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Self-propelled agricultural machinery — Assessment of stability —

Part 2: Determination of static stability and test procedures

Machines agricoles automotrices — Évaluation de la stabilité —

Partie 2: Détermination de la stabilité statique et modes opératoires d'essai

Reference number
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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 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 23, *Tractors and machinery for agriculture and forestry*, Subcommittee SC 3, *Safety and comfort*.

ISO 16231 consists of the following parts, under the general title *Self-propelled agricultural machinery — Assessment of stability*:

— *Part 1: Principles*

— *Part 2: Determination of static stability and test procedures*

Introduction

Self-propelled agricultural machinery with a ride-on operator (driver) can be exposed to the hazard of rolling or tipping over during the intended operation. A risk assessment is used to determine whether this hazard is to be considered in case of a specific machine and the protective measures to be used in order to avoid or minimize this hazard for the ride-on operator.

The risk assessment considers the operating conditions in which the machine is intended to be used, the physical properties of the machine, and the required skills to operate the machine as well as any other parameter which can have an impact on the risk for roll- or tip-over.

Self-propelled agricultural machinery — Assessment of stability —

Part 2:
Determination of static stability and test procedures

1 Scope

This part of ISO 16231 specifies a method to determine the centre of gravity of un-laden self-propelled machines, a method to determine the centre of gravity of laden machines and combinations with attachments, and methods to determine the static overturning angle.

NOTE Requirements related to self-protective structures and ROPS are to be dealt with in a separate International Standard.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 789-6, *Agricultural tractors — Test procedures — Part 6: Centre of gravity*

ISO 16231-1, *Self-propelled agricultural machinery — Assessment of stability — Part 1: Principles*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16231-1 and the following apply.

3.1
maximum operating slope
MOS
value indicating, for each type of self-propelled machine and each direction, the maximum slope in (%) on which the machine is intended to work according to good agricultural practice

3.2
slope compensation system
system to improve the functional performance of an agricultural machine working on slopes, without levelling the main body of the machine, such as a levelling of internal components, adjusting the kinematics of separating systems, or adjusting air flow or pattern or both

3.3
body levelling system
system to improve the function performance, drivers comfort, ability to work on slopes, and stability of an agricultural machine working on slopes, by means of levelling the main body of the machine in a longitudinal or transversal sense or a combination of both

4 Determination of the centre of gravity (COG) of a self-propelled machine

4.1 Method to determine and to calculate the centre of gravity of the un-laden machine

The centre of gravity of the un-laden machine is determined by means of scales and support stands (see Tables 1 and 2 and Figures 1, 2, and 3).

4.2 Remarks and items to observe during this procedure

4.2.1 Follow the procedure as outlined in ISO 789-6; this method is based on the increasing load on the supporting axle when the other axle is lifted and supported on a certain height; the lifting angle ω and the increased load on the scale allow determination of the height of the COG.

4.2.2 It is recommended to use steel wheels in order to avoid deviations due to changing wheel radius under changing load conditions. For calculation of the COG with the actual tires, see 4.3.

Any suspension system shall be locked. If locking the suspension system is not possible, then inflate all tires up to the maximum permissible pressure as specified by the tyre manufacturer. The difference in radius of the wheels on the fixed axle between horizontal and raised position shall not be higher than 1,5 % of the wheel radius.

4.2.3 Ensure that the plane of the scale is horizontal and flush with the ground plane.

4.2.4 Wheels on the scale shall be free to rotate, in order to exclude tangential forces on the tires. Therefore, the parking brake shall not be applied and the gearbox shall be in neutral or the transmission shall be in the position for towing the vehicle.

4.2.5 Although not required, lifting the side of the swivelling axle is preferred; in most cases, this is the axle with the smallest diameter wheels.

4.2.6 Raised wheels shall rest on wheel stands before reading the weight on the scale.

4.2.7 For easy installation of the wheel stands, it can be necessary to lock the swivelling axle with wedges when lifting the machine.

When resting on the wheel stands, the wedges shall be removed.

4.2.8 The accuracy of this method depends on the height of wheel stand as a proportion of the wheel base and the accuracy of the scale.

Accuracy of weighing during five consecutive measurements: all values shall fall within a range of 1,0 % of the maximum measured load from the fixed axle in raised position.

4.2.9 Calculate the COG, using the ± deviation of the accuracy of the scale and determine the deviation of the height of the COG.

This deviation shall not exceed ±4 %. In case the value exceeds ±4 %, the height of the wheel stands shall be increased in order to decrease the deviation.

Table 1 — Input data for calculation of centre of gravity(COG)

Data description	Symbol	Unit
Static load radius wheel fixed axle (see Figure 2)	R	mm
Static load radius wheel swivelling axle (raised axle) (see Figure 2)	r	mm
Wheel base (see Figure 1 top view)	W	mm
Load on left wheel fixed axle in horizontal position (see Figure 1 rear/front view)	F_{fl}	daN
Load on right wheel fixed axle in horizontal position (see Figure 1 rear/front view)	F_{fr}	daN
Load on swivelling axle in horizontal position (see Figure 1 rear/front view)	F_{sw}	daN
Load on fixed axle in raised position (swivelling axle supported on stand) (see Figure 3)	F_{far}	daN
Height of stand (see Figure 3)	L	mm
Distance between outer edges of tires on fixed axle (see Figure 1 top view)	o	mm
Width of tires on the fixed axle (see Figure 1 top view)	p	mm
Lateral offset of the swivelling axle pivot point (to the right is positive) (see Figure 1 top view)	a	mm

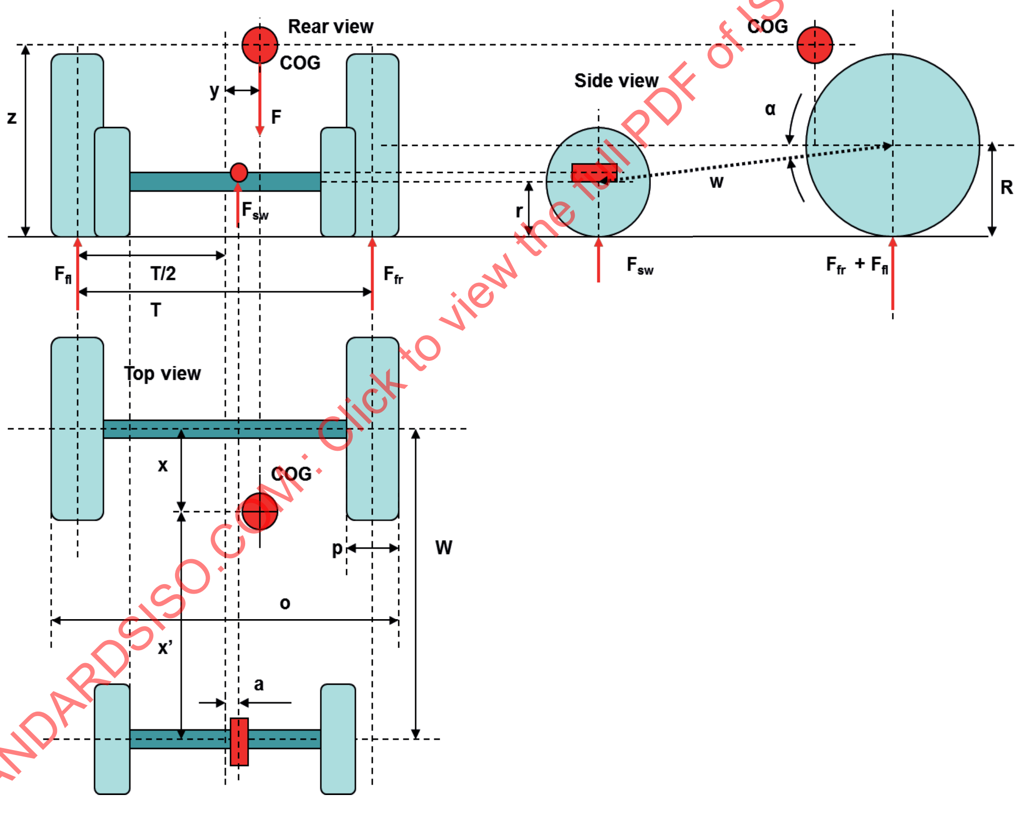

Figure 1 — Rear, top, and side view of the machine

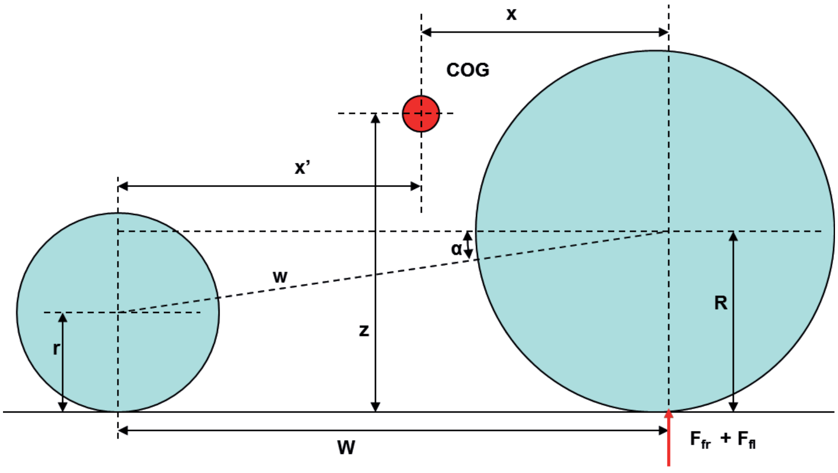

Figure 2 — Machine in horizontal position — Side view

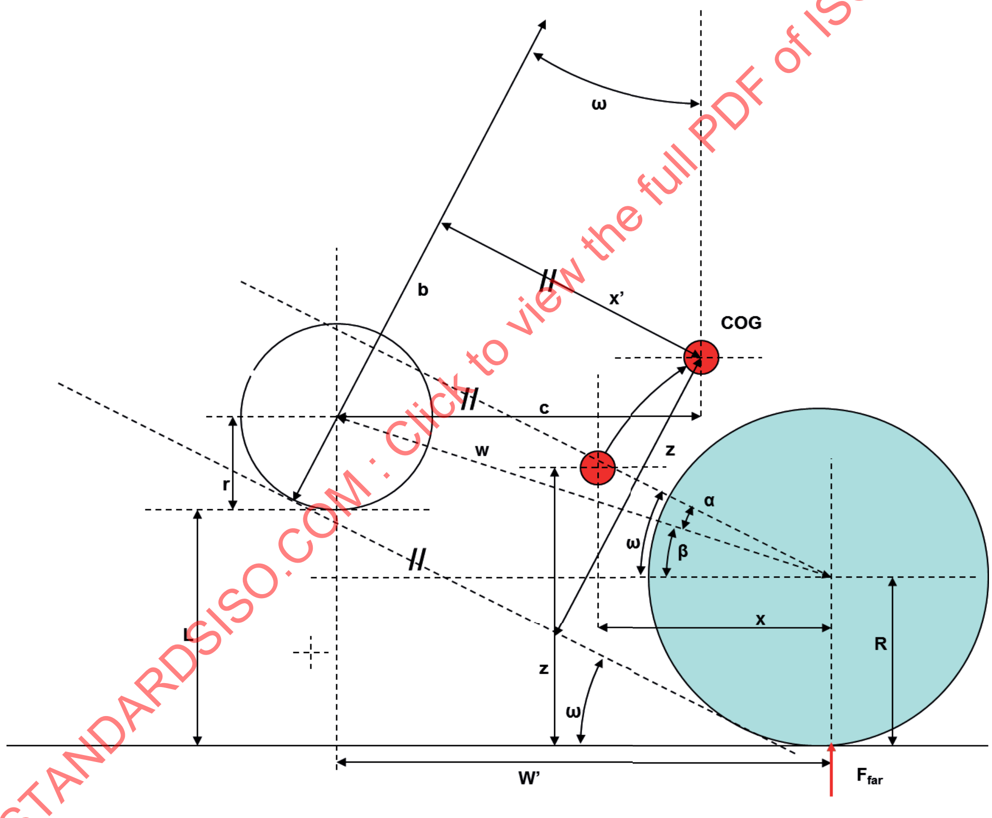

Figure 3 — Machine in raised position — Side view

Table 2 — Calculation of centre of gravity(COG)

Data description	Symbol	Unit	Calculation
Wheel track of fixed axle	T	mm	o – p
Total weight of the machine	F_t	daN	$F_{fr} + F_{fl} + F_{sw}$
Lateral position of COG (versus centre of fixed axle) (positive number means right from centre of fixed axle in Figure 1)	y	mm	$[(F_{fr} * T) + (T/2 + a) * F_{sw}] / F_t - T/2$
Longitudinal position of COG (versus centre line of swivelling axle)	x’	mm	$W * (F_{fr} + F_{fl}) / F_t$
Longitudinal position of COG (versus centre line of fixed axle)	x	mm	W - x’
Longitudinal distance between wheel centres	w	mm	$\sqrt{((R - r)^2 + W^2)}$
Vertical projection of wheel base in raised position	W’	mm	$\sqrt{(w^2 - (L + r - R)^2)}$
Angle formed by the line between wheel centres and horizontal through the centre of the fixed axle wheels	α	°	$\cos^{-1} (W / w)$
Angle formed by the line between wheel centres and horizontal through the centre of the fixed axle wheels in raised position	β	°	$\tan^{-1} ((L + r - R) / W')$
Lifting angle	ω	°	α + β
Vertical projection of longitudinal distance between COG and the swivelling axle in raised position	c	mm	$F_{far} * W' / F_t$
Auxiliary line for calculation (see Figure 3)	b	mm	r + (c / sin ω)
Height of COG	z	mm	b – (x’ / tan ω)

NOTE An example of calculation of centre of gravity is given in Annex A

4.3 Methods to determine the centre of gravity of a laden machine or a machine with attachments

4.3.1 Graphical method

4.3.1.1 Because weighing a laden machine with attachments under an angle is not practical and can be unsafe, it is advisable to determine the COG of the laden machine by means of a graphical method.

It is assumed that the weight and the COG of the load (e.g. grain) and the attachment(s) are known.

4.3.1.2 The following example shows a combine harvester with full grain tank and a header in the raised position (worst case field condition).

The COG of the empty machine is known (e.g. by the procedure 4.1) and marked on the scaled drawing of the machine as cog_a (see Figure 4). The COG of the grain in the tank can be defined graphically as cog_b. The mass of the grain represents, for instance 50% of the empty weight of the machine. The COG of the combination empty machine and grain load is marked as cog_d and falls on the line between cog_a and cog_b at 1/3 from cog_a. The mass of the header is, for instance, 20% of the empty mass of the machine. The COG of the attachment marked as cog_c is known (e.g. by weighing on a hoist under two angles). The COG of the combination empty machine and attachment falls on the line between cog_a and cog_c at 1/6 from cog_a. The COG of the combination loaded machine and attachment can be determined in a similar way. The height and the longitudinal position of the new COG can now be measured on the drawing. The same principles apply to determine the new lateral position (y) of the COG.

Example:

Table 3 — Input data for calculation of centre of gravity

Data description	Symbol	Unit	Example
Weight of the empty machine	m_a	daN	12 000
Weight of the grain	m_b	daN	6 000
Weight of the header	m_c	daN	2 400
Centre of gravity of the empty machine	cog_a	mm (x, z)	- - -
Centre of gravity of the grain	cog_b	mm (x, z)	- - -
Centre of gravity of the header	cog_c	mm (x, z)	- - -
Common centre of gravity of empty machine and grain	cog_d	mm (x, z)	- - -
Common centre of gravity of empty machine and header	cog_e	mm (x, z)	- - -
Common centre of gravity of empty machine, header, and grain	cog_f	mm (x, z)	- - -
Distance between cog_a and cog_b	k	mm	1 500
Distance between cog_a and cog_c	n	mm	3 600

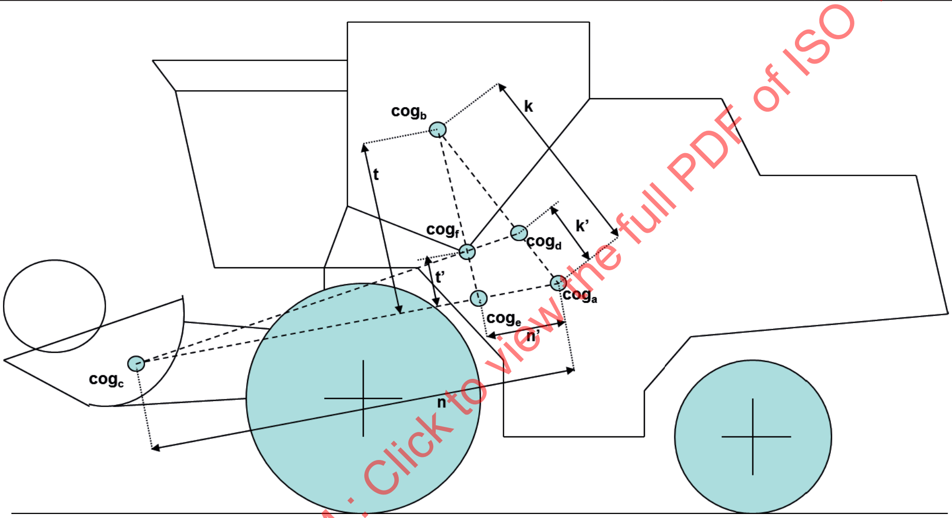

Figure 4 — Machine with attachment — Side view

Table 4 — Determination of the common centre of gravity — Graphical method

Data description	Symbol	Unit	Determination	Example
Weight exerted by common COG of empty machine and grain	m_{a+b}	daN	$m_a + m_b$	18 000
Distance between cog_a and cog_d	k'	mm	$(m_b*k)/(m_a+m_b)$	500
Weight exerted by common COG of empty machine and header	m_{a+c}	daN	$m_a + m_c$	14 400
Distance between cog_a and cog_e	n'	mm	$(m_c * n) / (m_a + m_c)$	600
Weight exerted by common COG of empty machine, grain and header	m_{a+b+c}	daN	$m_a + m_b + m_c$	20 400
Distance between cog_e and cog_b	t	mm	measured on the drawing	1 374
Distance between cog_e and cog_f	t'	mm	$(m_b * t) / (m_{a+c} + m_b)$	404

4.3.2 Mathematical method

NOTE A calculation sheet for determination of the common centre of gravity (COG), the static overturning angle (SOA) and the required static stability angle (RSSA) can be found at http://standards.iso.org/iso/16231-2/ed-1/.

$$x \frac{1}{M} \sum_{i=1}^{n} m_i * x_i \tag{1}$$

$$y \frac{1}{M} \sum_{i=1}^{n} m_i * y_i \tag{2}$$

$$z \frac{1}{M} \sum_{i=1}^{n} m_i * z_i \tag{3}$$

Table 5 — Determination of the common centre of gravity — By calculation

Description	Symbol	Unit	Calculation	Example
Weight of the empty machine	m_a	daN		12 000
Weight of the grain	m_b	daN		6 000
Weight of the header	m_c	daN		2 500
Horizontal distance from front axle centre to cog_a	x_a	mm		1 250
Horizontal distance from front axle centre to cog_b	x_b	mm		1 000
Horizontal distance from front axle centre to cog_c	x_c	mm		−1 500
Vertical distance from front axle centre to cog_a	z_a	mm		1 500
Vertical distance from front axle centre to cog_b	z_b	mm		2 500
Vertical distance from front axle centre to cog_c	z_c	mm		1 000
Total weight of the combination	M	daN	$m_a + m_b + m_c$	20 500
Horizontal distance from front axle centre to cog_f	x_f	mm	$((m_a * x_a) + (m_b * x_b) + (m_c * x_c)) / M$	841
Vertical distance from front axle centre to cog_f	z_f	mm	$((m_a * x_a) + (m_b * x_b) + (m_c * x_c)) / M$	1 692

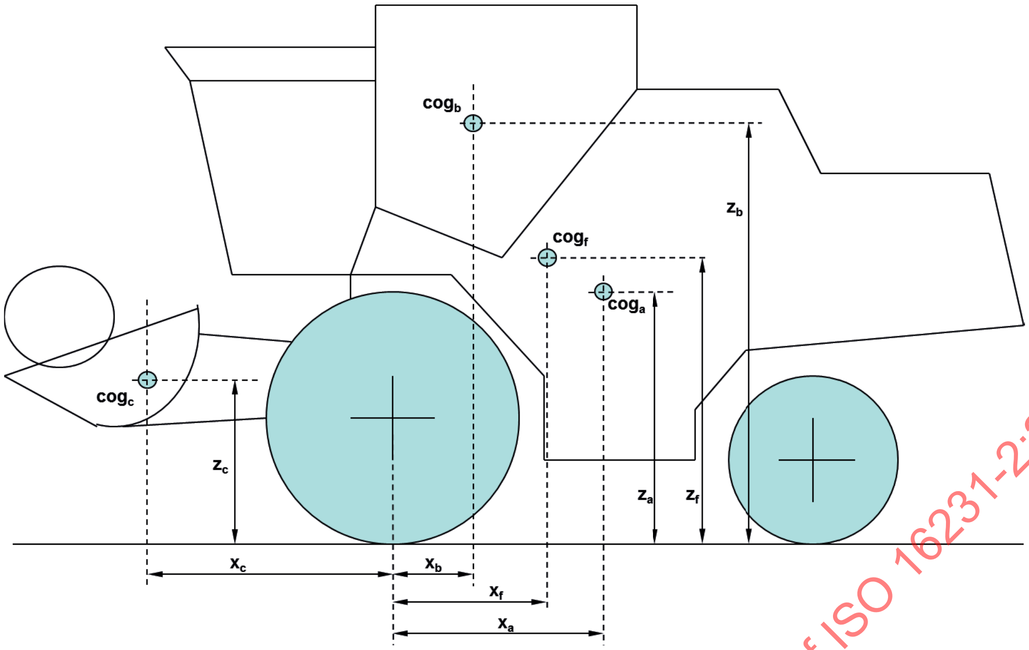

Figure 5 — Combined COG – by calculation

5 Static overturning angle (SOA)

5.1 General

The machine shall be equipped and adjusted for work and can be evaluated laden or unladen, depending on which condition provides the highest centre of gravity, in any operating configuration.

5.2 Lateral roll-over: Machines with one fixed and one swivelling axle (without axle swivel limiting device)

5.2.1 General

5.2.1.1 In order to keep continuous contact between the wheels and the ground, many self-propelled machines have one swivelling and one fixed axle.

This concept shall be taken into account when determining the SOA. For the purpose of this part of ISO 16231, it is assumed that the rolling line of the tyres on the fixed axle, when rolling laterally, is defined at 75 % of the tire width.

5.2.1.2 The stability triangle is formed by the lines AB, BC, and AC (Figure 6).

When placed on a tilt platform, the machine reaches, then exceeds the static overturning angle SOA, and rolls over when the vertical projection of the centre of gravity COG falls outside the surface formed by triangle ABC, where:

— A and C are the rolling points under the tires on the fixed axle, defined by the intersection of the lines AB and BC and the vertical projection of the fixed axle centreline,

— B is the intersection of the line through the COG and the pivot point of the swivelling axle and the ground surface. The worst case orientation of a machine for rolling over on a tilt platform is the orientation with the minimal distance between the COG and line AB. This is a plane perpendicular to line AB in which the COG moves during tilting. This means that the machine on the tilt platform shall be installed in a position where the line AB is parallel with the articulation of the tilt platform.

In a field condition, this means that the machine is running not parallel with the slope but slightly hill up. The height of the COG and the height of the pivot point of the swivelling axle are defining point B. The stability triangle is getting better with increased height of the pivot point or lower and more forward COG.

NOTE In the hypothetical case, where this pivot point could be designed at the height of the COG, the triangle would become a rectangle, and the vehicle would roll over only when the projection of the COG would exceed the line formed by the contact points of the front and the rear tire.

5.2.2 Graphical determination of the stability

5.2.2.1 A graphical method can be used to determine the SOA. The worst case side shall be considered. In case of doubt, both left hand (LH) and right hand (RH) rolling shall be evaluated. Figure 6 shows a top and lateral view of a vehicle with both the COG and the pivot point of the swivelling axle not in line with the centre line of the vehicle (values a and y ≠ 0)

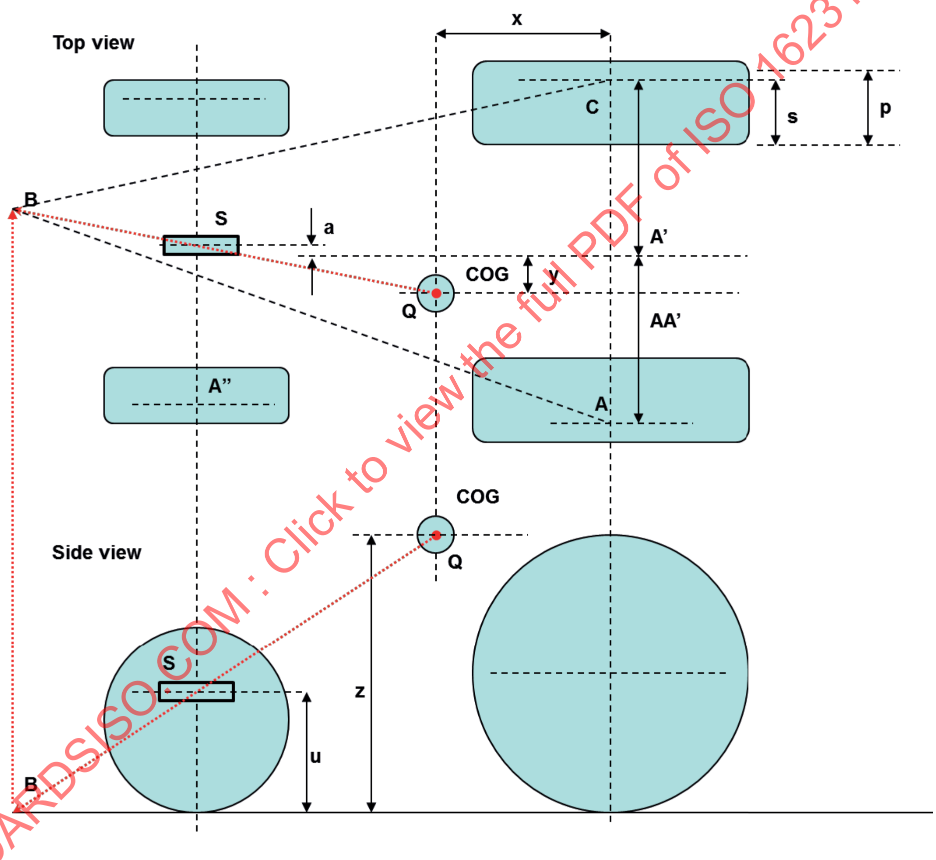

Figure 6 — Graphical determination of the stability triangle

5.2.2.2 The graphical determination of the stability triangle on a scaled drawing can be done by the following steps (see Figures 6 and 7):

a) draw line QS defined by the COG Q and the pivot point of the swivelling axle S in the side view and find the intersection with the ground line which defines point B;

b) draw a line of undefined length through point B and parallel with the centre lines of the axles in side view;

c) draw line QS in the top view;

d) the intersection of line QS in the top view and the line through point B in the side view, parallel to the centre lines of the axles, defines point B in the top view, which is the top of the stability triangle.

5.2.2.3 The graphical determination of the static overturning angle SOA on a scaled drawing can be done by the following steps (see Figure 7):

a) draw line BA;

b) find line DF in the top view by drawing a line through COG Q and perpendicular to line AB. The vertical plane defined by line DF is the plane in which the COG is moving when the vehicle is on the tilting platform, with line AB parallel to the articulation of the platform;

c) find line QD in the top view by drawing a line of undefined length, starting from COG Q, running parallel to line AB and define a position D on that new line;

d) find line AD in the view perpendicular to line AB by drawing a line through D parallel to line DF in the top view (this is the ground surface line);

e) find point QD in the view perpendicular to line AB by drawing a line parallel to line AB through point D with a length equal to z, the height of the COG;

f) rotate AQ and find intersection F with line AB;

g) the angle α is the static overturning angle SOA and equals DA/QD (%).

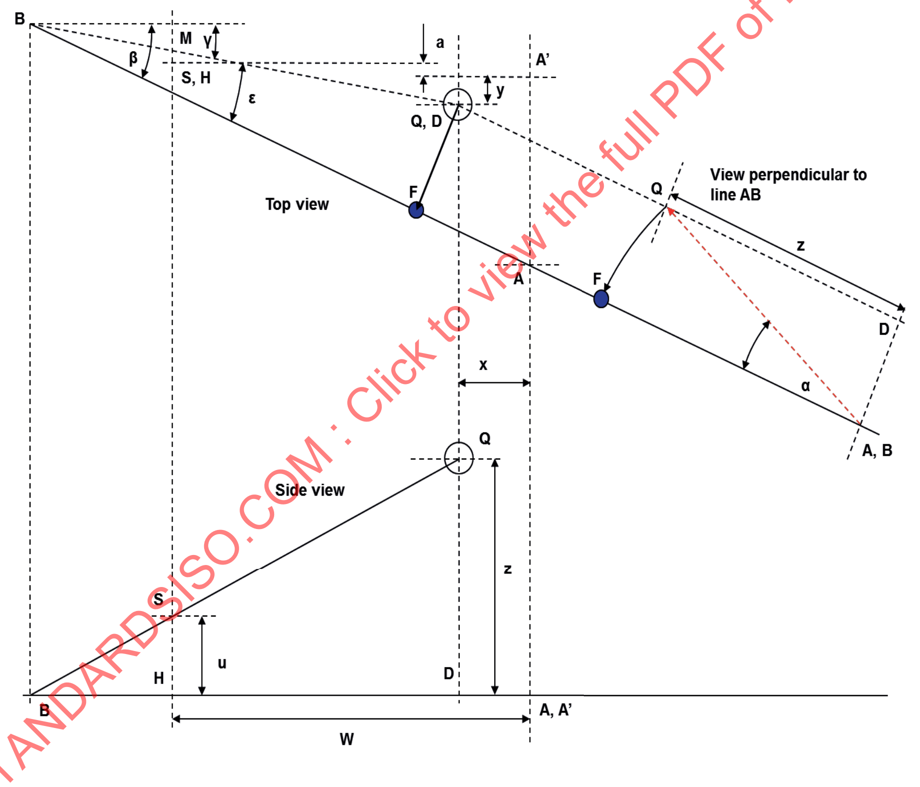

Figure 7 — Graphical determination of static overturning angle SOA

5.2.3 Determination of the stability by calculation

The SOA can be calculated by means of the formulae in Table 7 and Figure 7.

Table 6 — Input data for static overturning angle

Data description	Symbol	Unit
Wheel base	W	mm
Height of the pivot point of the swivelling axle	u	mm
Overall width on tires on the fixed axle	o	mm
Width of tires on fixed axle	p	mm
Overall width on tires on the swivelling axle	o’	mm
Width of tires on swivelling axle	p’	mm
Maximum angle of the swivelling axle, between horizontal and end of stroke	δ	°
Longitudinal position of COG (versus fixed axle)	x	mm
Lateral position of COG (RH side = +)	y	mm
Height of COG	z	mm
Offset of the swivelling axle pivot point (for simplicity, a = 0 in all calculations)	a = 0	mm

Table 7 — Calculations for static overturning angle

Data description: calculation of angle α with machine on a tilt platform	Symbol	Unit	Calculation
Distance between inner edge and rolling point of the fixed axle tire	s	mm	0,75 * p
Distance between inner edge and rolling point of the swivelling axle tire	s’	mm	0.75 * p’
Base line of stability triangle	AA’	mm	(o – 2 * (p – s)) / 2
Side view distance between point B and the vertical projection of the swivelling axle pivot point	BM	mm	u * (W – x) / (z – u)
See drawing	HM	mm	(BM * y) / (W - x)
See drawing	BH	mm	$\sqrt{}$ $(BM^2 + HM^2)$
Worst case side of the stability angle when rolling over	AB	mm	$\sqrt{}$ $((W + BM)^2 + (AA' + HM)^2)$
See drawing	HD	mm	$\sqrt{}$ $((W - x)^2 + y^2)$
Distance between point B and the vertical projection of the COG	BD	mm	BH + HD
Angle formed by the side AB and BM	β	°	$\cos^{-1}$ ((W + BM) / AB)
See drawing	γ	°	$\tan^{-1}$ (HM / BM)
See drawing	ε	°	β – γ
Shortest distance between the vertical projection of the COG and the side AB	DF	mm	BD * sin ε
Static overturning angle SOA without stroke limiting device on swivelling axle	α	°	$\tan^{-1}$ (DF / z)
Static overturning angle SOA without stroke limiting device on swivelling axle	α	%	DF * 100 / z

5.3 Lateral roll-over: Machines with one fixed and one swivelling axle with swivelling angle limiting device

Most self-propelled machines are equipped with a swivel angle limiting device on the swivelling axle, which, when hit during lateral rollover, restricts further swivelling of the axle prior to the complete overturn of the machine. The wheel of the fixed axle, opposite to line AB (see Figure 6), loses contact with the ground and lifts up. The body of the machine rolls around line AS and stops when the swivelling axle hits the stroke limiting device. At that point, the stability line is formed by the contact points of a front and a rear tire. The stroke limiting device is effective only when the angle of the swivelling axle keeps the vertical projection on the inside of the stability line formed by the tires, in order to absorb the dynamic effects of rolling around line AS.

The state of the art does not allow one to assess whether the inertia of the machine, caused by rolling around line AS, is reaching a level which results in a complete tip-over, despite of the new stability line. Each manufacturer shall assess whether the stroke limiting device is effective to stop the roll-over.

In this example, it is assumed that there is a margin of 1,25 or, in other words, the stroke limiting device is reached at less than 80 % from the stability line formed by the tires, else the SOA equals α. Figure 8 illustrates a simplified configuration of the angles α, σ, and δ (all angles in the same transversal plane).

NOTE 1 The next edition of this part of ISO 16231 is expected to include a more accurate method in which the angles are visualized in their respective plane by means of a 3D representation.

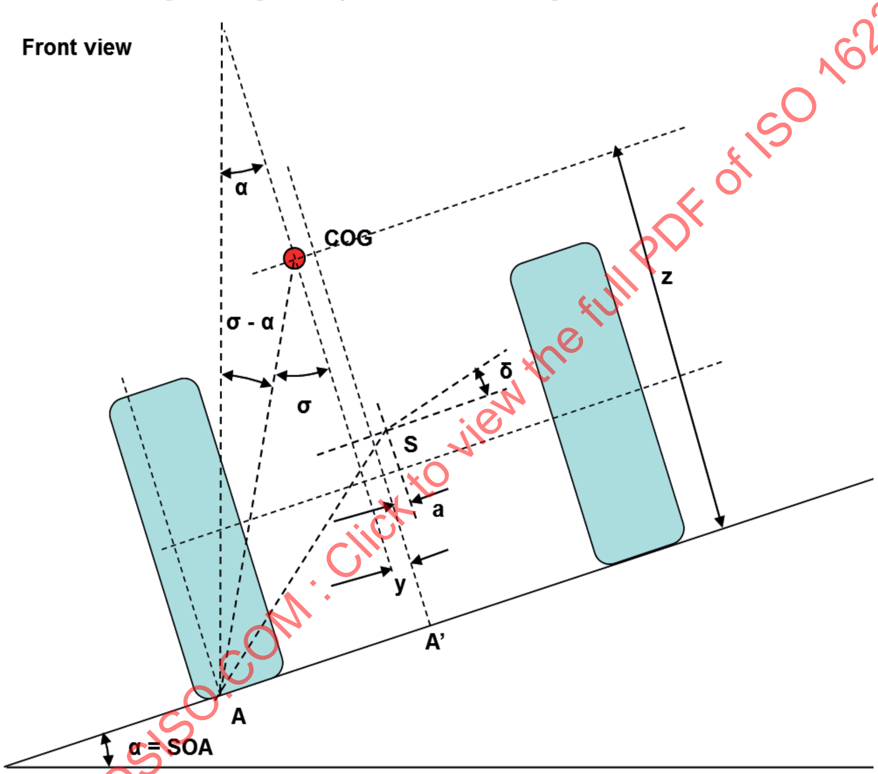

Figure 8 — Shift of centre of gravity COG during roll-over around line AS — 2D view

Table 8 — Calculations for static overturning angle (value σ)

Data description	Symbol	Unit	Calculation
Difference in track width between front and rear tire	Δo	mm	(o/2 – (p – s)) – (o′/2 – (p′ – s′))
SOA when rolling around the stability line formed by the tires	σ	%	(AA′ – y – (Δo * x / W)) * 100 / z
SOA when rolling around the stability line formed by the tires	σ	°	$\tan^{-1}$ (σ) (%)
Margin °	σ – α	°	σ – α
Margin %	σ – α	%	σ – α

Summary:

$$\sigma - \alpha \geq 1{,}25 * \delta: SOA = \sigma \quad (4)$$

$$\sigma - \alpha < 1{,}25 * \delta: SOA = \alpha \quad (5)$$

In case the margin $\sigma - \alpha$ meets or exceeds 1,25 times the angle of the swivelling axle, σ can be used as SOA value; otherwise α shall be used.

NOTE 2 The margin value of 1,25 is indicative only and shall be assessed for each model of machine

5.4 Lateral roll—over: machines without swivelling axle

5.4.1 Machines on tracks

The stability triangle is not relevant for machines on tracks, because the pivot line is the edge of the track rollers. In this case, the static overturning angle SOA (%) is the ratio between the lateral position of the centre of gravity COG (o/2 – y) and the height of the centre of gravity z. The machine reaches, then exceeds the static overturning angle SOA when the vertical projection of centre of gravity COG falls outside the pivot line.

$$SOA\,(\%) = (o/2 - y) / z\,(\%) \quad (6)$$

where “o” for steel tracks is the outer edge of the track shoes and “o” for rubber track belts is the outer edge of the rollers.

5.4.2 Machines with devices to lock the swivelling axle or to modify the stability triangle

Machines can have devices to modify the stability triangle as a function of the slope. These devices affect the static overturning angle SOA in a positive way. The determination of the static overturning angle SOA shall consider the positive impact of these solutions, according to the system applied, and the value σ can potentially be used as SOA (see 5.3).

5.4.3 Machines with individual wheel suspension

For machines with individual wheel suspension, 5.7 apply.

5.5 Tip forward and tip rearward

5.5.1 Tip forward

The machine tips forward when the vertical projection of the COG crosses the line of the contact point of the front wheels with the ground. In this case, the SOA (%) is the ratio between the horizontal position of the COG (x) and the height of the centre of gravity (z).

$$SOA\,(\%) = x / z\,(\%) \quad (7)$$

5.5.2 Tip rearward

The machine tips rearward when the vertical projection of the COG crosses the axle line of the rear wheels. In this case, the SOA (%) is the ratio between the horizontal position of the COG (W – x) and the height of the centre of gravity (z).

$$SOA\,(\%) = (W - x) / z\,(\%) \quad (8)$$

5.6 Body levelling systems

When a machine is equipped with a body levelling system, whether activated manually or automatically, then the capability of that system (its maximum levelling angle in %) for a particular direction shall be considered and added during determination of the SOA.

NOTE 1 A more refined method to determine the SOA on machines with body levelling systems is expected in the next revision of this part of ISO 16231.

NOTE 2 The reliability of the control system for automatic body levelling systems is not part of this part of ISO 16231.

5.7 Alternative methods

5.7.1 When there are not enough reliable data available or when there are appropriate facilities available, other methods are allowed to determine the SOA. Examples of other methods are the following:

— the machine is lifted respectively in the four directions by means of a hoist to angles equal to the rolling over angle;

— the machine is placed on a tilting platform respectively in the four directions to angles equal to the rolling over angle;

— virtual simulation models.

5.7.2 The test shall be stopped when the SOA is reached (when tip over is about to start) or when the SOA reaches a slope equal to 100 %.

6 Comparison of SOA and RSSA

6.1 The RSSA shall be determined for each type of machine.

The RSSA provides the calculated slope on which the machine is required to be stable. The RSSA is determined by using the MOS and SF values in Annex C, Table C.1. Information about the Safety Factor (SF) can be found in informative Annex D.

$$RSSA = MOS * SF \quad (9)$$

6.2 Compare SOA and RSSA. In case SOA is higher than the RSSA, the risk for roll-over or tip-over is low and no further roll-over protection is needed.

6.3 The operator station of machines with a body levelling system shall be equipped with the following:

— an acoustic or visual warning device which indicates to the operator when the machine is moving on a lateral or up-and-down slope greater than the 80 % of MOS. The warning shall activate when the slope reference value has been reached or exceeded for 3 s;

— a device continuously indicating the value of the slope.