



BSI Standards Publication

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

National foreword

This British Standard is the UK implementation of EN 16681:2016.

The UK committee abstained from voting on this standard as they are of the opinion that there are generally no requirements in the UK to consider seismic loading, and that the whole of the UK may be considered an area of very low seismicity in which the provisions of EN 16681 need not apply.

The role of racking structures is such that they reside in consequence classes CC1 or CC2. Exceptionally, however, certain racking structures may warrant an explicit consideration of seismic actions. Background information on application in the UK has been published in PD 6698:2009.

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

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

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

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Published by BSI Standards Limited 2016

ISBN 978 0 580 84027 2

ICS 53.080

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 August 2016.

Amendments/corrigenda issued since publication

Date	Text affected
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EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 16681

June 2016

ICS 53.080

English Version

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

Systèmes de stockage statique en acier - Systèmes de
rayonnages à tablettes ajustables - Principes pour le
calcul parasismique

Ortsfeste Regalsysteme aus Stahl - Verstellbare
Palettenregale - Leitsätze für die erdbebensichere
Gestaltung

This European Standard was approved by CEN on 7 April 2016.

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CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

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Ref. No. EN 16681:2016 E

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European foreword

This document (EN 16681:2016) 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 December 2016 and conflicting national standards shall be withdrawn at the latest by December 2016.

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

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0 Introduction

0.1 Effects of seismic actions on racking systems

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

Racking systems are constructed from steel components; although components are standardized, they are only standard to each manufacturer. These components differ from traditional steel components in the following regard:

- a) continuous perforated uprights;
- b) hook-in connections;
- c) structural components for racking, which generally consist of cold formed thin gauge members.

In respect of the loads, the self-weight of a rack structure is typically very small or negligible with respect to the total mass, whereas in a typical building the percentage of dead and permanent loads will be much greater.

The nature and the distribution of the goods stored on racking systems strongly affect the response and the safety of the structure under seismic actions. In fact:

- unit loads are in general simply supported vertically by the racking structure and kept in their position when loaded by inertial actions only by friction;
- unit loads are in general sub-structures with distinct dynamic characteristics in terms of frequency and damping, and their behaviour affect the response of the system.

During real earthquakes or earthquake simulated on shaking tables, movements of pallets on pallet beams were observed; these were either very small ones, contributing to the dissipation of energy by means of friction, or very large, with movements of the pallets that produced their falling between beams or outside the rack in the aisle. For this reason, friction between pallet and pallet beam and internal damping in the unit load has a relevant influence in the dynamic response of the rack and affects the entity of the inertial actions.

Also, the safety of the installation related to the movement and eventual falling of the pallets requires a proper assessment.

This European Standard deals with all the relevant and specific seismic design issues for racking systems, based on the criteria of EN 1998-1:2004, Eurocode 8.

0.2 Requirements for EN Standards for racking and shelving in addition to Eurocodes

While the basic technical description of an earthquake is the same for all structures, the general principles and technical requirements applicable for conventional steel structures have to be adapted for racking systems, in order to take into account the peculiarities of racking to achieve the requested safety level.

Also, the methods of analysis and the design requirements need to be addressed to the peculiarity of racking structures.

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

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

0.3 Liaison

CEN/TC 344 “Steel Static 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 Additional information specific to EN 16681

This European Standard is intended to be used with EN 1998-1, EN 15512 and related standards.

EN 1998-1 is the first of 6 parts; it gives design rules intended to be used for structures fabricated with conventional materials, including steel.

EN 15512 is the reference standard for the design of racking structures and components; it addresses the principles of the EN 1990, Eurocode, and EN 1993 series, Eurocode 3, to the adjustable pallet racking systems and it needs to be applied also when actions are produced by an earthquake.

1 Scope

This European Standard specifies the structural design requirements applicable to all types of adjustable pallet racking systems fabricated from steel members, intended for storage of unit loads and subject to seismic actions.

This European Standard gives also guidelines for the design of clad rack buildings in seismic zones, where requirements are not covered in the EN 1998 series.

This European Standard does not cover other generic types of storage structures. Specifically, this European Standard does not apply to mobile storage systems, drive-in, drive-through and cantilever racks or static steel shelving systems.

This European Standard does not apply to the design of seismic isolated racking structures.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.¹⁾

EN 1090-2, *Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures*

EN 1990 (all parts), *Eurocode - Basis of structural design*

EN 1993 (all parts), *Eurocode 3 - Design of steel structures*

EN 1998-1:2004²⁾, *Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings*

EN 15512:2009, *Steel static storage systems - Adjustable pallet racking systems - Principles for structural design*

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

EN 15629:2008, *Steel static storage systems - Specification of storage equipment*

EN 15635:2008, *Steel static storage systems - Application and maintenance of storage equipment*

EN 15878:2010, *Steel static storage systems - Terms and definitions*

ETAG 001 series, *Guideline for European technical approval of metal anchors for use in concrete*

1) Complementary rules to existing Norms specific for seismic applications are included in the following annexes:

- Annex I “Data to be exchanged between the Specifier/End User and the rack’s Supplier” as complement to EN 15629:2008
- Annex J “Complementary rules to EN 15635” as complement to EN 15635:2008
- Annex K “Complementary rules to EN 15629” as complement to EN 15629:2008

2) This document is impacted by the amendment EN 1998-1:2004/A1:2013.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 15878:2010 and EN 1998-1:2004 and the following apply.

3.1

associated mass

portion of the total mass of the structure affecting the seismic behaviour of the structural element or of the substructure analysed

3.2

mass regularity

in elevation: situation in which the mass of the individual load level remains constant or reduces gradually without abrupt changes from the base to the top of the rack

in plan: situation in which the mass is distributed without significant horizontal eccentricity with respect to the lateral resisting system

3.3

principal directions

down aisle direction and cross aisle direction in a rack

[SOURCE: EN 15878:2010, definitions 3.2.14 and 3.2.15, modified — the content of the defined term stems from these two original definitions]

3.4

PRSES

person responsible for storage equipment safety

[SOURCE: EN 15635:2008, 3.18]

3.5

rack filling grade reduction factor

R_F

statistical reduction factor intended to take into account the probability that not all of the pallets will be present and at their maximum weight at the time of the design earthquake

3.6

seismic weight

value of weight of a mass allowed in seismic design for the calculation of the seismic action

3.7

specifier

person or company that provides the supplier with a specification based on user's requirements

[SOURCE: EN 15629:2008, 3.23]

4 Symbols and abbreviations

4.1 Symbols

For the purposes 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.

$A_{E,d}$	design value of the seismic action for the reference return period
a_g	design ground acceleration on type A ground
a_{gR}	reference ground acceleration (PGA) for the reference return period of 475 years
b	distance between the uprights axes
β	lower bound factor for the design spectrum
$C_{\mu L} ; C_{\mu H}$	correction factors for unit load-beam friction coefficient (lower and upper bound values)
$d_{r,i}$	design inter-storey drift above storey i
ξ	viscous damping ratio expressed as percentage of critical damping
e_i	height of the centre of gravity of the unit load at level i
E	Young modulus of the material
E_d	value of the effect due to the design action
E_{D1}	design spectrum modification factor
E_{D2}	pallet weight modification factor
E_{D3}	design spectrum modification factor
E_{Edx}	effect due to the application of the seismic action along the horizontal axis x
E_{Edy}	effect due to the application of the seismic action along the horizontal axis y
E_{Edz}	effect due to the application of the seismic action along the vertical axis z
θ	inter-storey drift sensitivity coefficient
θ_i	inter-storey drift sensitivity coefficient between levels i and $i+1$
θ_p	rotation capacity of the beam-end connector
$F_{b,Rd}$	bearing strength of bolted connection
f_k	characteristic strength of the material
$F_{E,i}$	horizontal force at level i of the rack
$F_{v,Rd}$	bolt's shear strength
Φ_k	rotation at M_k , both positive and negative
G_i	permanent load
$G_{k,i}$	characteristic value of the permanent action

g	gravity acceleration
γ_I	importance factor
γ_M	material's factor
γ_f	load factor
η	damping correction factor
H	height of the frame bracing pitch or the distance from floor to first horizontal
H/b	height to minimum width ratio of an unit load
h_i	inter-storey height above the storey i
H_i	horizontal action on the unit load at level i
I	moment of inertia of the upright
k_S	coefficient related to number of tests
K	buckling length factor
K_D	effective spectrum modification factor
L	beam's length
λ	seismic shear force calculation coefficient in LFMA
$\bar{\lambda}$	adimensional slenderness (EN 15512 and EN 1993-1)
M_k	characteristic bending strength obtained from monotonic tests, both positive and negative
μ_m	mean value of the unit load-beam friction coefficient obtained from tests
$\mu_{n,i}$	individual test result of the unit load-beam friction coefficient
N_{Rd}	axial strength of a member
ΔN_{base}	additional vertical force at the base of the uprights
ΔN_i	additional vertical action at beam-upright intersection
μ_s	unit load-beam friction coefficient
P_c	constant downward load in the bending test
$P_{cr,E}$	Euler critical load
P_E	total gravity load in the seismic design situation
$P_{E,i}$	total gravity load at and above the considered storey i , in the seismic design situation
$P_{E,prod}$	total product weight on the rack
q	behaviour factor
q_d	displacement behaviour factor
q_{rack}	behavior factor of the rack

$Q_{k,i}$	characteristic value of a variable action
$Q_{P,max}$	specified weight of the unit load (see EN 15629, 6.7.1)
$Q_{P,rated}$	specified value of the weight of unit loads for the compartment, upright frame or global down aisle design (see EN 15512) as specified by the Specifier (see also EN 15629:2008, 6.7.1).
$Q_{p,rated,i}$	specified weight of the product stored at the level i in the seismic condition
R_d	design resistance of the element
R_F	rack filling grade reduction factor
s	standard deviation of a number of tests results
S	soil parameter
S_a	seismic coefficient specified in EN 1998-1:2004, 4.3.5.2 for the analysis of non structural components
$S_d(T)$	ordinate of the design spectrum (normalized by g)
$S_{d,mod}(T)$	ordinate of the modified design spectrum for racks (normalized by g)
$S_e(T)$	ordinate of the elastic spectrum (normalized by g)
T	period of vibration
T_1	fundamental period of vibration
T_B, T_C	limits of the constant spectral acceleration branch
T_D	period value defining the beginning of the spectrum constant displacement range
V_E	seismic base shear force
$V_{E,i}$	total seismic storey shear at the considered storey i
W_E	weight of the seismic mass considered in the analysis
$W_{E,G}$	weight of permanent loads
$W_{E,Q}$	weight of the variable loads
$W_{E,tot}$	total weight of the seismic mass of the rack
$W_{E,UL}$	seismic design weight of the unit load to be considered in the seismic analysis
$\psi_{2,i}$	combination factor for variable actions
Z	distance from the ground level to the fixing level of the rack

4.2 Abbreviations

LFMA	Lateral Force Method of Analysis
MRSA	Modal Response Spectrum Analysis
LDMA	Large Displacement Method of Analysis

5 Performance requirements and compliance criteria

5.1 Applicability

Non-seismic design shall comply with EN 15512. The reference to the tests and quality control of components and materials is based on EN 15512.

In case of very low seismicity conditions, the racking structures need not to be designed for earthquake (see also EN 1998-1:2004, 3.2.1, (5)P).

National Regulations shall be followed to define general conditions of applicability of the seismic design.

It is recommended to consider as very low seismicity cases either those in which the design ground acceleration on type A ground, $\gamma_I a_{gR}$, is not greater than 0,04 g, or those where the product $\gamma_I a_{gR} S$ is not greater than 0,05 g.

5.2 Performance requirements

5.2.1 No collapse requirement

The racking structure shall be designed and constructed to withstand the design seismic action without local or general collapse, retaining its structural integrity and a residual load bearing capacity after the seismic event.

Ultimate limit states are those associated with the collapse, or with other forms of structural failure, that may endanger the safety of people.

The structural system shall be verified as having the specified resistance and ductility.

5.2.2 Damage limitation requirement

No specific design requirement is prescribed in this European Standard. The movement of the stored unit loads does not constitute damage.

NOTE Reference is made to Annex J (normative) for integrity controls after a seismic event.

5.2.3 Movement of unit loads

Movement of unit loads shall be considered in the design when appropriate.

NOTE 1 Seismic accelerations can cause sliding of the pallets on the supporting beams, when the inertial horizontal forces on the pallet exceed the static friction force between pallet and beam.

This effect has been demonstrated by full scale tests to occur for small values of ground accelerations (low intensity earthquakes) with wooden or plastic pallets on painted or zinc coated steel beams, because of the structural amplification of the seismic forces at the highest storage levels.

The consequences of these phenomena are the reduction of the seismic action on the rack, due to the energy dissipation and the limitation of the horizontal action that can be transferred from the pallet to the rack structure, and the risk of unit loads falling, that can cause local or global collapse of the rack, or injury to people.

NOTE 2 The modification of the seismic response of the structure is considered in this European Standard by means of three coefficients that estimate the effects of typical phenomena of racking structures, such as energy dissipation due to the pallet-beam friction, damping due to the movement of the stored products, pallet flexibility, and others:

— E_{D1} and E_{D3} is the design spectrum modification factors,

— E_{D2} is the mass modification factor.

The PRSES shall assess the risks related to the sliding of the unit loads and the possibility of their falling from the rack.

The guidelines for this evaluation are given in 9.2.2.

6 Ground conditions and seismic action

6.1 General

The earthquake motion at a given point of the Earth's surface is defined in EN 1998-1 and related National Annexes.

When the soil properties are not known in sufficient detail to determine the site soil conditions, Ground type D is assumed.

6.2 Damping

When not otherwise specified, the viscous damping ratio ξ of the unloaded rack's steel structure, expressed as percentage of the critical damping, shall be assumed equal to:

$$\xi = 3 \%$$

NOTE The damping ratio of the loaded racking structure in operating conditions is higher and is taken into account in E_{D3} (see 7.5.2).

6.3 Importance factor γ_I

Importance factors not less than the ones defined in Table 1 shall be used. The Specifier is responsible for the selection of the Importance Class and the design life for the rack.

NOTE 1 The minimum 30 year design life is solely in relation to the seismic design and differs from the normal static design life of minimum 10 years as given in EN 15512.

Higher importance factors can be specified. Unless otherwise required, the importance factor for the rack need not to be greater than the importance factor specified for the part of the building in which the racks are located.

Table 1 — Importance factors for racks

Importance Class	Description	Importance factor γ_I	
		30 years design life	50 years design life
I	Warehouses with fully automated storage operations	0,67	0,8
II	Standard warehouse conditions, including picking areas	0,84	1,0
III	Any kind of rack with random public access for private customer	N/A	1,2
IV	Hazardous product storage (<i>Hazardous products storage is subject to the approval of National Authorities</i>) Strategic facilities	N/A	1,4

The default value of conventional warehouse racks shall be 30 years for Class I and II, and 50 years for clad rack buildings.

If National regulations require different design life this shall be considered.

NOTE 2 Importance class I: 20 % probability of exceedance of the seismic action in 30 years and 50 years.

Importance class II: 10 % probability of exceedance of the seismic action in 30 years and 50 years.

Importance class III: 5,8 % probability of exceedance of the seismic action in 50 years.

Importance class IV: 3,65 % probability of exceedance of the seismic action in 50 years.

6.4 Horizontal component of the seismic action

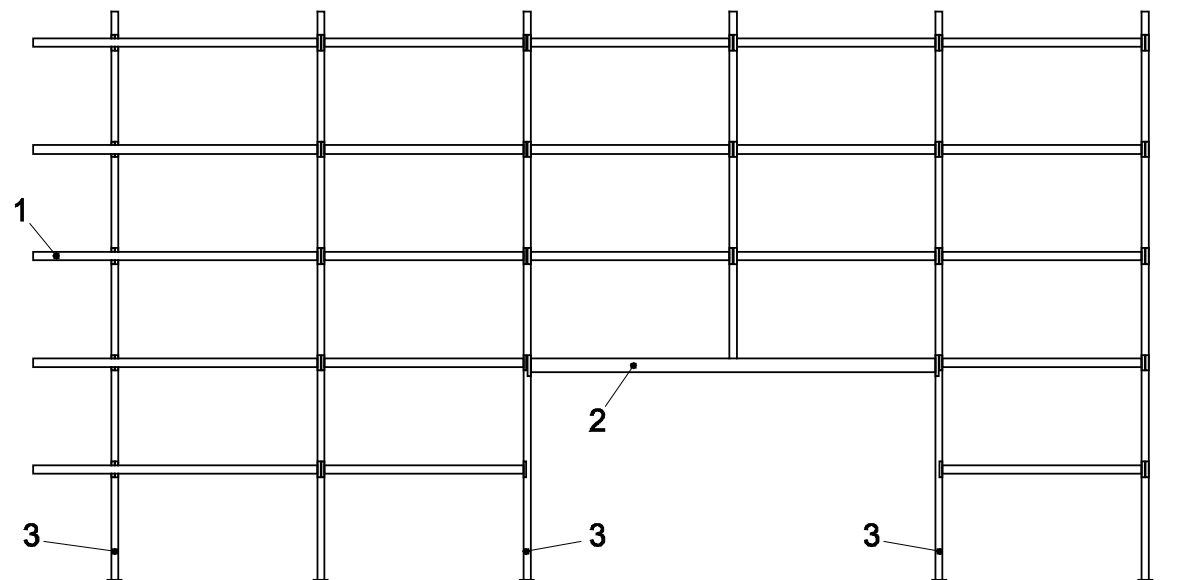
The horizontal component of the seismic action shall be evaluated according to EN 1998-1.

6.5 Vertical component of the seismic action

The vertical component of the seismic action shall be evaluated according to EN 1998-1.

The vertical component of the seismic action need only to be taken into account in the following relevant cases as shown in Figure 1:

- cantilever components;
- beams supporting columns (for example in order picking tunnels);
- elements or substructures supporting cantilevers or supported by beams.



Key

- 1 cantilever components
- 2 beams supporting columns (for example in order picking tunnels)
- 3 their directly associated supporting elements or substructures

Figure 1 — Elements to be designed for vertical component of the seismic action

6.6 Design ground displacement

The design ground displacement shall be evaluated according to EN 1998-1.

6.7 Racks supported by suspended floors

The design of racks supported by suspended floors shall be based on realistic model including the structure on which the rack is installed.

Alternatively, response spectra including the effect of the dynamic response of the supporting structure and its interaction with the supported rack can be used; guidance is given in Annex E (informative).

7 Methods of analysis

7.1 General

The reference method for the evaluation of the seismic effects on the racking structures is the modal response spectrum analysis. This shall be performed using a linear elastic model of the structure and the modified design spectrum $S_{d,mod}(T)$ defined in 7.5.1, and, when applicable, the design spectrum for the vertical component defined in 6.5.

7.2 Limitation of the vertical load referred to the critical Euler Load

In all cases when $\gamma_I a_{gR} S \geq 0,1g$ (or other value prescribed in the National Annex to EN 1998-1 or National Regulations) the following limitation shall be fulfilled:

$$P_E / P_{cr,E} \leq 0,5$$

where

P_E is the total gravity load of the rack in the seismic design situation;

$P_{cr,E}$ is the Euler critical load.

$P_{cr,E}$ shall be obtained either from buckling analysis or approximated according to Annex B, C and G of EN 15512:2009.

7.3 Inter-storey drift sensitivity coefficient

The requirement to account for second order effects is related to the maximum value of the inter-storey drift sensitivity coefficient defined as:

$$\theta_i = (P_{E,i} d_{r,i}) / (V_{E,i} h_i) \quad (1)$$

$$\theta = \max[\theta_i]$$

where

θ_i is inter-storey drift sensitivity coefficient for the fundamental mode at storey i;

$P_{E,i}$ is total gravity load above the considered storey, in the seismic design situation;

$d_{r,i}$ is design inter-storey drift, evaluated as the difference of the average lateral displacements at the top and bottom of the storey under consideration and calculated according to 7.4.7 by means of linear elastic 1st order analysis;

$V_{E,i}$ is total seismic storey shear at the considered storey i;

h_i is inter-storey height above the considered storey i;

θ is Inter-storey drift sensitivity coefficient for the fundamental mode.

Alternatively, the inter-storey drift sensitivity coefficient θ is obtainable as follows:

$$\theta = q_d \times P_E / P_{cr,E} \quad (2)$$

where

P_E is total gravity load of the rack in the seismic design situation;

$P_{cr,E}$ is Euler critical load;

q_d is displacements behaviour factor.

NOTE 1 The total gravity load in seismic conditions P_E is determined from the specified value of unit loads $Q_{p, rated}$ and the rack filling factor R_F defined in 7.5.4.

NOTE 2 Refer to the EN 1998 series for the definition of q_d .

7.4 Analysis procedures

7.4.1 General

The procedures described below shall be applied (see Tables 2 and 3).

Other methods of analysis can be used according to EN 1998-1.

7.4.2 Second order effects

7.4.2.1 General

When $\theta \leq 0,1$, second order effects can be neglected.

Second order effects shall be considered according to 7.4.2.2 for low dissipative concept and 7.4.2.3 for dissipative concept.

7.4.2.2 Low dissipative concept (behaviour factor $q \leq 2$)

Analysis methods directly considering second order effects shall be used (see Annex A); the applicable methods of analysis are summarized in Table 2.

Alternatively they can be approximated by multiplying seismic action effects obtained from first order analysis by a factor equal to $1/(1-\theta)$.

Amplification of 2nd order effects by factor $1/(1-\theta)$ is in general conservative; it is not recommended if $\theta > 0,3$ as results tend to be unduly conservative.

7.4.2.3 Dissipative concept (behaviour factor $q > 2$)

The applicable methods of analysis for dissipative design concept are summarized in Table 3.

If $\theta \leq \theta_1$ analysis methods directly considering second order effects should be used (see Annex A).

Alternatively they could be approximated by multiplying the seismic action effects obtained from first order analysis by a factor equal to $1/(1-\theta)$.

If $\theta \leq \theta_2$, pushover analysis according to EN 1998-1 or large displacement analysis presented in 7.4.5 (Large Displacement Method of Analysis - LDMA) shall be used.

If $\theta > \theta_2$, a time history analysis including large displacements and nonlinear behaviour of materials and connections shall be used.

Time-history analysis shall be according to EN 1998-1.

The following values may be assumed:

$$\theta_1 = 0,3$$

$$\theta_2 = 0,5$$

Table 2 — Summary of methods of analysis for low dissipative structural behaviour

θ	Method of analysis	Second order effects
$\theta \leq 0,1$	LFMA (7.4.3) or MRSA (7.4.4)	Negligible
$\theta > 0,1$		Shall be either considered directly in the analysis or approximated
NOTE For racks not regular in plan and elevation, refer to EN 1998-1.		

Table 3 — Summary of methods of analysis for dissipative structural behaviour

θ	Method of analysis	Second order effects
$\theta \leq 0,1$	LFMA (7.4.3) or MRSA (7.4.4)	Negligible
$\theta \leq \theta_1$		Shall be either considered directly in the analysis or approximated
$\theta \leq \theta_2$	Pushover analysis according to EN 1998-1 or LDMA according to 7.4.5	
$\theta > \theta_2$	Time history analysis including geometrical and material nonlinearity according to EN 1998-1	
NOTE For racks not regular in plan and elevation, refer to EN 1998-1.		

7.4.3 Lateral Force Method of Analysis (LFMA)

This method of analysis can be applied when response is not significantly affected by contribution of higher modes of vibration in each principal direction.

This requirement is considered fulfilled either for structures:

- that are stiffness and mass regular in elevation with fundamental period of vibration T_1 in the two principal directions less than the following values:

$$T_1 \leq 4 \times T_c$$

$$T_1 \leq 2 \text{ s}$$

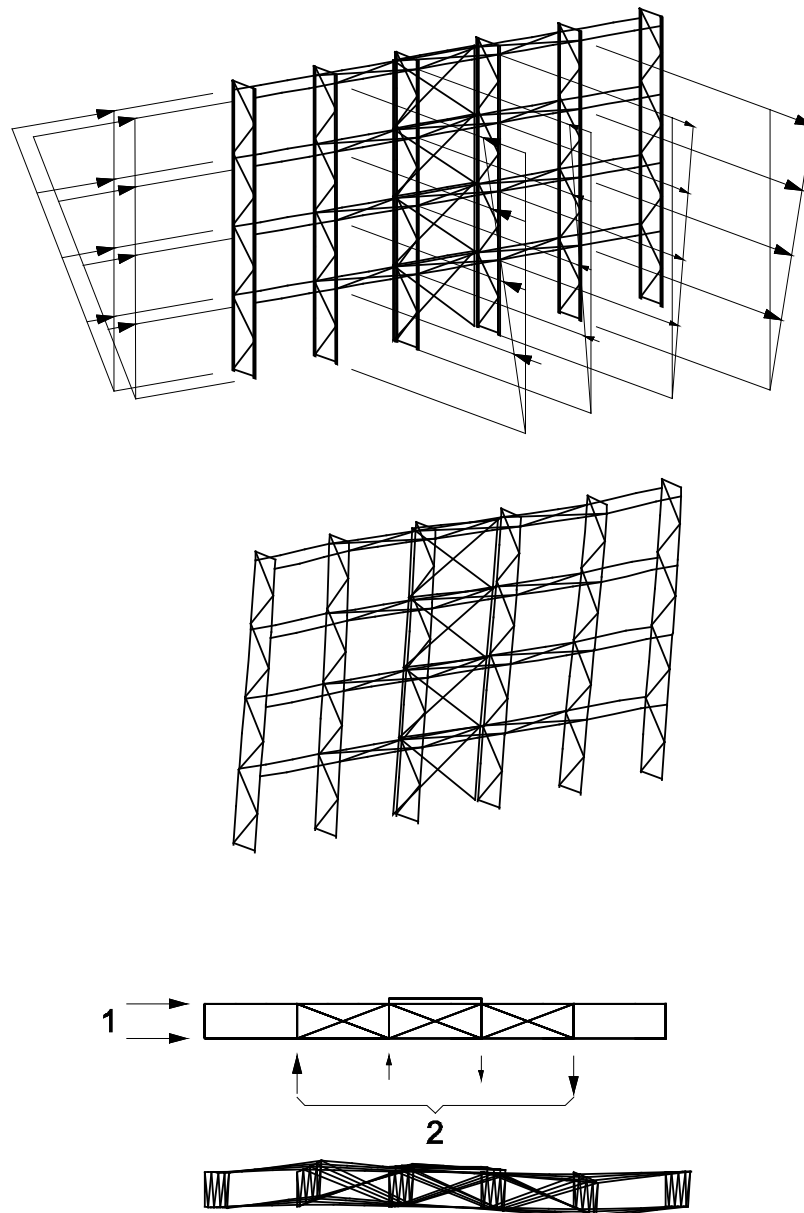
where T_c is the upper limit of the constant spectrum acceleration branch of the design spectrum, given in EN 1998-1 and in the relevant national Standards, or

- in which the modal mass associated to the fundamental period is greater than 90 % of the total mass.

See 8.1.4 for regularity.

For structures not regular in plan, the system of applied horizontal forces shall be homothetic to the three-dimensional fundamental modal shape, including the torsional component. Figure 2 shows an example of system of forces on a non-regular rack in plan.

NOTE The system of forces applied to the structure has a resultant equal to the base shear in the relevant direction, and a null resultant in the other direction.



Key

- 1 system of longitudinal actions
- 2 system of actions in transversal direction with null resultant

Figure 2 — Example of system of forces on rack non-regular in plan

Simplified formulas for the evaluation of the fundamental period typical for buildings are not allowed for racks.

The seismic base shear force V_E for each main direction is determined as follows:

$$V_E = S_{d,mod}(T_1) \times W_{E,tot} \times \lambda \quad (3)$$

where

- $S_{d,mod}(T_1)$ is ordinate of the modified design spectrum, in g units, defined in 7.5.1;
 T_1 is fundamental period of vibration for translational motion in the direction under consideration;
 $W_{E,tot}$ is total weight of the seismic mass of the rack.

$\lambda = 0,85$ for racks with 3 or more load levels (excluded floor) and $T_1 \leq 2T_c$; otherwise $\lambda = 1,0$.

If the fundamental period is not evaluated, the maximum value of the design spectrum shall be assumed.

The vertical distribution of the seismic base shear shall be according to EN 1998-1.

7.4.4 Modal Response Spectrum Analysis (MRSA)

The stiffness matrix of the model may include the terms that reduce the stiffness of the system due to the vertical loads.

For structures complying with the criteria for regularity in plan (see 8.1.4) the analysis can be performed using two planar models, one for each principal direction.

Structures not complying with these criteria shall be analysed by means of a spatial model.

The method shall be applied according to EN 1998-1.

NOTE In Annex A, MRSA methods including second order effects are presented.

7.4.5 Large Displacement Method of Analysis (LDMA)

When large displacements analysis is performed, the load history shall be defined as follows:

- 1) the target displacement is first calculated; the target displacement is the maximum horizontal displacement in the direction considered, obtained from MRSA multiplied by the behaviour factor q ; the point in which the target displacement is calculated is the target point;
- 2) the pattern of horizontal forces shall be determined using a distribution matching the modal shape of the fundamental mode in each of the two principal directions;
- 3) the vertical loads shall be first applied to the structure, then the horizontal forces shall be incremented until the target point reaches a displacement equal to 1,1 times the target displacement; under this condition the structure and all components must remain stable.

The nonlinear behaviour of materials and connections shall be taken into account.

7.4.6 Combination of the effects of the components of the seismic action

The horizontal and vertical components of the seismic action shall be combined according to EN 1998-1.

The general method applicable to racking structures is:

$$0,30 \times E_{Edx} \text{ "+" } 0,30 \times E_{Edy} \text{ "+" } E_{Edz} \quad (4)$$

$$E_{Edx} \text{ "+" } 0,30 \times E_{Edy} \text{ "+" } 0,30 \times E_{Edz} \quad (5)$$

$$0,30 \times E_{Edx} \text{ "+" } E_{Edy} \text{ "+" } 0,30 \times E_{Edz} \quad (6)$$

where

"+" implies "to be combined with"

E_{Edx} = action effects due to the application of the seismic action along the principal x-axis of the structure;

E_{Edy} = action effects due to the application of the same seismic action along the principal y-axis of the structure;

E_{Edz} = action effects due to the application of the vertical component of the design seismic action (when applicable).

The sign of each component in the above combinations shall be taken as the most unfavourable for the effect under consideration.

7.4.7 Displacements calculation

Displacements induced by the design seismic action shall be calculated according to EN 1998-1, based on the modified spectrum $S_{d,mod}(T)$ defined in 7.5.1.

NOTE For the evaluation of the displacements, the lower bound factor β is ignored in the definition of the design spectrum $S_d(T)$.

7.5 Design parameters for seismic analysis

7.5.1 General

The seismic design of racks shall be performed using the following modified design spectrum:

$$S_{d,mod} = K_D \times S_d(T) \quad (7)$$

where

$S_d(T)$ is the reference design spectrum defined in EN 1998-1

E_{D1} and E_{D3} are the design spectrum modification factors, with $E_{D1} \cdot E_{D3} \geq 0,4$

$$K_D = 1 - P_{E,prod} / P_E \times (1 - E_{D1} \times E_{D3}) \quad (8)$$

where:

P_E is the total weight of the rack in the seismic design situation (including dead weight, permanent weight, live load in the seismic situation and the stored product weight);

$P_{E,prod}$ is the total product weight stored on the rack, in the seismic design situation.

$K_D = E_{D1} \times E_{D3}$ can be assumed when $P_{E,prod}$ is greater or equal to 90 % of P_E .

7.5.2 Design spectrum modification factors

The design spectrum modification factors E_{D1} and E_{D3} take into account the curtailment and modification to the ordinate of the design spectrum.

a) E_{D1} is affected by the following parameters:

- 1) intensity of the seismic action;
- 2) number of load levels, total mass and flexibility of the racking structure, expressed by the period of vibration (dominant period in the direction considered);
- 3) maximum horizontal force that can be transmitted by the unit load to the beams, expressed in terms of the unit load-beam friction coefficient;

$$E_{D1} = \max[0,4; \mu_s / S_e(T_1) + 0,2] \leq 1,0 \quad (9)$$

where

- μ_s is the reference value of the unit load-beam friction coefficient given in 7.5.3
- T_1 is the fundamental period of vibration of the racking structure in the considered direction (the period with highest modal participating mass in the considered direction)
- $S_e(T_1)$ is the ordinate of the elastic spectrum defined in EN 1998-1 (normalized by g) with the viscous damping as defined in 6.2.

When unit loads are restrained on the beams by means of any special system (for example materials increasing the friction between pallet and beam), $E_{D1} = 1,0$.

b) E_{D3} is a reduction coefficient of the seismic action.

The value of E_{D3} is 0,80

NOTE 1 E_{D3} is introduced to account for the dissipative phenomena typical of the dynamic behaviour of racking structures under seismic actions that are not included in the mathematical formulation presented in this European Standard, but that are observed on racks that have suffered earthquakes, and from tests performed on shaking tables.

NOTE 2 The value of $E_{D3} = 0,8$ corresponds to a conventional viscous damping ratio ξ of 10 % of the loaded rack describing dissipative mechanisms existing in the whole system.

7.5.3 Unit load-beam friction coefficients

The following parameters shall be used to consider the effects of the friction between unit load and support beams:

- μ_s reference value of the friction coefficient
- $C_{\mu L}$ lower bound correction coefficient of the statistical distribution of μ_s
- $C_{\mu H}$ upper bound correction coefficient of the statistical distribution of μ_s

Reference values of μ_s and values of $C_{\mu L}$ and $C_{\mu H}$ are obtained from tests in accordance with Annex B.

If tests are not performed, $C_{\mu L} = 0,67$ and $C_{\mu H} = 1,50$ shall be assumed and recommended unit load-beam friction coefficients are given in Table 4.

Table 4 — Recommended reference values for the pallet-beam friction coefficient

Materials in contact	Environment	Reference value of pallet-beam friction coefficient μ_s
Steel beams – all coatings Wooden pallet	Warehouse normal conditions	0,37
Steel beams – all coatings Plastic and steel pallet	Warehouse normal conditions	0,15
NOTE Warehouse normal conditions are defined in EN 15629.		

In all other conditions, unit load-beam coefficients shall be defined by tests considering appropriate warehouse conditions.

7.5.4 Design seismic weight of the unit load

The design weight of the unit load $W_{E,UL}$ to be considered in the evaluation of the horizontal seismic action, shall be determined as follows:

$$W_{E,UL} = R_F \times E_{D2} \times Q_{P,rated} \quad (10)$$

where

R_F is rack filling grade reduction factor, related to the occupancy of stored goods in the rack that can be assumed during the seismic event, to be defined by the Specifier based on statistical evaluations: for analysis in cross aisle direction $R_F = 1,0$ shall be assumed; for analysis in down aisle direction $R_F \geq 0,8$ shall be assumed;

E_{D2} is unit load weight modification factor (see 7.5.5);

$Q_{P,rated}$ is specified value of the weight of unit loads for the compartment, upright frame or global down aisle design (see EN 15512) as specified by the Specifier (see also EN 15629:2008, 6.7.1).

NOTE E_{D2} modifies the period and the horizontal action.

Unless otherwise specified, $R_F = 1,0$ shall be considered.

7.5.5 Unit load weight modification factor

Unless otherwise specified, the values of E_{D2} in Table 5 shall be considered, depending on the type of unit load and stored goods for specified classes of the product.

Table 5 — Unit load weight modification factors

Class	E_{D2}	Stored good classes	Example
A	1,0	COMPACT CONSTRAINED	Frozen goods (cold storage) Steel sheet package Coils and paper rolls
B	0,8	WEAK	Big number of pieces stored on the pallet whose size is small in comparison to the pallet size, including goods stabilized by stretch wrapping
C	0,7	LOOSE AND UNCONSTRAINED	Goods that can easily move around, inside the container (e.g. granulated materials)
D	1,0	LIQUID	Unit load containing liquid that can slosh in the container

NOTE The unit load weight modification factor E_{D2} represents the effects of the interaction between the unit load and the racking structure. This coefficient affects the response to earthquake in terms of participating mass and modification of the period of vibration.

7.5.6 Other seismic weights

All the permanent and live loads other than the unit load weight shall be considered in the seismic analysis.

Refer to EN 15512 for the definition of:

- a) Dead loads:
 - 1) weights of materials and constructions;
 - 2) weights of fixed service equipment.
- b) Minimum floor and walkway loads.

Refer to EN 15512 for the design values.

7.5.7 Weight of the seismic masses

The weight of the seismic mass W_E shall be determined considering all the permanent and variable loads supported by the rack.

$$W_E = W_{E,G} + W_{E,Q} + W_{E,UL} \quad (11)$$

where

- $W_{E,G} = \sum G_{k,i}$ is the permanent load;
- $W_{E,Q} = \sum \psi_{2,i} Q_{k,i}$ is the variable load;
- $W_{E,UL}$ is the design seismic weight of the unit load defined in 7.5.4;
- $G_{k,i}$ is the characteristic value of the permanent load;
- $Q_{k,i}$ is the characteristic value of the variable load;
- $\psi_{2,i}$ is the combination factor of the variable loads, defined in 9.2.1.1.

7.5.8 Position of the centre of gravity of the unit load

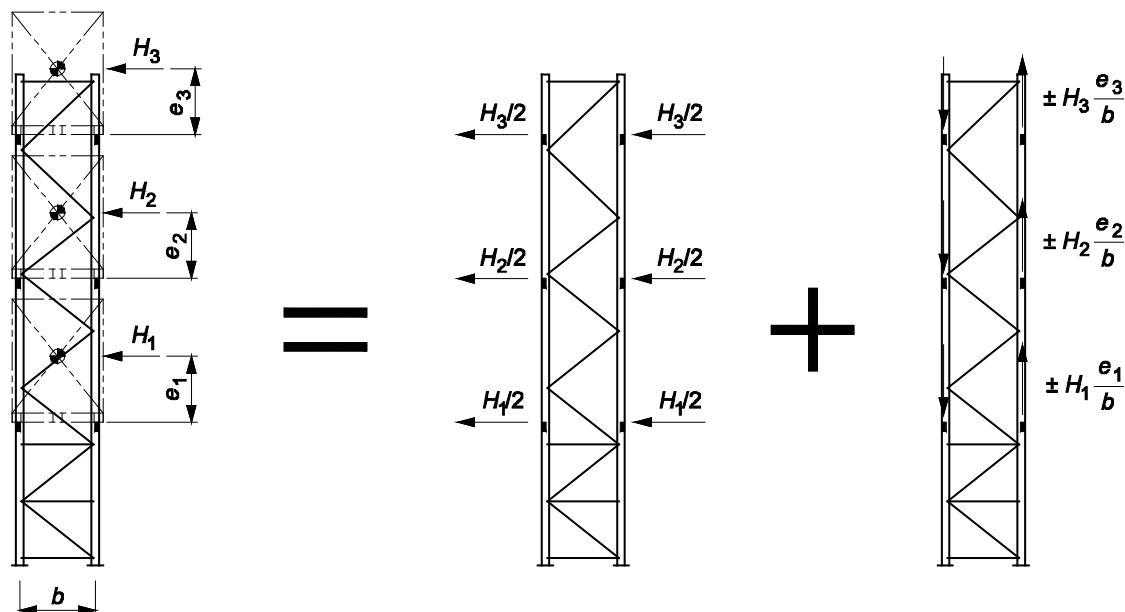
The position of the centre of gravity of the unit load above the beams shall be considered in the analysis as specified in the following of this clause.

- a) Cross aisle direction:

The elevation of the centre of gravity of the unit load with respect to the support beams (vertical eccentricity) shall be considered.

The masses of the unit loads shall be positioned above support beam level (at the elevation of their centre of gravity) for the evaluation of the period of vibration and of the seismic action and for the design of the pallet beams and their connections.

Figure 3 shows an example of the effect of the vertical eccentricity of the centre of gravity of the unit load.



Key

- b width of the upright frame
- H_1, H_2, H_3 seismic action acting on unit loads
- e_1, e_2, e_3 vertical eccentricity of the centre of gravity of the unit loads above pallet beams

Figure 3 — Effect of the vertical eccentricity of the centre of gravity of the unit load

NOTE In Annex C is presented a method to consider the effect of the vertical eccentricity of the centre of gravity of the of the unit load in the numerical model of the upright frame.

In some circumstances, the computational effort involved with this requirement is considerable. A practical alternative approach, that will reduce computational effort, is to place the mass at the beam level and to apply additional actions to the members as explained in Annex D (informative).

b) Down aisle direction:

In general, the vertical eccentricity of the unit load can be neglected in the analysis in down aisle direction, except for single bay racks.

In Figure 4 an example of the effect of the vertical eccentricity of the centre of gravity of the unit load in the model in down aisle direction is reported; it is shown that the overturning forces of adjacent unit loads are in opposite direction and their effect is null, apart in the side uprights where their effect can be neglected (except in the single bay runs).