both roughness and ride quality, could be achieved solving equations that describe mechanical system and motion. This is possible by means of analytical models having road profiles as input vectors; so, models allow to study road-vehicle dynamic interactions, and obtain both roughness and comfort evaluation indexes.

A *"full car 8 d.o.f."* model has been realized by the authors of this paper to represent as good as possible a real road vehicle, but the model needed to be calibrated.

The calibration process is described in the paper: it essentially consisted of comparison between accelerations recorded in a real vehicle during field tests and

calculated ones by means of the *"full car 8 d.o.f."* model moving on profiles reproducing the road surface of test site. As results, the main mechanical parameters of the model have been settled. In particular, vehicle equipment, field tests carrying out, data analyses, numerical comparison, iterations for parameters setting has been reported. Many field tests and simulations needed, because of the non-linearity of various rheological parameters of model, which depend on speed of motion.

The *"full car 8 d.o.f."*, after the calibration process – here described – could be useful for various applications, because it needs only a couple of road profiles as input data. In this way, the model allows to objectively evaluate – referring to the considered vehicle, that is quite representative of european cars – comfort and ride quality offered by a road pavement, by means of the same data (road profiles) used to determinate the most common roughness indexes (as, in particular, the IRI). Road authorities and managers could use these results to plan the pavement management policies and to establish road roughness limits in various situations, also considering the operating speeds of vehicles.

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