



BSI Standards Publication

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

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## National foreword

This British Standard is the UK implementation of EN 15512:2020+A1:2022. It supersedes BS EN 15512:2020, which is withdrawn.

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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

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## European foreword

This document (EN 15512:2020+A1:2022) 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of an identical text or by endorsement, at the latest by September 2022, and conflicting national standards shall be withdrawn at the latest by September 2022.

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

This document supersedes A1 EN 15512:2020 A1.

This document includes Amendment 1 approved by CEN on 14 January 2022.

The start and finish of text introduced or altered by amendment is indicated in the text by tags A1 A1.

Compared to EN 15512:2009, the overall document structure has been updated to be more similar to the Eurocode, several clauses were updated to current state of Standards and FEM recommendations, alternative options for testing setups were included. A probabilistic reliability study was carried out to verify reduced load factors were according to Eurocode principles resulting in minor adjustments on the material factors.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

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

## 0 Introduction

### 0.1 Racking

Racking systems are load bearing structures for the storage 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 and beams. Special beam to column (upright) connections and bracing systems are utilized, 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 standardized, 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 in addition to the Eurocodes

Because of the differences in shape of structural components, detailing and connection types 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 common design rules was the reason that 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.

### 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 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 standalone document and is intended to be used in conjunction with EN 15620, 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 the EN 1993 series for the Design of steel structures.

EN 15512 is intended for use by:

- 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.

## 1 Scope

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

This document does not cover other generic types of storage structures. Specifically, this document does not apply to mobile storage systems, drive-in, drive-through, pallet live storage, push back, shuttle systems, systems where two or more cranes operates one above another in the same aisle and cantilever racks or static steel shelving systems.

For the specific design of adjustable pallet racking for use in seismic areas, this document is to be used in combination with EN 16681.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1090-4, *Execution of steel structures and aluminium structures — Part 4: Technical requirements for cold-formed structural steel elements and cold-formed structures for roof, ceiling, floor and wall applications*

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 1992-4, *Eurocode 2 — Design of concrete structures — Part 4: Design of fastenings for use in concrete*

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 1993-1-8:2005, *Eurocode 3: Design of steel structures — Part 1-8: Design of joints*

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 16681, *Steel static storage systems — Adjustable pallet racking systems — Principles for seismic design*

EN ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature (ISO 6892-1)*

EN ISO 7438, *Metallic materials — Bend test (ISO 7438)*

### 3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 15878 and the following apply. ISO and IEC maintain terminological databases for use in standardization at the following addresses:

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

#### 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

quantity of material, 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, bolted to, or otherwise connected or 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 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 placement load

load caused by deposit and picking operations of a unit load into and out of the system, reflecting good practice

**3.10****quasi-rigid**

conceptual term allowing the assumption of full rigidity of the floor slab

**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****sway**

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

**3.14****buckling length**

system length of an otherwise similar member with pinned ends, which has the same critical buckling load as a given member or segment of member

**3.15****system length**

distance in a given plane between two adjacent points at which a member is braced against lateral displacement and/or torsion in this plane, or between one such point and the end of the member

**3.16****design working life**

assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance

**3.17****unit load**

individual item which can be placed or retrieved in one operation

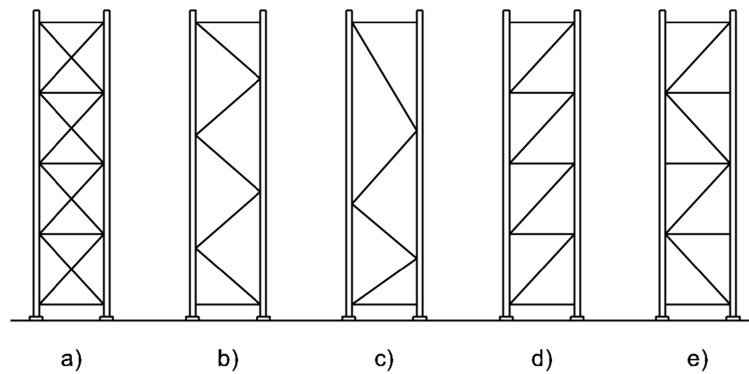
Note 1 to entry: e.g. a pallet or a container with goods in a racking system.

**3.18****un-stiffened element**

part of the cross-section which is connected to the remainder of the section along one longitudinal edge only

**3.19****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 and provide stability in the cross-aisle direction (see Figure 1)



**Key**

- a) "Tension Braced" Frame
- b) "D" Braced Frame regular
- c) "D" Braced Frame irregular
- d) "Z" Braced Frame
- e) "K" Braced Frame

**Figure 1 — Typical forms of upright frames**

**3.20**

**perforated member**

member with multiple holes regularly spaced along its length

**3.21**

**effective section properties**

properties for strength taking account of the effects of perforation, local and distortional buckling and effects of cold-forming

**3.22**

**equivalent section properties**

properties for stiffness taking account of perforation

**3.23**

**regular rack**

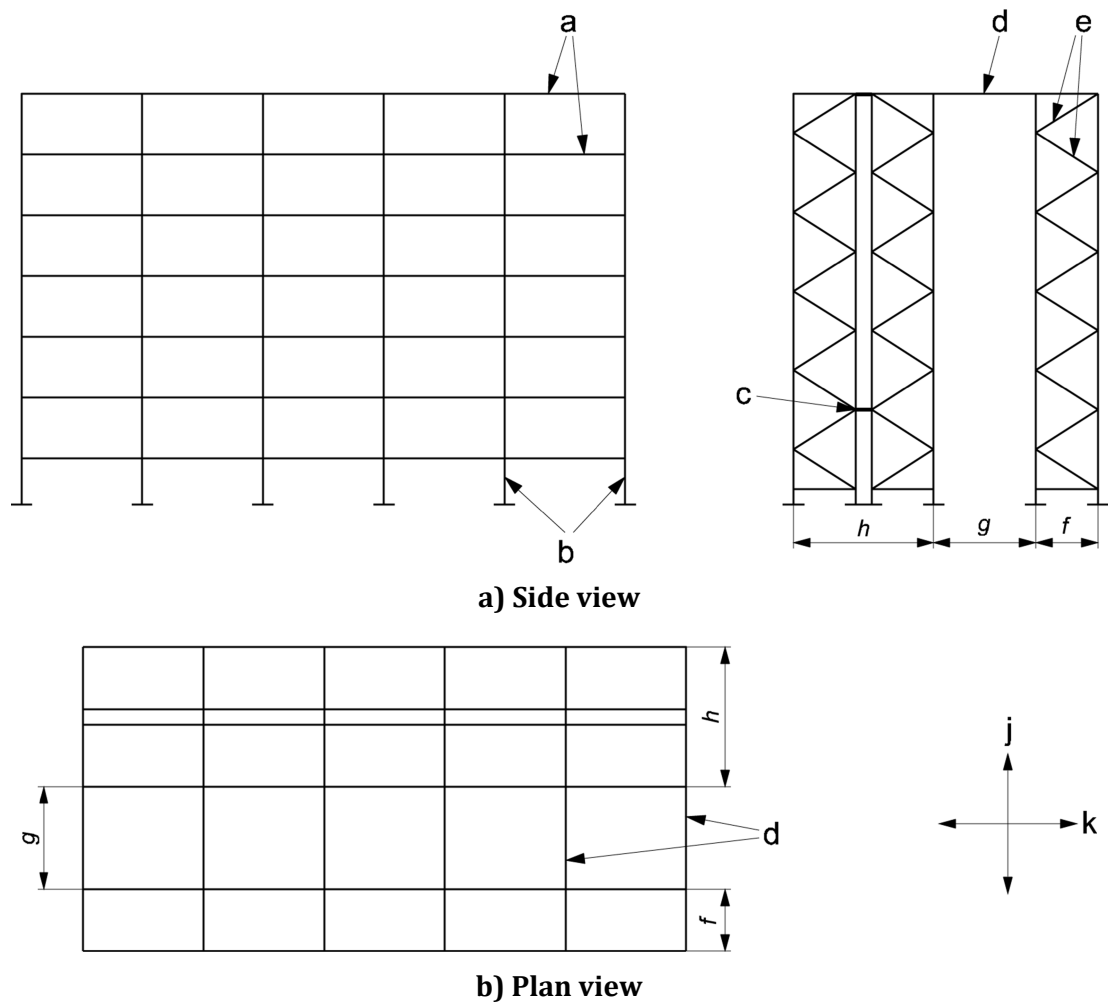
rack with components (beam, uprights, etc.) of the same type, length and vertical spacing

Note 1 to entry: Rack where the distance from the ground to the first beam level is different to the remainder may be considered as regular.

**3.24**

**un-braced racking systems**

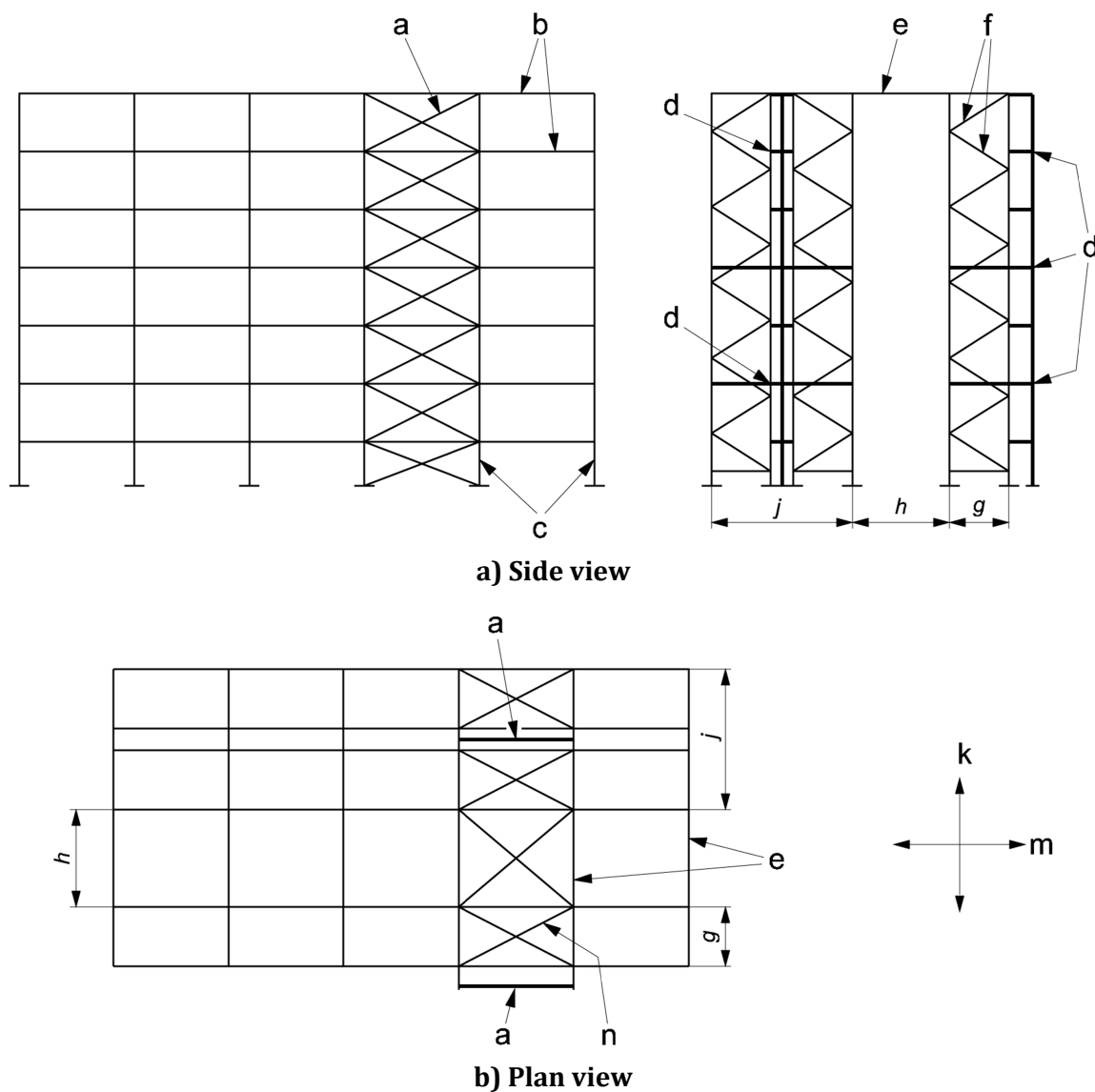
rack in which the down-aisle stability is provided by restraining effect of the beam-end connectors and not by spine bracing (see Figure 2)

**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****3.25****braced racking systems**

rack in which the down-aisle stability is provided by spine and plan bracing (see Figure 3)



#### Key

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

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

## 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                                                                                                                       |
| $A_{\text{eff}}$    | effective cross-sectional area, for continuously perforated uprights<br>$A_{\text{eff}} = \min \{ A_{\text{eff,lb}}; A_{\text{eff,db}} \}$ |
| $A_{\text{eff,lb}}$ | effective area of upright including only local buckling effects as obtained from stub column compression test                              |
| $A_{\text{eff,db}}$ | effective area of upright including also distortional buckling as obtained from compression test on upright                                |
| $A_g$               | gross cross-sectional area                                                                                                                 |
| $A_{\text{eq}}$     | equivalent cross-sectional area taking account of the effects of perforation (for stiffness only)                                          |
| $A_{\text{ph}}$     | accidental horizontal placement force                                                                                                      |
| $A_{\text{pv}}$     | 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                                                                                                                             |
| $f_{\text{ck}}$     | 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                                                                                                                |
| $I_{T,\text{eq}}$   | equivalent St. Venant torsion constant taking account of the effects of perforation                                                        |

|            |                                                                          |
|------------|--------------------------------------------------------------------------|
| $I_{eq}$   | second moment of area of equivalent section                              |
| $I_w$      | warping constant                                                         |
| $I_{w,eq}$ | equivalent warping constant taking account of the effects of perforation |
| $i$        | radius of gyration                                                       |
| $i_0$      | polar radius of gyration                                                 |
| $K$        | effective length factor                                                  |
| $k_d$      | stiffness of beam to column connector                                    |
| $k_s$      | coefficient related to number of tests                                   |
| $L$        | span                                                                     |
| $l$        | length                                                                   |
| $\ell$     | 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                                                |
| $Q_{bh}$   | back stop 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 normalized test results                        |
| $t$        | thickness of material                                                    |
| $t_{cor}$  | 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                                                              |
| $\alpha$                  | coefficient of linear thermal expansion                                           |
| $\alpha$                  | correction factor for yield strength                                              |
| $\alpha$                  | imperfection factor                                                               |
| $\beta$                   | beam coefficient                                                                  |
| $\beta$                   | correction factor for thickness                                                   |
| $\beta$                   | amplification factor for second-order effects                                     |
| $\gamma$                  | partial factor                                                                    |
| $\gamma_A$                | partial factor for accidental loads                                               |
| $\gamma_f$                | load factor                                                                       |
| $\gamma_G$                | partial factor for permanent loads                                                |
| $\gamma_M$                | material factor                                                                   |
| $\gamma_{M0}$             | partial factor for resistance of cross-sections whatever the class is             |
| $\gamma_{M1}$             | partial factor for resistance of members to instability assessed by member checks |
| $\gamma_{M2}$             | partial factor for resistance of cross-sections in tension to fracture            |
| $\gamma_Q$                | partial factor for variable loads                                                 |
| $\delta$                  | deflection                                                                        |
| $\theta$                  | Rotation                                                                          |
| $\lambda$                 | slenderness ratio                                                                 |
| $\bar{\lambda}$           | non-dimensional slenderness                                                       |
| $\nu$                     | Poisson's ratio                                                                   |
| $\rho$                    | density                                                                           |
| $\phi$                    | sway imperfection                                                                 |
| $\phi_0$                  | initial sway imperfection                                                         |
| $\phi_{\ell, \text{BEC}}$ | looseness of beam end connector                                                   |
| $\phi_{\ell, \text{fr}}$  | looseness of frame                                                                |
| $\chi$                    | reduction factor for buckling                                                     |
| Subscripts                |                                                                                   |
| b                         | buckling                                                                          |
| c                         | compression, capacity                                                             |
| cr                        | critical                                                                          |
| d                         | design                                                                            |
| db                        | distortional buckling                                                             |
| g                         | gross                                                                             |
| i                         | test number                                                                       |

|     |                             |
|-----|-----------------------------|
| k   | characteristic              |
| LT  | lateral torsional           |
| m   | mean value                  |
| n   | corrected value             |
| Rd  | design resistance           |
| Ed  | design value of actions     |
| ser | service                     |
| T   | torsional                   |
| TF  | torsional-flexural          |
| TFB | torsional-flexural buckling |
| t   | observed value at test      |

## 5 Assumptions and conventions

### 5.1 General

In addition to the assumptions of EN 1990 the following assumptions apply.

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.

### 5.2 Verticality

The maximum out-of-plumb of any upright in any direction should not exceed the values stated in EN 15620 in the unloaded condition immediately after installation.

If the designer specifies an initial out-of-plumb imperfection different from EN 15620 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.

### 5.3 Conventions for member axis

See EN 1993-1-1.

## 6 Basis of design

### 6.1 Requirements

#### 6.1.1 Basic requirements

Design shall comply with Eurocode series as specified in Clause 2, except as given in this standard.

#### 6.1.2 Design working life

For the purpose of determining the loading, a design working life of at least ten years shall be used, unless specified otherwise. However, this should not be construed as indicating any guarantee regarding the actual working life of the rack.

NOTE The working life of most racks is determined by wear and damage sustained during operation or by corrosion. Wear and damage 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. See also EN 15629 and EN 15635.

### 6.1.3 Requirements for pallet racking

Design shall be carried out on the basis of the project specification in accordance with EN 15629, the specified installation tolerances given in EN 15620 and the operational practice described in EN 15635.

**NOTE** 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.

## 6.2 Principles of limit state design

### 6.2.1 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 Annex B).

### 6.2.2 Ultimate limit state

The ultimate limit state (ULS) corresponds to the maximum load carrying capacity and shall be generally characterized 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.

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 fatigue.

For pick and deposit stations or shuttle rails, attention should be given to the possibility of fatigue at locations where frequent loading and unloading take place. Testing might be the only reliable solution. See also FEM 9.841 / FEM 10.2.10 [14].

### 6.2.3 Serviceability limit state

The structure shall be verified at the serviceability limit state (SLS).

**NOTE** This ensures the proper functioning of the storage system under service conditions.

## 6.3 Actions

### 6.3.1 General

The specifier may include additional actions to be considered to those in 6.3.

### 6.3.2 Permanent actions

#### 6.3.2.1 General

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

### 6.3.2.2 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.

### 6.3.3 Variable actions

#### 6.3.3.1 Unit loads to be stored

##### 6.3.3.1.1 General

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

The design of the racking shall be based on the maximum value of the unit load unless the requirements of 6.3.3.1.2 or 6.3.3.1.3 are satisfied in which case the relevant reduced values may be adopted.

Beams shall be designed to carry a compartment load using the maximum weight of the unit load specified at that beam level.

##### 6.3.3.1.2 Systems controlled by a warehouse management system

The warehouse management system (WMS) shall (as a minimum) be capable of:

- allocating the location of a pallet;
- rejecting any pallet in excess of the specified maximum weight;
- controlling the total weight of pallets in a bay excluding those pallets on the floor;
- controlling the total weight of pallets in a run (Run load) excluding those pallets on the floor.

Each part of the upright shall be designed for the load carried by that part, in accordance with the WMS. The load on each upright should be determined as shown in Figure 4.

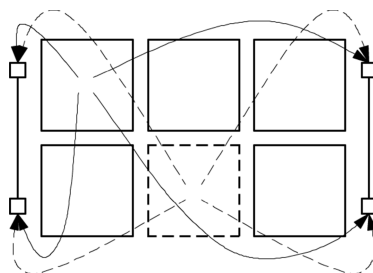


**Figure 4 — Allocation of the pallet weight to upright (example shows double deep pallet racking)**

Down-aisle global stability shall be based on the run load.

The fraction of the weight of each pallet is apportioned to each upright in the bay (this is shown for two of the 6 pallets in Figure 4 with the solid and dotted lines). The warehouse management system does not need to consider continuity effects of beams, but this should be considered in the rack design, if any. From this the load in the upright can be determined.

### 6.3.3.1.3 Systems with random storage

The following conditions shall be met for random storage:

- Location of the pallets in the rack shall be random. This clause shall not be used if unit loads are grouped.
- The maximum and average unit load shall be known at all times.
- A minimum of 5 000 pallets are being stored in the racking system concerned.

The requirement that unit loads shall not be grouped should be taken to mean that a particular type, or weight, of unit load is not placed with others of the same type and allocated to a particular compartment or bay but is randomly distributed throughout the run of racking.

In the following  $W_n$  is the load to be used for the design of the frame/upright or run as appropriate.

For  $n > N_{\min}$

$$W_n = m \times \ln(n) + c$$

where

$$m = \frac{W_{\max} - W_{\text{average}}}{\ln(N_{\min}) - \ln(N_{\max})}$$

$$c = W_{\text{average}} - m \ln(N_{\max})$$

$W_{\max}$  is the max unit load weight, as defined by the specifier;

$W_{\text{average}}$  is the average unit load weight, as defined by the specifier;

$N_{\min}$  is the number of unit loads per compartment – this is the basis for  $W_{\max}$ ;

$N_{\max}$  is the total number of unit loads in the racking system – this is the basis for  $W_{\text{average}}$ ;

$n$  is the number of unit loads under consideration

Cross-aisle stability and frame/upright design shall be based on the value of  $W_n$  determined where  $n$  = number of unit loads supported by the upright frame.

Down-aisle global stability shall be based on the value of  $W_n$  determined where  $n$  = number of unit loads in a run.

An example is given in Annex J.

NOTE The above procedure is in line with the SSRG 237 [21].

### 6.3.3.2 Unit load placement tolerance in the cross-aisle direction

If the system is designed such that unit loads are placed non-symmetrically then this shall be taken into account in the design of the rack, see also Annex K.

If the placement imperfection is random the increase of stress and deformation may be ignored if it does not exceed 12 % compared to the situation with the beam loaded symmetrically. When the increase is more than 12 % this effect shall be taken into account in the beam design as follows:

$$Q' = \eta Q$$

where

|                               |                        |
|-------------------------------|------------------------|
| if $\rho \leq 1,12$           | $\eta = 1$             |
| if $1,12 \leq \rho \leq 1,24$ | $\eta = 2 \rho - 1,24$ |
| if $\rho \geq 1,24$           | $\eta = \rho$          |

where

$$\rho = Q_e / Q;$$

$Q$  is the load on the beam where the pallet is placed in the planned position;

$Q_e$  is the load on the beam when the pallet is placed with the maximum misalignment.

### 6.3.3.3 Vertical placement loads

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

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

### 6.3.3.4 Horizontal placement loads

#### 6.3.3.4.1 General

Horizontal placement loads 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. The load need not be applied at more than one level simultaneously.

#### 6.3.3.4.2 Placement load

The minimum horizontal placement load  $Q_{ph}$  shall be determined as follows;

- a) Where goods are placed with manually operated mechanical equipment (e.g. forklift trucks).
  - 1) For beam levels up to 3 m  $Q_{ph}$  shall be at least 0,5 kN.
  - 2) For beam levels above 6 m  $Q_{ph}$  shall be at least 0,25 kN.
  - 3) For beam levels between 3 m and 6 m the value of  $Q_{ph}$  at each beam level shall be interpolated based on the boundary values above.
- 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.

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

#### 6.3.3.4.3 Application of the horizontal placement load in the down-aisle direction

A total load of  $2 \times Q_{ph}$  (where  $Q_{ph}$  is calculated at top beam level) distributed uniformly over all beam levels may be used to replace the concentrated load  $Q_{ph}$ .

NOTE In the down-aisle direction, the horizontal placement load arises at the beam levels and amplifies the down-aisle sway caused by frame imperfections. Replacing the concentrated loads with a uniformly distributed load avoids creating unnecessary load cases.

#### 6.3.3.4.4 Application of the horizontal placement load in the cross-aisle direction

In the cross-aisle direction the placement load shall be considered at the following locations;

- a) The top of the upright frame.
- b) Midway between two bracing nodes of the upright frame lattice.

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  $Q_{ph}\ell/6$ .

- c) The mid-span of a beam in the horizontal plane. This case need not be incorporated in the global cross-aisle analysis and a load of  $0,5 \times Q_{ph}$  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  $Q_{ph}$ .

#### 6.3.3.5 Backstop load

Where back stops are used the specifier shall define the load  $Q_{bh}$  and whether the back stop is a safety back stop or buffering back stop (as defined in EN 15629).

- Buffering back stops and pick and deposit stations with positioning devices shall be considered to give rise to variable actions.
- Safety back stops shall be considered to give rise to accidental actions.

For manually operated mechanical equipment:

$$Q_{bh} \geq 0,25 Q_u$$

where

$Q_u$  is the weight of unit load, or multiple loads placed simultaneously.

For automated systems back stops shall be designed for the greater of the quasi-static horizontal force due to the kinetic energy resulting from a malfunction of the S/R machine or  $0,25 Q_u$ .

NOTE 1 A procedure on how to design back stops is given in FEM 9.842-1 / FEM 10.2.11-1 [15].

NOTE 2 Buffering back stops 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.

NOTE 3 Safety back stops might be specified for automated systems (crane racking) to fulfil the requirements of EN 528 (see [9]).

$Q_{bh}$  shall only be taken into account when designing the following rack components in the direct vicinity of the back stop. These effects are all local:

- 1) The back stop device itself.

- 2) The connection of the back stop with the rack component concerned (beam or upright).
- 3) The part of the upright, or beam, to which the back stop is directly connected.
- 4) The upright frame bracing in the direct vicinity of this upright part.

For buffering back stops  $Q_{bh}$  shall be taken into account also for global effects, see 9.2.3.5.

#### 6.3.3.6 Effects of rack-guided equipment

The crane supplier shall provide loads applied by the crane to the rack:

- When picking and depositing.
- When moving.
- When travelling around curves (if applicable).
- When parked (the reduction factor given in Table 1 cannot be applied to this load situation).
- Horizontal buffer loads (if any).

The position at which the loads are applied shall be given.

**Table 1 — Total horizontal actions at guide rail level**

| Number of cranes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | $Q_{h,t}$                  |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| 1 or 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | $\Sigma Q_h$               |
| 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | $0,85 \Sigma Q_h$          |
| 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | $0,7 \Sigma Q_h$           |
| 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | $0,6 \Sigma Q_h$           |
| $\geq 6$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | $0,5 \Sigma Q_h \leq 5Q_h$ |
| <p>Key</p> <p><math>Q_h</math> is maximum specified lateral support load per crane.</p> <p><math>Q_{h,t}</math> is reduced sum (<math>\Sigma</math>) of <math>Q_h</math>-forces acting at the crane top guide rail, which is connected to a member joining all the upright frames together as shown in Figure 5.</p> <p>NOTE 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 each aisle simultaneously decreases as the number of crane aisles increases.</p> |                            |

Values in table are for ULS.

NOTE For SLS see FEM 9.831-1 [12] and FEM 9.832 [13].

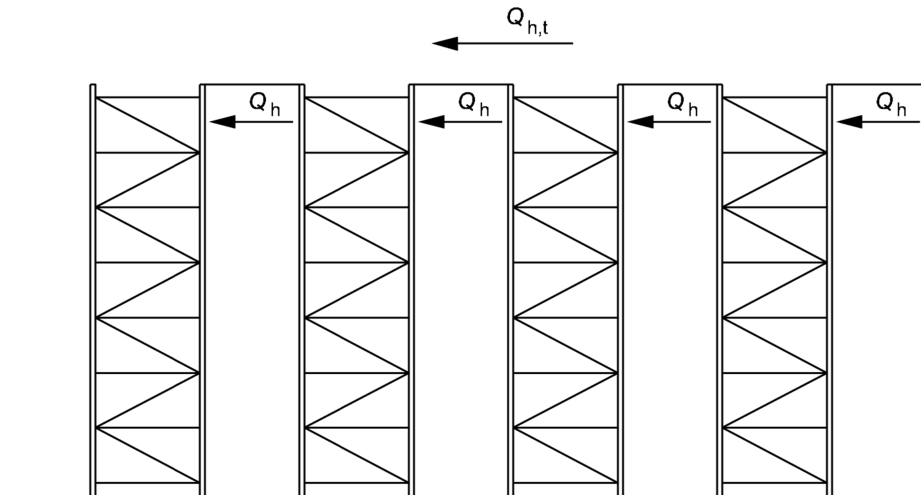


**Figure 5 — Horizontal loads from rack-guided equipment**

$Q_{h,t}$  shall be evaluated for the most unfavourable position of the cranes.

#### 6.3.3.7 Floor and walkway loads

The following minimum distributed or concentrated loads, whichever is most critical, shall be used in the design of floors or walkways unless specified otherwise by the specifier and indicated on the load notice.

NOTE 1 National regulations may require other/higher loads.

NOTE 2 See [12].

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

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

$Q_f = 2,0 \text{ kN}$  (concentrated load applied over a square  $100 \text{ mm} \times 100 \text{ mm}$ )

The above loads represent the 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

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

$Q_f = 2,0 \text{ kN}$  (concentrated load applied over a square  $100 \text{ mm} \times 100 \text{ mm}$ )

- c) Maintenance floors

$q = 2,0 \text{ kN/m}^2$

$Q_f = 1,5 \text{ kN}$  concentrated load applied in the most unfavourable position over an area of  $200 \text{ mm} \times 200 \text{ mm}$  of the floor

- d) On stairs narrower or equal to 1,2 m

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

$Q_f = 2,0 \text{ kN}$  (concentrated load applied over a square  $100 \text{ mm} \times 100 \text{ mm}$ )

e) On stairs wider than  $1,2 \text{ m}$

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

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

f) 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 EN 1991-1-1:2002, 6.3. The relevant static forces shall be multiplied by the dynamic factors given in Table 2 in order to differentiate between the effective vertical wheel loads of the different types of trucks.

**Table 2 — Dynamic factors for types of moving equipment**

|   | Type of moving equipment                                             | Dynamic factor |
|---|----------------------------------------------------------------------|----------------|
| 1 | Pedestrian controlled truck with velocity less than $5 \text{ km/h}$ | 1,2            |
| 2 | Ride on truck with a velocity less than $7,5 \text{ km/h}$           | 1,4            |
| 3 | Ride on truck with a velocity less than $10 \text{ km/h}$            | 2,0            |

The concentrated load shall be placed in the most unfavourable position and the configuration shall be provided by the specifier.

Pattern loading on floors and walkways need not be considered for the design of floor decking.

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.

#### 6.3.3.8 Handrail loads

Handrail loads may fall under National building regulations which may require different values for loads. However, the following minimum horizontal loads shall apply:

- Maintenance  $0,3 \text{ kN/m}$
- Any other (excluding Public access)  $0,5 \text{ kN/m}$

#### 6.3.3.9 Actions arising from installation and maintenance

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. After such an event the members affected need to be inspected. In the event of damage the member(s) shall be replaced.

If it is intended that the installers are supported by the racking structure then the rack shall be designed for the loads imposed.

#### 6.3.3.10 Wind loads

Wind loads shall be determined according to the relevant National Regulations. Wind effects during the construction phase shall be taken into account.

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.

NOTE If shielding effects of buildings are allowed by the wind code, then they can be applied to rack.

#### **6.3.3.11 Snow loads**

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

### **6.3.4 Accidental actions**

#### **6.3.4.1 General**

The live loads and placement loads specified in 6.3.3 shall be assumed to include adequate allowance for ordinary impact conditions.

#### **6.3.4.2 Seismic actions**

Where required, seismic actions shall be determined according to EN 16681 in conjunction with the relevant National Regulations.

#### **6.3.4.3 Accidental upward 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.

- 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)

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

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

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

where

$Q_u$  is the weight of unit load

The requirements for upward placement loads shall be verified by calculation or by testing according to A.3.3.

#### **6.3.4.4 Accidental horizontal load**

##### **6.3.4.4.1 General**

Impact damage caused by fork-lift trucks or other moving equipment against rack-uprights shall be avoided by appropriate operator training and safety measures.

##### **6.3.4.4.2 Unprotected uprights**

If the upright is not protected an accidental load 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 0,3 m height on the aisle side upright:

$A_{ph} = 2,5$  kN in the cross-aisle front to back direction.

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

These loads shall be treated as occurring separately.

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

Accidental horizontal load can be ignored unless provided by the specifier.

#### 6.3.4.4.3 Protected uprights

If protectors are connected to the rack then the rack shall be designed for the impact forces specified by the specifier.

NOTE Recommendations for the design of rack protectors are given in FEM 10.2.16 [19].

For industrial trucks with the layout, clearances and operation in accordance with EN 15620 and EN 15635 the accidental actions from fork lift trucks given in EN 1991-1-7 need not be applied.

### 6.4 Combination of actions

#### 6.4.1 General

- 1) Weight of unit loads and global rack imperfections shall together constitute a single action.
- 2) Placement loads shall constitute a separate action.
- 3) Accidental and placement loads need not be applied simultaneously.
- 4) Global imperfections according to 9.3.2 and horizontal placement loads according to 6.3.3.4 shall be combined in one direction at a time. The combination of global imperfections or horizontal placement loads in one direction with global imperfections or horizontal placement loads in the other orthogonal direction need not be considered.
- 5) Placement loads need not be considered at the serviceability limit state.

#### 6.4.2 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

$$\sum \gamma_G G_k + \gamma_Q Q_{k,1}$$

- considering all unfavourable variable actions which can occur simultaneously

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

- design for accidental load

$$\sum \gamma_A G_k + \sum_{i \geq 1} \gamma_A Q_{k,i} + \gamma_A A_k$$

where

$G_k$  is the characteristic value of permanent action (dead load);

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

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

$A_k$  is the characteristic value of an accidental load;

$\gamma_G$  is the partial factor for permanent loads;

$\gamma_Q$  is the partial factor for variable loads;

$\gamma_A$  is the partial factor for accidental loads.

### 6.4.3 Serviceability limit states

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

- considering only the most unfavourable variable action

$$\sum G_k + Q_{k,1}$$

- considering all unfavourable variable actions

$$\sum G_k + 0,9 \sum_{i \geq 1} Q_{k,i}$$

where the notation is defined in 6.4.2.

## 6.5 Partial factors

### 6.5.1 Load factors

The load factors  $\gamma_f$  given in Table 3 are minimum values and shall be applied independently of the design life.

NOTE National regulations may require higher load factors. Refer to Annex N for National A-deviations.

Table 3 — Load factors  $\gamma_f$ 

| Actions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Ultimate limit state    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | RC2                     |
| Permanent loads $\gamma_G$                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                         |
| with unfavourable effect                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 1,3                     |
| with favourable effect                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 1,0                     |
| imposed slab deformation unfavourable effect                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 1,3                     |
| imposed slab deformation favourable effect                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0,0                     |
| Variable loads $\gamma_Q$                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                         |
| unit loads                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 1,4                     |
| unit loads in crane operated systems                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 1,4 or 1,3 <sup>a</sup> |
| placement loads                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 1,4                     |
| other variable loads                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 1,5                     |
| Accidental loads                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                         |
| $\gamma_A$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 1,0                     |
| <p><sup>a</sup> Applicable for a crane-operated warehousing system including the weighing (see [14]) 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 for a global analysis. For beam design a load factor of at least 1,4 shall be applied.</p> <p>NOTE These factors are based on Reliability Class 2, other Reliability Classes can be used as appropriate, see EN 1990.</p> |                         |

### 6.5.2 Material factors

The material factors  $\gamma_M$  given in Table 4 are recommended values.

Table 4 — Material factors  $\gamma_M$ 

| Resistance                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Ultimate limit state |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | RC2                  |
| Resistance of cross-sections whatever the class is $\gamma_{M0}$                                                                                                                                                                                                                                                                                                                                                                                                       | 1,1                  |
| Resistance of members to instability assessed by member checks $\gamma_{M1}$                                                                                                                                                                                                                                                                                                                                                                                           | 1,1                  |
| Resistance of connections $\gamma_{M2}$                                                                                                                                                                                                                                                                                                                                                                                                                                | 1,25                 |
| Resistance of connections subject to testing and quality control (e.g. beam end connectors) see Annex M $\gamma_{M2}$                                                                                                                                                                                                                                                                                                                                                  | 1,1                  |
| <p>NOTE 1 The material factors <math>\gamma_{M0}</math> and <math>\gamma_{M1}</math> are derived from a reliability study [20] in combination with the load factors of Table 3 in accordance with EN 1990.</p> <p>NOTE 2 These factors are based on Reliability Class 2, other Reliability Classes can be used as appropriate, see EN 1990.</p> <p>NOTE 3 National regulations may require different material factors. Refer to Annex N for National A-deviations.</p> |                      |

## 7 Materials

### 7.1 Steel

#### 7.1.1 General

The nominal values of material properties given in this subclause 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.

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

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 of EN 1993-1-1:2005, Table 3.1 and EN 1993-1-3:2006, 3.1;
- 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 2 The minimum ratio in 7.1.1 differs from that specified in EN 1993-1-1 but is acceptable for racking products. See Annex I.

NOTE 3 National regulations may limit the use of other steels.

#### 7.1.2 Material properties

##### 7.1.2.1 General

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 7.1.4;
- using the testing regime specified in 7.1.3.

##### 7.1.2.2 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                           | $G = \frac{E}{2(1 + \nu)} \text{ N/mm}^2$                |
| Poisson's Ratio                         | $\nu = 0,3$                                              |
| Coefficient of linear thermal expansion | $\alpha = 12 \times 10^{-6} \text{ per } ^\circ\text{C}$ |
| Density                                 | $\rho = 7\,850 \text{ kg/m}^3$                           |

### 7.1.3 Steels with no guaranteed mechanical properties

#### 7.1.3.1 General

Steels with no guaranteed mechanical properties are:

- materials whose minimum values of the yield and tensile strength are not defined or guaranteed by the product standard (i.e. mild steel for cold-forming);
- materials with mechanical properties improved by reworking (i.e. cold-reduced steels);
- materials used considering guaranteed mechanical properties higher than those defined by the reference product Standard.

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.

#### 7.1.3.2 Additional tests on steel

The mechanical properties of basic materials shall be measured from tensile tests according to 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 strength higher than the guaranteed value;
- c) to demonstrate adequate ductility.

The minimum frequency of testing shall be one test from each 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 13.3.2, 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 7.1.4 for untested steels shall be used.

#### 7.1.4 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/mm <sup>2</sup> |
| Other steels        | 140 N/mm <sup>2</sup> |

#### 7.1.5 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.

### 7.1.6 Special selection of production material

A batch of material specially selected for a particular application can be used considering its actual mechanical properties determined by tests according to EN 1993-1-3:2006, 3.2.1(2); the nominal values of the yield and tensile strength considered for the design shall not exceed 90 % of the values obtained from the tests.

This procedure shall not be applied to materials for testing component in accordance with Annex A.

### 7.1.7 Fracture toughness

The material shall have sufficient fracture toughness to avoid brittle fracture at the lowest service temperature expected to occur during the intended life of the structure.

Brittle fracture of the material with thickness not greater than 5 mm in accordance to this standard need not to be considered for cold-rolled section (punched or unpunched) manufactured from continuously hot-dipped steel (e.g. sendzimir) at temperature higher than  $-30\text{ }^{\circ}\text{C}$  and for non hot-dipped steel at temperature higher than  $-50\text{ }^{\circ}\text{C}$ .

For untested steels covered by 7.1.4 the 5 mm thickness limit given above shall be reduced to 2 mm.

Material with J2 quality according to EN 10025, or grade MC according to EN 10149 are suitable under the conditions specified above.

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

### 7.1.8 Dimensional tolerances

#### 7.1.8.1 General

For the dimensional tolerances of cold-formed members reference is made to EN 1090-4.

#### 7.1.8.2 Tolerances on thickness

The provisions for design by calculation given in EN 1993-1-3 may be used for steel within given ranges of core thickness  $t_{\text{cor}}$ .

The ranges of core thickness  $t_{\text{cor}}$  for sheeting and members may be given in the National Annex. The following values are recommended:

- for sheeting and members:  $0,45\text{ mm} \leq t_{\text{cor}} \leq 15\text{ mm}$ ;
- for connections:  $0,45\text{ mm} \leq t_{\text{cor}} \leq 4\text{ mm}$ , see EN 1993-1-3, 8.1 (2).

Thicker or thinner material may also be used, provided that the load bearing resistance is determined by design assisted by testing.

The steel core thickness  $t_{\text{cor}}$  should be used as design thickness, where

$t = t_{\text{cor}}$  if tolerance  $\leq 5\text{ }%$

$t = t_{\text{cor}} (100 - \text{tolerance}) / 95$  if tolerance  $> 5\text{ }%$

with  $t_{\text{cor}} = t_{\text{nom}} - t_{\text{metallic coating}}$

where tolerance is the minus tolerance in %.

NOTE For the usual Z 275 zinc coating  $t_{\text{zinc}} = 0,04\text{ mm}$ .

For continuously hot-dip metal coated members and sheeting supplied with negative tolerances less or equal to the “special tolerances (S)” given in EN 10143, the design thickness (1) may be used.

If the negative tolerance is beyond “special tolerance (S)” given in EN 10143 then the design thickness according to (2) may be used.

$t_{nom}$  is the nominal sheet thickness after cold forming. It may be taken as the value  $t_{nom}$  of the original sheet, if the calculative cross-sectional areas before and after cold forming do not differ more than 2 %; otherwise the notional dimensions should be changed.

### 7.1.8.3 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.

## 7.2 Floor materials

### 7.2.1 Concrete floors

In the design of the base plate, the design resistance of the concrete or grout under local compressive stress shall be determined according to EN 1993-1-8:2005, 6.2.5 or using the following simplified approach:

$$f_{jd} = \beta_j \frac{f_{ck}}{\gamma_c}$$

where

$\beta_j$  = 2/3 is the foundation joint material coefficient;

$f_{ck}$  is the characteristic compressive cylinder strength for concrete;

$\gamma_c$  is the partial material factor for concrete = 1,5.

When the grade of concrete is not known, and a visual inspection indicates that the material is suitable the concrete may be assumed to be in strength class 20/25 according to EN 1992 for which:

$$f_{ck} = 20 \text{ N/mm}^2$$

Alternatively tests may be carried out to determine the actual strength of the concrete.

### 7.2.2 Bituminous floors

See Annex O.

### 7.2.3 Other floor materials

In the case of floors which are neither bituminous nor made from concrete, the advice of the supplier of the floor material, concerning its bearing strength, shall be sought. In assessing the characteristic strength of the material, due consideration should be given to the possibility of creep occurring and to the influence of temperature on the behaviour of the material. Attention should be given not only to the surface layers, but also to any sub layers of the floor whose performance can influence the behaviour of the base plate.

## 8 Durability

In order to ensure the durability of the structure under conditions relevant to both its intended use and intended life the following factors shall be considered at the design stage:

- a) environment;
- b) degree of exposure;

- c) shape of the members and the structural detailing;
- d) whether maintenance of protective coatings can be carried out.

Where different materials are connected together, corrosion due to the contact of unlike metals shall be prevented.

**NOTE** Normal protective coatings can be expected to give at least ten years life to first maintenance in dry internal conditions unless there is damage as a result of collision or misuse. External or corrosive conditions require special treatment.

## 9 Structural analysis

### 9.1 Structural modelling for analysis

#### 9.1.1 Structural modelling for analysis and basic assumption

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.

The method used for the analysis shall be consistent with the design assumptions.

#### 9.1.2 Joint modelling

##### 9.1.2.1 General

The behaviour of joints shall be taken into account.

- 1) If it can be shown that a splice has rotational stiffness, moment capacity and strength equal or greater than that of the weaker upright in the joint, its effects may be ignored in global analysis.
- 2) Looseness of the beam to upright connection and frame bracing connections shall be included in the characteristics of the joint or alternatively as additional imperfection.
- 3) Nonlinear connection behaviour in the analysis may be used provided that the nonlinear characteristic used is based on test results which demonstrate adequate rotation capacity. Alternatively, elastic-plastic analysis may be used if the sections undergoing plastic hinge action satisfy the criteria given in EN 1993-1-1 and EN 1993-1-3 for plastic design including the ductility requirements specified in these standards.
- 4) If the model shown in Figure 10 or Figure 11 is used, the bending moments at the beam end connectors and at the ends of the beams may be corrected to allow for the finite width of the uprights. Alternatively over half the width of the upright a rigid element may be included.

##### 9.1.2.2 Moment-rotation characteristics of beam end connectors

The moment-rotation characteristics of the beam to upright connections shall be determined as design values of stiffness and moment of resistance by test according to A.3.1.

##### 9.1.2.3 Moment-rotation characteristics of the connection to the floor

The stiffness of the upright to floor connection may be assumed as a pinned joint.

In the down-aisle direction, provided that the rack is loaded to at least 50 % of its capacity the stiffness of the upright to floor connection of a flat-ended upright may be assumed to be  $\frac{EI_{eq}}{h}$  per radian.

where

$EI_{eq}$  is the flexural rigidity of the upright in the down-aisle direction;

$h$  is the height to the first beam level with a minimum value of 1 m.

NOTE This is a conservative value based on manufacturer's tests over many years.

If a higher value of the stiffness of the floor to upright connection is used in the analysis, it shall be determined by test according to A.3.5.

#### 9.1.2.4 Bracing eccentricities

Eccentricities between system lines shall be taken into account unless the following conditions are fulfilled:

- a) The intersection point of the centre lines of a horizontal member and a diagonal or adjacent diagonals is not greater than a vertical dimension 'e' specified on Figure 6a) for down-aisle and Figure 6b) for cross-aisle.
- b) The eccentricity ' $c_1$ ' is not greater than 2,0 times the upright width and ' $c_2$ ' is not greater than 1,5 times the upright depth as shown in Figure 6 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.

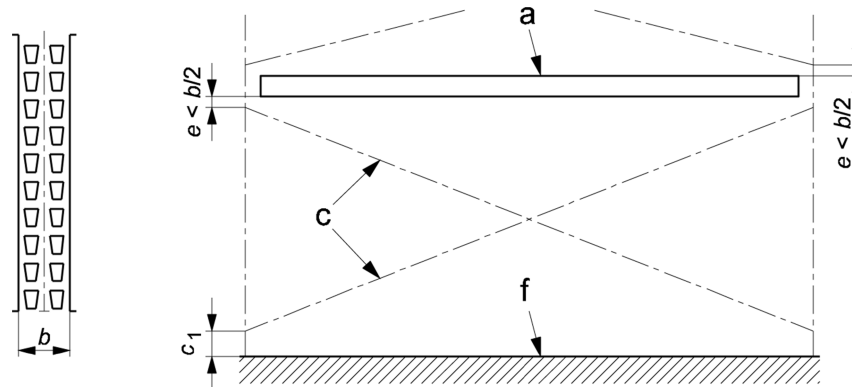
NOTE It is good practice for the angle of inclination of the diagonal from the horizontal to lie between 20° and 70°.

For seismic, wind and buffering back stops actions the effect of the eccentricities in excess of 5 % shall be considered.

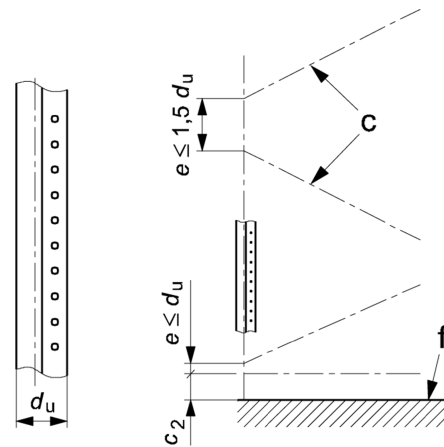
As a conservative approach, the limit of 5 % may be assessed as  $M_{Ed}/M_{Rd}$ . See for guidance [20].

$M_{Ed}$  is local bending moment due to eccentricity.

$M_{Rd}$  is moment capacity of the upright.



a) Eccentricities in spine bracing



b) Eccentricities in frame bracing

**Key**

- a horizontal member (e.g. pallet beam)
- b width of upright
- c system lines
- e (for 6a) distance from bracing node to top or bottom of beam
- f Floor
- $c_1$  distance from floor to lower spine bracing node point
- $d_u$  depth of upright
- e (for 6b) eccentricity between bracings
- $c_2$  distance from floor to lower bracing node point

**Figure 6 — Eccentricities**

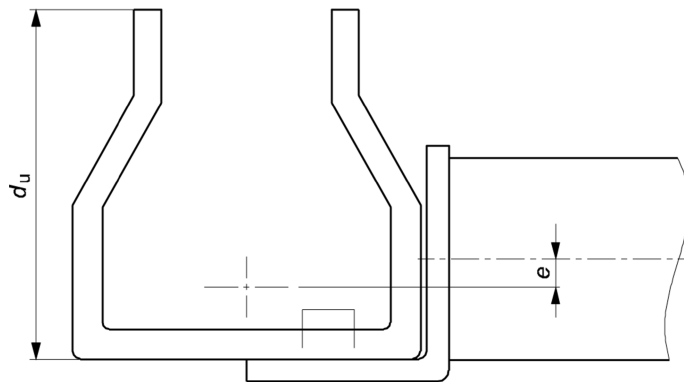
### 9.1.2.5 Beam to upright eccentricities

The effect of eccentricity 'e' in Figure 7 in excess of 5 % shall be considered.

As a conservative approach, the limit of 5 % may be assessed as  $M_{Ed}/M_{Rd}$ . See for guidance [20].

$M_{Ed}$  is local bending moment due to eccentricity.

$M_{Rd}$  is moment capacity of the upright.



#### Key

$d_u$  depth of upright

e Eccentricity

**Figure 7 — Eccentricity in the cross-aisle direction**

### 9.1.3 Ground-structure interaction

#### 9.1.3.1 General

The deformation properties of the floor shall be considered in the rack design subject to the provisions given in 9.1.3.3 and 9.1.3.4.

The rack supplier shall provide the reactions applied to the floor.

NOTE 1 The floor slab is the foundation to the racking and EN 15629 gives guidance to the specifier.

NOTE 2 Deformation of the floor slab can be due to a number of sources such as, applied rack load, mechanical handling equipment load.

NOTE 3 The floor rotation ( $\phi_{Floor}$ ) as defined in Table 5 is considered in the safety philosophy. Therefore the excess needs to be considered only.

NOTE 4 With regard to the interface between racking and the supporting warehouse floor, guidance is given by [16], [17] and [18].

#### 9.1.3.2 Floor slab parameters

Unless specified otherwise the following may be assumed by the rack designer

- Concrete grade at least C20/25.
- The slab satisfies the limitations of 9.1.3.3.
- The thickness of the structural floor (excluding any screed) complies with the thickness assumed in the design of the anchoring e.g. uprights, upright protectors, bracing system etc.

— There are no movement joints.

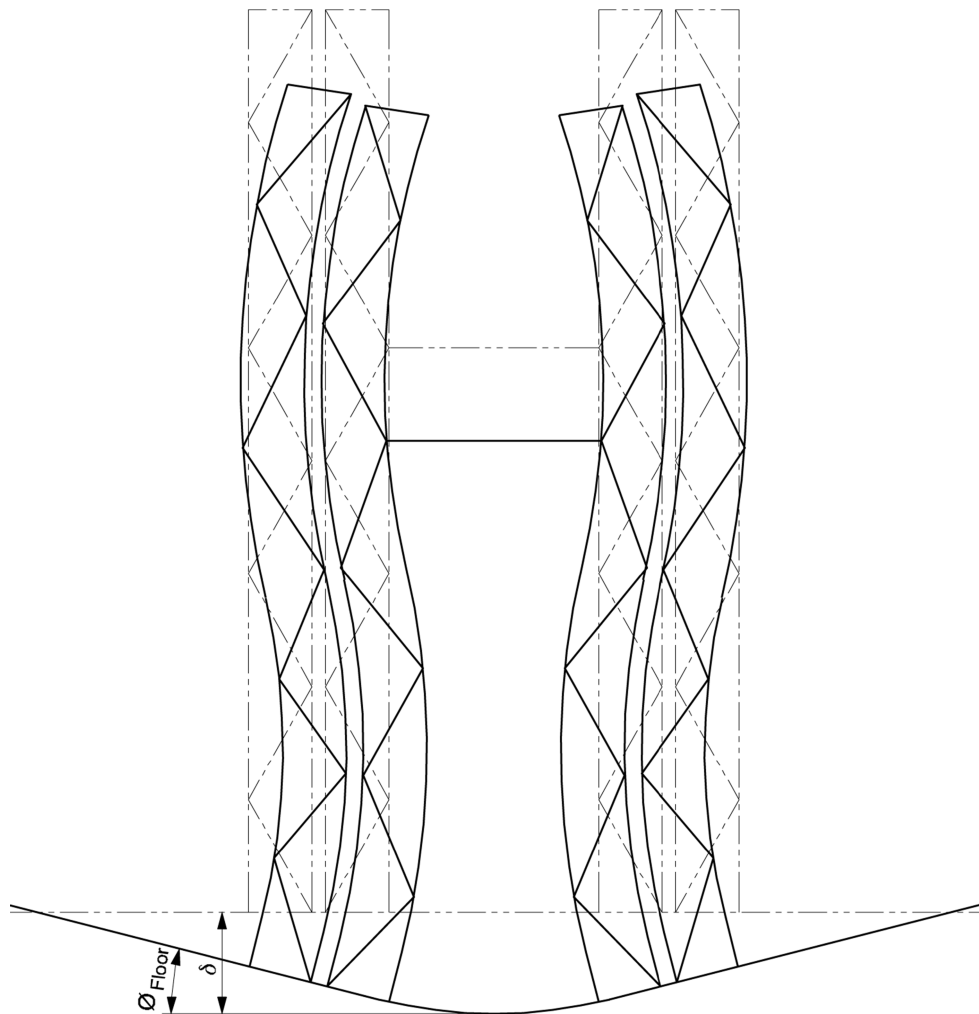
### 9.1.3.3 Slab deformation limits bolted frames

If the rotation of the floor slab ( $\phi_{\text{Floor}}$ ) is less than the limit given in Table 5 then the floor slab may be considered to provide a rigid foundation and, for the purposes of rack design, no consideration of floor slab deformation is required.

If the floor slab deformation exceeds the limit only the deformation in excess of the limit need to be considered.

**Table 5 — Floor deformation limits for quasi-rigid assumption**

| Specified Installation Out-of-plumb                                                                                                                                                                                                                                                                                                         | Limiting rotation $\phi_{\text{Floor}}$ in serviceability limit state (see Figure 8) |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| 1 / 350                                                                                                                                                                                                                                                                                                                                     | 1 / 700                                                                              |
| 1 / 500                                                                                                                                                                                                                                                                                                                                     | 1 / 1 000                                                                            |
| 1 / 750                                                                                                                                                                                                                                                                                                                                     | 1 / 1 500                                                                            |
| 1 / 1 000                                                                                                                                                                                                                                                                                                                                   | 1 / 2 000                                                                            |
| <p><b>NOTE 1</b> 1/350 out of plumb is related to class 400, 1/500 and 1/750 for class 300 and 1/1000 for class 100 and class 200, for additional information see EN 15620.</p> <p><b>NOTE 2</b> Class 400 refers to "wide aisle &amp; narrow aisle racking" and class 300 refers to "very narrow aisle racking" according to EN 15620.</p> |                                                                                      |

**Key**

|                |                 |
|----------------|-----------------|
| $\phi_{Floor}$ | slab rotation   |
| $\delta$       | slab deflection |

**Figure 8 — Example of the inter-relationship between floor slab and rack deflection**

#### 9.1.3.4 Slab deformation limits welded frames

For all welded rack frames the slab deformation exceeding  $\phi_{Floor} = 1/2\ 000$  shall be taken into account in the design.

#### 9.1.3.5 Inclusion of floor deformations in the analysis

One of the following methods shall be chosen.

**Method 1:** The rack and slab are modelled together.

**Method 2:** An iterative approach in cooperation with the floor slab designer. In this approach the deformation of the floor slab at the upright feet is included in the analysis and the reactions applied by the rack to the floor slab are calculated. The floor slab designer re-calculates the slab deflections. The design of the rack is repeated with the new deflections. This process is repeated until the difference between successive deflections is less than 5 % at which point the design can be taken to have converged.

**Method 3:** If the frames are not connected together in the cross-aisle direction (for example by top-tie beams or rack supported floors, see Figure 8) the cross-aisle analysis may be carried out with the out-of-plumb of the upright frames induced by the floor slab rotation being added to the out-of-plumb given in 9.3.2.

If the location of the rack on the slab is known then the analysis should be based on this known location. Otherwise the worst position of the rack with respect to the deformed slab should be considered, see Figure 9.

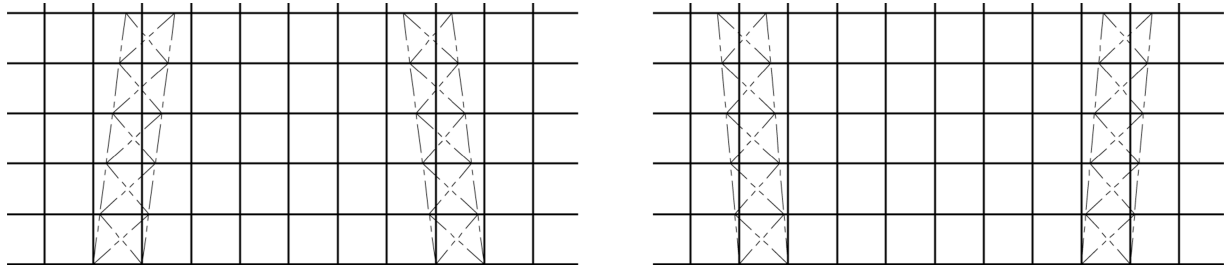


**Figure 9 — Mirrored imposed floor rotation**

#### 9.1.4 Racks braced against the building structure

If racks are braced against the building structure a mutual design of building and rack structure shall be carried out. The two structures will impose forces upon each other and these interaction forces depend on the lateral stiffness of both the rack and building.

### 9.2 Global analysis

#### 9.2.1 Effects of deformed geometry of the structure

The effects of the deformed geometry (second-order effects) should be considered if they increase the action effects significantly or modify significantly the structural behaviour.

Classification of the structure is based on the elastic critical load ratio for global buckling in each

relevant direction:  $\alpha_{cr} = \frac{V_{cr}}{V_{Ed}}$

where

$\alpha_{cr}$  is the factor by which the design loading would have to be increased to cause elastic instability in a global mode;

$V_{cr}$  is the elastic critical buckling load for global instability mode based on initial elastic stiffness's;

$V_{Ed}$  is the design loading on the structure.

Methods of estimating  $V_{cr}$  with sufficient accuracy for classification is given in Annex B.

An overview of allowed methods of analysis based upon classification is given in Table 6.

If  $\alpha_{cr} \geq 10$  the second order effects can be neglected. Method of analysis 0a and 1a may be used (first order linear analysis).

**NOTE 1** If  $\alpha_{cr} \geq 10$  the frame may be classified as non-sway, i.e. its response to in-plane horizontal forces is sufficiently stiff for it to be acceptably accurate to neglect any additional internal forces or moments arising from horizontal displacement of the nodes.

If  $3,333 \geq \alpha_{cr} > 10$  second-order effects may be treated indirectly. Method of analysis 0b and 1b may be used.

If  $\alpha_{cr} < 3,333$  second-order effects shall be treated directly in the analysis. Method of analysis 2 shall be used.

**NOTE 2** The limit at which a second-order analysis becomes mandatory is more generous than that in EN 1993-1-1. This is because pallet racks are industrially produced to higher tolerances than normal construction work, have semi-rigid joints and generally have a regular construction. In these circumstances, the agreement between the exact and approximate methods is much improved so that the range of validity of the approximate methods may be increased.

**NOTE 3** Un-braced racks are generally classified as sway frames in the down-aisle direction and therefore require consideration of second-order effects.

## 9.2.2 Method of analysis

### 9.2.2.1 General

Depending on the classification of 9.2.1 a method of analysis of Table 6 shall be adopted for a 2D or 3D analysis.

**NOTE** It is acceptable to use more advanced methods of analysis such as those in EN 1993-1-1.

**Table 6 — Method of analysis**

| Method of analysis                   |                                      | Material behaviour   | Geometric behaviour            | Global imperfections according to 9.3.2 | Initial bow imperfection according to EN 1993-1-1 / EN 1993-1-3 | Member check                                          |
|--------------------------------------|--------------------------------------|----------------------|--------------------------------|-----------------------------------------|-----------------------------------------------------------------|-------------------------------------------------------|
| 0a                                   | Approximate                          | Linear               | first order                    | ○                                       |                                                                 | according to 10                                       |
| 0b                                   |                                      |                      | first order with amplification | ○                                       |                                                                 | according to 10                                       |
| 1a                                   | Finite Element Analysis <sup>a</sup> | Linear               | first order                    | ○                                       |                                                                 | according to 10                                       |
| 1b                                   |                                      |                      | first order with amplification | ○                                       |                                                                 | according to 10                                       |
| 2a                                   |                                      | Linear or non linear | second order                   | ○                                       |                                                                 | according to 10                                       |
| 2b                                   |                                      |                      |                                | ○                                       | ○                                                               | according to 10, $\chi$ needs to account for TFB only |
| <sup>a</sup> Without warping effect. |                                      |                      |                                |                                         |                                                                 |                                                       |

**A1**

For each method of analysis the effect of local bracing imperfections according to 9.3.3 shall be checked.

### 9.2.2.2 Method of analysis 0 – Approximate

The method of analysis shall be in accordance with Annex B and members checks in accordance with Table 6.

### 9.2.2.3 Method of analysis 1 – Linear Finite Element Analysis

The method of analysis shall be in accordance with Clause 9.

### 9.2.2.4 Method of analysis 2 – 2nd order Finite Element Analysis

The method of analysis shall be in accordance with Clause 9.

## 9.2.3 Structural stability of frames

### 9.2.3.1 General

The following shall be considered in modelling the structure:

- a) The characteristics of joints according to 9.1.2 shall be taken into account.
- b) Torsion and warping shall be considered in the global analysis and member checks when they affect the global stability of the structure or where they are required for equilibrium.

NOTE 1 For upright frame design the influence of torsion on the flexibility is incorporated in the frame shear stiffness test according to A.2.8.

- c) In considering imposed loads from stored materials, the worst loading pattern (fully loaded and pattern loaded) shall be considered for each of the following criteria:
  - 1) Overall stability in the down-aisle direction.
  - 2) Bending and buckling of the uprights.
  - 3) Beam deflections and beam mid-span bending moments.
  - 4) Moments in beam to upright connectors.

NOTE 2 For a regular rack layout, it is sufficient to consider the pattern load cases as defined in Annex P.

NOTE 3 First order analysis may be considered for the effect of pattern load cases, when those results are combined with the results of a second order analysis of the fully loaded condition.

- d) For the analysis of the frames in cross-aisle direction it is allowed to consider that all interconnected frames are fully loaded.
- e) The local bracing imperfections need not be combined with the imperfections for global analysis. The local bracing imperfection forces and moments may be derived by a first order calculation.
- f) For the purpose of global analysis, system lines coinciding with either the centroidal axes of the gross cross-section of the members, the equivalent cross-section or the reduced cross-section from which the properties are determined shall be applied.
- g) Although the pallet rack is a spatial structure, it may be assumed, for the purposes of global analysis, that it can be treated as comprising of a set of plane frames lying in the vertical planes, parallel and perpendicular to the aisles, and in the horizontal plane, each of which is initially taken to operate independently. Imperfections in one plane may be neglected when carrying out the global analysis of the other plane.
- h) In member design, account shall be taken of effects in one plane which impinge on the behaviour in another, using appropriate interaction equations.

- i) Equivalent section properties shall be used for global analysis.
- j) Equivalent section properties shall be used to determine the elastic critical loads.
- k) Imperfections according to 9.3.

#### **9.2.3.2 Un-braced racking systems**

If all of the bays have the same configuration, the lesser of either five bays or the actual number of bays may be used.

Typical mathematical models are shown in Figure 10.