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Road vehicles — Heavy commercial vehicle combinations and articulated buses — Lateral stability test methods

Véhicules routiers — Ensembles de véhicules utilitaires lourds et autobus articulés — Méthodes d'essai de stabilité latérale

Reference number
ISO 14791:2000(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 14791 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 9, *Vehicle dynamics and road-holding ability*.

Annexes A and B form a normative part of this International Standard. Annexes C and D are for information only.

Introduction

The road-holding ability of heavy commercial vehicle combinations and articulated buses is a most important part of active vehicle safety. Any given heavy commercial vehicle combination, together with its driver and the prevailing environment, constitutes a closed-loop system that is unique. The task of evaluating road-holding ability is, therefore, very difficult because of the significant interaction of these driver/motor vehicle/trailer/road elements, each of which is in itself complex. A complete and accurate description of the behaviour of a heavy vehicle combination must necessarily involve information obtained from a number of tests of different types.

Because they quantify only a small part of the whole vehicle handling field, the results of the tests specified in this International Standard can only be considered significant for a correspondingly small part of the overall handling behaviour of heavy commercial vehicle combinations and articulated buses.

In addition, the results obtained from these tests apply only for combinations of identical types of vehicle units. The results will not describe the behaviour of the vehicle units separately.

Moreover, insufficient knowledge is available concerning the relationship between overall vehicle dynamic properties and accident avoidance. Since the number of variants of heavy truck combinations is tremendously large, each truck combination is unique. So the measured result is valid only for the tested vehicle or combination and the transition of the results to obviously similar vehicle combinations is, especially for heavy trucks, not possible. Therefore, it is not possible to use these test methods and the test results for regulation purposes.

INTERNATIONAL STANDARD **ISO 14791:2000(E)**

Road vehicles — Heavy commercial vehicle combinations and articulated buses — Lateral stability test methods

1 Scope

This International Standard specifies test methods to determine the lateral stability of heavy commercial vehicle combinations as defined in ISO 3833, including truck centre-axle trailer combinations and articulated buses. It is applicable to trucks and trailers having a mass exceeding 3,5 t and buses having a mass exceeding 5 t, i.e. vehicle categories N2, N3, O3, O4 and M3 according to 92/53/EEC.

The manœuvres specified in these test methods are not fully representative of real driving conditions, but are useful for determining the lateral stability of a heavy vehicle combination.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 1176:1990, *Road vehicles — Masses — Vocabulary and codes*.

ISO 3833:1977, *Road vehicles — Types — Terms and definitions*.

ISO 8855:1991, *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*.

ISO 9815:1992, *Passenger-car/trailer combinations — Lateral stability test*.

EC Council Directive No. 92/53/EEC. Annex II, *Definition of vehicle categories and vehicle types*.

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 8855 and the following apply.

3.1

vehicle unit

rigid (i.e. non-articulating) vehicle element operating alone or in combination with one or more other rigid elements joined at yaw-articulation joints

EXAMPLES Tractor, semitrailer and dolly.

3.2

rearward amplification

ratio of the maximum value of the motion variable of interest of a following vehicle unit to that of the first vehicle unit during a specified manœuvre

3.3
offtracking

lateral deviation between the path of the centreline point of the front axle of the vehicle and the path of the centreline point of some other part of the vehicle

NOTE 1 See 8.3 for determination of offtracking.

NOTE 2 In a single-lane-change manœuvre where the path of the other part of the vehicle is farther from the projection of the original path of the vehicle than is the path of the front axle, the path of the other part is said to “overshoot” the path of the front axle at that point. If the opposite is true, the path of the other part is said to “undershoot” the path of the front axle.

3.4
zero-damping speed

speed at which the damping coefficient of the free oscillatory yaw movements of the vehicle combination equals zero

3.5
reference-damping speed

speed at which the damping coefficient of the free oscillatory yaw movements of the vehicle combination equals 0,05

3.6
centreline point

point at the intersection of the ground plane and the x-z plane of symmetry of the part of interest, which point lies directly below a longitudinal reference position

NOTE For an axle, the longitudinal reference point is the wheel-spin axis. For other parts, the longitudinal reference point should be stated.

3.7
yaw-articulation angle

yaw angle of the x-axis of the intermediate axis system of a more forward vehicle unit in the intermediate axis system of a following vehicle unit, i.e. the angle between the x-axes of the two units with polarity determined by the rotation of the leading unit in the axis system of the following unit

NOTE The units involved are usually adjacent, but not necessarily so.

4 Test objectives

The primary objective of these tests is to determine the lateral stability of heavy commercial vehicle combinations and articulated buses.

The lateral stability is characterized by:

- rearward amplification of lateral acceleration and yaw velocity;
- dynamic offtracking;
- zero-damping speed;
- yaw damping, including mode-shape information.

Of these four performance measures, two, rearward amplification and dynamic offtracking, relate to forced response properties and the other two, zero-damping speed and yaw damping, relate to free response properties.

For a complete set of measurements, it is necessary to determine:

- steering-wheel angle;
- longitudinal velocity;
- yaw velocity of the first and the last vehicle units;
- lateral acceleration of the front axle of the first vehicle unit at or below the height of the wheel centre, and lateral acceleration of the centre of gravity of the last vehicle unit;
- articulation angles or articulation angular velocity between the vehicle units;
- offtracking of the most severely offtracking axle of the vehicle combination.

In order to acquire a deeper understanding of the behaviour of the vehicle combination, it is desirable to determine:

- lateral acceleration in the centre of gravity of each vehicle unit;
- yaw velocity of each vehicle unit;
- the roll angle of each vehicle unit, preferably above the rearmost axle;
- lateral velocity or slip angle of the rearmost axle of each vehicle unit;
- dynamic wheel loads of each vehicle unit;
- lateral motion of each axle in the combination;
- offtracking of the most severely offtracking point, other than an axle, of the vehicle combination.

The following test methods can be used to determine the various characteristics of the lateral stability:

- pseudo-random input;
- single lane-change;
- pulse input.

Pseudo-random input can be used to determine the maximum rearward amplification. It provides complete information about the frequency dependency of the rearward amplification.

With a single lane-change, rearward amplification and dynamic offtracking can be determined for a specific, realistic manœuvre. The single lane change may be carried out by applying either a single sine-wave steering input or by following a path producing a single sine-wave lateral acceleration input.

NOTE Rearward amplification measurements obtained using pseudo-random input and single lane-change will differ. The two test methods have a fundamental difference. The pseudo-random input method is intended to yield a full representation of the system gain in the frequency domain. The single-lane-change method, however, provides only the composite gain of the system as results from the distributed frequency content of the specific lane-change performed in the test.

Also, the measurements obtained from the two lane-change methods should be expected to differ, because the frequency content of the steering input will be different in the two cases. With the single sine-wave steering method, the steer input is defined, while for the path-following method the lateral acceleration is defined. In the first method, lateral acceleration depends on the dynamics of the vehicle combination and the properties of the steering system, e.g. lash and compliance. In the second method, steering depends on the same influences. This yields a different composite gain of the system as measured by the two methods.

The pulse input is used for determining zero-damping speed, yaw damping and yaw-velocity ratio.

The analyses for the pseudo-random method are made in the frequency domain. All other analyses are made in the time domain.

The methods chosen shall be indicated in the general data presentation (see annex A) and in the presentation of the test results (see annex B).

5 Measuring equipment

5.1 Description

Those of the variables listed in clause 4 which are selected for test purposes shall be monitored using appropriate transducers, and the data shall be recorded on a multichannel recorder with a time base. The typical operating ranges and recommended maximum errors of the transducer/recorder system are given in Table 1.

Table 1 — Variables, typical operating ranges and recommended maximum errors

Variable	Typical operating range	Recommended maximum error of combined system
Steering-wheel angle	± 180°	± 2°
Longitudinal velocity	0 to 35 m/s	± 0,3 m/s
Lateral acceleration	± 15 m/s^2	± 0,15 m/s^2
Articulation angles between vehicle units	± 30°	± 0,3°
Articulation angular velocity	± 50°/s	± 0,5°/s
Yaw velocity	± 50°/s	± 0,5°/s
Lateral displacement of vehicle axle centre-line points relative to the path of the front axle centreline point	± 10 m	± 0,05 m
Wheel loads	0 to rated axle load	± 2 % of full scale
Roll angle	± 15°	± 0,2°
Lateral velocity	± 10 m/s	± 0,2 m/s
Slip angle	± 10°	± 0,5°

Some of the transducers listed are neither widely available nor in general use. Many such instruments are developed by users. If any system error exceeds the maximum values recommended, this fact and the actual system error shall be stated in the general data.

5.2 Transducer installation

The required variables may be measured directly or indirectly. If a transducer does not measure the required variable directly, appropriate corrections for linear and angular displacement shall be made to its signals so as to obtain the required level of accuracy.

Transducers for measuring lateral acceleration shall be installed on the sprung mass.

Optionally, the transducer for measuring the lateral acceleration of the front axle of the first vehicle unit may be mounted on the front axle if this is a solid axle. In this case, the transducer shall be mounted at or below the height of the wheel centre, and the signal from this transducer need not be corrected for errors associated with roll.

5.3 Data processing

5.3.1 General

The frequency range relevant to these tests is between zero and the maximum utilized frequency, $f_{\text{max}} = 2$ Hz. According to the chosen data-processing method, i.e. analog or digital processing, the following stipulations shall be observed.

5.3.2 Analog data processing

The bandwidth of the entire combined transducer/recorder system shall be not less than 8 Hz.

In order to execute the necessary filtering of signals, low pass filters with order 4 or higher are required. The width of the passband (– 3 dB at frequency f_0) shall be not less than 8 Hz. Amplitude errors less than ± 0,5 % have to be attained in the relevant frequency range of 0 to 2 Hz. All analog signals shall be processed with filters having sufficiently similar phase characteristics in order to ensure that time delay differences due to filtering lie within required accuracy for time measurement.

NOTE Phase shifts may occur during analog filtering of signals with different frequency contents. Therefore, a data-processing method as mentioned in 5.3.2 is preferable.

5.3.3 Digital data processing

5.3.3.1 Preparation of analog signals

In order to avoid aliasing, the analog signals shall be filtered before digitizing. In this case low pass filters with order 4 or higher shall be employed. The width of the passband (– 3 dB at frequency f_0) shall be $f_0 > 5\,f_{\text{max}}$.

The amplitude error of the anti-aliasing filter should not exceed ± 0,5 % in the utilized frequency range from zero to f_{max}. All analog signals shall be processed with anti-aliasing filters having phase characteristics sufficiently similar to ensure that time delay differences lie within the required accuracy for time measurement.

Additional filters shall be avoided in the data acquisition system.

Amplification of the signals shall be such that, in relation to the digitizing process, the additional error is less than 0,2 %.

5.3.3.2 Digitizing

The sampling rate, f_s, shall be such that the attenuation of the anti-aliasing filter at all frequencies greater than $f_s - f_{\text{max}}$ is at least 60 dB.

In order not to exceed an amplitude error of 0,5 % in the relevant frequency range from zero to f_{max}, the sampling rate, f_s, shall be at least $30\,f_{\text{max}}$.

5.3.3.3 Digital filtering

For filtering of sampled data in data evaluation, phaseless (zero phase-shift) digital filters incorporating the following characteristics shall be used (see Figure 1):

- the passband shall range from 0 to 2 Hz;
- the stopband shall begin at < 6 Hz;
- the filter gain in the passband shall be 1 ± 0,005 (100 % ± 0,5 %);
- the filter gain in the stopband shall be < 0,01 (< 1 %);
- the filter gain between the passband and the stopband shall drop as fast as feasible.

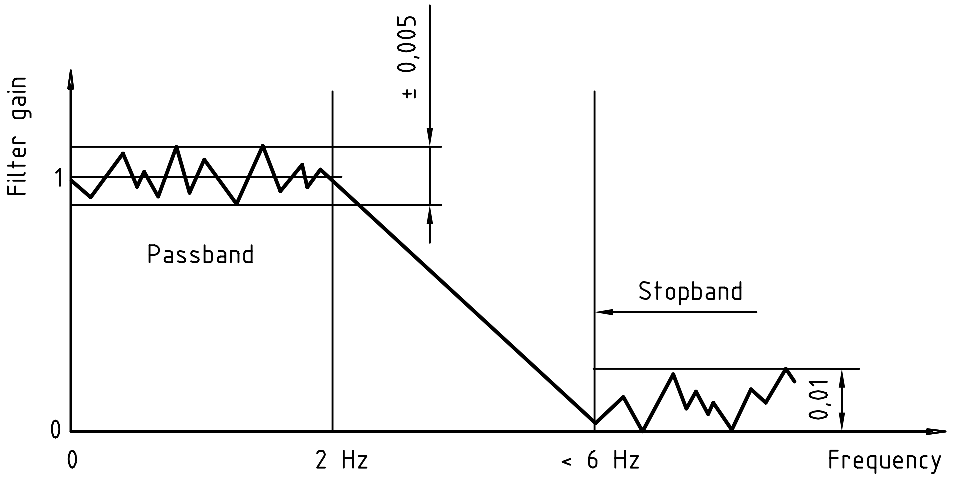


Figure 1 — Digital filter characteristics

6 Test conditions

6.1 Test tracks

All tests shall be carried out on a uniform hard surface which is free from contaminants and has not more than 2 % gradient as measured over any distance of 5 m or more in any direction and not more than 1 % gradient as measured over any distance of 25 m or more along the path of the vehicle. For standard test conditions, a smooth dry pavement of asphalt or cement concrete or a high-friction test surface is recommended.

The ambient wind speed shall not exceed 5 m/s. Wind velocity and direction shall be reported.

The test surface should be maintained over a minimum of 8 m track width. For the pseudo-random-input test, a track length sufficient to permit at least 30 s running at the test speed, in addition to the run-up and stopping requirements should be provided.

Yaw damping of vehicle combinations is known to be sensitive to the longitudinal slope of the test surface. Where this slope approaches the maximum allowable value (1 %), it is recommended that the test be conducted in both directions. Results should be averaged as described in 8.4.2.

6.2 Tyres

For standard test conditions, the tyres on the vehicle shall have been run in for at least 200 km, and they shall have a tread depth of at least 90 % of the original value over the whole tread width and circumference of the tyres. The tyres shall have been stored according to the tyre manufacturer's recommendation and shall not have been manufactured more than two years before the test. The date of manufacture of all tyres shall be reported.

The tread depth of any tyre shall not decrease more than 2 mm during the test. Tread depth and wear shall be reported.

Tyres shall be inflated to pressures as specified by the vehicle manufacturer for the test vehicle configuration at the ambient temperature. The tolerance for the cold-inflation pressure is ± 2 %.

Because tread depth may have a significant influence on test results, it is recommended that tread depth be taken into account when comparing vehicles or tyres.

6.3 Operating components

All operating components likely to influence the results of these tests (e.g. shock absorbers, springs and suspension parts) shall be inspected to check they meet the vehicle manufacturer's specifications and shall be properly adjusted and secured. The results of these inspections and measurements shall be recorded and, in particular, any deviations from the manufacturer's specifications shall be noted in the general data presentation.

6.4 Loading conditions

6.4.1 General conditions

In no case shall the manufacturer's maximum design total mass and the manufacturer's maximum design axle load (both defined in ISO 1176) be exceeded.

The axle loads, the centre-of-gravity height, the total mass and the yaw moment of inertia can be expected to influence the results. All of these parameters shall be reported.

Care shall be taken to ensure that the centre-of-gravity positions and the values of the moments of inertia are representative of normal, in-use loading conditions.

6.4.2 Maximum loading conditions

For the maximum loading condition, the total mass of a fully laden vehicle shall consist of the complete vehicle kerb mass (see 6.4.1) plus the maximum payload of interest, distributed in such a way that none of the maximum axle loads is exceeded. The centre-of-gravity height and the mass distribution of the payload should be established to reflect the application of interest and recorded in adequate definitions to determine the centre-of-gravity position in three dimensions and the yaw moment of inertia. The maximum loading condition is the standard test condition.

6.4.3 Minimum loading conditions

The total vehicle mass for each vehicle unit for the minimum loading condition shall consist of the complete vehicle kerb mass (see ISO 1176), plus the mass of the instrumentation. In the case of the first vehicle unit, the mass of the driver and, if applicable, the mass of an instrument operator or observer shall be added. The minimum loading condition is optional.

6.4.4 Other loading conditions

Other loading conditions representing special transport conditions are encouraged.

7 Test method

7.1 Warm-up

The vehicle shall be warmed up prior to the tests by driving at the test speed over a distance of at least 10 km.

7.2 Test speed

All tests, except the pulse input test of 7.6, shall be conducted at either 80 km/h, 90 km/h or 100 km/h depending on intended use of the vehicle, or at the maximum speed of the vehicle if it is less than 80 km/h. Tests at higher speeds are encouraged.

For each test run, the average speed shall be maintained within a tolerance of ± 2 km/h of the selected speed. A deviation of the vehicle speed of ± 3 km/h from the selected speed is permissible.

7.3 Lateral acceleration

In all of the proposed test manœuvres, the recommended value of the maximum lateral acceleration of the first unit is 2 m/s^2, but it may be decreased for the purpose of limiting the response of the last unit to no more than 75 % of the estimated rollover limit and no more than 75 % of any tyre friction limit. For the pseudo-random input test, it may be decreased further in order to keep all vehicle units within the linear regime.

Stepwise increase of the lateral acceleration and the use of outriggers on the last unit are strongly recommended in order to prevent rollover.

7.4 Pseudo-random input

Test runs shall be made by driving the vehicle at the required test speed and making continuous inputs to the steering wheel up to predetermined limits of steering-wheel amplitude. The limit is determined for a lateral acceleration level within the range in which the vehicle exhibits linear behaviour. This limit applies to all units in the combination.

Any mechanical limitations of the steering wheel shall not be engaged because of their effect on the harmonic content of the input. It is also important that the input be continuous because periods of relative inactivity seriously reduce the signal/noise ratio.

The frequency range of the steering input shall be from 0,1 Hz to as high as practicable but to at least 1,0 Hz. In order to ensure adequate high-frequency content, the input shall be energetic. Both the frequency and the amplitude of the input shall be varied randomly.

To ensure enough total data, at least 12 min of data is necessary unless the indicated confidence limits require a shorter or a longer time. Ideally, this should be a continuous run, but practical considerations may prevent this for two reasons. Firstly, the test track may not be sufficiently long to permit a continuous run of such a length; secondly, the computer used to analyse the data may be insufficiently, powerful to handle all the data at one time. In either case, it is permissible to use a number of shorter runs of at least 30 s duration.

7.5 Single lane-change

7.5.1 General

The vehicle shall be driven at the test speed in a straight line with (0 ± 0,5)°/s yaw velocity immediately before the lane-change manœuvre is performed.

The test shall be conducted for at least three frequencies, with a maximum frequency interval of 0,1 Hz. The frequencies shall be chosen so that maximum rearward amplification does not occur at either of the extreme frequencies.

A set of at least three acceptable runs are required for each combination of speed and frequency. Additional runs may be conducted as desired.

It is recommended that the measurements be carried out for both left and right turns.

7.5.2 Single sine-wave steering input

One full period sinusoidal steering-wheel input with the predetermined steering-wheel amplitude shall be applied followed by 5 s at the neutral steering position. The allowable amplitude error compared to the true sine wave is ± 5 % of the first peak. In order to obtain accurate and reproducible results, a steering machine is recommended. Attention shall be paid to the safety of the system.

7.5.3 Single sine-wave lateral acceleration input

The vehicle shall follow a marked test course so that a selected point of the front axle does not deviate more than ± 0,15 m from the desired path defined by the test course. The average peak value of the lateral acceleration of the front axle of the first vehicle unit shall not have a sample standard deviation greater than 0,2 $\mathrm{m/s^2}$ and its mean value shall be within 10 % of the desired lateral acceleration.

The test course consists of a preliminary straight start section, an initial straight section, a manœuvring section and an exit section. The layout is shown in Figure 2. The desired path shall be marked on the test surface in a manner which facilitates measurement of the path-following. Driving technique and a verification method for path-following as well as a method for measuring offtracking are described in annex C.

The coordinates, x (expressed in metres) and y (expressed in metres), of the manœuvring section of the test course for a given maximum lateral acceleration, a_y (expressed in metres per square second), test speed, v (expressed in metres per second), and frequency, f (expressed in hertz), are given by the equation below.

$$y = \frac{a_y}{(2\pi f)^2}\left[2\pi f \frac{x}{v} - \sin\left(2\pi f \frac{x}{v}\right)\right]$$

NOTE The permissible deviations from the desired path may lead to significant differences in the results compared to the ideal path especially for higher frequencies. Therefore the lane-change method with sine-wave steering input is recommended if a steering machine is used.

7.6 Pulse input

7.6.1 General

Preliminary tests or analyses should be conducted to determine the general quality of the vehicle response to a pulse-steering input. The pulse-input test is appropriate for lightly damped vehicles which display a sustained oscillatory response. Time histories from heavily damped vehicles whose response dies quickly are not appropriate for the data reduction methods described in 8.4.

7.6.2 Determination of estimated zero-damping speed

Preliminary tests or analyses should be conducted to produce an initial estimate of the zero-damping speed. This can be done by driving the combination at stepwise-increased speeds and applying a steering input to achieve trailer oscillation. The zero-damping speed should be approached cautiously, using moderate steering inputs. The zero-damping speed can also be estimated based on the results of the first few test runs.

7.6.3 Predetermined test speeds

The tests shall be conducted at predetermined test speeds. The lowest test speed shall be 40 km/h below the estimated zero-damping speed, or 40 km/h, whichever is the higher. Additional test speeds shall be performed at increments of not more than 20 % of the difference between the lowest test speed and the estimated zero-damping speed.

7.6.4 Test runs

The test runs shall be made by driving the vehicle combination at the predetermined test speeds (see 7.6.3) in a steady-state, straight ahead condition. To minimize errors due to linear extrapolation (see 8.4.2), the highest test speed shall be at least 90 % of the zero-damping speed which results from the curve fitting. For sufficient accuracy, at least three test runs shall be conducted at this speed and at each predetermined test speed.

Dimensions in metres

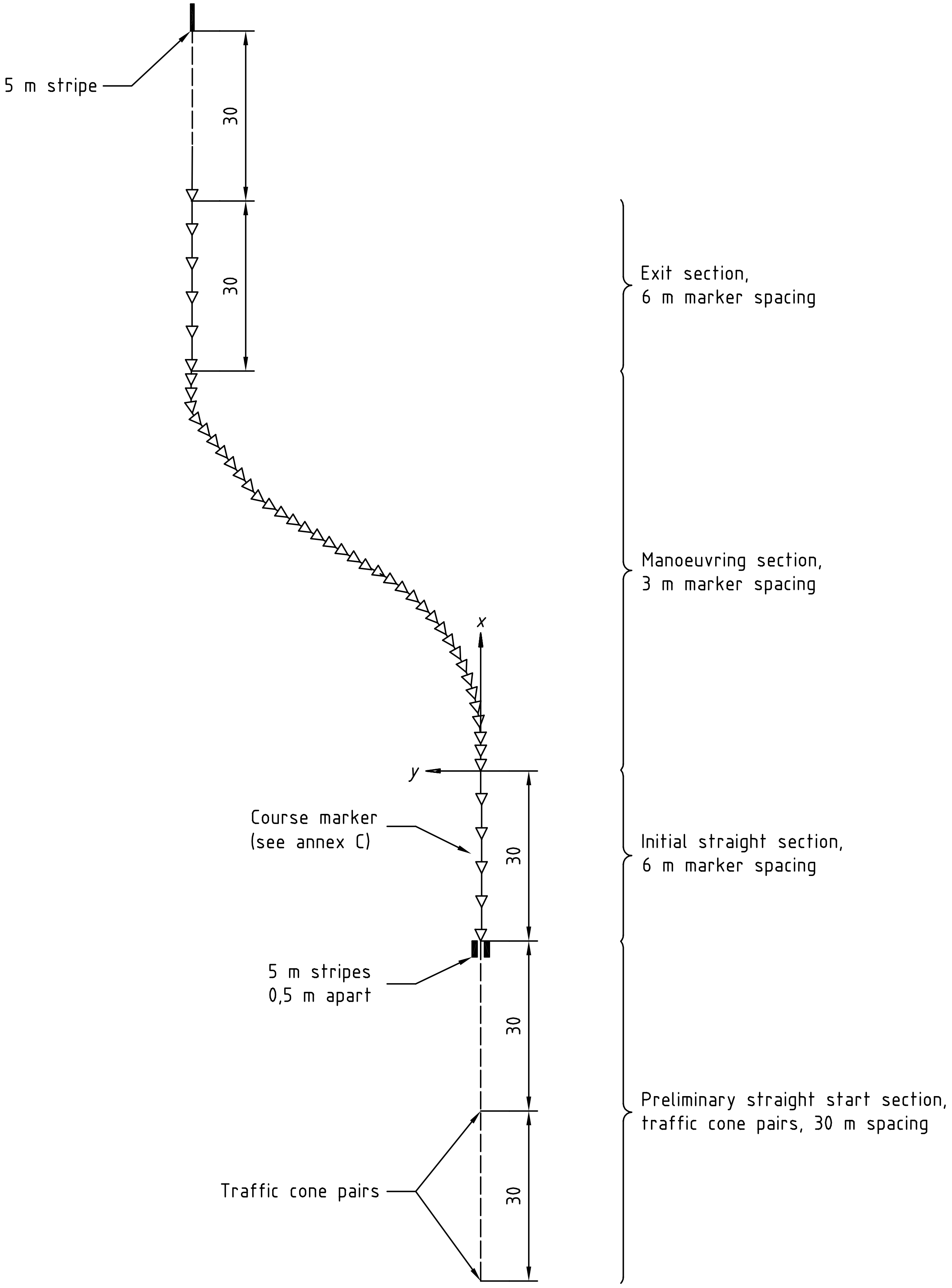


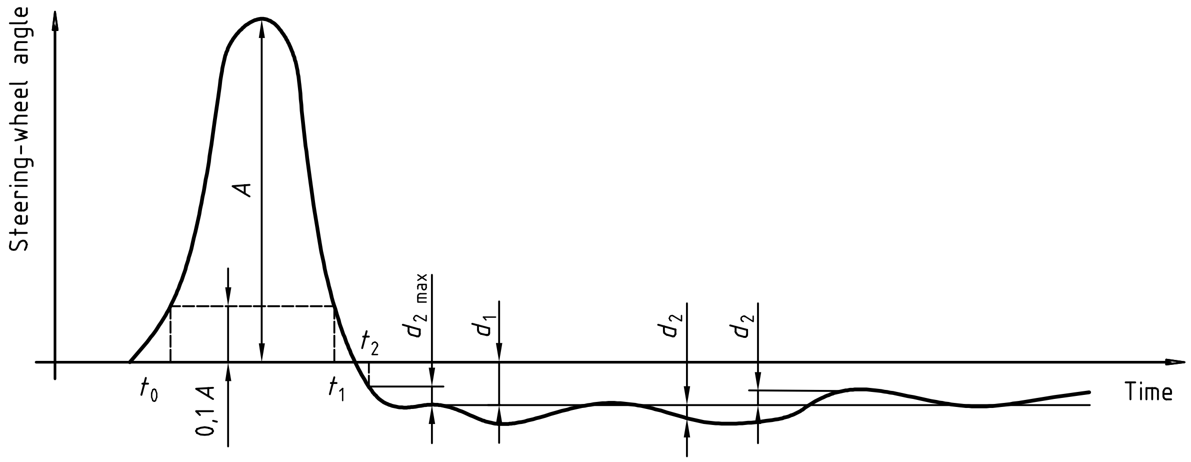
Figure 2 — Layout of test course

7.6.5 Steering impulse

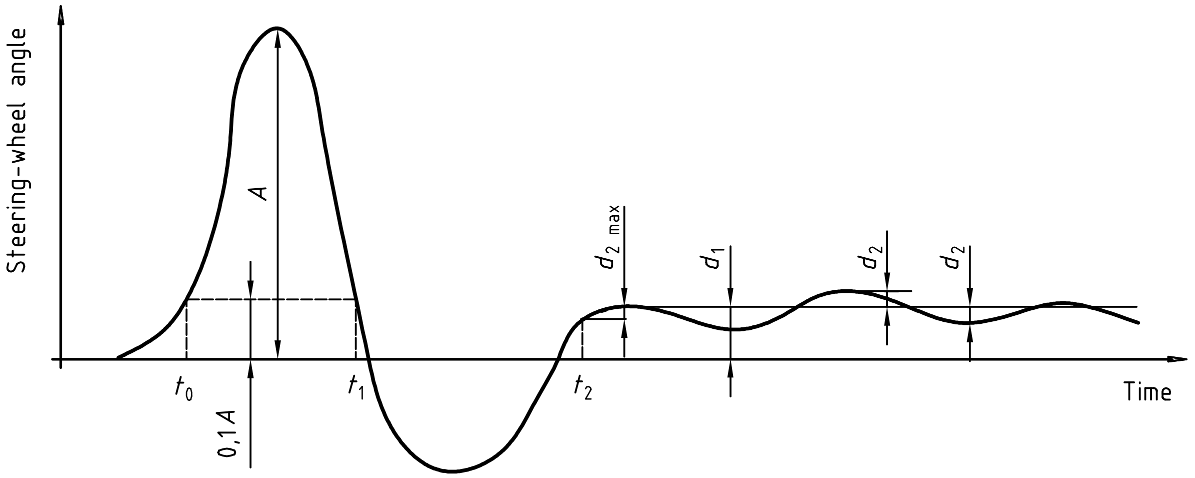
The trailer oscillation shall be initiated by applying a steering impulse of duration equal to or less than 0,6 s to the first vehicle unit. The magnitude of the steering-wheel angle shall be that which produces a maximum lateral acceleration according to 7.3. The steering impulse may be completed by returning the steering wheel directly to its initial position as in Figure 3 a) or by applying a subsequent steering correction in the opposite direction as in Figure 3 b) in order that the first vehicle unit may reapproach its initial path. After the steering impulse and any subsequent correction, the steering wheel shall be held fixed in the straight-ahead position. The duration ($t_2 - t_1$) of any steering correction shall not exceed 1,5 s.

The time, t_2, is defined as the time after which the steering-wheel angle remains within the limits that are imposed by the tolerance demand (i.e. $\pm d_{2\text{max}}$).

Starting from time t_2, the mean deviation, d_1, of the steering-wheel angle from the straight-ahead position shall not exceed ± 10 % of the magnitude of the initial steering impulse. Oscillations (d_2) shall not exceed an additional amount of ± 5 % of the initial steering impulse.



a) **Basic**



b) **With correction**

$t_1 - t_0 < 0{,}6$ s

$t_2 - t_1 < 1{,}5$ s

$|d_1|_{\text{max}} = 0{,}1\ |A|$

$|d_2|_{\text{max}} = 0{,}05\ |A|$

Figure 3 — Steering impulses

8 Data analysis and presentation

8.1 Preliminary analysis

Recorded time histories of the signals shall be displayed and examined visually. Results which do not fulfil requirements on longitudinal velocity and lateral acceleration or are considered not to be representative shall be discarded. The zero values of the signals need to be carefully controlled since there is no easy way to remove any bias in the recording.

8.2 Rearward amplification

8.2.1 General

In the standard test, the rearward amplifications of lateral acceleration and yaw velocity between the first and the last vehicle units are determined. The results from the pseudo-random-input test and the single-lane-change methods differ. A difference between the results from the two single-lane-change methods should also be expected.

8.2.2 Pseudo-random input

A spectral analysis shall be made of the steering-wheel-angle time history. The frequency content shall be adequate. The recommended ratio between maximum and minimum steering-wheel angle in the spectrum shall not be greater than 4:1.

The coherence functions shall also be established. If the vehicle combination is operated in a range where it exhibits linear behaviour and no extraneous noise is present in the signals, the coherence is close to unity. The measurement is acceptable if the coherence is at least 0,95 at frequencies in the vicinity of the maximum rearward amplification.

The gain of the frequency-response functions between the signals of the last and first vehicle units shall be calculated. If a number of short runs have been made instead of one long run, the calculated results can be averaged.

The maximum rearward amplification is the maximum gain. The frequency at which the maximum occurs shall be determined.

The gain, the coherence and the steering-wheel amplitude shall be plotted versus frequency and presented. The resolution bandwidth B_{e}, the measurement time t_{tot} and the record length (time) shall be reported. See annex B.

8.2.3 Single lane-change

The sampled signals are filtered with digital filters having a filter characteristic in accordance with 5.3.3.3.

The maximum values of the signals are determined from their time histories. The maximum value for each vehicle unit is the maximum of the absolute peak values.

The rearward amplification is the maximum value of the last unit divided by the maximum value of the first unit. The value of rearward amplification is computed and stored for each run that has been found to be acceptable. The 95 % confidence interval for the rearward amplification shall be determined for each respective combination of speed and frequency tested. Results shall be presented in the following form.

$$RA_{f,v} = \overline{RA}_{f,v} \pm HI(\overline{RA}_{f,v}) \qquad \text{(95 \% confidence)}$$

where $RA_{f,v}$ is the rearward amplification for the particular combination of speed (v) and frequency (f), $\overline{RA}_{f,v}$ is the mean value of the rearward amplification found for the individual runs at that speed and frequency, and $HI(\overline{RA}_{f,v})$ is half the width of the 95 % confidence interval of that mean (see annex D).

The maximum rearward amplification for a particular speed, $RA_{\max,v}$, is the largest value of $\overline{RA}_{f,v}$, with corresponding confidence interval, determined from tests at that speed over all values of f.

The maximum rearward amplifications shall be determined and reported for all speeds tested, together with confidence intervals and associated time histories (see annex B).

8.3 Offtracking

To determine transient offtracking from the single lane-change, the lateral distance (in the y_E-direction) between the paths of the centre of the front axle and the centre of the most severely offtracking axle of the last unit, is measured. If a single number is given it shall be the maximum offtracking. If the last unit overshoots the path of the first unit, the maximum level of overshoot shall be recorded. If the path of the last unit does not overshoot, the maximum amount of undershoot shall be recorded.

8.4 Zero-damping speed and yaw damping

8.4.1 Damping of articulation-angle oscillation

The sampled signals are filtered with digital filters having a filter characteristic according to 5.3.3.3.

From the time history of articulation angle, or the articulation angular velocity, all amplitudes starting with the third amplitude shall be determined (see Figure 4). If the zero crossing preceding the third amplitude occurs before time t_2 (see 7.6.5), the next amplitude shall be taken as A_1.

The mean value of the amplitude ratios, $\bar{r}$, shall be calculated separately for each articulation joint using the following formula:

$$\bar{r} = \frac{1}{n-2}\left(\frac{A_1+A_2}{A_2+A_3}+\frac{A_2+A_3}{A_3+A_4}+\frac{A_3+A_4}{A_4+A_5}+\ldots+\frac{A_{n-2}+A_{n-1}}{A_{n-1}+A_n}\right)$$

$A_{n\text{-}1} + A_n$ shall be at least 10 % of the $A_1 + A_2$ articulation joint.

The calculation of $\bar{r}$ shall be based upon at least seven amplitudes, unless the 10 % limit is reached before the seventh amplitude.

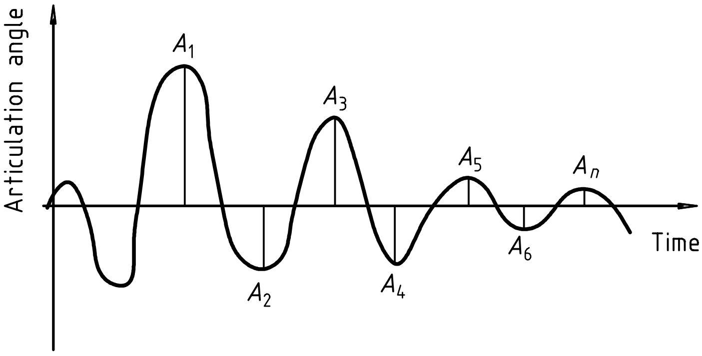


Figure 4 — Determination of amplitude

The damping ratio, D, is calculated according to:

$$D = \frac{\ln(r)}{\sqrt{\pi^2 + \left[\ln(r)\right]^2}}$$

The damping ratio shall be plotted as a function of driving speed. See annex B.

The damping ratio calculated from that articulation joint which gives the lowest damping shall be considered as the damping ratio of the vehicle combination.

8.4.2 Zero-damping speed

The zero-damping speed, v_{zd} (km/h), is defined as the speed at which the yaw damping equals zero. It shall be determined from the plotted values of damping ratio versus test speed by linear curve fitting, through the following regression:

$$D = C_1 + C_2 v_{zd} = 0$$

where C_1 and C_2 (h/km) are the regression coefficients.

$$v_{zd} = -\frac{C_1}{C_2}$$

At least three test runs shall have been performed at a speed of at least 90 % of the zero-damping speed which resulted from the curve fitting (see 7.6.4). If this requirement is not met or if, for safety reasons, driving at 90 % of the zero-damping speed is not feasible, then the zero-damping-speed criterion shall not be used in the presentation of results.

If the test was run in two directions because of a longitudinal slope of the test track, the average of the damping ratio in the two directions shall be used for the linear curve fitting.

8.4.3 Reference-damping speed

Reference-damping speed is defined as the speed at which the yaw-damping coefficient is 0,05. It shall be determined in the same way as the zero-damping speed (see 8.4.2) using the following formula.

$$v_{0,05} = \frac{0{,}05 - C_1}{C_2}$$

8.4.4 Reference-speed damping

Reference-speed damping is defined as the damping at the speed of 80 km/h. It shall be determined according to 7.3 using the following formula.

$$D_{80} = C_1 + 80\, C_2$$

8.5 Yaw-velocity ratio

When the yaw velocity of the vehicle units is measured, calculate the yaw-velocity ratio between the units according to the following formula.

$$R_{t/k} = \frac{1}{n-1}\left(\frac{\Psi_{k,1} + \Psi_{k,2}}{\Psi_{t,1} + \Psi_{t,2}} + \frac{\Psi_{k,2} + \Psi_{k,3}}{\Psi_{t,2} + \Psi_{t,3}} + \ldots + \frac{\Psi_{k,n} + \Psi_{k,n}}{\Psi_{t,n} + \Psi_{t,n}} \right)$$

where

$R_{t/k}$ is the yaw-velocity ratio between the t^{th} and the k^{th} vehicle units;

ψ_k is the yaw velocity of the k^{th} vehicle unit;

ψ_t is the yaw velocity of the t^{th} vehicle unit.

For determination of amplitudes see 8.4.1 and Figure 4.

Annex A
(normative)

General data sheet

Vehicle combination type: ....

Vehicle unit No.: ....

Type of vehicle: ....

Vehicle identification number: ....

Make, year, model, type: ....

Odometer reading: ....

Axle 1 (front): ....

suspension type ....

tyres: ....

make (retread) ....

date ....

size ....

tread depth ....

original tread depth ....

number of wheels ....

track width .... m

rim size ....

steering type (ratio) ....

drive type ....

Axle *n*:

suspension type

tyres:

make (retread) ....

date ....

size ....

tread depth ....

original tread depth ....

number of wheels ....

track width ....m

rim size ....

steering type (ratio) ....

drive type ....

Tyre inflation pressure (kPa):

Cold	Axle 1	Axle *n* ....
Hot, after warm-up	Axle 1	Axle *n* ....
Hot, after test	Axle 1	Axle *n* ....

Distance between axles:

axle 1 – axle 2 ....m

axle (*n*-1) – axle *n* ....m

Distance between axle 1 and rear coupling ....m

Distance between axle 1 and front coupling..m

Height above ground of coupling (in laden condition) .... m

Other data (in particular relevant suspension settings):

....

....

....

....

Vehicle loading conditions:

Vehicle kerb mass

axle 1: left wheel..kg right wheel ....kg

axle *n*: left wheels(s) ....kg right wheel(s) ....kg

Vehicle mass as tested

axle 1: left wheel..kg right wheel ....kg

axle *n*: left wheels(s) ....kg right wheel(s) ....kg

Static load on front coupling of vehicle unit .... N

Static load on rear coupling of vehicle unit .... N

Centre-of-gravity height above ground .... m

Yaw moment of inertia .... kg·m^2

Position of lateral accelerometer:

    height .... m

    distance behind axle 1 / front coupling .... m

Description of pay-load ....

Test conditions:

Test track: ....

    surface description ....

    lateral gradient .... %

    longitudinal gradient .... %

Weather conditions:

    temperature .... °C

    wind velocity .... m/s

    wind heading relative to direction of travel: .... °

Reference point for sideslip angle and lateral velocity: ....

Test methods:

    in time domain ....

    in frequency domain ....

Test personnel:

    driver ....

    observer ....

    data analyst ....

General comments:

....

....

....

....

Annex B
(normative)

Presentation of results

B.1 Rearward amplification

B.1.1 Pseudo-random input

Longitudinal velocity = (km/h)

Resolution bandwidth = (Hz)

Total measurement time = (s) Record length = (s)

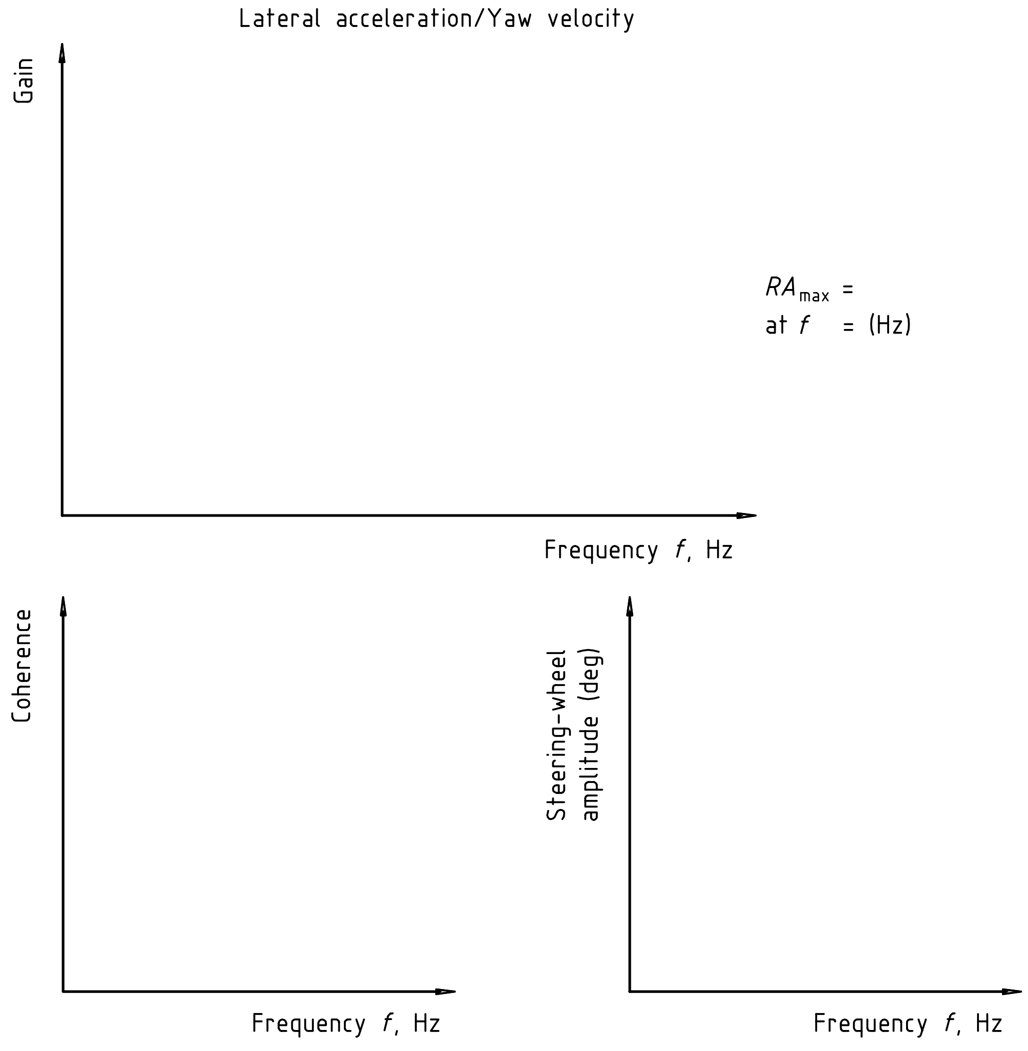


Figure B.1

B.1.2 Single lane-change

Single sine-wave steering input/Path-following lateral acceleration input

Longitudinal velocity =   (km/h)

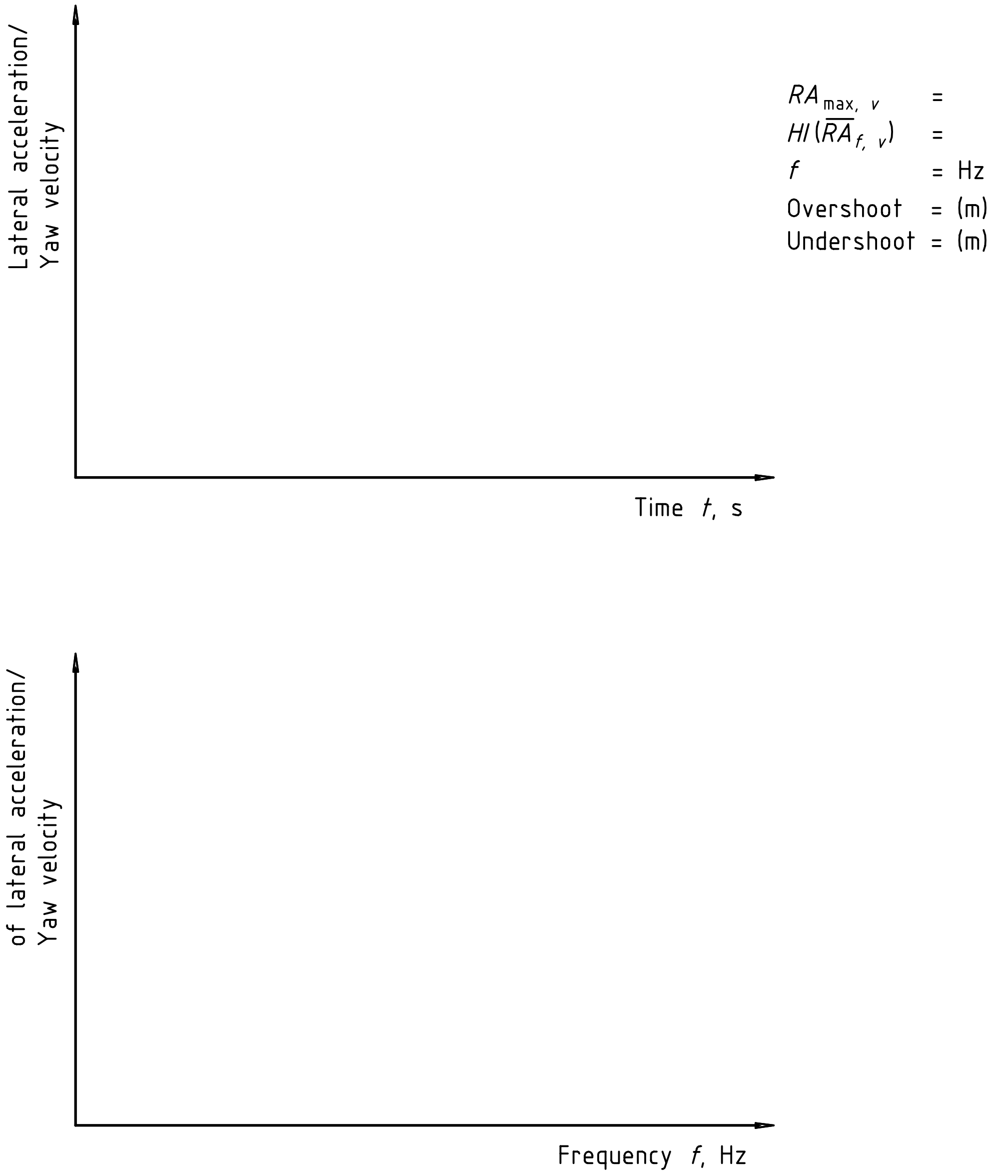


Figure B.2

B.2 Yaw damping

Pulse input

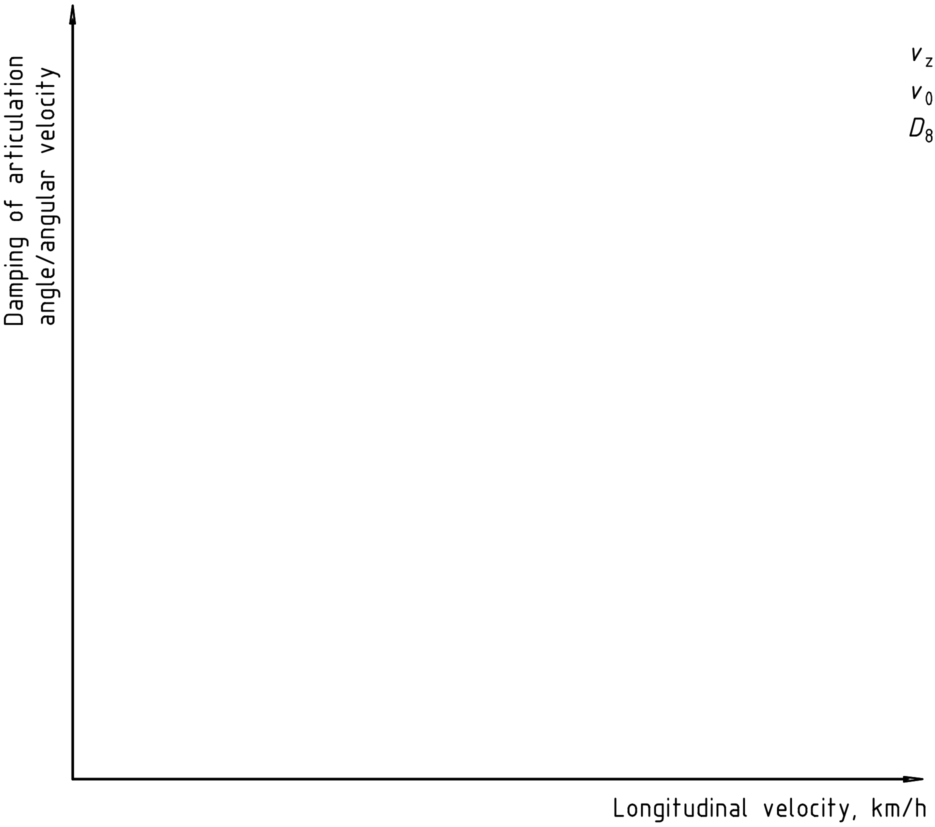


Figure B.3

Annex C
(informative)

Technique and verification for path-following

C.1 General

This appendix describes one very simple method, including "instrumentation", which can be used for (1) aiding the driver in following the precise path required for the path-following single lane-change method and (2) verifying that actual front axle path is within the requirements of the method. The system also allows for measuring the maximum offtracking of the rear axle of the vehicle with respect to the path of the front axle.

C.2 Driving technique

The definition of the test course is given in 7.5.3. For example, the test course may be marked by thin plates according to Figure C.1. Their geometry is associated with instrumentation described in [2] in the Bibliography. The pointed shape of these markers is seen as an aid to the driver in his task of driving the course within the required lateral displacement limits. The lateral dimension of the marker is equal to the allowable lateral position of the first axle of the test vehicle.

The basic instruction given to the test driver is simply to follow this course in a manner such that the path markers pass directly beneath his seat. To aid in this task, the driver is allowed to place visual markers (e.g. tape) on the windshield or elsewhere to help him consistently align the vehicle with the course. The driver is allowed necessary practice to become proficient at following the path.

C.3 Verification

A very simple water spray system is used to mark the path of the first and last axles during the test. The system uses spraying equipment, adapted to provide a stream of water directed onto the pavement from a nozzle mounted on the axle. The system leaves a well-defined water mark on the pavement indicating the path of the axle. With nozzles mounted on the first and last axles, the path of the first axle and the relative displacement (offtracking) of the last axle can be determined. The amount of water sprayed can be adjusted such that the marking lasts long enough to take the necessary measurements, but evaporates soon enough to allow repeated use of the same course without confusion from earlier markings.

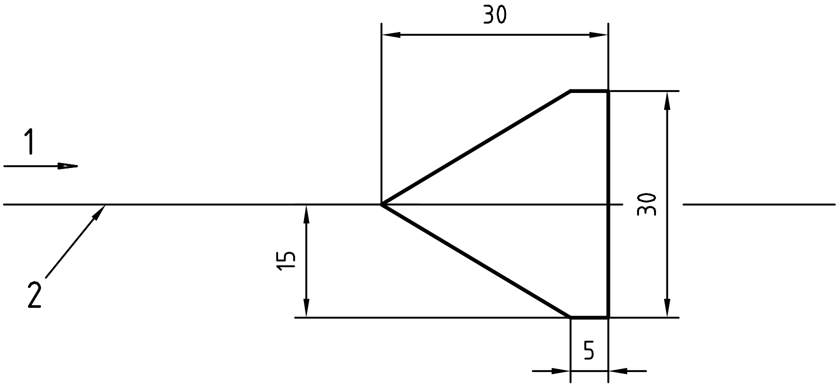
C.4 System hardware

A schematic diagram of the system for one axle is shown in Figure C.2. The system can for example be based on conventional hand-pump garden sprayer hardware.

The tank of the sprayer is modified to provide an air pressure inlet above the waterline. This inlet is fed with regulated pressure, and is also equipped with a safety relief valve to prevent over-pressurizing the tank.

The outlet path can be equipped with an inexpensive electric solenoid valve with push buttons for controlling both front and rear axle solenoids mounted in the cab.

Dimensions in centimetres



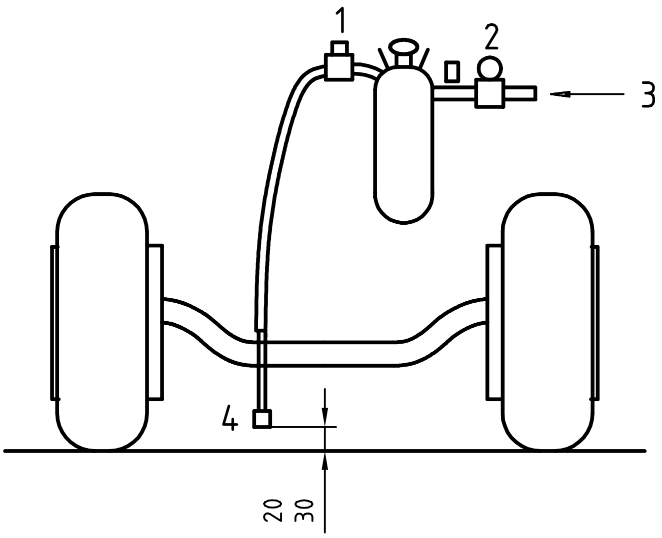
Key

1 Direction of travel

2 Test course

Figure C.1 — Plate used to mark the test course

Dimensions in millimetres



Key

1 Solenoid valve

2 Pressure regulator and safety relief valve

3 Air pressure

4 Nozzle

Figure C.2 — Axle path marker system

C.5 Front-axle system alignment

Alignment of the nozzle used on the front axle is accomplished as follows. In general, the philosophy of the approach is to align the marker system to the driver’s preference in aligning the vehicle on the course, that is, not to burden the driver with any concern about alignment of the marker.

A set of path markers is laid out on the pavement of the test track in a straight line. The driver is instructed to drive the vehicle in a straight line over the markers at low speed until he is satisfied that the vehicle is well aligned over the markers. He is then asked to stop the vehicle directly over a marker, and the water nozzle is adjusted laterally to align with the centre of the marker.

Next, the driver is asked to drive the vehicle over the same straight line set of markers at test speed and to apply the water-mark system in the process. If necessary the lateral position of the nozzle is then adjusted to obtain a condition wherein the water-mark position is centred on the markers.

With this alignment accomplished, a test run is considered valid if the front axle water-mark passes over some portion of each of the course markers.

C.6 Rear-axle system alignment

The use of the term "alignment" here is not exactly correct. "Zero calibration" would be more precise. That is, the approach used to determine offtracking from the first and last axle water-marks is not to attempt to perfectly align the two markers, but rather to determine the offset of the two markers when the vehicle is travelling in a straight line, and to use this dimension as a reference zero condition to correct offset measurements made in dynamic conditions. The method used is as follows.

After alignment of the front-axle nozzle, the lateral position of the rear-axle nozzle is adjusted to be approximately the same as the lateral position of the front-axle nozzle. The driver is then asked to drive the vehicle over the straight-line course at test speed and to apply both water-markers while doing so. This is done several times, and after each pass of the vehicle, the lateral displacement of the rear-axle mark relative to the front-axle mark is measured at several places along the straight-line course. An average value over several runs is used as the reference "zero offset" of the markers.

During subsequent dynamic testing, the peak lateral displacement of the two water-marks is measured immediately after each pass of the vehicle. The oscillatory response of the last unit makes it very easy to determine which mark comes from which axle. Further, the peak lateral displacement is determined, and a longitudinal measurement is also made from that point to a course reference point in order to locate the point of maximum offtracking along the course.

Annex D
(informative)

Calculation of confidence interval for the rearward amplification

The mean value of the rearward amplification for a particular combination of speed and frequency is calculated from

$$\overline{RA}_{f,\,v} = \frac{1}{n}\sum_{i=1}^{n} RA_{f,\,v,\,i}$$

The standard deviation is obtained from

$$S_{f,\,v} = \left[\frac{1}{n-1}\sum_{i=1}^{n}\left(RA_{f,\,v,\,i} - \overline{RA}_{f,\,v}\right)^2\right]^{1/2}$$

Half the width of a 95 % confidence interval of the mean value is

$$HI\left(\overline{RA}_{f,\,v}\right) = t_{95} \cdot S_{f,\,v}$$

where

v is the number of tests conducted at speed, v, and frequency, f;

$RA_{f,v,i}$ is the rearward amplification determined from the i^{th} test conducted at speed, v, and frequency, f

t_{95} is the value of Student’s t for a 95 % confidence interval. Values of t_{95} for n ranging from 3 through 10 are given in the following table:

n	3	4	5	6	7	8	9	10
Values of t_{95}	4,303	3,182	2,776	2,571	2,447	2,365	2,306	2,262

Bibliography

[1] SAE J2179, *A test procedure for evaluating rearward amplification of multi-articulated vehicles*.

[2] Winkler C.B *et al. Heavy vehicle size and weight — Test procedures for minimum safety performance standards*. Final technical report, NHTSA, US DOT, contract DTNH22-87-D-17174. University of Michigan Transportation Research Institute. Report No. UMTRI-92-13. April 1992. 118 pp.

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