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European Materials Handling Federation
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FEM Product Group
Racking and Shelving

October 2021

FEM 10.2.19

FEM Product Group
Racking and Shelving

FEM Code of Practice

The Design of Shuttle Racking.

October 2021

FEM RACKING AND SHELVING

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Foreword

This document provides a methodology for the design of steel pallet racking storage systems for shuttle systems.

FEM 10.2.19 is based on the safety and design concept of the European standards series “Steel Static Storage Systems” and provides supplementary design rules to suit the peculiarities of racking systems.

Racking systems are generally standard products where design by calculation alone may not be appropriate or may not lead to the most economical solutions. Due to differences in shape of structural components, detailing and connections additional technical information to that given in the Eurocodes is required and it is, therefore, usually appropriate to design on the basis of a combination of tests and calculation

Although the racking is a loading structure, national regulatory requirements demand the racking to be considered as "work equipment" and therefore subject to European Directive 89/391/EEC.

This document is not independent and is intended to be used in conjunction with EN 15512, EN 15620, EN 15629 and EN 15635.

1 Scope

This code of practice specifies the design requirements applicable to steel racking storage systems operated by shuttles and industrial trucks, S/R machines or aisle carriers, intended for storage of unit loads and subject to static loads and dynamic effects. This code does not cover small parts installations storing totes or cartons.

The principles established in this code may be used in conjunction with other codes or standards to design Shuttle racks subject to environmental loads such as wind, snow, earthquake etc.

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 15512, Steel static storage systems. Adjustable pallet racking systems. Principles for structural design.

EN 16681, Steel static storage systems. Adjustable pallet racking systems. Principles for seismic design.

EN 15620, Steel static storage systems. Adjustable pallet racking. Tolerances, deformations and clearances.

EN 15629, Steel static storage systems. Specification of storage equipment.

EN 15635, Steel static storage systems. Appliance and maintenance of storage equipment.

EN 15878, Steel static storage systems. Terms and definitions.

EN 528, Rail dependent storage and retrieval equipment - Safety.

Note: EN528 does not apply to the distribution shuttle

EN 1990, Eurocode 0 – Basis of structural design.

EN 1991-1-1, Eurocode 1: Actions on structures. Part 1-1. General actions. Densities, self-weight, imposed loads for buildings.

EN 1993-1-1, Eurocode 3: Design of steel structures. Part 1-1: General rules and rules for buildings.

EN 1993-1-3, Eurocode 3: Design of steel structures. Part 1-3: General rules. Supplementary rules for cold-formed members and sheeting.

EN ISO 6892-1, Metallic materials. Tensile testing. Part 1: Method of test at room temperature.

EN 10025, Hot rolled products of structural steels.

EN 10143, Continuously hot-dip coated steel sheet and strip. Tolerances on dimensions and shape.

EN 10162, Cold rolled steel sections. Technical delivery conditions. Dimensional and cross-sectional tolerances.

EN 10346, Continuously hot-dip coated steel flat products for cold forming - Technical delivery conditions.

EN ISO 7438, Metallic materials. Bend test.

EN ISO 9001, Quality management systems. Requirements.

EN 13001-2, Crane safety. General design. Part 2: Load actions.

All references to standards imply that for the system "Shuttle pallet racking" the considerations established for "Adjustable pallet racking" apply.

3 Terms and definitions

For the purposes of this document the terms and definitions given in EN 1993-1-1, EN 1993-1-3, EN 15512:2009, EN 15878:2010 and the following supplementary definitions apply.

3.1

lane rail

beam for shuttle movement in the Z direction and unit load storage

3.2

lane

space between frames in the Z direction and between beams in the Y direction, perpendicular to the operating aisle and which allows storage of the unit loads.

3.3

bracing lane

lane with bracing that provides stability in the X direction.

3.4

aisle carrier

machine that moves in the X direction and is used to move the shuttle, with or without the load unit, to its lane.

3.5

omnidirectional shuttle

machine capable of traveling in both X and Z directions, not requiring a distribution machine.

3.6

top tie beam

member joining the tops of the uprights across the lane in the X direction.

3.7

arm

load bearing component fixed to uprights

3.8

storage level

volume limited by the lane rail on which the shuttle moves and the next adjacent lane rail in the height.

3.9

distribution level

volume limited by the aisle rails on which the aisle carrier moves and the next adjacent aisle rails in the height.

3.10

aisle rail

beam for carrier movement in the X direction.

3.11

operating/distribution aisle

space giving access to lanes.

3.12

mono post

single upright tied to an adjacent upright frame by spacers.

3.13

lane rail support

element attached to the beams that supports the lane rail.

3.14

shuttle

machine that moves along a lane (Z direction) and is used to store/retrieve the load unit.

Note: EN528 uses the term “satellite” rather than shuttle.

4 Symbols

For the purpose of this document a number of the following symbols may be used together with standard subscripts which are given later.

Additional symbols and subscripts are defined where they first occur.

A symbol and subscript may have several meanings in this document.

In general, primary symbols are not defined with all the standard subscripts with which they may be used.

A_{ph}	Accidental action
E	modulus of elasticity
e	effective width for pressure spread on the base plate
E	Eccentricity
F	Action
f_t	yield strength obtained in the tensile test
f_u	ultimate tensile strength
f_y	yield strength of base material
G	shear modulus
G_k	characteristic value of a permanent action (dead load)
h	level height
I	second moment of area
L	distance between supports
M	bending moment
N	axial force
Q	variable action
Q_{ph}	horizontal placement load
Q_{pv}	vertical placement load
Q_u	unit load (weight of the pallet including stored items)
Q_s	shuttle weight (weight of the shuttle excluding the stored items)
q	uniformly distributed load
R	resistance
t	thickness
t_t	thickness of the base material observed by test
V	shear force
V	vertical load
γ	partial safety factor
γ_A	partial factor for accidental loads
γ_f	load factor
γ_G	partial factor for permanent loads

γ_M material factor

γ_Q partial factor for variable loads

ϕ sway imperfection

ϕ_0 initial sway imperfection

ϕ_s maximum sway imperfection

ϕ_l looseness of bracing beam end connection

χ stress reduction factor for buckling

Subscripts

b buckling

C compression, capacity

cr critical

d design

G gross

i test number

k characteristic

n corrected value

Rd design resistance

Ed design load

T Torsion

t value obtained from test

max maximum

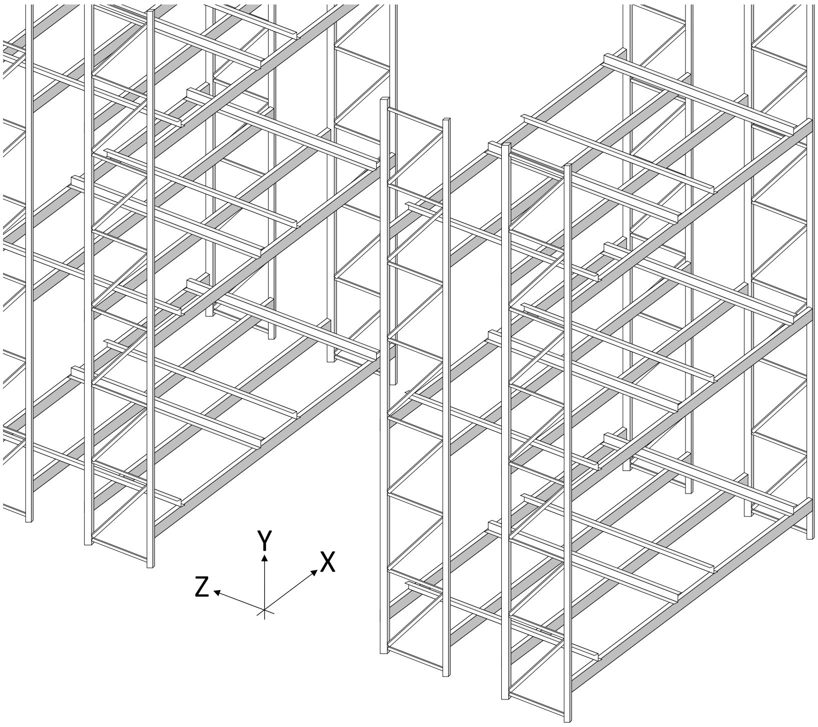
min minimum

R resistance

5 Basis of design

5.1 2.1 General

The convention for directions shall be as shown in Figure 1.



Key

X Down-aisle direction

Y Vertical direction

Z Cross-aisle direction

Figure 1 Convention for directions

Shuttle racking systems classification depending on material handling equipment:

- Shuttle racking operated by industrial trucks.
- Shuttle racking operated by S/R machines (see EN 15878, clause 5.5.3).
- Shuttle racking operated by aisle carrier
- Shuttle racking operated by omnidirectional shuttle – this type of machine is excluded from this document

5.2 2.2 Requirements

5.2.1 Basic Requirements

Shuttle racking systems for unit load storage are standard products for which design by calculation alone may not be appropriate. In addition to the test procedures specified in EN 15512, the relevant test procedures are given in Annex A.

Except where specific requirements are given to the contrary, the design procedures in this document shall be in accordance with EN 15512, EN 1990, EN 1993-1-1, EN 1993-1-3.

Use and maintenance shall be in accordance with EN 15635.

5.2.2 Design working life

See EN 15512.

5.3 Principles of limit state design

5.3.1 General

The design of the structure or its parts shall be carried out by one of the methods given in this document including the annexes.

5.3.2 Ultimate limit state (ULS)

See EN 15512.

The components that might be locally affected by fatigue are the lane rail, aisle rail and lane entrance guide. The Specifier shall provide the number of load cycles in order that the rack designer may evaluate if it is necessary to verify the fatigue of the lane rail. The data indicated in Annex H will be necessary.

NOTE: Beams, frames, rail supports and bracing structures are not normally affected by fatigue.

5.3.3 Serviceability limit state (SLS)

See-EN 15512.

5.4 Actions

5.4.1 General

All actions, either individually or in combination, included in this clause shall be considered for the design of the structure. The specifier can include additional actions.

5.4.2 Permanent actions

Weight of materials and construction. According to 15512.

5.4.3 Variable actions

In addition to the actions referred to in EN 15512 the actions due to the shuttle or aisle carrier shall be taken into account:

5.4.3.1 Unit loads to be stored

Unit loads shall be determined in accordance with the requirements of EN15629.

If the centre of gravity of the unit load does not coincide with the centre of the load make up accessory then the effect of this eccentricity should be taken into account in the analysis of the structure.

The design of the racking shall be based on the maximum value of the unit load unless the requirements of 5.4.3.1.1 or 5.4.3.1.2 are satisfied in which case the relevant reduced values may be adopted.

Beams and rails shall be designed to carry the loads derived from the maximum weight of the unit load specified at that level.

NOTE: It is the responsibility of the Specifier to determine whether the unit load is sufficiently stable to be transported on the shuttle. An assessment method is given in Annex J.

5.4.3.1.1 Systems controlled by a warehouse management system

According to EN 15512

5.4.3.1.2 Systems with random storage

According to EN 15512

5.4.3.2 Horizontal placement loads

Due to the lane rails any placement loads in the Z direction are shared across a large number of frames and may be neglected

In all other cases where there are beams along the X direction any placement loads in the X direction are shared across many frames and may be neglected.

NOTE: The minimum horizontal placement load is not intended to represent an impact load arising from misuse.

5.4.3.2.1 Horizontal placement load Industrial truck

If there are no beams between front uprights a minimum horizontal placement load Q_{ph} equal to 0,5KN shall be applied in the X direction at the level closest to the mid-height of the upright. This load need not be considered in the global analysis.

5.4.3.3 Horizontal guidance loads in the lane

Horizontal guidance loads (X and Z direction) in the lane shall be specified by the shuttle Specifier.

NOTE: In the absence of any specified loads this effect may be neglected.

5.4.3.4 Horizontal actions due to travelling, acceleration and deceleration

The effect of horizontal forces due to the shuttle in the lane in the Z direction during normal operation may be neglected.

5.4.3.5 Vertical placement load Industrial truck operation

With single unit load systems (i.e. when there is only one unit load per level per bay, or multiple loads placed simultaneously), load support beams, supporting arms (if any) and beam end connections on the aisle side face shall be designed for an additional downward vertical placement load Q_{pv} of 25% of the maximum load placed in the most unfavourable position for the particular determination (moment or shear force).

NOTE: The load distribution for the vertical placement load may be the same as for the unit load.

5.4.3.6 Vertical actions in the distribution aisle - Aisle carrier operated system

The concentrated loads transmitted to the rails through the wheels of the aisle carrier shall be considered in the most unfavourable position in each distribution level.

The value of these reactions shall be provided by the Specifier.

NOTE: See Annex I.

5.4.3.7 Vertical actions at storage level

The loads applied to the lane rail are caused by the shuttle plus the unit load during storage or retrieval.

These loads are transmitted to the rails in two ways:

a) As concentrated loads through the shuttle wheels and shall be considered in the most unfavourable position, the inertial forces shall be also considered (see Annex I);

NOTE: In the absence of specified values or other rational analysis the calculation of the wheel reactions should be based on the assumption that there are only 4 contact points of the wheels with the rail. In the case of pairs of wheels it is conservative to consider that the pair of wheels acts as one wheel.

b) As distributed loads once the unit load is in place on the rails.

5.4.3.8 Vertical actions due to shuttle transfer (S/R machine operated system)

The effect of the shuttle transfer from the S/R machine to the lane shall be taken into account as a vertical load. This load shall be provided by the Specifier.

In this document it is assumed that for S/R machine operated systems the position of the lifting carriage shall be;

- below the rail level when the shuttle leaves the lane (see Figure 2);
- above the rail level when the shuttle enters the lane (see Figure 4).

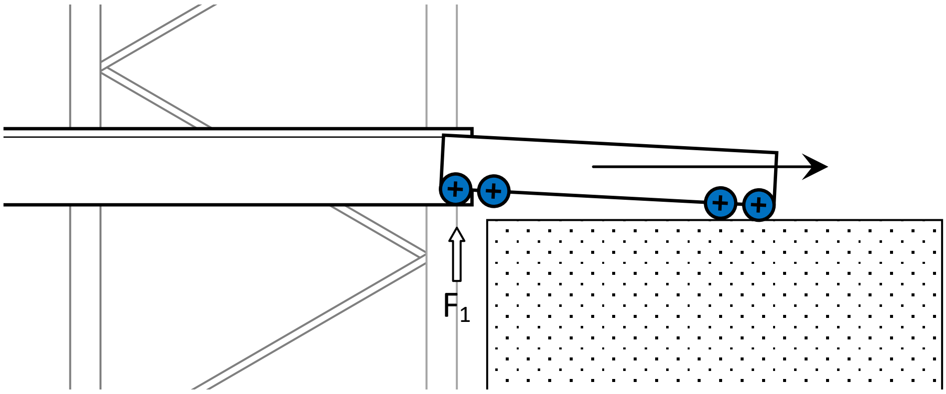


Figure 2 Example of loads due to shuttle transfer from lane

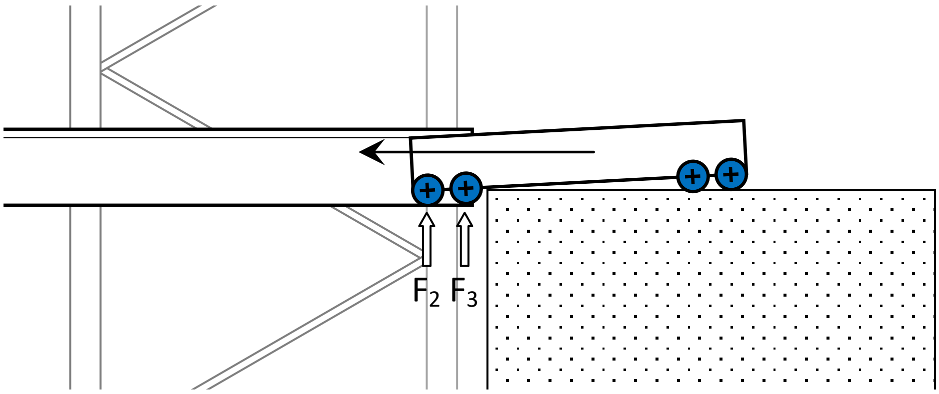


Figure 3 Example of loads due to shuttle transfer into lane

5.4.3.9 Vertical actions due to shuttle transfer (aisle carrier operated system)

The effect of the shuttle transfer to or from the aisle carrier shall be taken into account as a vertical load. This load shall be provided by the Specifier.

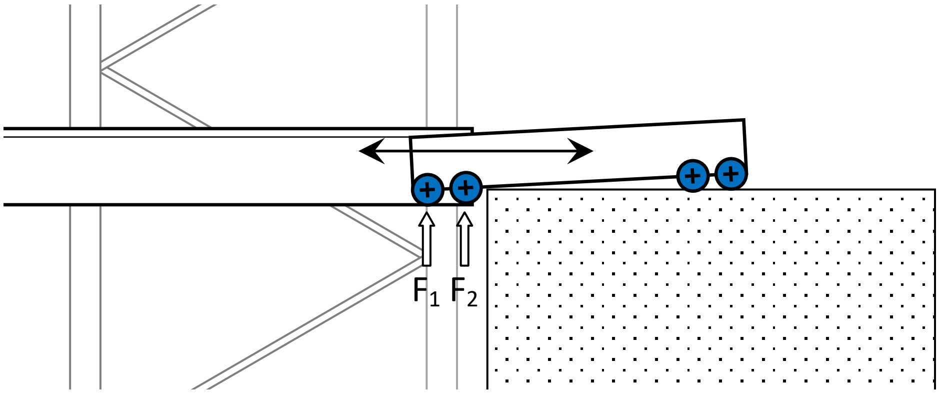


Figure 4 Example of loads due to shuttle transfer into or out of lane

5.4.3.10 Vertical actions due to aisle carrier transfer to or from the elevator

This load shall be provided by the Specifier.

5.4.3.11 Actions arising from floors, walkways and maintenance

ISO14122-2 gives a minimum load to consider for walkways and working platforms as 2kN/m^2

5.4.3.12 Actions arising from installation

See EN 15512.

5.4.3.13 Wind loads

See EN 15512.

5.4.3.14 Snow loads

See EN 15512.

5.4.3.15 Seismic actions

Seismic actions shall be determined according to the relevant National Regulations in conjunction EN 16681.

5.4.4 Accidental actions

5.4.4.1 Accidental actions from industrial trucks

See-EN 15512.

5.4.4.2 Accidental actions from S/R machines

See-EN 15512.

5.4.4.3 Accidental actions due to shuttle

5.4.4.3.1 Lane safety stop

Impact forces or energy of the shuttle against the lane safety stop shall be provided by the shuttle supplier.

NOTE 1: it is assumed that the pallet does not slide off the shuttle.

NOTE 2: it is assumed that the unit load and shuttle do not tip, and that the unit load remains stable.

The lane safety stop shall be designed for 100% of the nominal shuttle energy. Elements connected to, or supporting, the stop device shall also be designed for this energy.

The stiffness of the lane safety stop shall be less than the stiffness of the supporting rack

The lane safety stop may be permanently deformed after an impact by the shuttle. It shall be replaced when showing permanent deformation.

NOTE 3: This is important so that any damage occurs in the lane safety stop and not in the main rack structure.

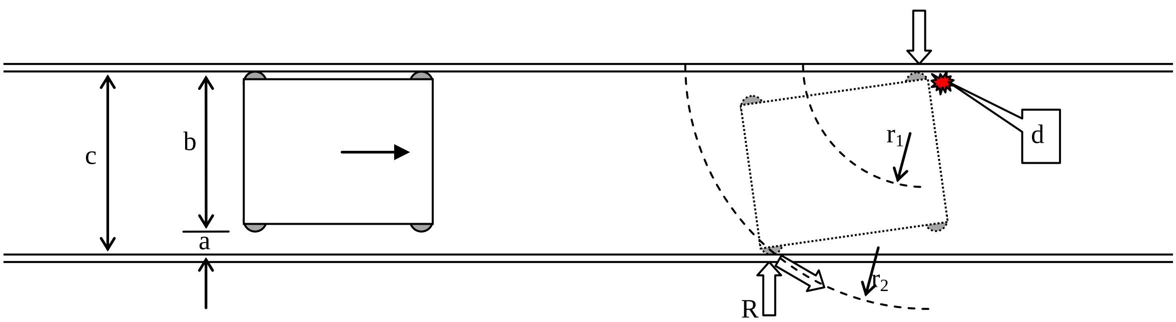
NOTE 4 : The energy should include the energy due to the mass of the shuttle, the energy due to the mass of the load plus the driving force of the motor as necessary.

5.4.4.3.2 Lane blockage

The accidental longitudinal force induced as result of the shuttle hitting an obstruction in the lane shall be provided by the shuttle supplier. For vertical loads applied by the shuttle refer to Annex I.

The accidental lateral force induced as result of the shuttle hitting an obstruction in the lane may be neglected.

NOTE: If the shuttle hits an obstruction in the lane this can cause the shuttle to yaw; this causes lateral load on the rail in addition to the force along the rail.



Key

a maximum gap between shuttle and rail;

b width of shuttle

c dimension between rails

d blockage

r_1 centre radius

r_2 impact radius

R horizontal guidance force

Figure 5 Horizontal action due to lane blockage

5.4.4.4 Accidental actions due to aisle carrier

Impact forces or energy of the aisle carrier against the buffer shall be provided by the aisle carrier supplier.

Alternatively rigid body analysis shall be done where the safety stop is fixed to the structure, considering at the centre of gravity of the affected elements (unit load and / or shuttle) a horizontal force equal to its weight, multiplied by the coefficient $\phi_{safetystop}$, that depends on the type of characteristic curve of the buffer.

$\phi_{safetystop}$ =1,25 for linear characteristics curve

$\phi_{safetystop}$ =1,60 for rectangular characteristics curve

NOTE 1: These values are taken from EN13001-2.

NOTE 2: it is assumed that the pallet does not slide off the shuttle.

NOTE 3: it is assumed that the unit load and shuttle do not tip, and that the unit load remains stable.

5.5 Combination of actions

5.5.1 General

Actions shall be combined at the Ultimate Limit State and at the Serviceability Limit State according to the rules given in EN15512.

The combinations to be considered shall be as given in Table 1.

Table 1 Combination of actions

Combination	Load state	Combination content				
1	SLS/ULS	G_k	Q_s	Q_{full}	Imp_z	
2	SLS/ULS	G_k	Q_s	Q_{pat}	Imp_z	
3	SLS/ULS	G_k	Q_s	Q_{full}	Imp_x	
4	SLS/ULS	G_k	Q_s	Q_{pat}	Imp_x	
5	ULS	G_k	Q_s	Q_{full}	Imp_z	$F_{ph,x}$
6	ULS	G_k	Q_s	Q_{pat}	Imp_z	$F_{ph,x}$
7	ULS	G_k	Q_s	Q_{full}	Imp_x	$F_{ph,x}$
8	ULS	G_k	Q_s	Q_{pat}	Imp_x	$F_{ph,x}$
9	ULS	G_k	Q_s	Q_{full}	Imp_z	$A_{ph,z}$
10	ULS	G_k	Q_s	Q_{full}	Imp_z	$A_{ph,z}$
11	ULS	G_k	Q_s	Q_{full}	Imp_x	$A_{ph,z}$
12	ULS	G_k	Q_s	Q_{full}	Imp_x	$A_{ph,z}$

Key	
G_k	Self-weight;
Q_s	Shuttle weight;
Q_{full}	Unit loads (fully loaded);

Q_{pat}	Unit loads (Pattern loading);
Imp_x	Global sway imperfection X direction;
Imp_z	Global sway imperfection Z direction;
$F_{ph,x}$	Placement load X direction;
$A_{ph,x}$	Accidental action X direction;
$A_{ph,z}$	Accidental action Z direction.

5.5.2 Shuttle and aisle carrier loads

The following situations shall be considered for all the shuttles and aisle carriers in the block:

Table 2 Load status and condition for shuttles and aisle carrier systems

Load status	**Condition**	
loaded	Standstill	Variable action
	Start moving	Variable action
	Braking	Variable action
	Emergency stop	Accidental action
	Accidental stop against safety stop	Accidental action
	Lane or aisle blockage	Accidental action
unloaded	Start moving	Variable action
	Braking	Variable action
	Emergency stop	Accidental action
	Accidental stop against safety stop	Accidental action

NOTE 1 In general, the actions on the structure caused by the unloaded shuttle or aisle carrier will be negligible with respect to the loaded one, unless the kinematic values (speed and acceleration) are greater in empty situation. In this case, dynamic forces should be considered in the worst situations.

NOTE 2 An emergency stop event results in the shuttles or aisle carrier stopping in a normal manner but with a higher deceleration

Following an emergency stop or activation of a safety stop the shuttles or aisle carrier and any goods involved in the event shall be checked before the system is restarted.

5.5.2.1 Industrial truck and S/R machine operated systems

Unless specified otherwise the rack design may be based on the assumption that only one shuttle is in the same location vertically at the same time. If more than one unit load is placed/retrieved in a single operation, then rack design shall be based on the number of unit loads or shuttles in operation at one time.

5.5.2.2 Aisle carrier operated systems

Unless specified otherwise the rack design may be based on the assumption that 50% of the shuttles are in the same location vertically at the same time.

5.6 Partial factors

Refer to EN15512

6 Materials

According to EN15512.

7 Durability

According to EN15512.

8 Structural analysis

8.1 Structural modelling for analysis

The calculation of a storage system shall be carried out in two steps. In the first step, a global analysis of the structure is carried out in order to determine the internal distribution of forces and displacements. In the second stage, the individual elements of the structure are checked to ensure that in the ultimate limit state they have adequate strength, and that in the serviceability limit state there are no unacceptable deformations.

See-EN 15512.

8.1.1 Ground structure interaction

See Table 3.

Table 3 Floor deformation limits for quasi-rigid assumption

	Quasi-rigid limit	
Truck operations	1/700	As for adjustable pallet racking (see EN15512)
Aisle carrier operations	1/1000	
S/R machine operations	1/2000	As FEM9.831-1

8.2 Global analysis

8.2.1 General

The global stability of the system shall be demonstrated by a rational analysis which takes account of the following factors:

a) The moment-rotation characteristics of the beam end connectors,
b) The moment-rotation characteristics of the upright to floor connection,
c) The shear stiffness of the bracing system with its connections,
d) The shear stiffness of the upright frames.

For the purpose of global analysis, system lines coinciding with the centroidal axes of the gross cross-section of the members shall be applied.

Storage systems are generally manufactured using cold-formed profiles and therefore elastic global analysis methods can be used. However, nonlinear connection behaviour in the analysis may be used provided that the nonlinear characteristic used is based on test results which demonstrate adequate rotation capacity. Alternatively, elastic-plastic analysis may be used if the sections undergoing plastic hinge action satisfy the criteria given in EN 1993-1-1 and EN 1993-1-3 for plastic design including the ductility requirements specified in these standards.

Bracing eccentricities and assembly eccentricities of beams to upright connections are treated in EN15512.

NOTE: In general, the rails for shuttles consist of thin-walled open cross section directly fixed to the uprights or mounted on arms which are connected to the uprights thereby giving a flexible bearing. Many conditions of this structural system, e.g. local load introduction into the rail, interaction between arm and rail etc., cannot be reliably determined from a theoretical analysis hence, the rack designer must decide on the need or not to perform a test (see Annex A).

8.2.2 Two-dimensional analysis

The structural behaviour of a shuttle racking system is generally a 3D behaviour. However, for the purposes of global analysis, that it can be treated as comprising of a set of plane frames lying in the vertical planes, parallel and perpendicular to the aisles, and in the horizontal plane, each of which is initially taken to operate independently. Imperfections in one plane may be neglected when carrying out the global analysis of the other plane. However, in member design, account shall be taken of effects in one plane which impinge on the behaviour in another, using appropriate interaction equations. Effects on the pallet beams shall be considered in the verification of them.

The forces coming from the two analyses shall be combined using the interaction formulas specified in EN 15512. Other elements should be calculated in one or the other plane of the racking system, as appropriate.

NOTE: The uprights are calculated by combining the axial load caused by stored load, etc., increased by any additional axial force caused by positioning loads, etc. with the bending moments in the direction of both axes of the cross-section. However, displacement imperfections, and placement loads can be considered in a single direction at the same time.

The procedure in this clause does not apply to storage systems which have discrete bracing towers along the length of the lane. A 3D analysis is necessary for such systems according to 8.2.3.

8.2.2.1 Analysis in the X-direction

For the design of the uprights, both the fully loaded condition and the pattern loaded condition shall be considered. For a regular rack layout it is sufficient to consider the pattern load case as shown in Figure 6.

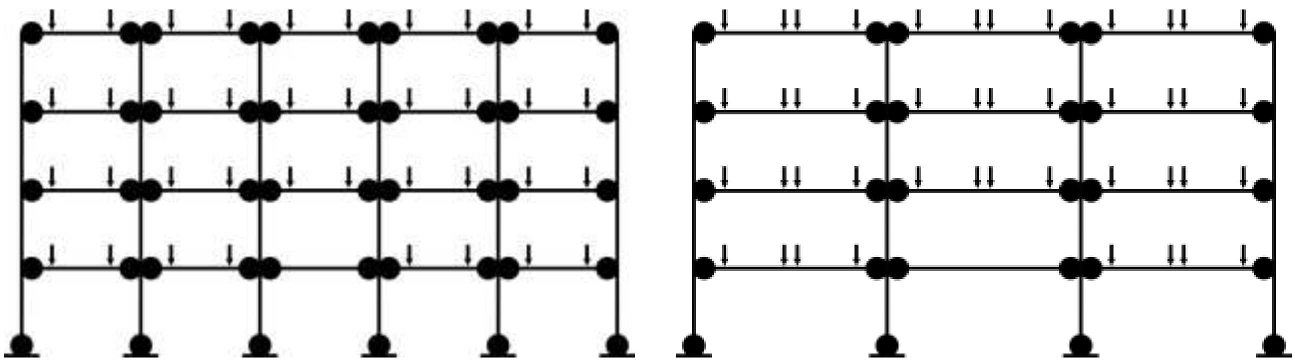


Figure 6 Typical loading pattern model for a rack system without bracing tower.

NOTE 1: If the lowest beam is near the ground, it may be more critical to omit the load from a single beam at the second level and the case shown in Figure 7 should also be considered.

NOTE 2: First order analysis may be considered for the design of pattern load cases, when those results are combined with the results of a second order analysis of the fully loaded condition.

NOTE 3: The pattern load shown in Figure 7 is modelled as a complete empty lane.

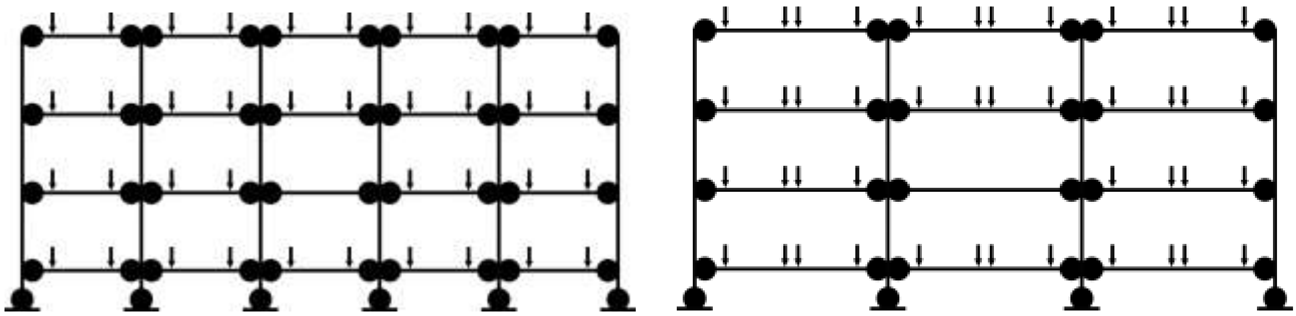
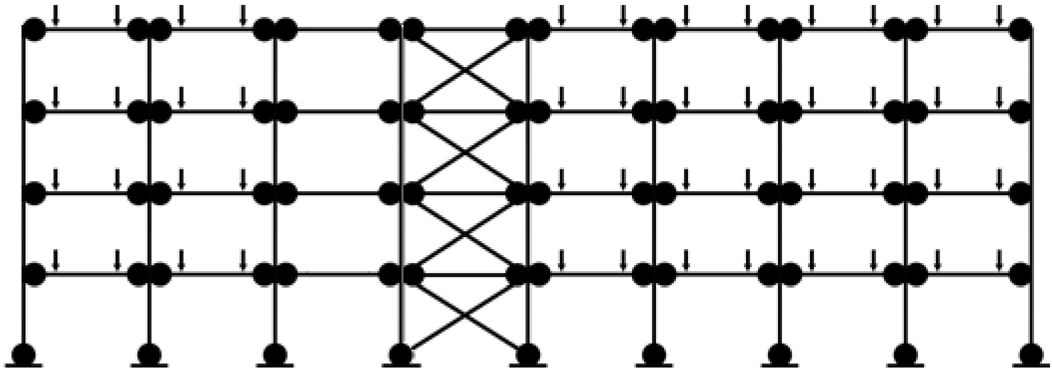


Figure 7 Additional loading pattern when the lowest beam is near the ground.

For the design of the uprights for a regular rack layout and vertical bracing (blind lane) both the fully loaded condition and the pattern loaded condition shall be considered with the exception of an unloaded lane as shown in Figure 8.



Key

● semi-rigid connection

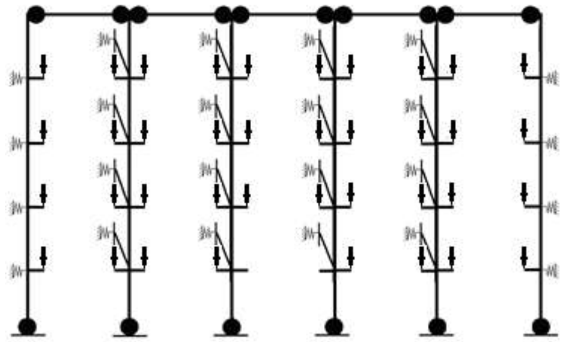
NOTE: If aisle rails are present, these may be considered in the model.

Figure 8 Typical loading pattern model for a rack system with bracing tower.

8.2.2.1.1 Industrial truck operated systems

In the case of industrial truck operated systems where the first plane or planes are different from the rest of the planes, the model shown in Figure 9 shall be considered.

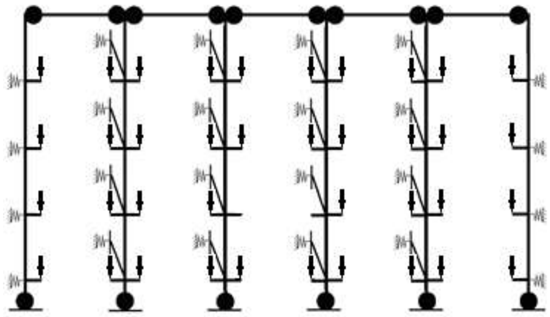
The effect of friction between the lane rail and pallet is unpredictable and should not be considered in the analysis.



NOTE: For forklift truck operations the first plane or planes often don`t have beams to ease the loading and unloading operations. The stability of the first plane or planes of a shuttle pallet racking is provided by the moment-rotation characteristics of the upright to floor connections, by the pallet beams of the shuttle that connect the first plane or planes with the rest of the planes and/or with additional beams located at the top of the rack.

Figure 9 Typical loading pattern for a rack system without bracing tower.

When the lowest lane rail is near the ground, the model shown in Figure 10 shall be considered.



Key

● semi-rigid connection

K Lateral stiffness

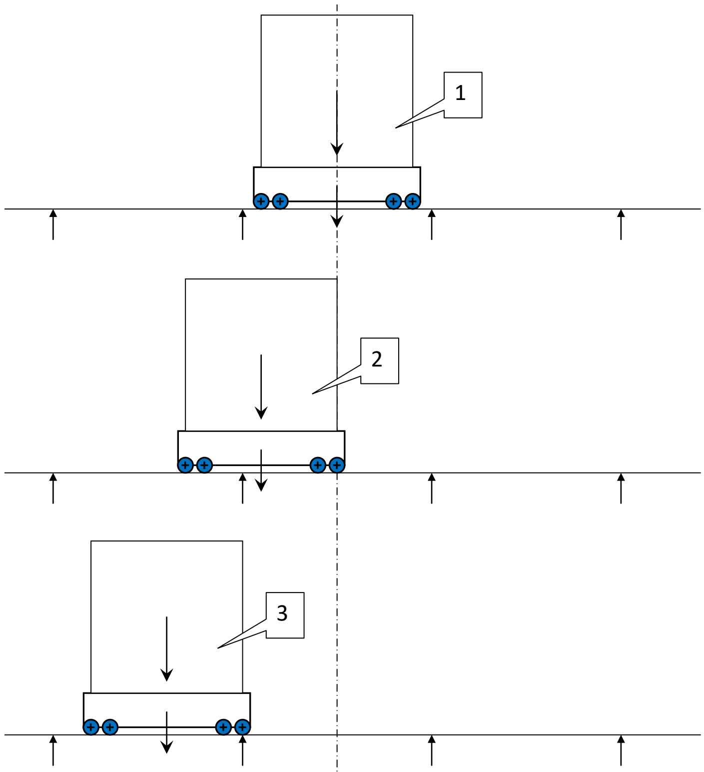
Figure 10 Additional loading pattern when the lowest storage level is near the ground

NOTE 1: The properties of the rotational semi rigid connection of the top tie beam end connector is obtained by test procedure A.3 of this document.

NOTE 2: The lateral stiffness provided by the lane rail can be obtained based on the procedures described in FEM 10.2.07 and FEM 10.2.17.

8.2.2.2 Analysis in the Z direction

For the verification of global stability in the down lane direction, the actions caused by imperfections as specified in 8.3 in combination with a fully loaded rack and a loaded stationary shuttle shall be considered. Three positions of the shuttle shall be considered as shown in Figure 11.



Key

1 Shuttle centre-of –gravity at mid-span

2 Shuttle wheel at mid-span

3 Shuttle wheel at support

Figure 11 Positions for loaded shuttle

For this model the reactions obtained from the verification of the lane rail may be used as point loads applied directly on the uprights or alternatively the lane rail may be included in the model. The connections between the lane rail and the upright may include a vertical linear spring representing the stiffness of the lane rail support. In addition, a torsion spring may be incorporated to represent the torsion properties of the lane rail support.

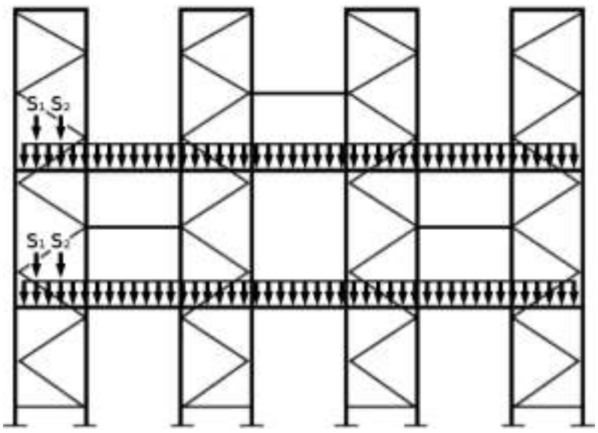


Figure 12 Example of model in Z direction including lane rail

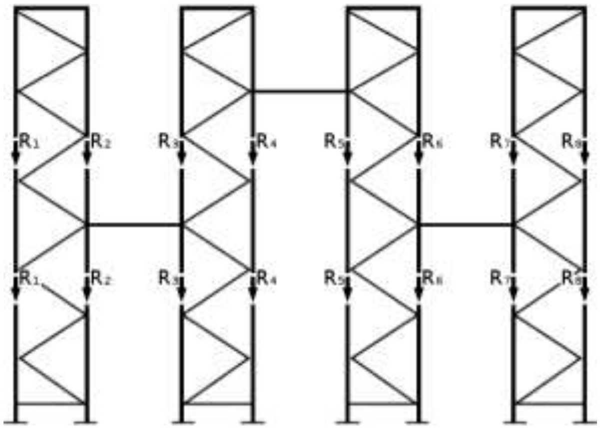


Figure 13 Example of model in Z direction without lane rail

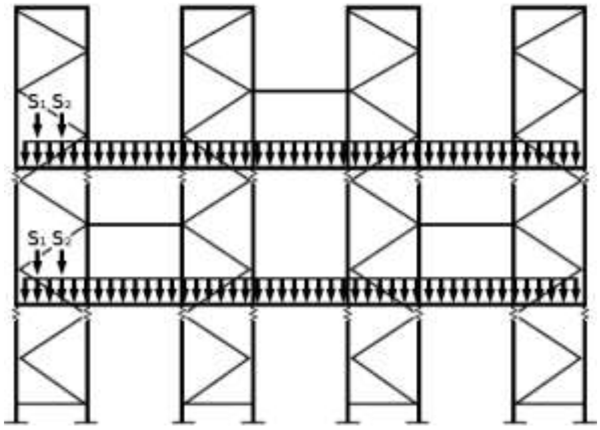


Figure 14 Example of model in Z direction

8.2.3 Three-dimensional analysis

According to EN 15512.

8.2.4 Effects of deformed geometry of the structure

According to EN 15512

8.2.5 Analysis method

The contents of this chapter must be considered in combination with the provisions of EN 15512.

8.2.6 Structural stability

According to EN 15512

8.3 Imperfections

Imperfections shall be considered according to EN15512 where;

n_{da} is the number of lanes plus 1

n_{ca} is the number of connected upright frames in the Z-direction, excluding mono-posts.

In the case of an arrangement comprising only mono-posts and a bracing system n_{ca} = 1.0

8.3.1 Industrial truck operated systems

In the case of systems without beams in the first plane (or planes), the global initial sway imperfection ϕ_{uls} (ultimate limit state) and ϕ_{sls} (serviceability limit state) shall be determined using the following values;

α_h =1,0

α_{da} =1,0

Sway imperfections in the down-aisle (X) direction for the other planes (with beams) and sway imperfections in the down-lane (Z) direction shall be in accordance with EN15512.

The maximum out-of-plumb of any upright in any direction should not exceed the values given in EN15620 for Wide-aisle and Narrow-aisle racking.

If the designer specifies a more onerous initial out-of-plumb imperfection than is given in EN15620 then the installation process shall be controlled in order to ensure that the design assumptions are achieved in practice.

9 Ultimate limit state

9.1 Resistance of cross-sections and elements

In accordance with EN 15512.

9.2 Design of components

In accordance with EN 15512.

9.2.1 Beam design

9.2.2 Loads on beams

The load on the beam should be considered as concentrated and applied at the connection with the lane rail support.

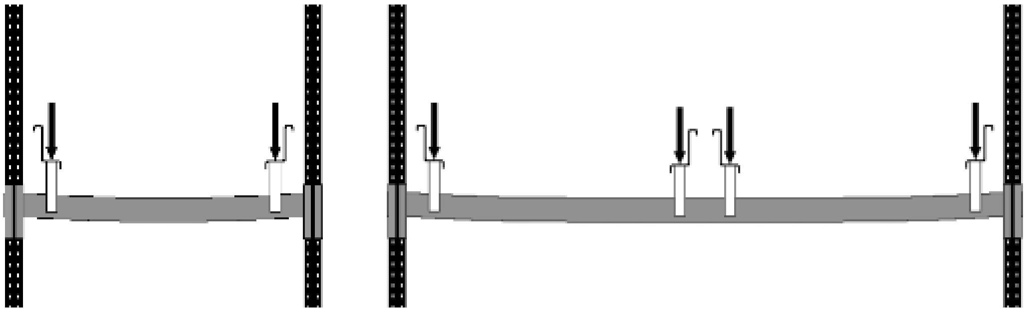


Figure 15 Situations with one or two loading levels per beam.

NOTE: Attention should be paid to the design of the supports of the lane rail to avoid crushing, crippling or buckling in a web.

The distribution of the beam loads may be calculated by using a continuous beam model supported on springs representing the column stiffness and beam rail to upright stiffness. If this is not done, then the minimum continuity factors given in Table 4 shall be used.

Table 4 Beam rail continuity factors

Condition	Correction factor
Up to 3 beams supporting the rail	1,15
Up to 4 beams supporting the rail	1,10
More than 5 beams supporting the rail	1,05
NOTE In order that these factors can be taken the difference in spacing between adjacent beams shall not exceed the average value by more than 7.5%.	

The beam check shall take into account the most unfavourable situation, including the load units, as well as the loads on the lane rail produced by the shuttle.

If the beam is also used as a tie beam been part of the bracing, the compression of the beam should be considered in the design.

9.2.2.1 Top tie beam

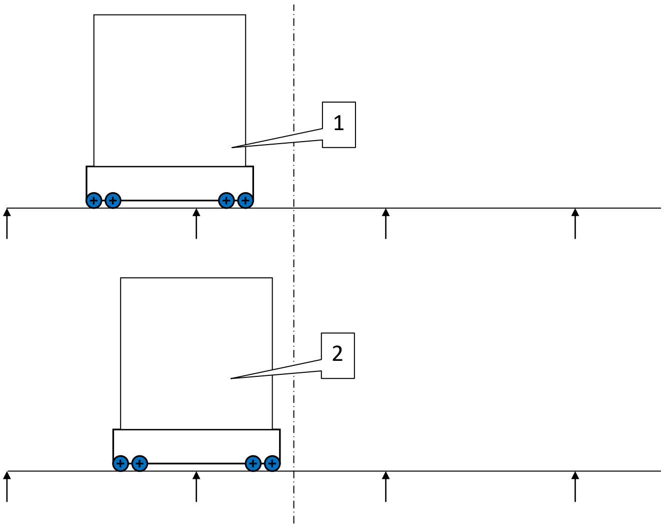
The verification of the top tie beam shall be carried out with the actions obtained from the global analysis.

9.2.3 Lane rail design

9.2.3.1 General

The lane rail shall be designed to support the worst situation. This shall include the following load conditions;

a) Rail fully loaded with unit loads;
b) Loaded shuttle with the shuttle wheels at mid-span of the first lane rail span (see Figure 16);
c) Loaded shuttle with the shuttle wheels equidistant from the second support (see Figure 16).



Key

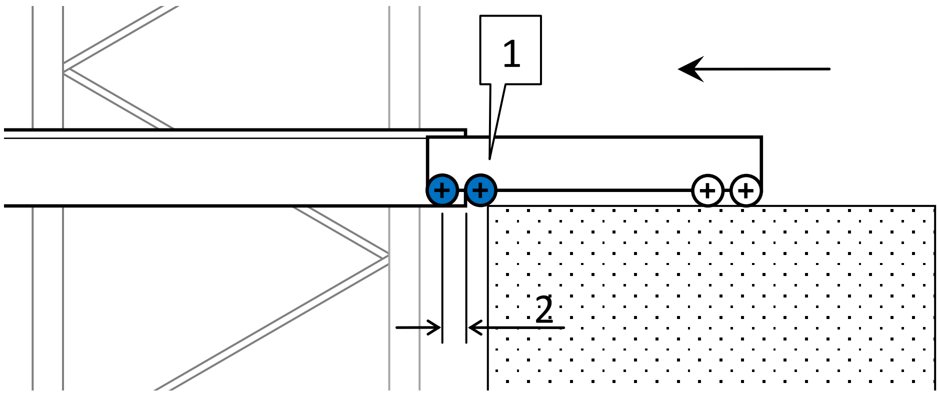
1 Shuttle wheel at mid-span

2 Shuttle over support

Figure 16 Positions for loaded shuttle

9.2.3.2 S/R machine and carrier operated systems (transfer)

The lane rail shall be designed to support the worst situation, including the movement of the shuttle loaded or empty and the stored load units if any.



Key

1 wheel at the instant of leaving the lifting carriage

2 minimum distance to lane rail end, where a wheel load will be supported by the lane rail

Figure 17 Situation with the shuttle enters the rack lane.

NOTE: Lane rails should be verified by testing according to Annex A.

If the specifications are different from the conditions of testing, rational finite element analysis calibrated by tests can be used.

Verification of the lane rail by test only covers the actions produced by load units and shuttle, including local effects. The tests do not include other actions such as those derived from assembly imperfection, produced by the wind (in rack-clad buildings) or the horizontal loads produced by shuttle acceleration. If the lane rail works under compression it should be considered in its design.

In designing the lane rail it is allowed to neglect effects of torsion due to the position of the wheel loads with regard to the shear centre of the lane rail and horizontal lane rail bending, because of a combination of positive effects due to friction and the horizontal guide wheels.

9.2.3.3 Industrial truck operated systems - transfer

Other than the vertical placement loads as given in 5.4.3.5 there are no other special requirements.

10 Serviceability limit state

In accordance with EN 15512.

10.1 Limits of deformation of the lane rail

10.1.1 Limits of deformation of the lane rail in the Y direction

The maximum vertical deformation of the lane rail under load and the local deflection of the lane rail, due to the shuttle wheel, shall not exceed the service criteria.

The service criteria shall be provided by the equipment supplier. Unless specified otherwise, Table 5 indicates the requirements.

Table 5 Maximum deformation of the lane rail under load

	deformation down[c]	**deformation up**[c]
Lane rail δ_3[a]	L/300 maximum 3,0mm	L/300 maximum 3,0mm
Local flange deflection due to wheel δ_4[b]	1,0mm	-
NOTE L is the length between supports		
[a] refer to Figure 18 [b] refer to Figure 19 [c] deformation of the rail shall include both torsional and bending effects		

When the lane rail is effectively continuous along several modules, both deformations upwards and downwards shall be taken into account.

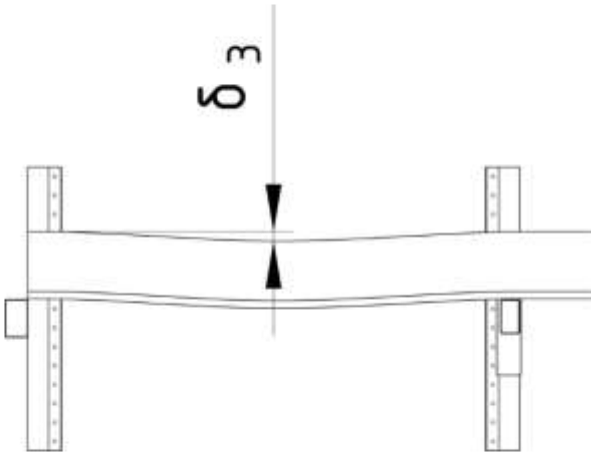
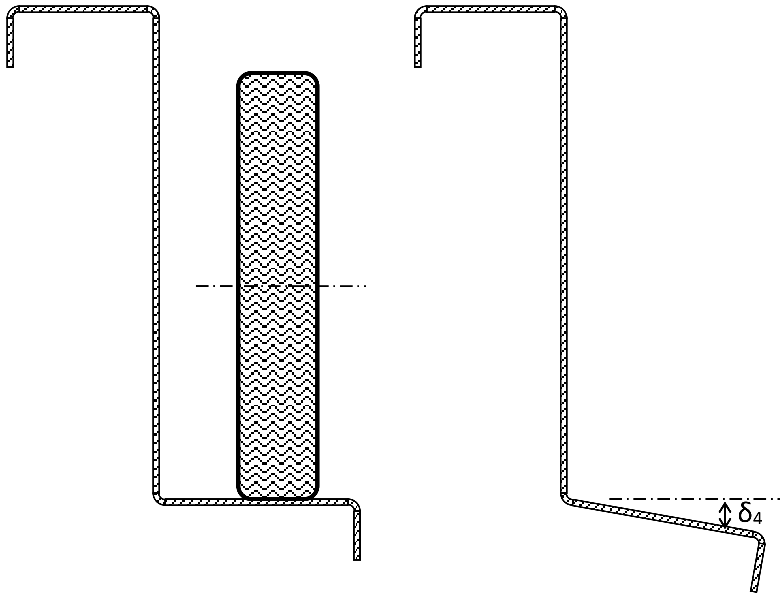


Figure 18 Lane rail deformations.

It is not necessary to combine the effects of the deformations of the beams and the lane rail simultaneously.



Key

δ_4 is the local deflection of the lane rail under each wheel

Figure 19 Local deflection of lane rail due to shuttle wheel.

10.2 Limits of deformation of the beam in the Y direction

The maximum bending values shall be provided by the Specifier in each project, taking into account the specific requirements of the installation.

NOTE: Different limits of deflection may be defined for the aisle beam than for other beams. If there is no specific requirement, it is recommended to use the maximum deformation values indicated Table 6.

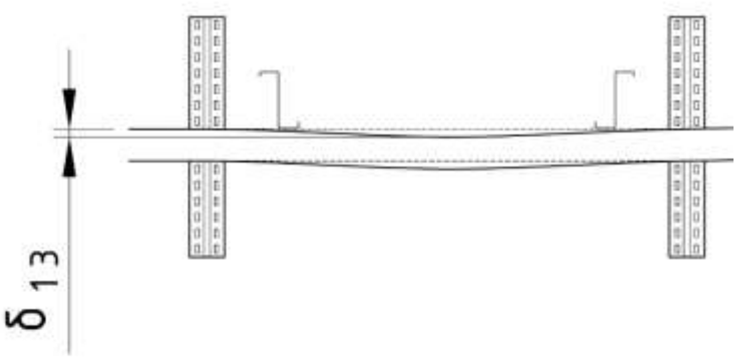
Table 6 Maximum deformation of the beam under load

	Bending deformation down
Beam	Maximum 5mm

10.3 Limits of deformation of the aisle rail in the Y direction

The maximum vertical deformation of the aisle rail under load shall not exceed the service criteria.

The service criteria shall be provided by the equipment supplier. Unless specified otherwise, Table 7 indicates the minimum requirements.



Key

δ_{13} is the deflection of the aisle rail

Figure 20 Deflection of aisle rail.

Table 7 Maximum deformation of the aisle rail under load

	Bending deformation down	**Bending deformation up**
Aisle rail δ_{13}	L/300 maximum 3,0mm	L/300 maximum 3,0mm
NOTE L is the length between supports		

10.4 Lateral deformations of the storage system

10.4.1 Industrial Truck operated systems

Refer to EN15620 for Wide-aisle or Very narrow aisle systems as relevant

10.4.2 S/R machine operated systems

For S/R machine operated systems, unless the Specifier has provided maximum deformations, the limits of frame deformations at serviceability limit state are those defined in FEM9.831-1 with control system D.

10.4.3 Aisle carrier operated systems

If the aisle carrier does not transfer between levels then it is not necessary to specify X and Z deformation limits for the rack in the aisles.

If the aisle carrier transfers between levels the deformation of the rack at the elevator position shall be considered. Refer to the shuttle supplier.

10.5 Elastic shortening of the upright

The effect of elastic shortening of the upright shall be taken into account when considering the height selection system by the Specifier or supplier of the handling equipment.

The values of elastic shortening shall be provided by the rack designer

NOTE 1: The displacement of any level on the Y-axis depends on the accumulation of the compressive stress on the length of each individual upright between levels below the considered level

NOTE 2: This is normally only applicable to S/R machine operated systems

NOTE 3: in very high aisle carrier installations, there can be differences between aisle rails heights at upper levels when one side of the aisle is fully loaded and the other is empty. This may affect the operation of the system and may necessitate restrictions in the way the rack is loaded.

11 Design of joints

According to EN15512.

11.1 Design of the rail-upright connection

The connections between the lane rail and the upright shall be verified with the actions obtained from the global model.

The resistance of the component and its union will be in accordance with the tests indicated in this standard.

12 9 Design assisted by testing

The tests specified in Annex A are in addition to those specified in EN 15512.

13 Marking and labelling – Identification of performance of rack installations

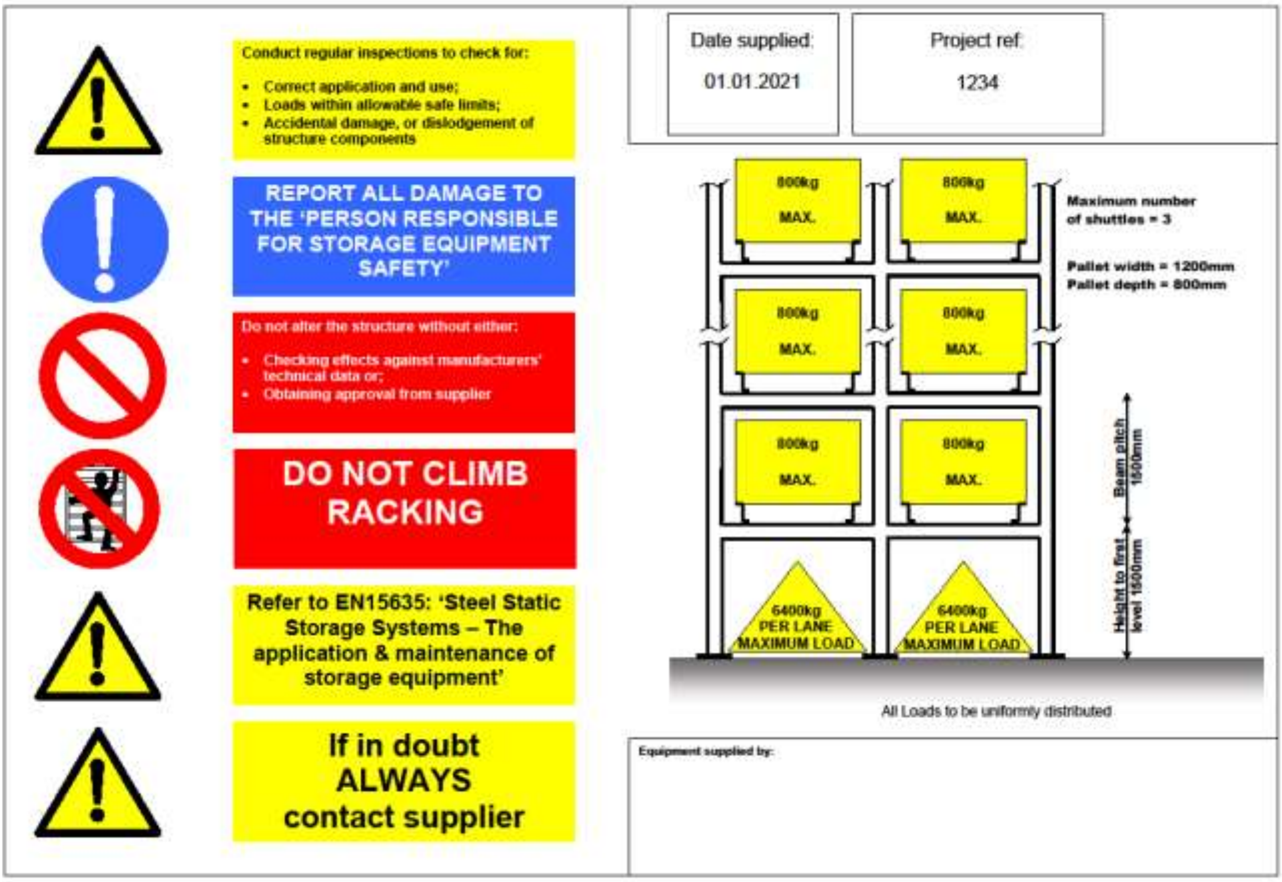


Figure 21 **Typical load notice**

Annex A
(normative)

Testing

A.1 Tests

Table A.1 Tests for design purposes

clause	Title	Test method
	Test on lane rails	A.2
	Test on lane rail to upright arms (Truck operation)	A.3
	Test on lane rail to beam support bracket	A.4
	Test of beam end connectors of the upper tie beam (Truck operation)	A.5
	Shuttle safety stop	A.6

A.2 Test on Lane rails

A.2.1 General and purpose of the test

Testing of the rails is required to evaluate the bearing capacity and deformation under load. The tests shall be carried out using a system comprising a left and right-hand rail over 3 supports (i.e. two spans).

NOTE: In general, the rails for shuttle consist of thin walled open cross section directly fixed to the uprights or mounted on arms which are connected to the uprights thereby giving a flexible bearing. Many conditions of this structural system, e.g. local load introduction into the rail, interaction between arm and rail etc., cannot be reliably determined from a theoretical analysis hence, the rack designer must decide on the need or not to perform a test.

The test shall cover the situation with lane carrier fully loaded (unit load being transported), where two basic load cases are to be examined as well as the situation with unit loads (pallets) resting on the beam lane rail. This gives 3 situations:

a) lane carrier in between two supporting beams (see Figure A.1);
b) lane carrier centred above supporting beam (see Figure A.1);
c) unit loads (pallets) resting on top flange of the beam lane rail.

The load make-up accessory may cover either the general case for any possible type or a particular case. Additionally, it must be taken into account that the lane rails are designed to withstand the loads of the shuttles.

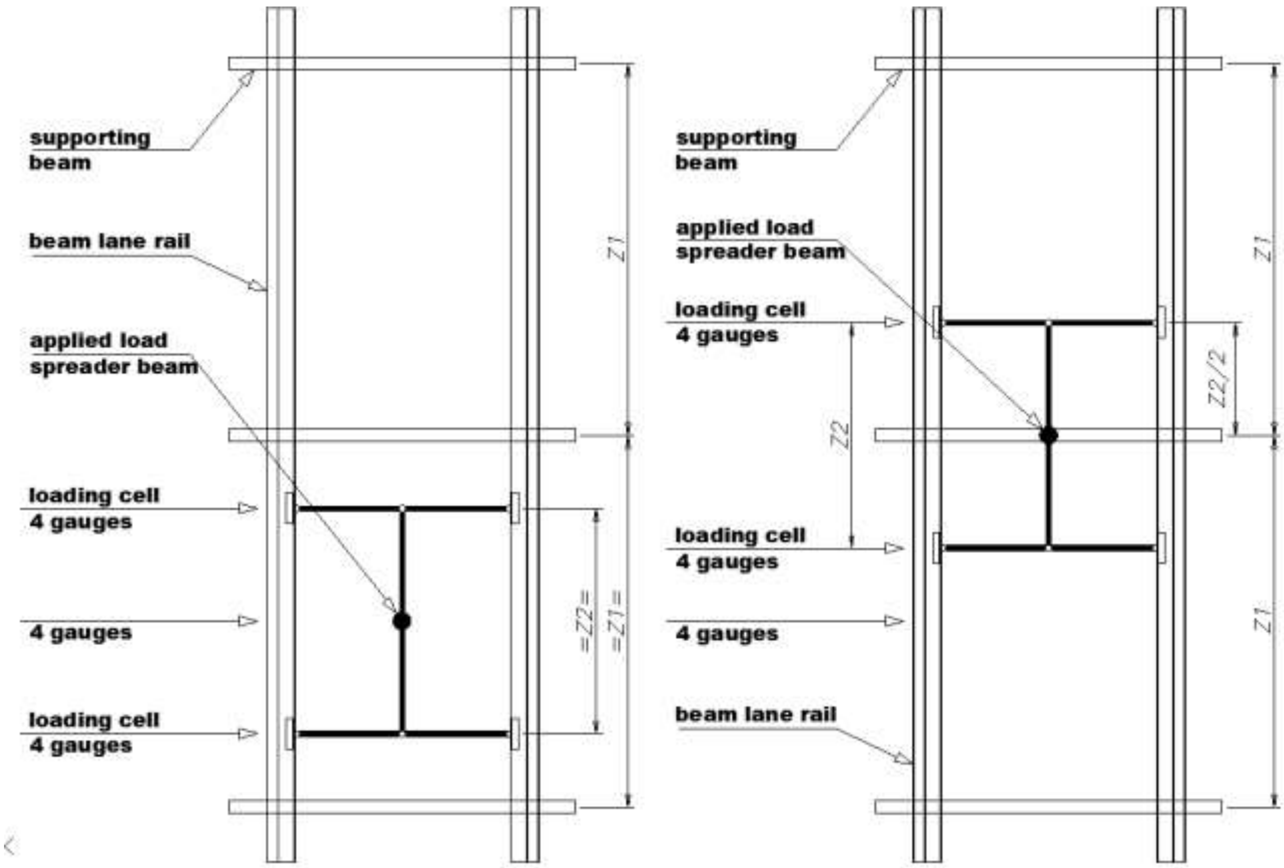
A.2.2 Test arrangements

A.2.2.1 General case

The test set up consists of a pair of beam lane rails running over two spans and supported by the relevant beam supports (or arms).

The method of load application shall not provide restraint to the lane rail.

The span (Z1 see Figure A.1) of the beam lane rail to be tested shall be at least ×10 bigger than the height of the lane rail (Y1 see Figure A.2).



Key

1 spreader beam;

2 measuring devices;

3 load cell;

4 beam lane rail;

5 supporting beam;

Z1 centre to centre distance of supporting beams;

Z2 lane carrier wheel centre to centre distance.

Figure A.1 Lane rail test a and b – load due to lane carrier

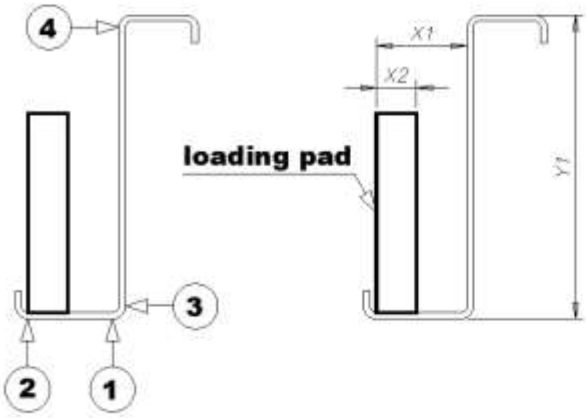
Measuring devices shall be positioned at the mid span of the lane rail. The gauges shall be positioned such that the rotation of the rail surface as well as the horizontal and vertical deflection can be determined (see Figure A.2). Two more sets of measuring devices shall be placed at the position of the load pads.

At load cell shall be positioned at each loading pad position.

The contact width of the loading pad shall not exceed 1cm unless stated otherwise by specifier (integrator, end client etc.).

Cross sectional dimensions of the lane rail shall reflect those adopted in practice. Where different rails are used either the different rails shall be tested, or conservative values used.

NOTE: it is acceptable to test weaker and/or more flexible rails and to use those values for other rails which can be shown to be stronger or stiffer.



Key

1-4 measuring devices;

5 loading pad.

Figure A.2 Position of gauges

A.2.2.2 Test procedure

Apply an initial load, F, equal to 10 % of the anticipated failure load, and then remove the load and re zero the measuring gauges.

NOTE 1: the purpose of this 10% load is to 'bed-in' the test pieces.

The load shall then be increased gradually either until the specimen can accept no more load (due to failure of the beam rail or connection) or excessive deformation of the specimen occurs.

NOTE 2: excessive deformations would hinder a smooth operating of the lane carrier under normal operational conditions.

A.2.2.3 Correction of the test results

The test results shall be corrected for variation in material strength and material thickness according to EN 15512, clause 13.3.5. A statistical evaluation of the test results shall be carried out in compliance with EN 15512, clause 13.3.3.

A.2.2.4 Derivation of results

The characteristic failure moment M_k shall be derived in accordance with EN15512 clause 13.3 for both the positive and negative bending tests. From these values of $M_{k,pos}$ and $M_{k,neg}$ the minimum effective section modulus W_{eff} can be determined

The effective section modulus $W_{eff} = M_k/f_y$

The moment of inertia of the beam rail can be determined by preparing an analytical (FE) model of the test arrangement and adjusting the moment of inertia of the beam rail in the analytical model until the results are in accordance with the observed test results.

A.2.2.5 Unit loads. Make-up general case

The test load is applied via knife edge bearings at the dimension b.

$$b = e + r$$

The distribution of the single loads shall be as defined in Figure A.3 to determine the sagging moments and properties.

In order to apply the moments and properties in the reverse direction (hogging) at the connection to the upright the loads shall be applied to both spans (the dotted arrows indicate the additional loads that are necessary).

The results shall be corrected as defined in Table A.2, in order to simulate the actual load distribution due to the pallet.

Table A.2 Number of single test loads and correction factors

Span L	Number of single loads	Correction factor for load (f_l) Sagging moment	Correction factor for load (f_l) Hogging moment	Correction factor for vertical deflection (f_z)
Up to 1,0m	1	2,00	1,48	1,60
1,0m to 1,5m	2	1,35	1,32	1,30
1,5m to 2,5m	4	1,00	1,02	1,00

$$F_t = f_l \times F$$

where

- F is the test load (single load);
- F_t is the theoretical uniformly distributed load.

$$F_{lz} = f_z \times F_z$$

where

- F_z is the test load (single load);
- F_{lz} is the theoretical uniformly distributed load.

If the twist of the lane rail measured in the test is less than 6° (having removed the effect of arms bending) then no further correction to the twisting is necessary. If the twist exceeds 6° then corrections shall be made in accordance with standard theory.

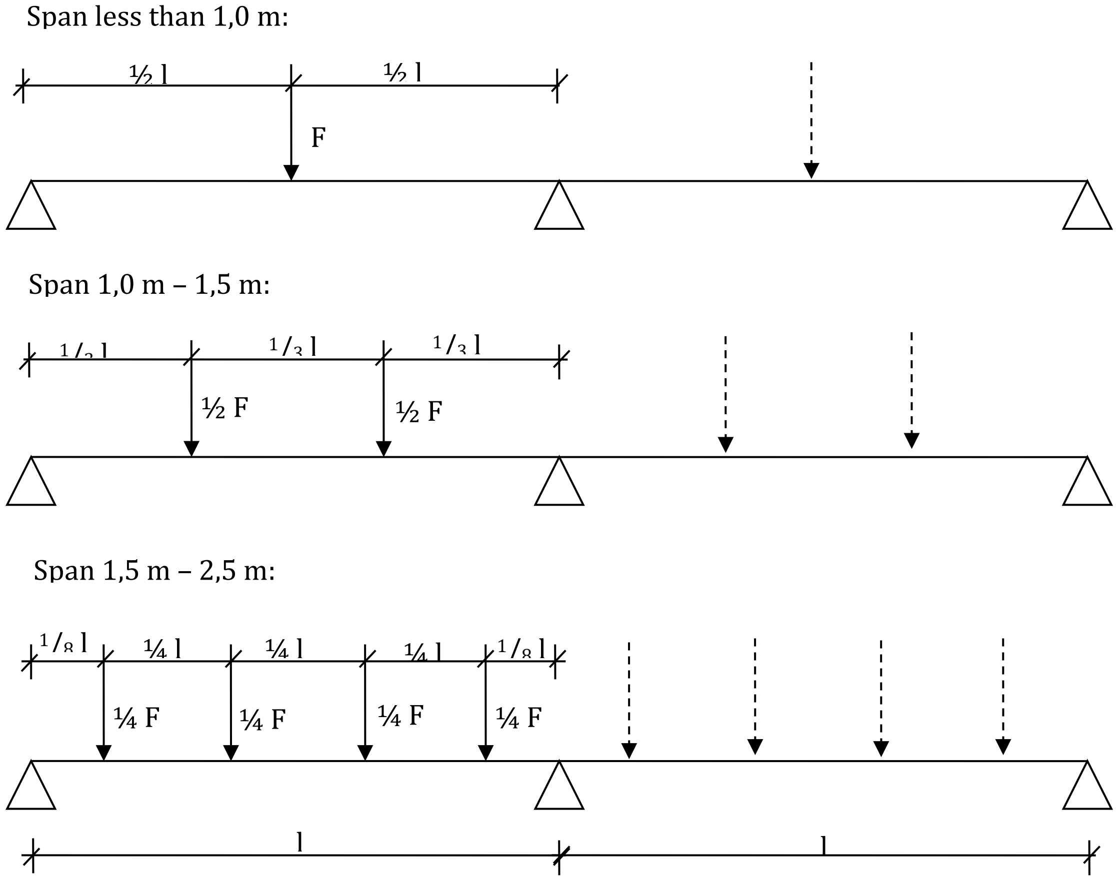


Figure A.3 Distribution of single test loads for general load make-up accessories

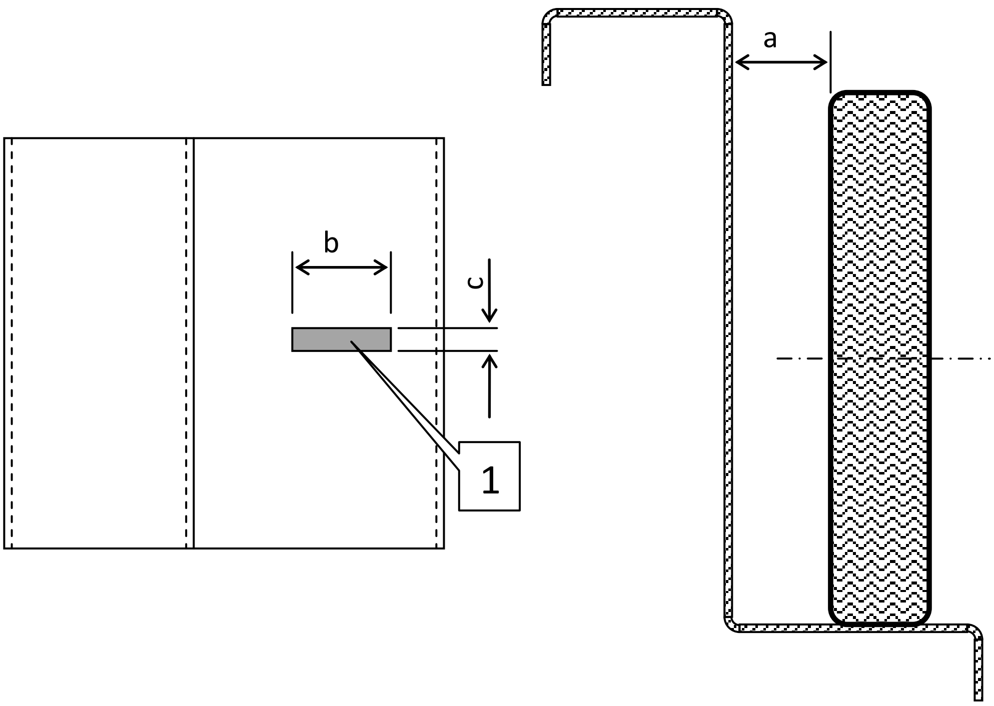
A.2.2.6 shuttle

The effect on the lane rail of the loaded shuttle must be taken into account and therefore the deformations and resistance must be controlled.

The number of individual loads to be applied, the position in the running surface and the separation between them will be that corresponding to the specific shuttle, depending on the provider's data.

- Dimensions of the shuttle, separation between wheel axles.
- Number of wheels and dimensions of the contact surface

The position to consider in the direction of the lane rail will be the most unfavourable possible.



Key

1 Contact surface b×c;

a distance from the wheel to the web of the lane rail.

Figure A.4 Detail of the footprint of the shuttle wheel on the lane rail.

A.2.3 Test procedure

The load shall be increased until failure in one on the lane rail connector (or arm), or lane rail or unacceptable deformation is observed.

A.2.4 Correction of the test results

The test results shall be corrected for variation in material strength and material thickness according to EN 15512, clause 13.3.5. A statistical evaluation of the test results shall be carried out in compliance with EN 15512, clause 13.3.3.

A.3 Test on lane rail to upright arms (Truck operation)

A.3.1 General and purpose of the test

In most cases the bracket is a thin walled cold formed section provided with hooks or bolts which are connected to system holes in the rack upright. If the capacity of the connection cannot reliably be derived from theoretical analysis, then the rotational stiffness and bearing capacity of the brackets shall be determined from tests.

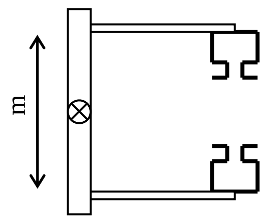
A.3.2 Test arrangements

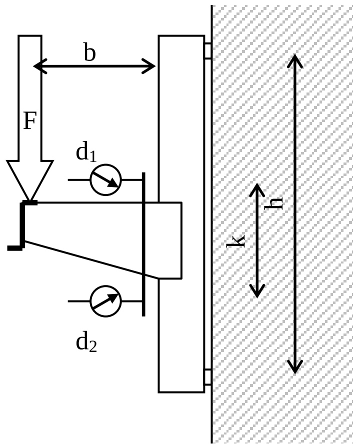
The test arrangement shall be as follows:

a) A pair of short upright pieces shall be connected to a relatively stiff testing frame at two points with a clear distance h between these connection points where:

h ≥ length of bracket to beam connection + 2 × upright face width

b) Two rail brackets shall be connected to the pair of upright pieces. The distance m between the outer edges of the brackets shall be in the range of 100 mm – 200 mm.
c) The test load is applied using a spreader beam.
d) The test load shall be introduced in the mid span of the spreader beam and shall be applied to the brackets via knife edge bearings.
e) The rotation shall be measured by either of the following:
   1) displacement transducers bearing onto a plate fixed to the bracket close to the upright connection (gauges d_1 and d_2 in Figure A.5)
   2) an inclinometer connected to the bracket close to the upright connection





Key

b lever arm;

d measuring devices;

F load device;

h length of test specimen;

k spacing of measuring devices;

m distance between outer edges of two brackets (m = 100 mm – 200 mm).

Figure A.5 Arrangement for testing of bracket.

A.3.3 Test procedure

Load the connector vertically. An initial load, F, equal to 10 % of the anticipated failure load may be applied to the assembly and then removed as a preload in order to bed in the components. The gauges should then be reset. The load, F, shall then be increased gradually until the maximum load is reached and the connection fails. The rotation of the connection shall be observed and, for each test, a plot of the moment and the rotation shall be made, in which:

$$M_t = b\,F$$

and

$$\theta = \frac{\delta_1 - \delta_2}{k}$$

where

δ_1 is the deflection measured by gauge d_1;

δ_2 is the deflection measured by gauge d_2.

A.3.4 Corrections of the observations

The test results shall be corrected for variation in material strength and material thickness according to EN 15512, clause 13.3.5. A statistical evaluation of the test results shall be carried out in compliance with EN 15512, clause 13.3.3. The correction factor C shall be determined for the bracket.

A.3.5 Derivation of the results and procedure to define moment-rotation curves

1. Derive adjusted moment-rotation curves for each test;
2. Calculate M_k and M_{Rd};
3. Find k_i from each curve using M_{Rd};
4. Calculate the design stiffness k_d.

For each upright and connector assembly, the characteristic failure moment M_k shall be calculated in accordance with Figure A.6. The design moment for the connection is then M_{Rd};

$$M_{Rd} = \frac{M_k}{\gamma_{M2}}$$

where

γ_{M2} is the partial safety factor for connections.

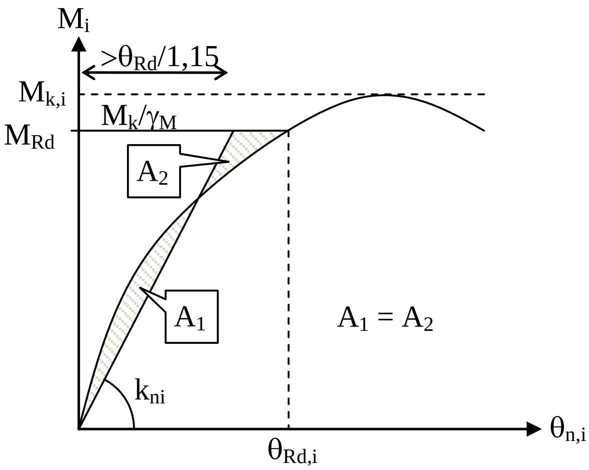


Figure A.6 Derivation of connector stiffness.

The design value, k_d, of the connector stiffness shall be taken as the average value:

$$k_d = \frac{1}{n}\sum_{i=1}^{n} k_{ni}$$

A.4 Test on lane rail to beam support bracket

A.4.1 Purpose of the test

The purpose of the test is to obtain a value of the strength and stiffness of the support bracket connecting the lane rail to the beam. It is influenced by several factors, particularly:

a) the type of the beam (shape, thickness and material);
b) the type of support bracket (shape, thickness and material);
c) the method of connecting the support bracket to the beam (typically bolted or welded).

All combinations of these factors shall be tested separately, unless it can be reasonably demonstrated that interpolation of results provides a conservative estimate of performance.

A.4.2 Test arrangements

The test arrangement shall be as follows.

a) A short length of beam shall be connected to a relatively very stiff testing frame at two points with a clear distance, h, between them. Over this distance, there shall be no contact during the test between the beam and the testing frame. A lane rail to beam support bracket shall be connected to be tested. Typical example of suitable test arrangement is shown in Figure A.8.

   $h \geq \max(3 \times j, 2 \times f, 400\text{mm})$

b) The load, F, shall be applied in the middle point between the bolts connecting the lane rail to the support bracket;
c) The direction of the load application shall be according to the expected behaviour;

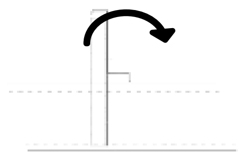
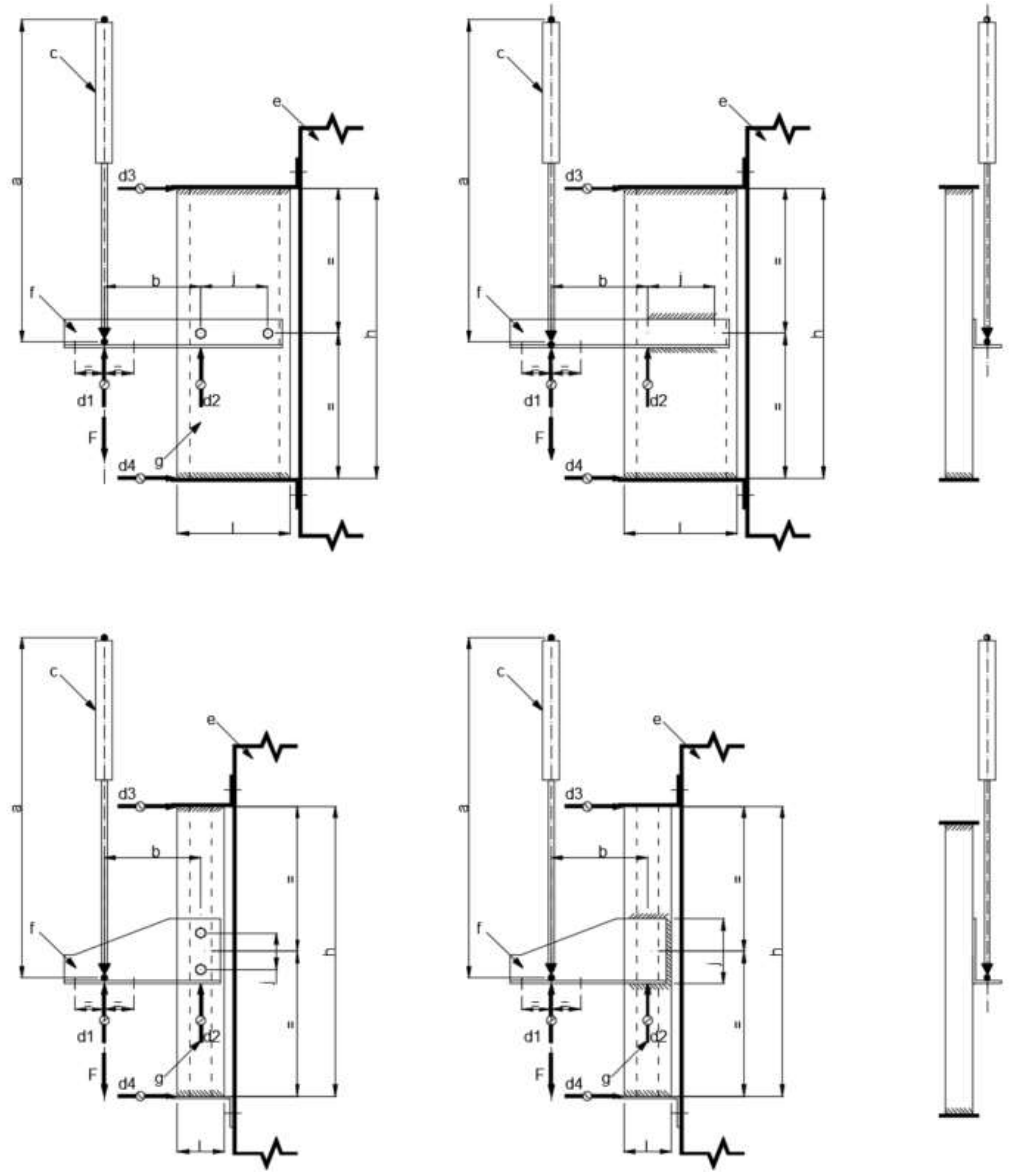


Figure A.7 Expected behaviour.

NOTE: twisting or sideways movement of the bracket may be prevented by a lateral restraint which, however, allows the lane rail to beam support bracket to move freely in the direction of the load. Alternatively, a pair of lane rail to beam support brackets may be tested in parallel.

d) The rotation shall be measured by either of the following:

   1) displacement transducers (Gauges d_1 and d_2 in Figure A.8);
   2) an inclinometer connected to the lane rail to beam support bracket.



Key

a ≥ 750 mm;

b is the distance between the gauges d_1 and d_2;

c load jack;

d measuring devices;

e test rig structure;

f lane rail to beam support bracket;

g beam;

h beam length;

j distance between bolts or welding length of connection between support bracket to beam;

l beam width;

F Load.

Figure A.8 Arrangement for lane rail to beam support bracket test showing typical connections.

A.4.3 Test procedure

The tests described in Figure A.8 load the lane rail to beam support bracket vertically downwards.

In case the support bracket is bolted to the beam, an initial load, F, may be applied to the assembly and then removed as a preload in order to bed in the components. This preload should be enough to allow the support bracket slide, because of the holes and bolts clearances, ensuring contact between support bracket, beam and bolts.

The gauges should then be reset. The load, F, shall then be increased gradually until the maximum load is reached and the lane rail to support bracket fails. The rotation of the connection shall be observed, and, for each test, a plot of the moment and the rotation shall be made, in which:

$$M_t = b\,F$$

and

$$\theta = \frac{\delta_1 - \delta_2}{b} - \frac{\delta_3 - \delta_4}{h}$$

where

- δ_1 is the deflection measured by gauge d_1;
- δ_2 is the deflection measured by gauge d_2;
- δ_3 is the deflection measured by gauge d_3 (where considered);
- δ_4 is the deflection measured by gauge d_4 (where considered).

A.4.4 Corrections to the observations

Correction to each observed value of failure moment shall be made in accordance with EN 15512, Clause 9.2.3.

The correction factor C shall be determined for each component of the connection, namely:

- the lane rail to beam support bracket,
- the beam,

A.4.5 Derivation of the results and procedure to define curves

In accordance with EN 15512, Clause A.3.1.5.

A.5 Test of beam end connectors of the upper tie beam (Truck operation)

A.5.1 Test layout

To determine the moment-rotation curve of the upper tie-beam end connectors (without palletized load), a portal-type test must be performed, see Figure A.9. It is essential that the beam end connectors are at the same distance from the upper end of the upright as in practice.

In the test a horizontal load is applied along the centre line of the beam and the horizontal deformation of the portal test is recorded at the same height. From these values, a moment-rotation curve is obtained.

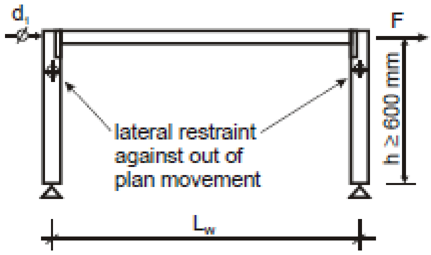


Figure A.9 Portal test for the determination of the average properties of the upper tie beam end connector

The portal test shall have a dimension (L_W = lane width) of approximately 1,5 m (or that which is used in practice). The details of the connection of the stringer to the upright shall conform to the manufacturer's instructions and shall be consistent with that made in practice.

A.5.2 Evaluation of the test, determination of the rigidity of rotation and the looseness

The results of the test must be adjusted for the effect of variations in the thickness of the material according to EN 15512.

NOTE: In practice, the rotations will be small, and it is unlikely that the resistance capacity or the bending moment can be exhausted in the elastic field. This means that the corrections for the strength of the material are not critical.

The average stiffness constant C_j of the upper beam end connector will be obtained by comparing the results of the test, with an analytical model according to Figure A.10. The value of C_j will be adjusted until there is agreement between the force displacement curve of the test and the relationship force-linear displacement of analytical results. The adjustment of the linear force-displacement relationship of the analytical model to a non-linear curve obtained from the tests must be carried out according to EN 15512 section A.2.6.4, where M_{Rd} (Design Moment) will be read as F_{ult} (Failure Force) / γ_M, and M (Moment) will be read as F (force) and θ (rotation) will be read as u (displacement).

The looseness of the connection will be determined in accordance with EN 15512 section A.3.2.2.2. This looseness must be subtracted from the observed curve and the stiffness determined accordingly.

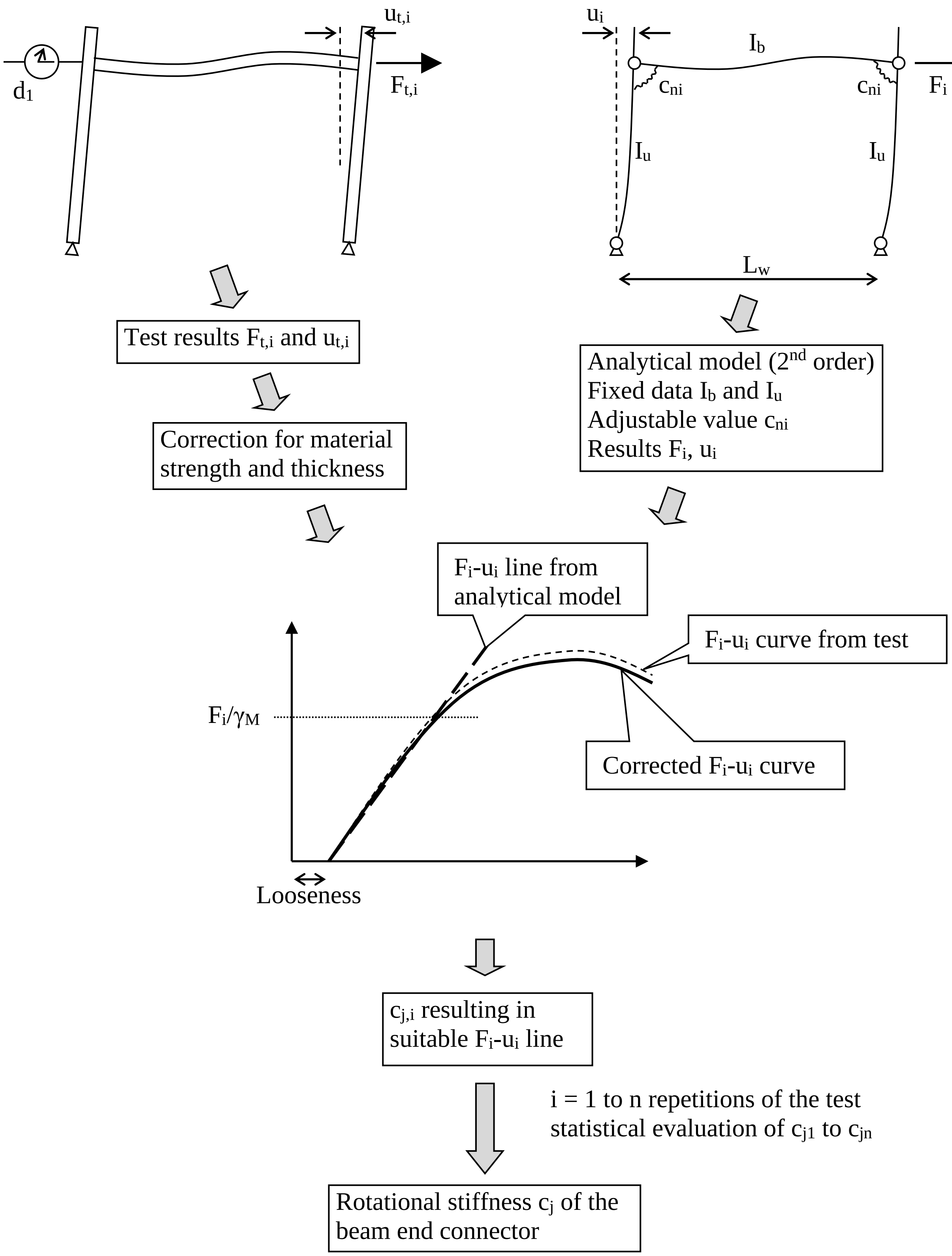


Figure A.10 Determination of C_j from the results of the portal test

A.6 Shuttle safety stop

A.6.1 General

Tests shall be carried out for the purpose of obtaining measurements of the performance of the safety stop with regard to energy absorption and deformation.

The safety stop shall be designed to absorb the 100% of the energy indicated.

A.6.2 Kinetic energy

The kinetic energy can be obtained with the following expression:

$$E_c = \frac{1}{2} m v^2$$

where

E_c is the kinetic energy;

m is the mass in movement (shuttle mass or shuttle mass + unit load mass);

v is the nominal velocity of the moving mass.

A.6.3 Assembly of specimens

Test specimens shall be assembled in accordance with the manufacturer's assembly instructions.

A.6.4 Number of tests

A minimum of two separate specimens shall be tested. All separate specimens must pass the test criteria.

A.6.5 Test reports

For each test series, the formal documentation shall be prepared, giving all the relevant data, so that the test series can be accurately reproduced.

In addition to the test results, the following minimum information shall be in the report:

a) Date of manufacture;
b) Product drawing numbers for the components under test;
c) Details of production and assembly process;
d) Material specification for the components under test including fixings;
e) Date of testing;
f) Actual dimensions of test components;
g) Actual material properties of test components;
h) Details of the test arrangement (dimensions, support conditions, connections, etc.);
i) Details of impact including direction, energy absorption and height of impact;
j) Measurements made during the test (load and deflections);
k) Observations regarding the onset of visible deformations (buckling, tearing, etc.);
l) Mode of failure;
m) Photographic evidence of the test.

A.6.6 Definition of failure load

The test specimen shall be deemed to have failed either when there is any visible or measurable damage in a component other than the end -stop or when the safety-stop fails to stop the shuttle.

A.6.7 Corrections to test load

The observed failure load shall be adjusted to take account of the actual thickness and yield stress of the test sample as given below:

If $\left(\frac{f_t}{f_y}\right)\times\left(\frac{t_t}{t}\right)\leq 1,15$ then no corrections are necessary within the accuracy of the impact specification.

Corrections are necessary and the required energy absorption shall be increased by the following factor:

$$\left(\frac{f_t}{f_y}\right)\times\left(\frac{t_t}{t}\right)-0,15$$

where

f_t is the observed yield stress for the specimen;

f_y is the specified yield stress;

t_t is the observed thickness for the specimen;

t is the nominal thickness for the specimen.

NOTE: any correction required should be carried out before the testing or a repeat of the test with the increased energy absorption will be required.

A.6.8 Testing

A full-scale test can be performed in a rack subassembly. In this test, a shuttle impacts the shuttle safety stop.

Two situations shall be tested;

- shuttle fully loaded travelling at its nominal speed;
- shuttle not loaded travelling at its nominal speed.

In case of fully loaded situation, the unit load shall be fixed to the shuttle in order to avoid sliding.

The rack subassembly must represent a realistic distribution and the first level shall be tested.

NOTE 1: This arrangement takes into account the dissipative effects of the rack, including the safety-stop of the shuttle and the components of the rack.

NOTE 2: Generally, a loaded shuttle has a lower nominal speed than an unloaded shuttle however, if the shuttle travels at the same speed irrespective of whether it is loaded or not then it is not necessary to test the unloaded shuttle condition.

A.6.9 Testing to determine the level of damage to be categorised as Green Risk for safety-stop (deformation assessment criteria)

A.6.9.1 A.5.9.1 General

It is allowable to test the safety-stop to obtain the value of the Green Risk level of damage.

This will vary for each safety-stop and will be determined by the testing program.

Inspectors can use this value to determine the risk category for damaged safety-stops and when the damaged components need to be replaced.

A.6.9.2 Number of tests

Three separate specimens shall be tested, to confirm the maximum safety-stop deflection of a particular safety-stop.

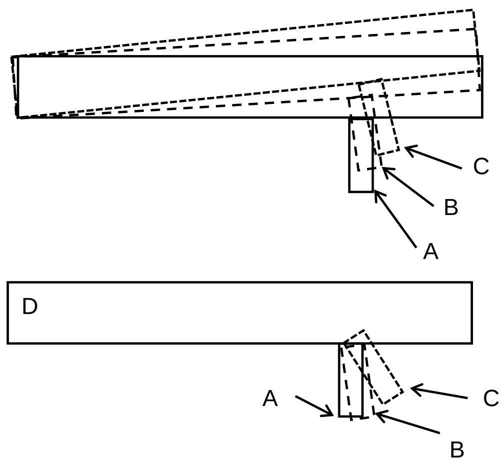
A.6.9.3 Test procedure

The testing procedure shall generally be in accordance with clause A.6.8. Instead of a single impact on the safety-stop, the impact shall be repeated a number of times on the same safety-stop until it cannot stop the shuttle (either due to being broken or the horizontal clearance is increased). The distance of the tip of the safety-stop or the angle of the safety-stop prior to the position where impact causes failure is the measurement required from each test, k_{ti} (see Figure A.11).

To obtain this value requires the measurement of the permanent deformation of the protector after each impact.

A.6.9.4 Analysis of the results

The deflection limit for Green Risk level damage, k_t, is the maximum value of k_{ti} from three tests.



Key

A is the shuttle safety stop fixed in accordance with manufacturer's instructions;

B is the permanent deformation of shuttle safety stop two impact tests before failure, k_{ti};

C is the position of the safety stop before final impact causes protector to fail (due to its broken or the horizontal clearance is increased);

D is the lane rail.

Figure A.11 Schematic diagram of repeated impact tests.

Annex B
(normative)

Installation tolerances.

B.1 General

The tolerances given in Table B.1 and Table B.2 are believed to represent a reasonable compromise between practicality of construction and wear and tear to the shuttle device; different tolerances may be specified in specific cases as noted in this clause.

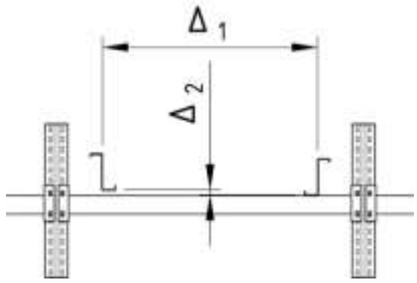
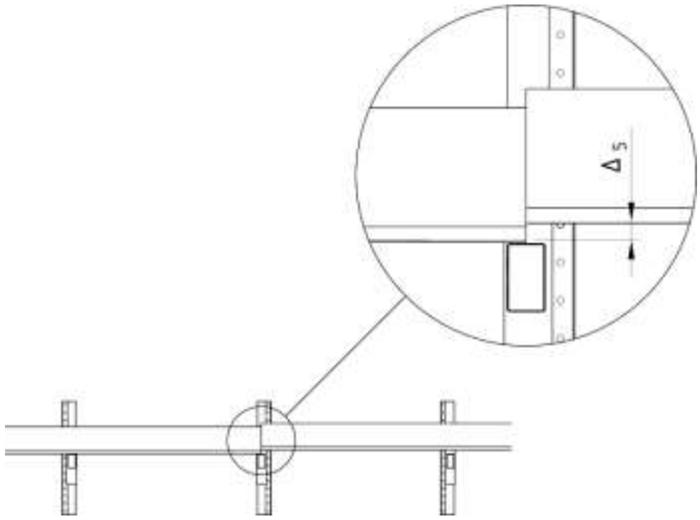
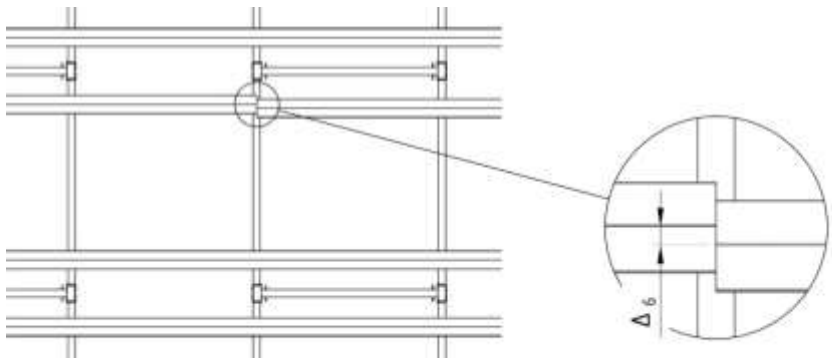
B.2 Lane entrance guide

If a lane entrance guide is required details and tolerances shall be agreed between the contracting parties.

B.3 Commissioning tolerances

After assembly, before the commissioning of the installation, the rack shall meet the requirements for assembly tolerances given in this Annex unless alternative values have been provided by the Specifier.

Table B.1 Shuttle systems - tolerances

Shuttle operated system	Tolerance
	
Δ_1 tolerance between guide faces of the lane rail. **Δ_2 tolerance on difference in lane rail height across the lane**	$\Delta_1 = \pm 2{,}0$mm $\Delta_2 = \pm 2{,}0$mm
	
Δ_5 vertical step in lane rail	$\Delta_5 = 1{,}0$mm
	
Δ_6 horizontal step in lane rail	$\Delta_6 = 1{,}0$mm

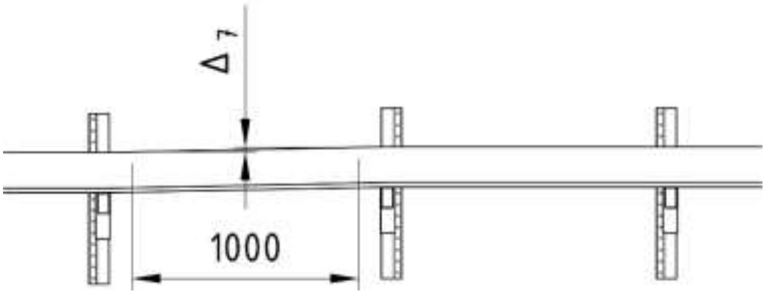
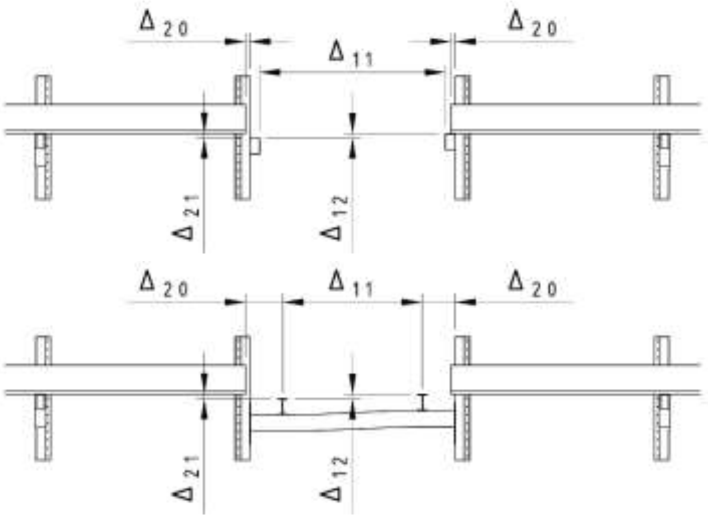
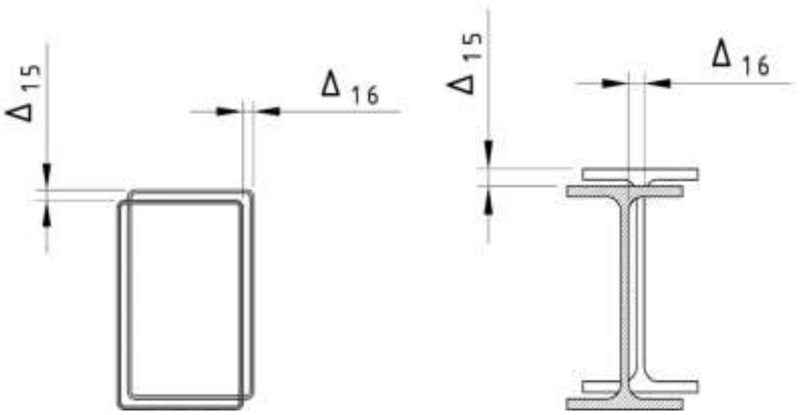
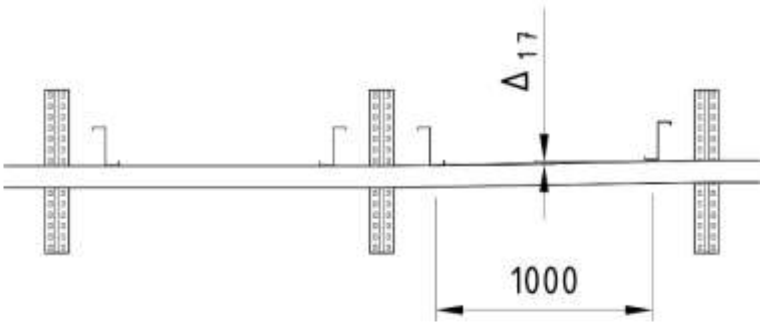
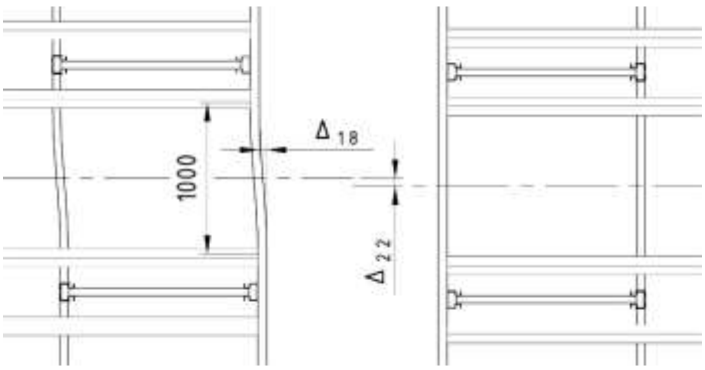
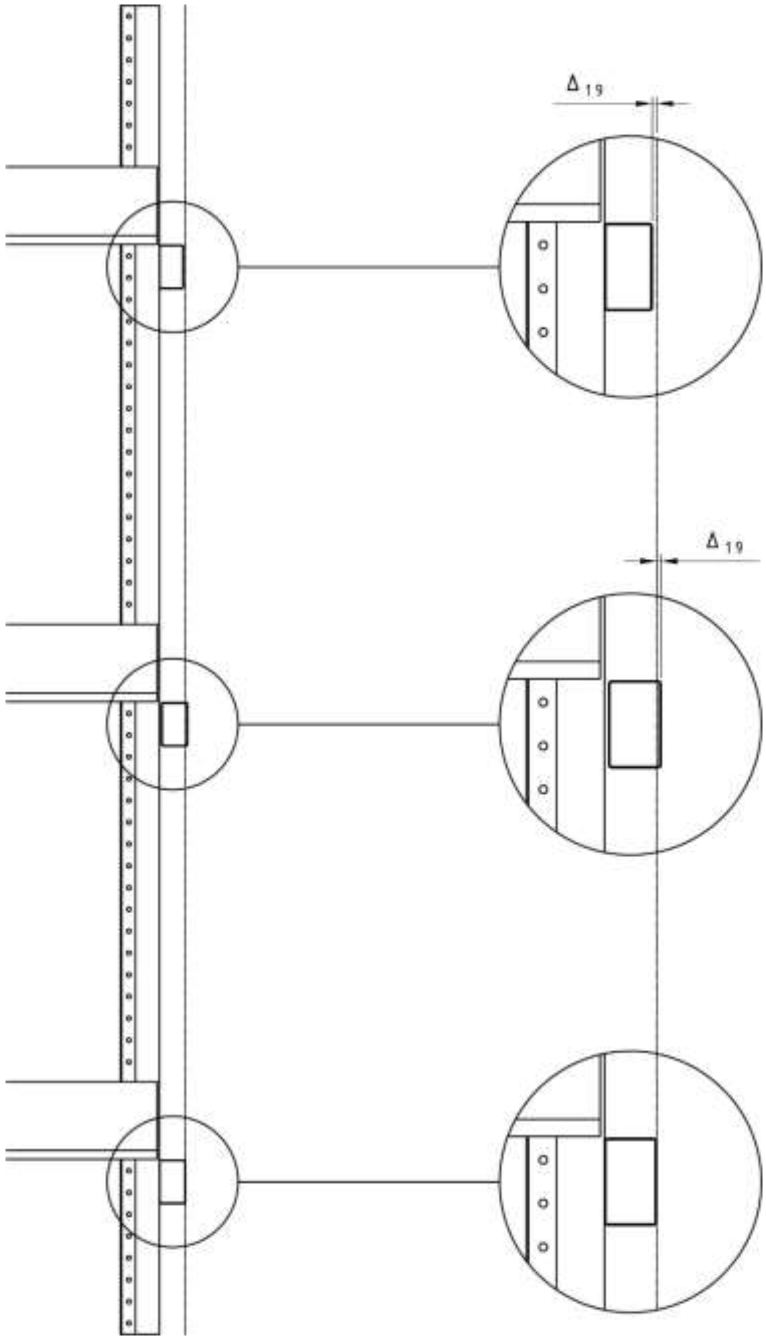
Shuttle operated system	Tolerance
 	
Δ_7 tolerance on slope of lane rail	Δ_7 = 3,0‰ Maximum 15mm over the length of the rail

Table B.2 Aisle carrier systems - tolerances

Aisle carrier operated system	Tolerance
 	
Δ_{11} tolerance between running faces of the aisle rail. **Δ_{12} tolerance on difference in aisle rail height across the aisle** **Δ_{20} position tolerance for end of lane rail to aisle rail** **Δ_{21} tolerance of lane rail to aisle rail running surface**	Δ_{11} = ±3,0mm Δ_{12} = 5,0mm Δ_{20} =±5,0mm Δ_{21} =+0 -4mm

Aisle carrier operated system	Tolerance
	
Δ_{15} vertical step in aisle rail[a] **Δ_{16} horizontal step in aisle rail[a]**	Δ_{15} = 1,0mm[a] Δ_{16} = 1,0mm[a]
	
Δ_{17} horizontal slope in aisle rail	Δ_{17} = 3,0‰ Maximum 15mm over the length of the rail
	
Δ_{18} tolerance on the alignment of aisle rail **Δ_{22} tolerance on the alignment of lane centreline**	Δ_{18} = refer to FEM9.831-1 Δ_{22} = refer to FEM9.831-1

<table>
<tr><th>Aisle carrier operated system</th><th>Tolerance</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Δ_{19} tolerance on vertical alignment of aisle rails[b]</td><td>$\Delta_{19} = \pm 2{,}0$mm[b]</td></tr>
<tr><td colspan="2">[a] In the ‘as-rolled’ condition some hot-rolled profiles may not be able to achieve the Δ_{15} tolerance and may need grinding – refer to FEM9.831-1 clause 4.5 and 4.6.</td></tr>
<tr><td colspan="2">[b] Δ_{19} is only relevant at the elevator position for aisle carriers that change level</td></tr>
</table>

Annex C
(normative)

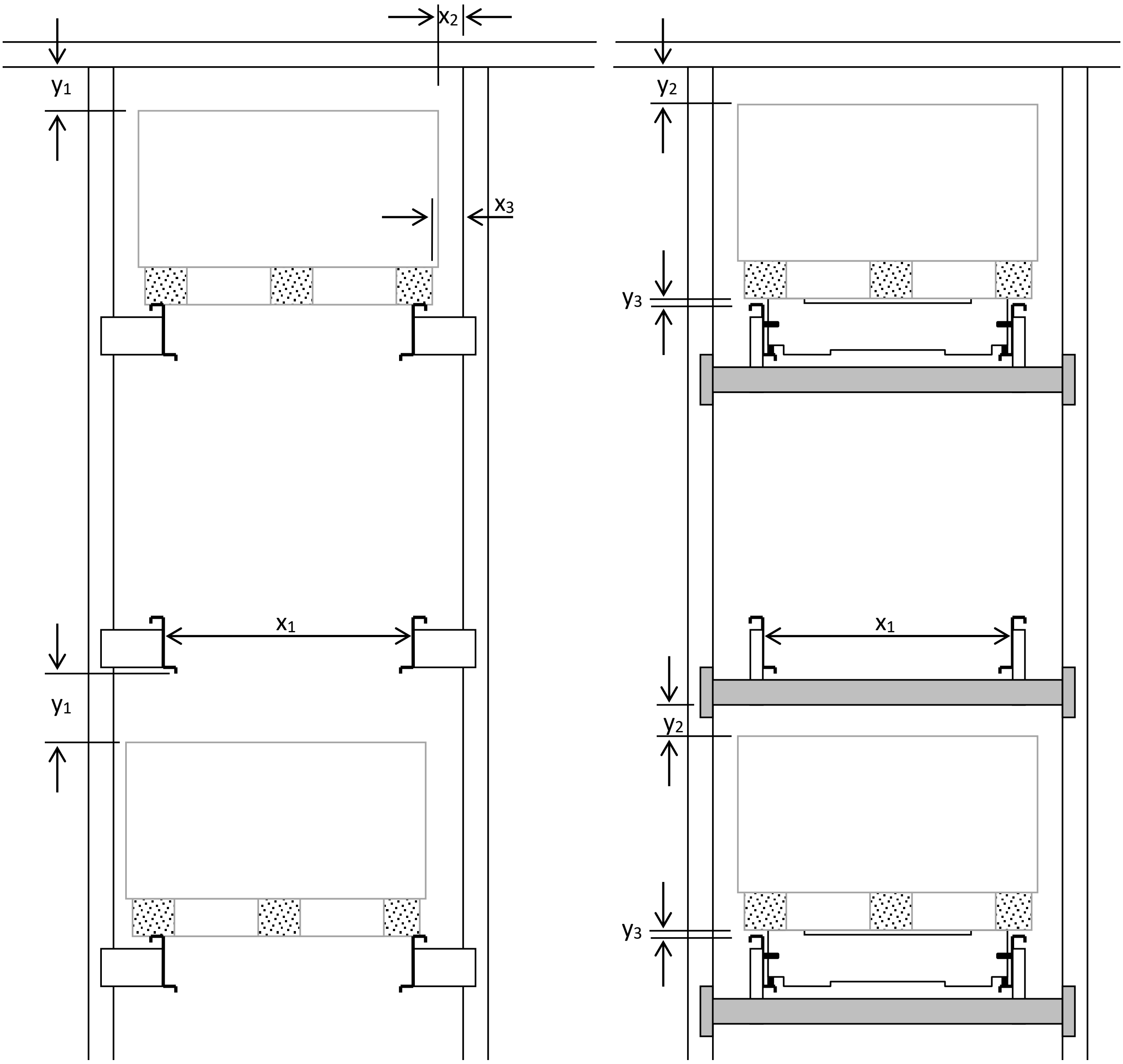
Clearances and dimensional limits

C.1 Lane clearances

In addition to the provisions of EN 15620, the following clearances shall be considered.

Clearances shall be considered in relation to the overall dimensions of the unit load including any overhang.

Unless specified otherwise, Table C.1 indicates the recommended values:



Key

x_1 is the horizontal clearance between lane rails;

x_2 is the horizontal clearance between the unit load and the upright;

x_3 is the horizontal clearance between the load make up accessory and the upright;

y_1 is the vertical clearance when the unit load is placed on the lane rail between the top of the unit load and the bottom part of the arm, the beam, the lane rail, the sprinkler systems or any other device whichever is the lowest;

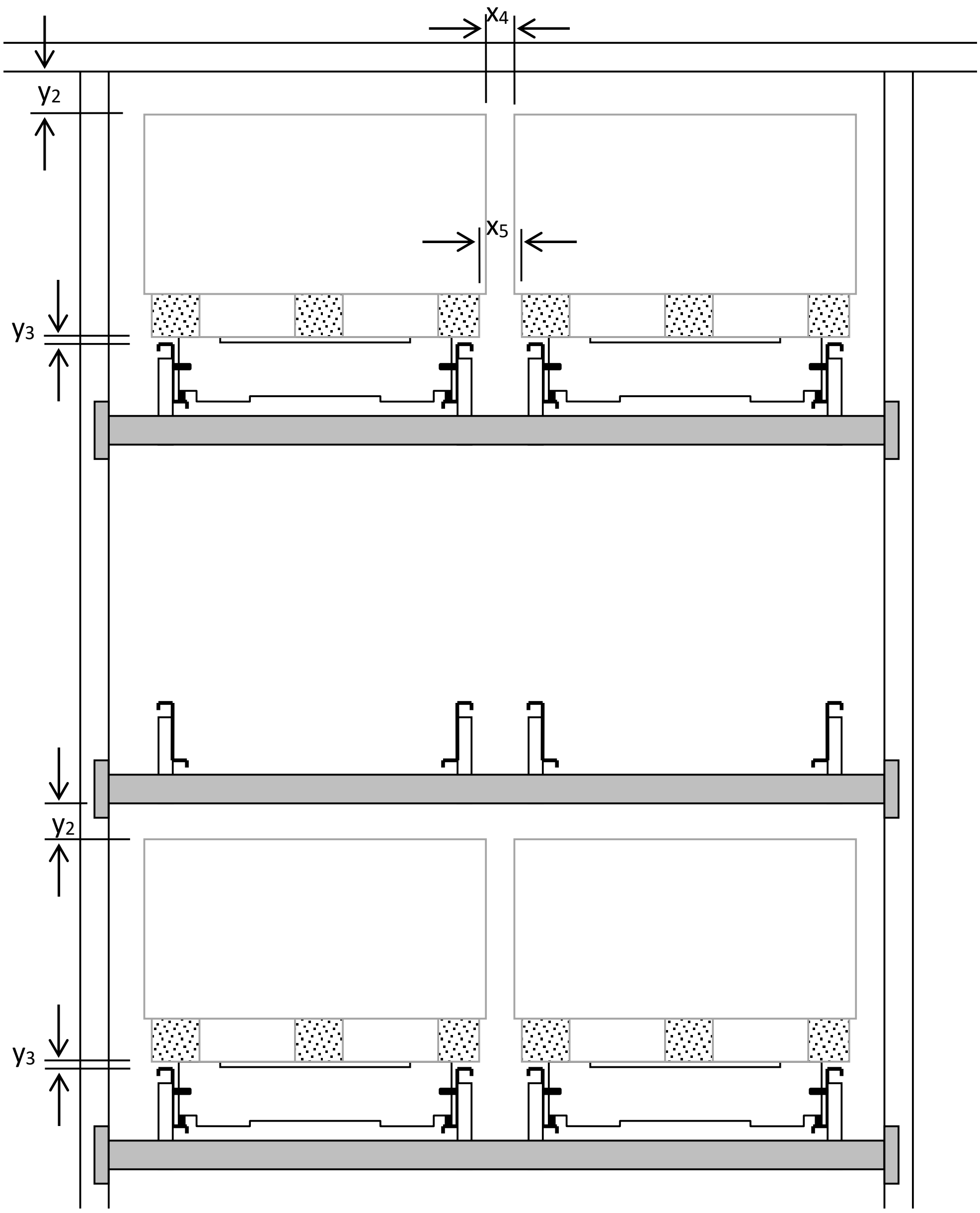
y_2 is the vertical clearance when the unit load is lifted on the shuttle between the top of the unit load and the bottom part of the arm, the beam or the lane rail whichever is the lowest;

y_3 is the lifting stroke of the shuttle inside the lane.

Figure C.1 Vertical and horizontal clearances

Clearance x_1 shall;

a) Satisfy the clearances required by the shuttle
b) Provide support for pallets on the lane rail
c) Provide support for shuttles on the lane rail.



Key

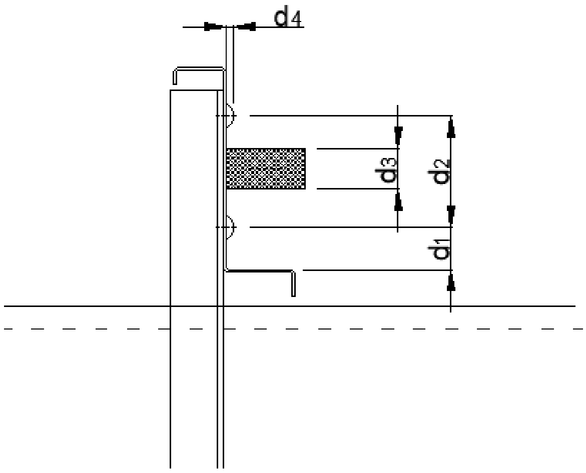
x_4 is the horizontal clearance between unit loads;

x_5 is the horizontal clearance between load make up accessories;

y_2 is the vertical clearance when the unit load is lifted on the shuttle between the top of the unit load and the bottom part of the arm, the beam or the lane rail whichever is the lowest;

y_3 is the lifting stroke of the shuttle inside the lane.

Figure C.2 Vertical and horizontal clearances



Key

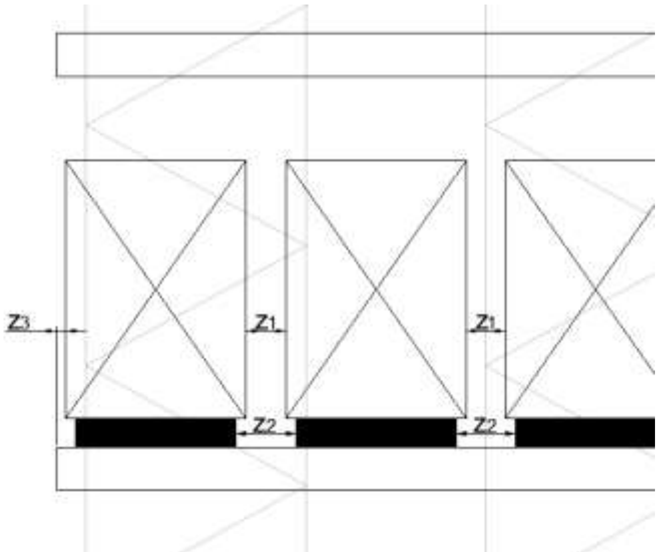
d_1 is the vertical dimension between the running surface and the bottom bolt;

d_2 is the vertical dimension between rails;

d_3 is the free contact surface for guidance wheel;

d_4 is the screw head protrusion.

Figure C.3 Vertical and horizontal dimensions



Key

z_1 is the horizontal clearance between unit loads;

z_2 is the horizontal clearance between load make up accessories;

z_3 is the horizontal clearance between the edge of the lane rail and the unit load placed closest to the aisle.

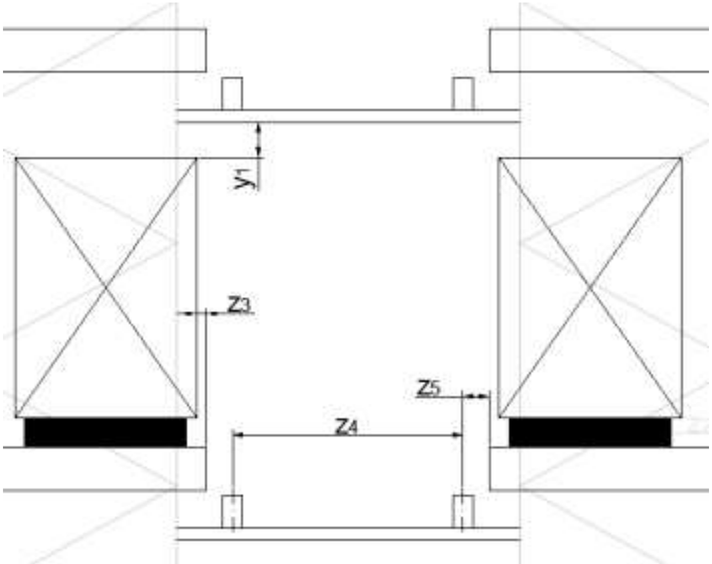
Figure C.4 Vertical and horizontal clearances

Table C.1 Recommended lane clearances

Clearance	Industrial truck operated systems	S/R machine operated systems	Aisle carrier operated systems
x_1	To be defined by shuttle supplier	To be defined by shuttle supplier	To be defined by shuttle supplier
x_2, x_3	≥ 75mm for top storage level up to 9m ≥ 100mm for top storage level higher than 9m	≥ 75mm	≥ 75mm
x_4, x_5	≥ 100mm (top storage level up to 9m) ≥ 125mm (top storage level higher than 9m)	≥ 100mm	≥ 100mm
y_1	≥ 100mm for any storage level up to 6m ≥ 125mm for any storage level up to 9m ≥ 150mm for any storage level up to 13m	≥ 100mm	≥ 100mm
y_2	$= y_1 - y_3$	$= y_1 - y_3$	$= y_1 - y_3$
y_3	25mm	25mm	25mm
z_1, z_2	50mm	50mm	50mm
z_3	50mm	50mm	50mm
d_1, d_2, d_3, d_4	To be defined by shuttle supplier	To be defined by shuttle supplier	To be defined by shuttle supplier

C.2 Aisle clearances for S/R machine and aisle carrier operated systems

In addition to the provisions of FEM 9831, the following clearances shall be considered.



Key

z_4 is the horizontal clearance between aisle rails;

z_5 is the horizontal clearance between the lane rail and the aisle rail.

Figure C.5 Aisle clearances for aisle carrier operated systems

The horizontal clearance between aisle rails z_4 shall;

a) Satisfy the clearances required by the aisle carrier
b) Provide support for shuttles on the lane rail.

Table C.2 Recommended lane clearances

Clearance	S/R machine operated systems	Aisle carrier operated systems
z_4	To be defined by shuttle supplier	To be defined by shuttle supplier
z_5	To be defined by shuttle supplier	To be defined by shuttle supplier

Annex D
(informative)

Placement in industrial truck operated systems

D.1 Placement in industrial truck operated systems

Shuttle racking systems should not be considered as providing any unit load guidance.

The loading sequence shall consider the following:

a) Shuttle;

- Truck shall take up position centrally in front of the storage lane,
- Shuttle shall be raised to the storage level,
- Shuttle shall be lined up with the lane rails using side shift. The shuttle shall not impact the side of the rails,
- Shuttle shall be carefully and centrally lowered onto the lane rails,
- Forks shall be removed from the shuttle and then lowered.

b) Unit load;

- Truck shall take up position centrally in front of the storage lane,
- Unit load with no forward tilt on the forks shall be raised to the storage level,
- Unit load shall be lined up with the racking lane using side shift, clear of the uprights, and with the unit load positioned centrally between the lane rails,
- Unit load shall be carefully and centrally lowered on to the lane rails, without touching other unit loads or the shuttle or other parts of the racking structure and the unit load released from the forks. Once in contact with the lane rails the unit load shall not be slid or dragged along or across the lane rails,
- Forks shall be removed from the unit load and then lowered.

Annex E
(informative)

Recommendations for hot-rolled symmetrical lane rails

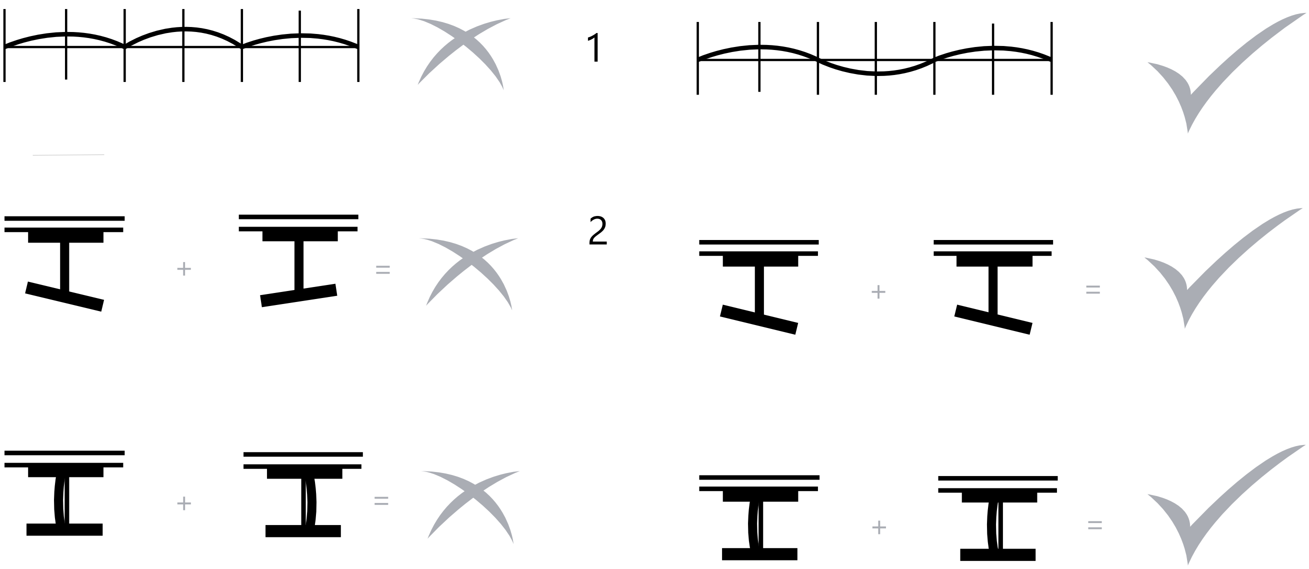
E.1.1 Recommendations

The manufacturing tolerances of the section of hot-rolled lane rails are determined by the manufacturing process and cannot be adjusted later. The following steps should be followed to minimize the installation and mounting tolerances of the lane rails:

- Refer to the standard EN 10.034;
- Refer to the standard EN 10.210-2;
- Refer to the standard EN 10.056-2;
- Buy all the material for the project from the same production batch, in such a way the possibility of large tolerance deviations between the lengths of the material supplied are reduced.

Connect the lengths of the lane rail taking into account the direction of the tolerance (see Figure E.1).

It may not be possible in practice to get results 1 and 2 simultaneously.



Key

1 is the plan view;

2 is the beam section shape along the length.

Figure E.1 Method to take into account section tolerances in the assembly of the lane rail.

Annex F
(normative)

Recommendations for cold-rolled profiles

F.1 General

For the dimensional tolerances of cold-formed members reference is made to EN1090-4.

F.2 Lane rail

The height tolerance of the lane rail Δ_{10} shall be ±1.0mm (see Figure F.1)

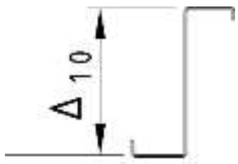


Figure F.1 Height tolerance of lane rail.

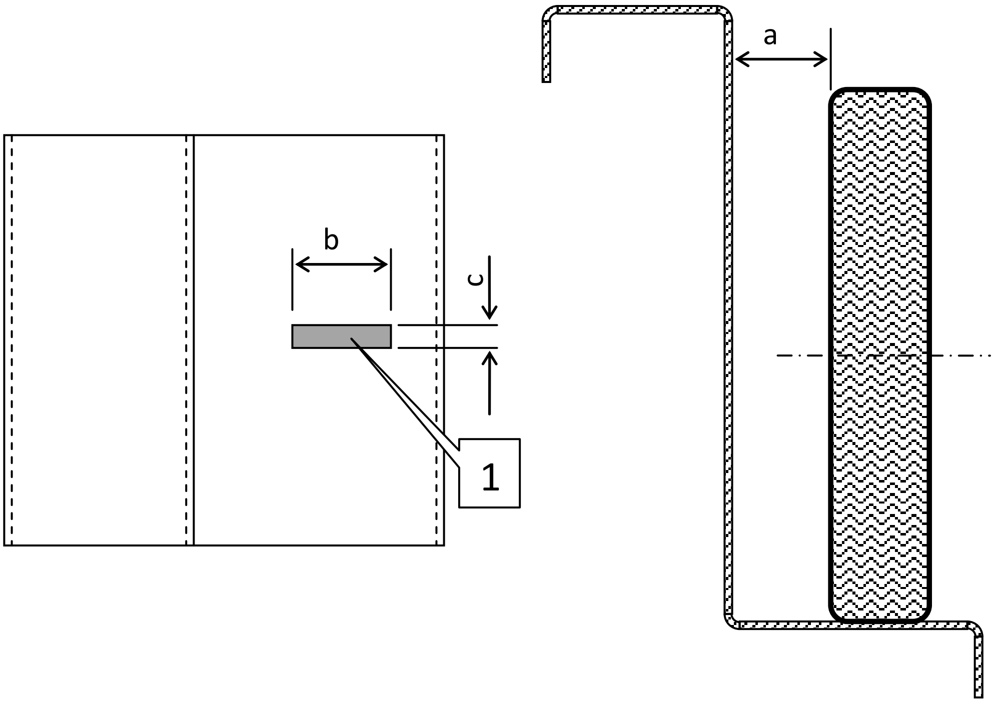
Annex G
(informative)

Data to be provided by shuttle/carrier supplier and rack supplier

G.1 Information to be provided by the shuttle/carrier supplier

a) Shuttle/carrier dimensions;
b) Number and positioning of wheels of the shuttle/carrier (position of the measurement should be stated i.e. to the outer edge/centre of the wheel etc.);
c) Performance of the shuttle/carrier (acceleration, deceleration, speeds);
d) Accidental impact actions;
e) Shuttle/carrier wheels reactions in relevant positions (either the static and dynamic loads should be stated, or the necessary dynamic factors should be given for the various loading conditions);
f) Contact area of the wheels with the rail (see Figure G.1);
g) The closest position of the wheel set to the end of the lane rail, when the shuttle is entering or leaving the storage level and associated wheel reactions;
h) lane rail dimensions i.e. maximum allowed height of a possible lip on the bottom flange of the lane rail;
i) Limit of admissible deformation of the rails (horizontal, vertical and rotation);
j) Weight of shuttle/carrier (maximum and nett);
k) Position of the wheel set to the end of the lane rail, when the shuttle is entering or leaving the elevator (if relevant) and associated wheel reactions;
l) Horizontal guidance forces caused by a lane blockage;
m) limiting deflection limits of the rack (where the limits given in 10.4.2 and 10.4.3 are not applicable);
n) wheel material for the main wheels and guide wheels;
o) number and position of the guide wheels (including dimension of the guide wheel above the rail surface and width of the guide wheel);
p) nominal position of the running wheels on the beam rail (see Figure G.1) and position of the running wheels at the maximum eccentricity.

Note: Refer to Annex H for fatigue



Key

1 is the contact surface b×c;

a is the distance from the wheel to the web of the lane rail.

Figure G.1 Idealised contact area of wheel and rail

Annex H
(informative)

load cycles for fatigue design

For fatigue verification of the components of the system it is necessary to know both the number of load cycles (combination of one input plus one output and return to the delivery point) as well as the type of load cycles.

For the calculation of load cycles per hour, it can be done according to the indications of the FEM 9.860 recommendations.

Table H.1 Information required for fatigue verification

Maximum capacity in terms of double runs per h	
Reduction factor for Average Capacity over a year	
Number of working hours/day	
Number of working days/week	
Number of working weeks/year	
Design life in years	
Number of horizontal storage addresses per aisle	

Annex I
(informative)

Background documents

Concept	Formula	Source
Dynamic effect on the support of the unit load	$V_{Ri} = V_{Ri,est} \pm \frac{F_{i,p}h_p + F_{i,c}h_c + F_{i,\ell}h_\ell}{\ell_R}$	5.1.4.2 DIN 15350:1992
Vertical transfer action	$\phi_t = 1 + \left(\frac{\pi}{2}\right)^2 \frac{v^2}{gr}\zeta_G$ $\alpha_G = \frac{f_q e_G}{v}$	EN 13001-2
Driving force	$F_D \leq V_{Ri,est}\mu_h$	5.1.4.3 DIN 15350:1992
Buffer impact	ϕ_{buffer}	EN 13001-2

The static load in each wheel of the aisle carrier $V_{Ri,est}$, shall be calculated considering the load to be stored as a rigid body in standstill situation. The position of the centre of gravity of the shuttle and unit load together shall be considered to obtain these reactions.

In situations of horizontal movement of the loaded aisle carrier (acceleration or deceleration), the inertia effect produced by the unit load and shuttle shall be added algebraically to the initial static force, $V_{Ri,est}$, in each wheel axis,

$$V_{Ri} = V_{Ri,est} \pm \frac{F_{i,p}h_p + F_{i,c}h_c + F_{i,\ell}h_\ell}{\ell_R}$$

where

- G_p is the unit load centre of gravity;
- G_c is the shuttle centre of gravity;
- G_l is the aisle carrier centre of gravity;
- $F_{i,p}$ is the unit load horizontal inertial load due to the variation in speed;
- $F_{i,c}$ is the shuttle horizontal inertial load due to the variation in speed;
- $F_{i,\ell}$ is the aisle carrier horizontal inertial load due to the variation in speed;
- h_p is the unit load centre of gravity distance from the running surface;
- h_c is the shuttle centre of gravity distance from the running surface;
- h_ℓ is the distribution shuttle centre of gravity distance from the running surface;
- ℓ_R is the distance between wheels axis.

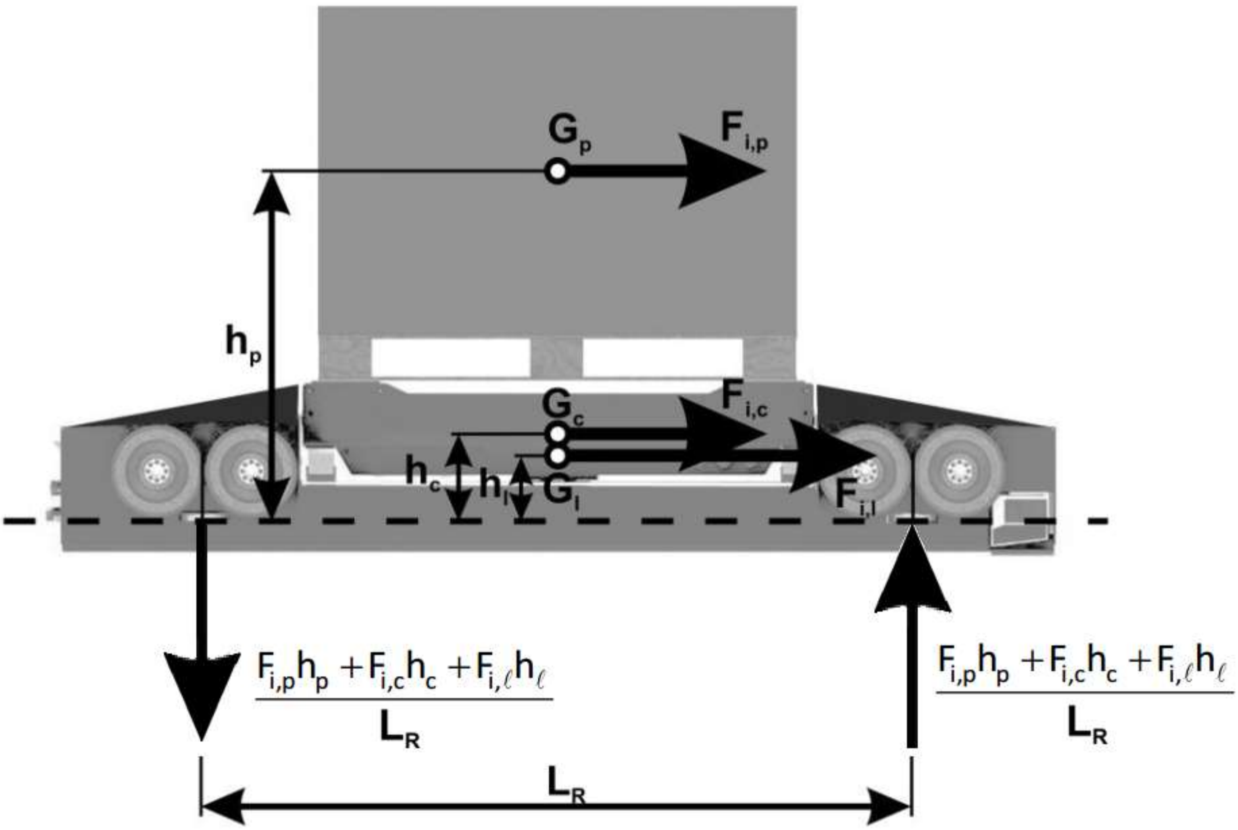


Figure I.1 Inertial effect of the masses

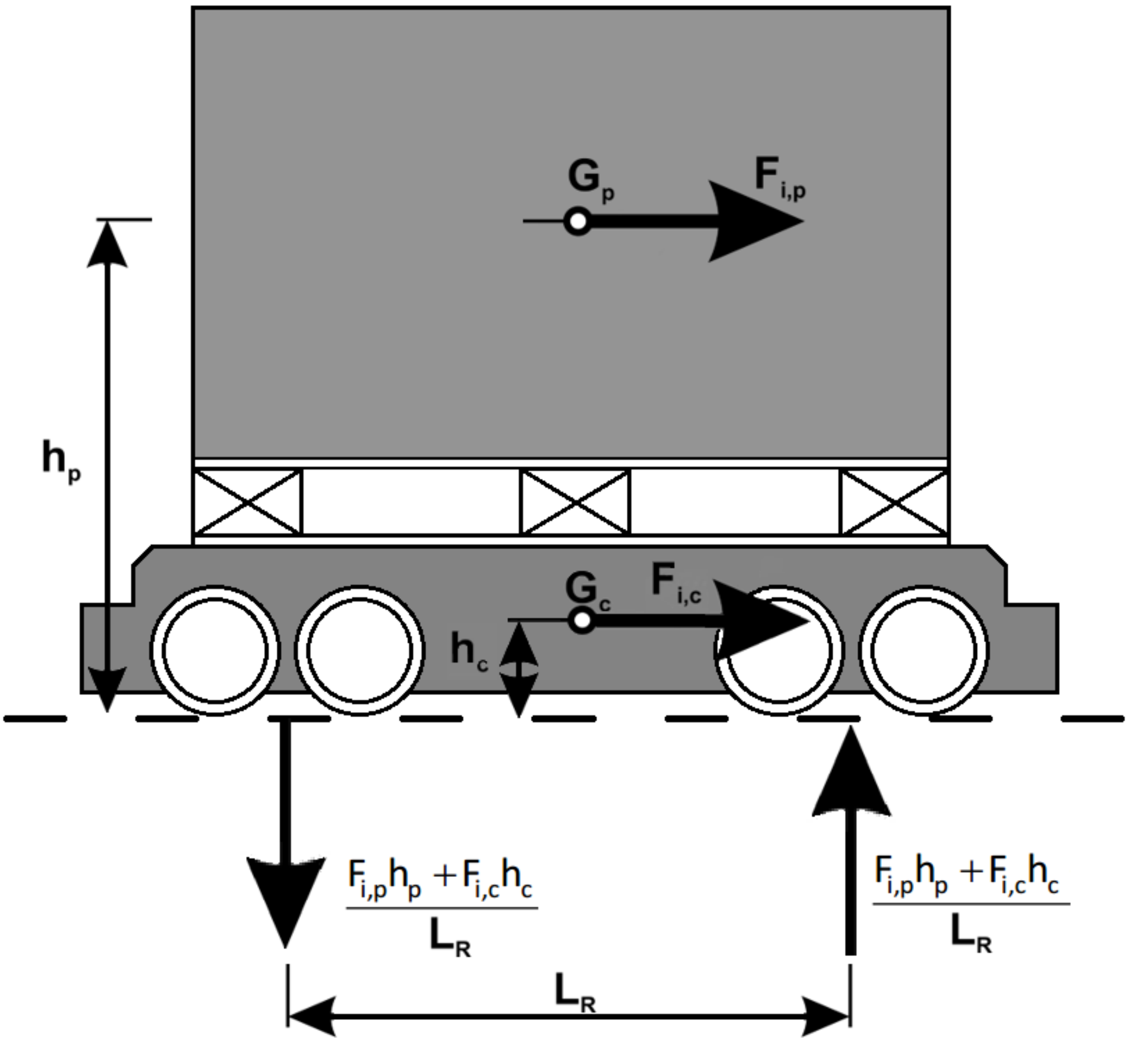


Figure I.2 shuttle travelling in the lane.

Annex J
(informative)

Assessment of the stability of the stored goods

J.1 General

The purpose of this test is to determine whether or not the proposed load can be safely transported on the shuttle.

In this Annex, methods to assess the stability of the unit load for overturning, and the "tilt test" used to verify the strength and stability of the goods stored in the unit load (e.g. stretch wrapping, banding), in order to prevent the risk of their failure and falling, are presented.

J.2 Recommended aspect ratio of the unit load

The following height to minimum width ratio H/b is recommended to reduce the possibility of the unit load overturning.

$$\frac{b}{H} > 0{,}17a$$

where

a is the maximum horizontal acceleration of the mechanical handling equipment $a \leq 1{,}5 m/s^2$;

H is the height of the unit load (m);

b is the width of the unit load in the movement direction (m).

The pallet load is assumed to have a uniform weight distribution (footprint and height).

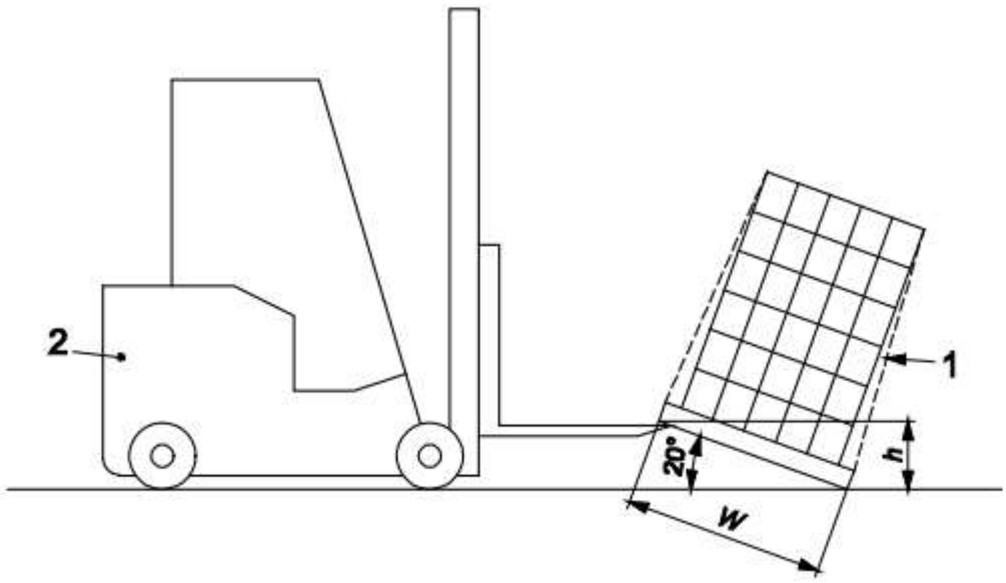
J.3 Pallet "tilt test"

The purpose of the test is to ensure that the means used to secure the merchandise in the unit load are sufficiently strong and rigid to keep the merchandise from sliding during operations.

The basic test procedure is as follows:

- step 1: the merchandise is bound in the unit load with a securing method;
- step 2: the pallet is lifted on one side to a height that produces an angle of 20° between the ground and the bottom surface of the pallet;
- step 3: if the merchandise remains restrained in place for at least 5 min without appreciable movement, the load secured to the pallet is considered to have adequate confinement and passes tilt test;
- step 4: if the merchandise shifts appreciably or the securing material breaks, the merchandise shall be re-secured using another industry- approved method and retested.

Figure J.1 and Table J.1 show the procedure for the execution of the "tilt test".



Key

1 is the product secured in the unit load;

2 is the forklift truck;

W is the pallet width.

Figure J.1 Pallet tilt test.

Table J.1 Pallet width and required lift

Pallet width W (mm)	Required lift h (mm)
1200	437
1100	400
1000	364
900	330
800	291

The recommendations and advice contained in this Guidance Note are based on specifications, procedures and other information that have been collected by the FEM from its members. They represent what is, as far as FEM is aware, the best available data at the time of publication on the instruction and use of the equipment concerned in the general conditions described and are intended to provide guidance for such use.

The suitability of this Guidance Note must be determined by the judgement of the person applying it in accordance with the conditions in which use is envisaged and subject to all relevant statutory requirements.

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