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Heavy commercial vehicles — Vehicle stability during tipper body operation — Tilt-table test method

Véhicules utilitaires lourds — Stabilité du véhicule pendant l'utilisation de benne basculante — Méthode d'essai avec table basculante

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. www.iso.org/directives

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 33, *Vehicle dynamics and chassis components*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

A test method is presented for estimating the steady-state rollover threshold of vehicles with a tipper body, using a tilt table device at different inclination angles of the tipper body. Knowledge of a vehicle unit's lateral stability limits during tipping operation is important to prevent rollover, understand operational safety limits, and validate vehicle modelling and design efforts.

Heavy commercial vehicles — Vehicle stability during tipper body operation — Tilt-table test method

1 Scope

This document provides a tilt-table test method for estimating vehicle lateral stability during tipping (or dump) operations. The test method results in a limit curve that creates an envelope of the tipper vehicle unit's rollover threshold, at different tipper body inclinations. This document is applicable to both rear and side tipping vehicles.

This document applies to heavy commercial vehicles and commercial vehicle combinations, as defined in ISO 3833, equipped with rearward or sideways tipping (or dump) bodies (trucks and trailers with maximum weight above 3,5 tonnes, according to ECE and EC vehicle classification, categories N2, N3, O3 and O4).

NOTE The stability envelope can be applied to autonomous construction vehicles.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 15037-2:2002, *Road vehicles — Vehicle dynamics test methods — Part 2: General conditions for heavy vehicles and buses*

ISO 16333:2011, *Heavy commercial vehicles and buses — Steady-state rollover threshold — Tilt-table test method*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8855, ISO 15037-2 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
tipper body
device on a commercial vehicle unit that contains the payload and can be rotated around an axis

Note 1 to entry: Unloading in a tipping operation is performed by tilting the tipper body around its pivot axis until the payload is discharged.

Note 2 to entry: In some countries this term is more commonly known as a dump body.

3.2
tipping hinge
revolute joint between the *tipper body* (3.1) and associated subframe, forming the axis about which the tipper body revolves during a tipping operation

3.3
sideways tipping
tipping operation performed with the *tipper body* (3.1) pivot axis nominally parallel to the x-axis of the vehicle

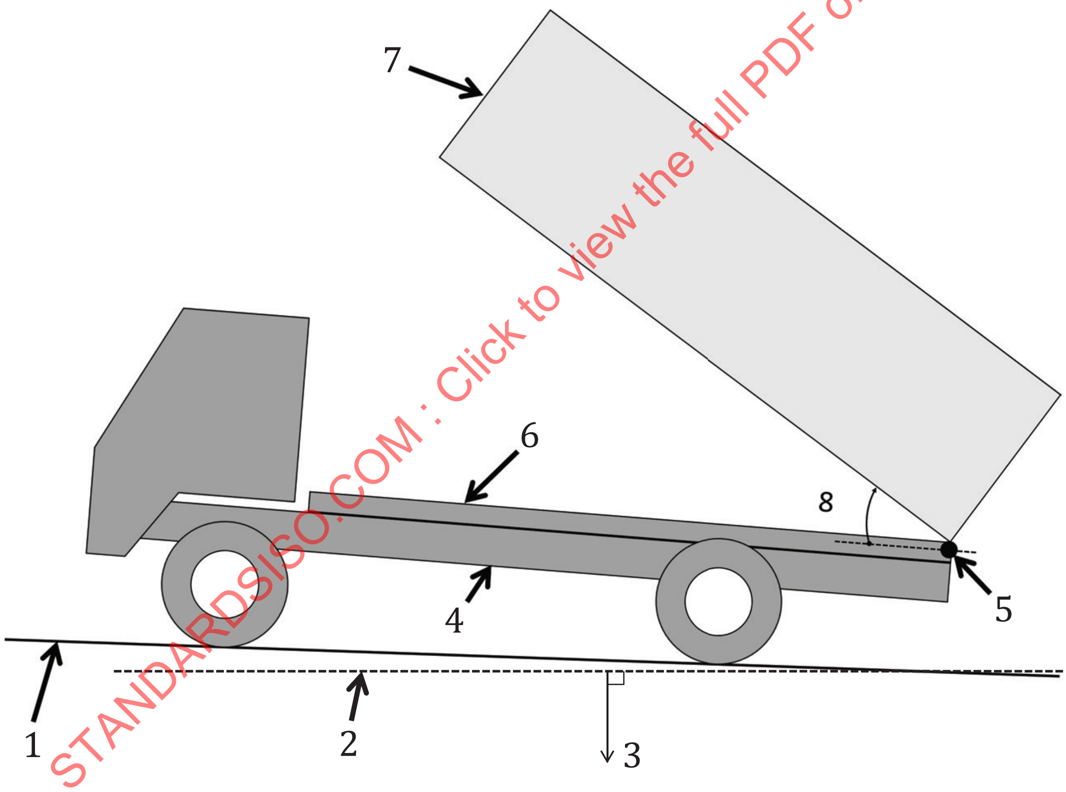
Note 1 to entry: This is principally a roll motion of the tipper body.

3.4
rearward tipping
tipping operation performed with the *tipper body* (3.1) pivot axis nominally parallel to the y-axis of the vehicle

Note 1 to entry: This is principally a pitch motion of the tipper body.

3.5
tipper body pitch angle
θ_B
pitch angle between the chassis frame and the *tipper body* (3.1), to be measured within a distance less than 1 000 mm from the *tipping hinge* (3.2)

Note 1 to entry: See Figure 1.



Key

1 road plane
2 ground plane
3 gravity vector
4 chassis frame
5 tipping hinge
6 subframe
7 tipper body
8 tipper body pitch angle (θ_B)

Figure 1 — Side view of tipper vehicle with rearward tipping

3.6
chassis frame pitch angle
θ_{Ch}
pitch angle between the chassis frame and the ground plane, to be measured within a distance less than 1 000 mm from the *tipping hinge* (3.2)

Note 1 to entry: See Figure 2.

Note 2 to entry: Chassis frame pitch angle includes contributions from *road plane elevation angle* (3.9) (see ISO 8855:2011, 2.7.1), chassis suspension pitch, tyre compression, etc.

3.7
angle of repose
α
steepest angle at which a sloping surface formed of a particular loose material is stable

3.8
global tipper body pitch angle
θ_G
pitch angle between the *tipper body* (3.1) and the ground plane

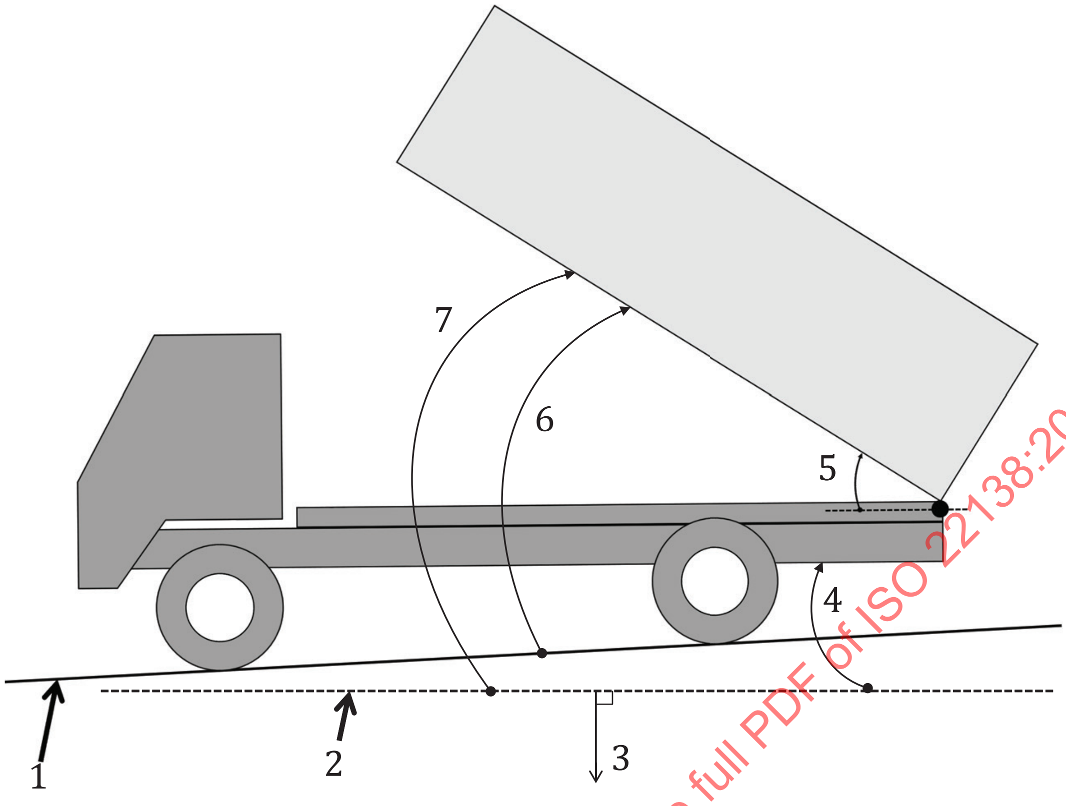
Note 1 to entry: It is calculated as the sum of *chassis frame pitch angle* (3.6) and *tipper body pitch angle* (3.5), which is $\theta_G = \theta_{Ch} + \theta_B$.

Note 2 to entry: See Figure 2.

Note 3 to entry: This angle is influenced by the payload's *angle of repose* (3.7).

3.9
road plane tipper body pitch angle
θ_R
pitch angle between the *tipper body* (3.1) and the road plane

Note 1 to entry: See Figure 2.



Key

1 road plane
2 ground plane
3 gravity vector
4 chassis frame pitch angle (θ_{Ch})
5 tipper body pitch angle (θ_B)
6 road plane tipper body pitch angle (θ_R)
7 global tipper body pitch angle (θ_G)

Figure 2 — Tipper vehicle pitch angles

3.10
tilt table
apparatus for supporting a vehicle on a nominally planar surface and for tilting the vehicle in roll by rotating that surface about an axis nominally parallel to the x-axis of the vehicle

Note 1 to entry: A tilt table is composed of a single structure supporting all tyres of the vehicle on a contiguous surface, alternatively multiple structures supporting one or more axles on separated but nominally coplanar surfaces.

3.11
tilt axis
axis around which the *tilt table* (3.10) rotates, nominally parallel to the x-axis of the vehicle

3.12
tilt angle
ϕ_T
angle between the ground plane and a vector that is in the plane of the *tilt table* (3.10) surface and is perpendicular to the *tilt axis* (3.11)

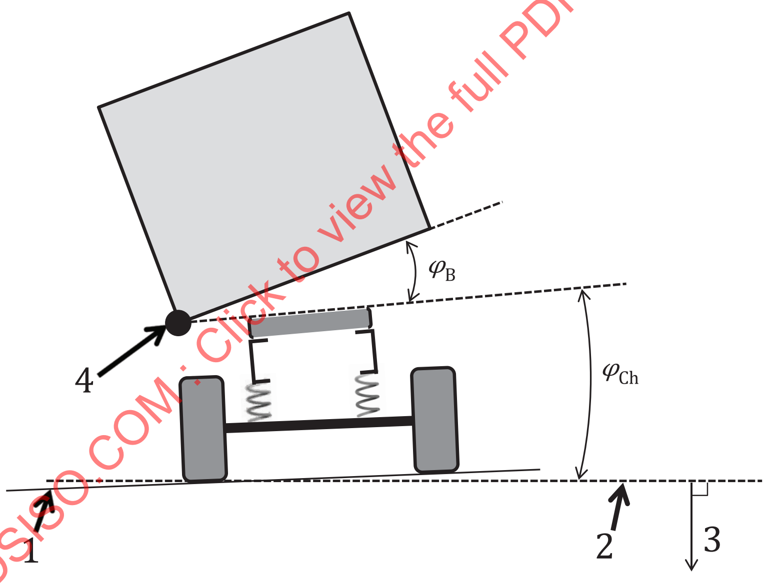
3.13
critical wheel lift
first moment when one or more wheels lifts from the table surface, following which stable roll equilibrium of the vehicle cannot be maintained

3.14
trip rail
rail or kerb fixed to the *tilt table* (3.10) surface and oriented longitudinally beside the low-side wheels when tipping in the vehicles roll direction, to prevent the vehicle from sliding sideways

3.15
critical tilt angle
ϕ_{Tc}
tilt angle (3.12) at *critical wheel lift* (3.13)

3.16
tipper body roll angle
φ_B
roll angle between the chassis frame and the *tipper body* (3.1), to be measured within a distance less than 500 mm from the *tipping hinge* (3.2)

Note 1 to entry: See Figure 3.



Key
1 road plane
2 ground plane
3 gravity vector
4 tipping hinge

Figure 3 — Rear view of sideways tipping vehicle

3.17
chassis frame roll angle
φ_{Ch}
roll angle between chassis frame and the ground plane, to be measured within a distance less than 500 mm from the *tipping hinge* (3.2)

3.18
global tipper body roll angle
φ_G
roll angle between *tipper body* (3.1) and ground plane

Note 1 to entry: It is equal to the sum of *the chassis frame roll angle* (3.17) and the *tipper body roll angle* (3.16) $\varphi_G = \varphi_{Ch} + \varphi_B$.

4 Principle

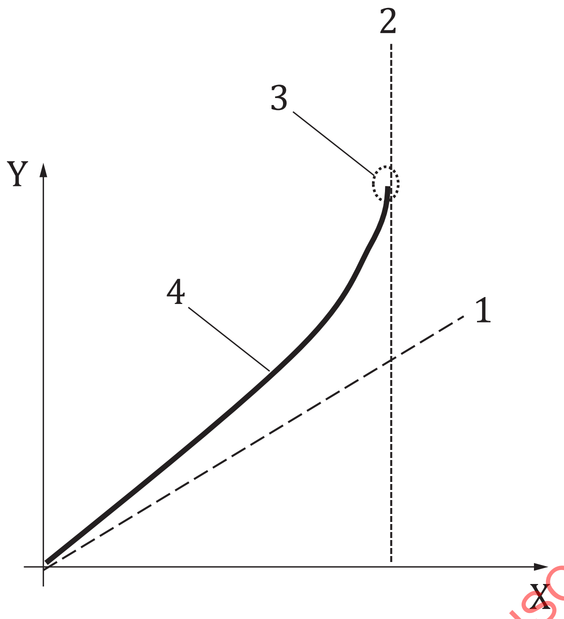
This document specifies a test method for determining vehicle lateral stability during tipping operation. The tipper stability test conducted on a tilt table is a physical simulation of the roll-plane quasi-static response of a tipper vehicle subjected to a roll moment. In real-world operation, the roll moment may result from tipper body use, as well as uneven lateral loading (e.g. generated by uneven discharge during tipping operation), side-slope conditions of the road plane, deformation of the road surface at one wheel, strong side-wind and similar.

In this test method, the tipper vehicle, with a given tipper body pitch or roll angle, is installed on a tilt table with the vehicle's longitudinal axis oriented parallel to the tilt axis. The roll moment is gradually increased by increasing the tilt angle, until the vehicle becomes unstable in roll, as shown in Figure 4. Safety restraints or supports are used to prevent the actual complete rollover of the vehicle. The test is repeated for several tipper body pitch or roll angles, respectively, to generate an envelope of the tipper vehicle's stability performance, both with respect to tipper body angle and tilt angle. In the case of rearward tipping vehicle, the tyres of the first axle should be in contact with the tilt table surface at the start of each test attempt.

As the tilt angle increases during the test, vertical load is gradually transferred from the tyres on one side of the vehicle (high-side) to the other side (low-side). Tyres on the unloaded high-side will eventually lift from the tilt table surface. Typically, wheel lift does not take place simultaneously for all axles. In many cases, lift-off occurs at different tilt angles for each axle. The increase of tilt angle should be stopped simultaneously with the vehicle becoming unstable in roll. Safety restraints or supports should be arranged in such a manner that the roll motion of the vehicle is arrested immediately after critical wheel lift occurs.

ISO 16333:2011, Annex B presents a discussion on the conceptual and practical sources of error when using a tilt table, which are applicable to the test method in this document.

Results from this test method are valid for the conditions present during test execution. During unloading of a tipper vehicle, conditions may vary (wind speed, road surface inclination, payload distribution, etc.), which shall be considered when comparing test results with real-world tipper operation. See Annex C for additional information on the stability envelope of tipper vehicles and a comparison of test results with real life tipper operation.



Key

X tilt angle (ϕ_T)

Y vehicle roll angle

1 rigid body motion

2 critical tilt angle (ϕ_{Tc})

3 instability, critical wheel lift

4 tipper vehicle roll angle

Figure 4 — Vehicle roll angle versus tilt angle

Sufficient knowledge is not available concerning the relationship between overall vehicle dynamic properties and accident avoidance, during tipping operation. A substantial amount of work is necessary to acquire sufficient and reliable data on the correlation between accident avoidance and tipper vehicle stability properties. Consequently, any application of this test method for regulation purposes will require proven correlation between test results and accident statistics.

Body angle and vehicle roll angle sensors are necessary features for autonomous tipping vehicles to safely control or limit tipping operation relative to the envelope of tipper stability.

5 Variables

The variables that shall be determined for conformance with this document are:

— critical tilt angle (ϕ_{Tc}) at each studied tipper body angle (in pitch or roll);

— axle loads as function of tipper body angle (in pitch or roll), on flat and horizontal road surface.

It is recommended that the following variables are also determined:

— tilt angle (ϕ_T) at each individual axle's wheel lift;

— tipper body angle relative to ground plane (see Table B.1);

— chassis frame angle relative to ground plane (see Table B.1).

6 Measuring equipment

The measuring equipment, transducer installation and data processing shall be in accordance with ISO 15037-2. Typical operating ranges of the variables to be determined for this document are shown in Table 1 and in ISO 15037-2.

It is recommended to use inclinometers to determine tipper body pitch and roll angles, or other angular transducers with sufficient accuracy (see Table 1).

Table 1 — Variables, typical operating ranges and recommended maximum errors of variables not listed in ISO 15037-2:2002

Variable	Typical operating range	Recommended maximum errors of the combined transducer and recorder system
Tilt angle	±30°	±0,1°
Maximum tilt-angle variance at axle positions [a]	±0,2°	±0,05°
Maximum heading angle error between vehicle and tilt table axis	±1,0°	±0,5°
Tilt rate	<0,1°/s	0,2 %
Distance	≤2 000 mm	±2 mm
Axle load	(0 to 20) t	±10 kg or ±0,2 %
Tipper body pitch angle	±60°	±0,5°
Chassis frame pitch angle	±10°	±0,5°
Global tipper body pitch angle	±70°	±0,5°
Tipper body roll angle	±60°	±0,5°
Chassis frame roll angle	±10°	±0,5°
Global tipper body roll angle	±70°	±0,5°

[a] Tilt table property.

7 Test conditions

7.1 General

The test conditions described in ISO 15037-2 shall apply to this document. General data of the test vehicle shall be recorded, in applicable parts, as specified in ISO 15037-2 (see Annex A). Test conditions shall be recorded as specified in ISO 15037-2 and ISO 16333 (see Annex A).

The limits and specifications indicated below shall be maintained during the test. Any deviations shall be identified in the test report.

7.2 Tilt table properties

The tilt table shall have the properties given in Table 1. Tilt-angle variance at each vehicle axle during measurements shall not exceed ±0,1°. Maximum tilt-angle variance implies requirements on tilt table stiffness; surface flatness and/or alignment of individual axle tables (see ISO 16333:2011, Annex B). All tests shall be carried out on a hard platform surface with a uniform coefficient of friction. The surface friction shall be sufficient to prevent the vehicle from sliding sideways or a trip rail shall be used (see 8.2.1.2).

7.3 Ambient conditions

Indoor testing is recommended, but outdoor testing is permitted. However, in the outdoor case, wind speeds shall be recorded and reported. Ambient wind speed is recommended to be less than 2 m/s.

NOTE The test results are only valid for low wind speed conditions and tipper operation at higher wind speeds should be handled with care. See Annex C for information on deviations between test conditions and real tipper vehicle usage.

7.4 Test vehicle

7.4.1 General vehicle condition

The test vehicle condition shall be in accordance with the vehicle manufacturer's configuration, particularly with respect to bodywork design, chassis suspension and tyre configuration. The tyre pressure should be set to the recommended pressure for the static tyre load with tipper body down.

If inclination sensors are integrated on-board the vehicle unit, corresponding values shall be recorded throughout test execution and included in the report.

7.4.2 Loading conditions and suspension

The payload shall be secured in such a manner that it cannot move, leak or be discharged. The vehicle should have all its intended equipment mounted during the test.

The suspension should be in normal height position for the intended tipping operation, so the test results are representative of real-world operations. Furthermore, any suspension control system should be active in such a manner that its behaviour represents real-world usage, including temporal effects. The test procedure typically takes longer than real-world operations, given maximum tilt rate limits. Hence, time effects associated with any vehicle control system shall be considered. Any deviation between test and real application behaviour shall be reported.

7.4.3 Fluids

Consumable liquids, such as fuel, should be at the level that yields the most conservative values of the stability performance. Liquid levels elsewise (e.g. hydraulic oil) should be at normal operation level.

8 Test method for rearward tipping vehicle

8.1 Preparation

8.1.1 Measure unladen weight

Measure and record the unladen vehicle weight, so that once the laden vehicle weight is measured the payload weight can be determined by calculation. It is recommended to measure and include individual static axle loads in the test report.

8.1.2 Loading of vehicle

Load the vehicle until the desired test weight is reached for the intended application. The test weight may be equal to the legal weight or the maximum technical weight.

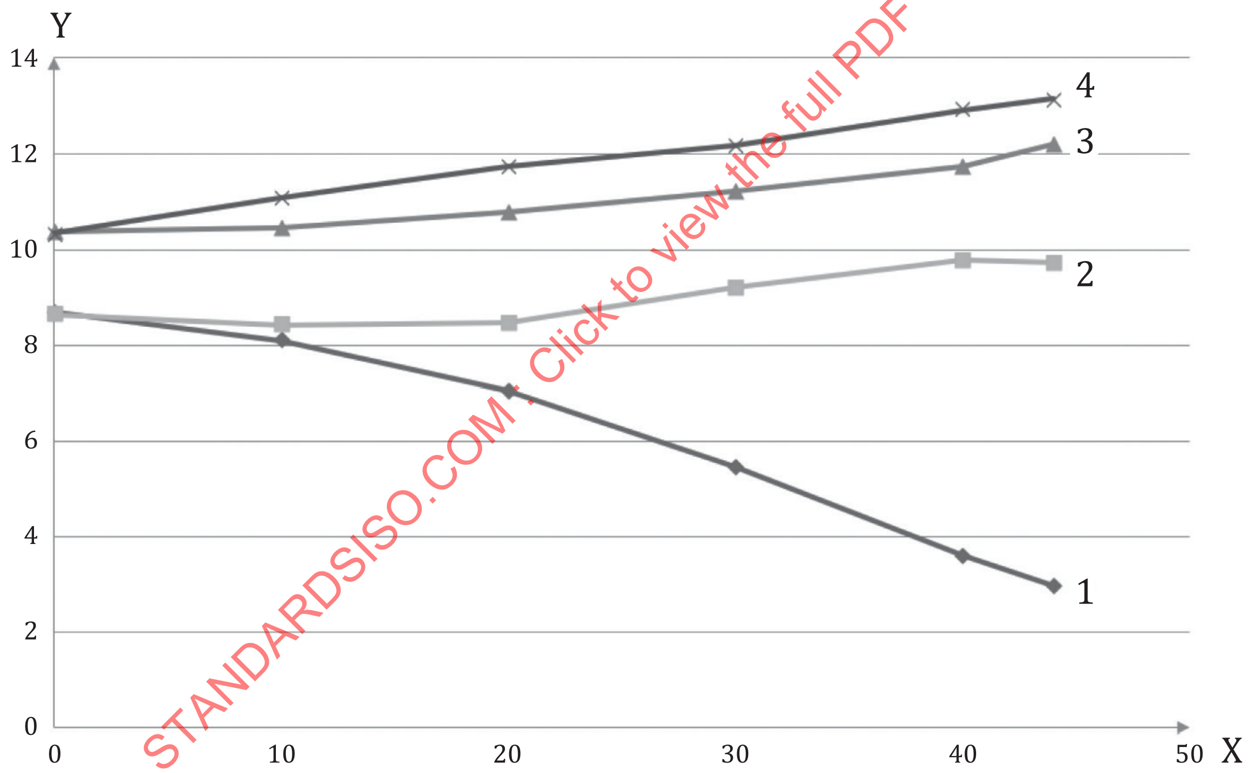
The load shall be equally distributed throughout the tipper body and secured in such a way that it does not move during the test. This will give repeatable and comparable test results, useful for future reference. It will also provide a straightforward comparison of corresponding results from simulations. It is recommended that the loading material density is consistent with the intended application, so the centre of gravity is representative at the given vehicle weight. The angle of repose (3.7) of most materials (sand, gravel, rocks, etc.) subjected to tipping operation is typically less than the maximum tipper body pitch angle. If such material is applied, it is recommended that the load is secured by inserting several temporary bulkheads inside the load container, preventing movement during the test. These bulkheads may, for example, be produced from sheets of plywood or similar.

8.1.3 Measure axle load redistribution due to tipper body pitch angle

The purpose of this measurement is to observe the redistribution of axle loads as a function of the tipper body pitch angle, on a flat and horizontal road surface.

Measure static axle loads of each axle as function of the tipper body pitch angle. Report the results in graphical and tabular form, examples shown in Figure 5 and Table B.2. Measure the axle weights on a flat and horizontal road surface, i.e. with negligible road plane elevation and camber angles. Start with the tipper body down (i.e. at zero degrees tipper body pitch angle), then repeat the axle load measurements at 10° increments of the tipper body pitch angle until the maximum tipper body pitch angle is reached. Check the front axle weight at each increment, to evaluate the risk of vehicle pitch instability at the next test increment. Stop increasing the tipper body pitch angle if instability (zero front axle weight) is likely at the next test increment.

NOTE This measurement also serves as a test to confirm that the vehicle configuration has sufficient pitch stability during rearward tipping.



Key

X tipper body pitch angle [°]

Y axle load [tonne]

1 first axle

2 second axle

3 third axle

4 fourth axle

Figure 5 — Example of axle load as function of tipper body pitch angle, on horizontal road surface

For safety reasons, the front axle load should be sufficient at any given tipper body pitch angle to prevent the vehicle from turning over backwards during the rearward tipping test on a tilt table. It is recommended that a minimum of 5 % gross vehicle weight is present at the front axle at the tipper body pitch angle of current interest, when measured on a horizontal road surface.

It is also recommended to report the corresponding chassis frame pitch angle with each recorded tipper body pitch angle. The tipper body angle related to discharge of payload during tipper operation is related to the angle of response (3.7). Hence the discharge is governed by the global tipper body pitch angle (3.8) and not the road plane tipper body pitch angle (3.9).

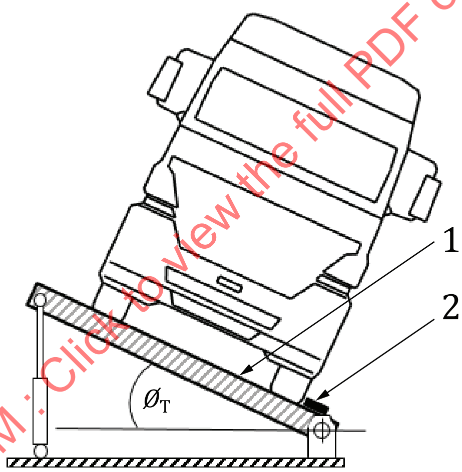
It is recommended that inclinometers are set to record the absolute angle relative to the ground plane.

The various inclinometer measurements may be presented as a table, see Table B.1 for an example.

8.2 Tilt table test procedure

8.2.1 Installation of vehicle on tilt table

Install the test vehicle on the tilt table surface, see Figure 6, according to the procedures in 8.2.1.1 to 8.2.1.6. Any deviation shall be reported.



Key

1 tilt table surface

2 trip rail

Figure 6 — Tilt table

8.2.1.1 Alignment

The X-axis of each test vehicle unit shall be parallel to the tilt table pivot axis within ±1°.

8.2.1.2 Lateral constraint

For the standard test condition, the surface of the tilt table shall be such that tyre friction is adequate to preclude the vehicle sliding sideways at the critical tilt angle. Additional safety restraints should be used to arrest lateral motion in the event that the vehicle would slide sideways on the table surface.

It is recommended that a trip rail is provided immediately adjacent to the low-side tyre of each axle to prevent the vehicle from sliding sideways at high tilt angles. The maximum height of the trip rail shall be either 60 mm or one-third of the height between the wheel rim and the tilt table, whichever is larger. If a trip rail is used, the geometry of the trip rail shall be recorded.

NOTE 1 Table surfaces that achieve friction coefficients approaching unity are available. See ISO 16333:2011, Annex B.

NOTE 2 The use of trip rails can be expected to influence the result of the test by increasing critical tilt angle slightly. See ISO 16333:2011, Annex B.

8.2.1.3 Longitudinal constraint

Longitudinal constraints on the vehicle should be applied at one axle only. When applicable, the transmission shall be in neutral and differential locks shall not be applied. The parking brakes may be applied to constrain the vehicle in the longitudinal direction, unless it is determined that parking brake application will have a significant impact on tipper stability performance.

The normal response of heavy vehicle suspensions during tilt tests typically requires small, but free longitudinal motion of the axles. When individual axle tilt tables are used, care should be taken that such motion can safely take place on the surfaces of the tables.

If a longitudinal constraint is provided by blocking tyres of a steering axle, the steering system should be locked appropriately.

8.2.1.4 Roll restraints

Safety restraints shall be provided that are capable of fully arresting the roll motion of the test vehicle immediately after critical wheel lift occurs. Such restraints may include, but are not limited to, straps attached to the vehicle or tipper body. The restraints will require periodic adjustment as the tilt angle is increased to avoid constraining the vehicle before roll instability is reached. It is recommended that the safety straps be inspected regularly and replaced if any wear or damage is observed.

8.2.1.5 Auxiliary vertical support

Some test vehicles may require auxiliary vertical support at the coupling joint. For example, a centre axle trailer or a semitrailer coupled to a converter dolly requires support of the drawbar at the pintle hitch. In such cases, a mechanism shall be provided that:

a) provides the necessary vertical support in a manner representative of normal use,

b) maintains alignment according to 8.2.1.1, and

c) provides no significant roll coupling at the support point.

8.2.1.6 Suspension condition

It is recommended that prior to each test each suspension of the test vehicle is placed in a nominally neutral trim condition (i.e. with respect to hysteresis resulting from Coulomb friction). This applies to both roll or pitch deformations. Means to return the suspension to the nominal trim condition include, but are not limited to the following.

— Reinstalling the vehicle on the table prior to each test, while rolling the tyres at least a distance equal to their circumference. Check alignment, see 8.2.1.1, after each reinstallation.

— For suspensions with air springs, substantially displacing the suspension vertically by inflating/deflating the air springs equally on left and right sides.

NOTE 1 Initial conditions of hysteresis in the suspensions do not typically have a significant effect on the steady-state rollover threshold of the vehicle. However, initial conditions do influence the behaviour of the vehicle in earlier stages of the tilting process.

NOTE 2 Check that the conditions in 7.4.2 are maintained prior to each test event.

8.2.2 Test execution on tilt table

The critical tilt angle of each tilt test shall be reported, see Table B.3 for an example. It is recommended that each tilt test is repeated at least three times. The number of tilt tests performed at each tipper body pitch angle shall be reported. A test sequence consists of at least one valid tilt test, while observing all conditions specified in this document. The test procedure is repeated for multiple tipper body pitch angle increments, see 8.2.2.3, in order complete a full test series.

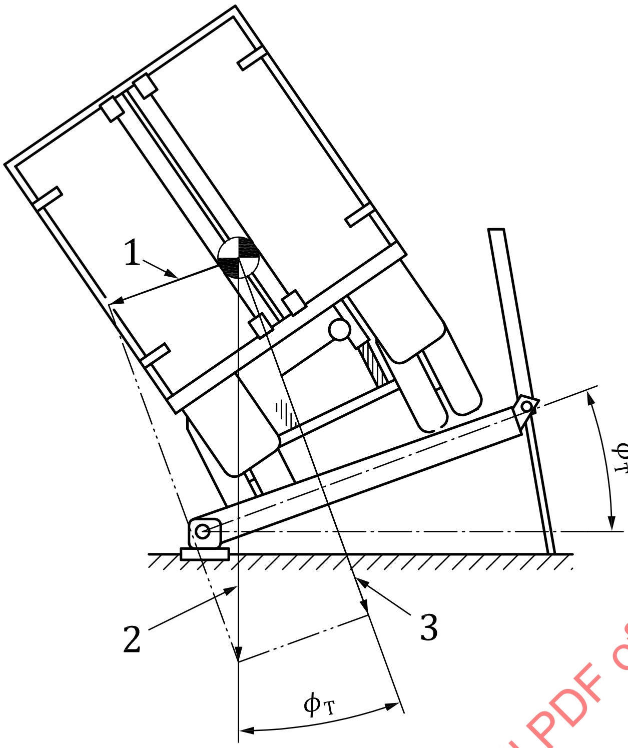
8.2.2.1 Practice trials

Practice trials are recommended prior to testing to ensure proper adjustment of the safety restraints, establish the test sequence, learn when wheel lift and other significant events may take place, and test wheel lift indicator devices if used. Typically, a preliminary tilt would be initiated with safety restraints adjusted in a very conservative manner, e.g. one that would not allow the free roll motion of the vehicle as required during an actual test. The tilt would be proceeded cautiously, with several pauses typically at wheel lift points for readjustment of safety restraints.

8.2.2.2 Tipper body down

Start at the zero-degree tipper body pitch angle condition, i.e. tipper body down and resting on chassis frame. Tests shall be initiated at a tilt angle of (0 ± 0,5)°.

Raise the tilt table slowly and continuously from zero tilt angle until the vehicle becomes unstable. Record the critical tilt angle. The vehicle roll-over point occurs when the direction of the gravitational force vector, from the vehicle centre of gravity, points outside the lower wheel track, see Figure 7 (where m is the mass of the vehicle and g is the gravitational acceleration). The lower the centre of gravity height, the higher the tilt angle will be at tip-up. The tilt rate near the expected tipping point shall not exceed 0,05°/s. During a tilting process it is permissible to stop periodically to adjust safety restraints and to allow the vehicle to settle. However, once stopped do not decrease the tilt angle before continuing the tilting process. Tilting should be stopped as quickly as possible following the critical wheel lift (see 8.2.1.4).



Key

1 simulated centrifugal force = $m \cdot g \cdot \sin(\phi_T)$

2 actual weight = $m \cdot g$

3 simulated weight = $m \cdot g \cdot \cos(\phi_T)$

Figure 7 — Tilt table and centre of gravity of vehicle

Some vehicle frames are more compliant than others, and the upslope tires on different axles may lift from the tilt table surface at different tilt angles. It is recommended to stop tilting momentarily when any one wheel lifts from the platform, to inspect the safety straps. The tilt angles when individual wheels lift may be reported.

Restart tilting slowly until the critical tilt angle is reached. Measurement accuracy may be affected by twisting of the chassis and any such observations should be reported.

Slowly return the tilt table to zero tilt angle. Determine and report the final state of the suspensions. If suspension final conditions vary significantly from initial conditions as a result of malfunctions, such as air system leaks, the malfunctions shall be corrected and the test shall be repeated.

8.2.2.3 Tilt test at incremental steps of tipper body angle

Perform tilt tests, following the procedures described in 8.2.2.2, for 10° incremental steps of the tipper body pitch angle, see Table B.3. The vehicle should be driven off and back onto the tilt table between each increment in tipper body pitch angle, to release any hysteresis of the suspension and body mounts. The test series shall be ended with a tilt test at the maximum tipper body pitch angle, if possible.

Following each test increment, inspect the tipper body and tipping hinge mechanism for any damage or mechanical deformation. Any deviation shall be reported. Terminate the test series if significant or unsafe deformation is observed.

Tilt tests shall be conducted in each the vehicle roll direction (i.e. both with left and right track on the tilt table low-side), if there is reason to suspect any significant difference in critical tilt angles.

9 Test method for sideways tipping vehicle

9.1 Preparation

9.1.1 Measure unladen weight

Measure and record the unladen vehicle weight, so that once the laden vehicle weight is measured the payload weight can be determined by calculation. It is recommended to measure and include individual static axle loads in the test report.

9.1.2 Loading of vehicle

Load the vehicle until the desired test weight is reached for the intended application. The test weight may be equal to the legal weight or the maximum technical weight.

The load shall be equally distributed throughout the tipper body and secured in such a way that it does not move during the test. This will give repeatable and comparable test results, useful for future reference. It will also provide a straightforward comparison of corresponding results from simulations. It is recommended that the loading material density is consistent with the intended application, so the centre of gravity is representative at the given vehicle weight. The angle of repose (3.7) of most materials (sand, gravel, rocks, etc.) subjected to tipping operation is typically less than the maximum tipper body roll angle. If such material is applied, it is recommended that the load is secured by inserting several temporary bulkheads inside the load container, preventing movement during the test. These bulkheads may, for example, be produced from sheets of plywood or similar materials.

9.1.3 Measure axle load redistribution due to tipper body roll angle

The purpose of this measurement is to observe the redistribution of axle loads as a function of the tipper body roll angle, on a flat and horizontal road surface.

Measure static axle loads of each axle as function of the tipper body roll angle. Report the results in graphical and tabular form, similar to examples shown in Figure 5 and Table B.2 but with roll angles instead of pitch angles. Measure the axle weights on a flat and horizontal road surface, i.e. with negligible road plane elevation and camber angles. Start with the tipper body down (i.e. at zero-degree tipper body roll angle), then repeat the axle load measurements at 10° increments of the tipper body roll angle until maximum tipper body roll angle is reached. Check the sum of wheel load on the track which is subject to load decrease, at each increment, to evaluate the risk of vehicle roll instability at the next test increment. Stop increasing the tipper body roll angle if instability (zero track weight) is likely at the next test increment.

It is also recommended to report the corresponding chassis frame roll angle with each recorded tipper body roll angle.

It is also recommended that inclinometers are set to record the absolute angle relative to ground plane.

The various inclinometer measurements may be presented as a table.

9.2 Tilt table test procedure

9.2.1 Installation of vehicle on tilt table

Install the test vehicle on the tilt table surface, according to 8.2.1. Any deviation shall be reported. The vehicle shall be positioned with the track subjected to load increase (as function of tipper body roll angle) on the low-side of the tilt table.

9.2.2 Test execution on tilt table

The critical tilt angle of each tilt test shall be reported. See Table B.3 for an example (adjust the example to tipper body roll angle). It is recommended that each tilt test is repeated at least three times. The number of tilt tests performed at each tipper body roll angle shall be reported. A test sequence consists of at least one valid tilt test, while observing all conditions specified in this document. The test procedure is repeated for multiple tipper body roll angle increments, see 9.2.2.3, to complete a full test series.

9.2.2.1 Practice trials

See 8.2.2.1 for recommendations on practice trials prior to testing.

9.2.2.2 Tipper body down

Start at the zero-degree tipper body roll angle condition, i.e. tipper body down and resting on chassis frame. Tests shall be initiated at a tilt angle of (0 ± 0,5)°.

Raise the tilt table slowly and continuously from zero tilt angle until the vehicle becomes unstable. Record the critical tilt angle. The tilt rate near the expected tipping point shall not exceed 0,05°/s. During a tilting process it is permissible to stop periodically to adjust safety restraints and to allow the vehicle to settle. However, once stopped do not decrease the tilt angle before continuing the tilting process. Tilting should be stopped as quickly as possible following critical wheel lift (see 8.2.1.4).

Some vehicle frames are more compliant than others, and the upslope tires on different axles may lift from the tilt table surface at different tilt angles. It is recommended to stop tilting momentarily when any one wheel lifts from the platform, to inspect the safety straps. The tilt angles when individual wheels lift may be reported.

Restart tilting slowly until the critical tilt angle is reached. Measurement accuracy may be affected by twisting of the chassis and any such observations should be reported.

Slowly return the tilt table to zero tilt angle. Determine and report the final state of the suspensions. If suspension final conditions vary significantly from initial conditions as a result of malfunctions, such as air system leaks, the malfunctions shall be corrected and the test shall be repeated.

9.2.2.3 Tilt test at incremental steps of tipper body angle

Perform tilt tests, following the procedures described in 9.2.2.2, for 10° incremental steps of the tipper body roll angle. The vehicle should be driven off and back onto the tilt table between each increment in tipper body pitch angle, to release any hysteresis of the suspension and body mounts. The test series shall be ended with a tilt test at the maximum tipper body roll angle, if possible.

Following each test increment, inspect the tipper body and tipping hinge mechanism for any damage or mechanical deformation. Any deviation shall be reported. Terminate the test series if significant or unsafe deformation is observed.

For vehicles able to perform sideways tipping both to the left and the right, tilt tests shall be conducted in each tipping direction, if there is reason to suspect any significant difference in critical tilt angles.

10 Data evaluation and presentation of results

10.1 General

Test vehicle and test conditions shall be presented in the test report in accordance with ISO 15037-2 and Annex A. Each change in vehicle equipment or condition (e.g. different loading conditions) shall be documented.

10.2 Characteristic values

Characteristic values shall be reported in tabular form. See Table B.3 for an example.

It is also recommended that test results are presented as graphically in the test report. A graphical example of test results is shown in Figure B.1 (compare with Table B.4).

Annex A
(normative)

Test report – General data and test conditions

A.1 General data

The test report for general data shall be as given in ISO 15037-2:2002, Annex A.

A.2 Test conditions

The test report for test conditions shall be as given in ISO 16333:2011, Annex A (including ISO 15037-2:2002, Annex B).