FEM RACKING AND SHELVING PRODUCT GROUP

(European Racking Federation – ERF / FEM R&S)

FEM 10.2.07

THE DESIGN OF

'DRIVE-IN AND DRIVE-THROUGH RACKING'

DRIVE-IN DESIGN CODE

September 2012

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This FEM document has been prepared by Working Group 2 (WG2) of Product Group Racking & Shelving of FEM and deals with the requirements of the design of Static Steel Drive-in and Drive through Racking. A clear understanding of these aspects is required for the provision of safe storage design as a compliment to the safe working conditions of the product.

FEM RACKING AND SHELVING PRODUCT GROUP

(European Racking Federation)

Purwell Cottage, Purwell Lane, HITCHIN

Herts SG4 0NF, United Kingdom

Tel: +44 (0) 1462 454 296

Secretary General: Colin Hinton

Email: info@erfed.org Website: www.erfed.org

The following Working Group members were actively involved in the preparation of this document:

Chairman:	Oliver Kraus	VLB	Germany
Members	Joseph Hepp	Agoria	Belgium
	Denis Jehin	Agoria	Belgium
	Alberto Climent	CISMA	France
	Bruno Huse	VLB	Germany
	Dirk Schulz	VLB	Germany
	Stefano Calzolari	ACAI	Italy
	Stefano Sesana	ACAI	Italy
	David Smidek	DMH R&S	Netherlands
	Kees Tilburgs	DMH R&S	Netherlands
	Gregorio Fernandez	FEM-AEM	Spain
	Alejandro Perez	FEM-AEM	Spain
	Karl-Gustav Carlsson	MHG	Sweden
	Jack Holden	SEMA	United Kingdom
	Paul Hutchinson	SEMA	United Kingdom
	Alan Worrell	SEMA	United Kingdom

PREFACE TO THESE GUIDELINES FOR THE

DESIGN OF DRIVE-IN AND DRIVE -THROUGH RACKING

European Federation ERF / FEM R&S

Drive-In and Drive-Through Racking (DIR and DTR), as most racking and shelving systems, is a specific type of steel structure insufficiently covered by existing standards in the field of steel construction design, as for instance the Eurocode 3 standard series: EN 1993 “Design of steel structures”.

The European racking industry associated in the “FEM Racking and Shelving Product Group” (European Racking Federation) – ERF / FEM R&S therefore took the initiative and funded the development of a number of Codes of Practice and eventually standards for the design of storage systems.
For the most common type of equipment for the storage of pallets, pallet racking, this has been:

FEM 10.2.02: 2001, “The design of steel static pallet racking”, recently replaced by

EN 15512: 2009 , “Steel static storage systems – Adjustable pallet racking systems – Principles for structural design”.

Until now no Code of Practice or standard has been published with principles for the design of DIR and DTR. This new FEM Code covers not only the structural design of Drive-In Racks and Drive-Through Racks but deals additionally with important non-structural aspects:

- Pallet quality, dimensions and tolerances, even more important compared to standard pallet racking. Geometrical requirements of the system components and overall geometrical design (e.g. minimum clearances required).

- Choice of appropriate handling equipment for safe entering into and driving in the relatively narrow rack lanes (see figure below). Together with appropriate driver training. See also EN 15635.

ERF / FEM R&S is pleased that with the completion of this Code FEM 10.2.07 a next important step is made to the harmonization of the design of the most important types of storage equipment.

Ir. C.J. Tilburgs

Technical Chairman of ERF / FEM R&S

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Foreword

This document defines the design procedure for Drive-In Racks and Drive-Through Racks.

Drive-In Racks and Drive-Through Racks are pallet storage systems differing from adjustable pallet racking in terms of their structural elements, structural behaviour and method of operation.

FEM 10.2.07 is based on the safety and design concept of the European standards series “Steel Static Storage Systems” and provides supplementary design rules where the peculiarities of Drive-In Racks and Drive-Through Racks do not allow the full application of EN 15512.

1 Scope

This Industry Code of Practice specifies the structural design principles and requirements applicable to all types of Drive-In and Drive-Through rack systems manufactured from steel members intended for the storage of unit loads and subjected to predominantly static loads and operated in accordance with EN15635.

This Industry Code of Practice does not cover other generic types of storage structures. Nevertheless, the principles established in this code may be used in conjunction with other codes or standards to design Drive-in and Drive-Through racks subject to environmental loads such as wind, snow, earthquake etc.

2 Normative references

- EN 1993: EUROCODE 3: Design of steel structures including;
- Part 1.1: General rules and rules for buildings.
- Part 1.3: Supplementary rules for cold-formed members and sheeting.
- Part 1.8: Design of joints.
- EN ISO 6892-1: Metallic materials. Tensile testing. Method of test at ambient temperature.
- EN 10025-1: Hot rolled products of structural steels. General technical delivery conditions.
- EN 10025-2: Hot rolled products of structural steels. General delivery conditions for non-alloy structural steels.
- EN 10025-3: Hot rolled products of structural steels. Technical delivery conditions for normalized / normalized rolled weldable fine grain structural steels.
- EN 10143: Continuously hot-dip coated steel sheet and strip. Tolerances on dimensions and shape.
- EN 10346: Continuously hot-dip coated steel flat products. Technical delivery conditions.
- EN 10149-1: Hot rolled flat products made of high strength steels for cold forming. General delivery conditions.
- EN 10149-2: Hot rolled flat products made of high strength steels for cold forming. Delivery conditions for thermomechanically rolled steels.
- EN 10149-3: Hot rolled flat products made of high strength steels for cold forming. Delivery conditions for normalized or normalized rolled steels.
- EN 15512 Steel static storage systems – Adjustable pallet racking systems– Principles for structural 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 – Application and maintenance of storage equipment.
- EN 15878 Steel static storage systems – Terms and definitions.

— ISO 4997: Cold reduced carbon steel sheet of structural quality.

— ISO 7438: Metallic materials - Bend test.

3 Terms and Definitions

In addition to the definitions used in EN 1993-1-1 and EN 1993-1-3 and those contained in EN 15512:2009 and EN 15878:2010 the following supplementary definitions are used in this document.

3.1
beam rail
beam for supporting the pallets.

3.2
block
group of interconnected lanes.

3.3
bracket
element supporting the beam rail and connecting it to the upright.

NOTE Sometimes the beam rail may be bolted directly to the upright.

3.4
clearance
nominal dimension between items to ensure safe operation related to a tolerance–free, undeformed system.

3.5
Drive-In Rack - DIR
system of racking that provides blocks of storage where pallets are stored two or more deep and where access is gained by driving a forklift truck into a lane with pallets supported along their sides on beam rails supported from the uprights. In DIR, the forklift truck drives into a lane and reverses out.

3.6
Drive-Through Rack - DTR
similar to DIR but in DTR the forklift truck could Drive-Through the lane if there are no pallets in the lane.

NOTE Drive-Through racking lanes are not designed as access routes through the racking but allow full access for pallets to be placed from either end of the aisle, enabling the first-in first-out logistic principle.

3.7
gangway (transfer aisle)
space for movement or transport but not giving access to the picking or loading faces.

3.8
lane
space between adjacent rows of uprights, perpendicular to the operating aisle, allowing the stacker or forklift truck to enter the space and to pick and deposit unit loads in depth and height.

3.9
mono post
single upright tied to an adjacent upright frame by spacers.

3.10
operating aisle
space giving access to lanes.

3.11
pallet guard rail

member parallel to the beam rail, or an integral part of it, which provides visual guidance to help the operator to centre the unit load at the lane entry.

3.12
plan bracing
top horizontal bracing structure.

NOTE Together with the vertical bracing and upright frames this stabilises the storage system.

3.13
spacer
structural component joining a mono-post, or upright frame, with another upright frame in the down-lane direction.

3.14
top tie beam
member joining the tops of the uprights across the lane.

3.15
top tie beam end connector
connector welded to or otherwise formed as an integral part of a tie beam, which has hooks or other devices, which engage in holes or slots in the upright.

3.16
unit load
individual stored item, e.g. a loaded pallet.

3.17
upright frame
two or more upright sections linked together by means of a lattice and fitted with base plates, intended to support the storage levels.

3.18
vertical bracing
bracing structure in the vertical plane.

NOTE Together with the plan bracing and upright frames this stabilises the storage system in the cross-lane direction.

4 Symbols

A number of the following symbols may be used together with standard subscripts which are given later. In general, primary symbols are not defined with all of the standard subscripts with which they may be used.

A cross-sectional area

A_{ph} accidental horizontal action

C rotational / translational stiffness

d position of the vertical load from the outer edge of bracket

E modulus of elasticity

e_{max} maximum distance between a vertical load on a bracket and the centre line of the upright

F action

f_u ultimate tensile strength

f_y yield strength of base material

G shear modulus

G_k characteristic value of permanent action (dead load)

H horizontal action

I second moment of area

M bending moment

n number of tests

Q variable action

Q_{ph} horizontal placement load

Q_u unit load (weight of a pallet including stored items)

R resistance

W section modulus

θ rotation

Φ initial sway imperfection

Φ_S specified maximum installation out of plumb

Φ_l out of plumb due to the looseness of the top tie beam end connectors

χ stress reduction factor for buckling

Subscripts

b buckling

cr critical

d design

i test number

k characteristic

max maximum

min minimum

R resistance

5 Basis of design

5.1 Structural arrangements

5.1.1 General

For braced DIR, cross-lane stability is provided by vertical bracing normally at the rear of the rack, see Figure 1. Other configurations are possible, for example a relatively stiff tower, a connected pallet rack or a centrally braced system. The stabilising effect of the vertical bracing is transmitted to the unbraced uprights by means of top tie beams, plan bracing and frame bracing. In the down-lane direction upright frame bracing provides stability.

There are two types of DTR; braced and unbraced (see Figure 4). For an unbraced DTR the cross-lane stability is provided by the restraining effect of the top-tie to upright connection and of the upright to floor connection, see Figure 2. For a braced DTR extra stability lanes are provided that are used for vertical bracing. These extra lanes cannot be used for storage. In the down-lane direction the upright frame bracing provides stability.

For a typical layout arrangement see Figure 3.

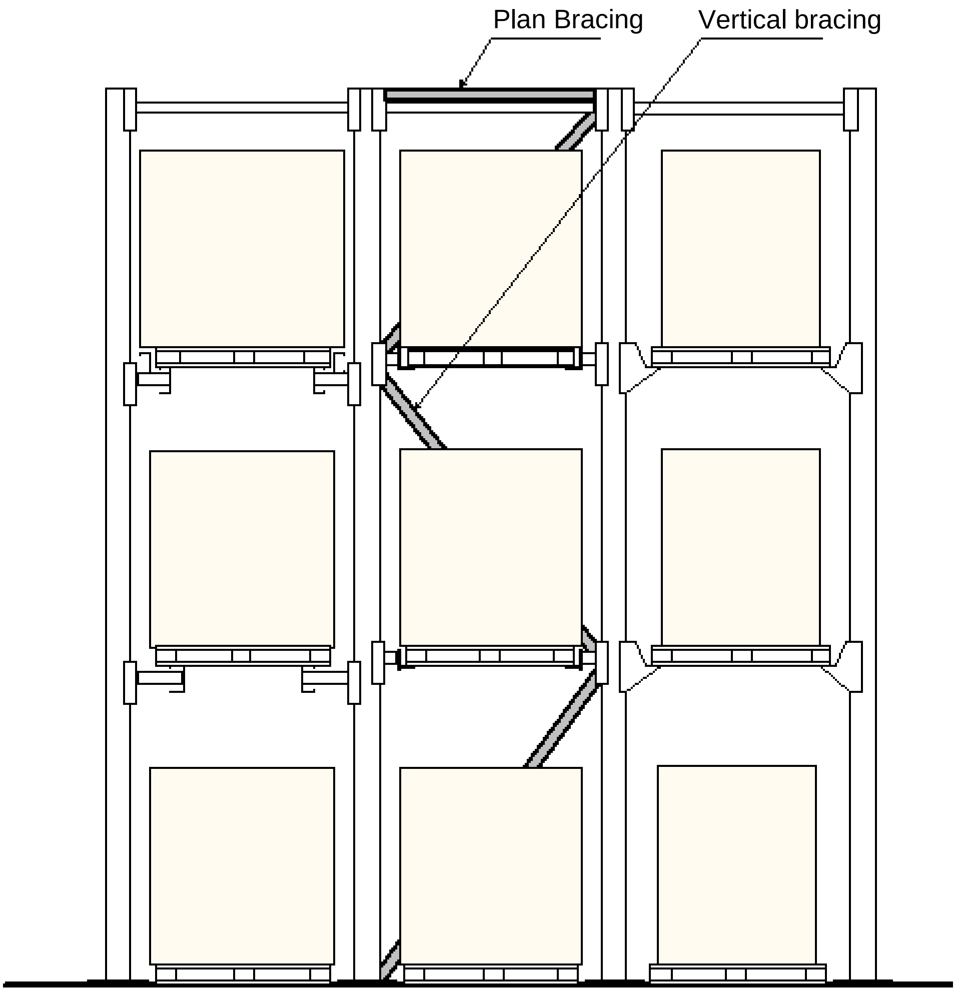


Figure 1 - Typical configuration of a braced Drive-In Rack structure (various types of side arms and pallet rails are shown)

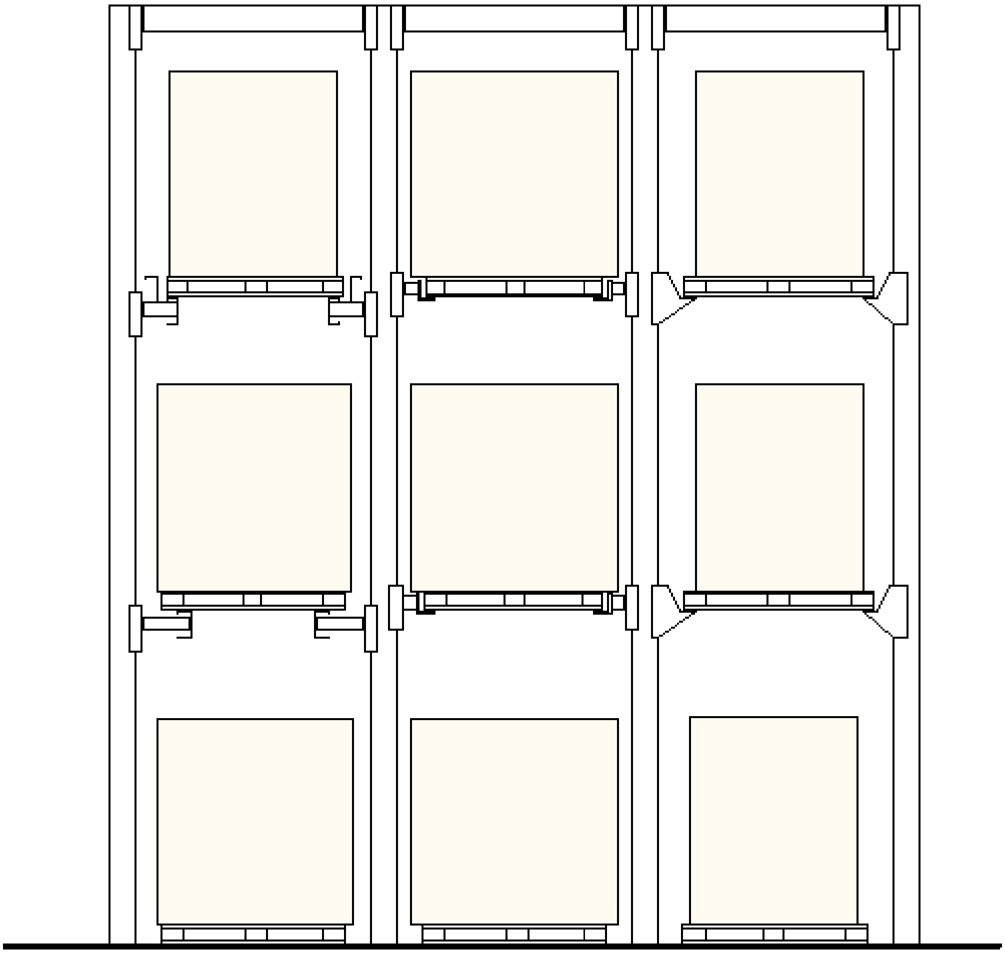


Figure 2 - Typical configuration of an unbraced Drive-Through Rack structure (various types of side arms and pallet rails are shown)

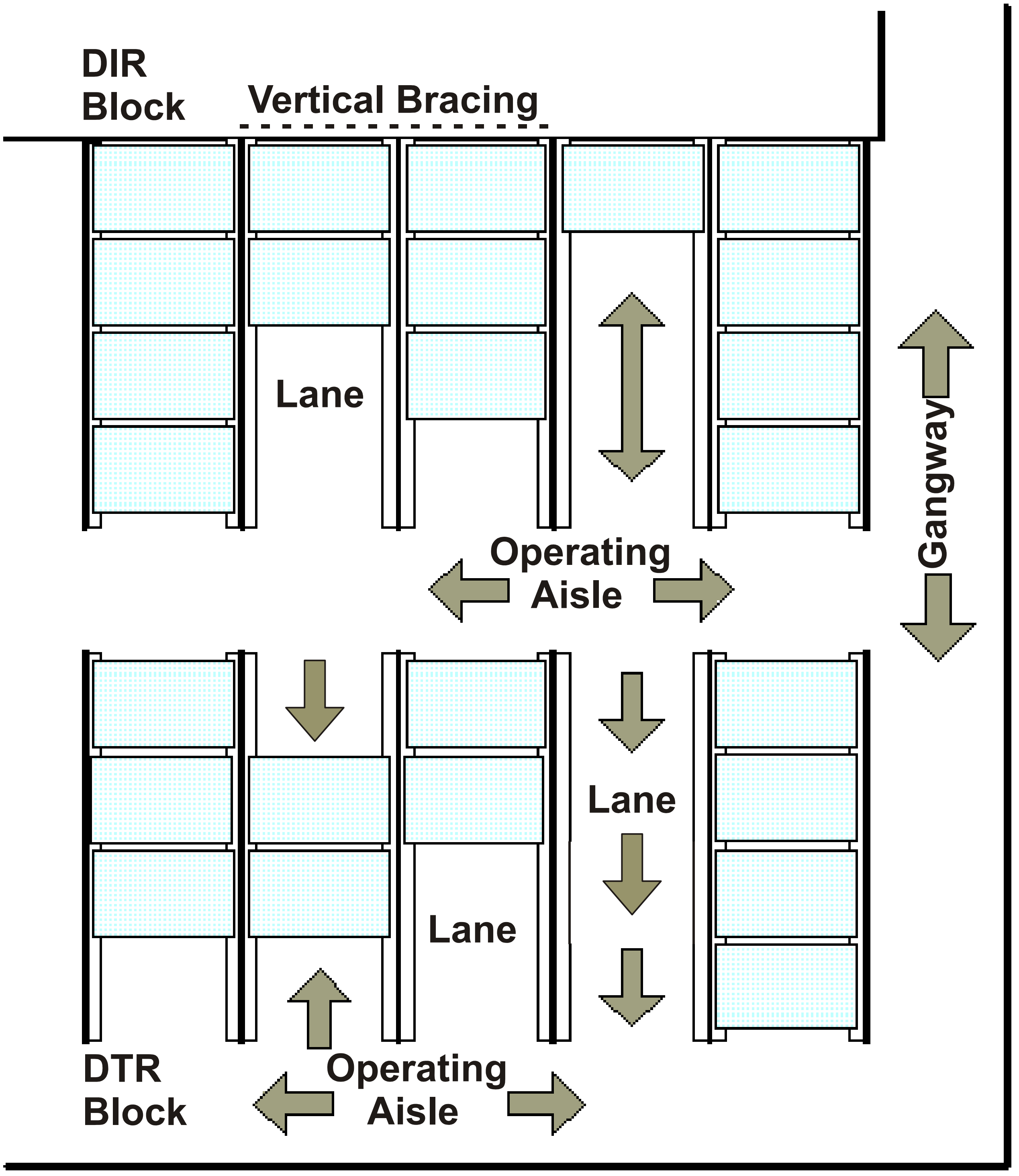


Figure 3 - Layout of a Drive-In Rack and a Drive-Through Rack

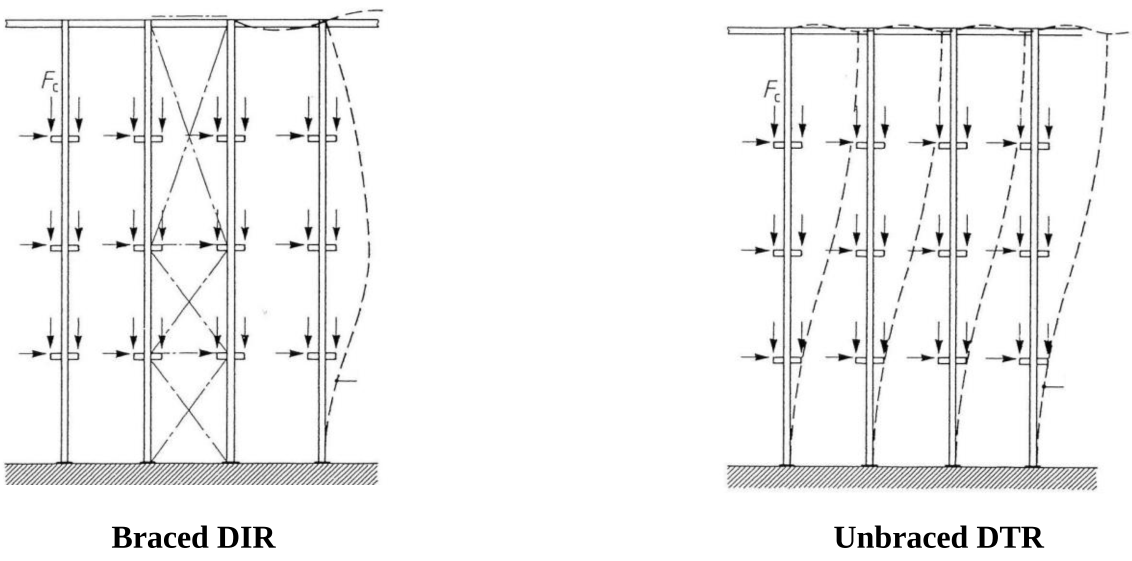


Figure 4 - Difference in flexural buckling behaviour between DIR and unbraced DTR

5.1.2 Down-lane direction

In the down-lane direction each row of uprights is braced generally by using adjustable pallet racking style upright frames or by means of some form of cross bracing, see Figure 5.

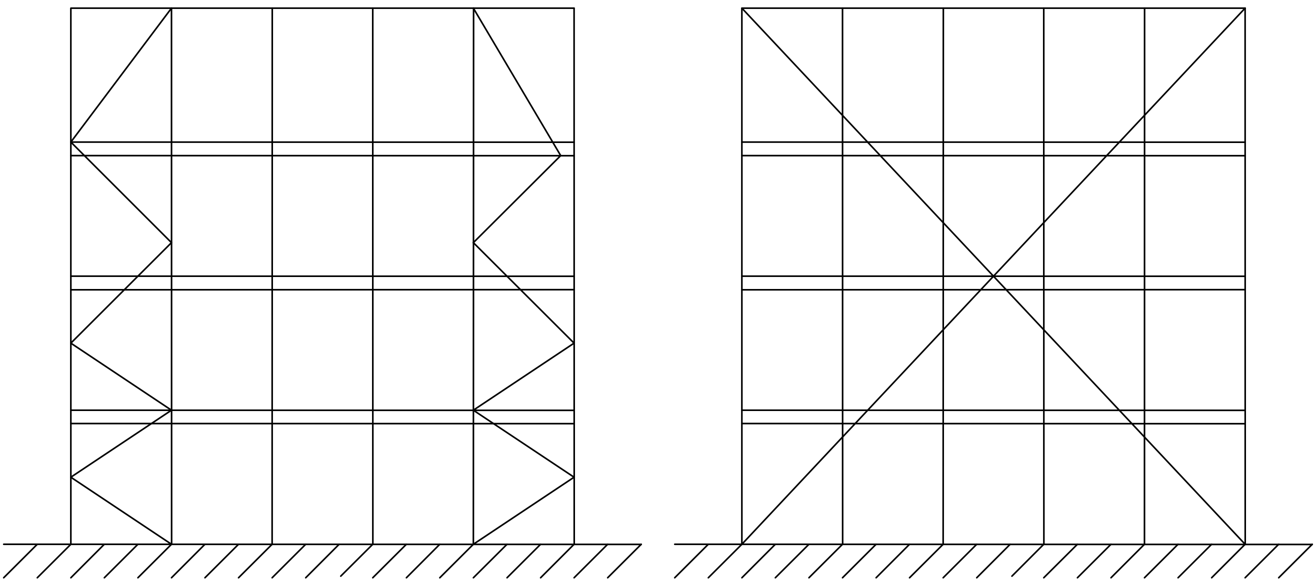


Figure 5 - Down-lane stability system for two different structural configurations

5.1.3 Cross-lane direction

In the cross-lane direction each row of uprights is braced generally by using plan and vertical bracing and/or portal frames see Figure 6.

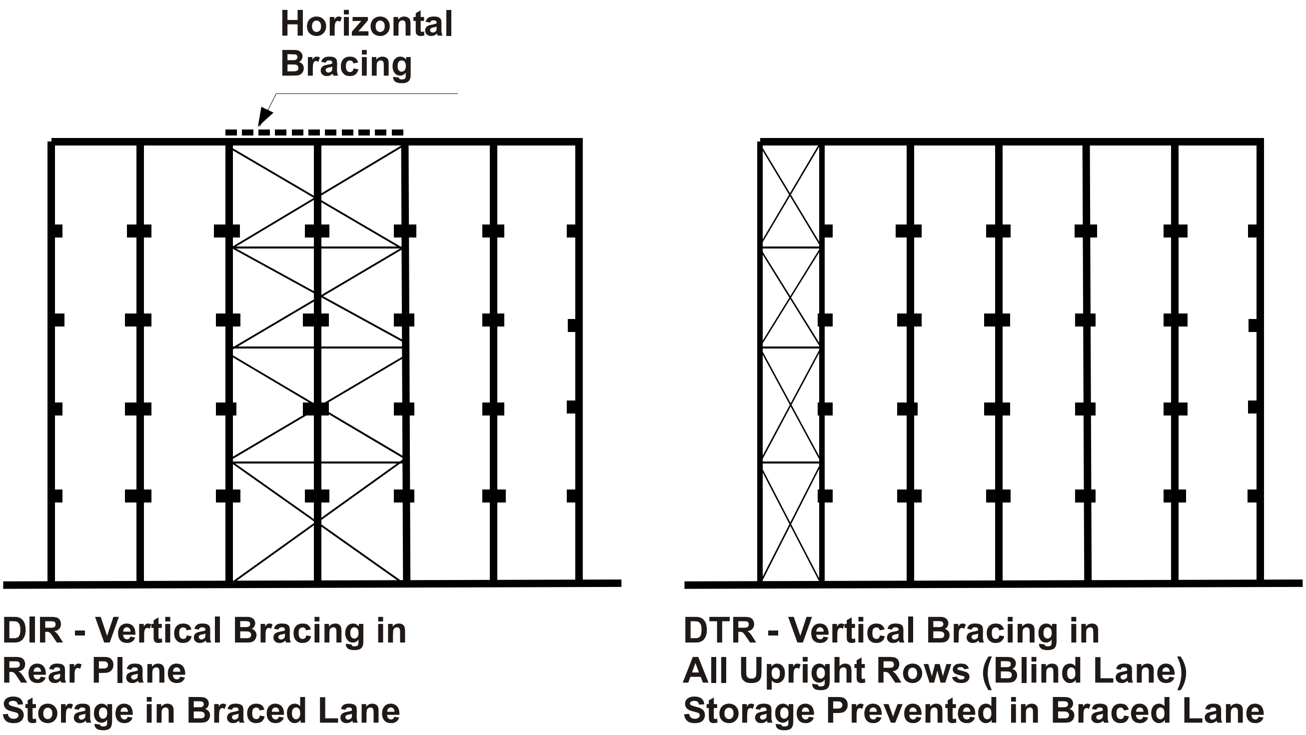


Figure 6 - Cross-lane stability system

5.2 Requirements

5.2.1 Basic requirements

DIR and DTR are standard products for which design by calculation alone may not be appropriate. Test procedures are therefore specified where current analytical methods are not given, or are not appropriate. The relevant test procedures are given in Clause 13.

Except where specific requirements are given to the contrary, the design procedures in this document shall be in accordance with EN 15512:2009.

Design shall be carried out on the basis of the project specification, see EN 15629, the specified installation tolerances given ANNEX C and the operational practice described in EN 15635. Truck mast stiffness and side shift shall meet the requirements given in EN 15635, clauses 8.6.1 and 8.7.

5.2.2 Design working life

See EN 15512:2009, clause 5.1.4.

5.2.3 Durability

See EN 15512:2009, clause 8.9.

5.2.4 Floor flatness

Refer to ANNEX C.

5.2.5 Truck Guide rails

Where truck guide rails are specified the supplier of the truck shall define the clear dimension between the guide rails, the lane entrance guidance and guide rail as well as anchoring requirements and installation tolerances.

5.3 Methods of design

See EN 15512:2009, clause 5.2.

5.4 Imperfections

5.4.1 General

The influence of imperfections shall be considered in the analysis by taking due account of:

- frame imperfections according to 5.4.2 and 5.4.3
- member imperfections according to EN 1993-1-1, 5.3.2 (11).

Member imperfections may be neglected in modelling structures for global analysis; however they shall be included for member checks.

NOTE If the buckling curves are applied bow imperfections are taken into account implicitly.

The effects of frame imperfections shall be considered in global analysis either by means of an initial sway imperfection or by a closed system of equivalent horizontal forces see Figure 7.

Initial sway imperfections shall apply in orthogonal horizontal directions, but may only be considered in one direction at a time.

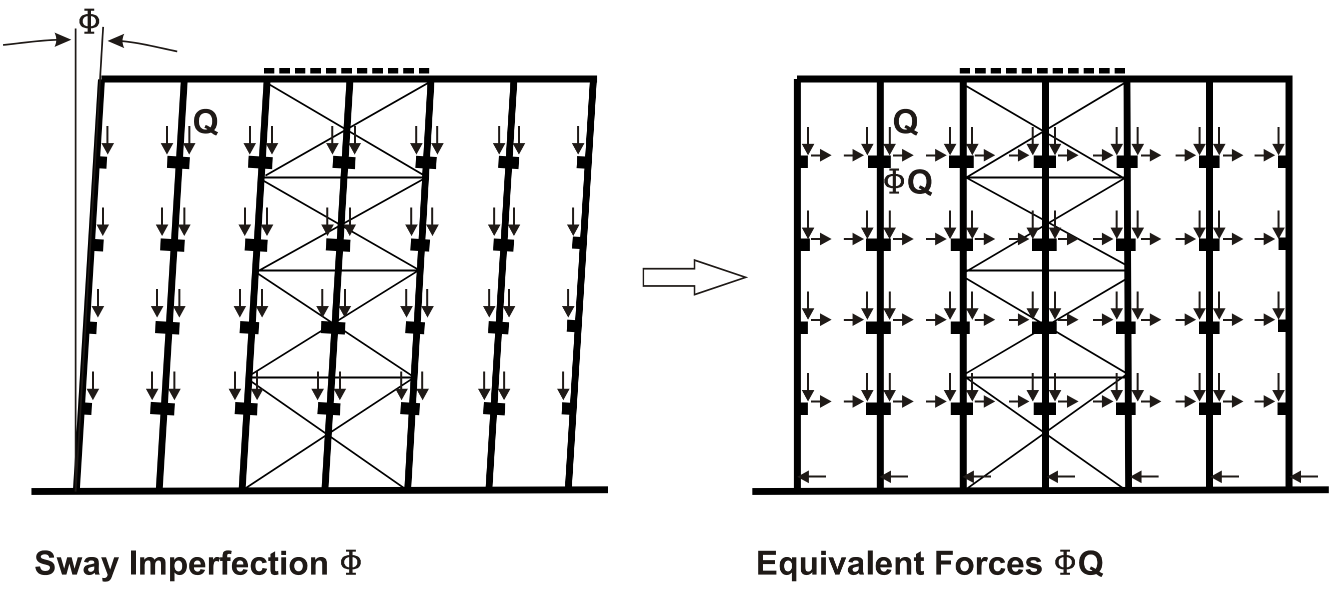


Figure 7 - Equivalent horizontal forces

5.4.2 Imperfections for the design of braced systems

The sway imperfection to consider $\Phi = \sqrt{(\frac{1}{2} + \frac{1}{n_\ell}) \times (2\Phi_s + \Phi_l)} \geq \frac{1}{500}$

where:

In the down-lane direction n_ℓ = number of connected upright frames per lane (excluding mono-posts),

If the down-lane stability of a number of mono-posts is provided by a bracing system n_l = 1.

NOTE: In case of mono-posts the connection between beam rail and mono-post is critical which means that the verticality of the mono-post is not independent.

In the cross-lane direction n_ℓ = number of connected lanes per Drive-In block.

Φ_s = Maximum specified installation out of plumb divided by the height (see ANNEX C).

Φ_l = Looseness of top tie beam end connector.

If the effect of the looseness of the top tie beam to upright connector is included in the modelling of the connection used in the global analysis, □Φ_l may be set equal to zero in the above equations.

In case of double entry racks the three dimensional global anti-symmetrical sway behaviour shall be considered (shown in Figure 9), as well as the symmetrical mode (shown in Figure 8), and the imperfections shall be applied accordingly.

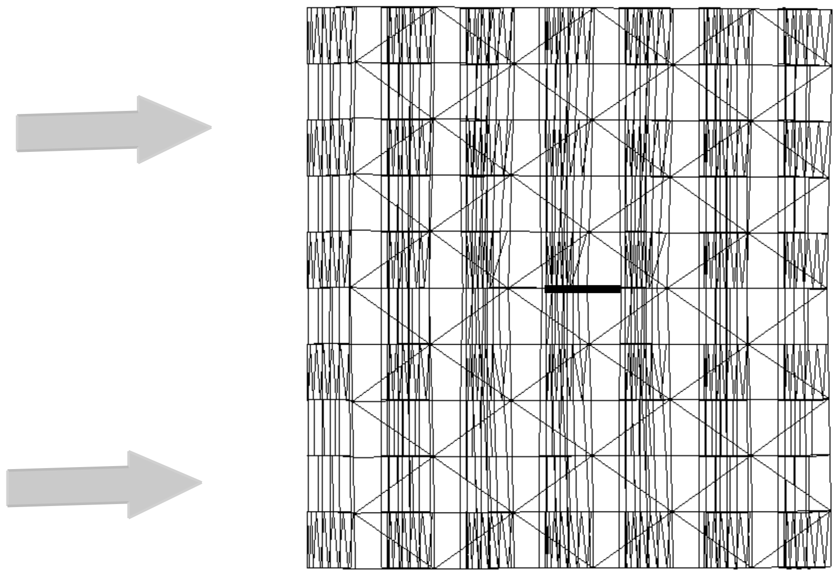


Figure 8 - Plan view of symmetrical sway mode in a double-entry Drive-In Rack

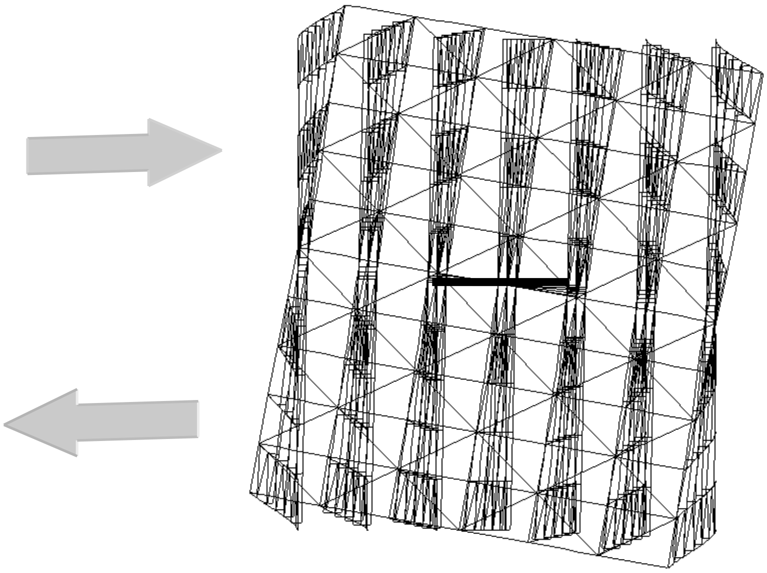


Figure 9 - Plan view of anti-symmetrical sway mode in a double-entry Drive-In Rack

5.4.3 Imperfections for the design of unbraced systems

The sway imperfection ϕ shall be determined from;

$\phi = \phi_s + \phi_l$ >=1/500,

ϕ_s = Maximum specified installation out of plumb divided by the height (see ANNEX C),

ϕ_l = Looseness of top tie beam end connector.

6 Actions and combination of actions

6.1 General

All actions in clause 6 shall be taken into account in the design of the structure. They shall be considered either individually or in combination.

6.2 Permanent actions

See EN 15512:2009, clause 6.2.

6.3 Variable actions

6.3.1 General

See EN 15512:2009, clause 6.3.1.

6.3.2 Unit loads to be stored

The weight of unit load to be used in the design shall be determined in accordance with the requirements of EN 15629.

For global analysis the designer may assume that both the distribution of load in any lane and the distribution within the volume of the block is uniform unless an alternative load distribution is defined by the end User or Specifier.

The treatment given in EN15512:2009, clause 6.3.2 whereby reduced loads may be used for different aspects of the design is not permitted for DIR and DTR.

6.3.3 Load eccentricities

If the nature of the load is such that the centre of gravity of the load does not coincide with the centre of the pallet then this shall be taken into account in the analysis (see EN 15629).

6.3.4 Vertical placement loads

Vertical placement loads imposed during depositing or removing goods as recommended in EN 15635 are covered by the partial safety factor of the unit load and therefore no vertical placement load needs to be taken into account.

6.3.5 Horizontal placement loads

The minimum horizontal placement load Q_{ph} equals 0.5kN (variable action) shall be applied in the cross-lane direction at the level closest to the mid-height of the upright. This load shall be considered on a single upright and any potential distribution by the beam rails shall be neglected.

NOTE 1 The minimum horizontal placement load is not intended to represent an impact load arising from misuse.

NOTE 2 The placement load in the down-lane direction may be neglected as it will be distributed to a number of upright frames.

NOTE 3 The effect of the placement load on a single upright may be considered by superposing this onto the results for the worst case upright taken from the global analysis.

6.4 Actions due to impact (accidental forces)

6.4.1 General

An accidental load shall be taken into consideration, but not at the same time as the horizontal placement load. Accidental loads are intended to reflect minor impacts in restricted areas.

The accidental horizontal load A_{ph} shall be applied from floor to 0.4 m height. The load may occur on the first two uprights in the down-lane direction at the entry of the lane but shall only be applied to one upright at a time:

A_{ph} = 2.5 kN in the down-lane direction;
A_{ph} = 1.25 kN in the cross-lane direction.

These loads shall be treated as occurring separately.

Accidental actions from fork lift trucks are given in EN 1991-1-7. Such actions need not apply for industrial trucks when the layout, clearances and operation are in accordance with this code and EN 15635.

NOTE 1 The racking is not normally designed to resist forces resulting from pallet or truck guidance.

NOTE 2 Large horizontal forces can be induced by misuse of the racking. For example, if pallets are pushed against a horizontal section of the pallet guard rail, or are pushed along the beam rail or are impacted against stored pallets. Forces of this nature are viewed as system abuse and are not considered as accidental design loads and are not permitted.

6.4.2 Back stop forces

As a minimum requirement a floor mounted buffering back-stop shall be provided to prevent impact with the vertical bracing. This back-stop shall be positioned with a clearance of at least 100mm between the unit load and the vertical bracing see Figure 10.

If this provision is fulfilled then rack mounted back-stops are not required. Alternatively, depending upon the outcome of a risk analysis carried out by the warehouse Safety Manager, backstops at load levels can be provided to protect the vertical bracing. The distance between the optional back-stop and the nominal position of the unit load shall be at least 50 mm.

A horizontal force Q_{ph} of not less than $0.25Q_u$ shall be considered for the design of the back-stop system where Q_u is the weight of the pallet including stored items. If the operational methods (working speed, type of truck, driver skill etc.) are such that this force is exceeded then a higher force shall be specified by the end user.

The back stop force shall be distributed to the structure in a manner that reflects the behaviour that is achieved in practice and verification shall be done accordingly.

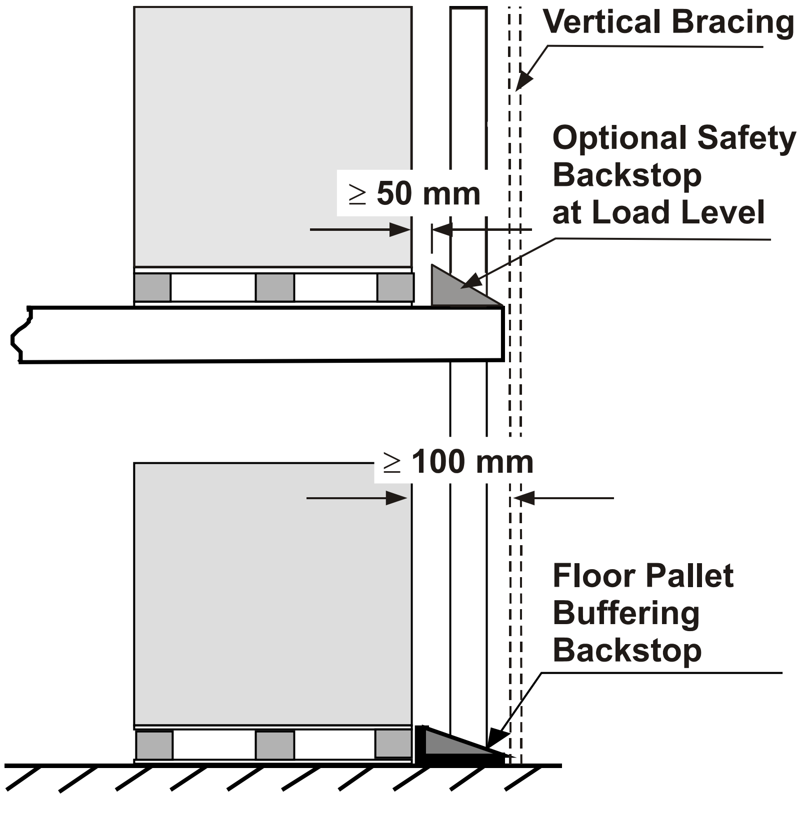


Figure 10 - Back-stop applications in DIR

6.5 Actions arising from installation

See EN 15512:2009, clause 6.3.7.

6.6 Seismic actions

This document does not give recommendations for DIR / DTR under seismic loading. Where it is required seismic actions shall be determined according to the relevant National Regulations in combination with FEM 10.2.08 as applicable.

6.7 Load combinations

The load combinations given in table 6-1 shall be considered in the design (taking into account that imperfections and placement loads may act in either direction). Accidental loads need not be considered in combination with pattern load effects.

If further actions are present e.g. seismic, then additional load combinations shall be considered.

Table 6-1

No	Combination content			
1	G	Q_{full}	$Imp_{d\text{-}l}$	
2	G	Q_{pat}	$Imp_{d\text{-}l}$	
3	G	Q_{full}	$Imp_{c\text{-}l}$	
4	G	Q_{pat}	$Imp_{c\text{-}l}$	
5	G	Q_{full}	$Imp_{d\text{-}l}$	$F_{ph.c\text{-}l}$
6	G	Q_{pat}	$Imp_{d\text{-}l}$	$F_{ph.c\text{-}l}$
7	G	Q_{full}	$Imp_{c\text{-}l}$	$F_{ph.c\text{-}l}$
8	G	Q_{pat}	$Imp_{c\text{-}l}$	$F_{ph.c\text{-}l}$
9	G	Q_{full}	$Imp_{d\text{-}l}$	$A_{ph.d\text{-}l}$
10	G	Q_{full}	$Imp_{d\text{-}l}$	$A_{ph.c\text{-}l}$
11	G	Q_{full}	$Imp_{c\text{-}l}$	$A_{ph.d\text{-}l}$
12	G	Q_{full}	$Imp_{c\text{-}l}$	$A_{ph.c\text{-}l}$

Key

G Self-weight

Q_{full} Unit loads (fully loaded)

Q_{pat} Unit loads (pattern loading)

$Imp_{d\text{-}l}$ Global sway imperfection down-lane

$Imp_{c\text{-}l}$ Global sway imperfection cross-lane

$F_{ph\ c\text{-}l}$ Placement load cross-lane

$A_{ph\ d\text{-}l}$ Accidental load down-lane

$A_{ph\ c\text{-}l}$ Accidental load cross-lane

NOTE 1 Combinations 1 and 3 are for the global analysis of the structure and combinations 1 to 12 are for the upright check (see 10.5.2).

NOTE 2 Back-stop forces and actions arising from installation are not included in the overview.

The following loading arrangements are sufficient to consider the pattern load effects for the design of the upright see Figure 11.

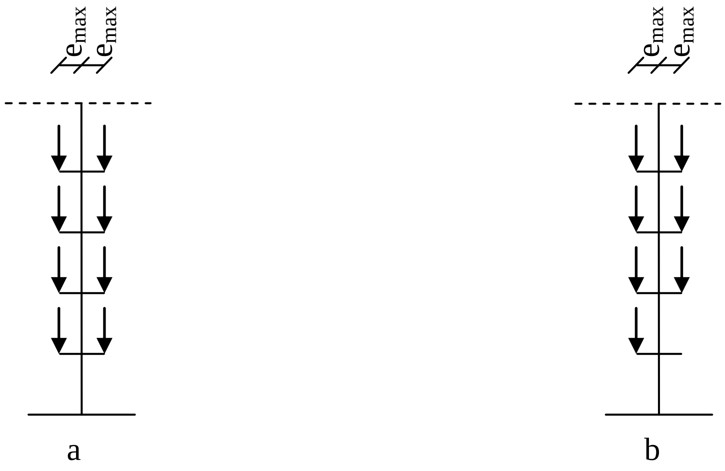


Figure 11 – Loading arrangements

NOTE Pattern loading situation b is not permitted due to the loading and unloading sequence specified in EN15635. However it should be considered in ULS design in order to take into account an empty pallet placed in the lowest load level. Other load patterns which are not permitted but may happen due to misuse or human error are covered by the safety factors for pallet load.

7 Partial factors and combination rules

See EN 15512:2009, clauses 7.1 – 7.6.

Read beam end connector as top tie beam end connector.

NOTE DIR and DTR are never crane operated systems.

8 Steel

See EN 15512: 2009, chapter 8.

Read pallet rack as DIR and DTR.

Dimensional tolerances are defined according to EN 15512:2009 clause 8.5.

9 Global analysis of DIR and DTR

9.1 General considerations

The structural behaviour of a DIR system and some DTR systems is generally a 3D behaviour. Therefore the cross-lane and the down-lane direction shall be considered simultaneously in global analysis. The global stability of the system shall be demonstrated by a rational analysis which takes account of the following factors:

i) The moment-rotation characteristics of the tie beam end connection. This shall be based on tests according to Annex A4.

ii) The moment-rotation characteristics of the upright to floor connection. See 9.5.

iii) The shear stiffness of the bracing system with its connections.

iv) The shear stiffness of the upright frames. Refer to EN 15512:2009 clause 10.2.3.

v) Bracing eccentricities shall be considered in the calculation model if the limits given in EN 15512:2009 clause 8.6 are exceeded.

In this chapter and ANNEX B several calculation methods are given to take into account this interaction between the two directions by means of 3D models or by means of particular rules for splitting the global system into cross-lane and down-lane sub systems.

Reference shall be made to EN 15512:2009, clause 10.1, reading pallet rack systems as DIR / DTR systems, cross-aisle as down-lane and down-aisle as cross-lane.

It is not permitted to take into account in the numerical analysis the stabilising effects provided by the friction and diaphragm action of the pallets located on the supporting beam rail as this is considered to be unpredictable and unreliable.

NOTE Plan bracing will transfer horizontal loads in the cross-lane direction to the plane of the vertical bracing and thereby introduce additional axial force into uprights adjacent to the plan braced lanes.

9.2 Structural modelling for analysis and basic assumptions

9.2.1 General

The calculation model and basic assumptions for the calculations shall reflect the structural behaviour at the relevant limit state with appropriate accuracy and reflect the anticipated type of behaviour of the cross-sections, members, joints and bearings. Features such as lack of member continuity, connection behaviour etc. shall be modelled. The method used for the analysis shall be consistent with the design assumptions.

Eccentricities at the brackets shall be considered in the calculation model if the limits given in EN 15512:2009 clause 8.7 are exceeded.

It is permitted to neglect vertical translational springs at the base plate in the global analysis if the recommendations of 10.7 are met.

9.2.2 Position of load application

The point of application of the load shall be as shown in Figure 12.

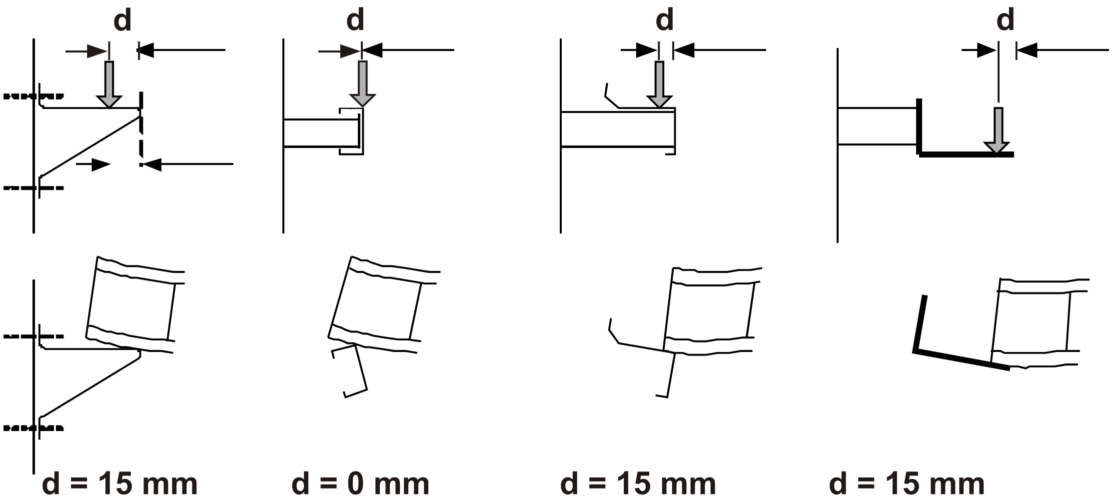


Figure 12 - Position of load application

The lever arm to be considered in the design is given in Figure 13.

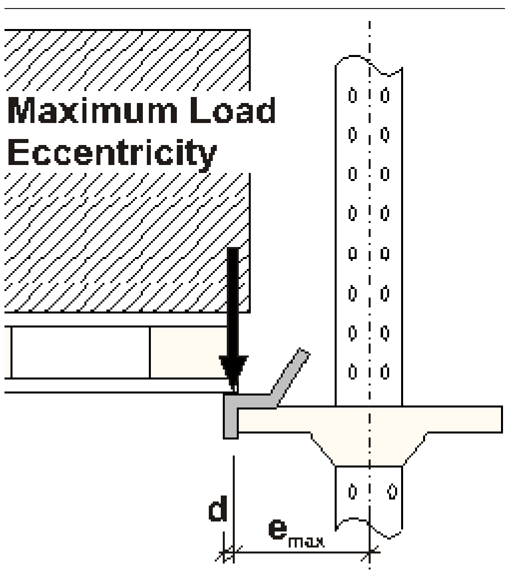


Figure 13 - Definition of the lever arm

9.3 Design procedure

9.3.1 General

The analysis shall be undertaken by considering down-lane and cross-lane directions. The interaction formulae given in clause 10.5 shall be used to combine the forces as appropriate.

9.3.2 Actions

Actions and combinations are specified in clause 6.

9.3.3 Design values

The design value of an action at both the ultimate and serviceability limit state shall be obtained by multiplying the actions by load factors and load combination factors given in chapter 7.

9.3.4 Down-lane Load combinations

It is sufficient to consider the rack to be fully loaded in the global analysis of both the Ultimate and Serviceability Limit states. Pattern load need only be considered for the local analysis of the upright. Down-lane sway imperfections or the corresponding equivalent horizontal forces and, where relevant, back stop forces shall also be taken into account.

9.3.5 Cross-lane Load combinations

It is sufficient to consider the rack to be fully loaded in the global analysis of both the Ultimate and Serviceability Limit states. Pattern load need only be considered for the local analysis of the upright. Cross-lane sway imperfections or the corresponding equivalent horizontal forces shall be taken into account.

9.4 Global Analysis methods

9.4.1 General

Global analysis shall be carried out in accordance with one of the alternative methods given below. The most complex analysis that is normally adopted is method 2.

The main design requirements of these methods are given in tabular form in ANNEX E.

For open sections the effects of torsional and flexural torsional buckling need to be taken into account.

NOTE In DTR systems in which each row of uprights has its own sway stabilisation system in the cross-lane direction (either bracing or moment resisting frame) a 2D calculation may be used modelling the cross-lane and down-lane directions separately.

9.4.2 Method 1

This is a three-dimensional second order analysis taking into account global non-verticality (system) imperfections as well as member (upright) bow imperfections. The analysis shall be carried out using direct second order analysis and not an amplification factor method.

The global imperfections shall be taken as the initial sway imperfection together with the individual member bow imperfection. The member bow imperfections shall be taken from EN1993 1.1 in accordance with the buckling curve as specified in EN 1993 part 1.3.

At the end of this procedure only “resistance verifications” of the cross sections are to be performed, because all the effects of global and local imperfections are modelled in the 3D- FE model. This means that the FE-model shall be able to represent all the determinative combinations of the initial global lateral sway of the structure together with the initial bow imperfections of the uprights, which must be modelled in the down-lane and cross-lane direction at the same time.

A correction for torsional, lateral torsional, distortional and flexural torsional effects according to ANNEX F shall be carried out if Method 1 is adopted.

NOTE If it can be demonstrated that the upright profile is not susceptible to torsional effects then no further corrections are required. Otherwise, correction for torsional effects is required. At the time of writing commonly available software cannot explicitly take into account torsion effects (e.g.: torsion imperfections, Saint Venant and warping restraints, end conditions at member ends). Therefore, an analytical correction is needed depending upon the shape of the upright profiles.

9.4.3 Method 2

Method 2 is a three-dimensional second order analysis taking into account initial global sway imperfections. The analysis shall be carried out using direct second order analysis and not an amplification factor method.

The determination of the buckling length in the cross-lane direction is based on a strut that is fully laterally restrained at the top and at the base and takes into account the rotational stiffness of the top tie beam end connectors as well as the upright to floor connections. The buckling length can be calculated either by means of the analysis of the single upright in 2D or by means of the 3D model. The top of the uprights shall be laterally restrained.

A correction for the effects of torsional and flexural torsional buckling shall be carried out in accordance with EN15512 clause 9.7.5.

9.4.4 Method 3

Method 3 is a three-dimensional first order analysis method where the cross-lane buckling length of the relevant upright has to be determined taking into account the sway stiffness of the global structural system.

Initial sway imperfections shall be:

- for the global analysis in the cross-lane direction the value obtained from clause 5.4.1 multiplied by a factor of 3
- for the global analysis in the down-lane direction the value obtained from clause 5.4.1
- for the local analysis of the upright in the cross-lane direction the value obtained from clause 5.4.1

NOTE: The factor of ×3 is to allow for the enhancement of loads in the bracing system due to 2^{nd} order effects. It is used for the evaluation of the stiffness of the system and for the evaluation of the internal actions at the ULS in all the elements of the rack, including bracing diagonals, upright frames, connections, floor anchors.

The cross-lane design procedure is a three-stage approach as defined below:

Stage 1 – Check for sufficient rigidity of the structure and determination of internal forces.

Method 3 shall not be applied if the resulting horizontal deflection at the top of the second row of uprights from the rack entrance under unfactored unit load and imperfection actions is greater than 3H / 500.

The internal forces and the worst case upright shall be determined at the ULS.

NOTE The worst case upright is likely to be the upright with the highest compression force due to the combination of the pallet weights and the overall block bracing deformations although this will only be the case if the configuration of the block of racking is uniform.

Stage 2 – Determination of the spring constant C_{global}.

The equivalent lateral spring constant C_{global} shall be determined by a three dimensional first order analysis under the effect of horizontal unit loads (H_1) as shown in Figure 14. In the figure the unit loads H_1 can act as shown or can all act in the same direction. Both cases shall be considered and the worst case taken in the determination of C_{global}.

NOTE: In Figure 14 the forces are shown for a uniform rack arrangement. If this is not the case then the unit loads should be adjusted accordingly.

$C_{global} = H_1 / u$

Where:

H_1 = unit load on one upright,

u = cross-lane deflection of second row of uprights from the entrance of the lane.

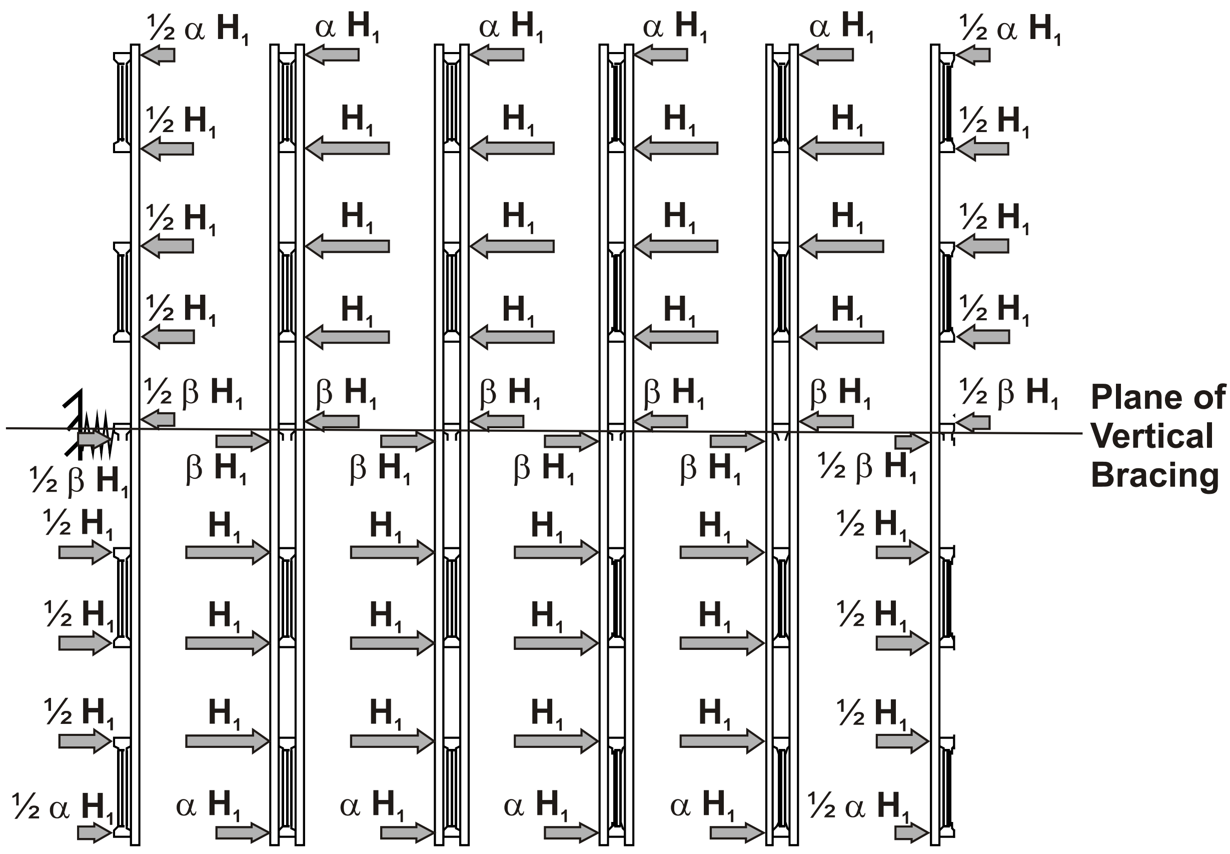


Figure 14 - Top view of block of racking showing application of unit load per upright

α and β are the factors as a proportion of the span of the beam rail.

Stage 3 - Member check of the critical upright.

The member check is based on a strut that is free to move laterally at the top under partial restraint by C_{global} and C_{top} and may be rotationally restrained at the top and bottom by springs (see Figure 15). The flexural buckling length shall be determined by means of a buckling analysis of the determinative upright. See ANNEX D for various typical end conditions.

The buckling length can be calculated either by means of the analysis of the single upright in 2D (considering the translational spring C_{global}) or by means of the 3D model.

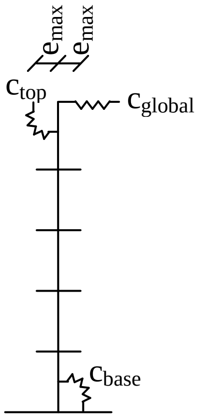


Figure 15 - Structural model for upright member check

C_{top} consists of the rotational spring stiffness of the top tie beam and of the top tie beam end connector. It can be determined from the following equation:

$$\mathrm{C_{top}} = \frac{2C_\varphi C_{tt}}{C_\varphi + C_{tt}}$$

$$\mathrm{C}_{tt} = \frac{6EI_{tt}}{L_W}$$

Where:

C_φ = Rotational stiffness of the top tie beam end connector (see clause A.3),

C_{tt} = Rotational spring stiffness due to bending of the top tie beam,

I_{tt} = Second moment of area of the top tie beam,

L_W = Centre to Centre distance of the lane.

NOTE: The presence of pallets in the lane causes the uprights to buckle in the same direction which leads to the expression for C_{tt} above.

Imperfection and sway deformations in the cross-lane direction induce additional internal forces into the upright frames in the down-lane direction due to global torsion. These forces shall be added in the member check.

9.4.5 Other methods

Refer to ANNEX B

9.5 Moment-rotation characteristics of the upright to floor connection

See EN 15512:2009, 10.2.5.

The moment-rotation properties of the floor connections vary depending on the axial load at the base of the uprights. In the global analysis the stiffness of the upright to floor connection shall be based on the axial loads in the uprights.

For a set of uprights with different axial forces, the mean value of the stiffness may be used if the variation of the axial force of each one is not greater than ± 10 %. When there is a greater variation than this, then the values of failure moment and stiffness corresponding to the individual axial force of each single upright shall be used.

In general a non-linear model taking into account the variation of the stiffness and of the bending capacity with the axial load at the uprights' bases may be used for the global analysis.

Alternatively, a constant value of the stiffness of the upright to floor connection can be used. For the ULS analysis the floor stiffness shall be determined for the mean value of the axial load at the SLS and the ULS.

For the SLS sway verification, the floor stiffness shall be determined for the axial load at the SLS.

The Euler critical load of an upright shall be determined by a linear buckling analysis, or another appropriate method, using a constant stiffness of the upright to floor connection.

Table9-1 —Upright force for the determination of floor connection stiffness at the ULS in the global analysis and upright member check at the SLS sway check.

Table 9-1 —Upright force for the determination of floor connection stiffness

	Global analysis	ULS Member check	SLS sway check
Either	Spring stiffness as a function of axial load	Mean of SLS and ULS	Spring stiffness as a function of axial load
Or	Mean of SLS and ULS	Mean of SLS and ULS	SLS

NOTE: The SLS spring stiffness may always be used.

9.6 Racks braced against the building structure

It is recommended that DIR should be a stand-alone structure.

If the racks are braced against the building structure, the two structures will impose forces upon each other. These forces shall be calculated and the owner of the building or his representative shall be informed of these forces and their location.

NOTE These interaction forces should be calculated taking into account the relative stiffness of the rack compared to the warehouse. The rack designer should consult the warehouse designer.

10 Member checks

10.1 Calculation of section properties

See EN 15512:2009, clause 9.2.

10.2 Beams

10.2.1 General

Where relevant, the design of cold-formed racking members in bending shall take into account the following:

- lateral buckling;
- torsion;
- local buckling;
- web crippling;
- flange curling;
- inelastic behaviour;

See EN 15512:2009, clauses 9.4.7 – 9.4.10.

10.2.2 Beam rail

In the case of an asymmetric section bending will be about the principal axes and will generally also result in torsion. An analytical approach is given in EN15512:2009 clause 9.6 which generally does not lead to an optimal solution and so a test procedure is given in ANNEX A.

10.2.3 Top tie beam

The forces in the top tie beam are bending, shear and compression. Design shall be in accordance with EN15512:2009, clause 9.6.

10.3 Top tie beam end connectors

The forces in the top tie beam end connectors are bending, shear and axial load. These internal loads shall be obtained from the global analysis (see chapter 9) and shall be combined as given in EN 15512:2009 clause 9.5.4.

The mechanical properties of top tie beam end connectors shall be determined according to Annex A4.

Safety pins (or bolts) shall be fitted as prescribed.

10.4 Beam rail to upright connection

The beam rail can be connected directly to the uprights or via brackets. The symmetrical as well as the asymmetrical (beam rail loaded only on one side of the upright) load case shall be considered.

In most cases the rail to upright connection is a bracket made from thin walled cold formed section provided with hooks or bolts which are connected to system holes in the rack upright. Alternatively the beam rail may be bolted directly to the upright. The vertical deflection, the load carrying capacity and optionally also the rotational stiffness of this connection shall be determined from tests as given in Annex A2, unless a rational analysis can reliably determine these properties.

The design loads for the brackets shall be taken either from the global analysis or from clause B 1.2.

$E_{Ed} / E_{Rd} <= 1.0$ shall be satisfied.

10.5 Compression members

10.5.1 General

Compression members shall be checked according to EN 15512:2009, clause 9.7.

10.5.2 Uprights

10.5.2.1 General

It is permissible to use a first order analysis to take into account the effect of the placement and accidental loads, when those results are combined with the results of a second order analysis.

10.5.2.2 Down-lane flexural buckling

Where down-lane stability is provided by upright frames, the buckling length factor shall be obtained from EN15512:2009, 9.7.4.3 (b) and (c).

10.5.2.3 Cross-lane flexural buckling

The cross-lane buckling length is given in chapter 9 and depends upon the choice of analysis method.

10.5.2.4 Torsional buckling

The effects of upright torsion shall be taken into account. Values for L_{eT} are given in EN 15512:2009 clause 9.7.5.2.

NOTE If the beam rail is taken to be part of the upright frame bracing system, the detailing of the beam rail to upright connection affects the torsional restraint and, therefore, the flexural torsional buckling length. Special attention is required for the end uprights that are connected on one side only.

Mono-posts shall be torsionally restrained as well. Refer to EN 15512:2009 clause 9.7.5.2.

NOTE Torsional restraint can be provided by down-lane spacers, beam rails with appropriate connections etc.

10.6 Design of splices

It is not recommended to use splices in the rack uprights. If splices are unavoidable they shall be designed according to EN15512:2009 clause 9.8.

10.7 Design of base plates

The design of the baseplate shall be carried out using elastic methods and shall take into account all the relevant eccentricities. Both the compressive and tensile load situations shall be considered as relevant.

See EN 15512:2009, clause 9.9.

NOTE: Elastic methods only are permitted in order to achieve sufficient stiffness and to avoid any need to include vertical translational springs in the global analysis.

10.8 Floor materials

See EN 15512:2009, clauses 9.10.1 – 9.10.3.

10.9 Design of anchor bolts

See EN 15512:2009, clause 9.10.4.

11 Serviceability limit state

11.1 General

The verification of the serviceability limit state ensures the proper functioning of the elements under service conditions. In general, it is sufficient to consider deformations or deflections, which affect the use of the structure.

Storage systems shall be proportioned such that the deflections are within the limits agreed between the client and the designer as being appropriate to the intended use, the nature of the handling equipment, any National Regulations and also within the limits given in this code.

11.2 Limiting values

11.2.1 Beam rail

Under the loads defined in chapter 6 and the serviceability limit state combinations defined in chapter 7 the limiting values for deformations of the beam rail are as follows (see Figure 16):

- $D_B \leq$ the larger of 5mm or 1/100th of the length of the arm,
- $D_R \leq$ 10mm (at any position on the beam rail),
- maximum twist = 6 degrees.

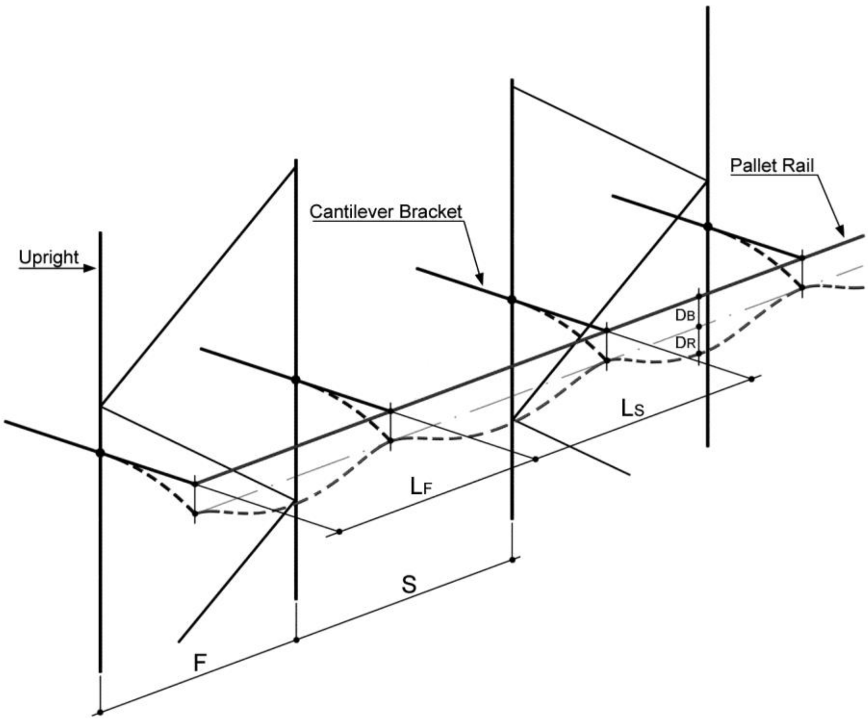


Figure 16 - Deformation of the load support level (cantilever bracket plus pallet rail)

This deflection calculation shall be based on a single line of uprights with a single row of loads and need not include the deformation of the uprights.

The horizontal deflection of an individual beam rail (at the pallet bearing location) shall be less than 5mm.

11.2.2 Sway deflection

The maximum calculated sway deflection (SLS) at the top of the rack calculated using a second order analysis (i.e. method 1,2 or 4) shall not exceed;

— H / 200 in general

— H / 350 for the vertical bracing (if present),

— H / 350 for unbraced racks.

NOTE: If methods 3 or 5 are used it is not necessary to carry out a SLS deflection check as this is implicit in the methods.

In some cases more stringent limits may be specified to suit the use of the installation. This deflection limit shall be incorporated into the design calculations.

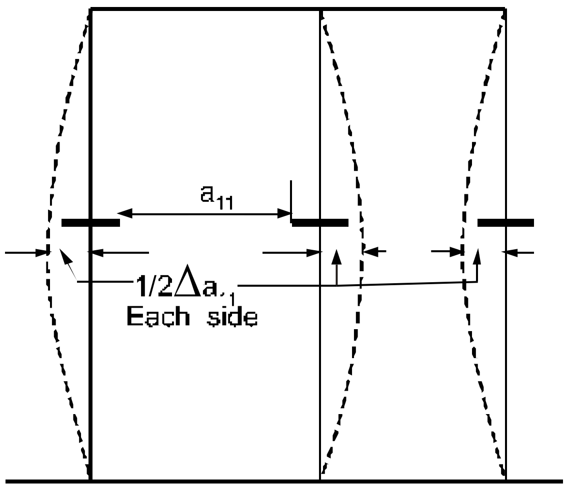
11.3 Minimum pallet bearing

The minimum pallet bearing depends upon the pallet tolerance. For pallets with a width tolerance of less than ±10mm the bearing width (a_0, see Figure 18) shall be at least 25 mm. For pallets with a width tolerance of less than ±5mm the bearing width (a_0) shall be at least 20 mm.

The minimum pallet bearing is achieved by verifying

$\Delta a_{11} <= w_{ss} - a_5 - a_0$ (see ANNEX C).

where w_{ss} is the width of the beam rail support surface.



KEY

a_{11} is the nominal dimension between pallet rails.

$\frac{1}{2}\Delta a_{11}$ is the bending deflection of a single upright.

Δa_{11} is the increase in the distance between the uprights because of loading.

Figure 17 - Measurement of upright bending deflection

The increase in clear width a_{11} (see Figure 17) is determined as follows:

$\Delta a_{11} = [5.5(n + 1)\, e_b + 0.4\, h_u]10^{-3}\, [F_b . h_u{}^2 / E . I_u]$

where

I_u = Moment of inertia of the upright,

h_u = Total upright length,

n = Total number of cantilever bracket levels which can be loaded,

F_b = Reaction force on the cantilever bracket based on the unfactored load per metre applied to the pallet rail (neglecting continuity of the beam rail),

e_b = Distance between the point of application of F_b and centre of the upright,

E = Young's modulus of elasticity.

NOTE The formula above is an empirical formula which gives good agreement with practical operational situations.

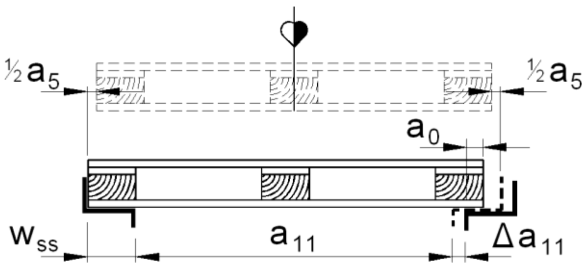


Figure 18 Minimum pallet bearing a_0

12 Marking and labelling

All installations shall display, in one or more conspicuous locations, a permanent Load warning notice stating that the rack is designed according to this Code of practice showing the maximum permissible unit load and the maximum permissible load per lane in clear legible print. Suitable Load warning notices are given in EN15635.

Where the permissible loads are not identical throughout the installation, these load notices shall be placed in such a way that the maximum permissible unit load is identified for each location throughout the structure.

13 Test methods and evaluation of results

See EN 15512:2009, chapter 13 and ANNEX A, Table 12 shall be read as follows:

Table 13-1 — Tests for material and design purposes

EN15512 Clause reference	**Title**	**Test method**	
8.1.4	**Material tests – EN 15512**	A.1	
8.1.4.2	Tensile tests	A.1.1	mandatory only for steel not given in EN 1993-1-1, table 3.1 or EN 1993-1-3, 3.1a / 3.1b
8.1.1 (b)	Bend tests	A.1.2	mandatory only for steel not given in EN 1993-1-1, table 3.1 or EN 1993-1-3, 3.1a / 3.1b
	Tests on components and connections – EN 15512	A.2	
9.7.2	Stub column tests	A.2.1	mandatory for perforated members
9.7.2	Distortional buckling tests on uprights	A.2.2	mandatory
5.3.2	Looseness tests on top tie beam end connectors	A.2.5	mandatory
9.9	Tests on floor connections	A.2.7	optional
10.3.1	Tests for shear stiffness of frames	A.2.8	mandatory
9.7.6	Bending tests on upright sections	A.2.9	optional

FEM10.2.07 Clause reference	**Tests on components and connections – FEM 10.2.07**		
10.4	Test on rail to upright connections	A.2	mandatory except for bolted bracket connections
10.2.2	Test on beam rails	A.3	optional, depending upon rail type
9.1	Test of top tie beam end connectors (portal test)	A.4	mandatory

ANNEX A

Test methods and evaluation of tests

A1 General

General requirements for test setups, test specimens, reporting and test interpretation of results are given in EN15512:2009 chapter 13.

For component tests not given in the following see Annex A of EN15512:2009.

A2 Test on rail to upright connections

A2.1 General and purpose of the test

In most cases the rail to upright connection is a bracket made from thin walled cold formed section provided with hooks or bolts which are connected to system holes in the rack upright. Alternatively the beam rail may be bolted directly to the upright. The vertical deflection and the load carrying capacity of this connection shall be determined from tests, unless a rational analysis can reliably determine these properties.

NOTE: Additionally the rotational stiffness may be determined if it is to be included in the global analysis. Assuming a rigid connection is a conservative assumption in the global analysis.

A2.2 Test arrangements

A2.2.1 Load on one side of bracket

The test arrangement shall be as follows (see figure A1):

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

b) Two rail brackets shall be connected to the pair of upright pieces,

c) The test load is applied using a spreader beam or equivalent system,

d) The test load shall be applied at the mid span of the spreader beam and shall be transferred to the brackets via knife edge bearings and load pads,

NOTE: It may be necessary to stabilise the load spreaders.

The test load shall be introduced to the beam rail at a distance b from the outer edge, where: b = 15 mm + bending radius at the edge of the rail.

NOTE: As the position of the load is specified with respect to the edge of the beam rail this means that more than one lever arm may have to be tested.

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.1),

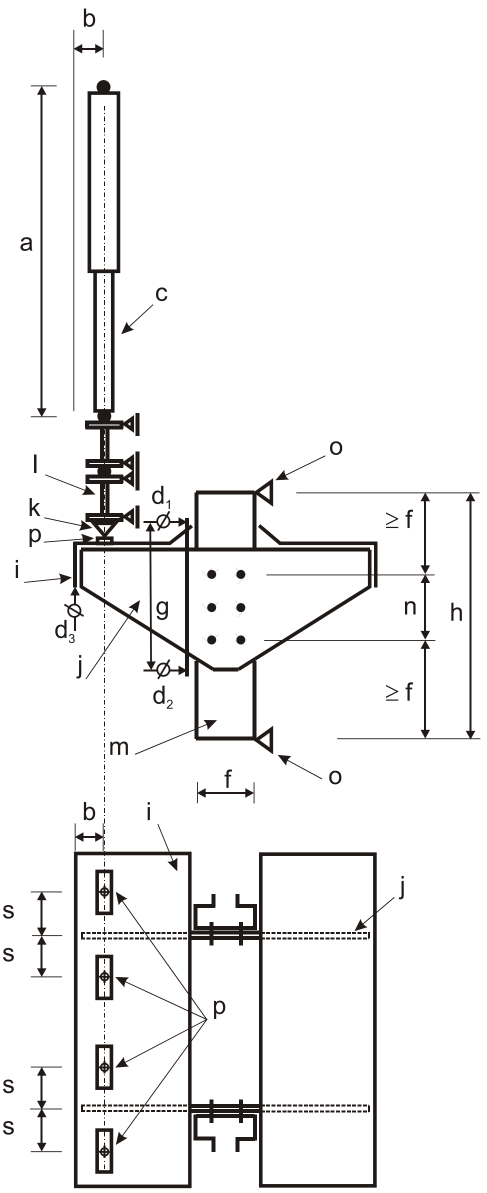
NOTE These transducers can be mounted horizontally as shown or may be mounted vertically but, in either case the rotation should be measured at the edge of the upright.

2) an inclinometer connected to the bracket close to the upright connection.

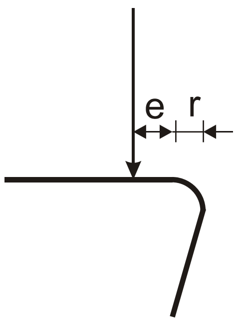
f) The vertical deflection shall be measured by gauge d_3 at the outer edge of the beam rail,

g) In the case of a single sided bracket arrangement the lever arm shall be taken as the dimension from the point of application of the load to the face of the upright,

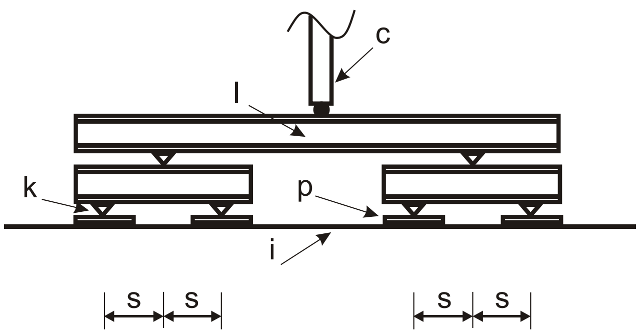
h) In the case of a double sided bracket arrangement the lever arm shall be taken as the dimension from the point of application to the centre of the bracket,



Position of load on rail:



Arrangement of load spreaders:



Key

a ≥ 750 mm

b = e + r, distance between load and outer edge of rail

c load jack

d_1, d_2, d_3 measuring devices

e = 15 mm

f upright face width

g spacing of measuring devices

h distance between connection points ≥ n + 2 × f

i rail section

j rail bracket

k knife edge bearing

l load spreader

m upright section

n dimension from top to bottom of connection

o connection to the test rig structure

p load pad 150 × 20 × 10 [mm]

r radius of rail

s = 150 mm (distance between centres of load pad and bracket)

Figure A.1 – Schematic arrangement for testing of rail to upright connection

A.2.2.2 Load on both sides of bracket

This test is only necessary in case of a double sided bracket. The test arrangement shall be as explained in A.2.2.1 with the following difference:

1) The load shall be simultaneously applied on both sides,

2) Measurements shall be made on both sides.

NOTE : This test measures shear and the moment and rotation is not relevant in this test.

A 2.3 Test procedure

A2.3.1 Load on one side of bracket

See chapter A.2.4.3 of EN 15512, but read “connector” as “bracket”.

A2.3.2 Load on both sides of bracket

See chapter A.2.4.3 of EN 15512, but read “connector” as “bracket”.

A2.4 Corrections to the observations

See chapter A.2.4.4 of EN 15512, but read “connector” as “bracket”. Divide the test force by two in case of test A.2.2.1 and by four in case of test A.2.2.2 to obtain results for one single bracket.

A2.5 Derivation of the results

See chapter A.2.4.5.1 of EN 15512, but read “connector” as “bracket”.

A3 Test on Beam rails

A3.1 General and purpose of the test

Testing of the pallet rails is required to evaluate the bearing capacity and deformation under load. The tests shall be carried out using a reduced system with rail sections over two spans and applying single loads.

NOTE: In general the pallet rails of Drive-In / Drive-Through Racks consist of thin walled open cross sections directly fixed to the uprights or mounted on brackets 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 bracket and rail etc., cannot be reliably determined from a theoretical analysis.

The load make-up accessory may cover either the general case for any possible type or a particular case if special load make-up accessories are agreed and explicitly defined in the contractual documents of a project.

A3.2 Test arrangements

A3.2.1 General case

The set up consists of a rail running over two spans and supported by the relevant brackets (if any) which are connected to rack frames. The test load is applied as shown in figure A3 and figure A4 via knife edge bearings at the dimension b (= e + r).

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

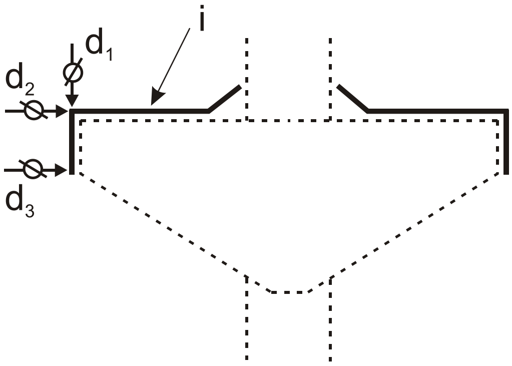
NOTE The method of application shown in figure A4 is one possible means of achieving this.

The distribution of the single loads shall be as defined in figure A3 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 A1, in order to simulate the actual load distribution due to the pallet.

Measuring devices shall be positioned at the mid span. 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 fig. A2. Furthermore the vertical deflection of the brackets shall be measured.



Key

d_1 measuring device for vertical deflection

d_2, d_3 measuring devices for rotational deflection

i rail section

Fig. A.2 – Position of gauges

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 1,0 m	1	2,00	1,48	1,60
1,0 m – 1,5 m	2	1,35	1,32	1,30
1,5 m – 2,5 m	4	1,00	1,02	1,00

$F_t = f_l \times F$

where:

F test load (single load)

F_t theoretical uniformly distributed load

$F_{lz} = f_z \times F_z$

where:

F_z test load

F_{lz} theoretical uniformly distributed load

If the twist of the beam rail measured in the test is less than 6° (having removed the effect of bracket 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.

Table A.1 – Number of single test loads and correction factors.

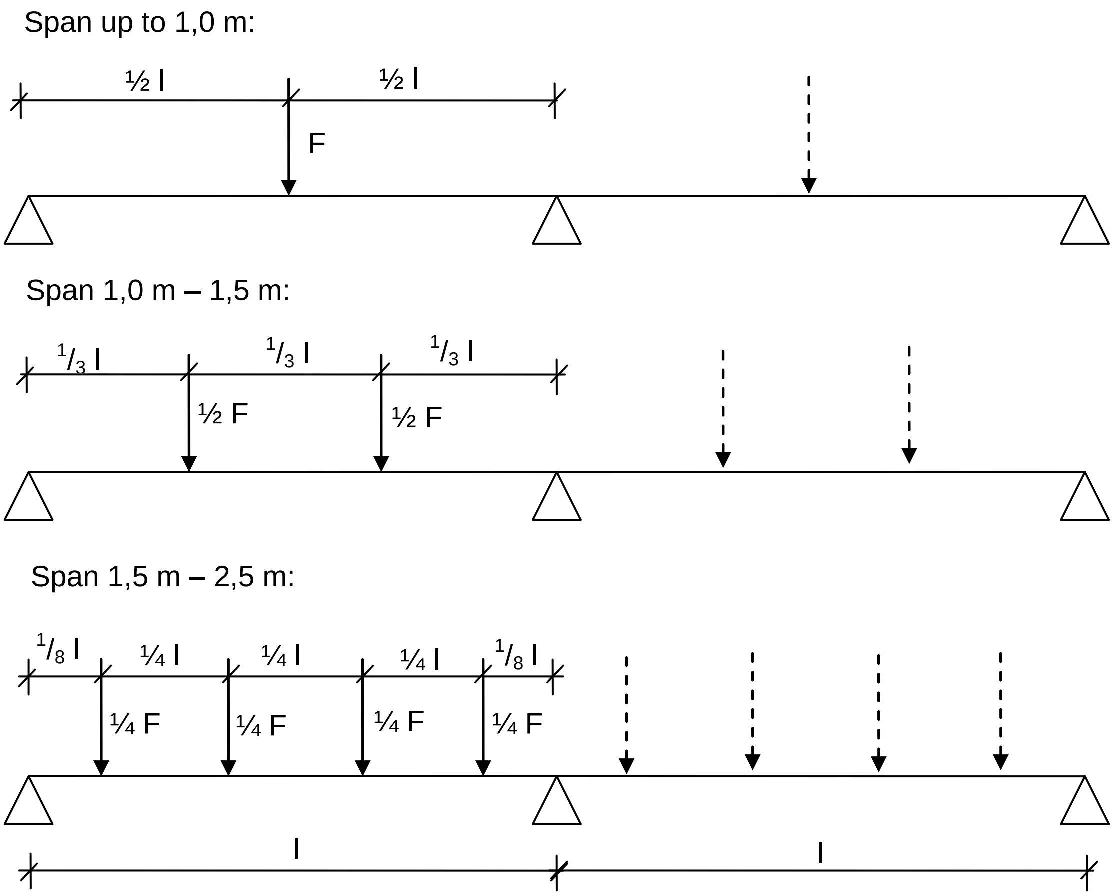
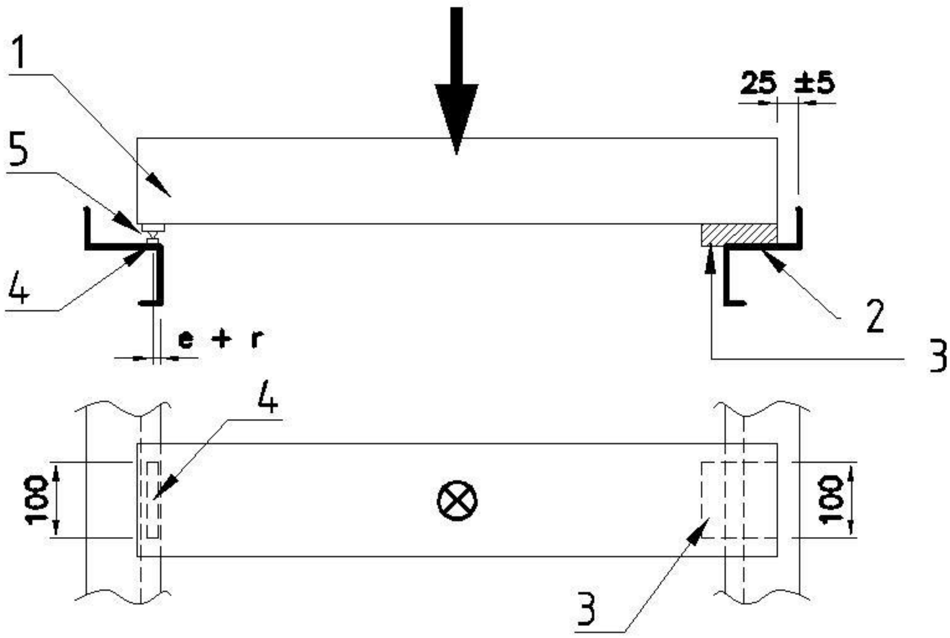


Figure A.3 – Distribution of single test loads for general load make-up accessories.



KEY

1 spreader beam

2 low friction contact surface e.g. Teflon®

3 wooden block

4 pressure pad 100×20×10

5 edge bearing

Figure A.4 –Application of test loads.

A3.2.2 Particular load make up accessory

In the case of a particular load make-up accessories the blocks of the relevant type shall be positioned such that the minimum bearing width of the tested rail is 20 mm and the most unfavourable load position shall be taken into account, see figure A5. It is necessary to vary the position of the LMA to obtain the determinative load case for both sagging and hogging bending at both SLS and ULS.

The distance between the load make-up accessories shall be 25 mm.

The test load shall be applied at a distance e = 0.2 of the LMA width (see fig A5) so that rotation of the LMA edges is taken into account. The test load shall be distributed uniformly on the load make-up accessory in the down-lane direction.

The position of the load and position of the LMA in the down lane direction shall be as in practice.

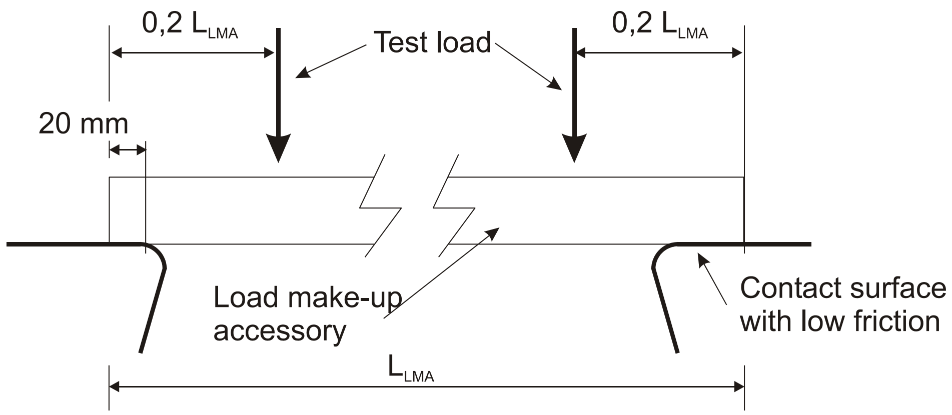


Figure A.5 – Position of the load make-up accessory and application of test loads

A3.3 Test procedure

The load shall be increased until failure in one of the brackets or in the rail or until unacceptable deformation is observed.

A3.4 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.

A4 Test of top tie beam end connectors

A4.1 Test arrangement

To determine the moment rotation curve of the top tie beam end connectors a portal test shall be carried out, see figure A.6. It is essential that the beam end connectors are located at the same distance from the upper end of the upright as in practice.

A horizontal test load is applied along the centre line of the beam and the sway deflection is recorded at the same height. From these values a moment rotation curve is obtained.

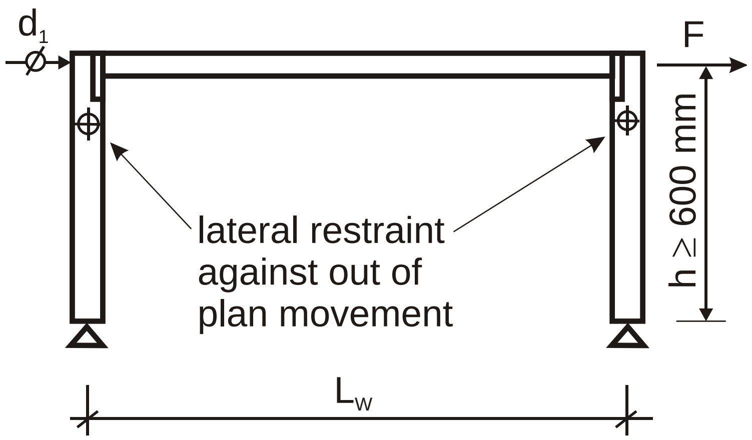


Fig. A.6 – Portal test for determination of the average beam end connector properties

The portal should have a dimension (lane width L_W) of approximately 1.5m (or as is used in practice). The beam to upright connection detail shall be according to the manufacturers' instructions and shall be as realised in practice.

A4.2 Test evaluation, determination of the rotational spring constant and looseness

The results from the test shall be adjusted for the effect of variations in material thickness ref EN15512 clause 13.3.3.

NOTE: In practice the rotations will be small and in the elastic region and it is unlikely that the full moment capacity will ever be experienced. This means that corrections for material strength are not critical.

The average spring constant C_φ of the top tie beam end connector shall be obtained by comparing the test results with an analytical model according to figure A6. The value of C_φ shall be adjusted until there is agreement between the force-translation curve from the test and a linear force-translation relationship from analytical results. Fitting the linear force-translation relationship of the analytical model to the non-linear curve obtained from the tests shall be carried out in accordance with clause A.2.4.5.2 of EN 15512:2009, where M_{Rd} shall be read as F_{ult}/γ_M , M shall be read as F and Θ shall be read as u.

Looseness of the connection shall be determined according to EN15512 clause A.2.5. This looseness shall be subtracted from the observed curve and the stiffness determined accordingly.

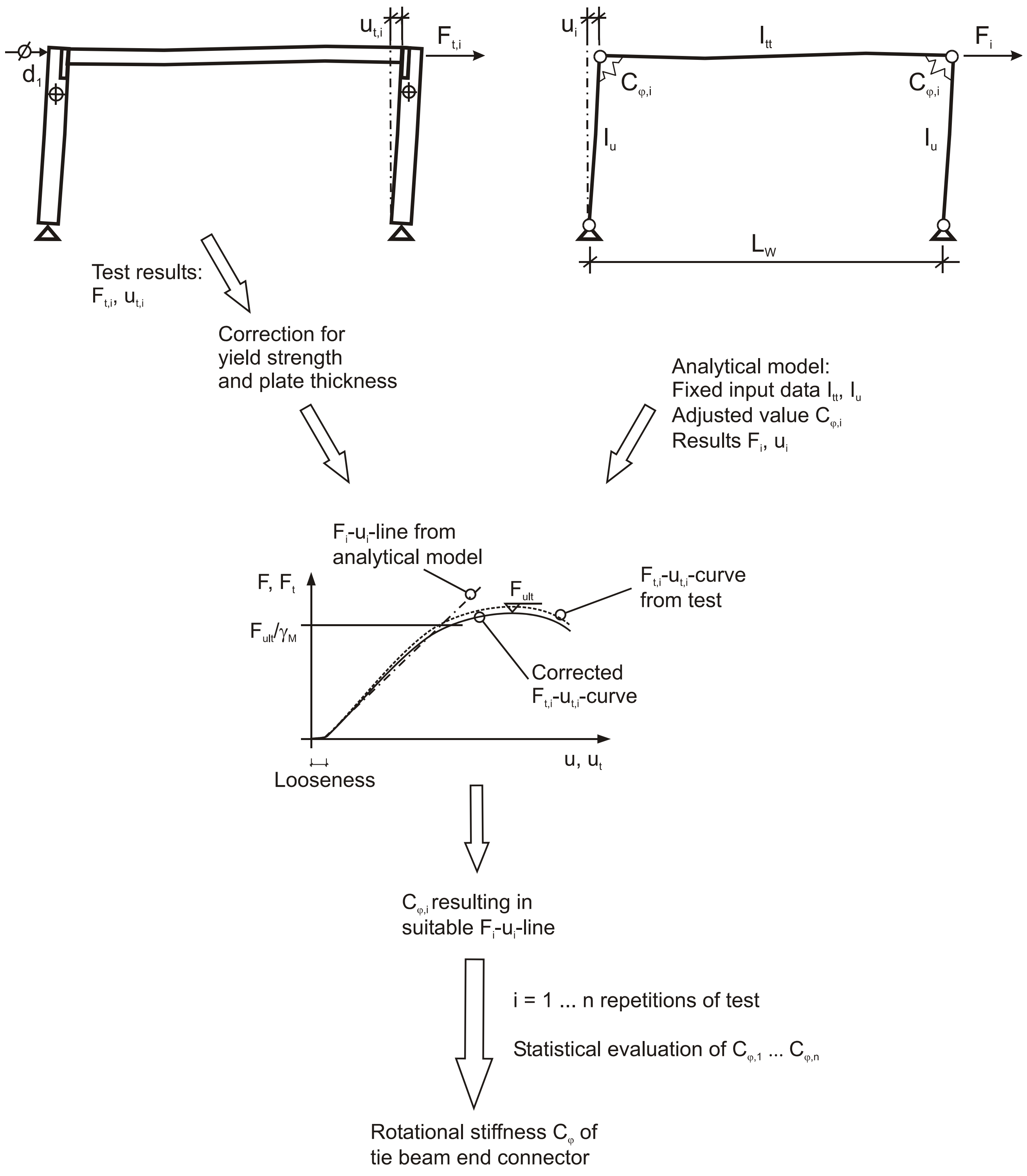


Fig. A.7 – Determination of C_φ from portal test results

ANNEX B

Alternative analysis methods

B.1 General

B.1.1 Details of the alternative analysis methods

The methods provided in this annex are based on a two dimensional structural calculation. The first alternative, method 4, represents a non-linear analysis whereas the second alternative, method 5, is a linear first order analysis.

In both methods the favourable effects of the beam rails are not taken into account.

B.1.2 Load distribution on uprights

In a DIR the upright forces are different to the theoretical values for a continuous beam on rigid supports due to:

- variation in the compression of the uprights,
- vertical flexibility of the rail to upright connection.

The distribution of the column 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 following minimum continuity factors shall be used for checking the upright.

i)	Up to 3 uprights in the lane of the rack block	correction factor 1.15
ii)	4 uprights in the lane of the rack block	correction factor 1.10
iii)	More than 5 uprights in the lane of rack block	correction factor 1.05

In order that these factors can be taken the difference in spacing between adjacent uprights shall not exceed the average value by more than 7.5%.

B.2 Method 4 – Unfolded Rack Method

B.2.1 General

The Unfolded Rack Method makes allowance for the spatial behaviour of a DIR by decomposing the rack structure into three interactive separate planes: vertical bracing, plan bracing and frame bracing.

NOTE The calculation procedure is based on the publication "The Behaviour of Drive-In Storage Structures [M H R Godley - 16th International Specialty Conference on Cold-Formed Steel Structures, Orlando 2002]".

B.2.2 Frame stiffness

The upright frame is modelled by applying the relevant spring stiffness in the down-lane direction, see figure B.1. This incorporates the effect of the frame bracing.

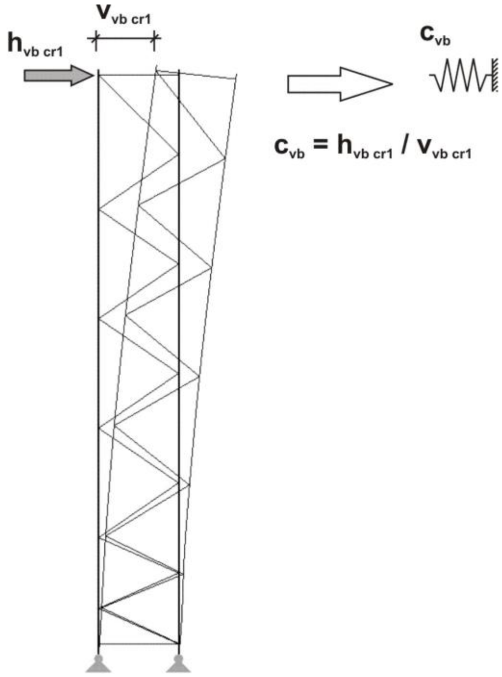


Figure B.1 — Spring constant of frame

B.2.3 Plan bracing

A planar model comprising the elements of the plan bracing including the top tie beams is created with the spring constants (c_{vb}) of the frame bracing introduced at all rack frame locations see figure B.2.

B.2.4 Vertical bracing

The vertical bracing is modelled and is connected to the relevant upright row of the DIR.

B.2.5 Uprights and loads

The geometrical properties, rotational stiffness of the upright to floor connections and of the top tie beam end connectors as well as the loads are summed and replaced by a single equivalent substitute upright section including the relevant substitute spring constants.

In the case of the second cross-lane row of uprights from the entrance of the lane the set of uprights comprises all internal uprights. Consequently, the edge uprights of this particular row must be modelled separately and connected to the substitute uprights.

The edge upright is generally not critical but shall be verified.

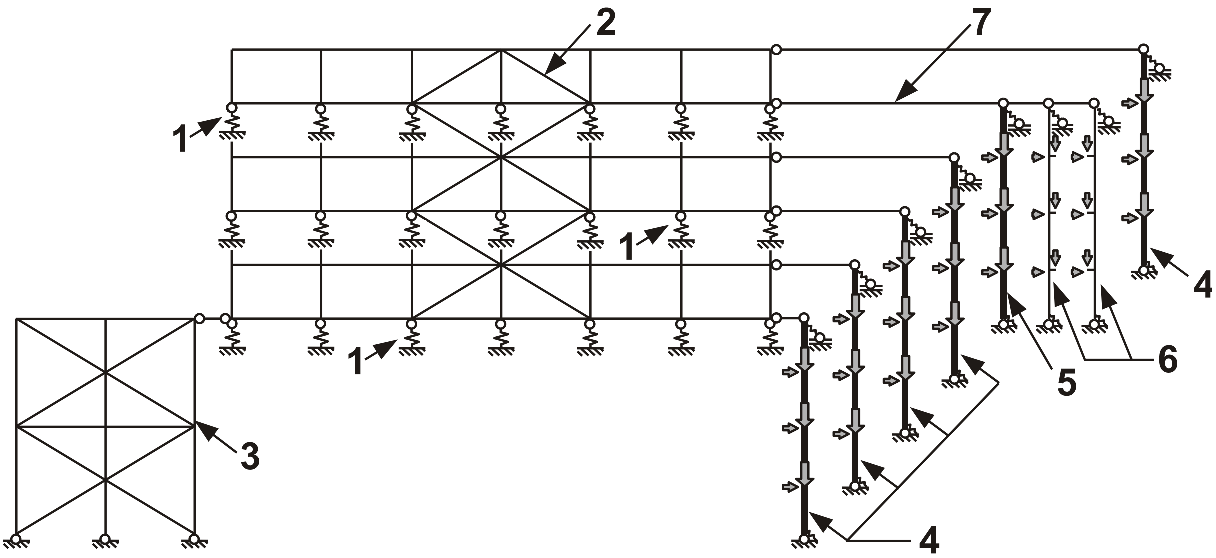
For all other cross-lane rows of uprights the set of uprights to be replaced by substitute members and substitute loadings consist of all uprights of one cross-lane row.

The substitute uprights are connected to the planar model for the plan bracing by rigid pin-ended members.

B.2.6 Planar analysis model

The calculation of internal forces for cross-lane sway shall be carried out taking into account 2nd order effects. Table 9.1, chapter 9.5 shall be considered for the modelling of the spring constants of the upright to floor connections. Stabilising effects of the pallets rails shall be neglected. Fig B.2 shows an example of the planar analysis model.

Imperfection and sway deformations in the cross-lane direction induce additional internal forces into the upright frames in the down-lane direction due to global torsion. These forces are the reactions at the springs (1) and shall be added.



Key

1) Translational spring c_{vb} for frame bracing

2) Plan bracing

3) Vertical bracing

4) Substitute upright comprising properties, spring constants and loads of one complete cross-lane row of uprights

5) Substitute upright comprising properties, spring constants and loads of one cross-lane row of internal uprights

6) Edge uprights with relevant properties, spring constants and loads

7) Rigid pin-ended members

Figure B.2 — Planar calculation model for the Unfolded Rack Method

B.2.7 Member checks

See chapter 10.

B.3 Method 5 – Linear planar method

B.3.1 General

Method 5 represents a two dimensional first order calculation procedure for the cross-lane direction. The three dimensional rack structure is decomposed into three separate planes enabling a two dimensional structural calculation. Due to this simplified analysis correction factors shall be used and a minimum stiffness of the global rack structure is required since the structural behaviour of a DIR in cross-lane direction is governed by its spatial load transfer and by 2^{nd} order effects.

In the following the simplified determination of the stiffness of the global structural system in the cross-lane direction is described.

NOTE: In general method 5 conservatively underestimates the actual lateral stiffness of the structural system, because it does not take into account:

the stiffening effects of the connection between the top tie beams and the uprights, in the vertical plane,

the stiffening effect due to continuity of the top tie beams in the horizontal plane (if top beams are continuous),

restraint offered by the lightly loaded uprights to the more heavily loaded ones,

B.3.2 Basic requirements for method 5

Method 5 shall not be applied if the resulting horizontal deflection at the top of the second cross-lane row of uprights from the rack entrance under characteristic pallet and imperfection loading is greater than 3H / 500.

The initial sway imperfection shall be the value obtained from clause 5.4.1 multiplied by a factor of 3.

NOTE: the factor of ×3 is to allow for the enhancement of loads in the bracing system due to 2^{nd} order effects.

B.3.3 Global system stiffness against cross-lane sway

Method 5 is a five stage process as given below in which the buckling length of the critical upright is determined.

B.3.3.1 Stage 1 – Down-lane stiffness of upright frames

Determine the spring constant C_{vb} representing the stiffness of the upright frame under unit load in the down-lane direction by means of a plane frame analysis, see figure B.1.

B.3.3.2 Stage 2 – Sway stiffness of vertical bracing

Determine the spring constant C_{rb} representing the stiffness of the vertical bracing under unit load in cross-lane direction by means of a plane frame analysis, see figure B.3.

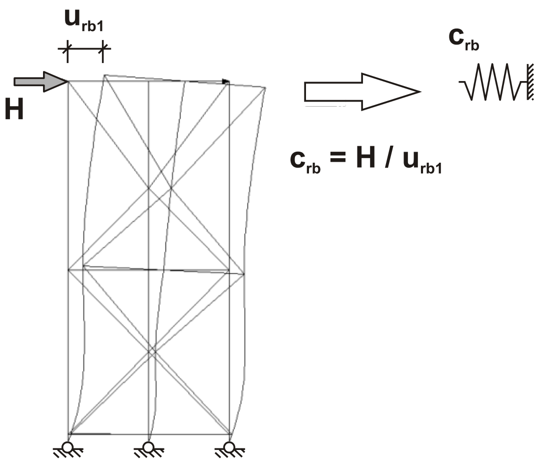
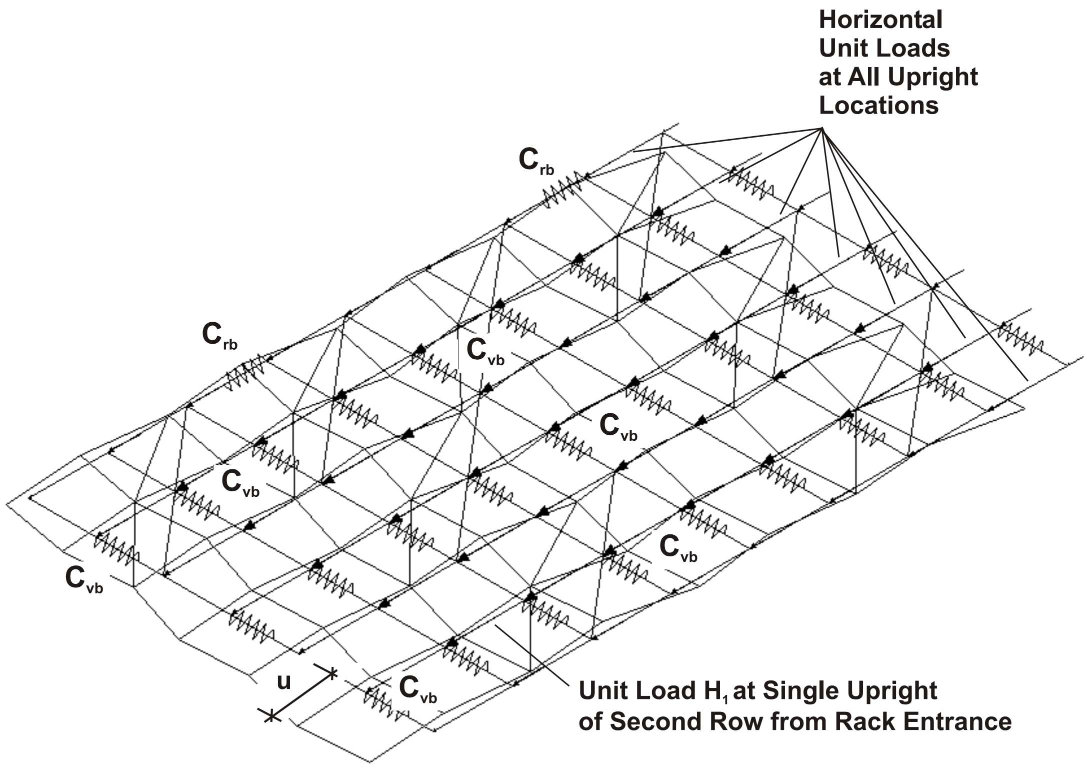


Figure B.3 — Determination of the spring constant representing the vertical rear bracing

B.3.3.3 Stage 3 – Sway stiffness of top horizontal plane

Determine the global stiffness C_{global} of the top horizontal plane at the second upright row from the rack entrance under the applied loads by means of a plane frame analysis, see figure B.4. The arrangement of the unit loads is given in Figure 14.



$c_{global} = H_1 / u$

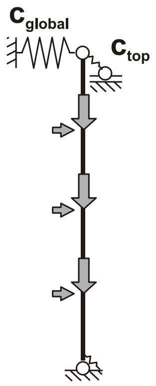


Figure B.4 — Determination of the global translational stiffness from cross-lane deflection u

B.3.3.4 Stage 4 – Check of stiffness requirement

The displacement at the top of the second upright row from the rack entrance shall be less than the limit given in clause B.3.2.

If the deflection requirement is not fulfilled either steps 1-4 shall be repeated with a stiffened system until the calculated deflection is smaller than 3H/500 or an alternative calculation method shall be chosen.

B.3.3.5 Stage 5 – Determination of the cross-lane buckling length

See chapter 9.4.4, calculation stage 3.

B.3.4 Member checks

The member forces due to the initial sway imperfection in the cross-lane direction shall be based on the value obtained from clause 5.4.1 multiplied by a factor of 3.

Imperfection and sway deformations in the cross-lane direction induce additional internal forces into the upright frames in the down-lane direction due to global torsion. These forces are the reactions at the springs (c_{vb}) and shall be added.

See chapter 10.

ANNEX C

Minimum required clearances and spacing due to tolerances and deformations for manually operated systems

C.1 Purpose of clearances

Clearances are required to ensure safe operation conditions in depositing and picking by skilled (trained and instructed) operators within the storage system environment concerned and with the intended mechanical equipment.

C.2 Parameters influencing the minimum required clearances

The following, non-exhaustive list, affect the minimum required clearances;

- Floor flatness,
- Rack production tolerance,
- Rack installation tolerance,
- Rack deformation,
- Lift truck properties,
- Pallet tolerances.

C.2.1 Floor flatness serviceability requirements

For storage (rail) levels up to 6m the floor flatness is not a critical parameter in the effective use of Drive-In Racks provided that the floor flatness satisfies at least class FM3 according to EN15620;

DIN 18202 group 3 is an alternative.

For storage (rail) levels over 6m the floor flatness is not a critical parameter in the effective use of Drive-In racks provided that the floor flatness satisfies at least class FM3 according to EN15620;

DIN 18202 group 4 is an alternative.

NOTE 1: A consideration of the effect of rack verticality and the forklift truck driving on the floor shows that there is a risk of contact between pallet/load and rack. However, in practice the truck driver will continuously compensate for this by adjusting the position of the truck in the lane, thereby aiming to maintain a constant clearance between pallet/load and rack. This is normally done by observing the position of the pallet stringer with respect to the beam rail.

NOTE 2: End users should note that a new warehouse intended to allow for high racking (e.g. 9m+ to topmost level) is likely to give greater operational efficiency with a better floor flatness, for example satisfying class FM2 according to EN15620; DIN 18202 group 4 is an alternative.

C.2.2 Rack production and installation tolerances

Rack production and installation tolerances shall be as given in Table C1.

The following rack tolerances are specifically relevant with regard to safe operation:

1) Non-verticality in cross-lane direction C_z.

2) Clear width between the uprights bordering a lane. This clear width depends on the following (see Figure C.1):

   i) Nominal design dimension between the centres of the upright. To be determined considering the requirements given in C.3 and C.4,

   ii) Length tolerance of the top tie beam (δA_{TOP}),

   iii) Initial bow imperfection of the mono-post uprights and upright frames in cross-lane direction (J_z),

NOTE: Experience suggests that along a lane this imperfection will be in the same direction and may be neglected.

   iv) Installation tolerance at the bottom of the upright with respect to the clear lane width (δA_{BOTTOM}).

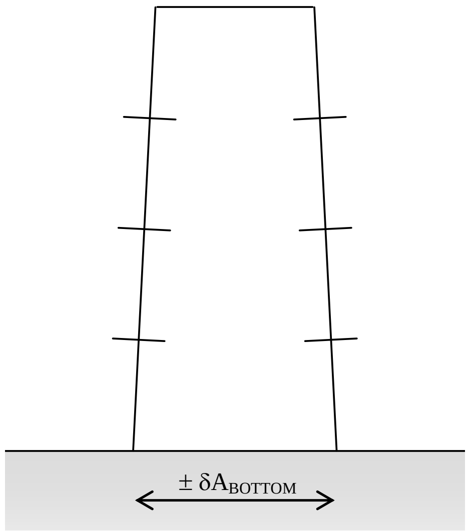
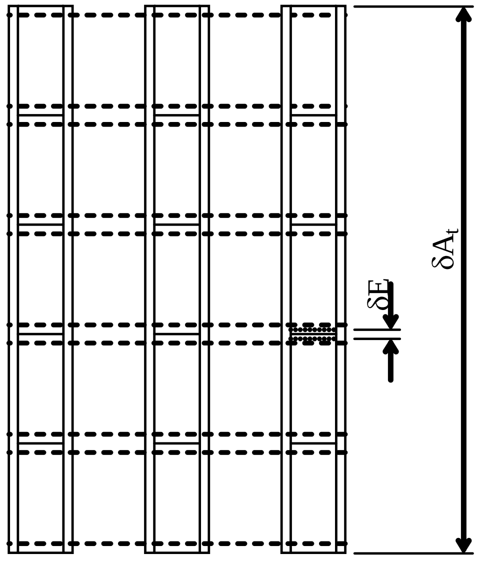


Figure C1 – Variation of the clear lane width affects safe pallet bearing width

TABLE C1: Tolerance limit values for the installed rack (at hand-over)

Type of tolerance (see Figure C2)	Description	Limit value
	Horizontal tolerances	
δA_{TOP}	Maximum variation in width of individual lane (at top) (mm)	± 1.5
δA_{BOTTOM}	Maximum variation in width of individual lane (at bottom) (mm)	± 5.0
δA_T (n)	Total deviation in rack length cumulative at top or bottom (mm). Where n is the number of lanes	± 2.0 n
δE	Frame alignment in the down-lane direction (measured separately at top and bottom) (mm)	± 3.0
C_z	Maximum out-of-plumb upright in the cross-lane direction	1/500
D	Rack depth (mm)	± 5.0 per frame
J_x, J_z	Maximum bow imperfection of upright	1/1000
C_x	Maximum out-of-plumb upright in the down-lane direction	1/500
	Vertical tolerances	
L	Maximum deviation of bracket level with regard to the top of baseplate level (mm)	± H/250
M	Maximum variation of pallet support level between both sides of the pallet (mm)	6.0



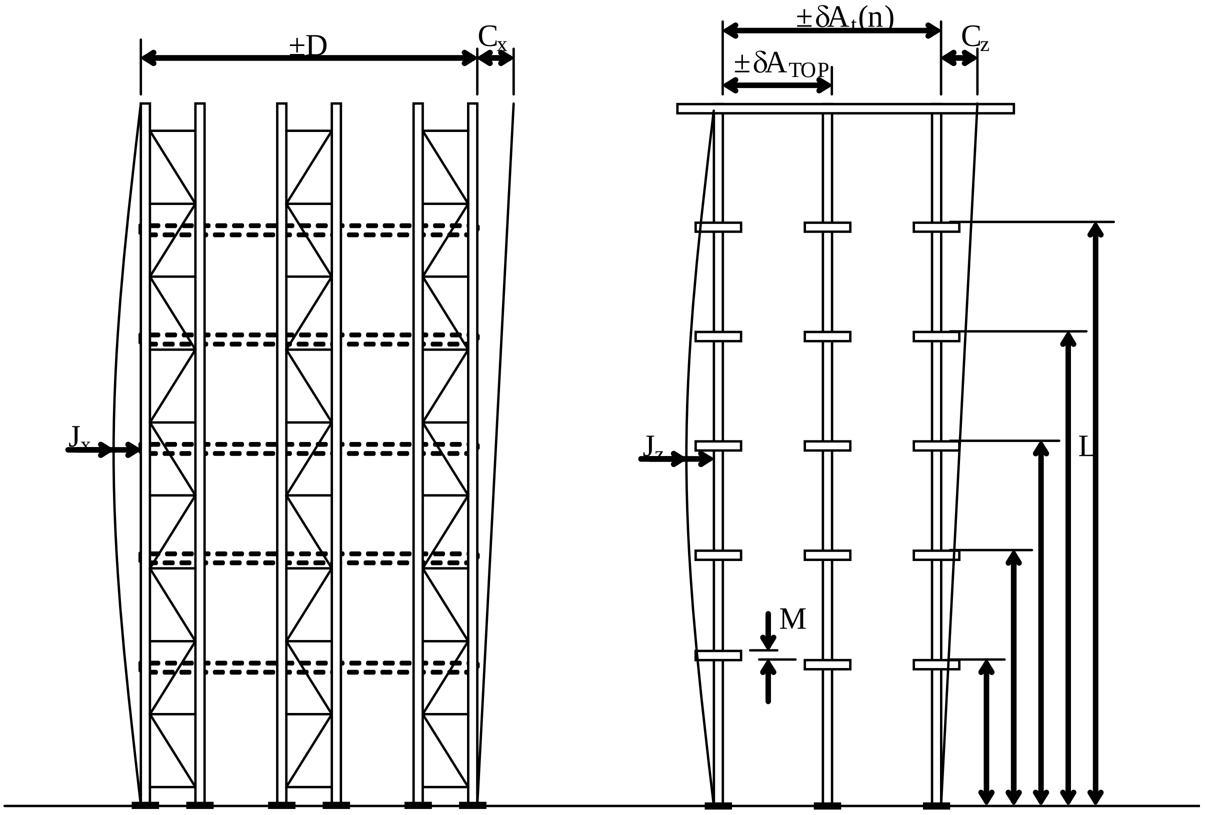


Figure C2: Relevant rack production and installation tolerances

C.2.3 Rack deformations

Refer to 11.2 and 11.3.

The deformation limits and clearances are based on the operational method for placing pallets in DIR/DTR given in EN15635 (2008).

NOTE: The cross-lane sway deformation need not be considered herein as the effect of this deflection is corrected by the forklift truck driver through the use of side shift during the placement operation. This means that the forklift truck operator positions the pallet centrally onto the beams rails and this will generally require that side shift is used when placing the pallet.

C.2.4 Lift truck properties

Lift trucks shall be equipped with side-shift for operation at storage levels above 6m.NOTE: This assists to correctly deposit the pallet on the pair of beam rails and it is recommended for all applications. Mast stiffness shall be in accordance with EN15635 (2008) clause 8.7.

The maximum lifting height shall be sufficient to allow driving down lane without touching the pallet rail.

The lane width and detailing of the baseplate connection shall ensure that the lift truck can enter and drive in a lane with adequate clearances. Relevant truck dimensions are given in figure C3.

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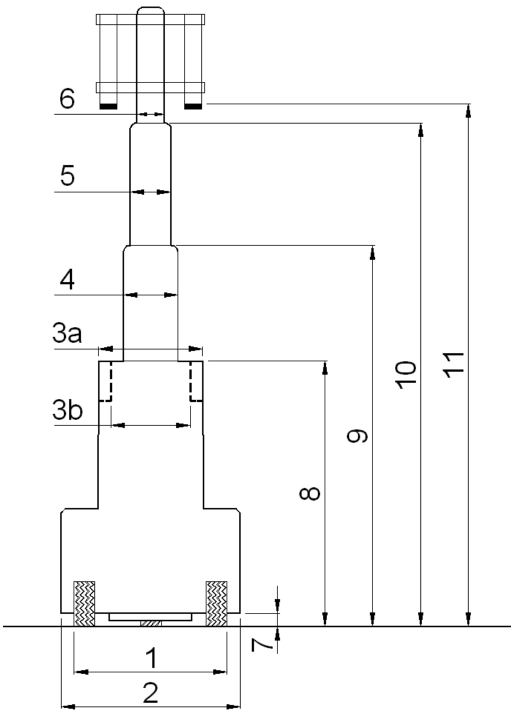


Figure C 3 Relevant truck dimensions for the cross lane direction

Key

See next page

1 Between the outer tyre edges

2 Overall width

3a Width of cabin (standard)

3b Width of cabin (special for DIR / DTR)

4 Width of lower mast (including any attached equipment)

5 Width of middle mast (if any, and including any attached equipment

6 Width of upper mast (including any attached equipment)

7 Ground clearance

8 Height of overhead guard (cabin)

9 Height of lower mast

10 Height of middle mast

11 Lift height

C.2.5 Pallet tolerances

Unless demonstrated otherwise;

Manufacturing tolerance + shrinkage = - 10 mm

NOTE: The dimensional change of plastic pallets and some wooden pallets can exceed this value.

C.3 Minimum clearances relating to the safe placement and retrieval of pallets

C.3.1 General

The clearances specified shall be considered in relation to the overall dimensions of the pallet and load (i.e. Unit load dimension including any pallet load overhang) and the type of beam rail, with or without a pallet guard element.

The clearances specified are based upon operational experience and assume:

- compliance with clause C.2;
- lift truck operators to be trained and instructed in the operation of DIR or DTR as well as the lift truck type concerned;
- that the rack operation manual also considers EN 15635:2008, clause 8.6.

With regard to the clearance considerations there are 5 potentially critical positions (see Figure C4):

- Pallet or truck body with respect to the baseplate, upright and floor rail (if present) Item 1; clearances a_7 and a_8 in Figure C6,

- Truck cabin in relation to the beam rail outer side (Item 2; clearance a_9 in Figure C6),
- Truck mast in relation to the beam rail (Item 3; clearance a_{10} in Figure C6),
- Pallet edge with regard to the pallet beam rail guard, if any (Item 4; clearance ½ a_5 in Figure C7),
- Pallet load with regard to the upright (Item 5; clearance a_1 in Figure C7).

The effect of static truck lean due to floor flatness tolerance is shown in figure C5.

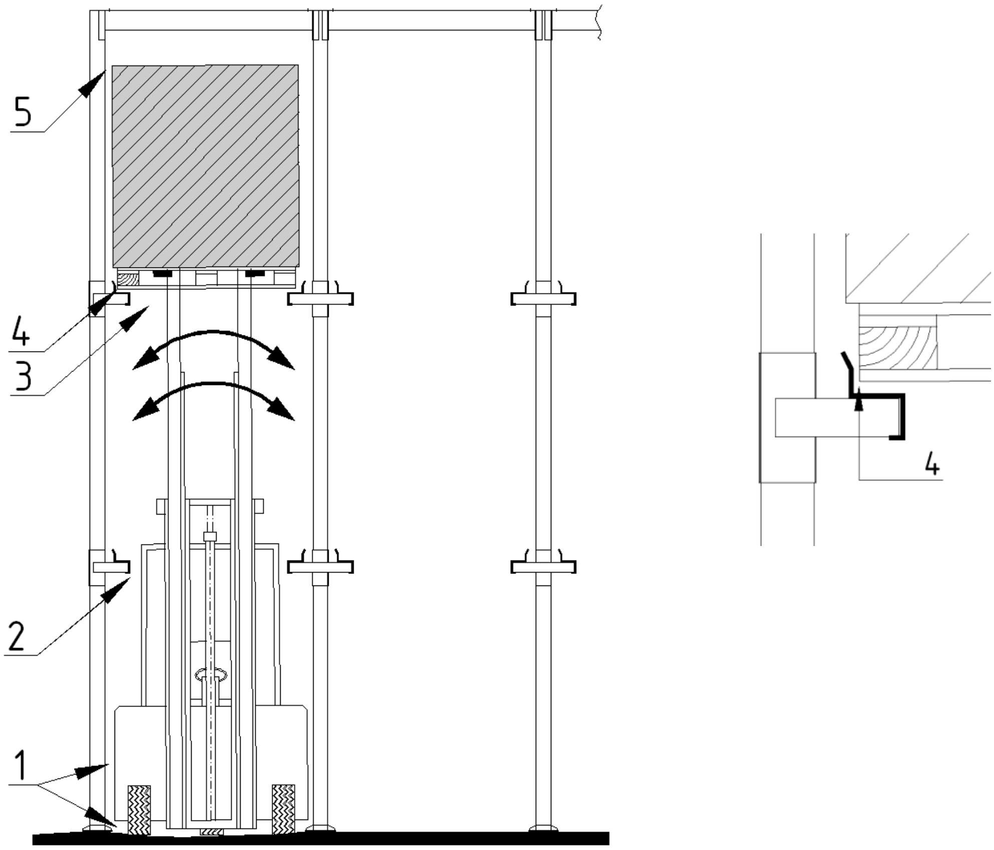
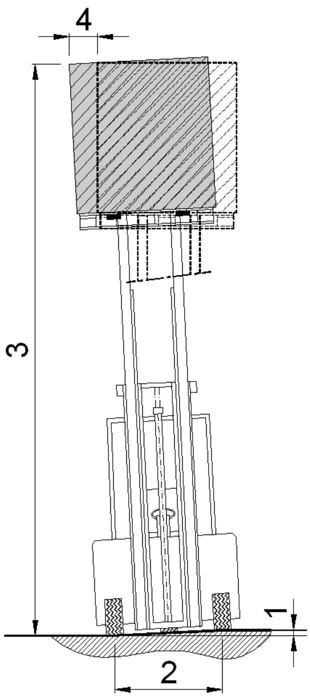


Figure C 4: Relevant positions for the specification of minimum clearances.



Key

1 Floor unevenness over wheel base

2 Wheel base

3 Maximum lifting height to top of unit load

4 Static lean

Figure C 5 Static lean due to floor unevenness

For example: at 11m height with a wheel base of 1300mm and a floor unevenness of 3mm

Static lean = 11000×3÷1300 = 25mm

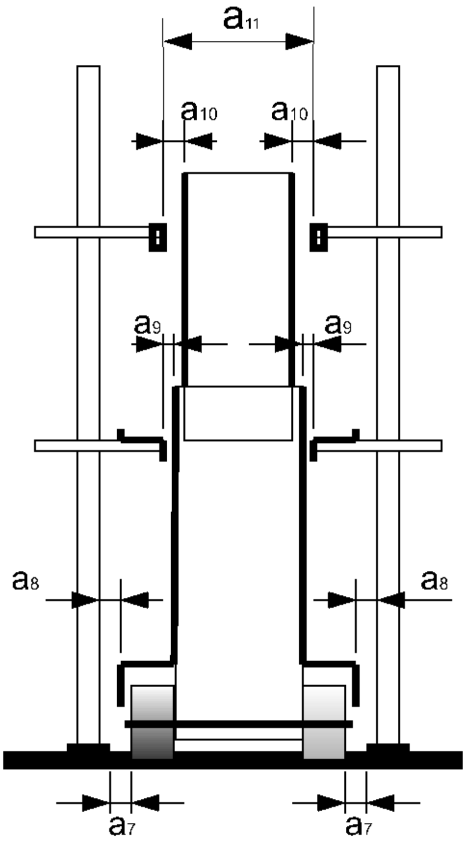
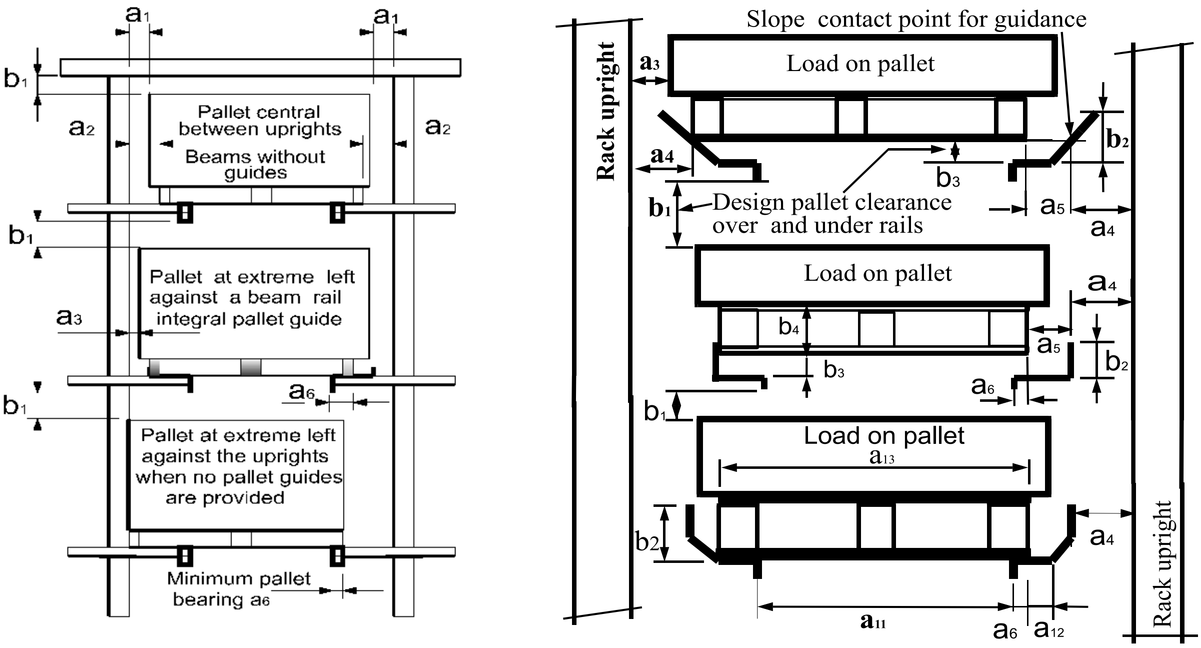


Figure C.6 – Horizontal clearances with regard to the truck and pallet rail in the cross-lane direction

NOTE: The limit for a_9 may require that the cage of the forklift truck is modified.



(a) Placement of pallets **(b) Beam guard rails**

Figure C.7 – Vertical and horizontal spacing and clearances

C.3.2 Horizontal unit load clearances in case no pallet rail guards

The clearance between the edge of the pallet and the upright (a_2) or between the load and upright (a_1) shall be at least 75mm.

If the topmost storage level is higher than 8m and the truck is not guided, and/or there is a relatively high turnover then a_1 and a_2 shall be at least 100mm.

C.3.3 Spacing and horizontal pallet clearance

C.3.3.1 Spacing between pallet and upright

The spacing between the pallet load or pallet and the upright during placement of the pallet shall be at least a_3 = 45 mm and a_4 = 45 mm (see Figure C.5) when the pallet is positioned 25 mm (b_3) above the horizontal support surface of the beam rail.

C.3.3.2 Spacing between beam rails

The spacing, a_{11}, between the beam rails shall:

- Comply with the required clearances a_9 and a_{10};

- Provide safe support for the pallets on the beam rail under all circumstances. For pallets with a width tolerance not larger than ±10mm the bearing width a_0 shall be at least 25 mm. If it can be demonstrated that the pallet width tolerance is not larger than ±5mm the bearing width a_0 shall be at least 20 mm. This results in the nominal pallet bearing width dimension a_6 (see Figure C7).

NOTE: The pallet width tolerance takes into account manufacturing tolerances and shrinkage effects. ISO6780 (2003) gives manufacturing tolerance of +3mm -6mm.

C.3.3.3 Spacing between beam rails incorporating pallet guards

In case of a pallet guard :

$a_{11} <=$ (Nominal pallet width) + $a_5 - 2 \times w_{ss}$

The minimum required beam rail pallet supporting surface w_{ss}

$w_{ss} \geq a_0 + \Delta a_{11} + a_5 = a_5 + a_6$

In case of a sloping pallet guard

$a_{12} > 20$mm for bracket level heights <=5m

$a_{12} > 35$mm for bracket level heights >5m

NOTE : The specified tolerance with regard to the nominal pallet width is a variable affecting the minimum required pallet supporting surface. Special attention is required for non-standard pallets e.g. plastic pallets.

C.3.4 Horizontal truck clearances

The following is a guideline for DIR/DTR operated by non-guided lift trucks.

See Figure C6.

The spacing between the wheels of the fork lift truck and the side of the base plates or floor rail shall be at least a_7 = 50 mm.

The spacing between the wheels or body of the fork lift truck and the side of the uprights shall be at least a_8 = 50 mm.

The following minimum clearance dimensions each side of the truck should be taken for the spacing between the truck and the side of the pallet beam rails:

- At the lowest bracket level (could be at truck cabin level), a_9 = 60 mm;

- Other bracket levels with storage (rail) levels up to 6m and interfacing with the truck mast, a_{10} = 75 mm.

Other bracket levels with storage (rail) levels over 6m, a_{10} = 100 mmThe end user might specify lower clearances when appropriate for the application.

C.3.5 Clear width between the beam rail side guards

The spacing, a_5, between the pallet and a guard rail side shall be at least 50 mm when the pallet is positioned 25 mm (b_3) above the horizontal support surface of the beam rail and just touching one of the guard rail elements, see Figure C.5(b).

C.3.7 Clear compartment height

The clearance, $b_{1,}$ between the top of the pallet load and bottom surface of the rack cantilever bracket or beam rail, whichever is the lowest, when the pallet is placed on the horizontal support surface of the beam rail shall be;

- up to a storage level of 6000 mm : b_1 >= 100 mm,
- at a storage level of 9000 mm : b_1 >= 125 mm,
- at a storage level of 13000 mm : b_1 >= 150 mm.

Linear interpolation is allowed.

C.3.8 Height of pallet guard

The height of the pallet guard (b_2) shall comply with;

$b_2 \geq 45$ mm $\leq b_4$.

$b_2 \leq b_4$ (Pallet height) If there is load over hang.

C.3.9 Spacing of unit loads in the down-lane direction

The spacing between unit loads (including any specified load overhang) shall be at least 25mm, except that at floor level this may be reduced.

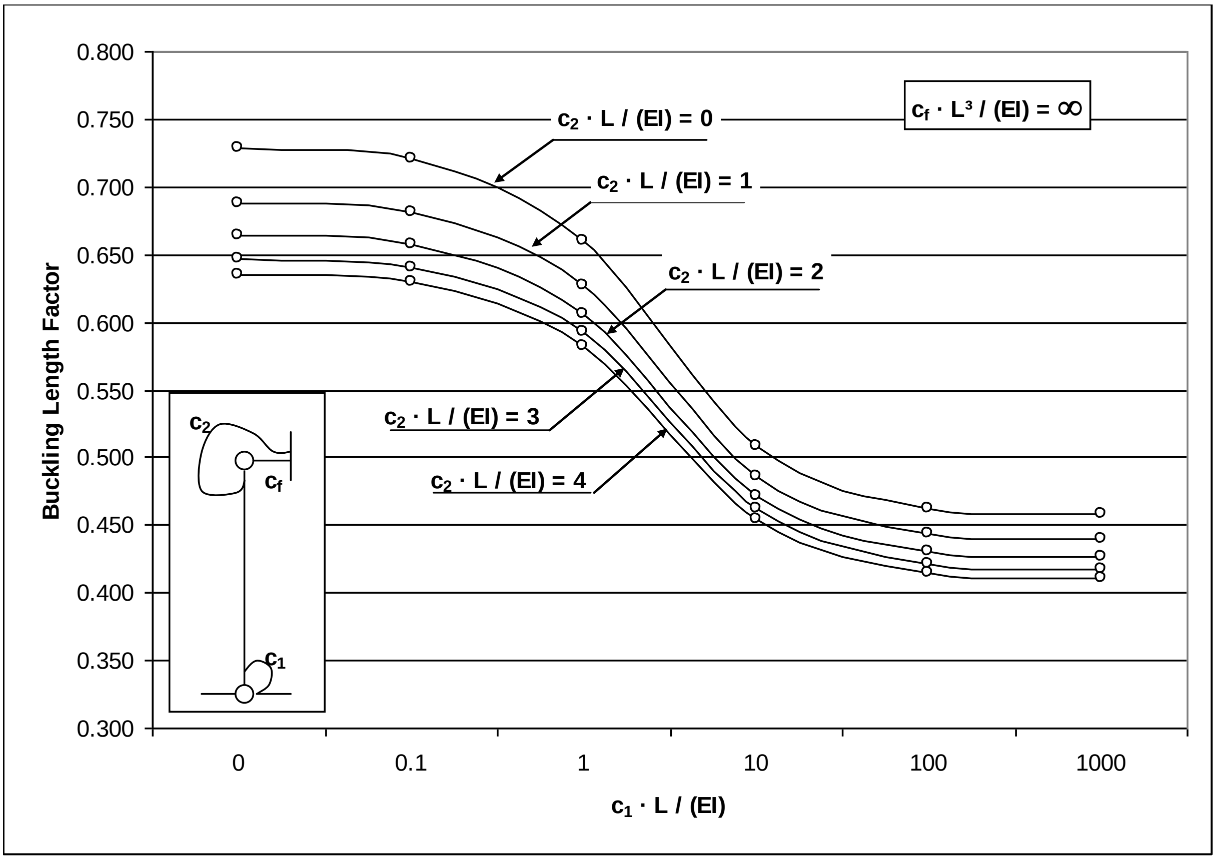
ANNEX D

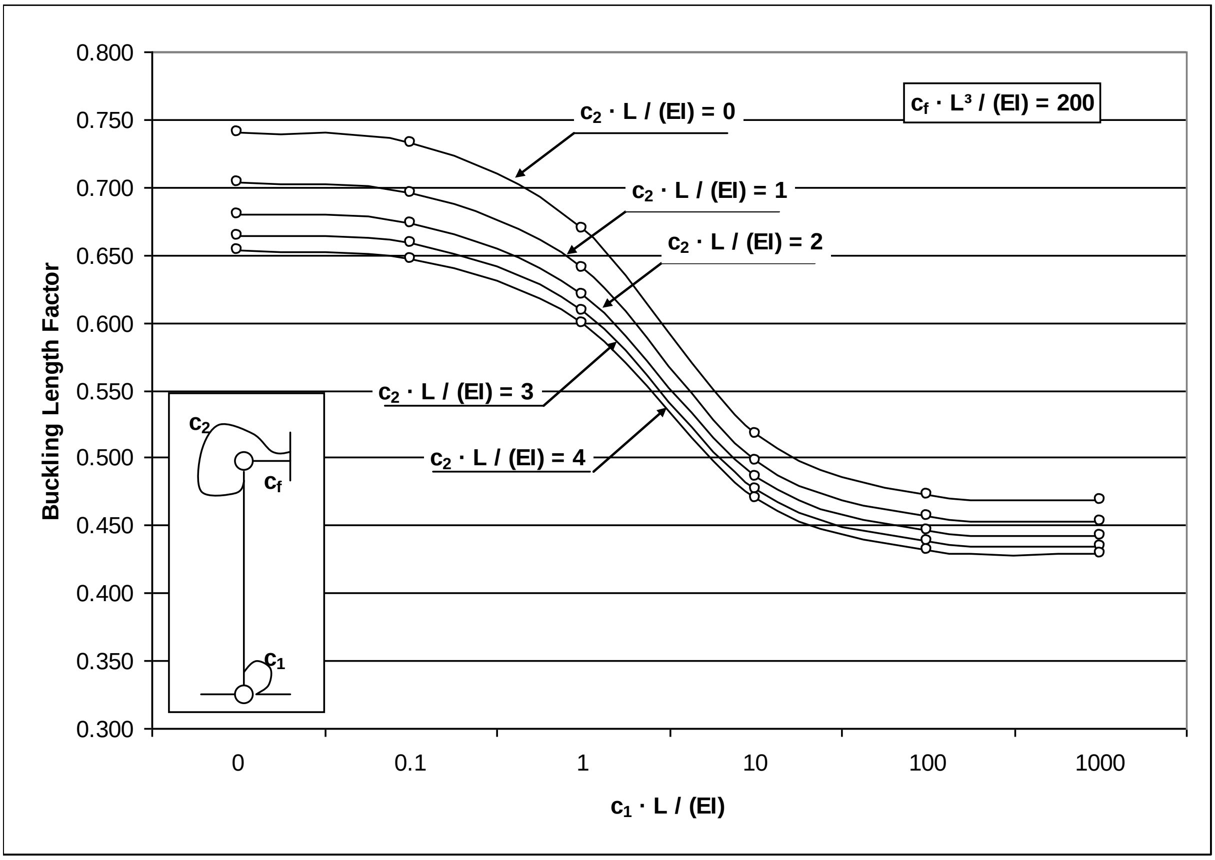
Buckling Curves (Informative)

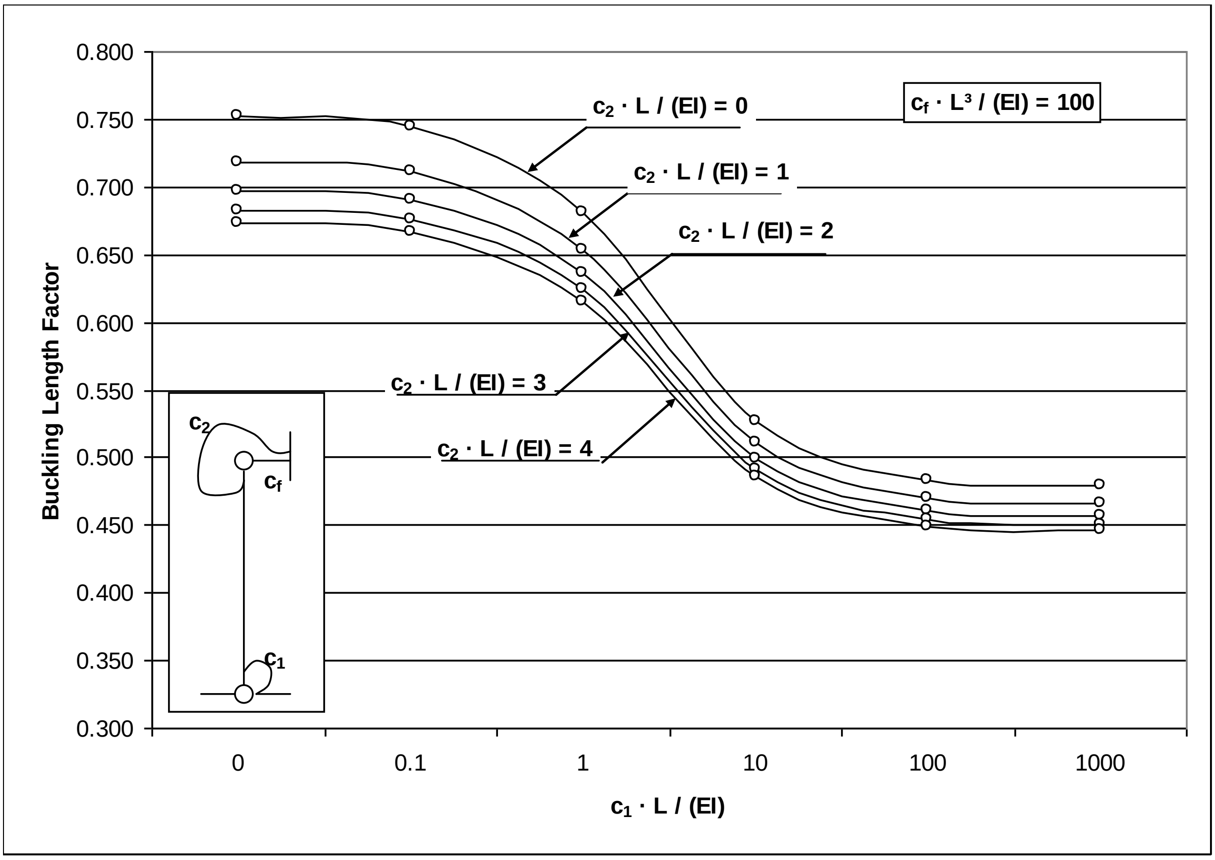
D.1 General

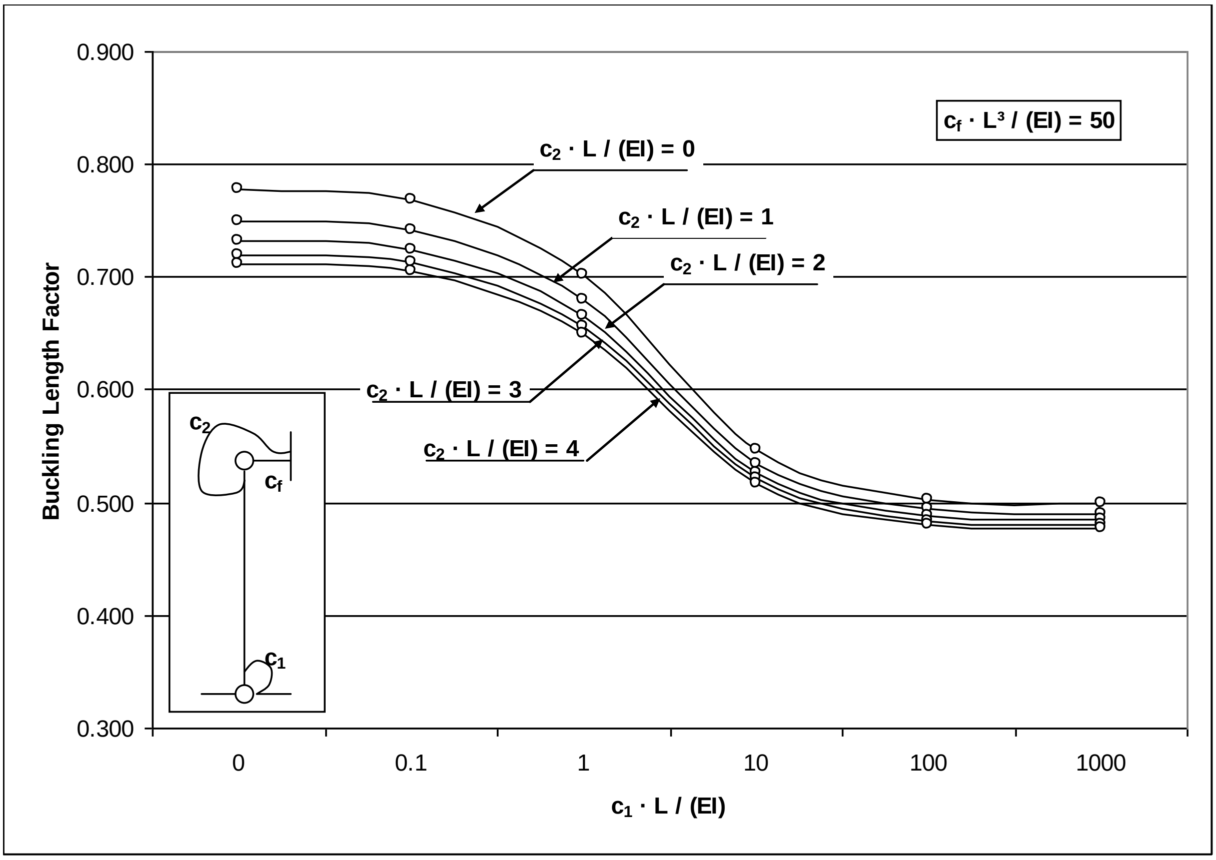
This annex is based on a regular spacing of storage levels.

D.2 One load level

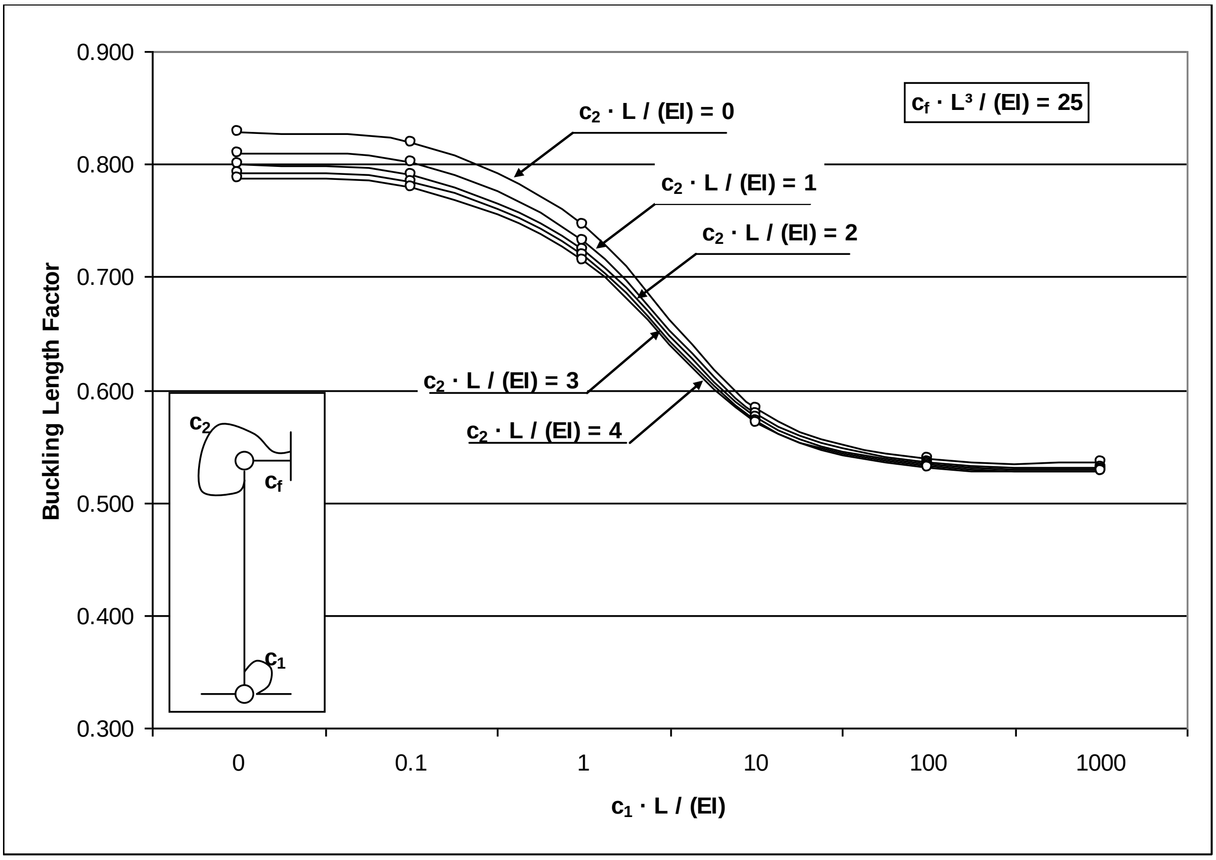



0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
Buckling Length Factor
c2 · L / (EI) = 0
c2 · L / (EI) = 1
c2 · L / (EI) = 2
c2 · L / (EI) = 3
c2 · L / (EI) = 4
cf · L³ / (EI) = 200
c2
cf
c1
0
0.1
1
10
100
1000
c1 · L / (EI)


0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
Buckling Length Factor
c2 · L / (EI) = 0
c2 · L / (EI) = 1
c2 · L / (EI) = 2
c2 · L / (EI) = 3
c2 · L / (EI) = 4
cf · L³ / (EI) = 100
c2
cf
c1
0
0.1
1
10
100
1000
c1 · L / (EI)

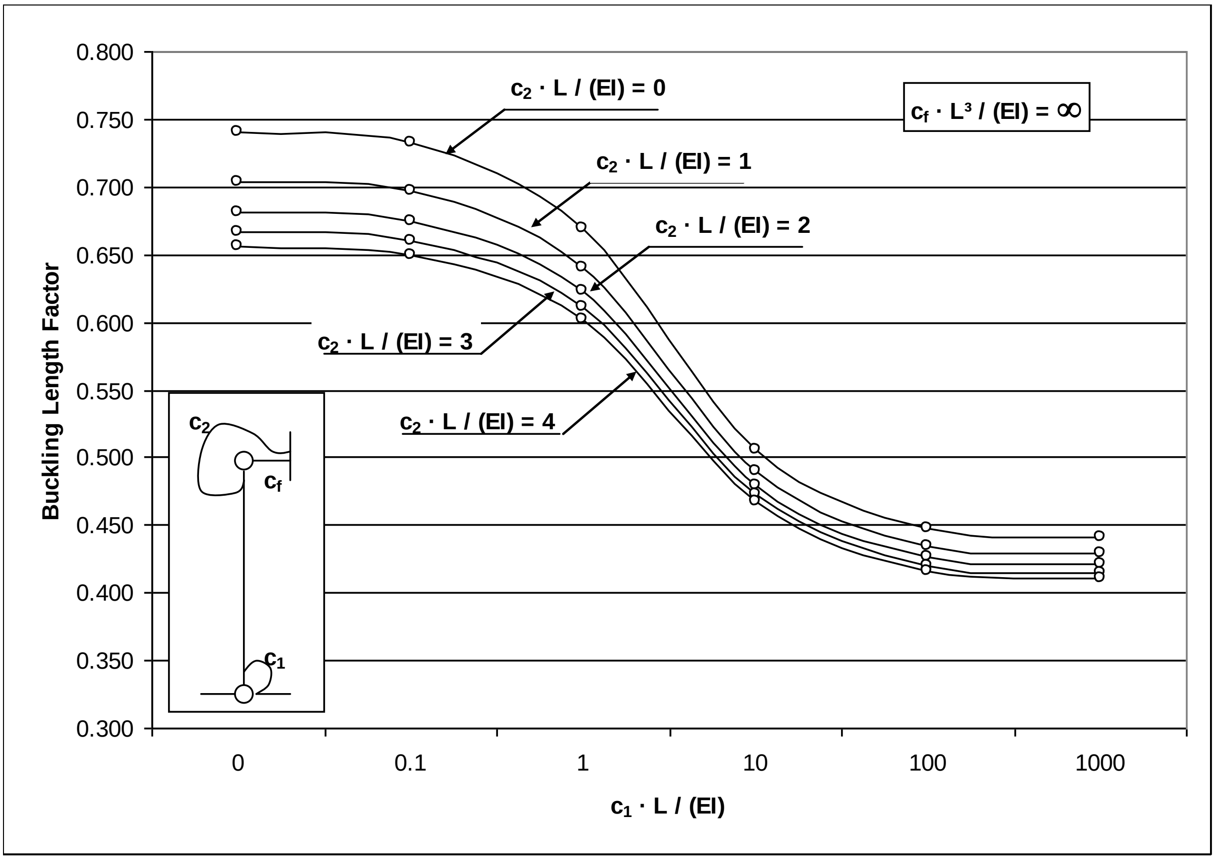


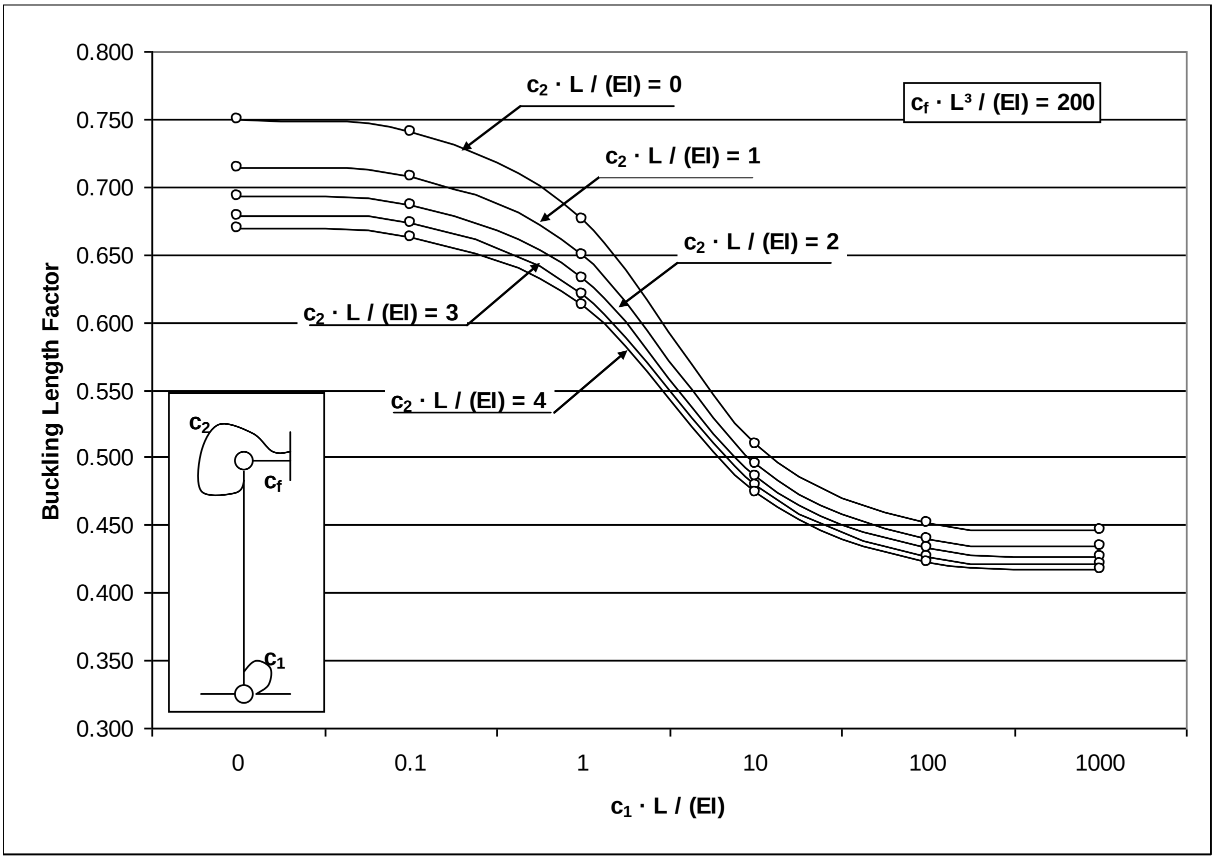
cf · L³ / (EI) = 50
c2 · L / (EI) = 0
c2 · L / (EI) = 1
c2 · L / (EI) = 2
c2 · L / (EI) = 3
c2 · L / (EI) = 4
Buckling Length Factor
0.900
0.800
0.700
0.600
0.500
0.400
0.300
c2
cf
c1
0
0.1
1
10
100
1000
c1 · L / (EI)

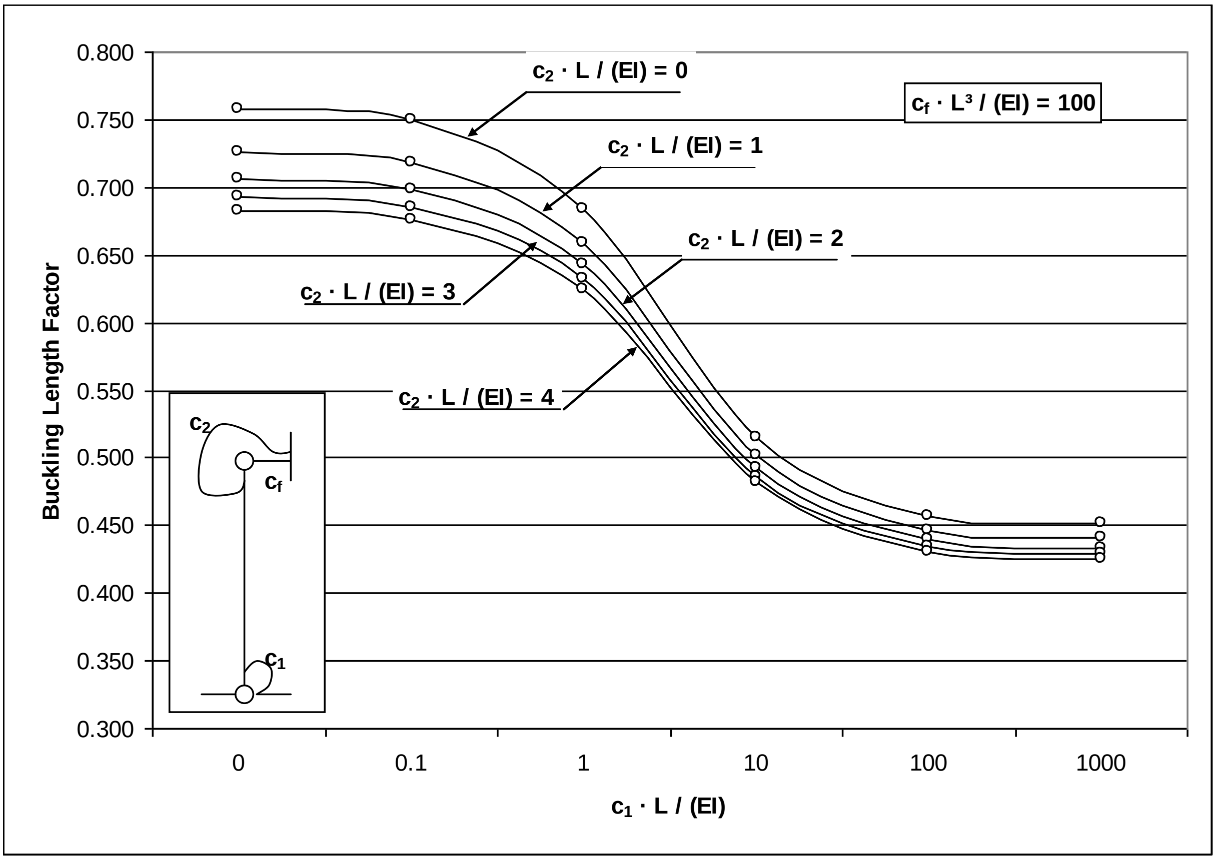


cf · L³ / (EI) = 25
c2 · L / (EI) = 0
c2 · L / (EI) = 1
c2 · L / (EI) = 2
c2 · L / (EI) = 3
c2 · L / (EI) = 4
Buckling Length Factor
0.900
0.800
0.700
0.600
0.500
0.400
0.300
c2
cf
c1
0
0.1
1
10
100
1000
c1 · L / (EI)

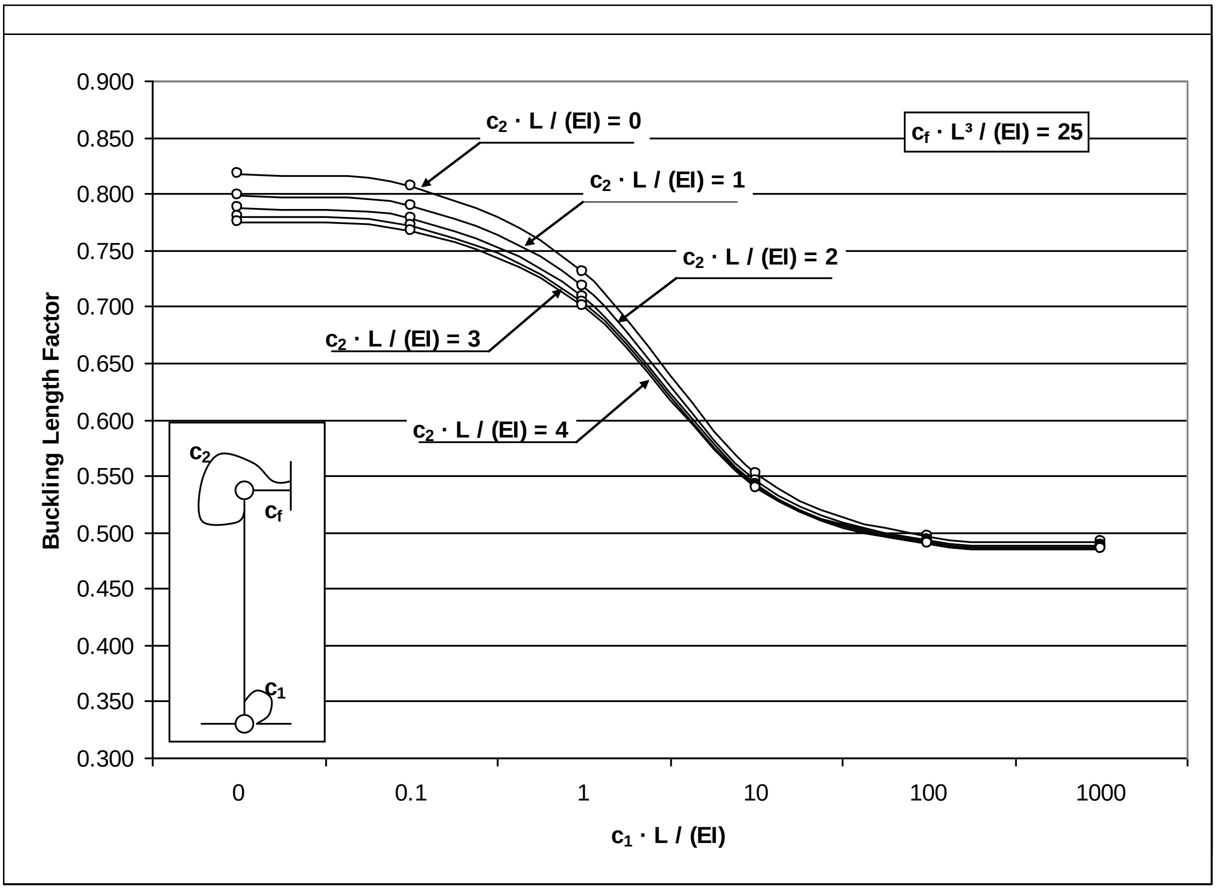
D.3 Two and more load levels







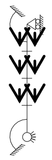
c2 · L / (EI) = 0
cf · L³ / (EI) = 100
c2 · L / (EI) = 1
c2 · L / (EI) = 2
c2 · L / (EI) = 3
c2 · L / (EI) = 4
c2
cf
c1
Buckling Length Factor
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0
0.1
1
10
100
1000
c1 · L / (EI)



c2 · L / (EI) = 0
cf · L³ / (EI) = 25
c2 · L / (EI) = 1
c2 · L / (EI) = 2
c2 · L / (EI) = 3
c2 · L / (EI) = 4
c2
cf
c1
Buckling Length Factor
0.900
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0
0.1
1
10
100
1000
c1 · L / (EI)

ANNEX E

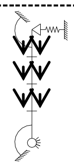
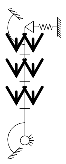
Summary of analysis methods (Informative)

			IMPERFECTIONS			LOADING CONDITIONS				
TYPE OF ANALYSIS	**METHOD**	**F.E. MODEL**	Upright member imperfections (1)	Global system non-verticality (2)	Single upright non-verticality (3)	Self weight	Accidental placement load	Determinative upright fully loaded	Determinative upright pattern loaded	**KIND OF VERIFICATIONS** (TORSIONAL PROBLEMS TO BE ADDITIONALLY CONSIDERED)
2^{ND} ORDER ANALYSIS IN INDEFINITE ELASTIC FIELD	1	3D MODEL OF THE WHOLE DRIVE-IN STRUCTURE, INCLUDING MEMBER BOW-IMPERFECTIONS	X	X		X	X	X	X	**ULS:** RESISTANCE OF CROSS SECTIONS AND CONNECTIONS
			X	X		X	X		X	**SLS:** LATERAL DEFLECTION
	2	3D MODEL OF THE WHOLE DRIVE-IN STRUCTURE BUCKLING LENGTH FROM THIS SCHEME: 	TREATED BY MEANS OF APPROPRIATE BUCKLING CURVE	X		X	X	X	X	**ULS:** RESISTANCE OF CROSS SECTIONS AND CONNECTIONS + MEMBER STABILITY VERIFICATIONS, WITH DETERMINATIVE UPRIGHT FULLY LATERAL RESTRAINED AT THE TOP
				X		X	X		X	**SLS:** LATERAL DEFLECTION
	4	2D MODEL OF THE DETERMINATIVE UPRIGHT ALIGNMENT, WITH THE INFLUENCE OF THE LATERAL STIFFNESS OF THE WHOLE STRUCTURE		X		X	X	X	X	**ULS:** RESISTANCE OF CROSS SECTIONS AND CONNECTIONS + MEMBER STABILITY VERIFICATIONS WITH DETERMINATIVE UPRIGHT FULLY LATERAL RESTRAINED AT THE TOP
				X		X	X		X	**SLS:** LATERAL DEFLECTION

1) Initial bow imperfection of the uprights.

2) Initial non verticality of the drive-in block or equivalent horizontal forces.

3) Lateral displacement of the drive-in block under equivalent horizontal forces determines the spring stiffness C_{global}

TYPE OF ANALYSIS	METHOD		F.E. MODEL	IMPERFECTIONS: Upright member imperfections (1)	IMPERFECTIONS: Global system non-verticality (2)	IMPERFECTIONS: Single upright non-verticality (3)	LOADING CONDITIONS: Self weight	LOADING CONDITIONS: Accidental placement load	LOADING CONDITIONS: Determinative upright fully loaded	LOADING CONDITIONS: Determinative upright pattern loaded	KIND OF VERIFICATIONS (TORSIONAL PROBLEMS TO BE ADDITIONALLY CONSIDERED)
1^{ST} ORDER ANALYSIS	3	1st STEP	3D MODEL OF THE WHOLE DRIVE-IN STRUCTURE	TREATED BY MEANS OF APPROPRIATE BUCKLING CURVE	X						**SLS:** SWAY DEFLECTION CHECK
		OTHER STEPS	C_{global} 			X	X	X	X		**ULS:** RESISTANCE OF CROSS SECTIONS AND CONNECTIONS + MEMBER STABILITY VERIFICATIONS
						X	X	X		X	
	5	1st STEP	SET OF THREE 2D MODELS		X						**SLS:** SWAY DEFLECTION CHECK
		OTHER STEPS	C_{global} 			X	X	X	X		**ULS:** RESISTANCE OF CROSS SECTIONS AND CONNECTIONS + MEMBER STABILITY VERIFICATIONS
						X	X	X		X	

ANNEX F

Torsional Correction

The bending resistance reduced by lateral torsional buckling effect shall be determined from the test according to EN15512 clause A2.9.

The axial strength of the cross-section shall be defined as:

$N'_{Rd} = \chi_2 / \chi_1 N_{Rd}$

Where:

$N_{Rd} = A_{eff} f_y / \gamma_M$

$\chi_1 = \min (\chi_y; \chi_z; \chi_{db})$

$\chi_2 = \min (\chi_1; \chi_{bT}; \chi_{bFT})$

$\chi_{bT}; \chi_{bFT}$ are reduction factors for the torsional flexural buckling modes

And $\chi_y; \chi_z; \chi_{db,}$ are as defined in EN15512

Bibliography

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