FEM RACKING AND SHELVING PRODUCT GROUP

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

FEM 10.2.06 - Part 1

THE DESIGN OF

'HAND LOADED LOW RISE STEEL STATIC SHELVING'

VERIFICATION BY EXPERIMENTAL METHODS

SHELVING DESIGN CODE – Part 1

September 2012

FEM RACKING AND SHELVING PRODUCT GROUP

(European Racking Federation)

The Design of 'Hand Loaded Steel static shelving by experimental methods'

September 2012

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

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Contents

Page

Foreword

This document defines the design procedure for hand loaded Static Steel Shelving verified by testing. Shelving systems are generally standard products where design by calculation alone may not be appropriate or may not lead to the most economical solutions. It is, therefore, usually appropriate to design on the basis of testing or a combination of tests and calculation.

FEM 10.2.06 is based on the safety and design concept of the European standards series “Steel Static Storage Systems” and provides supplementary design rules to suit the peculiarities of Shelving systems.

1 Scope

The design principles given in this code apply to hand loaded shelving and beamed shelving systems in an indoor environment.

These procedures do not apply to rack-supported buildings (integrated systems, silos), systems supporting dynamic storage or mobile storage systems.

In hand loaded shelving systems, the unit loads do not normally exceed 25kg.

Shelving systems are not designed to be climbed upon by operatives.

Part 1 covers shelving up to 3.0m high, not supporting walkways and floors (Low rise shelving) and excluding impact from mechanical handling equipment. In part 1 verification is by experimental methods It is always possible to use part 2 for the design of low rise shelving that satisfies the criteria for part 1.

Part 2 deals with all other types of shelving not covered by part 1 and covers high-rise shelving and shelving supporting walkways and floors or where powered warehouse equipment may also be supported by the shelving. In part 2 verification is by analytical methods which may be augmented by testing. In the case of ancillary structures, where shelving system components are employed for the main structural members, the relevant sections of these design procedures are also applicable.

NOTE: The equipment considered in part 1 is work equipment but does not normally constitute construction equipment.

2 Normative references

EN 1993: Eurocode 3: Design of steel structures including;

- Part 1.1: General rules and rules for buildings.
- Part 1.3: Supplementary rules for cold-formed members and sheeting.
- Part 1.8: Design of joints.

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

EN 10025-1: Hot rolled products of structural steels. General technical delivery conditions.

EN 10025-2: Hot rolled products of structural steels. General delivery conditions for non-alloy structural steels.

EN 10025-3: Hot rolled products of structural steels. Technical delivery conditions for normalized / normalized rolled weldable fine grain structural steels.

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

EN 10346: Continuously hot-dip coated steel flat products. Technical delivery conditions.

EN 10149-1: Hot rolled flat products made of high strength steels for cold forming. General delivery conditions.

EN 10149-2: Hot rolled flat products made of high strength steels for cold forming. Delivery conditions for thermomechanically rolled steels.

EN 10149-3: Hot rolled flat products made of high strength steels for cold forming. Delivery conditions for

normalized or normalized rolled steels.

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

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

EN 15629: Steel static storage systems – Specification of storage equipment.

EN 15635: Steel static storage systems – Application and maintenance of storage equipment.

EN 15878: Steel static storage systems – Terms and definitions.

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

ISO 7438: Metallic materials - Bend test.

3 Terms and Definitions

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

3.1
one piece frame
an upright frame, usually perforated, which is manufactured from a single sheet of material within which the profile of the upright has been formed by cold-forming the edges.

3.2
back sheet or side sheet (cladding)
steel sheet panels as defined in EN 15878 but which may also be used as structural elements to provide sway stability to the shelving structure.

3.3
reinforced shelf
a shelf which is strengthened along its edges, and sometimes between its edges, in either the cross-aisle or down-aisle direction in order to enhance its load carrying capacity.

3.4
non-structural shelf
a shelf which is connected to the upright in such a way that only vertical shear can be transmitted between the shelf and the upright.

3.5
perforated member
a member with multiple holes regularly spaced along its length.

3.6
low-rise shelving
shelving less than 3.0m high and not supporting floors or walkways.

3.7
high-rise shelving
shelving more than 3.0m high or supporting floors or walkways.

3.8
dead load
the weight of all permanent construction, and fixed service equipment.

3.9
perforated shelf
a shelf with holes in the flat part of the shelf.

NOTE: perforated shelves are often specified to allow water from sprinklers to pass through the system.

3.10
live loads
live loads are those loads produced by the use and exploitation of the structure and do not include environmental loads such as wind load, earthquake load, or dead load.

3.11
structural shelf
a shelf which is connected to the upright in such a way that tension forces and/or bending moments in addition to vertical shear can be transmitted between the shelf and the upright.

3.12
starter bay
a bay of shelving capable of standing alone with a frame at either end of the shelf (see Figure 1).

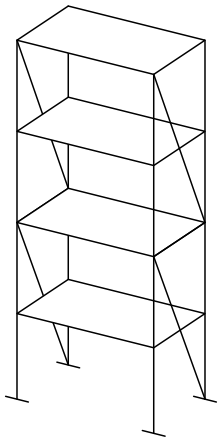


Figure 1 Starter bay

3.13
extension bay
a bay of shelving that is incapable of standing alone with a frame at only one end of the shelf (see Figure 2).

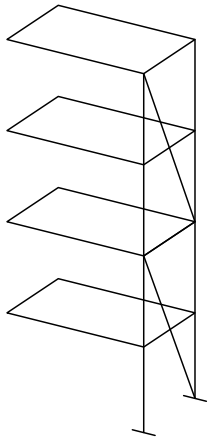


Figure 2 Extension bay

4 Symbols (for part 1)

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

d dimension

F action

f_u ultimate tensile strength

f_y yield strength of base material

G_k characteristic value of permanent action (dead load)

H horizontal action

n number of tests

Q variable action

Q_{pv} vertical placement load

R resistance

θ rotation

γ correction/load/material factor

δ deflection

Subscripts

i test number

k characteristic

m mean

max maximum

min minimum

R resistance

ser service

x x direction

z z direction

Editorial note: We have not defined the axis system. Do we need to do so? Or can we refer to figure 1 in EN15620?

5 Basis of design

5.1 Structural arrangements

5.1.1 General

In shelving systems, shelves are usually connected directly to the uprights by means of bolts, lugs or clips, or the shelf may be supported on beams. Such beams may be stepped in order to provide a flush loading surface. Down-aisle stability may be achieved by the action of semi-rigid joints between the shelves or beams and the upright, or by bracing or sheeting in the spine of the rack. Typical arrangements for achieving down-aisle stability are shown in Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7. In Figure 3, Figure 4, and Figure 5, down-aisle stability is provided by full and partial spine bracing respectively. In Figure 6 the back sheeting acts as spine bracing. In Figure 7, the semi-rigid shelf or beam to upright connections stabilise the system. Normally the shelves act as plan bracing to stabilise the front face of the rack.

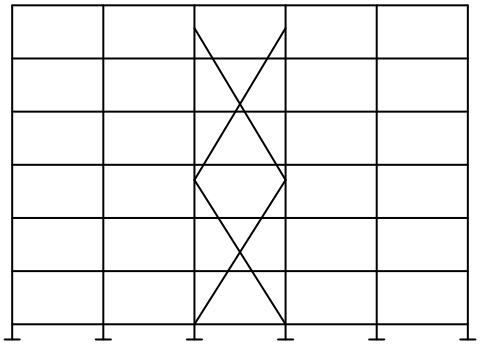


Figure 3 System fully braced in the down-aisle direction

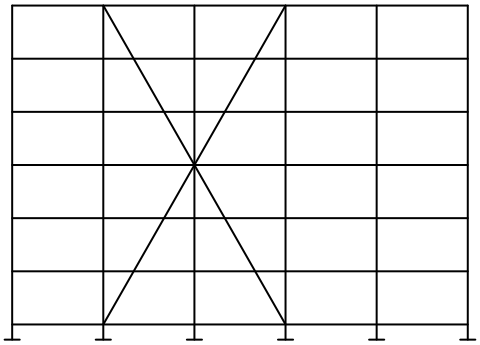


Figure 4 System fully braced in the down-aisle direction

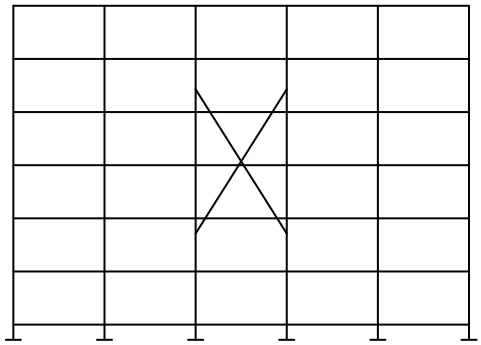


Figure 5 System partially braced in the down-aisle direction

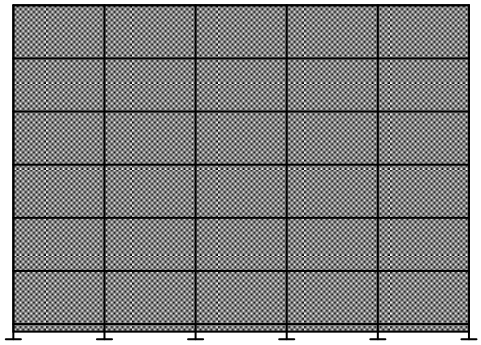


Figure 6 Back cladding provides down-aisle stability

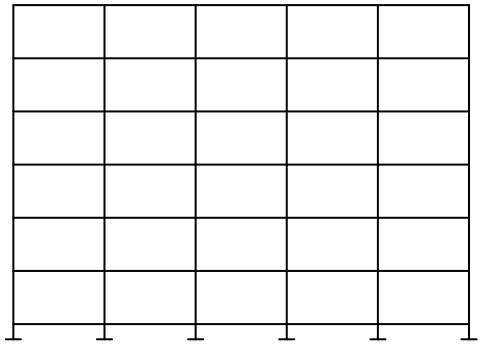


Figure 7 Semi-rigid shelf to upright connections provide down-aisle stability

In the cross-aisle direction, stability is achieved by bracing or by sheeting (integral in the case of one piece frames), or by the action of semi-rigid connections between the shelf and the upright. Figure 8 shows typical frame bracing arrangements.

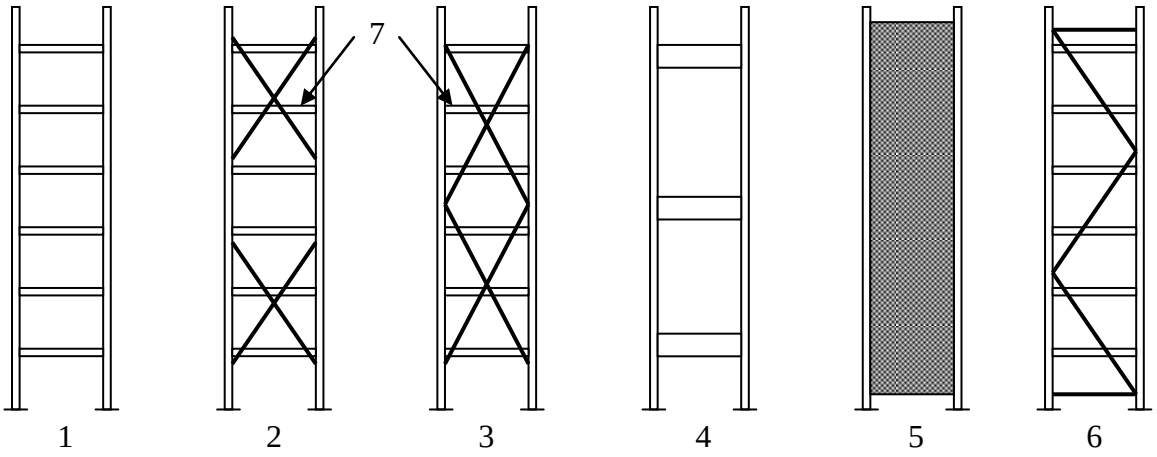


Figure 8 Typical upright frame bracing arrangements

KEY

1. Open
2. Cross-braced
3. Cross-braced
4. Battened
5. Clad
6. Braced
7. Shelves

Back or side sheets, intermittently fastened to the upright with rivets, bolts or clips, may be used in the cross-aisle or down-aisle directions to provide stability to the structure by tension field action.

NOTE: The design of such sheets is normally determined by the strength of the connection to the upright, to which careful attention should be given.

5.1.2 Shelf connections

Structural shelves will normally be required to act as plan bracing (diaphragm action) to stabilise the front uprights and transfer the stabilisation forces to the spine bracing. The engineer shall take account of the whole range of possible shelf positions in assessing the load carrying capacity of the structure and shall advise the User accordingly.

NOTE: It is a characteristic of shelving systems that adjustment of the shelf positions and the number of shelves in a bay is often a simple process which can be carried out by the user. To ensure safe operation of the shelving system the User should be advised of any restrictions on the number and positions of shelves in the system.

Connections between shelves and uprights may be categorised as structural or non-structural. A non-structural shelf may not be accounted for as a structural member in assessing the overall stability of the complete system.

The behaviour of the connection between the shelf and upright is a significant factor in the structural integrity and stability of the shelving system. A variety of clips, hooks and lugs have been devised to connect the shelves and uprights together. In general the behaviour of this connection cannot be determined from theory and so is assessed by testing.

5.1.3 Design working life

A notional design working life of at least 10 years shall be considered. This should not be construed as indicating any guarantee regarding the actual working life of the shelving system.

Shelving systems are supplied to satisfy a dry interior environment. In case of an aggressive environment the Specifier shall specify the surface treatment.

NOTE: It is the duty of the operator of a shelving system to ensure that it is properly used and that any damage is repaired immediately. The working life of most shelving systems is determined by wear and damage sustained during operation or by corrosion. These cannot be pre-determined at the design stage and are not covered by this clause.

5.2 Methods of design

5.2.1 General

It shall be verified by testing according to section 9 that at both the ultimate limit state and the serviceability limit state:

$$\sum \gamma_f F \leq \frac{R_k}{\gamma_M}$$

where

γ_f = relevant load factor according to 7.1.1

γ_M = material factor according to 7.1.2

F = effect of an action defined in section 6

R_k = resistance at the relevant limit state

5.2.2 Limit states

5.2.2.1 Ultimate limit state

The ultimate limit state corresponds to the maximum load carrying capacity and is generally characterised by one of the following:

- Strength (including widespread yielding, rupture, buckling and transformation into a mechanism);
- Stability against overturning and sway;
- Excessive local deformation.

5.2.2.2 Serviceability limit state

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

5.3 Imperfections

In the case of low-rise shelving designed by testing the non-verticality is taken into account in the test set up by means of the horizontal forces.

6 Actions and combination of actions

6.1 Combination of actions

Combination of actions is taken into account in the test method. The combination of imperfections or placement loads in one direction with imperfections or placement loads in the other direction need not be considered.

6.2 Weights of materials and constructions

Where verification is carried out by testing the self-weight of the structure is automatically considered in the test. Where the shelving is required to support fixed services equipment suitable allowance shall be included in the test or the weight of such equipment shall be considered as an imposed load.

6.3 Variable actions

6.3.1 Goods to be stored

The end User, or the Specifier in consultation with the end User, shall specify the maximum weight and gross dimensions of goods to be stored and any special requirements regarding their distribution. The Specifier may simply specify a shelf load. Unless specified otherwise the shelf load may be assumed to be uniformly distributed.

NOTE: Due to manual handling regulations the maximum weight of a single load is 25kg refer to ANNEX C (informative).

6.3.2 Vertical placement loads

The following takes into account the effect of vertical placement loads arising from use of the installation as a result of good practice in the placement and removal of unit loads.

Provided that the capacity of the shelf exceeds 80kg (uniformly distributed load) vertical placement loads may be neglected.

If the application is known to involve the storage of unit loads in excess of 15kg each and there are less than 5 unit loads per shelf then a vertical placement load Q_{pv} of 100% of the maximum unit load, placed in the most unfavourable position for the particular determination (moment or shear but not deflection) shall be taken into account in the design of the shelf in addition to the normal shelf load. Refer to A2.5.

6.3.3 Horizontal placement loads

The test takes into account the effect of horizontal placement loads arising from use of the installation as a result of good practice in the placement and removal of unit loads and takes into account the effect of sliding loads into place. No further allowance need be made except as noted below.

6.3.4 Horizontal ladder load

If it is intended that the shelving should support a ladder then the effect of this shall be included. A minimum value of 0.25 kN applied at the top of the shelving or at the height of the ladder support rail shall be considered. If this is not included in the test (or design) then ladders shall not be leant against the shelving.

NOTE: The above force is based on the assumption of a 100kg person standing on the ladder which is at an angle of 1:4.

6.4 Actions due to impact (accidental forces)

Impact loads need not be considered in the case of low-rise shelving verified according to part 1.

NOTE: It is assumed in this part that any equipment is operated with sufficient care to avoid damage to the system.

6.5 Actions arising from installation

These loads need not be considered in the case of low-rise shelving designed according to part 1.

NOTE: It is assumed that low-rise shelving can be installed without the need to climb on the shelving.

6.6 Earthquake loads

Earthquake loads need not be considered in the design of low-rise shelving.

NOTE: The risks involved in the use of low-rise shelving in a seismic zone are generally low and consequently seismic effects are not generally taken into account.

7 Partial factors

7.1.1 Load factors

The load factors γ_f are given in Table 1.

	Ultimate limit state	Serviceability limit state
Permanent actions γ_G		
- with unfavourable effect	1.3	1.0
- with favourable effect	1.0	1.0
Variable actions γ_Q		
Live loads (ladder load)	1.5	1.0
Unit shelf loads	1.4	1.0
Placement loads	1.4	NA

Table 1 Load factors γ_f

NOTE: The load factors specified in this code are lower than those given in the structural Eurocodes. This is acceptable because the imposed loading is restricted by load notices (see 12) and the shelving is inspected on a regular basis (see recommendations of EN 15635).

7.1.2 Material factors

In this part the value of material factor may be taken as $\gamma_M = 1.0$ in the tests specified in Annex A.

NOTE: This is acceptable because the tests are based on higher loads.

NOTE: In some nations different γ_M factors may be specified (see EN15512 Annex I).

8 Steel

Refer to EN 15512, clause 8.1, 8.2, 8.3, 8.4 and 8.5.

8.1 Durability

Refer to EN 15512, clause 8.9.

9 Structural verification

9.1 Design by testing

In part 1 the load capacity of low rise shelving structures is confirmed by acceptance and/or strength tests. The configuration for the tests shall be three bays long and single sided, as shown in ANNEX A.

The basis of the loading for both the acceptance test and the strength test shall be the service load on the shelf, W_{ser}. The test structure shall be loaded with a combination of shelf loads and horizontal loads in the patterns shown in ANNEX A (normative).

9.2 Floor materials

Refer to EN 15512, clause 9.10.

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, should be sought. In assessing the characteristic contact pressure of the material, due consideration should be given to the possibility of creep occurring and to the influence of environmental factors 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 may influence the behaviour of the structure.

9.3 Design of floor fixing

9.3.1 General

Low rise shelving more than 1.6m high with a height to depth ratio exceeding 5:1 shall be fixed to the floor as defined below.

Where

- height is the height to the top of the frame;
- width is the width of the single frame or, in the case of a double sided run the width may be taken as the overall width of the two frames provided that the frames are connected together with a device capable of resisting both tensile and compressive forces.

NOTE: It is noted that this limit is different to the limit in some other codes:

The design forces in the floor fixings shall be calculated for the most onerous load combination at the ultimate limit state but shall, in any case, have a minimum design resistance of 0.4 kN in tension and 0.7 kN in shear, however not simultaneously.

Alternatively overturning of the shelving may be prevented by attaching to the building wall, in which case the building wall shall be capable of carrying the applied forces.

NOTE: It is conventional to assume that this fixing force is 0.1 kN per bay in tension or shear.

Where the concrete slab is placed directly on the soil, the tensile stresses in the upper layers of the concrete are generally small and the top of the slab may be considered as being in the compression zone.

9.3.2 Ladder leant against shelving

If the shelving is intended to have a ladder leant against it then the floor fixings shall be designed accordingly.

10 Verification of shelving systems

10.1 General

Verification of strength, stiffness and overall stability is carried out by testing according to ANNEX A. No further analysis is required.

10.2 Design of beams, shelves and clips

Verification of strength and stiffness is carried out by test according to ANNEX A. No further analysis is required.

10.2.1 Design strength for shelves

The resistance of shelves shall be determined by testing according to ANNEX A.

Where shelves are required to act as diaphragms they shall be capable of doing so. The shelf shall be capable of transmitting the required stabilisation forces.

NOTE: The strength of a shelf is normally determined by testing due to the difficulty in determining the appropriate section properties for use in an analytical method.

10.2.2 Deflection of beams and shelves

The deflection of shelves shall be determined by testing according to ANNEX A.

NOTE: The deflection of a shelf is normally determined by testing due to the difficulty in determining the appropriate section properties for use in an analytical method.

10.2.3 Design of shelf clip/lug

Shelves are supported by a variety of novel devices e.g. clips, lugs etc. The strength and stiffness of these devices shall be determined by testing according to ANNEX A.

Where shelves are required to act as diaphragms the clips/lugs shall be capable of transmitting the required stabilisation forces.

NOTE: The nature of shelf clips/lugs and the complex shape of some designs means that the capacity of these elements is normally determined by testing due to the difficulty in determining the appropriate properties for use in an analytical method.

11 Serviceability limit state

11.1 Requirements for deflections

Shelving systems shall be so proportioned that the deflections are within the limits agreed between the client, the designer and the competent authority as being appropriate to the intended use.

Recommended limits for deflections are given in 11.2. In some cases e.g. archives, more stringent limits (or exceptionally less stringent limits) will be appropriate to suit the use of the installation.

11.2 Limiting values

Under the loads defined in section 6 and the serviceability limit state combinations defined in 6.1, the limiting values for deflections are as follows:

maximum vertical deflection in a beam span/200

maximum twist in a beam	6°
maximum vertical deflection at the edges of a shelf	span/200
sway deflection	height/200

12 Marking and labelling

12.1 Identification of the performance of shelving installations

All installations shall display, in one or more conspicuous locations, a permanent notice stating that the installation is designed according to these FEM requirements and which shows the maximum permissible shelf load and the maximum permissible bay load in clear legible print. Suitable Load warning notices are given in EN 15635.

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

12.2 Shelving configuration

Load application and configuration information (in the form of drawings if appropriate) shall be furnished with each installation, one copy of which shall be retained by the User or owner and another by the manufacturer, distributor or other representative for use by any inspecting body.

NOTE: It is recommended that this information is retained for 10 years.

If the use of the installation is permissible in more than one configuration, the permissible loads shall be presented as a function of the different relevant parameters. This information may optionally be furnished in a table. The User and owner shall be informed by conspicuous text on the drawings and/or tables that deviations from stipulations may impair the safety of the installation. The owner is responsible for all changes to the configuration which shall follow the drawings or tables and which should be carried out under the supervision of a competent person.

13 Test methods and evaluation of results

13.1 General

Tests carried out for the purpose of obtaining performance data shall be in accordance with ANNEX A.

Table 2 gives an overview of the design tests specified in ANNEX A.

EN 15512 Clause reference	Title	Test method	
8.1.4	Material tests – EN 15512	A.1	
8.1.4.2	Tensile tests	A.1.1	mandatory only for steel not given in EN 1993-1-1, table 3.1 or EN 1993-1-3, table 3.1a / 3.1b
8.1.1 (b)	Bend tests	A.1.2	mandatory only for steel not given in EN 1993-1-1, table 3.1 or EN 1993-1-3, table 3.1a / 3.1b
	Tests on components and assemblies	A.2	
	Shelf test Three-bay test		mandatory mandatory

Table 2 Tests for material and design purposes

13.2 Requirements for tests

13.2.1 Equipment

Refer to EN 15512, clause 13.2.

13.2.2 Support conditions

Refer to EN 15512, clause 13.2.

13.2.3 Application of the test load

Refer to EN 15512, clause 13.2.

13.2.4 Increments of the test load

Refer to ANNEX A.

When the load is applied continuously, the rate of loading shall be slow enough to ensure that static conditions prevail. Deformations shall be observed at regular intervals, and frequently enough to define the behaviour clearly.

13.2.5 Assembly of the test specimens

Refer to EN 15512, clause 13.2.

13.2.6 Test reports

Refer to EN 15512, clause 13.2.

13.3 Interpretation of test results

13.3.1 Definition of failure load

The test component shall be deemed to have failed when:

a) the applied test loads reach their upper limit;

b) deformations have occurred of such a magnitude that the component can no longer perform its design function.

13.3.2 Corrections to test results

Raw test results shall be adjusted to account for differences between the actual thickness of the material used in the test and the nominal thickness specified by the manufacturer, and to account for the difference between the yield stress of the material in the test sample and the minimum yield stress guaranteed by the manufacturer. The way in which adjustments are to be made depends upon the nature of the test being made, and is described for each test separately in ANNEX A (normative). Refer to EN15512 clause 13.3.5.

When samples are prepared for tensile tests to determine the yield stress of the material, they shall be cut from an undamaged region of the test piece, away from heat affected zones, and away from bends in the section and from other areas where cold working effects can influence the result.

NOTE: Alternatively the test pieces may be cut from the original coil, before cold forming.

NOTE: Manufacturers may select steel grades which are close to the nominal yield stress.

13.3.3 Derivation of characteristic values

13.3.3.1 General case

Where three or more tests are carried out and after the individual results of a group of tests have each been corrected for variations in thickness and yield stress, the characteristic value of the parameter being measured, R_k, shall be calculated as follows:

$$R_k = R_m - k_s s$$

Where

R_m = the mean value of the adjusted test results;

$$R_m = \frac{1}{n}\sum_{i=1}^{n} R_{ni}$$

R_{ni} = individual test result, corrected for thickness and yield stress;

n = number of tests results in the group (n >=3);

s = the standard deviation of the adjusted test results;

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(R_{ni} - R_m\right)^2}$$

k_s = coefficient given in Table 3.

n	k_s
3	3.37
4	2.63
5	2.33
6	2.18
7	2.08
8	2.00
9	1.95
10	1.92
15	1.82
20	1.76
30	1.73
40	1.71
50	1.69
100	1.68
∞	1.64

Table 3 k_s coefficient based on 95 % fractile at a confidence level of 75 %

13.3.3.2 Corrections with less than three test results

1) If only one test is carried out, then the characteristic resistance R_k corresponding to this test shall be evaluated as:

$$R_k = 0.9 \,.\, \gamma_k \,.\, \mathrm{R_{ni}}$$

Where

R_{ni} is the observed failure load adjusted for variations in yield stress and thickness.

γ_k shall be taken as follows, depending on the failure mode.

Case 1: Yielding failure $\gamma_k = 0.9$

Case 2: Failure due to gross deformation $\gamma_k = 0.9$

Case 3: Failure due to local buckling $\gamma_k = 0.8$

Case 4: Failure due to overall stability $\gamma_k = 0.7$

NOTE: This is based on EN1993-1-3 A6.3.3.

2) If two tests are carried out, and the test results are within 10% of the mean value, R_m, the characteristic resistance, R_k shall be evaluated as:

$$R_k = \gamma_k \cdot R_m$$

If the test results do not lie within 10% of the mean, then the characteristic resistance, R_k shall be obtained by treating the least favourable test result (normally the lowest) as a single result in (1) above.

13.3.4 Characteristic values for a family of tests

A family of tests shall consist of a series of tests in which (normally) one design parameter (e.g. span, thickness) is varied. This section enables a family of test results to be treated as a single entity. In order to carry out the evaluation of the characteristic strength, a suitable expression which defines the relationship between the test results and one or more relevant parameters in the test series shall be used. This design expression may be based on the appropriate equations of structural mechanics or on an empirical basis.

13.3.5 Corrections to the failure loads or moments

Refer to EN 15512, clause 13.3.5.

ANNEX A (normative)

Test methods and evaluation of tests

A1 General

General requirements for test setups, test specimens, reporting and test interpretation of results are given in clause 13.

A2 Test on shelves under vertical loading

A2.1 General and purpose of the test

The purpose of the test is to determine the load-deflection characteristic of the shelf or compartment (taken to comprise beams and shelf panels) and to measure its ultimate load capacity.

The test deals with the normal situation of uniformly distributed loads. Specific projects may have particular requirements but these are outside the scope of this document.

If the shelf panels are not steel then appropriate material properties and corrections shall be taken into account e.g. wood-based products refer to EN1995.

A2.2 Test arrangement

The shelf, or shelf panels, shall be mounted in the same way as they would be mounted in normal conditions, either on beams or on corner connections as appropriate. Provision shall be made to measure the deflection at each corner of the shelf and at the centre of each unsupported edge. Care should be taken to ensure that curling of the flanges, which may develop as the test proceeds, does not affect deflection observations (see Figure 9).

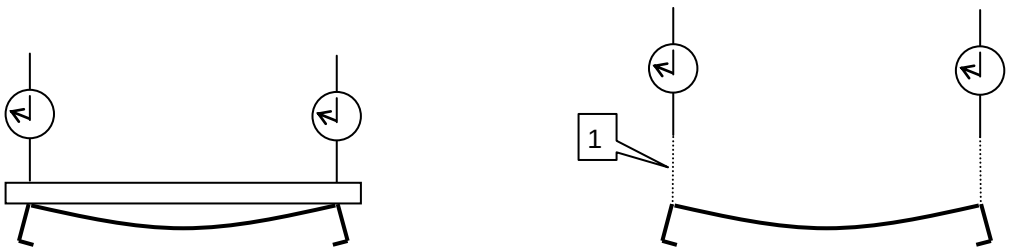


Figure 9 Method to mount gauges

KEY
1. Thin wire

A typical arrangement for a single shelf is shown in Figure 10 and for beamed shelving in Figure 11.

NOTE 1: Certain applications may necessitate limiting the deflection at the centre of the shelf. However, it is not possible to specify a design limitation in codified guidance. Therefore, it is recommended that this central deflection should be recorded so that the data are available if required.

NOTE 2: Measurement at mid-length of the transverse edges may be omitted if it can be shown that it is not critical.

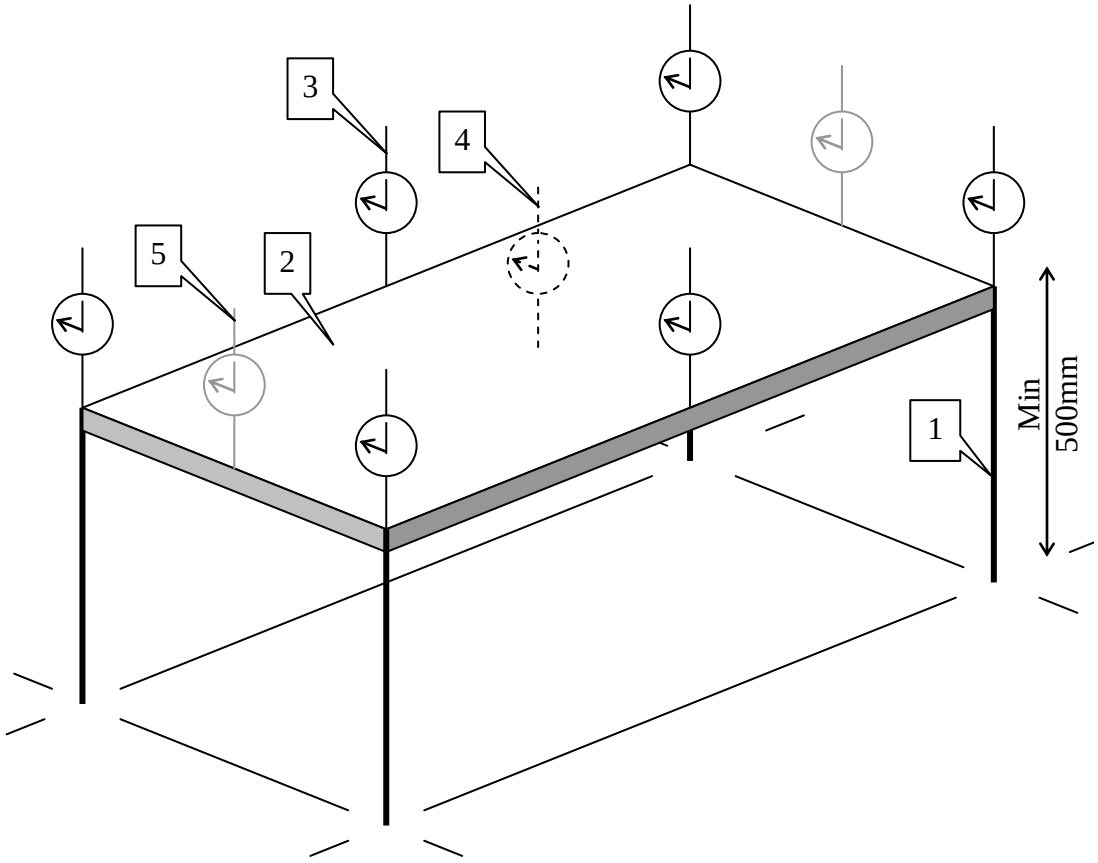


Figure 10 Shelf under vertical loading

KEY

1. Upright
2. Shelf
3. Gauge
4. Gauge (see note 1)
5. Gauge (see note 2)

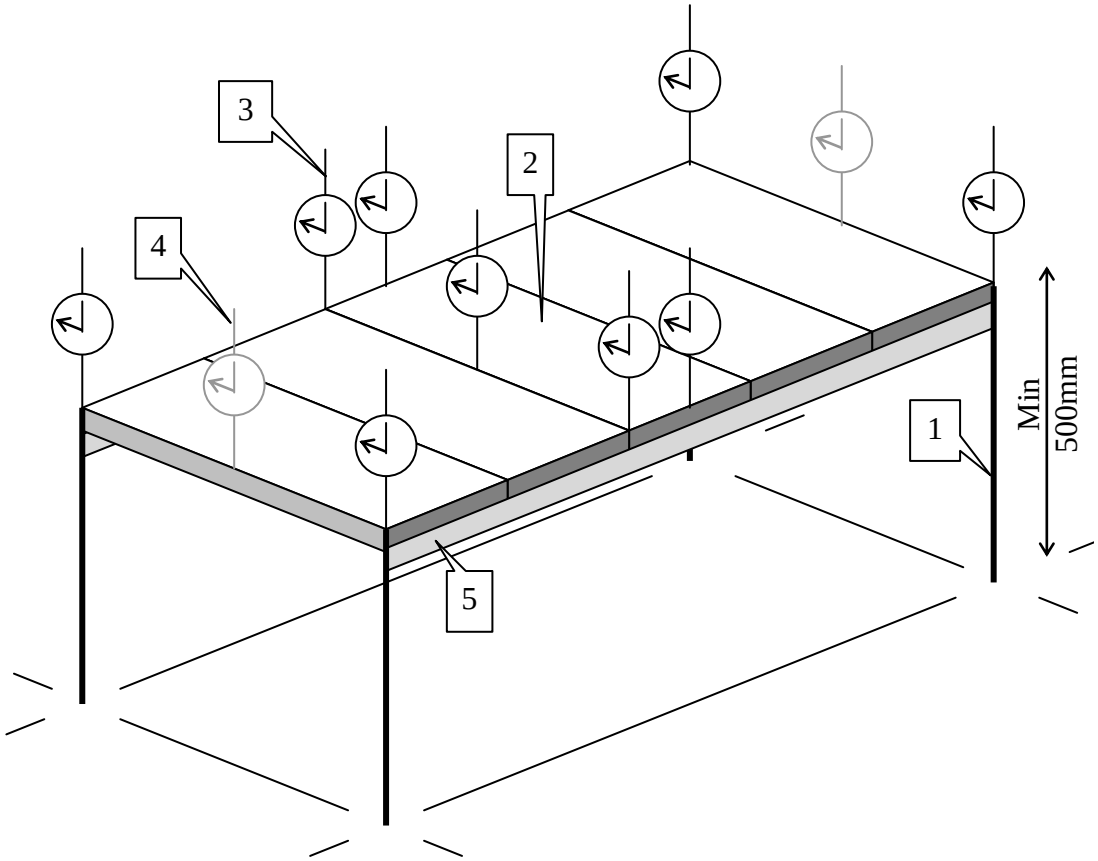


Figure 11 Combined shelf and beam under vertical loading

KEY

1. Upright
2. Shelf panel
3. Gauge
4. Gauge (required if the shelf panel edge details are different)
5. Beam

The following mechanical and dead loading arrangements are considered to be acceptable approximations to a uniformly distributed load.

The load shall be applied as a uniformly distributed load over the whole surface of the shelf.

Load may be applied as dead load or using hydraulic, mechanical or air bag systems (see A2.4).

A2.3 Test Method

The load shall be increased in increments until failure of the shelf occurs. The deflections given in A2.2 shall be recorded at each completed load increment. The failure load shall be the last completed load increment.

NOTE: It is recommended that the load increments should be sufficiently small to generate an accurate load vs. deflection curve. In any case at least 5 load increments should be applied up to the expected service load.

A2.4 Load application

A2.4.1 Dead load

When dead load is used the size of the load units shall be chosen such that unrealistic results are not obtained as a consequence of bridging. If at any stage of the test the load units come into contact then the test result shall be discarded.

The recommended minimum number of load units across the width and in the direction of the span is given in Table 4 and Table 5.

Shelf width	Number of load units
Up to 400mm	2
401mm to 600mm	3
More than 601mm	4

Table 4

Shelf span	Number of load units
Up to 800mm	4
801mm to 1300mm	6
More than 1301mm	8

Table 5

The shelf load obtained from the test shall be corrected for moments or deflection (as appropriate) to represent a uniformly distributed load according to Table 6.

A2.4.2 Mechanical and hydraulic systems

With hydraulic or mechanical systems the load shall be applied as a statically determinate symmetrical array. The recommended minimum number of load units across the width and in the direction of the span is given in Table 4 and Table 5.

The shelf load obtained from the test shall be corrected for moments or deflection (as appropriate) to represent a uniformly distributed load according to Table 6.

NOTE: It is recommended that each concentrated load should be transferred to the shelf via a 75 mm × 75 mm × 5 mm steel plate and a board at least 3mm thick.

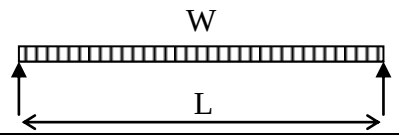
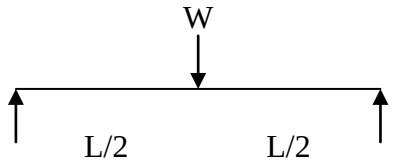
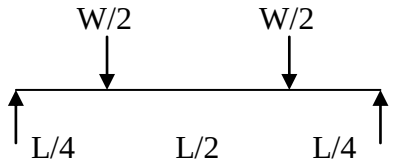
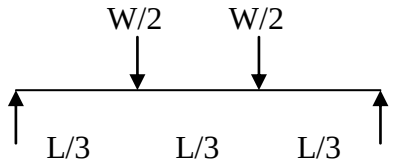
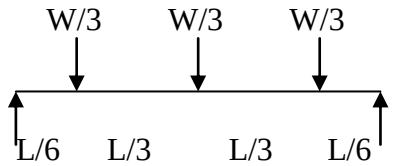
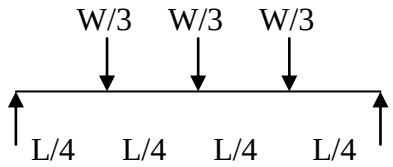
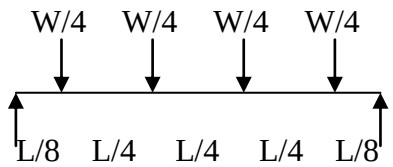
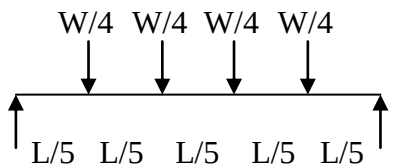
Loading pattern	β_M	β_Δ
	1.0	1.0
	2.0	1.6
	1.0	1.1
	1.33	1.36
	1.11	1.05
	1.33	1.27
	1.0	1.02
	1.2	1.21

Table 6

A2.4.3 Air bag systems

A general arrangement of the test is given in Figure 12. The load shall be measured by load cells and shall not be measured via the pressure in the air bag. The air-bag shall not overhang the edges of the shelf.

NOTE: It is recommended that the air-bag should be as close as possible to the shelf size.

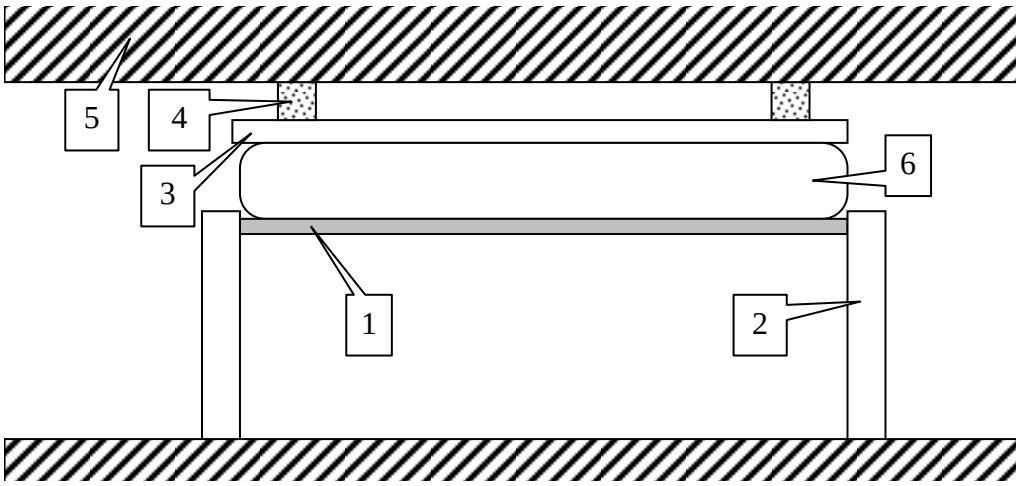


Figure 12 Vertical load induced by an air bag

KEY

1. Test shelf
2. Upright/frame
3. Load spreader
4. Load cells
5. Test frame
6. Air Bag

A2.5 Evaluation of the results

The results from the test shall be adjusted for the effect of variations in material thickness and yield strength.

The deflection value (SLS) shall be corrected for variations in material thickness according to EN 15512 clause 13.3.5 and the value shall be the mean value.

A graph of the load, against the average central deflection of each pair of parallel shelf edges shall be plotted until at least the serviceability limit. In cases with differing edge designs, the lowest value shall be adopted in the design.

$d = d_c – (d_{e1} + d_{e2})/2$

where

d_c is the deflection at the middle of the span

d_{e1} and d_{e2} are the displacements at the supports

The ultimate bearing capacity (ULS) shall be corrected for variations in material thickness and material strength according to EN 15512 clause 13.3.5 and the characteristic value shall be determined according to 13.3.3.

If it is necessary to consider a vertical placement load the corrected ultimate uniformly distributed load from the test shall be reduced by the following factor (see also Figure 13).

NOTE: It is not necessary to apply this factor to the deflection limited load.

$K = 0,9 + 1,8 \cdot a – 0,9 \cdot a^2 \geq 1,00$

where $a = (\text{number of unit loads})^{-1}$ or (length of unit load / shelf length)

If an enhancement of the test load is necessary the recorded deflections shall be reduced by the factor 1/K.

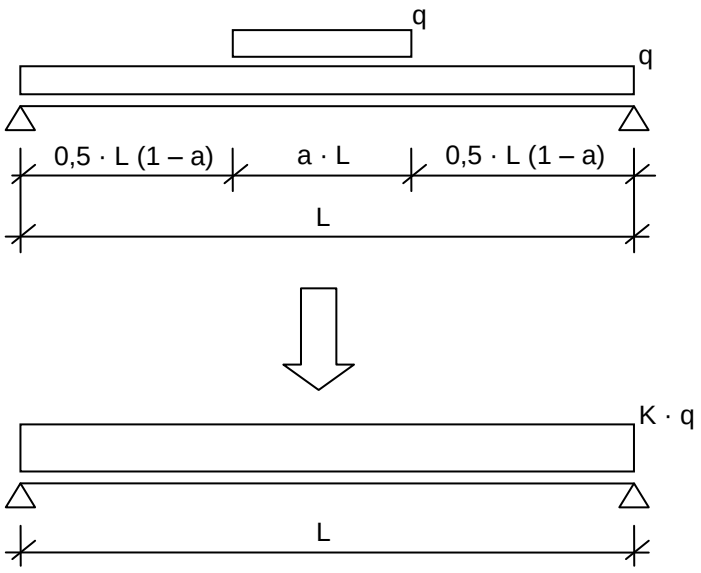


Figure 13 Enhancement of the UDL to consider a vertical placement load

A3 Full scale test

A3.1 Purpose of the test

Full scale tests shall be made to determine the load capacity (strength test) or to verify a target load capacity (acceptance test) of the structure.

The purpose of this test is to determine overall structural behaviour and not the capacity of the shelf itself. The capacity of the shelf is determined from A2.

NOTE: This test is intended to consider overall structural behaviour and not to test the shelf itself. Due to this it is permissible to artificially strengthen the shelves such that they do not fail during this test, thereby potentially reducing the number of tests required. This could be done for example by placing timber sheets on top of the shelves to prevent premature failure. If the shelving is unbraced with the shelves or beams being the active bracing members it is not permissible to strengthen them.

The results of the test may be used to establish the design capacity of the structure tested or of a family of similar standard structures, of which the tested structure is demonstrably the weakest example.

NOTE: Full scale tests carry with them some level of hazard. It is important that the testing Engineer take adequate precautions to prevent uncontrolled collapse of the test structure. This may necessitate the use of a separate restraining structure around the test structure. It is important that this restraining structure does not interfere with the test structure during the test.

A3.2 Test arrangement

The test configuration shall be at least three bays long and single sided, as shown in Figure 14. The height shall be the maximum specified for the product and the beam or shelf span and spacing shall be the most structurally demanding of the range of possible configurations. This normally means that there should be enough fully laden shelves or beams in the test structure to match the load capacity of the upright frame, subject to the limit that the shelf spacing shall not be less than the maximum specified by the manufacturer. Furthermore, the shelves shall be positioned to maximise the distance from the bracing node to any shelf. However, careful consideration should be given to other configurations.

The test arrangement shall ensure that any uprights carrying compression due to the bracing system shall carry the vertical load due to bays on both sides. This does not apply if the system is designed such that every bay is braced.

NOTE: It may be necessary to test more than one configuration.

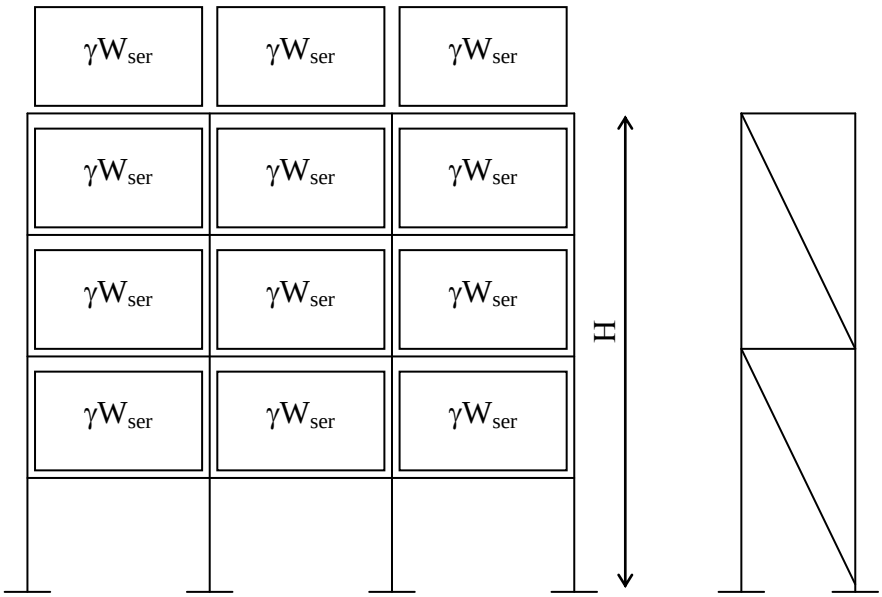


Figure 14 Loaded rack for full scale test

In Figure 14, Figure 15 and Figure 16 the top-most level is intended to be a dust cover, however, for the purpose of this test it shall be fully loaded as a standard shelf.

The initial verticality of each upright shall be measured and included in the test report.

The sway force shall be applied in the direction of the predominant initial out-of-plumb.

NOTE: It is recommended that the test should be installed as vertically as possible as actual non-verticality is included in the test load. Furthermore, all uprights should be leaning in the same direction.

A3.3 Test method

A3.3.1 Material correction factors

In all tests the properties of the steel used in critical components of the test structure shall be measured. Both material thickness and yield strength shall be measured. This may be done on coupons cut from undamaged areas of the tested structure, after the test if desired.

The correction shall be based on the largest correction to the test values for the frame uprights and the relevant bracing system for the direction under consideration (excluding the shelf, baseplate and anchors).

NOTE: Materials may be selected for the test and should be as close as possible to the specified value of thickness and yield strength.

NOTE: Experience shows that variation in material properties of the shelf is not relevant in the stability tests on Low-rise shelving.

A3.3.2 Strength test

The test structure shall be loaded with a combination of shelf loads and horizontal loads in the patterns shown in Figure 14, Figure 15 and Figure 16.

Two separate tests shall be made. In the first test, the horizontal load shall be applied in the cross-aisle direction, as shown in Figure 15, at the topmost position and the horizontal deflection shall be measured at the same position. In the second test, the horizontal load shall be applied in the down-aisle direction, as shown in Figure 16, shared equally between the front and rear faces of the assembly.

The horizontal deflection of both the front and rear faces shall be measured and the most unfavourable shall be used in the test evaluation.

The shelf loads shall be incrementally increased up to the ultimate load resulting in a failure of a part of the structure. The vertical and horizontal loads shall be increased together in the same ratio throughout the test. If the shelving is intended to support a ladder the horizontal load specified in 6.3.4 shall be applied from the start of the test.

The critical deformations shall be observed, and a running plot of such deformations against the load made as a means of monitoring the progress of the test. Observations of deformations should be made at least five regular increments of the load. Where significant non-linearity is observed, the frequency of observation should be increased.

NOTE: It is often advantageous to apply a bedding-down load not exceeding the specified service load for the structure, and then to remove it prior to the start of the test.

The cross-aisle horizontal loads (F_z) shall be 1% of the bay load subject to a minimum value of 0.1 kN and shall be applied at the topmost level.

The down-aisle horizontal loads shall be applied at the topmost level (refer to Figure 17, Figure 18 or Figure 19 for the value of the horizontal load).

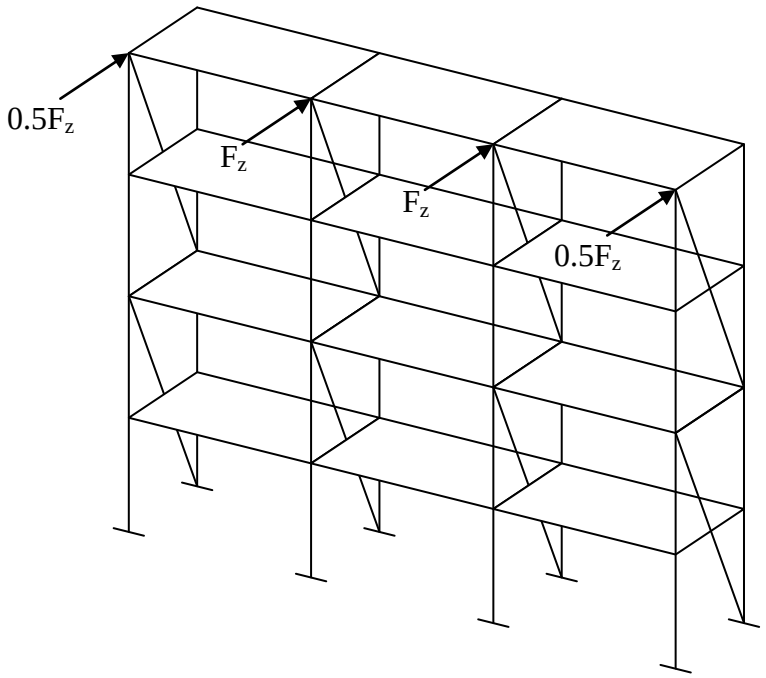


Figure 15 Cross-aisle horizontal loads

$$F_z = \frac{n_s \gamma W_{ser}}{100}$$

Where; n_s = number of shelf levels

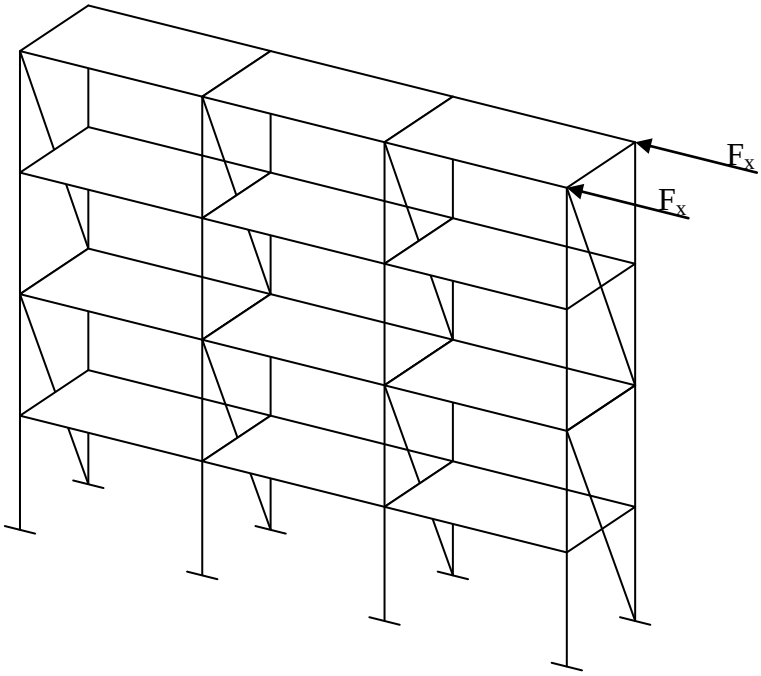


Figure 16 Down-aisle horizontal loads

NOTE: In case of an unbraced system F_x = 0.25%×bay load×number of bays.

Real bracing frequency	F_x	Test set-up
	0.25%×2	
	0.25%×3	
	0.25%×4	
	0.25%×5	
	0.25%×6	
	0.25%×7	
	0.25%×8	

Figure 17 Down-aisle test load depending on the number of bays per bracing

Some systems may comprise only starter bays. Figure 18 gives the appropriate test load.

Figure 18 Down-aisle test load for systems with starter bays only

Some systems may have bracing in every bay. Figure 19 gives the appropriate test load.

Figure 19 Down-aisle test load for systems with bracing in every bay

A3.3.3 Acceptance test

This test shall be carried out to verify a specified load capacity. The test procedure shall be as given for the strength test (A3.3.2) except that the load is not increased to failure but to the target load. In this test the target load is the specified load (W_{ser} in Figure 14) multiplied by the load factor, multiplied by 1.5, and the worst case material correction factor for thickness and material strength according to 13.3.2 (i.e. in Figure 14. γ = γ_f×1.5×material correction×thickness correction).

NOTE: The value of 1.5 above takes into account the effect of possible statistical scatter of the (unknown) failure load.

The horizontal deflection of both the front and rear faces shall be measured and the most unfavourable shall be used in the test evaluation.

Alternatively the simplified test procedure may be used applying the target vertical load in a single load increment followed by the horizontal load.

The target load shall be maintained for at least 30 minutes and the structure should not show any signs of significant distortion. On removal of the load the residual deflection should not exceed 20% of the maximum observed deflection.

It is not necessary to correct the results of this test according to clause 13.3.3.

NOTE: In the case of the acceptance test it is sufficient to carry out a single test for each direction.

NOTE: This acceptance test is not the same as the acceptance test specified in EN1993-1-3.

The test structure shall be loaded with a combination of shelf loads and horizontal loads in the patterns shown in Figure 14, Figure 15 and Figure 16.

NOTE: It is often advantageous to apply a bedding-down load not exceeding the specified service load for the structure, and then to remove it prior to the start of the test.

The cross-aisle horizontal loads (F_z) shall be 1% of the bay load subject to a minimum value of 0.1 kN and shall be applied at the topmost level.

The down-aisle horizontal loads shall be applied at the topmost level (refer to Figure 17, Figure 18 or Figure 19 for the value of the horizontal load).

NOTE: In case of an unbraced system F_x = 0.25%×bay load×number of bays in the test set up.

A3.4 Evaluation of the results

The ultimate loads resulting from the strength test (see A3.3.3) shall be corrected according to 13.3.3.

The sway deflection resulting from a strength test is determined from the mean load deflection curve where the relevant deflection shall correspond to the unfactored load of the shelving configuration, see Figure 20.

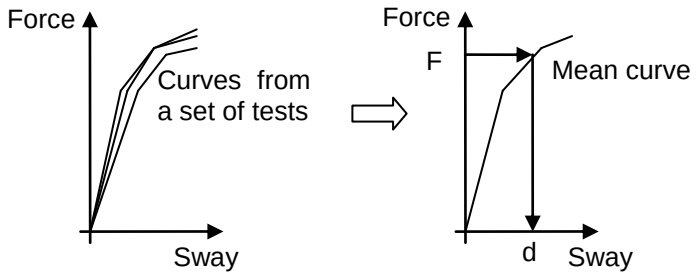


Figure 20 Determination of the sway deflection from a strength test

In the acceptance test the sway deflection shall be determined by dividing the sway under the maximum load applied to the shelving system by 1.5 and the partial safety factor:

$d = d_{test} / \gamma_F$

where

d = sway under nominal load

d_{test} = sway corresponding to the maximum test load

A4 Shelf clip test

Provided that the shelf is supported by standard shelf clips/lugs this is tested by indirect means in the shelf test A2 and A3.

ANNEX B (normative)

TOLERANCES

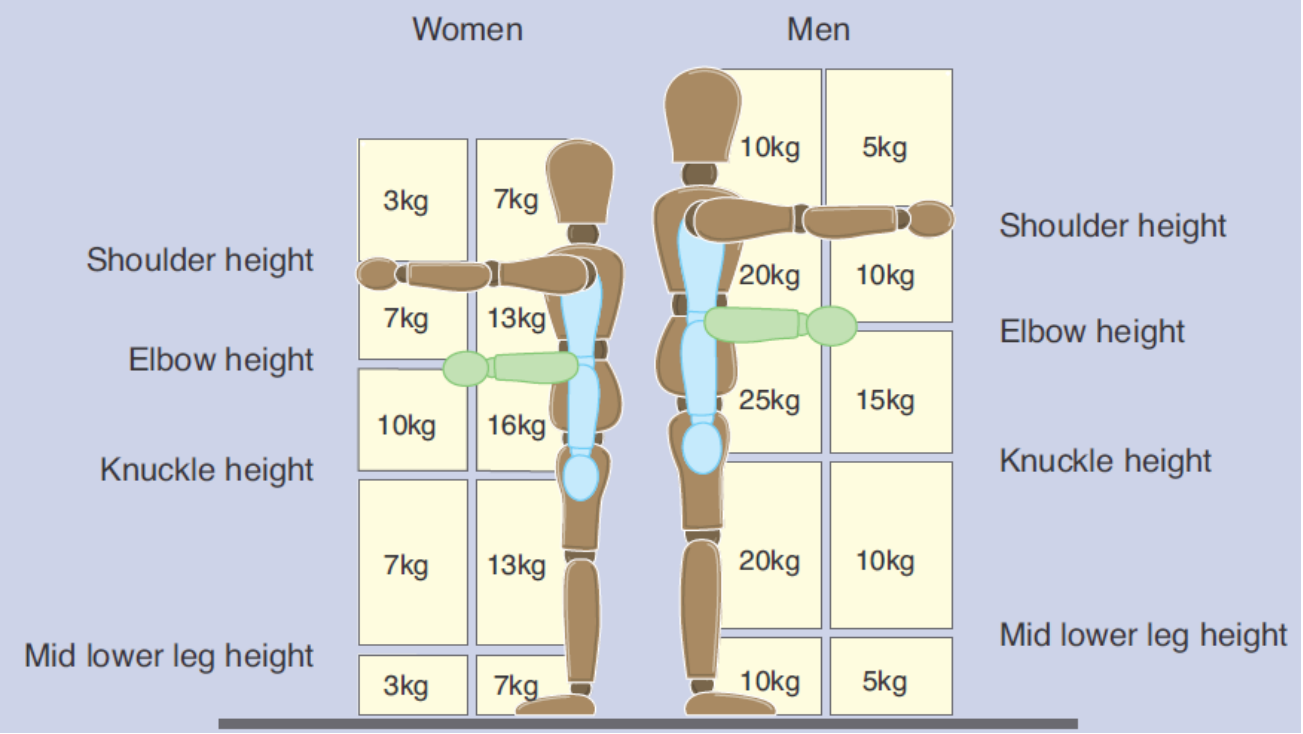
B.1 General

B.1.1 Installation tolerance

The maximum allowed out of plumb in the cross-aisle direction and in the down-aisle direction is H/350.

ANNEX C (informative)

Lifting and lowering limits



Bibliography