19
REGULATIONS

A vehicle cannot be sold and obtain the necessary registration for driving on public roads, unless it is built according to legal specifications. In Europe the agreement of these specifications with existing laws is demonstrated, by two official documents: the *certificate of homologation* and the *certificate of conformity*.

The first document proves that the vehicle is designed according to legal requirements. It is issued by a public authority in charge of this function; in Italy, for instance, that authority is the Department of Transportation. The homologation certificate is issued on the basis of a technical report of the manufacturer and the completion of given tests, performed on prototypes of that vehicle.

The second document proves that any produced vehicle is identical, in terms of homologation requirements, to the tested and approved prototype; this document is issued by an appointed representative of the manufacturer, for instance the general manager of the final assembly plant. Vehicle conformity can, at any time, be verified by the public authority in charge, by inspection of samples of produced vehicles and tests for requirements of the homologation certificate.

Homologation requirements are set by government laws, which impose minimum and maximum accepted values and the related test methods to be used for their verification; the manufacturer is free to identify the most suitable technologies to be employed for their fulfillment.

These requirements are relevant to part of the vehicle functions we have already introduced in previous chapters, particularly for:

- outside visibility;
- minimum dynamic performance necessary to grant a safe drive;

G. Genta, L. Morello, *The Automotive Chassis, Volume 2: System Design*, Mechanical Engineering Series,

- occupant protection in case of collision;
- reduction of the environmental load caused by vehicle traffic, with particular reference to polluting gases, carbon dioxide, outside noise and waste produced by disposal of older vehicles.

The above laws are issued by each national government; in the past, some laws have also been developed by international institutions to enhance the free movement and sale of vehicles in countries other than that of their origin.

The European Community has already faced, in the 1960s, the problem of harmonization of national laws, to remove any impediment to the free circulation of goods within the Community and to grant the citizens of member states the availability to buy state of the art vehicles; this job has recently been carried over and completed by the European Union.

The European Union behaves like a supranational body, requiring all member states to develop laws complying with a common standard; these supranational laws are called *Directives* and will be cited with the letter D, followed by a figure showing the year of enactment and a following number. For instance the D70/156 directive was the hundred and fifty sixth law approved in 1970 regarding vehicle homologation; at the end of the last century and in the present one, the complete year figure is cited.

In parallel with Directives, *Regulations* have been also issued, summarizing in a single document all approved test procedures relevant to given homologation functions; these documents are quoted with the letter R, followed by a progressive number, unique for each title, independent of any addition or modification.

Since Directives must be established before national laws, they must be available in advance of their enforcement time; in their formulation, they provide an enforcement year for new homologations and one for new registrations.

No member state is allowed to prohibit sale, registration or circulation of any vehicle complying with the Directives in force.

In this chapter we will consider Directives and Regulations impacting chassis component design and vehicle system functions.

The following paragraphs will summarize laws regarding:

- vehicle system;
- wheels;
- steering system;
- braking system;
- chassis structures;
- gearbox.

The information discussed here is an updated summary at the time of writing this book and should be considered as a reference only; we suggest that

anyone requiring sure guidelines look through the primary documents and check for new updates. This can be easily done by visiting the Internet sites of the European Union dedicated to this purpose; anyone can download excerpts of the Official Gazette.

The site:

http://europa.eu.int/eur-lex/lex/it/index.htm

contains a suitable research engine for looking into Directives using keywords or their identification numbers.

The site:

http://www.unece.org/trans/main/wp29/wp29regs.htm

contains all vehicle regulations and their updates.

An index of current documents is reported in Table 19.1; the content of these documents is summarized in the following sections.

The European Union situation should be considered a typical example of the government approach to vehicle homologation; different States could have slightly different legislation, which must be carefully considered in the case the vehicle is sold and registered in different countries.

19.1 VEHICLE SYSTEM

19.1.1 Homologation and general characteristics

The D 70/156 Directive defines the homologation procedure reported in summary in the previous section; according to this Directive, the manufacturer is obliged to submit an *information form*, reporting all vehicle characteristics that cannot be altered without a new homologation.

The information form reports the following information regarding the issues we are concerned with.

General data

These consist of the manufacturer's data, the position of the Vehicle Identification Number (VIN) identifying body, chassis and engine, and the vehicle category. The following vehicle categories are identified:

- M_1: vehicles for transporting people with fewer than eight seats, in addition to the driver's seat;
- M_2: vehicles for transporting people with more than eight seats, in addition to the driver's seat and with a maximum overall weight of 5 t;[1]

[1]Rules were issued before the compulsory introduction of the SI measuring system. Newer updates report masses, instead of weights.

TABLE 19.1. European Unions Directives and Regulations with impact on chassis design.

Theme	Reference	Contents
Vehicle system	D70/156	General information necessary for the homologation of vehicles and trailers.
	D83/403	Completion of the above with off road vehicles.
	D92/21	Modification of the above for mass and dimensions.
	D92/53	Modification and new text for D70/156
	D95/48	Modification of the above for conformity control.
	D98/14	Modification of the above for procedures.
	D70/220	Gaseous emissions measurement.
	D80/1268	Fuel consumption measurement.
	D1999/100	Modification of the above for new consumption cycles.
	R101	Fuel consumption measurement.
	D2000/53	Disposal of waste deriving from vehicle disposal.
Wheels	D78/549	Shape of fenders and wheel wells.
	D92/23	Homologations of tires.
	D94/78	Update of D92723 for procedures.
	D2001/43	Prescriptions on tire noise.
	R30	Tire homologation for M_1 vehicles.
	R54	Tire homologation for M_2 and M_3 vehicles.
	R64	T type spare wheel tire homologation.
Steering	D70/311	Admitted steering devices and operating forces.
	D74/297	Driver protection in case of collision.
	D91/662	Modification of the above.
	D1999/7	Update of the D70/311 for powersteering.
	R12	Steering system homologation for driver protection.
	R79	Further update of D70/311 for powersteering.
Brakes	D71/320	Braking systems for M, N, O vehicles.
	D91/422	Modification of the above for dates of enforcement.
	D98/12	Modification of the above for ABS introduction.
	R13	Braking system homologation for M, N, O vehicles.
	R90	Spare lining homologation.
Struct.	D96/79	Occupant protection for M_1 vehicles.
Gearbox	D75/443	Prescriptions for speedometer and reverse gear.
	D97/39	Update of the above.
	R39	Speedometer and reverse gear homologation.

- M_3: as above, but with an overall weight exceeding 5 t;
- N_1: vehicles for transportation of goods with maximum weight exceeding 1 t, but lower than 3.5 t;
- N_2: vehicles for transportation of goods with maximum weight exceeding 3.5 t, but lower than 12 t;

- N_3: vehicles for transportation of goods with a maximum weight exceeding 12 t;
- O_1: trailers with a maximum weight not exceeding 0.75 t;
- O_2: trailers with a maximum weight exceeding 0.75 t, but lower than 3.5 t;
- O_3: trailers with a maximum weight exceeding 3.5 t, but lower than 10 t;
- O_4: trailers with a maximum weight exceeding 10 t.

Vehicle characteristics

These consist of three pictures and a vehicle scheme showing the main dimensions; the number of axles and wheels is reported, showing permanent or part-time driving wheels. An outline scheme of the chassis frame, if any, should be included, showing the material used for side beams.

Weights and dimensions

Among the main dimensions, the wheelbase and interaxis (for vehicles of more than two axles) must be reported under full weight conditions; for trailers, the distance between the hook and first axle pivot must be declared; for road tractors, the saddle pivot longitudinal and elevation position must be referenced to the vehicle. All dimensions are defined by the ISO 586 standard. All tracks must also be declared.

The weight of the bare chassis frame (if any) must be declared, not including cabin, fluids, spare wheel, tools and driver; the weight breakdown on the axles must be also declared.

Also the weight of the vehicle completed with body or cabin (depending on the product sold by the manufacturer) and other items must be declared and its breakdown on the axles; if the vehicle is a semi-trailer, the weight on the hook must also be claimed.

Finally, maximum allowed weight has to be declared and its breakdown on axles and hook (if any).

Transmission

The transmission is described by a draft scheme, including data on its weight, architecture (single stage, double stage, etc.), type of control (manual or automatic), transmission ratios (gearbox and final drives) and the vehicle speed that can be obtained on the existing gears at an engine speed of 1,000 rpm.

Suspensions

Suspension schemes must be attached, including the damping and elastic characteristics of shock absorbers and springs; allowed tire sizes must be declared.

Steering system

A scheme of the steering mechanism and column must also be included; maximum design forces on the steering wheel and maximum steering angles at the wheel and the steering wheel must be declared. For these angles, the vehicle turning radii for right and left turns must be declared.

Brakes

As we will describe later, service, emergency and parking brakes must be fully described.

The engine, body and other vehicle systems not included in the chassis must also be described.

A *homologation form* certifies the released homologation and reports for each of the characteristics of the information form:

- the conformity of the presented prototypes to the described items;
- the conformity of those characteristics to legal requirements;
- the positive execution of tests;
- the existence of required drawings.

The D 70/156 Directive also reports all forms to be used for information and for the certificate of conformity.

The D 87/403 Directive completes the previous documents with the definition of off-road vehicles; these are vehicles of M_1 and N_1 categories, featuring these characteristics:

- at least one front and one rear driving axle, one of which can be disengaged by the driver;
- at least one self-locking or locking differential;
- the gradeability of at least 30%, with no trailer;
- at least one of the following requirements:

    1. angle of attack α_a of, at least, 25°;
    2. angle of exit α_u of, at least, 20°;
    3. ramp angle α_r of, at least, 20°;
    4. ground clearance h_2, under the front axle of, at least, 180 mm;
    5. ground clearance h_2, under the rear axle of, at least, 180 mm;
    6. ground clearance between the axles h_1 of, at least, 200 mm.

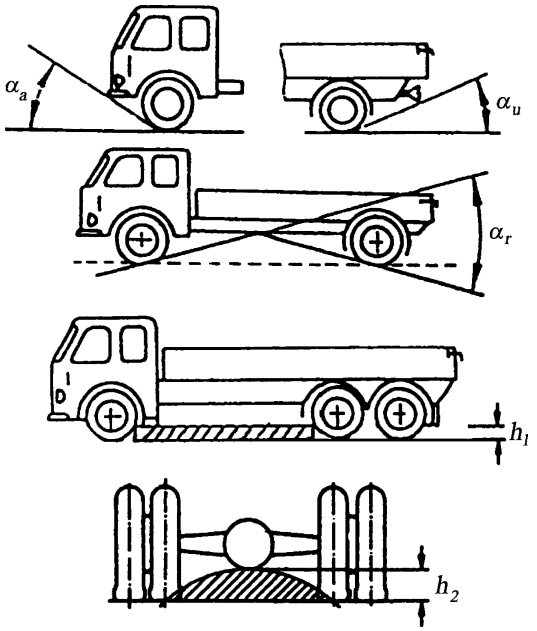

FIGURE 19.1. Front and rear attack angles α_a and α_p; α_r ramp angle; ground clearance h_1 and h_2.

Figure 19.1 defines with the help of sketches the reported dimensions.

Front and rear attack angles measure the capacity of a vehicle to face sudden slope changes in normal and reverse driving without any interference between chassis and ground; the ramp angle, on the other hand, refers to a sudden slope change in both directions.

The ground clearance between axles is the maximum height of an ideal parallelepiped that can be inserted between the axles and under the chassis; ground clearance under the axle refers to the lower point between the two contact points of the wheels on the same axle.

Other geometrical prescriptions are assigned to other kinds of vehicles.

The D 91/21 Directive updates the previous ones by specifying that an M_1 motor vehicle should feature a maximum speed of at least 25 km/h; in addition, it introduces mass as a measurement instead of weight.

The same Directive establishes maximum vehicle dimensions:

- 12,000 mm of overall length;
- 2,500 mm of overall width;
- 4,000 mm of overall height.

The maximum allowed vehicle mass must be, at least, the total of vehicle curb mass plus the product of offered passenger seats multiplied by 75 kg, which is assumed as the average weight of a passenger, including his hand baggage.

Mass breakdown on the axles may be calculated by positioning the passenger reference weight at the R point of each seat; sliding seats must be set at their rearmost position. Allowed baggage must be uniformly distributed on the trunk floor.

Measured vehicle mass, at prototype homologation or control of conformity, is admitted within a tolerance field of ± 5% around the declared values.

The D 92/53 Directive presents many updates of D 70/156 for the forms and homologation procedure. In this revision, specific rules are introduced regarding small volume productions and end of series productions, along with rules concerning waivers; the concept of equivalence between homologations granted by different member States is also introduced.

It is also established that each member State issuing homologation certificates must arrange statistical control plans on operating vehicles, suitable to detect possible non-compliance with the homologated prototypes; in case of non-conformity, the issuing State must inform other States of the event and must organize the compulsory recovery plan for the existing vehicles.

All applicable Directives and Regulations are reported in Attachment IV of this document.

19.1.2 Consumption and emissions

Directive D 70/220 and its following updates report the applicable rules of the European Union member states on the emission of polluting gases from motor vehicles; this Directive also subsumes the following ones about fuel consumption measurement.

The outstanding point of this Directive, in force for vehicles of the M_1 and N_1 types, consists in the definition of a transient driving cycle, which is defined to simulate vehicle usage in an urban environment. This cycle, also reported by the fuel consumption measurement Directive, consists of a speed-time history to be assigned to every vehicle to be homologated; it is related to high density urban traffic, where overtaking or slowing down is almost impossible.

The vehicle is tested on a dynamometer roller bench; a brake acting on the rollers is able to replicate vehicle driving resistance faithfully. The same rollers drive, in addition, a flywheel battery; each flywheel can be engaged or disengaged on the brake: a suitable flywheel combination can simulate vehicle inertia.

For this test, a *reference mass* is defined as the curb vehicle weight, with fuel supply, increased by 180 kg, corresponding to the average transported payload.

Table 19.2 reports the different reference mass classes and the corresponding rounded value for the equivalent inertia[2]; available flywheels must be able to replicate all reported equivalent inertia classes.

[2]Note the incongruity of measuring weight and inertia with the same units.

TABLE 19.2. Table for calculating the equivalent inertia of a vehicle, as a function of reference mass.

Reference mass P_r [kg]	Equivalent inertia [kg]
$P_r < 750$	680
$750 < P_r \leqslant 850$	800
$850 < P_r \leqslant 1{,}020$	910
$1{,}020 < P_r \leqslant 1{,}250$	1,130
$1{,}250 < P_r \leqslant 1{,}470$	1,360
$1{,}470 < P_r \leqslant 1{,}700$	1,590
$1{,}700 < P_r \leqslant 1{,}930$	1,810
$1{,}930 < P_r \leqslant 2{,}150$	2,040
$2{,}150 < P_r$	2,270

Brake torque absorption must be able to reproduce vehicle driving resistance at a constant speed of 50 km/h. For different speeds, only the parabolic relationship of torque with speed is requested.

To adjust the brake during a constant speed drive of the vehicle on a level road, in third gear or in D position for automatic transmissions, the intake manifold pressure is measured. Vehicles must be loaded with their reference weight and tires must be correctly inflated. To compensate for wind effect, the results of two measurements in opposite directions are averaged.

The same vehicle is set on the dynamometer and the brake is adjusted to reproduce the same manifold pressure.

The test bench is provided by a CRT monitor showing the actual vehicle speed on the bench, in combination with a band representing the driving cycle, with a tolerance of $\pm$ 2 km/h. The driver must follow this indicator, avoiding transient corrections that could affect the consumption measurement.

Figure 19.2 shows the speed-time diagram of the urban cycle for emission and consumption measurement; this cycle must be followed four more times.

All gases emitted by the exhaust pipe during the test are collected in bags, whose content is measured and analyzed after the test to determine HC, CO, NO_x and CO_2 levels; weighted gases are divided by the ideally travelled distance on the bench.

The D 80/1268 Directive prescribes the same cycle for fuel consumption measurement in an urban environment. This value was combined also with 90 and 120 Km/h constant speed fuel consumption, to supply the potential customer with more complete information.

This Directive was afterwards modified by introducing a second driving cycle of the suburban type, to be applied after the urban cycle. This cycle is reported in Fig. 19.3.

Table 19.3 shows a summary of the most important features of the two driving cycles.

Directive D 1999/100 imposes these cycles also for fuel consumption measurement; the consumption is calculated by standard formulas, depending on

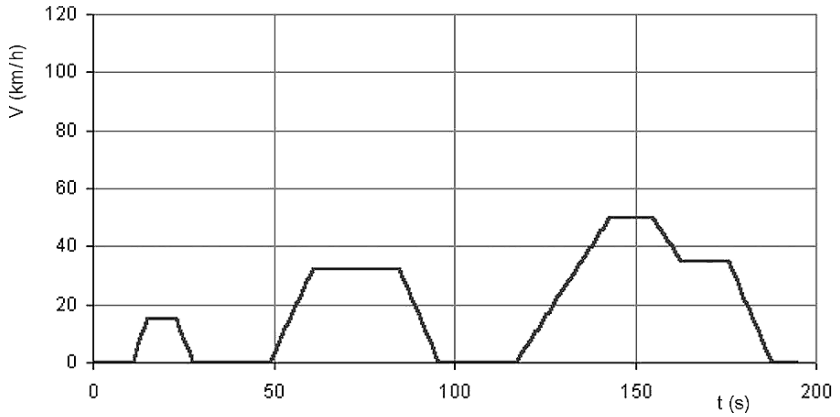

FIGURE 19.2. Speed-time diagram of the urban cycle for emissions and consumption measurement.

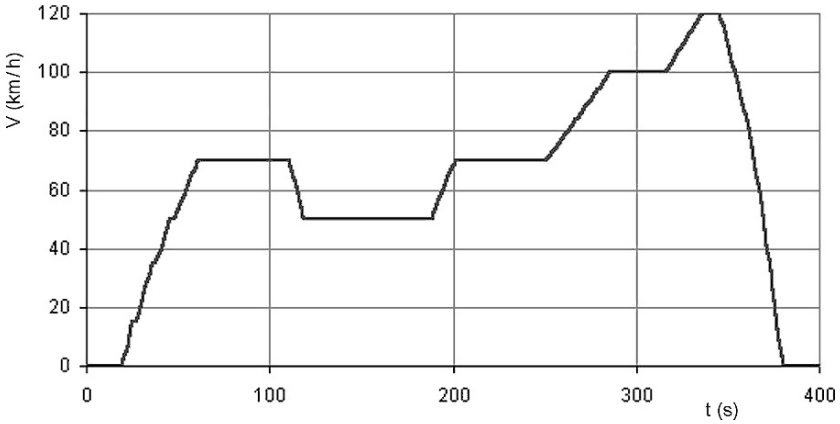

FIGURE 19.3. Speed-time diagram of the suburban driving cycle for emissions and fuel consumption measurement.

TABLE 19.3. Characteristics of the urban and suburban driving cycles.

Characteristic		Urban cycle	Suburban cycle
Travelled distance	[km]	$4\times1.013 = 4.052$	6.955
Duration	[s]	$4\times195 = 780$	400
Average speed	[km/h]	18.7	62.6
Maximum speed	[km/h]	50.0	120

the chemical composition of the fuel (gasoline, diesel, LPG, natural gas), starting with the emission value of CO_2 measured in g/km.

This value is the only allowed statement from manufacturers to customers on matters of fuel consumption; fuel consumption is also subject to conformity control from the issuer of the homologation certificate.

The same cycles must be used for electric energy consumption and range measurement in electric vehicles.

Regulation R 101 summarizes all topics on fuel consumption measurement.

19.1.3 Recyclability

Each year about 12 million vehicles are scrapped in the European Union; they correspond to about 0.5 % of the total production.

Directive D 2000/53 establishes rules to control waste products from these vehicles by component and materials recycling.

These rules also address improvements to the environmental operations of companies involved in this activity.

To prevent noxious waste formation, a set of laws has been introduced to limit the use of some substances for vehicle and component manufacturers, making recycling easier and avoiding dangerous waste treatment.

Member states must adopt laws suitable for reaching the following overall targets.

- The recovery percentage (materials not sent to a landfill) of scrapped vehicles must be at least 85% of the average vehicle weight, while at least 80% of the weight must be reemployed. For vehicles produced before 1980, lower targets can be set, but not lower than 75% for recovery and 70% for recycling.

- The recovery percentage must reach 95% by 2015 and the recycling percentage 85% of the average vehicle weight.

For this purpose, components and materials must be code labelled, to enhance identification and classification for selective recovery.

Scrapped vehicle treatment must include:

- batteries and LPG bottles removal;

- removal of explosive materials, such as air bags;

- removal and separated collection of fluids, like fuels, lubricants, cooling fluids, brake oil, air conditioning fluids and others, unless they are necessary to parts reemployment;

- removal of all components including mercury.

Other scheduled operations include:

- catalyst removal;
- selective removal of parts containing copper, aluminum and magnesium;
- tires and big plastic elements removal (bumper, dashboard, reservoirs);
- glass removal.

The economic accomplishment of these operations implies a number of additional design rules:

- banning certain materials, such as asbestos, lead, cadmium, esavalent chromium, etc.
- indelible material labelling of any component;
- designing components with a reduced number of materials;
- designing an easy disassembly;
- identification of components suitable for a second life.

In the near future, it is likely that manufacturers will be obliged to accept the burden of disassembly.

19.2 WHEELS

Directive D 78/549 is conceived as an implementation of D 70/156 for M_1 vehicles; it concerns fenders, sometimes part of the body, sometimes of the chassis (wheel wells).

The following rules refer to a running vehicle with wheel parallel to the longitudinal axis; Fig. 19.4 illustrates what we will report in this paragraph.

Within the sector defined by the radial planes through the wheel axis, which build up an angle of 30° before and 50° after the wheel with reference to the vehicle motion direction, the total width of the fender q must be sufficient to cover the width b of the tire, taking into account all possible combinations of tires and rims admitted by the manufacturer in the homologation information form.

In case of twin tires the total width of the two tires, as they are assembled on the wheel hub, must be taken into account.

The rear rim of the fender must be, at least, 150 mm higher than the wheel axis; in addition, the tangency point of the fender rim with a plane at 150 mm over the wheel axis (point A on Fig. 19.4) must be outside the equator plane of the tire, or, in case of twin tires, outside the equator plane of the outer wheel.

Profiles and location of fenders must be as close as possible to the tire; particularly with reference to the sector previously defined, the following prescriptions must be applied.

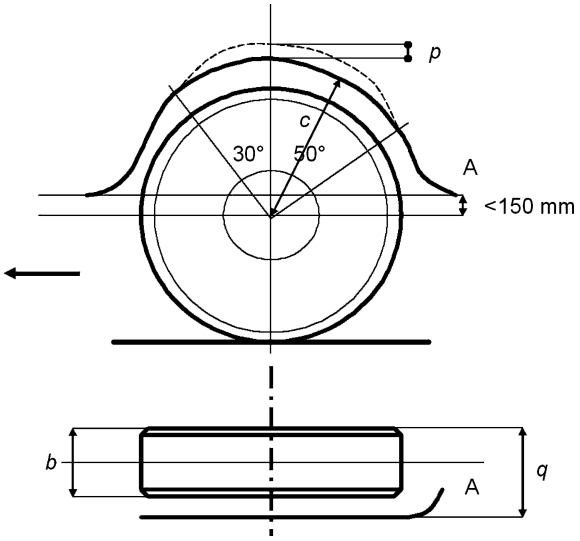

FIGURE 19.4. Dimensions for the fender and the wheel well, the object of homologation rules; the curved solid line represents the outer fender rim.

- The projection, on the tire equator plane, of distance p between the outer rim of the fender and its topmost point, must be at least 30 mm. This dimension can be progressively reduced to zero on the radial planes previously defined.

- The distance c between fender rims and wheel axis cannot be higher than twice the static radius R of the tire. In vehicles with adjustable trim, the above conditions must be satisfied when the vehicle is in the normal drive position requested by the manufacturer.

- Fenders can be built with more than one element; in this case gaps are not admitted between the different elements.

- Fender profile and tire position must be such that at least one type of snow chain can be mounted on the driving wheels, for one of the tire dimensions admitted by the manufacturer.

According to Directive D 92/23 and its updates on the D 94/78, member States are also required to homologate tires also as a component, independent of the vehicle where they should be installed.

This directive reports the standard identification system that was explained in the first volume. This system allows us to identify geometrical dimensions, inflation pressure and admitted load at reference conditions.

The homologation certificate of a tire must report the following information:

- application category;
- type of structure;
- maximum allowed speed;
- maximum admitted load with simple and twin assembly;
- the necessity of any tube;
- the type, as between the following: for cars; reinforced; for commercial and industrial vehicles; for temporary use on spare wheels (T type);
- description and dimensions of carcass structure;
- admitted rim dimensions for its application.

The Directive D 2001/43 limits the rolling noise produced by the tire, in order to contribute to the vehicle overall noise reduction; although we do not comment about Directives on outside noise, because this topic is part of the engine and its intake and exhaust systems design, we will describe briefly what pertains to the tire.

This Directive presents a reproducible test method to evaluate the noise produced by tires rolling on a paved road.

Tires are classified in the following categories:

- C1: tires for M_1 vehicles; class C1 is divided in subclasses, according to the dimension W;
- C2: tires for M_2 and M_3 vehicles with a load capacity index ≤ 121 and speed category $\geqslant$ N; class C2 is divided in subclasses, according to the tire application;
- C3: tires for M_2 and M_3 vehicles with a load capacity index $\leqslant 121$ and speed category $\leqslant$ M and with a load capacity index $\geqslant 122$ for twin assemblies; class C3 is divided in subclasses, according to the tire application.

The proposed test method consists of driving a vehicle with the test tire on a measurement course, as represented in Fig. 19.5; the vehicle must be launched and cross the course with idle gear and engine off.

This directive prescribes also the remaining test conditions, the specifications of the pavement and how to process signals from the microphones M.

The test speed is:

- 80 km/h for tires of C1 and C2 classes;
- 70 km/h for tires of C3 class.

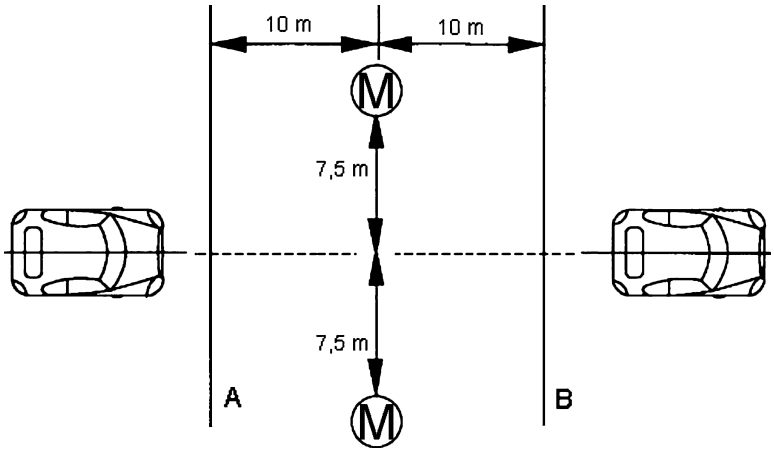

FIGURE 19.5. Test course for measuring tire rolling noise; on the course AB the vehicle is running at semi-constant speed, with idle gear and engine off. Points M represent the measuring microphones.

TABLE 19.4. Noise limits in [dB(A)] for the different tire classes; W is measured in [mm].

Class	Subclass	Limit [dB(A)]
C1	$W \leqslant 145$	72
C1	$145 < W \leqslant 165$	73
C1	$165 < W \leqslant 185$	74
C1	$185 < W \leqslant 215$	75
C1	$W > 215$	76
C2	normal	75
C2	snow	77
C2	special	78
C3	normal	76
C3	snow	78
C3	special	79

Noise limits are reported in Table 19.4. More severe limits are expected after 2007.

Regulations R30, R54, R64 summarize all matters respectively for M_1vehicles, for M_2 and M_3 vehicles and for T type wheels.

A T type wheel is a spare wheel, complete with tire and disc, with differences only in design details, that limits its application to certain conditions only.

The development of these wheels is justified by the need for bulk containment in the trunk, when more than one tire size applies to a vehicle, or when the ordinary wheels are judged to be too expensive.

Four different categories are identified:

- category 1: consists of a wheel where the disc has a design different from that of the homologated tires; the wheel is inflated at a pressure prescribed for temporary use;
- category 2: consists of a wheel where both disc and tire have a different design from that of the homologated tires; the wheel is inflated at a pressure prescribed for temporary use;
- category 3: consists of a wheel of the same design as that of the homologated tires, but transported flat; the tire is inflated when necessary;
- category 4: consists of a wheel where both disc and tire have a design different from the homologated tires; the tire is inflated only when necessary.

These wheels must observe the rules of R30 regulation, implying that the tire is designed for the load of the heavily loaded wheel and for a maximum speed of at least 120 km/h; T wheels must show an indelible label prescribing a use limited to a short distance and 80 km/h maximum speed.

The same indications must be reported in the user manual, which also prohibits the simultaneous use of more than one T wheel on the same vehicle.

In addition, a full load braking test must be performed with the T wheel in all possible positions; the braking test is the same as prescribed by R13 regulation: with a pedal load lower than 500 N, the vehicle must stop from 80 km/h within the distance:

$$s \leqslant 0,1V + \frac{V^2}{150} \ , \tag{19.1}$$

where V is the speed in [km/h].

The required performance must be obtained without wheel lock, deviation from the initial path or excessive corrections on the steering wheel.

19.3 STEERING SYSTEM

Directive D 70/311 is one of the oldest and requires that any motor vehicle, with more than 25 km/h as maximum speed and with at least four wheels, be equipped with a steering system; this rule applies also to trailers, but not to rail vehicles, agricultural and earth-moving machines.

For the steering system, the Directive means any device having the function of changing the driving path of a vehicle. It includes:

- the control (the steering wheel),
- the transmission from the control to the steering wheels,
- steering wheels,

- any device suitable for producing auxiliary energy for assistance; this auxiliary energy can be mechanic, hydraulic, pneumatic or any combination of the above, including energy storage.

Three categories of vehicles are identified with:

- manual steering, where steering energy is supplied by the driver's muscle power only;

- power steering, where this energy is partly supplied by the driver, partly by an assistance device;

- self-steering, where this energy is only supplied by sources different from the driver.

The control device must grant an easy and safe control of the vehicle; if necessary the steering system may be implemented by power assistance.

The control device must be manageable and ergonomic and must be conceived so as to allow an adjustable steering. The motion direction of the control device must be clearly correlated to the expected change of path of the vehicle.

The control force to be applied in order to obtain a turning radius of 12 m, starting from a straight direction, must in no case exceed 25 kg.

If a power assistance device is applied in order to observe this rule, the control force, when the assistance energy is missing, cannot exceed 60 kg. Vehicle steering must be guaranteed in the event of total or partial failure of the auxiliary system.

Self-steering devices are not admitted for vehicles as they are defined by this Directive.

It should be noticed that this condition applies only if all steering wheels are self-steering; for this purpose, hydrostatic steering (steering wheel moving a hydrostatic power distributor with wheels steered by hydrostatic actuators) is, for instance, not admitted, but an additional axis on a truck, steering only under the action of the cornering forces, is admitted.

Directive D 74/297 specifies the behavior of the steering wheel after a collision test against a barrier at 48.3 km/h; the test is done with no load or dummies. According to this directive the upper part of the steering column must not move back horizontally more than 12.7 cm with reference to any point of the body not involved in the collision.

In addition, the energy that the steering column must absorb during the secondary impact of the dummy against the steering wheel is specified; when the steering wheel is impacted by a test block of about 35 kg of mass, launched at a speed of 24.1 km/h, the reaction exerted by the test block cannot exceed 1,111 daN.

The steering wheel should be designed so as not to present any unevenness or sharp edges, which threaten to increase the danger or the severity of injuries

to the driver after the impact. In addition, it should be designed, built and assembled so as not to present any accessory element able to snag driver's clothing during normal driving operation.

Directive D 1999/7 specifies minimum values for braking efficiency on those vehicles that use the same energy source for both power steering and power braking.

Regulation R 12 reports all matters regarding driver protection in case of collision and describes test conditions in detail.

Regulation R 79 summarizes all matters regarding homologation and introduces important updates, opening the possibility of applying *full power* systems, where the motion transmission between steering wheel and wheel is not mechanical.

In this document, the technical progress needed to make the following items possible is examined:

- the elimination of the steering column for safety,
- the easy transfer of controls to both sides of the vehicle,
- the automatic intervention of steering control, to avoid collisions or rollovers.

According to the above targets this document allows steering wheel and wheel to be connected by other than mechanical positive means.

Systems in which the driver has the primary vehicle control, but in which automatic control systems can also intervene, are defined as *Advanced Driver Assistance Steering Systems* (ADASS).

Steering systems assisted by means that are in part outside the vehicle are defined as *Lane Guidance, Lane Keeping or Heading Control* if they have the job of maintaining a preset trajectory; they are classified as *Automatically Commanded Steering Function.*

Systems like ADASS can also include devices able to monitor path deviation or correction in such a way as to improve the vehicle's dynamic behavior.

This Regulation allows the application of such systems if their presence does not degrade the operation of the conventional control system. They must be designed in such a way as to enable the driver to inhibit their operation deliberately; in case of emergency, a mechanical positive link between steering wheel and wheels must be reestablished.

If the same source of energy used for steering the car is used for different devices, steering must be guaranteed. If this source is shared with the braking system, steering must be given priority; in case of failure the braking efficiency must not decay below certain limits.

The system must also be designed so as not to allow speeds over 10 km/h in case of failure; if the energy source is not available or has failed, at least 24 double steering pad loops of 40 m must be driven at a limited speed of 10 km/h with the same performance as an undamaged system.

TABLE 19.5. Maximum forces S on the steering wheel, for a curve of radius R, starting from a straight path for a duration T, in case of damaged and undamaged system.

Category	Undamaged system			Damaged system		
	S [daN]	T [s]	R [m]	S [daN]	T [s]	R [m]
M_1	15	4	12	30	4	20
M_2	15	4	12	30	4	20
M_3	20	4	12	45	6	20
N_1	20	4	12	30	4	20
N_2	25	4	12	40	4	20
N_3	20	4	12	45	6	20

In case of failure of the control transmission, no sudden steering angle change is allowed.

The vehicle must be driven starting from a straight path to a constant radius curve, as prescribed in Table 19.5, at 10 km/h. The steering wheel force necessary to perform the maneuver in the prescribed time should be recorded for the undamaged system. The same test should be repeated with a damaged system by measuring same values.

19.4 BRAKING SYSTEM

The D 71/320 Directive, together with the updates introduced by D 91/422 and by D 98/12, specifies braking systems for vehicles of the M, N and O categories.

This directive considers as a braking device any mechanical system having the function of decreasing the speed or stopping a vehicle gradually, or preventing further motion when stopped.

This device is composed of a control, a brake and a transmission connecting the above elements together.

The brake is the device developing forces opposed to vehicle motion.

Brake types taken into consideration are:

- *friction brakes*;
- *electric brakes* (where braking forces are developed by any electro-magnetic action between parts with relative motion, but not in contact);
- *fluid brakes* (where braking forces are developed by a fluid interposed between parts with relative motion);
- *engine brake* (where braking forces are produced by an artificial increase of the engine braking effect);
- *inertia brakes* (where the braking forces on a trailer are produced by the reaction between the trailer and the tractor).

The Directive defines transmission as any device connecting control with brakes; this transmission can be mechanical, hydraulic, pneumatic, electric or mixed. When braking is performed or assisted by an energy source independent of the driver, but under his control, the energy storage applied to the system is also considered to be part of the transmission.

The following braking modes are defined:

- *adjustable braking*, when the driver can, at any time, increase or decrease the force on the control;
- *continuous braking*, when a train of vehicles is braked by a unique control that can be moderated by the driver, at his driver's seat, and when the braking energy comes from the same source (as well as the muscle power of the driver);
- *semi-continuous braking* similar to above, but with energy coming from more than one source (one source can be the muscle power of the driver);
- *automatic braking* is the braking of a trailer that occurs automatically when it is uncoupled from its tractor or when towing devices are broken; in this case, the braking efficiency of the rest of the train must remain unaffected;
- *retarder braking*, when a supplementary device is able to exert and maintain a braking force on the vehicle, for a long time, without reduction in efficiency; the term retarder includes the entire system and its control; at this time regenerative braking systems (used on electric and hybrid vehicles) are not considered to be part of the braking system.

A generic braking system, as described at the beginning of this paragraph, must perform one of the following functions.

- *Service brake*: must allow vehicle speed control, stopping it quickly and safely at any speed or road slope; it must be adjustable; it must be operated by the driver at the driver's seat, with both hands on the steering control.
- *Emergency brake*: must allow the vehicle to be stopped in a reasonable space, when the service brake is malfunctioning; it must be adjustable; it must be operated by the driver at the driver's seat, with one hand on the steering control.
- *Parking brake*: must allow the vehicle to remain unmoving on a climbing or descending slope, even when the driver is absent.

Devices providing service, emergency and parking braking can have common parts or devices, provided they fulfill the following specifications:

- two independent controls must be available; for all vehicle categories but M_2 and M_3, each control (except the retarder control) must return to rest position when released; this rule does not apply to the parking brake when locked in the braked position;

- service brake control must be independent of the emergency or parking brake control.

Braking system specifications are different for road pavement with high and low friction coefficients.

High friction coefficient

For service brakes, a stop test of 0 type, with cold brakes (when the brake temperature, measured on the disc or on the outside of the drum, is lower than 100°C) is specified to be performed with unloaded and fully loaded vehicle and engine disengaged.

In addition, a stop test of 1 type should be performed, including repeated braking, as for the following scheme, and of 2 and 2 A type, after long descents.

The type 1 test is performed on a loaded vehicle, after having warmed up the brakes, according to the rules shown in Table 19.6.

The type 2 test provides that brakes are used when the vehicle is driving a course on a slope of 6%, 6 km long, at 30 km/h with the most suitable gear ratio and the retarder, when applicable.

Test type 2 A is similar to the previous one, but with a slope of 7%.

During this test, service, emergency and parking brakes cannot be used. The gear ratio must be chosen in order to run the engine at a speed not over the maximum value specified by the manufacturer. An integrated retarder (which can be operated by service brakes) can be used in such a way as not to operate the service brakes.

Test 2 A substitutes test 2 for tourism or long distance buses of category M_3, and for vehicles of category N_3 allowed to tow trailers of category O_4.

All above tests must be run on a high friction coefficient paved road.

The braking system efficiency is evaluated by measuring the stopping distance, the average deceleration and the response time.

The stopping distance is the distance travelled by the vehicle from the time the brake control is actuated to the time the vehicle is completely stopped; the initial speed of the test is defined as the speed at the time the driver starts to actuate the brake control.

TABLE 19.6. Rules for performing a type 1 test: V_1 and V_2 are the initial and final speed for the test, $V_{\max}$ is the vehicle maximum speed and Δt is the time between following brakings. The required number of repeated brakings is n.

Category	V_1 [km/h]	V_2 [km/h]	Δt [s]	n
M_1	$0.8{\cdot}V_{\max}, \leqslant 120$	$0.5{\cdot}V_1$	45	15
M_2	$0.8{\cdot}V_{\max}, \leqslant 100$	$0.5{\cdot}V_1$	55	15
M_3	$0.8{\cdot}V_{\max}, \leqslant 60$	$0.5{\cdot}V_1$	60	20
N_1	$0.8{\cdot}V_{\max}, \leqslant 120$	$0.5{\cdot}V_1$	55	15
N_2	$0.8{\cdot}V_{\max}, \leqslant 60$	$0.5{\cdot}V_1$	60	20
N_3	$0.8{\cdot}V_{\max}, \leqslant 60$	$0.5{\cdot}V_1$	60	20

TABLE 19.7. Minimum performance of the service brake system for 0 type tests, with disengaged engine.

Category	V [km/h]	s [m]	a_x [ms^{-2}]	F [N]
M_1	80	$\leqslant 0.1V + \frac{V^2}{150}$	$\geqslant 5.8$	500
M_2	60	$\leqslant 0.15V + \frac{V^2}{130}$	$\geqslant 5$	700
M_3	60	$\leqslant 0.15V + \frac{V^2}{130}$	$\geqslant 5$	700
N_1	80	$\leqslant 0.15V + \frac{V^2}{130}$	$\geqslant 5$	700
N_2	60	$\leqslant 0.15V + \frac{V^2}{130}$	$\geqslant 5$	700
N_3	60	$\leqslant 0.15V + \frac{V^2}{130}$	$\geqslant 5$	700

TABLE 19.8. Minimum performance of the service brake system for 0 type tests, with engaged engine.

Category	V [km/h]	s [m]	a_x [ms^{-2}]	F [N]
M_1	160	$\leqslant 0.1V + \frac{V^2}{130}$	$\geqslant 5$	500
M_2	100	$\leqslant 0.15V + \frac{V^2}{103,5}$	$\geqslant 4$	700
M_3	90	$\leqslant 0.15V + \frac{V^2}{103,5}$	$\geqslant 4$	700
N_1	120	$\leqslant 0.15V + \frac{V^2}{103,5}$	$\geqslant 4$	700
N_2	100	$\leqslant 0.15V + \frac{V^2}{103,5}$	$\geqslant 4$	700
N_3	90	$\leqslant 0.15V + \frac{V^2}{103,5}$	$\geqslant 4$	700

In the formulae below, suitable for measuring the braking efficiency, V is the initial speed, s the stopping distance, F the force on the brake pedal, a_x the average obtained deceleration.

The minimum result in Table 19.7 must be measured when the engine is disengaged, and in Table 19.8 when the engine is engaged. On the same tables, the maximum allowed value for F is reported.

Emergency brakes must be able to obtain:

$$s \leqslant 0.1V + \frac{2V^2}{150} \ , \tag{19.2}$$

for vehicles of category M_1,

$$s \leqslant 0.15V + \frac{2V^2}{130} \ , \tag{19.3}$$

for vehicles of categories M_2 and M_3 and:

$$s \leqslant 0.1V + \frac{2V^2}{115} \ , \tag{19.4}$$

for vehicles of categories N.

If the emergency brake is operated by a hand lever, the performance must be obtained with a force on the lever below 400 N for vehicles M_1, and below 600 N for the remaining categories.

TABLE 19.9. Minimum performance for service brakes, in case of transmission failure, in a 0 type test with engaged engine.

Category	V [km/h]	s [m], loaded vehicle	s [m], unloaded vehicle
M_1	80	$\leqslant 0.1V + \frac{100}{30}\frac{V^2}{150}$	$\leqslant 0.1V + \frac{100}{25}\frac{V^2}{150}$
M_2	60	$\leqslant 0.15V + \frac{100}{30}\frac{V^2}{130}$	$\leqslant 0.15V + \frac{100}{25}\frac{V^2}{130}$
M_3	60	$\leqslant 0.15V + \frac{100}{30}\frac{V^2}{130}$	$\leqslant 0.15V + \frac{100}{30}\frac{V^2}{130}$
N_1	70	$\leqslant 0.15V + \frac{100}{30}\frac{V^2}{115}$	$\leqslant 0.15V + \frac{100}{25}\frac{V^2}{115}$
N_2	50	$\leqslant 0.15V + \frac{100}{30}\frac{V^2}{115}$	$\leqslant 0.15V + \frac{100}{25}\frac{V^2}{115}$
N_3	40	$\leqslant 0.15V + \frac{100}{30}\frac{V^2}{115}$	$\leqslant 0.15V + \frac{100}{30}\frac{V^2}{115}$

In case of failure of any part of the transmission, residual system efficiency must allow the minimum values in Table 19.9, when a force not higher than 700 N is applied to the control, on a 0 type test with disengaged engine.

After a 1 type test, results on a stop test must be better than the limits shown in Table 19.7, reduced to 80%, or to the limits of 0 type test, reduced to 60%.

After a 2 type or 2 A type test, stopping distance must be better than:

$$s \leqslant 0.15V + \frac{1,33V^2}{130} \ , \tag{19.5}$$

for category M_3,

$$s \leqslant 0.15V + \frac{1,33V^2}{115} \ , \tag{19.6}$$

for category N_3.

Vehicles of categories M_3 and N_3 must pass the three tests; vehicles in the remaining categories must pass only type 0 and type 1 tests.

The parking system device must be able to hold a vehicle in place on a slope (both uphill and downhill slopes must be tested) of at least 18%; for vehicles allowed to tow trailers, the parking system device must hold vehicle and trailer in place on a slope of 12%.

If the parking brake is a hand brake, the force on the lever must not exceed 400 N for vehicles of M category and 600 N for the remaining categories. If it is a pedal brake, the limits are upgraded to 500 N and 700 N respectively. A device that must be actuated more than one time to achieve full performance is allowed.

Other limits are prescribed for vehicles of category O and for the response time of pneumatic brake systems.

The last Directive above also considers ABS or antilock systems; by *antilock system*, this Directive refers to all components regulating the slip of one or more wheels during braking.

Many prescriptions apply to this system; we will quote the main ones only.

Any failure of the electric system or to sensors, including the electric supply, wiring harness, control systems, or pressure modulator must be signaled to the driver by a warning light.

This light must be on when the ABS system is on and the vehicle is stopped; the light goes off, after a short period, to demonstrate that the system is working.

In case of any failure, the residual braking efficiency is defined by Table 19.9.

Only off-road vehicles of categories N_2 or N_3 can have devices able to switch off the ABS system or to modify its operational mode.

ABS systems must also maintain their efficiency when brakes are operated for a long period of time.

Low friction coefficient

For all categories of vehicles, when friction coefficient μ_x is between 0.2 and 0.8, the following relationship is applied:

$$z = \frac{a_x}{g} \geqslant 0.1 + 0,85(\mu_x - 0,2) \ , \tag{19.7}$$

where a_x is the obtained longitudinal deceleration and g is the gravity acceleration; z is called the *braking level*.

If we call:

f_i	the friction used by the axle i,
F_{xi}	the braking force of the axle i,
F_{zi}	the vertical force on axle i during braking,
P_i	the static vertical force on axle i,
P	the vehicle weight,
h_G	the center of gravity height,
l	the vehicle wheelbase,

we obtain:

$$f_1 = \frac{F_{x1}}{F_{z1}} = \frac{F_{x1}}{P_1 + z\frac{h_g}{l}Pg} \ , \tag{19.8}$$

$$f_2 = \frac{F_{x2}}{F_{z2}} = \frac{F_{x2}}{P_2 - z\frac{h_G}{l}Pg} \ ,$$

for a two-axle vehicle.

These formulae consider the pitch rotation equilibrium of a symmetric vehicle during braking; a complete justification of these formulae is given in Part IV.

For every load condition, the friction applied to the front axle must be higher than applied to the rear one:

- for any braking level between 0.15 and 0.18, for vehicles of M_1 category; however in the range between 0.3 and 0.45 the opposite is admitted if the friction used by the rear axle does not exceed by 0.05 the value given by $\mu_x = z$ (equal friction relationship) on a diagram representing f_i as function of z;

- for any braking level between 0.15 and 0.18, for vehicles of N_1 category; this condition is considered fulfilled if, for braking levels between 0.15 and

0.30, the used friction curves of each axle lie between the two parallel lines given by the following equations:

$$\mu_x = z + 0.08 \quad \text{and} \quad \mu_x = z - 0.08, \tag{19.9}$$

and if the curve of the friction used by the rear axle (which can cross the line $\mu_x = z - 0.08$), for braking levels between 0.3 and 0.5, respects the relationship:

$$z \geqslant \mu_x - 0.08, \tag{19.10}$$

and, between 0.5 and 0.61, respects the relationship:

$$z \geqslant 0.5\mu_x + 0.21; \tag{19.11}$$

- for any braking level between 0.15 and 0.30, for other vehicle categories; this condition is considered fulfilled if, for braking levels between 0.15 and 0.30, the used friction curves of each axle lie between the two parallel lines given by the following equations:

$$\mu_x = z + 0.08 \quad \text{and} \quad \mu_x = z - 0.08, \tag{19.12}$$

and if the curve of friction used by the rear axle, for braking levels $z \geqslant 0.3$, follows the relationship:

$$z \geqslant 0.3 + 0.74(\mu_x - 0.38). \tag{19.13}$$

This set of conditions is used to design the braking distributor, when the braking system is without ABS or has an electronic brake distributor (EBD).

For vehicles with ABS, the value of obtainable z must be at least 75% of that with an ideal brake distributor.

Brake lining

Directive D 98/12 also includes a test procedure that can be applied when a vehicle is modified by installing a new type of brake lining, when such vehicle is already homologated, according to the said Directive.

The new brake lining must be verified by comparison of its efficiency with that obtained with the original lining at the vehicle homologation test, and it must comply with the specifications on the information form.

In this case, a roller dynamometer is also allowed, where roller inertia meets vehicle values at the homologation test.

As for the entire vehicle, liners must be tested on test types 0, 1, 2 and 2 A; results are acceptable if the average deceleration, at the same force on the pedal, are included in a tolerance band as wide as the 15% value obtained by the vehicle homologation tests.

Lining friction tests are also specified to prove conformity of production; they are performed on a simplified bench, simulating a single brake.

The Regulation R13 summarizes all aspects of the above directives and introduces criteria about regenerative braking, by distinguishing between A type systems, which are not integrated with the braking system, and B type systems, which are integrated. The braking effect on A type systems is obtained by releasing the accelerator pedal only, on M_1 vehicles and with a separate control on N_1 vehicles.

To these systems all prescriptions must be applied; the 0 type test must be performed without regenerative braking.

Regulation R90 applies to braking linings used as spare parts.

19.5 STRUCTURES

The structural behavior of a vehicle is the subject of many Directives about what must and must not occur in a collision test, as regards front, rear and lateral impacts, for M_1 vehicles.

Chassis structures work together with the vehicle body in determining the behavior in front and rear impact, but the body plays a major role also if these structures are not limited to an underbody only, but there is a true separated chassis frame; the energy absorbed by the body deformation is fundamental. For side impact, the underbody plays a marginal role.

Nevertheless we will outline, for the sake of completeness, the D 96/79 Directive, which defines test procedures to guarantee occupant safety in case of front impact.

The vehicle impacts a deformable barrier, according to the scheme in Fig. 19.6; the vehicle under test must be at the reference weight condition.

On each of the front seats, a dummy Hybrid III type must be accommodated and wear the provided passive restraint systems. The accommodation geometry and seat adjustment is specified by this Directive.

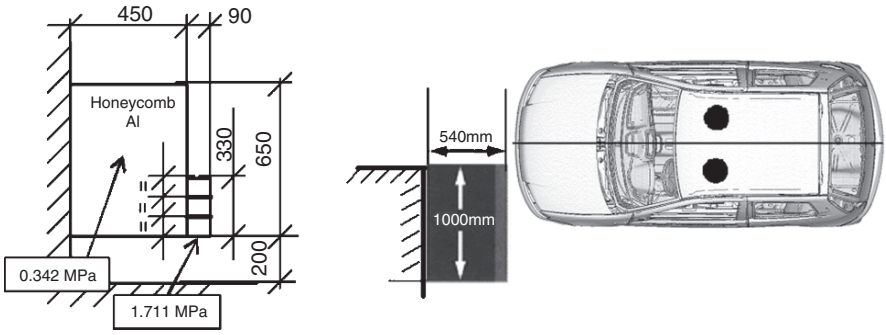

FIGURE 19.6. Scheme of the impact test against a deformable offset barrier, to demonstrate occupant protection capacity. At left is the side view of the barrier; at right, the upper view of the impact position.

The vehicle can be driven on its own or by an external device; at the impact time the steering system must be free and the propulsion system idle.

The impact speed must be 56 km/h, with a tolerance band of ±1 km/h. However, if the impact speed is higher and the test results comply with prescriptions, the test is considered as passed.

The vehicle path must be offset by 40% of the vehicle width (with a tolerance of ±20 mm), with reference to the vertical symmetry plane of the barrier. This offset was introduced, differently from the previous Directive, to take into account for the fact that most collisions between vehicles are not symmetric, but offset to their normal driving direction; cars homologated for countries with left-hand drive must have right-hand steering wheels and must be tested in symmetric position, as in the above scheme.

The barrier is positioned so as to have the first contact point with the vehicle on the driver's side.

The deformable barrier is designed to simulate a reference vehicle that is hit in the collision; for this purpose, it is made up of more elements:

- a main honeycomb aluminum structure;
- an element with the shape and position of a bumper, made of aluminum honeycomb;
- a reaction plate, bolted to a foundation;
- a cover plate for the bumper, made again of aluminum.

The front side of the barrier must be perpendicular to the vehicle impact direction with a tolerance of ±1°. The foundation mass must be at least 70,000 kg and its displacement must be limited by a concrete block. Barrier dimensions are shown on the left in Fig. 19.6.

During this test, many measurements are made to verify the performance criteria; different accelerometers are set on the dummy and on the car and the impact scene is shot by a high speed video camera.

The performance criteria involve the following limits:

- dummy head acceleration, processed according to a particular method taking into account the impact duration time;
- shear and traction forces on the dummy neck;
- thorax compression and compression speed;
- femur compression, as a function of time;
- tibia compression;
- rotula shear.

The values of these limits are derived by biomechanics studies on the human body and are continuously refined.

Beside the homologation test, rating tests by specialized independent laboratories and of specialized magazines become more and more relevant; the most famous of these is Euro NCAP (European New Car Assessment Programme).

Euro NCAP is a consortium between the main German Motoring Club (ADAC), the German, English and Dutch Transportation Ministries, the European Union and other partners, whose objective is to inform consumers about the passive safety of cars available on the market; information on Euro NCAP and available test results can be read on the internet site:

www.euroncap.com.

These tests results are scored and usually balanced in a final overall figure on vehicle safety, ranging from excellence to adequacy, measured by the number of stars.

There are tests similar to those reported by regulations but with additional severity in test procedures (for instance, by increasing impact speed) and in their evaluation scale, as well as new tests analyzing issues not already regulated (for instance, pedestrian impact was already rated before the issuance of the related law).

The peculiarity of rating tests is that they have reached a high level of reputation and have become important markers of product competitiveness. As a matter of fact, rating results have become an additional standard for car manufacturers.

Finally, the quest for higher rating evaluations contributes to raising the safety level of the operating fleet and promoting the improvement of the existing regulations.

19.6 GEARBOX

Regulations about the gearbox are few because this system has a low impact on functions covered by laws.

We also include in this section the prescription for the speedometer, because the pulse generator for the speed signal is usually within the gearbox. The final gear rotation speed is a simple indicator of wheel and car speed.

The Directive D 75/443 provides that all vehicles must have a reverse gear and a speedometer (with odometer).

A precision control is specified, according to the following procedure. The vehicle must have a set of homologated tires and the test must be repeated for any kind of speedometer included in the vehicle production.

The load on the axle having the speedometer installed (usually the driving axle) is defined by the D 70/156 Directive.

The vehicle must be tested at 40 km/h, 80 km/h and 120 km/h; the last value is substituted by 80% of the maximum speed, specified by the manufacturer, if this last is lower than 150 km/h.

The speed measured by the odometer cannot be lower than the actual speed.

At the specified speeds, the following relationship between indicated speed V_1 and actual speed V_2 must be verified:

$$0 \leqslant V_1 - V_2 \leqslant \frac{V_2}{10} + 4 \ . \tag{19.14}$$

The D 97/39 Directive updates the above for issues about the information form. The Regulation R39 is a summary of this topic.