

Steel static storage systems — Adjustable pallet racking systems — Principles for structural design

ICS 53.080

National foreword

This British Standard is the UK implementation of EN 15512:2009.

The UK participation in its preparation was entrusted to Technical Committee MHE/8, Steel shelving, bins and lockers.

A list of organizations represented on this committee can be obtained on request to its secretary.

BSI, as a member of CEN, is obliged to publish BS EN 15512 as a British Standard. However, attention is drawn to the fact that during the development of this European Standard, the UK committee voted against its approval as a European Standard.

The UK committee considers that this standard is too complex overall for use by the small and medium sized enterprises that make up the majority of UK suppliers of this material. In addition, the UK committee would like users to be aware that the sway imperfection formula (see Subclause 5.3.2) originates from the structural steel industry where tolerances are much lower than those routinely achieved in the mirror industry, and where a typical building comprises of three or four levels and ten or so bays, as compared to structures in the mirror industry which normally have more levels and certainly many more bays

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 October 2009
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ISBN 978 0 580 57183 1

Amendments/corrigenda issued since publication

Date	Comments

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 15512

March 2009

ICS 53.080

English Version

**Steel static storage systems - Adjustable pallet racking systems
- Principles for structural design**

Systèmes de stockage statiques en acier - Systèmes de
rayonnages à palettes réglables - Principes applicables au
calcul des structures

Ortsfeste Regalsysteme aus Stahl - Verstellbare
Palettenregale - Grundlagen der statischen Bemessung

This European Standard was approved by CEN on 17 January 2009.

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Ref. No. EN 15512:2009: E

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Foreword

This document (EN 15512:2009) has been prepared by Technical Committee CEN/TC 344 “Steel static storage systems”, the secretariat of which is held by UNI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2009, and conflicting national standards shall be withdrawn at the latest by September 2009.

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

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

Introduction

0.1 Racking

Racking systems are load bearing structures for the storage and retrieval of goods in warehouses. The goods to be stored are generally on pallets or in box-containers.

Racking is constructed from steel components including upright frames, beams and decking. Special beam to column (upright) connections and bracing systems are utilised, in order to achieve a three dimensional steel 'sway' or 'braced' structure with "aisles" to enable order pickers, industrial trucks or stacker cranes to reach the storage positions. Although components are standardised they are only standard to each manufacturer. These components differ from traditional column and beam structures in the following regard.

- 1) Continuous perforated uprights.
- 2) Hook-in connections.
- 3) Structural components for racking generally consist of cold formed thin gauge members.

0.2 Requirement for EN Standards for racking and shelving in addition to the Eurocodes

Because of the differences in shape of structural components, detailing and connection type's additional technical information to the Eurocodes are required, in order to have reliable state of the art guidance for the practicing designer involved in designing racking.

The scope of CEN/TC 344 is to establish European Standards providing guidance for the specification, design, methods of installation, accuracy of build and guidance for the user on the safe use of steel static storage systems.

This, together with the need for harmonised design rules was the reason that the European Racking Federation ERF / FEM Racking and Shelving has taken the initiative for CEN/TC 344. CEN/TC 344 is in the course of preparation of a number of European Standards for specific types of racking and shelving and particular applications which exist as European Standards (EN) and working group activities (WG) as follows:

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 - The specification of storage equipment.

EN 15635: Steel static storage systems - The application and maintenance of storage equipment

WG 3c: Terms and Definitions.

WG 4: Technical Principles for the Design of Adjustable Drive-in and Drive-through Racking Systems.

WG 5a: Technical principles for the Design of Pallet Racking Systems in Seismic Regions.

WG 5b: Technical Principles for the Design of Drive-in and Drive-through Racking Systems in Seismic Regions.

WG 6: Technical Principles for the Design of Shelving Systems.

WG 7: Technical Principles for the Design of Cantilever Racking Systems.

WG 8: Technical Principles for the Design of Mobile Racking Systems.

WG 9: Principles of Health and Safety during the installation of Racking Systems.

The intention is for these EN-Series “Racking and Shelving” to be published sequentially over a period of ten years.

In drafting these documents, liaisons with other CEN/TC's will occur as appropriate.

0.3 Liaison

CEN/TC 344 “Steel Storage Systems” liaise with CEN/TC 250 “Structural Eurocodes”, CEN/TC 135 “Execution of steel structures and aluminium structures” and CEN/TC 149 “Power-operated warehouse equipment”.

0.4 Racking and Shelving and Work Equipment regulations

Although racking is a load bearing structure, national regulatory requirements may require that racking be considered as ‘work equipment’ and therefore may be subject to the European Directive 89/391/EEC. This document is not a stand alone document and is intended to be used in conjunction with EN15620, EN 15629 and EN 15635.

0.5 Additional information specific to EN 15512

EN 15512 is intended to be used with EN 1990 – Basis of Structural Design, EN 1991 – Actions on structures, and EN 1993 for the Design of steel structures.

EN 1993-1 is the first of six parts of EN 1993 – Design of Steel Structures. It gives generic design rules intended to be used with the other parts EN 1993-2 to EN 1993-6. It also gives supplementary rules applicable only to buildings.

EN 1993-1 comprises eleven subparts EN 1993-1-1 to EN 1993-1-11, each addressing specific steel components, limit states or materials.

EN15512 may also be used for design cases not covered by the Eurocodes (other structures, other actions, other materials) serving as a reference document for other CEN TC’s concerning structural matters.

EN 15512 is intended for use by

committees drafting design related product, testing and execution standards,

designers and structural engineers,

relevant authorities.

Numerical values for partial factors and other reliability parameters are basic values that provide an acceptable level of reliability assuming an appropriate level of workmanship and quality management.

As part of the design process, reference to EN 15629 and EN 15635 shall be required to ensure that both specifier and designer are aware of the interface constraints in each other's responsibility and to allow an effective design to be produced.

1 Scope

This European Standard specifies the structural design requirements applicable to all types of adjustable beam pallet rack systems fabricated from steel members intended for the storage of unit loads and subject to predominantly static loads. Both un-braced and braced systems are included.

This European Standard gives guidelines for the design of clad rack buildings where requirements are not covered in EN 1993. The requirements of this European Standard also apply to ancillary structures, where rack components are employed as the main structural members.

This European Standard does not cover other generic types of storage structures. Specifically, this European Standard does not apply to mobile storage systems, drive-in, drive-through and cantilever racks or static steel shelving systems, nor does this European Standard establish specific design rules for the assessment of racking in seismic areas.

2 Normative references

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

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

EN 1990, *Eurocode - Basis of structural design*

EN 1991-1-1:2002, *Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings*

EN 1993-1-1:2005, *Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings*

EN 1993-1-3:2006, *Eurocode 3 - Design of steel structures - Part 1-3: General rules - Supplementary rules for cold-formed members and sheeting*

EN 10002-1, *Metallic materials - Tensile testing – Part1: Method of test at ambient temperature*

EN 10143, *Continuously hot-dipped coated steel sheet and strip - Tolerances on dimensions and shape*

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

EN 10326, *Continuous hot-dip coated strip and sheet of structural steels - Technical delivery conditions*

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

EN 15629, *Steel static storage systems - The specification of storage equipment*

EN 15635, *Steel static storage systems - The application and maintenance of storage equipment*

prEN 15878, *Steel static storage systems - Terms and definitions*

EN ISO 7438, *Metallic materials - Bend test (ISO 7438:2005)*

EN ISO 9001, *Quality management systems - Requirements (ISO 9001:2000)*

ETAG No 001, *Guideline for European Technical Approval of Metal Anchors for Use in Concrete*

3 Terms and definitions

For the purposes of this document, the following terms and definitions given in prEN 15878 apply.

- 3.1**
accidental action
action, usually of short duration but of significant magnitude, that is unlikely to occur on a given structure during the design working life
- 3.2**
basic material
flat steel sheets or coiled strip, possibly cold reduced from which the rack components are pressed or rolled
- 3.3**
batch of steel
quantity of steel, all to the same specification, produced by one supplier at one time
- 3.4**
beam
horizontal member linking adjacent frames and lying in the horizontal direction parallel to the operating aisle
- 3.5**
beam end connector
connector, welded to or otherwise formed as an integral part of the beams, which has hooks or other devices which engage in holes or slots in the upright
- 3.6**
compartment load
load which can be loaded into one compartment of a rack or shelving structure from one side
- 3.7**
double entry rack
run of racking accessible from two adjacent operating aisles connected by run spacers
- 3.8**
global analysis
determination of a consistent set of internal forces, moments and displacements that represent the entire three dimensional load bearing rack structure, which are in equilibrium with a particular set of actions on the structure
- 3.9**
perforated member
member with multiple holes regularly spaced along its length
- 3.10**
placement load
load caused by deposit and picking operations of a unit load into and out of the system, reflecting good practice
- 3.11**
single entry rack
run of racking accessible from a single operating aisle
- 3.12**
spine bracing
sway bracing in the vertical plane parallel to the main aisle of the rack, linking adjacent frames

3.13

spring-back

tendency of a cold-formed section to undergo spontaneous cross-sectional distortion when it is cut from a longer length

3.14

stiffened element

stiffened element of a cross-section is a part of the cross-section which is connected to the remainder of the section along both longitudinal edges

3.15

sway

horizontal displacement of structure in addition to any initial out of plumb

3.16

unit load

individual stored item that can be placed or retrieved in one operation

3.17

un-stiffened element

an un-stiffened element of a cross-section is a part of the cross-section which is connected to the remainder of the section along one longitudinal edge only

3.18

upright frame

two (often perforated) upright sections linked together by a system of bracing members

NOTE Typical examples are shown in Figure 1.

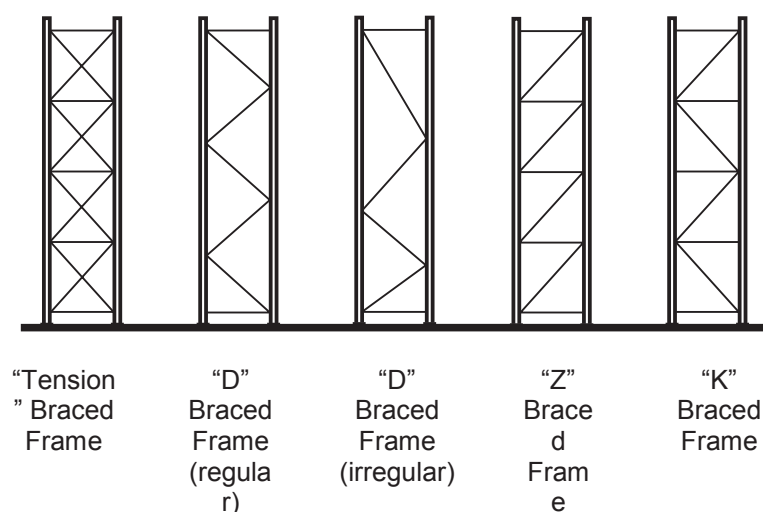


Figure 1 — Typical forms of upright frames

4 Symbols

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

Additional symbols and subscripts are defined where they first occur.

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

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

A	accidental action
A	cross sectional area
A_{eff}	effective cross sectional area
A_g	gross cross sectional area
A_{ph}	accidental horizontal placement force
A_{pv}	accidental vertical placement force
b	width of upright
b_p	notional plane width of element
E	modulus of elasticity
e	effective bearing width of base plate
e	eccentricities
f_{ck}	characteristic cylinder strength of concrete
f_t	observed yield strength in test specimen
f_u	ultimate strength
f_y	yield strength
f_{ya}	average yield strength
f_{yb}	basic yield strength ($=f_y$)
G	shear modulus
G_k	characteristic value of permanent loads (dead loads)
h	storey height
I	second moment of area
I_T	St Venant torsion constant
I_w	warping constant
i	radius of gyration
i_0	polar radius of gyration
K	effective length factor
k_b	stiffness of beam to column connector

k_s	coefficient related to number of tests
L	span
l	length
ℓ	effective length or buckling length
M	bending moment
N	axial load
n	number of tests
n_c	number of uprights in the down aisle direction in a run of bays
n_s	number of beam levels
Q	variable load
Q_f	concentrated load on floor
Q_h	maximum specified lateral load per crane
Q_{ph}	horizontal placement load
Q_{pv}	vertical placement load
Q_u	weight of unit load
q	distributed load
R_m	mean value of adjusted test results
R_n	corrected failure load
R_t	observed failure load
s_n	standard deviation of the normalised test results
t	thickness of material
t_c	core thickness of material exclusive of coatings
t_t	observed core thickness in test specimen
V	shear force
V	vertical load
V_{cr}	elastic critical value of vertical load
W	section modulus
W	total load on a beam
α	coefficient of linear thermal expansion

α	correction factor for yield strength
α	imperfection factor
β	beam coefficient
β	correction factor for thickness
β	amplification factor for second order effects
γ	partial factor
γ_A	partial factor for accidental loads
γ_f	load factor
γ_G	partial factor for permanent loads
γ_M	material factor
γ_Q	partial factor for variable loads
δ	deflection
θ	rotation
λ	slenderness ratio
$\bar{\lambda}$	non-dimensional slenderness
ν	Poisson's ratio
ρ	density
ϕ	sway imperfection
ϕ_0	initial sway imperfection
ϕ_1	looseness of beam end connector
χ	stress reduction factor for buckling

Subscripts

b	buckling
c	compression, capacity
cr	critical
d	design
db	distortional buckling
FT	flexural torsional

g	gross
i	test number
k	characteristic
LT	lateral torsional
m	mean value
n	corrected value
Rd	design resistance
Sd	design strength
ser	service
T	torsional
t	observed value at test

5 Basis of design

5.1 Requirements

5.1.1 Basic requirements

Pallet racks 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 Annex A.

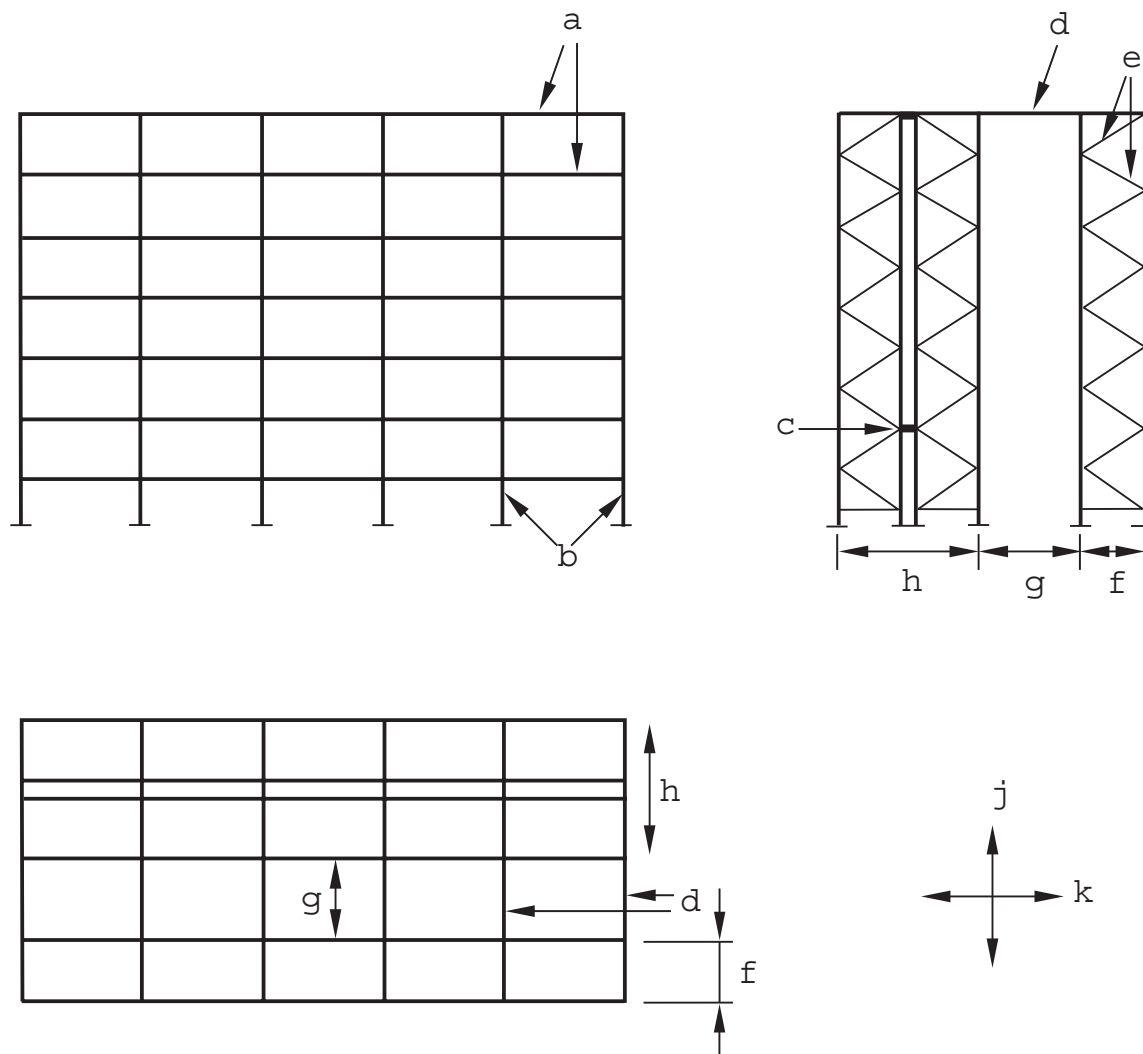
Except where specific requirements are given to the contrary, the design procedures in this document shall be in accordance with EN 1990, EN 1993-1-1 and EN 1993-1-3.

Design shall be carried out on the basis of the specified installation tolerances given in EN 15620 and the operational practice described in EN 15635.

For racking in seismic zones see bibliography, reference 3.

5.1.2 Un-braced racking systems

The configuration of a typical un-braced pallet rack is shown in Figure 2 in which the down-aisle stability is provided by the restraining effect of the beam end connectors. In the cross-aisle direction, stability is provided by the bracing in the frames which, in the case of the double entry rack shown, shall be linked together in the height by run spacers.



Key

- a beams
- b upright frames
- c run spacers
- d top tie (when required)
- e frame bracing
- f single entry rack
- g aisle
- h double entry rack
- j cross aisle
- k down aisle

Figure 2 — Example of an un-braced pallet racking structure

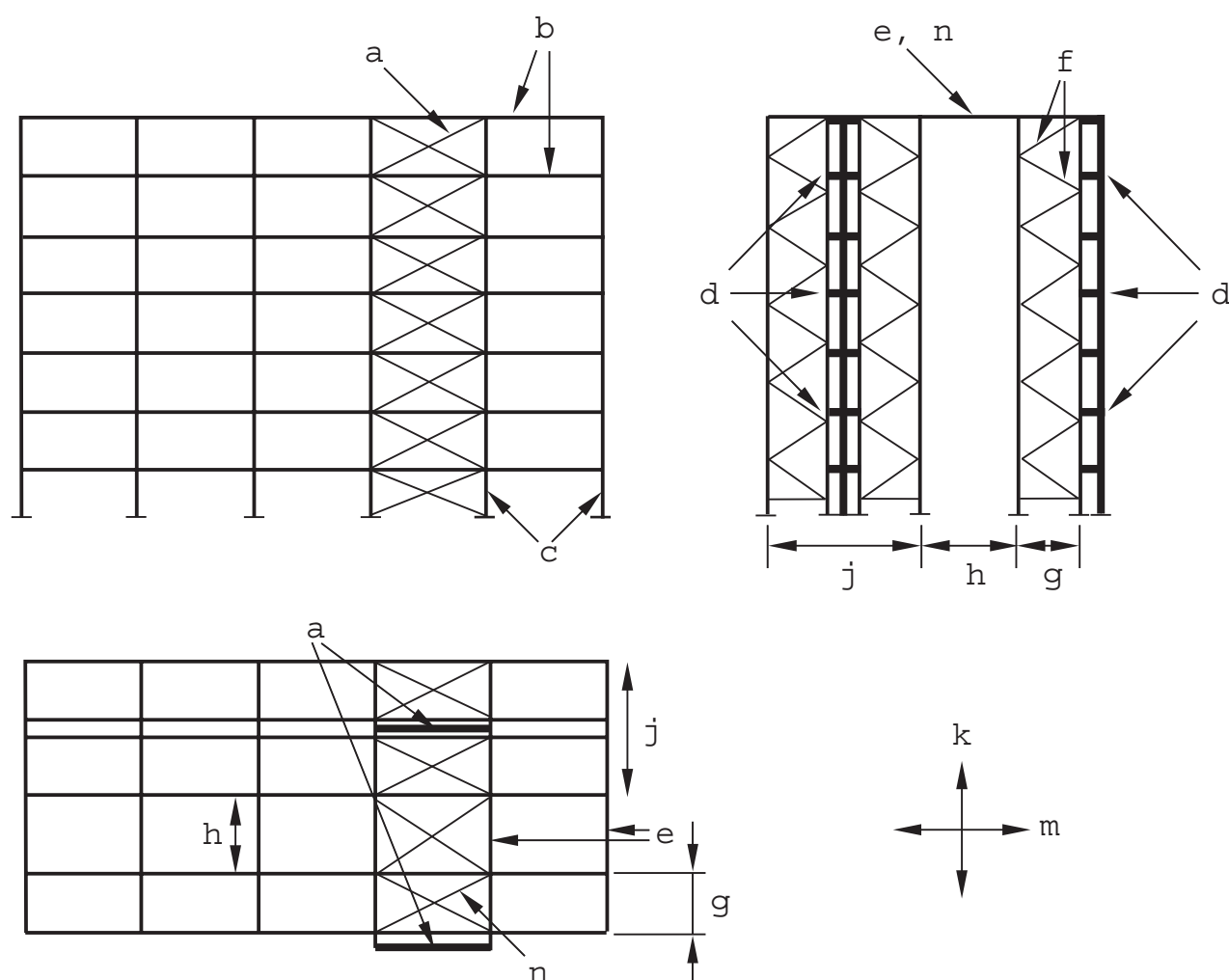
5.1.3 Braced racking systems

In a braced pallet rack (see Figure 3) forces acting in the front and rear plane shall be transferred to the spine bracing at the rear of the rack as shown in Figures 4, 5 and 6.

The stabilising effect of the spine bracing is transmitted to the un-braced uprights at the front and rear of the rack normally by means of plan bracing.

Cross-aisle stability is provided by means of braced frames.

Racks may be braced over only part of the height in which case both braced and un-braced design considerations shall be taken into account.



Key

a	spine bracing	g	single entry rack
b	beams	h	aisle
c	upright frames	j	double entry rack
d	bracing brackets	k	cross-aisle
e	top ties (when required)	m	down-aisle
f	frame bracing	n	plan bracing

Figure 3 — Example of a configuration of a braced pallet rack structure

In double entry braced racks, the plan bracing shall be designed so that an anti-symmetric mode with unacceptable deflections cannot develop in which one rack sways down-aisle in one direction and the other in the opposite direction as shown in Figures 4 and 5 thus rendering the spine bracing ineffective.

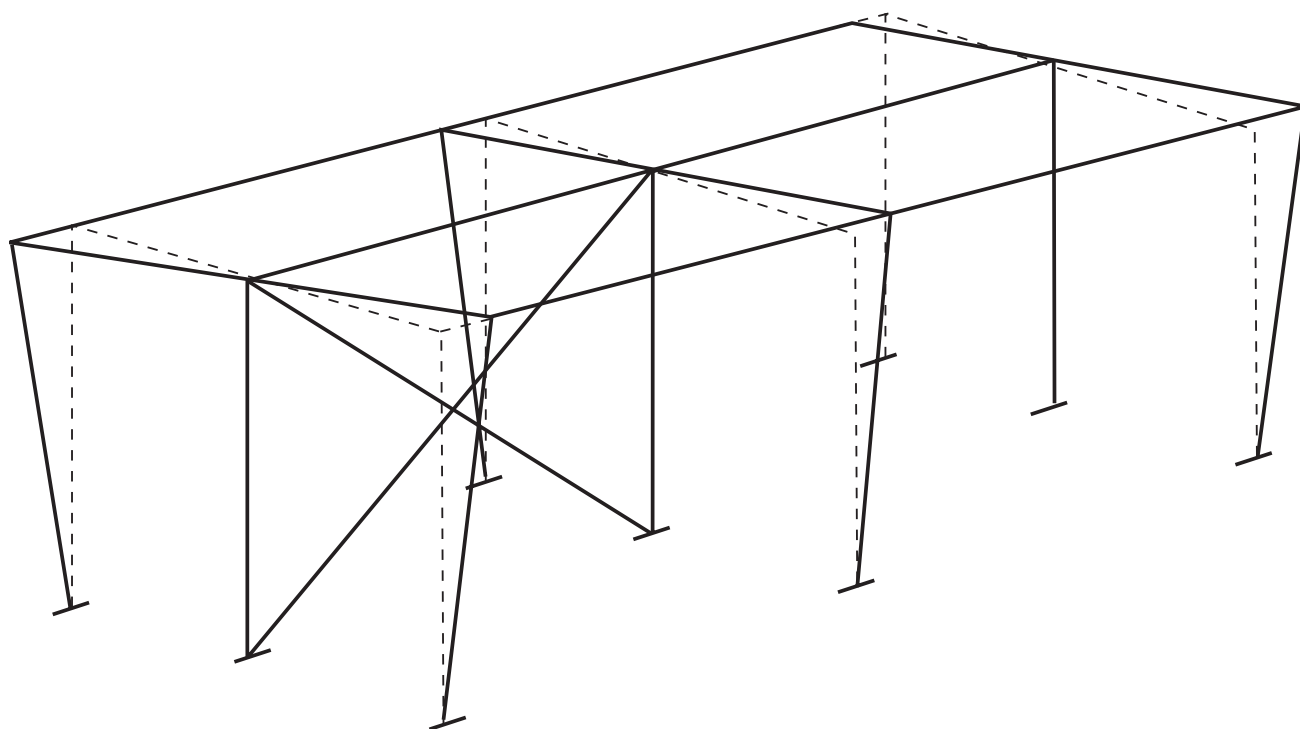
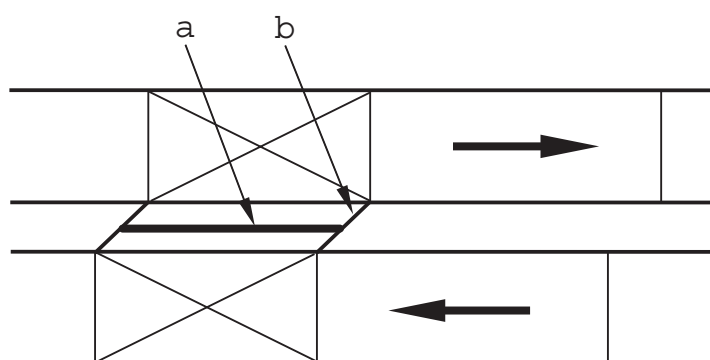


Figure 4 — Anti-symmetrical sway mode in a double entry pallet rack

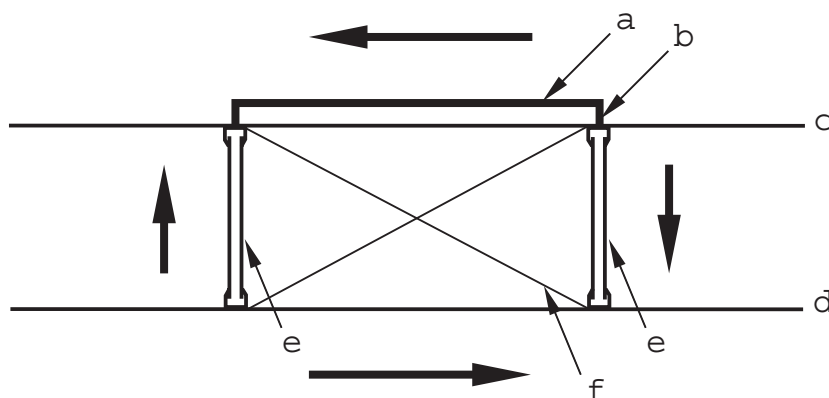


Key

- a spine bracing
- b bracing brackets

Figure 5 — Plan view of alternative anti-symmetric sway mode in a double entry pallet rack

In single entry braced racks, the detailing and design shall ensure that the spine bracing is fully effective especially when pallets overhang the beams at the rear of the rack as shown in Figure 6.



Key

- a spine bracing
- b bracing brackets
- c rear plane of racking
- d front plane of racking
- e upright frame
- f plan bracing

Figure 6 — Load path for bracing forces on a braced single entry pallet rack

5.1.4 Design working life

For the purpose of determining the loading, a notional design working life of at least ten years shall be used. However, this should not be construed as indicating any guarantee regarding the actual working life of the rack. For pick and deposit stations attention should be given to the possibility of low cycle fatigue at locations where frequent loading and unloading take place.

NOTE The working life of most racks is determined by wear and damage sustained during operation or by corrosion. These cannot be pre-determined at the design stage and are not covered by this clause. It is assumed that the rack is properly used and that any damage is repaired immediately. See also EN 15629 and EN 15635.

5.1.5 Floor tolerances and deformations

For rack design the flatness deviations and deformations of the building floor upon which the rack is to be installed may be ignored when the building floor is in accordance with the relevant limit values specified in EN 15620.

5.2 Methods of design

5.2.1 General

The design of the structure or its parts shall be carried out by one of the methods given in this document including the Annexes (Amplified sway method and approximate equations are given in Annexes B and C). In all cases the details of the members and connections shall be such as to realise the assumptions made in the design without adversely affecting any other part of the structure.

5.2.2 Ultimate limit state

The ultimate limit state corresponds to the maximum load carrying capacity and shall be generally characterised by one of the following.

- a) Strength (including widespread yielding, rupture, buckling and transformation into a mechanism).

- b) Stability against overturning and sway.
- c) Excessive local deformation.
- d) Fracture due to fatigue.

NOTE This document contains no further reference to fatigue. It is therefore implicit that normal rack structures are not subject to fatigue and that this document should not be used for the design of installations subject to many cycles of load or incorporating details which may be vulnerable to low cycle fatigue without proper consideration of the effect of repeated loading. Low cycle fatigue is likely to be significant in the case of pick-up and deposit stations or satellite rails.

5.2.3 Serviceability limit state

The verification of the serviceability limit state ensures the proper functioning of the elements under service conditions. It shall be sufficient simply to consider deflections or other deformations which affect the appearance or effective use of the structure.

The deformations shall be calculated making due allowance for any second-order effects and the rotational stiffness of any semi-rigid joints.

5.3 Imperfections

5.3.1 General

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

- a) frame imperfections according to 5.3.2;
- b) bracing system imperfections according to 5.3.3;
- c) member imperfections according to 5.3.5.

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

5.3.2 Sway frame imperfections in un-braced systems

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.

NOTE More sophisticated modelling of the global imperfection than an initial sway imperfection or a closed system of equivalent horizontal forces may be carried out; however, care needs to be taken in the generation of the model to reflect the practical application.

The effect of looseness of the beam to upright connector shall be included in the calculation of the frame imperfection.

The sway imperfection ϕ shall be determined from:

$$\phi = \phi_s + \phi_l \quad (1)$$

where

$\phi \geq 1/500$ for ultimate limit state design only;

ϕ_s = maximum specified out-of-plumb divided by the height (see 8.5.7.2).

ϕ_l = looseness of beam-upright connector determined according to A.2.5

NOTE If the effect of the looseness of the 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.

These initial sway imperfections shall apply in all horizontal directions, but may only be considered in one direction at a time.

The initial sway imperfections may be replaced by a closed system of equivalent horizontal forces. These equivalent horizontal forces shall be applied at each level and shall be proportional to the factored vertical loads applied to the structure at that level, as shown in Figure 7.

For the design of the base plate and floor fixings, the horizontal reactions at each base support shall be determined using the sway imperfection ϕ and not the equivalent horizontal forces. In the absence of actual horizontal loads, the net horizontal reaction is zero.

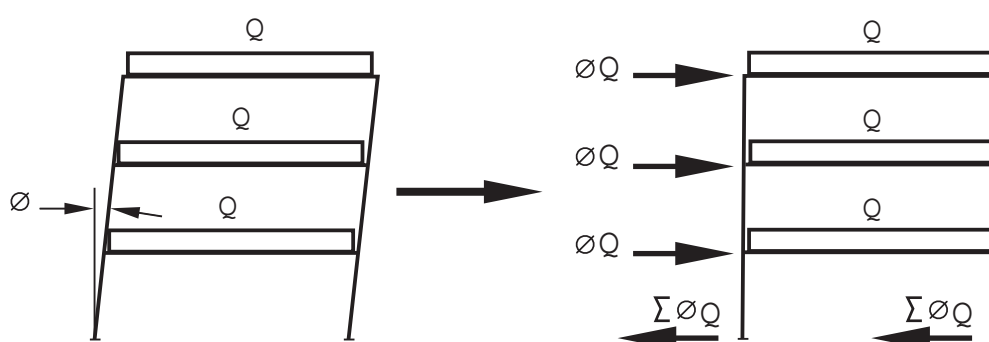


Figure 7 — Equivalent horizontal forces

5.3.3 Bracing system imperfections

5.3.3.1 General

This clause is applicable to both upright frames and frames braced in the down-aisle direction.

The effects of imperfections in bracing systems which contribute to the lateral stability of the structure shall be taken into account by including an initial geometric imperfection in the bracing system (see Figure 8).

Both global imperfections according to 5.3.3.2 and local imperfections according to 5.3.3.3 shall be considered. These imperfections need not be added together.

5.3.3.2 Imperfections in the vertical bracing system and its connections

The imperfections described in this section shall be included in the global analysis.

The initial sway imperfection shall be determined from:

$$\phi = \sqrt{\left(\frac{1}{2} + \frac{1}{n_f}\right)} 2\phi_s \quad (2)$$

where $\phi \leq 2\phi_s$ and $\phi_s \geq 1/500$.

In the down aisle direction n_f is equal to the number of upright frames in one row of bays.

In the cross-aisle direction, n_f shall be taken as the number of upright frames connected together (e.g. by top ties, run spacers or by intermediate floors) and acting together.

NOTE Rational analysis may allow the use of more than one row of upright frames in the cross aisle direction (e.g. due to the top bracing or the diaphragm action of a floor).

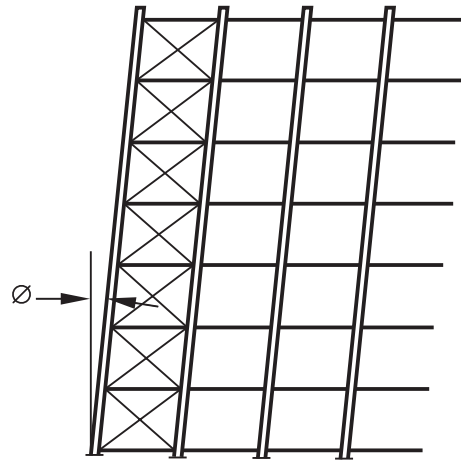


Figure 8 — Global bracing imperfections

5.3.3.3 Local bracing imperfections

Local bracing imperfections give rise to self equilibrating systems of forces (see Figure 9) which shall be used in the design of the bracing members and their connections only. A first-order analysis may be used.

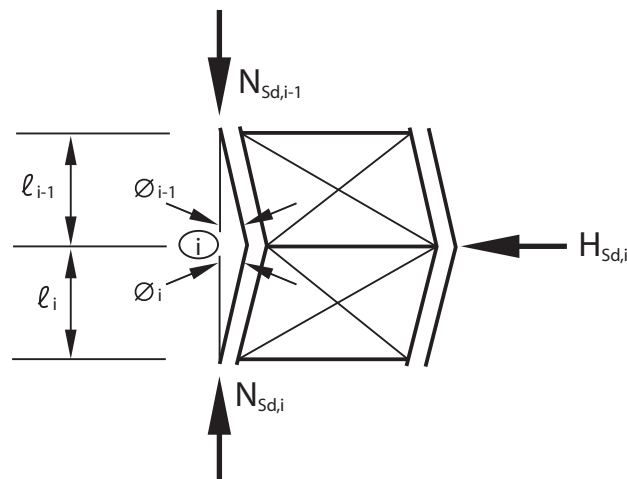


Figure 9 — Local bracing imperfections

For uprights without splices $\phi_o = 1/400$

For uprights which incorporate splices $\phi_o = 1/200$

$$l_i \geq l_{i-1}; \phi_{i-1} = \sqrt{0,5 \times \left(1 + \frac{1}{n_u}\right)} \phi_o \text{ but } \leq \phi_o \quad (3)$$

$$\text{and } \phi_i = \phi_{i-1} \frac{\ell_{i-1}}{\ell_i}$$

Where n_u = number of uprights per bracing system

$$\ell_i \leq \ell_{i-1}; \quad \phi_i = \sqrt{0,5 \times \left(1 + \frac{1}{n_u}\right)} \phi_0 \text{ but } \leq \phi_0 \quad (4)$$

$$\text{and } \phi_{i-1} = \phi_1 \frac{\ell_i}{\ell_{i-1}}$$

The initial geometric imperfection may be applied as a horizontal force $H_{Sd,i}$

where

$$H_{Sd,i} = N_{Sd,i-1} \phi_{i-1} + N_{Sd,i} \phi_i;$$

$H_{Sd,i}$ is summed over all connected uprights;

N_{Sd} = design axial load in a member.

If $\ell_i = \ell_{i-1}$; $N_{Sd,i} = N_{Sd,i-1}$; $\phi_i = \phi_{i-1}$; then $H_{Sd,i} = 2N_{Sd,i} \phi_i$

5.3.4 Imperfections in racks partially braced in the down-aisle direction

This clause applies to frames where the cross-bracing shown in Figure 8 extends over the lower part of the height. The initial sway imperfection ϕ in 5.3.3 shall be applied over the braced portion of the height. The initial sway imperfection ϕ in 5.3.2 shall be applied over the un-braced portion of the height.

In these equations:

$n_c = n_f$ total number of frames in the down-aisle direction;

n_s = number of un-braced beam levels.

5.3.5 Member imperfections

Depending upon the type of structural analysis the effects of imperfections on member checks shall be incorporated either by using the appropriate buckling factors given in 9.7.4.2 or by using the global analysis method of 10.1.3.

6 Actions and combinations 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

6.2.1 General

The permanent actions shall comprise the weight of all construction, including walls, floors, ceilings, stairways and fixed service equipment.

6.2.2 Weights of materials and construction

In estimating dead loads for the purposes of design the actual weights of materials and constructions shall be used. The weight of fixed service equipment, such as sprinklers, electrical feeders, and heating, ventilating, and air conditioning systems, shall be determined and taken into account whenever such equipment is supported by the structural members of the rack.

6.3 Variable actions

6.3.1 General

Where applicable, the design shall take into account actions from the following variable loads.

- a) Unit loads.
- b) Vertical placement loads.
- c) Horizontal placement loads.
- d) Rack-guided equipment loads.
- e) Floor and walkway loads.
- f) Thrusts on handrails.
- g) Actions from imperfections (i.e. frame, bracing, member, loading).
- h) Impact and accidental loads.
- i) Wind loads.
- j) Snow loads.
- k) Seismic actions.

Variable actions from other equipment connected to the structure shall be determined and taken into account in the design.

6.3.2 Unit loads to be stored

Unit loads shall be determined in accordance with the requirements of EN 15629.

The global analysis and design may be carried out using the specified value of the weight of unit loads and assuming that the rack is uniformly loaded in every bay. This approach may only be used when:

- a) The management system in the warehouse can reliably identify unit loads in excess of the specified value and control their distribution within the rack.
- b) The specified weight of unit load shall not be less than 80% of the maximum weight of unit load.

- c) All beams are designed to carry the maximum weight of unit load.
- d) In upright design the worst case load distribution shall be considered where maximum weight of unit load shall be applied to the upper storage positions up to the specified bay load.
- e) The bay load used in the global analysis and design is never exceeded.

If the placement imperfection is not systematic but random the increase of stress and deformation due to loading imperfections at the limit of placement tolerance may be ignored if it does not exceed 12% compared to the beam loaded symmetrically. When the increase is more than 12% the effect on the beam design shall be taken into account as follows:

Where the placement imperfection is not systematic and random placement accuracy is predicted then account of this effect shall be used in the beam design as follows:

$$Q' = \eta Q \quad (5)$$

$$\begin{aligned} \text{if } \rho \leq 1,12 & \quad \eta = 1 \\ \text{if } 1,12 \leq \rho \leq 1,24 & \quad \eta = 2\rho - 1,24 \\ \text{if } \rho \geq 1,24 & \quad \eta = \rho \end{aligned}$$

where

$$\rho = \frac{Q_e}{Q}$$

Q = Load on the beam where the pallet is placed in the planned position.

Q_e = Load on the beam when the pallet is placed with the maximum misalignment.

6.3.3 Vertical placement loads

The following minimum vertical placement loads shall be applied in applications where unit loads are placed in position.

- a) If goods are placed with mechanical equipment.

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

- b) If goods are hand loaded.

Load support beams or supporting arms (if any) and end connections shall be designed for an additional vertical placement load Q_{pv} of 100% of the maximum weight of unit load, placed in the most unfavourable position for the particular determination (moment or shear force).

The downward placement load need not be applied when checking beam deflections or when designing upright frames and other components.

6.3.4 Horizontal placement loads

6.3.4.1 General

In applications where unit loads are placed in position, the following minimum horizontal placement loads (variable actions) shall be applied in both the cross-aisle and the down-aisle direction at the most unfavourable location. They shall be applied in one direction only, not in both directions simultaneously.

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

An accidental overload shall be taken into consideration (see 6.4) but need not be considered at the same time as the horizontal placement load.

6.3.4.2 Effects of operational methods

The following operational methods shall be used to determine the horizontal placement load.

- a) Where goods are placed with manually operated mechanical equipment (e.g. forklift trucks).
- 1) For racks up to 3 m in height, Q_{ph} shall be a load of 0,5 kN applied at any height up to the top of the rack.
 - 2) For racks over 6 m in height, Q_{ph} shall be the worst case of either a load of 0,25 kN applied at the top of the rack or a load of 0,5 kN applied at any height up to 3 m.
 - 3) For racks with heights between 3 m and 6 m, Q_{ph} shall be the worst case of a load at the top of the rack whose magnitude is determined by linear interpolation between 1) and 2) or a load of 0,5 kN applied at any height up to 3 m.
- b) Where goods are placed by automatic storage and retrieval equipment, Q_{ph} and its position shall be specified by the materials handling equipment supplier. However, it shall never be less than 0,25 kN.
- c) Where backstops are used it shall be clearly defined whether these are safety backstops or buffering backstops and the design load Q_{ph} shall be defined by the specifier. For manually operated mechanical equipment this shall be subject to a minimum value of 0,25 Q_u in the plane of the upright frame, where Q_u is the weight of unit load.

Buffer back stops and pick and deposit stations with positioning devices shall be considered to give rise to variable actions whereas safety backstops shall be considered to give rise to accidental actions. The actions arising from both of these shall be used with the relevant load factors.

NOTE 1 Buffering backstops are considered to be undesirable because they encourage misuse. In some circumstances they are specified for adjustable pallet racking to help the driver with positioning however the forces resulting from these operations are of a high magnitude and are very difficult to quantify precisely.

NOTE 2 Safety backstops might be specified for automated systems (crane racking) to fulfil the requirements of EN 528.

- d) Q_{ph} as specified above shall be taken into account when designing the following rack components in the direct vicinity of the backstop. These effects are all local.
- 1) The backstop device itself.
 - 2) The connection of the backstop with the rack component concerned (beam or upright).
 - 3) The part of the upright to which the backstop or the beam to which the backstop is directly connected.
 - 4) The upright frame bracing in the direct vicinity of this upright part.

Because of damping and spreading effects, a reduced Q_{ph} may be considered as:

$Q_{ph} = 0,1Q_u$ for frame anchoring design assuming based on the upright being unloaded with Q_{ph} acting on one frame in the topmost position;

$Q_{ph} = 0,1Q_u$ for overall frame design (bracing and upright) and Q_{ph} acting on one frame on the top most pallet position.

e) If the goods are hand loaded.

$$Q_{ph} = 0,25 \text{ kN}$$

6.3.4.3 Application of the horizontal placement load in the down-aisle direction

In the down-aisle direction, the horizontal placement load arises at the beam levels and amplifies the down-aisle sway caused by frame imperfections.

In order to avoid creating unnecessary load cases, the concentrated load Q_{ph} may be replaced by a total load of $2Q_{ph}$ distributed uniformly over all beam levels.

6.3.4.4 Application of the horizontal placement load in the cross-aisle direction

In the cross-aisle direction, the most unfavourable location for the placement load shall be either:

- a) the top of the upright frame in order to maximise the forces in the bracing system, midway between two bracing nodes of the upright frame lattice in order to maximise the cross-aisle bending moment. In this case, the critical load location is generally in the lowest length of upright between bracing points. If the spacing of bracings is non-uniform, other locations shall also be investigated.

NOTE In order to determine the design bending moments, a global analysis of the complete upright frame need not be carried out. It is sufficient to add positive and negative bending moments of magnitude $Q_{ph} \cdot l/6$.

- b) The mid-span of a beam in the horizontal plane in order to provide the maximum minor axis bending moment. This case need not be incorporated in the global cross-aisle analysis and a load of $0,5 Q_{ph}$ shall be considered to be carried by a single beam in the horizontal plane through the neutral axis. It is permissible to ignore the interaction with the vertical load causing Q_{ph} .

If the installation is designed for loads to be rolled or slid into position, the placement loads Q_{ph} generated by the loading process shall be determined and used for in the design.

6.3.5 Effects of rack-guided equipment

In racking operated by rack-guided cranes, the probability of all cranes imposing horizontal loads in the same direction and at the same position in the rack simultaneously decreases as the number of cranes increases, therefore if the upright frames are coupled over the aisles, the total horizontal force $Q_{h,t}$ at guide rail level shall be the value given in Table 1.

Table 1 — Total horizontal actions at guide rail level

Number of cranes	$Q_{h,t}$
1 or 2	ΣQ_h
3	$0,85 \Sigma Q_h$
4	$0,70 \Sigma Q_h$
≥ 5	$3 Q_h$

Where:
 Q_h is maximum specified lateral support load per crane.
 $Q_{h,t}$ is reduced sum (Σ) of Q_h -forces acting at the crane top guide rail, which is connected to a member joining all the upright frames together as shown in Figure 10.

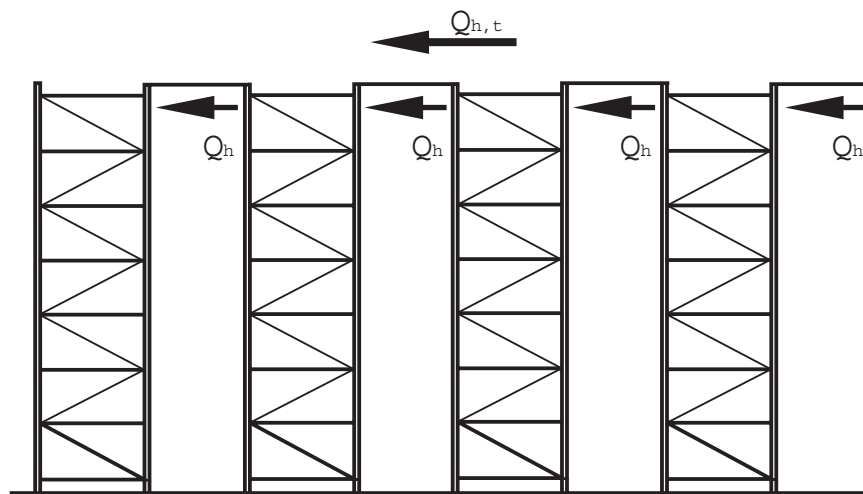


Figure 10 — Horizontal loads from rack-guided equipment

If the horizontal load Q_h is specified as a result of an eccentric one sided force applied to the crane rail then the values given in Table 1 shall not be used.

$Q_{h,t}$ shall be evaluated for the most unfavourable position of the cranes. However, it may be distributed over several frames in the down-aisle direction using plan bracing.

The horizontal load from rack-guided equipment shall be taken combined with the placement load if this constitutes the worst case.

If a rack-guided system includes cranes which operate beyond the end of the rack or on curved track, advice shall be sought from the manufacturer regarding the horizontal forces to be resisted by the racking.

When storage and retrieval equipment is used, the accidental forces as a result of a crane traversing a bend at the design speed shall be taken into account.

Consideration shall be given to accidental impact forces in the down-aisle direction, if any, occasioned by a crane hitting a rack-mounted buffer.

6.3.6 Floor and walkway loads (see also EN 1991-1-1)

The following distributed or concentrated loads, whichever is most critical, shall be used in the design of floors or walkways.

- a) On floors and walkways intended for access only and not more than 1,2 m wide.

$$q = 2,5 \text{ kN/m}^2 \quad (\text{distributed load})$$

$$Q_f = 2,0 \text{ kN} \quad (\text{concentrated load applied over a square } 50 \text{ mm} \times 50 \text{ mm})$$

The above loads represent the design load on any one bay for the local design of the beams and uprights. The overall load on the structure may be reduced to $q = 1,0 \text{ kN/m}^2$ for the verification of global stability.

- b) On floors wider than 1,2 m or intended for storage or on which trolleys may run.

$$q = 3,5 \text{ kN/m}^2 \quad (\text{distributed load})$$

$$Q_f = 3,0 \text{ kN} \quad (\text{concentrated load applied over a square } 100 \text{ mm} \times 100 \text{ mm}).$$

- c) On stairs narrower than 1,2 m

$$q = 3,0 \text{ kN/m}^2 \quad (\text{distributed load})$$

$$Q_f = 3,0 \text{ kN} \quad (\text{concentrated load applied over a square } 100 \text{ mm} \times 100 \text{ mm}).$$

On stairs wider than 1,2 m

$$q = 3,5 \text{ kN/m}^2 \quad (\text{distributed load})$$

$$Q_f = 3,0 \text{ kN} \quad (\text{concentrated load applied over a square } 100 \text{ mm} \times 100 \text{ mm}).$$

- d) Where moving equipment applies dynamic forces to the structure, these effects shall be taken into account as quasi-static actions with the relevant load factor, see EN1991-1-1 Clause 6.3. The relevant static forces shall be multiplied by the following dynamic factors in order to differentiate between the effective vertical wheel loads of the different types of trucks.

1) Pedestrian controlled truck with velocity less than 5 km/h 1,2.

2) Ride on truck with a velocity less than 7,5 km/h 1,4.

3) Ride on truck with a velocity less than 10 km/h 2,0.

The concentrated load shall be placed in the most unfavourable position.

Pattern loading on floors and walkways need not be considered.

Due consideration shall be given to the effects of horizontal forces applied by the equipment and how these forces are to be accommodated by the structure.

If the loads arising from stored materials or racking systems supported by the floor exceed the stated values, the actual load shall be used. Particular attention shall be given to the concentrated loads applied by upright frames.

NOTE 1 National regulations may require different values for floor and walkway loads.

NOTE 2 Floor and walkway areas are often used for unofficial storage. The values given in 6.3.6 should therefore be regarded as minimum design loads. In areas with higher than average headroom, consideration should be given to using greater design loads than those specified.

6.3.7 Actions arising from installation

Where the installation method statement plans for the installers to use safety harnesses suitable anchorage points capable of arresting an accidental fall shall be provided. Residual deformations of the members can occur in the event of a fall.

6.4 Actions due to impact (accidental loads)

6.4.1 General

The live loads and placement loads specified in 6.3 shall be assumed to include adequate allowance for ordinary impact conditions. Provision shall be made in the structural design for uses and loads that involve unusual vibration or dynamic forces.

Impact damage caused by fork-lift trucks or other moving equipment against rack-uprights shall be avoided by appropriate operator training and safety measures. The minimum requirements for the protection of corner uprights shall be as follows.

- a) An upright protector with a height of not less than 400 mm shall be positioned at the end upright of each run of racking between cross-aisles.
- b) An upright protector shall be positioned at those uprights positioned at all aisle and gangway intersections.
- c) The upright protector shall be designed for an energy absorption of at least 400 Nm in any direction at any height between 0,10 m and 0,40 m.
- d) The upright protector shall be positioned in such a way that, after its deformation by absorbing an impact, the upright will not be damaged.
- e) Rack protection may be designed theoretically; alternatively testing shall be carried out for the purpose of acceptance. Tests shall be on the basis of a mass being dropped or swung into the protector to model the energy absorption requirement of 400 Nm.

NOTE 1 Uprights other than corner uprights may be protected in a direction normal to the aisle at the option of the user.

NOTE 2 The protection of uprights of racking served by mechanically guided handling equipment need not be necessary.

NOTE 3 As an alternative to the use of upright protectors, the installation may be designed to survive the complete removal of a section at the bottom of an upright.

NOTE 4 Accidental actions from fork lift trucks are given in EN 1991-1-7. Such actions need not apply for industrial trucks with the layout, clearances and operation in accordance with EN 15620 and EN 15635.

6.4.2 Accidental vertical actions

Rack components directly above a unit load shall be able to absorb the following accidental vertical force A_{pv} . In general, this force shall be applied at the end of a beam in order to verify that the connector does not disengage. Upward placement loads are accidental variable actions and shall be considered with a load factor γ_A according to 7.4.

- a) if goods are placed with manually operated mechanical equipment (e.g. fork lift trucks)

$$A_{pv} = 5,0 \text{ kN}$$

- b) if goods are placed with automatic mechanical equipment: (e.g. stacker cranes, storage and retrieval machines)

$$A_{pv} = 0,5 Q_u$$

but $A_{pv} \geq 0,25 \text{ kN}$

and $A_{pv} \leq 5,0 \text{ kN}$

where Q_u = weight of unit load.

The requirements for upward placement loads shall be verified by calculation or by testing according to A.2.6.

6.4.3 Accidental horizontal load

An accidental overload in the horizontal direction shall be taken into consideration:

- a) If the goods are placed with manually operated but not guided mechanical equipment (e.g. fork lift trucks):

From floor to 0,4 m height on the aisle side upright:

— $A_{ph} = 2,5 \text{ kN}$ in the cross-aisle front to back direction;

— $A_{ph} = 1,25 \text{ kN}$ in the down-aisle direction.

These loads shall be treated as occurring separately. It is permissible to deviate from the requirements of EN 1991-1-7 with regard to fork trucks if the conditions of use justify the deviation. See EN15635.

NOTE The above accidental overload load may be taken by the upright itself or it may require that each upright should be reinforced or protected.

- b) If the goods are placed with automatic mechanical equipment (e.g. stacker cranes or storage and retrieval machines) or with manually guided handling equipment (e.g. VNA machines):

— $A_{ph} = 0,5 \text{ kN}$ in either the down-aisle or cross-aisle direction (accidental overload).

NOTE The specified value of A_{ph} may not be acceptable for certain types of equipment and the machinery to be used should be checked and confirmed (i.e. during a malfunction the load may increase until the clutch on the delivery device slips).

6.5 Wind loads

Where required wind loads shall be determined according to the relevant National Regulations.

When a rack is exposed to wind, no account shall be taken of the shielding effects of fully or partially loaded racks upwind of the run in consideration. Each individual row of racking (between adjacent aisles) shall be designed to resist the full wind pressure, suction and wind friction forces.

For a clad rack installation the assembled rows need not be capable of resisting more than the wind force calculated for the complete assembly.

The fully or partially loaded rack shall be considered to be impermeable to wind in the loaded areas unless the effect of permeability can be quantified.

NOTE When determining the limiting deflections for the proper functioning of automatic equipment, a lower value of wind load may be used when specified by the supplier of the equipment.

6.6 Snow loads

Where required snow loads shall be determined according to the relevant National Regulations.

6.7 Seismic actions

Where required, seismic actions shall be determined according to the relevant National Regulations.

7 Partial factors and combination rules

7.1 General

Weight of unit loads and global rack imperfections shall together constitute a single action. Placement loads shall constitute a separate action.

Global imperfections and placement loads shall be combined in one direction at a time. The combination of imperfections or placement loads in one direction with imperfections or placement loads in the other orthogonal direction need not be considered.

7.2 Combinations of actions for the ultimate limit state

The design values of actions shall be combined using the following rules, whichever gives the larger value:

considering only the most unfavourable variable action;

$$\sum \gamma_G G_k + \gamma_Q Q_{k,1} \quad (6)$$

considering all unfavourable variable actions which can occur simultaneously;

$$\sum \gamma_G G_k + 0,9 \sum_{i \geq 1} \gamma_Q Q_{k,i} \quad (7)$$

design for accidental load.

$$\sum \gamma_{GA} G_k + \sum_{i \geq 1} \gamma_{QA} Q_{k,i} + \gamma_A A_k \quad (8)$$

where

G_k = characteristic value of permanent action (dead load);

$Q_{k,1}$ = characteristic value of one of the variable loads;

$Q_{k,i}$ = characteristic value of a typical variable load;

A_k = characteristic value of an accidental load;

γ_G = partial factor for permanent loads;

γ_Q = partial factor for variable loads;

γ_A = partial factor for accidental loads.

7.3 Combination of actions for serviceability limit states

The design values of actions shall be combined using the combination factors ψ_0 , as given in EN 1990. For pallet racking the simplified combination rules given in Equations (5), (6) and (7) may be used, whichever gives the larger value:

considering only the most unfavourable variable action;

$$\sum \gamma_G G_k + \gamma_Q Q_{k,1} \quad (9)$$

considering all unfavourable variable actions;

$$\sum \gamma_G G_k + 0,9 \gamma_Q \sum_{i \geq 1} Q_{k,i} \quad (10)$$

where the notation is defined in 7.2.

Placement loads need not be considered at the serviceability limit state.

NOTE 1 The weight of the unit loads vary up to a maximum which is used in design. The specifier should define a design value for the weight of the unit load (or different design values of the weight of the unit load for the upright frame and/or down aisle global design), which will not be exceeded, see EN 15629. This can result in the specification of design weights which are conservative, thus justifying the 0,9 combination factor for load combinations.

NOTE 2 Unless unusual conditions prevail, it is usual that the goods to be stored plus the global imperfections constitute the action with the largest effect.

7.4 Load factors

The load factors γ_f are given in Table 2.

NOTE National regulations may require different load factors.

Table 2 — Load factors γ_f

Actions	Ultimate limit state	Serviceability limit state
Permanent loads γ_G		
- with unfavourable effect	1,3	1,0
- with favourable effect	1,0	1,0
Variable loads γ_Q		
unit loads	1,4	1,0
unit loads in crane operated systems	1,4 or 1,3 ¹	1,0
placement loads	1,4	1,0
other live loads	1,5	1,0
Accidental loads		
γ_A	1,0	
γ_{GA}	1,0	
γ_{QA}	1,0	

¹Applicable for a crane-operated warehousing system including the weighing of all unit loads and the rejection of all unit loads weighing more than the design load of the rack, the load factor for unit loads may be reduced from 1,4 to 1,3.

NOTE The statistical uncertainty regarding the magnitude of weight of unit loads is considerably less than that for the conventional variable actions in building construction (wind, snow, floor load, etc). Furthermore the user exerts a high level of control in the operation of the system. Consequently unit loads have a load factor between that for other live loads and permanent actions. The main uncertainty in the load-related performance of a pallet rack is in the interaction with the loading equipment. It is considered that these effects are incorporated in the accidental loads and placement loads which reflect the likely result of good practice (see 6.3).

7.5 Material factors

The material factors γ_M for ultimate limit state and serviceability limit state verifications are given in Table 3.

Table 3 — Material factors γ_M

Resistance	Ultimate limit state	Serviceability limit state
Resistance of cross-sections	1,0	1,0
Resistance of connections	1,25	1,0
Resistance of connections subject to testing and quality control (e.g. beam end connectors) see Annex A	1,1	1,0

7.6 Stability against overturning

Using a load factor corresponding to the ultimate limit state, it shall be verified that the empty rack is stable under the action of a single horizontal placement load in the most unfavourable position.

The horizontal placement load shall be resisted by the self-weight of the rack and the floor anchorages.

In every upright frame the base plates shall be fixed squarely to the uprights and secured to the floor through any shimming material or grouting necessary to ensure that the uprights are solidly supported under the whole area of the base plate. The shimming material shall be steel and shall be prevented from shifting relative to the base plate.

7.7 Racks braced against the building structure

If the racks are braced against the building structure, the two structures can 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.

8 Steel

8.1 General

8.1.1 Preliminary considerations

The nominal values of material properties given in this section should be adopted as characteristic values in design calculations for the manufacture of racking products. Steels shall be suitable for cold-forming, welding and galvanising where appropriate.

Specified steels according to Table 3.1 of EN 1993-1-1:2005, and 3.1a and 3.1b of EN 1993-1-3:2006, the properties and chemical composition of which are in compliance with the relevant standards, fulfil the requirements of this section.

Other steels may be used provided that:

- their properties and chemical composition are at least equivalent to steels, for which the standards are listed in Table 3.1 of EN 1993-1-1:2005 and 3.1 of EN 1993-1-3:2006,
- if the steel is for cold-forming, it fulfils the requirements of the bend test A.1.2. and the ratio of the characteristic ultimate tensile strength to the characteristic yield strength satisfies $f_u/f_y \geq 1,05$ where f_y , f_u = characteristic tensile yield strength and tensile ultimate strength of the basic material.

NOTE 1 The minimum ratio in 8.1.1 differs from that specified in EN 1993-1-1 but is acceptable for racking products.

NOTE 2 See Annex D relating to research into the use of materials with a close ratio between f_u and f_y

8.1.2 Material properties

The nominal values of the yield strength f_y and the ultimate strength f_u for structural steel shall be obtained by

- adopting the values $f_y = R_{eh}$ and $f_u = R_m$ direct from the relevant product standard,
- using the simplification given in 8.1.5,
- using the testing regime specified in 8.1.4.

8.1.3 Design values of material coefficients (general mechanical properties)

The following properties of steel shall be assumed in design.

- Modulus of Elasticity $E = 210\,000 \text{ N/mm}^2$.
- Shear Modulus $G = E/[2(1 + \nu)] \text{ N/mm}^2$.

- c) Poisson's Ratio $\nu = 0,3$.
- d) Coefficient of linear thermal expansion $\alpha = 12 \times 10^{-6}$ per $^{\circ}\text{C}$.
- e) Density $\rho = 7850 \text{ kg/m}^3$.

8.1.4 Steels with no guaranteed mechanical properties

8.1.4.1 General

For steels in this category a series of tensile tests may be used to justify the values to be used or a lower bound value of yield strength may be used.

8.1.4.2 Additional tests on steel

The mechanical properties of basic materials shall be measured from tensile tests according to section A.1.1. The results of tensile tests shall be subject to statistical control, see 13.3.3.

When conducting the following procedures for coils:

- a) testing to determine the minimum guaranteed mechanical properties for the steel used in production;
- b) to justify the use in design of a yield stress higher than the guaranteed value;
- c) to demonstrate adequate ductility.

The minimum frequency of testing shall be one test from each original coil (after slitting and cold-reducing, if cold-reducing is part of the process). Samples shall be taken lengthwise from the middle of the width near the end of the coil.

The results of the mechanical tests shall be statistically analysed in accordance with 13.3.3, in order to derive characteristic values of the yield or ultimate tensile strength of the material for design purposes. Where at least 100 test results have been accumulated over a long period, those in excess of 100 which are more than 12 months old shall be discarded from the analysis (see Annex A)

For sheets and sections, the mechanical properties given in 8.1.5 for unspecified steels shall be used.

8.1.5 Untested steels

The following values of f_{yb} shall be assumed if the steel grade is not specified or if the basic material is not available for testing:

Hot rolled sections 200 N/mm²;

Other steels 140 N/mm².

8.2 Average yield strength of sections

Where required, the average yield strength (f_{ya}) shall be determined for members as defined in EN 1993-1-3.

8.3 Special selection of production material

When a coil of material is specially selected for a particular application, excluding testing material, and the design strength to be used is in excess of the nominal design strength for that material, the maximum value of the design strength shall not exceed 90% of the value given on the test report for the coil.

8.4 Fracture toughness

Brittle fracture of material below 6 mm in thickness need not be considered for temperatures down to -35 °C for non hot-dipped steel sheet in accordance with this specification.

For untested steels covered by 8.1.5 the 6 mm thickness limit given above shall be reduced to 2 mm.

NOTE Further guidance on this subject can be found in EN 1993-1-10

8.5 Dimensional tolerances

8.5.1 General

Tolerance limits of sections and members shall be in accordance with EN 10162.

The dimensional and mass tolerances of rolled steel sections, structural hollow sections and plates shall conform to the relevant product standard unless more severe tolerances are specified.

For structural analysis and design the nominal values of dimensions shall be used.

8.5.2 Thickness of material

The design rules given in this document shall be limited to the following core thickness t_c exclusive of coatings unless specified otherwise, where:

$$0,5 \leq t_c \leq 8,0 \text{ mm}$$

The use of thinner steel is not precluded but the load bearing capacity shall be determined by appropriate tests. If components with thicker steels are used they shall be designed in accordance with EN 1993-1-1. Design expressions for base plates (see 9.9) may be used with a material thickness greater than 8 mm.

8.5.3 Tolerances on thickness

The design rules given for cold-formed members have been developed on the basis of thickness tolerances of half the tolerances specified as normal in EN 10326:2004. When larger tolerances are used, the nominal values of thickness shall be adjusted to maintain the equivalent reliability (see EN 1993-1-3).

For continuously hot-dip metal coated material with a nominal thickness $\leq 1,5$ mm supplied with the restricted special tolerances given in EN 10143, the design thickness t shall be taken as equal to the nominal core thickness t_c .

In the case of continuously hot-dip metal coated steel sheet and strip conforming to EN 10147, the core thickness t_c shall be as given in EN 1993-1-3.

NOTE The thickness of the zinc protection is usually a total of 0,04 mm for 275 g/m².

8.5.4 Width and depth of a cold-formed section

The width and depth of plane elements of a section shall fulfil the requirements in Table 4 and 5.

Table 4 — Tolerances on width b_o of stiffened plane elements - Dimensions in mm

Thickness t	$b_o \leq 50$	$50 < b_o \leq 100$	$100 < b_o \leq 220$
$t < 3,0$	$\pm 0,75$	$\pm 1,00$	$\pm 1,00$
$3,0 \leq t < 5,0$	$\pm 1,00$	$\pm 1,00$	$\pm 1,25$
$5,0 \leq t \leq 8,0$	$\pm 1,00$	$\pm 1,25$	$\pm 1,50$

Table 5 — Tolerances on width b_o of un-stiffened plane elements: Dimensions in mm

Thickness t	$b_o \leq 40$	$40 < b_o \leq 80$	$80 < b_o \leq 120$
$t < 3,0$	$\pm 1,20$	$\pm 1,50$	$\pm 1,50$
$3,0 \leq t < 5,0$	$\pm 1,50$	$\pm 1,50$	$\pm 2,00$
$5,0 \leq t \leq 8,0$	$\pm 2,00$	$\pm 2,00$	$\pm 2,00$

8.5.5 Member straightness

The initial maximum deviation of a member from the exact straight line shall be less than 1/400 of the member length measured with respect to the two ends.

8.5.6 Twist

The initial twist of a member 'as installed' shall be, at mid span, less than 1° per metre for symmetric sections and 1,5° per metre for asymmetric sections.

8.5.7 Tolerances with regard to design and assembly

8.5.7.1 General

All tolerances are defined in the 'as-built' situation prior to operation of the storage system. The deformation under load shall be taken as measured after application of the first imposed load.

8.5.7.2 Verticality

The maximum out-of-plumb of any upright in any direction shall be height/350 measured in the unloaded condition immediately after installation.

If the designer specifies an initial out of plumb imperfection the installation process shall be controlled in order to ensure that the design assumptions are achieved in practice.

NOTE The maximum out-of-plumb is a frame imperfection which influences the design.

8.6 Bracing eccentricities

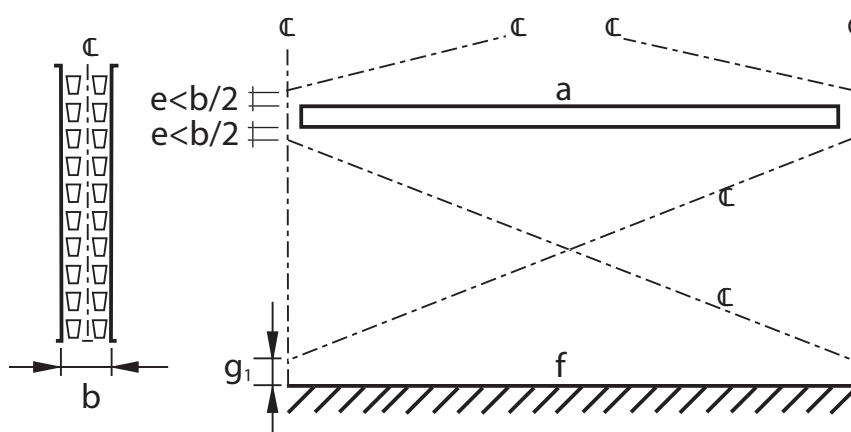
If the eccentricities between system lines exceed the limits specified below, they shall be included in the global analysis and the resulting secondary moments shall be included in the member design.

The effects of bracing eccentricities may be neglected if the following conditions are fulfilled.

- The intersection point of the centre lines of a horizontal member and a diagonal falls within a vertical dimension 'e' equal to one half of the upright width 'b' (see Figure 11 a)).
- The eccentricity ' g_1 ' is not greater than 2,0 times the upright width and ' g_2 ' is not greater than 1,5 times the upright depth as shown in Figure 11 b). Where beams are used as horizontal members, the intersection point shall be taken as the intersection of the centre lines of a diagonal and the top or bottom flange line.

NOTE 1 It is good practice for the angle of inclination of the diagonal from the horizontal to lie between 20° and 70° .

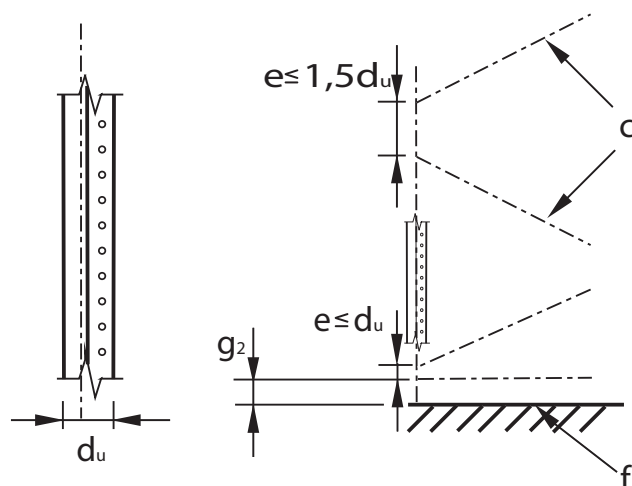
NOTE 2 If 8.6 requires a global analysis including eccentricities in the cross aisle direction, the bases shall be considered to be pinned unless the base stiffness is determined by test according to A.2.7



Key

- a pallet beam
- b width of upright
- c system lines
- e distance from bracing node to top or bottom of beam
- f floor
- g_1 distance from floor to lower spine bracing node point

Figure 11 a) — Eccentricities in spine bracing



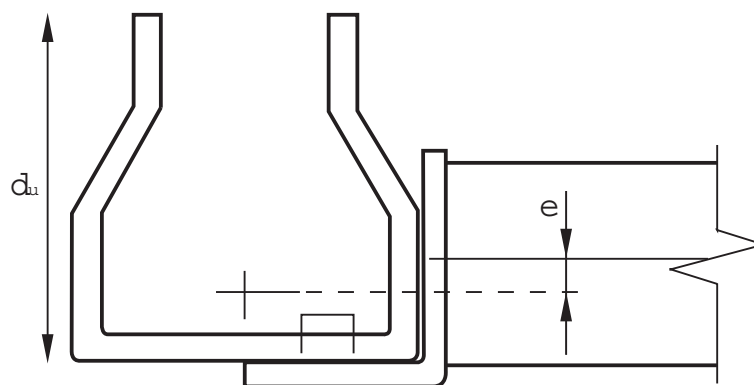
Key

- c system lines
- d_u depth of upright
- e eccentricity between bracings
- f floor
- g_2 distance from floor to lower bracing node point

Figure 11 b) — Eccentricities in frame bracing

8.7 Eccentricities between beams and uprights

The centroidal axis of the beam may not coincide with the centroidal axis of the upright. This results in an eccentricity 'e' in the cross-aisle direction as shown in Figure 12.



Key

- d_u depth of upright
- e eccentricity

Figure 12 — Eccentricity in the cross-aisle direction

The eccentricity e in Figure 12 may be neglected where 'e' is less than 0,25 d_u .

NOTE This eccentricity e in Figure 12 may be important and should be included in both the global analysis and the member design if, for example, the beams are connected to the outside of the upright frames.