



BSI Standards Publication

Road restraint systems — Validation and verification process for the use of virtual testing in crash testing against vehicle restraint system

National foreword

This British Standard is the UK implementation of EN 16303:2020. It supersedes PD CEN/TR 16303-1:2012, PD CEN/TR 16303-2:2012, PD CEN/TR 16303-3:2012 and PD CEN/TR 16303-4:2012, which are withdrawn.

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English Version

Road restraint systems - Validation and verification process for the use of virtual testing in crash testing against vehicle restraint system

Dispositifs de retenue routiers - Processus de vérification et de validation pour l'utilisation d'essais virtuels dans les essais de choc contre un dispositif de retenue pour véhicules

Rückhaltesysteme an Straßen - Validierungs- und Nachweisverfahren für die Nutzung von Computersimulationen bei Anprallprüfungen an Fahrzeug-Rückhaltesysteme

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European foreword

This document (EN 16303:2020) has been prepared by Technical Committee CEN/TC 226 “Road equipment”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2021, and conflicting national standards shall be withdrawn at the latest by February 2021.

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

This document supersedes CEN/TR 16303-1:2012, CEN/TR 16303-2:2012, CEN/TR 16303-3:2012 and CEN/TR 16303-4:2012 (which have been merged).

In comparison to the previous Technical Reports, this document contains the following changes:

- some symbols and abbreviations have been modified;
- the roadmap for the validation of the numerical vehicle model has been updated and acceptance conditions have been provided;
- the validation requirements for virtual testing against vehicle restraint systems have been updated;
- the verification evaluation criteria for finite element model have been updated;
- the template of the report has been updated.

Annexes A, B and C are normative and Annexes D to J are informative.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

This document provides a common basis for the use of virtual testing to reproduce vehicle impacts against vehicle restraint systems including safety barriers, crash cushions, terminals and passive safety devices in accordance with the EN 1317 (all parts) and the EN 12767:2019.

This document provides requirements to establish the degree to which the numerical models of vehicle restraint system and of vehicle are an accurate representation of the real world from the perspective of the intended uses of the model.

In this document a methodology is defined to validate the results obtained with computational mechanics work and to verify the reliability of the virtual test. It also includes a report template and incorporates specific content for general requirements for the competence of entities performing virtual testing.

General recommendations based on experiences for developing numerical models of vehicle restraint systems and vehicles for virtual tests are also given.

Two main modelling approaches have been considered:

- finite element (FE) method;
- multi-body (MB) approach.

1 Scope¹

This document defines the accuracy, credibility and confidence in the results of virtual crash test to vehicle restraint systems through the definition of procedures for verification, validation and development of numerical models for roadside safety application. Finally it defines a list of indications to ensure the competences of an expert/organization in the domain of virtual testing.

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.

EN 1317-1:2010, *Road restraint systems - Part 1: Terminology and general criteria for test methods*

EN 1317-2:2010, *Road restraint systems - Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers including vehicle parapets*

EN 1317-3:2010, *Road restraint systems - Part 3: Performance classes, impact test acceptance criteria and test methods for crash cushions*

ENV 1317-4:2001, *Road restraint systems – Part 4: Performance classes, impact test acceptance criteria and test methods for terminals and transitions of safety barriers*

EN 12767:2019, *Passive safety of support structures for road equipment - Requirements and test methods*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp/ui>

3.1

independent expert

third-party qualified expert in virtual testing with experience on vehicle restraint systems and/or passive safety devices, independent from the organisation or the construction product he assesses (see Annex B)

3.2

numerical model

complete mathematical 3-D model of vehicle restraint systems, passive safety devices and vehicles

Note 1 to entry: It refers to a numerical model which might be analytical or discrete and aims to reproduce the basic physical phenomena of a subject.

3.3

passive safety device

support structures for road equipment tested according to EN 12767:2019

¹ The scope of this document is also applicable to passive safety devices.

3.4

real test

real test performed at a test house according to the relevant standard

3.5

test item

device to be assessed using virtual testing

3.6

validated model

numerical model of the roadside or passive safety device or vehicle that fulfils the requirements of this document after being checked and agreed by an independent expert

3.7

validation

set of activities defined to assess whether a numerical model can be considered representative of a physical system or part in a specified range of conditions

3.8

vehicle restraint system

device tested according to EN 1317-1 and EN 1317-2, EN 1317-3 or EN 1317-4

3.9

verification

set of activities defined to check whether a numerical model is reliable and numerically stable

3.10

virtual test or virtual testing

activities related to the use of a numerical model to reproduce a real test and/or to simulate an impact

4 Symbols and abbreviations

For the purposes of this document, the following symbols and abbreviations apply:

ASI	acceleration severity index
CoG	centre of gravity
D	dynamic deflection
D_m	measured maximum dynamic deflection of the real test, in metres (m)
D_{m_mod}	measured maximum dynamic deflection of the real test with a tolerance of $\pm 0,15$ m, in metres (m)
D_{VT}	measured maximum dynamic deflection of the virtual test, in metres (m)
FE	finite elements
FEA	finite elements analysis
HGV	heavy goods vehicle
LD	lateral displacement
LD_m	measured lateral displacement of the real test, in metres (m)
LD_{m_mod}	measured lateral displacement of the real test with a tolerance of $\pm 0,15$ m, in metres (m)
LD_{VT}	measured lateral displacement of the virtual test, in metres (m)

MB	multi-body
MBA	multi-body analysis
THIV	theoretical head impact velocity
TT	type test
VI	vehicle intrusion
VI_m	measured vehicle intrusion of the real test, in metres (m)
VI_{m_mod}	measured vehicle intrusion of the real test with a tolerance of $\pm 0,15$ m, in metres (m)
VI_{VT}	measured vehicle intrusion of the virtual test, in metres (m)
VT	virtual test or virtual testing
W	working width
W_m	measured working width of the real test, in metres (m)
W_{m_mod}	measured working width of the real test with a tolerance of $\pm 0,15$ m, in metres (m)
W_{VT}	measured working width of the virtual test, in metres (m)
ΔF	change in force
Δs	change in displacement

5 Requirements for numerical vehicle model

5.1 Modelling

A complete 3D numerical model of a real test vehicle according to EN 1317-1:2010 respectively EN 12767:2019, as relevant, shall be created. The geometry of the vehicle and all inertial properties shall be reproduced accurately. The numerical model shall include at least:

- frame;
- body;
- suspensions systems, front and rear;
- wheels;
- steering system;
- windows;
- engine block;
- ballast.

Vehicle specifications under test conditions shall be as specified as in EN 1317-1:2010, Table 1 and the EN 12767:2019, 5.3, as relevant.

The vehicle shall be fitted with, as a minimum, one accelerometer for measurement in the longitudinal (forward) direction, one for the lateral (sideways) direction, one for the vertical direction (downward) and an angular velocity sensor (rate sensor). The accelerometers shall be mounted as prescribed by the EN 1317-1:2010. Vehicular accelerations shown by this accelerometer shall be used for the calculation of the severity indices, according to EN 1317-1:2010.

The model shall be able to reproduce the comparable deformation observed in the type test.

5.2 General vehicle model behaviour assessment

For the validation of the numerical vehicle model, tests shall be performed according to this document, comparable parameters shall be measured and the results shall be fully documented.

The validation tests that shall be carried out to ensure the numerical stability and the capability of the numerical model are divided in categories dealing with vehicle setup, vehicle suspension and steering kinematics, handling and crashworthiness.

5.3 Test methodology

5.3.1 General

The scope of the following analysis is to ensure the stability and robustness of the vehicle model and the level of reliability of the results.

The finite element model and the multi body vehicle model shall be validated with the same requirements and limits.

This procedure consists of a fixed number of compulsory tests and a series of additional tests that can be performed depending on the intended use of the model.

For the vehicle model in order to be considered validated all compulsory tests shall be completed without error terminations for the specified time.

In general the analysis shall be performed when the vehicle development is completed. Modification(s) will require to perform some or the full set of the tests again.

In special situations where requirements of this document cannot be satisfied, deviations from the given rules shall be reported and motivations shall be explained and then checked and agreed by an independent expert (see Annex B). These exceptions shall only be motivated by technical and not by economical reasons. An exception can be e.g. if the measurement in a real test cannot be reproduced consistently.

5.3.2 Test description

5.3.2.1 Compulsory test

The tests are grouped in four different sets:

- Set 1. – Vehicle setup;
- Set 2. – Vehicle suspension and steering kinematics;
- Set 3. – Vehicle handling;
- Set 4. – Vehicle crashworthiness.

The tests included in Table 1 shall be performed to complete the vehicle validation.

The table includes the scope of the test, the results to be provided and the acceptance conditions (limits).

Table 1 — Vehicle validation roadmap compulsory tests

Set 1. – Vehicle setup		
Test 1.1 - Idle test (described in C.2)		
Scope: Verify stability of the vehicle model and general setup when stationary	Results to be provided: — Acceleration time (filtered: filter class CFC60) — Suspensions movement time history	Limits: — Filtered accelerations: $a < \pm 3,0 \cdot 9,81 [\text{m/s}^2]$ — Suspension movement: $\Delta s < 20 [\text{mm}]$ for all vehicles except heavy goods vehicles with mass of 38 tons $\Delta s < 80 [\text{mm}]$ for heavy goods vehicles with mass of 38 tons
Set 2. – Vehicle suspension and steering kinematics		
Test 2.1 – Isolated suspensions system (constrained vehicle) – full compression (described in C.3.1)		
Scope: Verify suspension kinematic and loading and unloading capacity	Results to be provided: — Comparison between input curves and response — Identify the suspension maximum compression	Limits: — Allowed variation between input curves and response: $\Delta F < 0,05 \cdot F^0$ Where F^0 is the suspension force when stationary, displacement $s^0 = 0 [\text{mm}]$ (see Figure F.7 and F.8)
Test 2.2 – Isolated suspensions system (constrained vehicle) – full extension (described in C.3.1)		
Scope: Verify suspension kinematic and loading capacity	Results to be provided: — Comparison between input curves and response — Identify the suspension maximum extension	Limits: — Allowed variation between input curves and response: $\Delta F < 0,05 \cdot F^0$ Where F^0 is the suspension force when stationary, displacement $s^0 = 0 [\text{mm}]$ (see Figure F.7 and F.8)
Test 2.3 – Isolated steering system (constrained vehicle) – full rotation both sides (described in C.3.2)		
Scope: Verify steering kinematic	Results to be provided: — Comparison between left and right wheel steering angle (time Vs angle curves) — Identify the steering maximum angle with slip-free rolling of the wheels	Limits: — Verify Ackerman principle (described in E.1.5 and Figure E.2)

Set 3. – Vehicle handling		
Test 3.1 - Linear track test (described in C.4.1)		
Scope: Verify the general behaviour of the vehicle (steering and suspension system) and its capability to run. The model shall be able to follow the linear trajectory for about 1,0 s.	Results to be provided: — Trajectory plot — Energies balance in time	Limits: — Following the linear trajectory for minimum of 1,0 [s] with the maximum speed — Acceptable deviation Δs_0 from the linear trajectory with the length L_t: $\Delta s_0 < 0,1 * L_t$
Test 3.2 - Test on curvilinear track (described in C.4.2)		
Scope: Verify the general behaviour of the vehicle (steering and suspension system) and its capability of steering under an applied load or by rotating the steering wheel and returning in neutral (without steering) when the force is removed, or the steering wheel is in neutral position. The model shall be able to follow the curvilinear trajectory for about 1,0 s.	Results to be provided: — Trajectory plot — Energies balance in time	Limits (with a speed of 30 % of test speed): — The steer shall be applied until the vehicle rotates at least 20[°] from the original direction — After reaching the 20[°], the model shall follow the curvilinear trajectory of about 1,0 [s] with an acceptable angle deviation of: $\Delta \beta < \pm 5[^\circ]$ — Then, when the steering is removed, the trajectory shall reach a straight line
Test 3.3 - Step test (described in C.4.3)		
Scope: Verify dynamic behaviour of the suspension system and general robustness of the model to demonstrate the damping of the suspension.	Results to be provided: — Spring suspension change in length Vs time curve. — Kinetic and total energy time histories	Limits: — Falling from a step height of $\Delta H = 80[\text{mm}]$ with a vehicle speed of 25[km/h], the length vs time curve oscillation shall be damped to 50 % of the first peak, in 2 cycles
Set 4. – Vehicle crashworthiness		
Test 4.1 - Against rigidwall (EN 1317-2:2010) (described in C.5)		
Scope: Verify the capability of suffering strong deformations. Control of the contact definition.	Results to be provided: — Post-impact analyses (severity indices for cars) — Kinetic and total energy time histories	Limits: — Severity indices tolerance according to 8.3.8 — Total energy lost < 10 %

Test 4.2 – Front collision test (EN 12767:2019, EN 1317) (described in C.5)		
Scope: Ensure that the front characteristics of the test vehicle are within a specified range.	Results to be provided: — Velocity time histories	Limits: — Limits according to EN 12767:2019, Clause 6 and Clause 7

A more detailed test description is provided by the guidelines within Annex C.

If one of the above virtual tests is not relevant for the analysis to be performed, the entity performing VT activity shall explain his motivations inside the final validation report and those motivations shall be checked and agreed by the independent expert.

Tests defined in Set 2 are mandatory only for new vehicles models, not for further revisions of existing validated models. Some minor modifications (e.g. Mass) may be accepted if explained without further testing (see Annex A, Virtual Testing – Template for Report).

5.3.2.2 Additional test

Additional tests could be done to evaluate features of the vehicle that are not evaluated by the test in Table 1 such as the suspension failure (using a test similar to the “Isolated suspensions tests”) or a front vehicle deformation.

5.4 Verification

For the verification of the numerical vehicle model, requirements of 5.3.2 shall be fulfilled.

5.5 Reporting

All tests shall be reported in vehicle model verification and validation report (see Annex A).

If vehicle models are modified the validated vehicle model shall be mentioned as basis (report reference to vehicle model validation report) and all changes shall be described in detail.

6 Requirements for numerical model of vehicle restraint system

6.1 Modelling

A complete 3D numerical model of the vehicle restraint system shall be created. The geometry of the vehicle restraint system and all inertial properties shall be reproduced accurately, according to the reference drawings of the test item. The numerical model shall include:

- device components;
- components connections;
- fixation to the roadbed / anchoring;
- ground (any soil, asphalt, concrete);
- boundary conditions (e.g. attached terminals or safety barriers).

6.2 Validation and verification

The vehicle restraint system model shall be verified by a simulation that includes the effects of gravity. The validation and verification test should cover the same simulation time used for the real test described in Clause 8.

Verification requirements of Table 9 for FEA and Table 10 for MBA shall be fulfilled as a minimum for the verification test described above.

6.3 Reporting

The modelling, verification of the vehicle restraint system shall be described in detail according to the report template in Annex A.

7 Requirements for numerical model of passive safety device

7.1 Modelling

A complete 3D numerical model of the passive safety device shall be created. The geometry of the passive safety device and all inertial properties shall be reproduced faithfully, according to the reference drawings of the test item. The numerical model shall include:

- device components;
- components connections;
- fixation to the roadbed / anchoring;
- ground (any soil, asphalt, concrete);
- boundary conditions.

7.2 Validation and verification

The passive safety device model shall be verified by a simulation that includes the effects of the gravity. The validation and verification test should cover the same simulation time used for the real test described in Clause 8.

Verification requirements of Table 9 for FEA and Table 10 for MBA shall be fulfilled as a minimum for the verification test described above.

7.3 Reporting

The modelling, verification and validation of the passive safety device shall be described in detail according to the report template in Annex A.

8 Requirements for validation of virtual testing against test item

8.1 General

To enable the numerical model to be validated, virtual testing shall be in compliance with the TT performed to assess performance levels of vehicle restraint systems.

The virtual testing shall be performed with the same mass, same speed and same angle as in the TT.

All deviations from real test setup shall be described in detail and justified (e.g. simplified boundary conditions for terminals).

8.2 Test specifications

8.2.1 Safety barriers

8.2.1.1 General

Vehicle impact tests shall be carried out in compliance with criteria given in EN 1317-2:2010, Table 1. Type and characteristics of vehicles are described in EN 1317-1:2010, 5.2.

8.2.1.2 Containment category

Tests shall be carried out according to methods given in EN 1317-1:2010, Clause 5 and in EN 1317-2:2010, Clauses 4 and 5.

8.2.1.3 Impact severity

Tests shall be carried out according to methods given in EN 1317-1:2010, Clauses 5, 6, 7 and 8 and in EN 1317-2:2010, Clauses 4 and 5.

8.2.1.4 Deformation of safety barrier

Tests shall be carried out according to methods given in EN 1317-1:2010, Clause 5 and in EN 1317-2:2010, 3.5, Clauses 4 and 5.

8.2.2 Crash cushions

8.2.2.1 General

Vehicle impact tests shall be carried out in compliance with criteria given in EN 1317-3:2010, Table 1. Type and characteristics of vehicles are described in EN 1317-1:2010, 5.2.

8.2.2.2 Restraint category

Tests shall be carried out according to methods given in EN 1317-1:2010, Clause 5 and in EN 1317-3:2010, 5.3 and 5.6.

8.2.2.3 Impact severity

Tests shall be carried out according to methods given in EN 1317-1:2010, Clauses 5, 6, 7 and 8 and in EN 1317-3:2010, 6.4.

8.2.2.4 Deformation of crash cushion

Tests shall be carried out according to methods given in EN 1317-1:2010, Clause 5 and in EN 1317-3:2010, 6.5.

8.2.2.5 Vehicle redirection zone

Tests shall be carried out according to methods given in EN 1317-1:2010, Clause 5 and in EN 1317-3:2010, 6.3.

8.2.3 Terminals

8.2.3.1 General

Vehicle impact tests shall be carried out in compliance with criteria given in EN 1317-4:2001, Table 1. Type and characteristics of vehicles are described in EN 1317-1:2010, 5.2.

8.2.3.2 Restraint category

Tests shall be carried out according to methods given in EN 1317-1:2010, Clause 5 and in ENV 1317-4:2001, 5.1 and 5.2.

8.2.3.3 Impact severity

Tests shall be carried out according to methods given in EN 1317-1:2010, Clauses 5, 6, 7, 8 and in ENV 1317-4:2001, 5.3.

8.2.3.4 Deformation of terminals

Tests shall be carried out according to methods given in EN 1317-1:2010, Clause 5 and in ENV 1317-4:2001, 5.4.

8.2.3.5 Vehicle redirection zone

Tests shall be carried out according to methods given in EN 1317-1:2010, Clause 5 and in ENV 1317-4:2001, 5.5.3.

8.2.4 Passive safety device

8.2.4.1 General

Vehicle impact tests shall be carried out in compliance with criteria given in EN 12767:2019.

Type and characteristics of vehicles are described in EN 1317-1:2010, 5.2 and EN 12767:2019, 5.3.

8.2.4.2 Test method

Tests shall be carried out according to methods given in EN 12767:2019, Clause 7 and Annexes A and B.

8.2.4.3 Detached elements and penetration

Tests shall be carried out according to methods given in EN 12767:2019, 8.3.3.

8.2.4.4 Vehicle behaviour

Tests shall be carried out according to methods given in EN 12767:2019, 8.4.

8.2.4.5 Impact severity

Tests shall be carried out according to methods given in EN 1317-1:2010, Clauses 5, 6, 7 and 8 and EN 12767:2019, 8.5.

8.2.4.6 Energy absorption categories

Tests shall be carried out according to methods given in EN 12767:2019, A.3.

8.2.4.7 Classes of occupant safety

Tests shall be carried out according to methods given in EN 12767:2019, A.4.

8.2.4.8 Additional requirements for cantilever and gantry sign supports

Tests shall be carried out according to methods given in EN 12767:2019, 6.2.7.

8.3 Comparison tables

8.3.1 General

The Virtual Test shall be compared to the corresponding real test. To validate the model the requirements described in the following subclauses shall be satisfied and reported in the validation report.

In special situations where requirements of this document cannot be satisfied, deviations from the given rules shall be reported and motivations shall be explained and then checked and agreed by an independent expert (see Annex B). These exceptions shall only be motivated by technical and not by economical reasons. An exception can be e.g. if the measurement in a real test cannot be reproduced consistently.

The accordance with the real test and the general requirements shall be reported as shown in Tables 2 to 5.

“Yes” is to be ticked if there is agreement between the virtual test and the real test; furthermore when a criterion is defined, “yes” means that the criterion is satisfied.

Table 2 shall be used for safety barriers, Table 3 for crash cushions, Table 4 for terminals and Table 5 for passive safety device.

Table 2 — Comparison table – Safety barriers

Qualitative validation requirements - critical behaviour of test vehicle and item	Is VT in accordance with result from real test?
Containment level (EN 1317-2:2010, 3.5 and Clause 4)	Yes/no
Rollover (EN 1317-2:2010, 4.3)	Yes/no
Exit box (EN 1317-2:2010, 4.3)	Yes/no
Wheel trajectory (EN 1317-2:2010, 4.3)	Yes/no
Failure of longitudinal elements	Yes/no
Failure modes	Yes/no
Penetration of parts of the test item inside the vehicle	Yes/no
Quantitative validation requirements - essential characteristics	Is VT in accordance with the requirements
Dynamic deflection criterion (8.3.3)	Yes/no
Working width criterion (8.3.4)	Yes/no
Vehicle intrusion criterion (8.3.5)	Yes/no

Table 3 — Comparison table – Crash cushion

Qualitative validation requirements - critical behaviour of test vehicle and item	Is VT in accordance with result from real test?
Containment level (EN 1317-3:2010, 5.3 and 5.6)	Yes/no
Rollover (EN 1317-3:2010, 6.3)	Yes/no
Redirection zone (EN 1317-3:2010, 6.3)	Yes/no
Failure of longitudinal elements	Yes/no
Failure modes	Yes/no
Penetration of part of the crash cushion inside the vehicle	Yes/no
Quantitative validation requirements - essential characteristics	Is VT in accordance with the requirements
Lateral displacements criterion (8.3.6)	Yes/no

Table 4 — Comparison table – Terminals

Qualitative validation requirements - critical behaviour of test vehicle and item	Is VT in accordance with result from real test?
Containment level (ENV 1317-4:2001, 5.1 and 5.2)	Yes/no
Rollover (ENV 1317-4:2001, 5.5.3)	Yes/no
Redirection zone (ENV 1317-4:2001, 5.5.3)	Yes/no
Failure of longitudinal elements	Yes/no
Failure modes	Yes/no
Penetration of part of the terminal inside the vehicle	Yes/no
Quantitative validation requirements - essential characteristics	Is VT in accordance with the requirements
Lateral displacements criterion (8.3.6)	Yes/no

Table 5 — Comparison table – Passive safety devices

Qualitative validation requirements - critical behaviour of test vehicle and item	Is VT in accordance with result from real test?
Speed class (EN 12767:2019, 7.4)	Yes/no
Rollover	Yes/no
Energy absorption category (EN 12767:2019, A.3)	Yes/no
Occupant safety class (EN 12767:2019, 8.5)	Yes/no
Penetration	Yes/no
Collapse modes (EN 12767:2019, 8.3.2)	Yes/no

The above tables shall be part of the verification and the validation report, see Annex A.

NOTE A description of failure modes is given in Annex J.

8.3.2 Additional Comparison table for cars

When the virtual test and the real test are performed with a car additional parameters shall be compared to assess the quality of the virtual testing. Therefore, the validation process requires additional criteria that are described in Table 6. "Yes" is to be ticked if there is agreement between the virtual testing and the real test in accordance with the criteria defined.

Table 6 — Additional comparison table

Criteria	Is VT in accordance with result from real test?
ASI criterion (8.3.8)	Yes/no
THIV criterion (8.3.8)	Yes/no
Time histories criteria (8.3.9)	Yes/no

The above table shall be part of the final validation report, see Annex A.

8.3.3 Dynamic deflection for safety barrier

The dynamic deflection (D_m) from the real test shall be compared with the one calculated from the virtual test (D_{VT}).

The difference between the two dynamic deflections shall be less than the value calculated with the formula below:

for TB 11 test:

$$|D_m - D_{VT}| \leq (0,1 + 0,2 \times (D_m)) \quad (1)$$

for other tests:

$$|D_m - D_{VT}| \leq (0,1 + 0,1 \times (D_m)) \quad (2)$$

where:

D_m is dynamic deflection (expressed in metres[m]) of the real barrier (crash test result), not normalized;

D_{VT} is the dynamic deflection (expressed in metres[m]) of the virtual test reproducing the real crash test.

In case D_m cannot be evaluated from high speed photographic or video recordings, the Formulae (1) and (2) are modified as follows using a tolerance of 0,15 m:

for TB 11 test:

$$|D_{m_mod} - D_{VT}| \leq (0,1 + 0,2 * D_{m_mod}) \quad (3)$$

for other tests:

$$|D_{m_mod} - D_{VT}| \leq (0,1 + 0,1 * D_{m_mod}) \quad (4)$$

where:

$$D_{m_mod} = D_m \pm 0,15 \text{ m} \quad (5)$$

8.3.4 Working width for safety barrier

The working width (W_m) from the real test shall be compared with the one calculated from the virtual test (W_{VT}).

The difference between the two working widths shall be less than the value calculated with the formula below:

for TB 11 test:

$$|W_m - W_{VT}| \leq (0,1 + 0,2 \times (D_m)) \quad (6)$$

for other tests:

$$|W_m - W_{VT}| \leq (0,1 + 0,1 \times (D_m)) \quad (7)$$

Where:

- W_m is the working width (expressed in metres (m)) of the real barrier (crash test result), not normalized;
- W_{VT} is the working width (expressed in metres (m)) of the virtual test reproducing the real crash test;
- D_m is dynamic deflection of the real barrier (crash test result) expressed in metres (m), not normalized.

In case W_m cannot be evaluated from high speed photographic or video recordings, the Formulae (6) and (7) are modified as follows using a tolerance of 0,15 m:

for TB 11 test:

$$|W_{m_mod} - W_{VT}| \leq (0,1 + 0,2 * D_{m_mod}) \quad (8)$$

for other tests:

$$|W_{m_mod} - W_{VT}| \leq (0,1 + 0,1 * D_{m_mod}) \quad (9)$$

where:

$$D_{m_mod} = D_m \pm 0,15 \text{ m} \quad (10)$$

$$W_{m_mod} = W_m \pm 0,15 \text{ m} \quad (11)$$

8.3.5 Vehicle intrusion for safety barrier

The vehicle intrusion (VI_m) from the real test, calculated only for buses and HGV as indicated in EN 1317-2:2010, 3.5 shall be compared with the one calculated from the virtual test (VI_{VT}).

The difference between the two vehicle intrusions shall be less than the value calculated with the formula below:

$$|VI_m - VI_{VT}| \leq (0,3 + 0,1 \times (D_m)) \quad (12)$$

where:

- VI_m is the vehicle intrusion (expressed in metres (m)) of the real barrier (crash test result), not normalized;
- VI_{VT} is the vehicle intrusion (expressed in metres (m)) of the virtual test reproducing the real crash test;
- D_m is dynamic deflection of the real barrier (crash test result) expressed in metres (m), not normalized.

In case VI_m cannot be evaluated from high speed photographic or video recordings, the Formula (12) is modified as follows using a tolerance of 0,15 m:

$$|VI_{m_mod} - VI_{VT}| \leq (0,3 + 0,1 * D_{m_mod}) \quad (13)$$

where:

$$D_{m_mod} = D_m \pm 0,15 \text{ m} \quad (14)$$

$$VI_{m_mod} = VI_m \pm 0,15 \text{ m} \quad (15)$$

8.3.6 Lateral displacements for crash cushion and terminals

The lateral displacement LD_m for crash cushion and terminals from the real test, shall be compared with the one calculated from the virtual test LD_{VT} .

The difference between the two lateral displacements shall be less than the value calculated with the formula below:

$$|LD_m - LD_{VT}| \leq (0,1 + 0,2 * (LD_m)) \quad (16)$$

Where:

- LD_m is the lateral displacement (expressed in metres (m)) of the real barrier (crash test result);
- LD_{VT} is the lateral displacement (expressed in metres (m)) of the numerical model reproducing the real crash test.

In case LD_m cannot be evaluated from high speed photographic or video recordings, the Formula (16) is modified as follows using a tolerance of 0,15 m:

$$|LD_{m_mod} - LD_{VT}| \leq (0,1 + 0,2 * LD_{m_mod}) \quad (17)$$

where:

$$LD_{m_mod} = LD_m \pm 0,15 \text{ m} \quad (18)$$

8.3.7 Comparison between final shapes of test item

Final shapes of tested and simulated vehicle restraint systems shall be compared and reported.

8.3.8 Severity indices

EN 1317-1:2010 defines procedures to calculate severity indices values when a car is used in a crash test for roadside hardware approval. That allows the comparison of these indexes within the validation process of a virtual test.

The tolerance for ASI is defined in Table 7.

Table 7 — ASI tolerance

	Tolerance	Time max ASI
ASI	$\pm 0,1$	$\pm 0,05$ s

The tolerance for THIV is defined in Table 8.

Table 8 — THIV tolerance

	Tolerance	Time flight
THIV	± 3 km/h	$\pm 0,05$ s

ASI and THIV are the rounded values according to EN 1317-1:2010.

8.3.9 Vehicle motion time histories

Validation shall be based also on time history according to the following procedure.

The comparison is based on longitudinal and transversal components (related to the test item) of the vehicle's velocity in the plane motion and on the yaw angle.

The virtual test is considered validated when the following requirements are matched:

- The numerical longitudinal and transversal components of the velocity related to the test item remain inside a window built around the physical velocity components until the farthest in time amongst the max ASI time and the time of flight is reached.

The variation limits for the window are: ± 4 % of the initial resultant velocity and $\pm 0,01$ s in time.

For frontal tests with crash cushion, terminals (approaches 1 and 2) and passive safety devices, the comparison will be based only on global resultant velocity.

- The numerical yaw angle of the vehicle remains inside a window built around the physical yaw angle until the farthest in time amongst the max ASI time and the time of flight is reached.

The variation limits for the window are: $\pm 2,5^\circ$ of the yaw angle and $\pm 0,01$ s in time.

8.4 Reporting

The validation status including strength and weaknesses of the virtual test and the numerical model shall be described in detail according to the report template in Annex A.

For comparison of conditions of virtual test and real test the impact speed, impact angle and impact point shall be documented in the validation and in the new performance report (see Annex A). In addition the interaction between vehicle and vehicle restraint system shall be described in detail. Important model parameters shall be documented and justified.

In order to evaluate the capability of numerical models and the reliability of simulation results all important limits shall be described in detail. Different modelling techniques, simplifications and model assumptions might restrict or exclude some assessments (e.g. if no dummy is implemented in the vehicle model, a dummy contact with VRS cannot be predicted)

9 Requirements for verification of virtual testing against vehicle restraint systems and passive safety devices

9.1 General

If verification criteria do not satisfy limits described in 8.3, the entity performing VT activity shall explain his motivations inside the final validation report and those motivations shall be checked and agreed by the independent expert.

9.2 Finite element model verification

Initial penetrations are not allowed at the beginning of the run between test item and vehicle.

The following evaluation included in Table 9 and Table 10 shall be performed from the time when model preloading is finished and initial velocity applied until the time when:

- The vehicle leaves the restraint system, or,
- The vehicle crosses the exit box, or,
- The vehicle stops.

Table 9 — Verification evaluation criteria for finite element model

Verification evaluation criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e. kinetic, potential, contact, etc.) shall not vary more than 10 % from the beginning, considering also the eroded energy.		
Hourglass Energy of the analysis solution is, at any time, less than 5 % of the total initial energy at the beginning of the run.		
Hourglass Energy of the analysis solution at the end of the run is less than 10 % of the total internal energy at the end of the run.		
At the end of the run, the hourglass energy of the part/material with the highest amount of hourglass energy is less than 5 % of the total internal energy.		
Mass added to the total model is less than 5 % of the total model mass at the beginning of the run.		
The physical component with the most mass added had less than (0,5 kg + 10 % of its initial mass) added.		
The moving parts/materials in the model have less than 5 % of mass added to the initial moving mass of the model.		

9.3 Multi-body model verification

Table 10 — Verification evaluation criteria for multi-body model

Verification evaluation criteria	Change (%)	Pass?
Total energy of the analysis solution shall not vary more than 10 % from the beginning		

9.4 Standard report and output parameters

Virtual test results and comparison with the real test results shall be described inside the “Verification and Validation Report”, see Annex A.

Annex A (normative)

Virtual testing – Template for report

A.1 General

The report for the virtual testing contains one or more parts related to validation (one for each validated test) and one or more parts related to the evaluation of new performances (one for each virtual test). Any missing data shall be justified.

The template could also be used as a guideline to report the results of other numerical activities in which road hardware is evaluated/analysed/studied through virtual testing.

The same report for virtual testing may include the results of several tests.

A.2 Verification and validation report

A.2.1 General

The validation report is intended to include the following information as a minimum, in the order given below. All drawings and associated documents shall be clearly dated.

A.2.2 Validation report cover

The following is the list of information as a minimum to be included in the validation report cover:

- a) Report title
- b) Name/code of test item and its class in accordance with standard (e.g. H2 barrier)
- c) Name of person/group/institute performing the VT activity and writing the report
- d) Compiled by
- e) Approved by
- f) Validation number and/or validation report number/reference code
- g) Date of report
- h) Name of client
- i) Number of pages including annexes

A.2.3 Verification and Validation report indices

- a) Table of contents
- b) Index of figures
- c) Index of tables