AS 4084—1993

Australian Standard®

Steel storage racking

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This Australian Standard was prepared by Committee BD/62, Steel Storage Racking. It was approved on behalf of the Council of Standards Australia on 28 September 1992 and published on 15 February 1993.

The following interests are represented on Committee BD/62:

Association of Consulting Engineers Australia

Australian Institute of Steel Construction

Department of Occupational Health, Safety and Welfare, W.A.

Metal Trades Industry Association of Australia

Queensland University of Technology

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This Standard was issued in draft form for comment as DR 90146.

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First published as AS 4084—1993.

PUBLISHED BY STANDARDS AUSTRALIA
(STANDARDS ASSOCIATION OF AUSTRALIA)
1 THE CRESCENT, HOMEBUSH, NSW 2140

ISBN 0 7262 7889 0

PREFACE

This Standard was prepared by the Standards Australia Committee on Steel Storage Racking in response to several requests from the Australian racking industry, to improve uniformity of racking performance and enhance public safety.

The design aspect of the Standard is based on permissible stress method and is intended to supplement AS 1250 and AS 1538.

Reference has been made to the American Rack Manufacturers Institute Specification (RMI), the British Storage Equipment Manufacturers Association (SEMA) and the European Racking Code FEM 10.2.02.

A Commentary provides background material to the requirements of this Standard.

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STANDARDS AUSTRALIA

Australian Standard

Steel storage racking

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE This Standard sets out minimum requirements for the design (in permissible stress method), fabrication and erection tolerances, test methods, operation and maintenance.

This Standard applies to adjustable static pallet racking made of cold-formed or hot-rolled steel structural members. It covers both the situation where racking is installed within a building and where the racking forms part of the building frame.

The Standard does not cover drive-in and drive-through racking, cantilever racking, mobile racking or racking made of materials other than steel.

1.2 REFERENCED DOCUMENTS The following documents are referred to in this Standard.

AS
1170 SAA Loading Code
1170.2 Part 2: Wind loads

1250 SAA Steel Structures Code

1538 Cold-formed Steel Structures Code

2121 SAA Earthquake Code

1.3 DEFINITIONS For the purpose of this Standard, the definitions below apply.

1.3.1 Adjustable pallet racking—storage system comprising upright frames perpendicular to the aisles and independently adjustable, positive locking shelf beams, spanning between the frames parallel to the aisles, and designed to support unit loads (see Figures 1(a) to 1(c)).

1.3.2 Aisle width—space along which the unit load handling equipment operates (see Figure 2(a)).

1.3.3 Base plate—bearing plate bolted or welded to the underside of the column to transmit vertical and horizontal forces into the floor, and provide structural fastening of the upright frame to the floor.

1.3.4 Bay height—maximum vertical distance from the ground to the highest point of the unit load in a racking structure (see Figure 2(b)).

1.3.5 Bay width—see definition of shelf beam length (see Clause 1.3.24 and Figure 2(b)).

1.3.6 Ceiling clearance—minimum vertical distance between the highest part of the upright frame or the highest part of the unit load on the top shelf beam level and the underside of the ceiling or the support steelwork for the ceiling (see Figure 2(b)).

1.3.7 Closed-face racking—adjustable pallet racking where the unit loads are supported by the shelf beams (see Figure 1(b)).

1.3.8 Columns—vertical members that comprise the upright frame and are subject to compressive forces parallel to their longitudinal axes and have provision for random attachment of shelf beams.

1.3.9 Column protector—component in front of the upright frame that is secured to either the floor or column, or both and designed to resist minor impact loads as specified in Clause 1.6.2 (see Figure 1(a)).

1.3.10 Column width—maximum horizontal distance of an upright frame column measured from flange to flange (outside).

1.3.11 Diagonal brace—diagonal member in the vertical plane to supplement horizontal braces to join columns together and form a trussed upright frame that is rigid and stable, and designed to withstand applied design loads (see Figure 1(b)).

1.3.12 Finished tolerance—tolerance of the unloaded racking after fabrication and erection prior to initial loading.

1.3.13 Fully automatic operation—operation of machines by fully remote controlled robots without manual interference.

1.3.14 Horizontal brace—horizontal member that joins two columns together in an upright frame by bolting or welding (see Figure 1(b)).

1.3.15 Manual operation—operation of machines and positioning of equipment controlled by an operator.

1.3.16 Open-face racking—adjustable pallet racking where the unit loads are supported by stub arms attached to the columns (see Figure 1(c)).

1.3.17 Operating clearance—nominal clearance dimension between static and moving parts to ensure safe operation.

1.3.18 Row length—maximum horizontal length of continuously connected bays in a racking structure and is the sum of column widths plus bay widths.

1.3.19 Row spacer (backtie)—horizontal member, usually bolted to upright frames to maintain distance between upright frames in a double-sided racking layout and designed to resist applied design loads, and provide moment connection between racking, and rigidity to the structure (see Figures 1(a) and 2(a)).

1.3.20 Shelf beam—horizontal member securely locked into the upright frame by means of shelf beam connectors and designed to support vertical loads and resist horizontal loads (see Figure 1(a)).

1.3.21 Shelf beam connector—device welded to the shelf beam ends, secured by means of patented boltless connections or bolted to upright frames and designed to transmit forces into the upright frames and provide stability within the racking structure (see Figure 1(b)).

1.3.22 Shelf beam deflection—maximum vertical distance measured from the beam ends to the lowest point of the beam in a loaded condition.

1.3.23 Shelf beam height—vertical distance from the top to the underside of the shelf beam (see Figure 2(b)).

1.3.24 Shelf beam length—horizontal distance between the inner faces of columns in adjacent upright frames (see Figure 1(a)).

NOTE: This dimension is needed to conveniently manoeuvre pallets into a bay taking into account unit load width and minimum clearances required.

1.3.25 Shelf beam safety device—usually patented positive locking device, secured to the shelf beam connector to prevent dislodgement of the shelf beam from the upright frame when subjected to upward forces.

1.3.26 Tolerance—permissible positive or negative variation from nominal dimension or position resulting from either manufacture or erection, or both.

1.3.27 Unit loads—laden individual pallets or equivalent load modules.

1.3.28 Unit load clearance—distance between unit load and racking component.

1.3.29 Unit load column clearance—maximum horizontal distance from the inside face of the column to the nearest part of the unit load (see Figure 2(b)).

1.3.30 Unit load depth—horizontal dimension of the unit load measured perpendicular to the unit load width (see Figure 2(a)).

1.3.31 Unit load depth clearance—minimum horizontal distance between adjacent unit loads in a double-sided racking situation (see Figure 2(a)).

1.3.32 Unit load height—maximum height measured from the underside of the pallet to the highest point of the unit load (see Figure 2(a)).

1.3.33 Unit load height clearance—minimum vertical distance between the highest point of the unit load and the underside of the shelf beam (see Figure 2(b)).

1.3.34 Unit load overhang—maximum horizontal distance the unit load protrudes beyond the outer face of the racking (see Figure 2(a)).

1.3.35 Unit load width—horizontal dimension of the unit load measured parallel to the operating aisle (see Figure 2(b)).

1.3.36 Unit load width clearance—minimum horizontal distance between adjacent unit loads on a common shelf beam (see Figure 2(b)).

1.3.37 Upright—vertical member (column) of the upright frame.

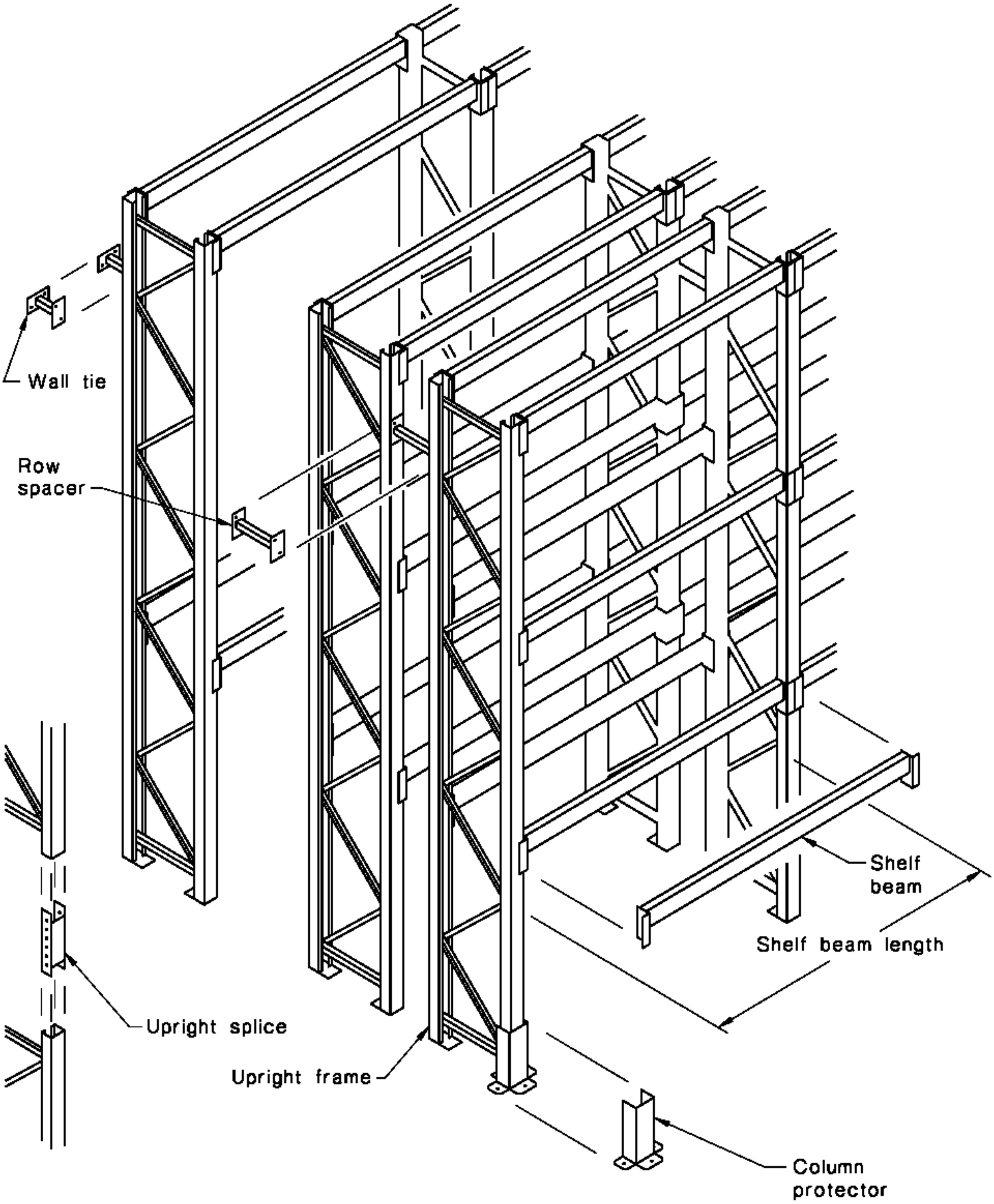
1.3.38 Upright frame—vertical frame assembly composed of uprights and bracings to support design loads transmitted through shelf beams and operating equipment.

1.3.39 Upright frame height—maximum vertical height of an upright frame assembly including baseplates and packing plates (when required).

1.3.40 Upright splice—vertical member used to splice two columns together to form a composite column and designed to support vertical loads and resist horizontal loads (see Figure 1(a)).

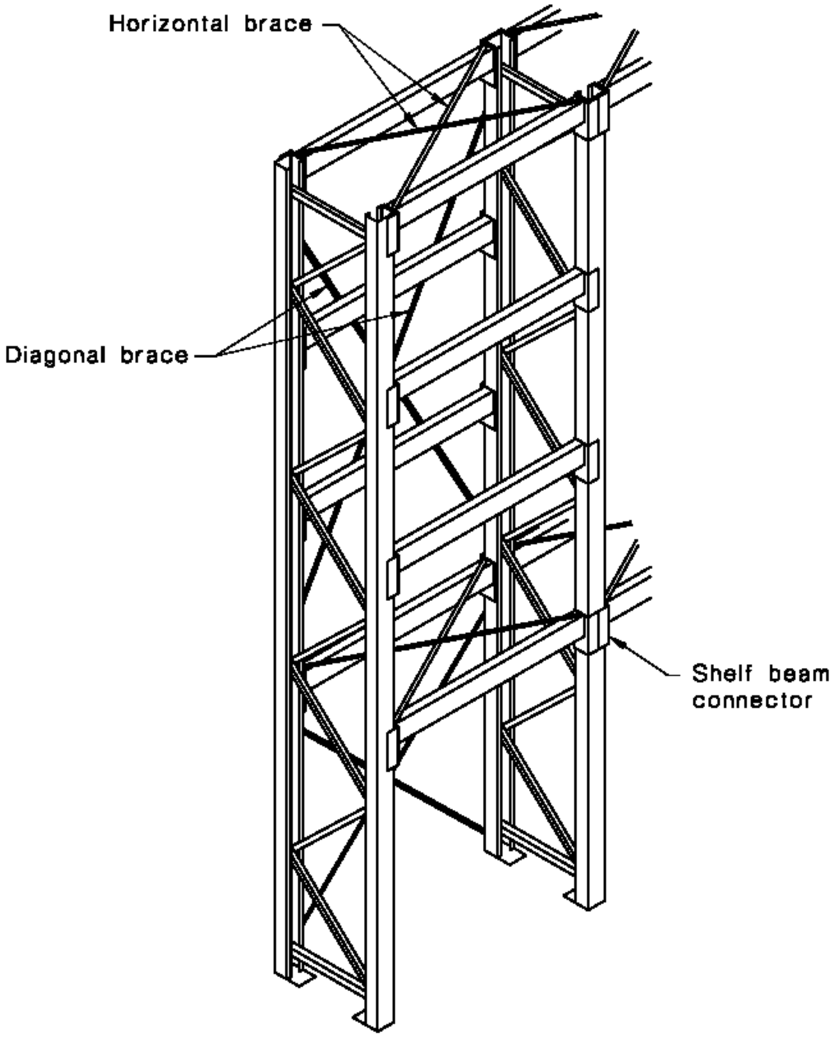
1.3.41 Vertical clearance—minimum vertical distance between the floor and the underside of the lowest shelf beam; or minimum vertical distance between the top of the lower shelf beam and the underside of the upper shelf beam (see Figure 2(b)).

1.3.42 Wall tie (ceiling tie)—horizontal or vertical member that connects the upright to a wall (or ceiling) to provide stabilizing forces and reduce overturning moments (see Figure 1(a)).



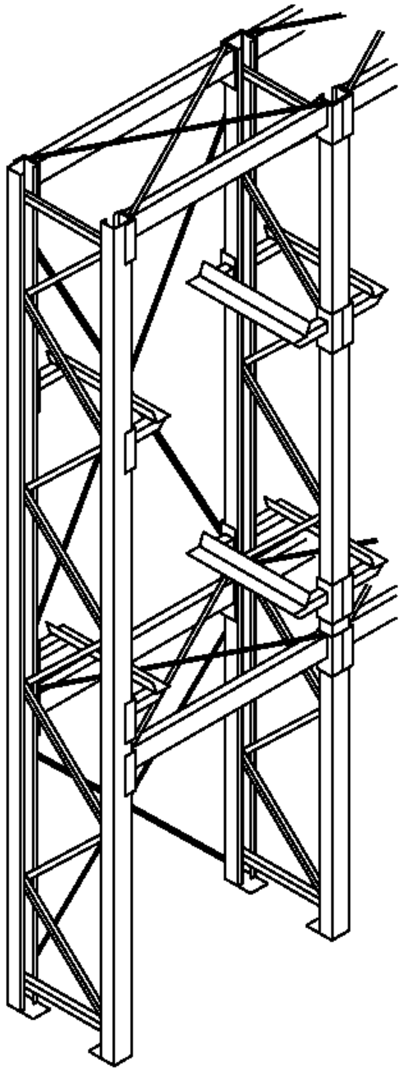
(a) Unbraced racking

FIGURE 1 (in part) ADJUSTABLE PALLET RACKING



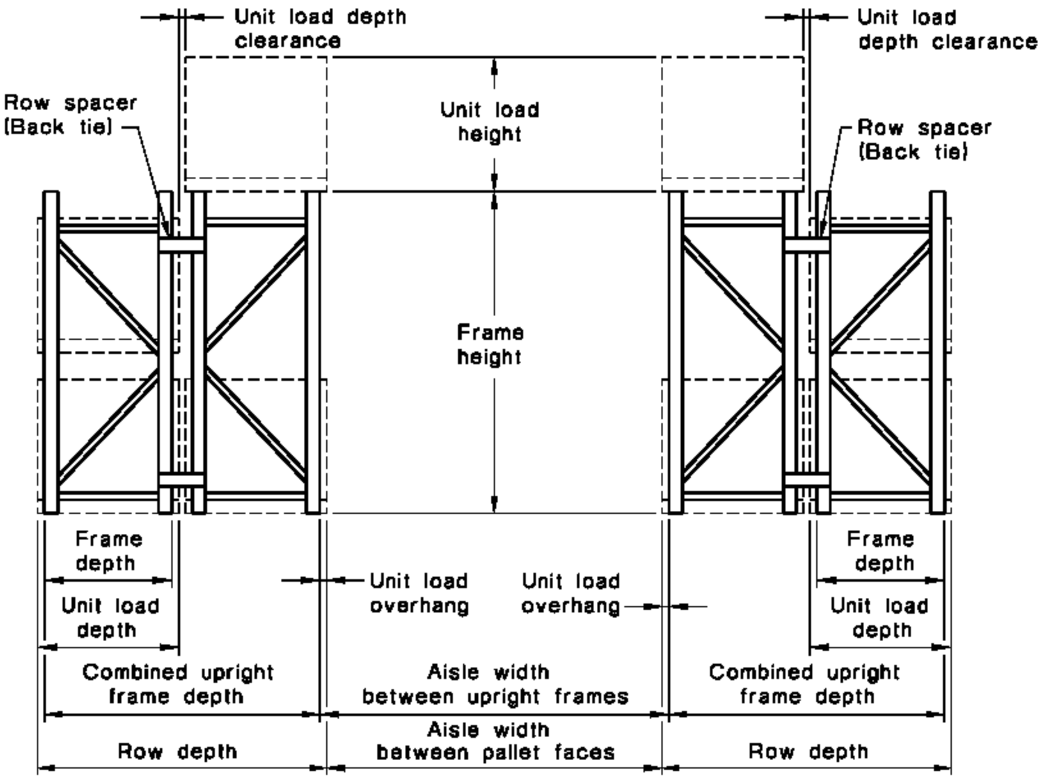
(b) Braced closed-face racking

FIGURE 1 (in part) ADJUSTABLE PALLET RACKING

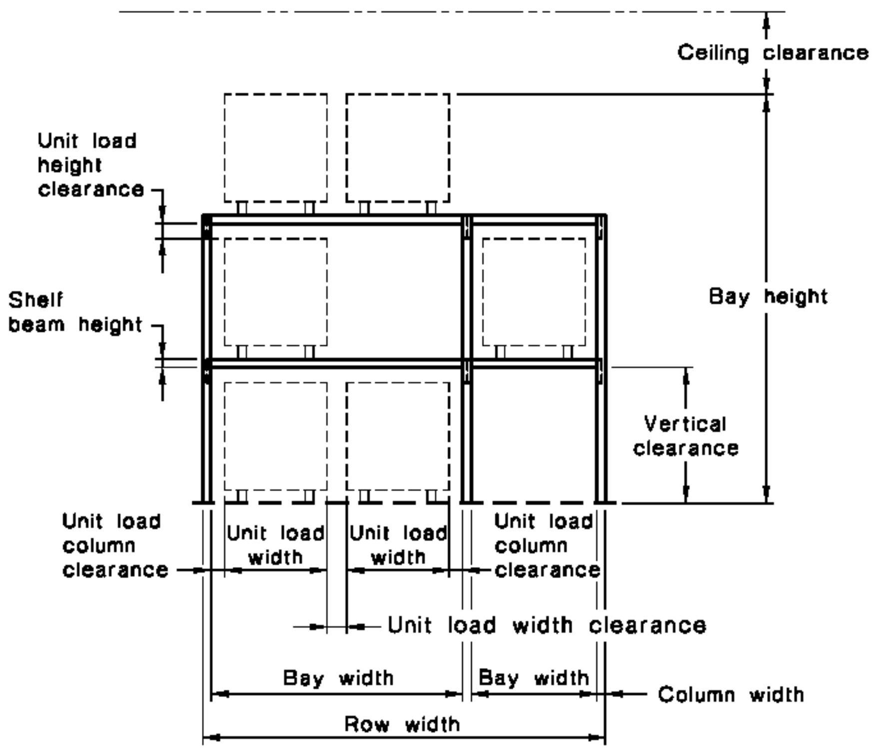


(c) Braced open-face racking

FIGURE 1 (in part) ADJUSTABLE PALLET RACKING



(a) Aisle width and related dimensions



(b) Clearance width and related dimensions

FIGURE 2 DEFINITIONS

1.4 NOTATION Symbols used in this Standard are listed below.

The dimensional units for length and stress in all expressions or equations are to be taken as millimetres (mm) and megapascals (MPa), respectively, unless specified otherwise.

A	=	gross area of cross-section
A_b	=	cross-sectional area of the horizontal brace
A_{corr}	=	net cross-sectional area corresponding to the net section used in calculating $I_{min.}$
A_d	=	cross-sectional area of the diagonal brace
A_f	=	sum of the $A_{net\ min.}$ of the uprights of an upright frame
$A_{net\ min.}$	=	minimum cross-sectional area obtained by passing a plane through the upright normal to the axis of the upright
$A_{x\ corr}$, $A_{y\ corr}$	=	net cross-sectional area corresponding to that net section used in calculating $I_{x\ min.}$, $I_{y\ min.}$, respectively
a	=	vertical distance between the horizontal brace axes
B	=	flange width as shown in Figure 3(a)
B^*	=	full width of flange elements, parallel with flange, including stiffeners
b	=	horizontal distance between the neutral axes of the uprights
C	=	numerical value
D	=	column width as shown in Figure 3(a)
E	=	modulus of elasticity (200 x 10^3 MPa)
F_a	=	maximum permissible average axial compression stress
$F_{a,net\ min.}$	=	maximum permissible axial compression stress to be applied to the full unreduced gross section
F_b	=	maximum permissible bending stress in tension and compression on the extreme fibres of a laterally-unbraced beam
$F_{b,net\ min.}$	=	maximum permissible bending stress to be applied to the full unreduced gross section
F_o	=	elastic flexural or torsional buckling stress
F_{oc}	=	elastic buckling stress in an axially-loaded compression member
F_{od}	=	distortional buckling stress
F_{ox}, F_{oy}, F_{oz}	=	values of F_{oc} for flexural buckling about the x and y axes, respectively or torsional buckling about the z axis
F_Y	=	yield stress of the steel taking into account any variation due to manufacturing processes

F_{Ya} = weighted average yield point

F'_p = maximum permissible bearing stress

f_a = calculated axial stress in a member, equal to the axial force divided by the full cross-sectional area of the member

f_{by} = calculated maximum tensile or compressive stress in a member bent about the *x* and *y* axes. They shall be based on the section moduli about the *x* and *y* axes of the full unreduced gross section

f'_c = characteristic compressive cylinder strength of concrete at 28 days

G = shear modulus of steel (80 000 MPa)

h = total height of upright frame

I = minimum net second moment of area of the uprights of an upright frame about the gravity axis of the upright frame perpendicular to the plane of the upright frame

I_{br} = second moment of area of the horizontal brace about its own axis perpendicular to the plane of the upright frame

I_c = minimum net second moment of area of one upright about its own major axis perpendicular to the plane of the upright frame

$I_{min.}$ = second moment of area of that net section which results in the minimum second moment of area about the axis about which buckling is being considered

I_w = cross-sectional torsion warping constant computed for the gross section assuming sharp corners

$I_{x\ min.}$, $I_{y\ min.}$ = second moment of area of that net section which results in the minimum second moment of area about the *x* and *y* axes, respectively

J = St. Venant torsion constant of the cross-section computed for the gross section assuming sharp corners

K = effective length factor

K_d = buckling coefficient computed for elastic buckling in distortional mode

K_x = effective length factor for buckling about the *x* axis

K_y = effective length factor for buckling about the *y* axis

K_z = effective length factor for torsional buckling

k = factor reflecting the effects of vertical load distribution on an upright frame

L = unsupported length of member

L_{long} = length of the horizontal brace measured between the neutral axis of the uprights

L_{short} = shortest distance between the intersection of the neutral axis of one of the two diagonal braces with the neutral axis of the horizontal brace; or

= shortest distance between the intersection of one diagonal brace with the neutral axis of the horizontal brace to the intersection of the neutral axis of the horizontal brace with the neutral axis of the upright

L_x = length of member unsupported against bending about the x axis

L_y = length of member unsupported against bending about the y axis

L_z = length of member unsupported against twisting

l_x, l_y, l_z = effective lengths for buckling about the x, y and z axes, respectively

n = number of bays which are interconnected

P_{cr} = elastic buckling load for an upright frame

Q = form factor of a compression member including effect of slots for perforation

$Q_{max.}$ = Q for stub upright of thickness $t_{max.}$

$Q_{min.}$ = Q for stub upright of thickness $t_{min.}$

r = radius of gyration of the gross cross-section

r_{o1} = polar radius of gyration of the gross cross-section about the shear centre assuming sharp corners

r_x = radius of gyration of the gross cross-section about the x axis assuming sharp corners

r_y = radius of gyration of the gross cross-section about the y axis assuming sharp corners

S = clear span measured between faces of adjacent uprights

s = stiffener dimension shown in Figure 3(a)

t = nominal steel thickness of any element or section exclusive of coatings

$t_{max.}$ = maximum thickness of stub upright in a series of tests with identical cross-section and hole dimensions and configurations

$t_{min.}$ = minimum thickness of stub upright in a series of tests with identical cross-section and hole dimensions and configurations

W_{fb} = total of all superimposed gravity loads supported by the upright frame at that beam level

W_{tb} = total of all superimposed gravity loads supported by the racking at that beam level

x = principle centroid axis of uprights in the plane of upright frame

y = axis perpendicular to the principle centroid axis

x_o, y_o = coordinates of the shear centre of the cross-section

$Z_{x\ min.}$ = elastic section modulus of the full unreduced gross section

$Z_{x,net\ min.}$ = elastic section modulus of the net effective section calculated with the extreme compression or tension fibre at F_Y

β_x, β_y = monosymmetry section constant about the x and y axes, respectively

η = imperfection parameter

θ = initial out-of-plumb

ν = Poisson's ratio (0.25)

ϕ = angle between horizontal and diagonal braces

ϕ_1 = angular rotation caused by looseness of the beam upright connector or looseness of bracing members due to oversize bolt holes

ψ_o = design value for maximum initial out-of-plumb (deviation from vertical)

Ω = load factor for compression members (1/0.6)

1.5 USE OF ALTERNATIVE MATERIALS OR METHODS This Standard assumes the use of steel of structural quality as specified in AS 1538 for the design of cold-formed steel structural members and AS 1250 for the design of hot-rolled steel structural members. It shall not be interpreted so as to prevent the use of materials or methods of design or construction not specifically referred to herein, provided that the requirements of Section 3 are complied with.

1.6 GENERAL REQUIREMENTS FOR RACKING INSTALLATIONS

1.6.1 General To comply with this Standard, a racking shall comply with all of the following:

(a) The racking installations shall have, in one or more conspicuous locations, a permanent corrosion-resistant plaque not less than 125 mm long and 250 mm high with minimum 25 mm high lettering and mechanically secured to the racking structure at 2.0 m above the floor level, which shall contain the following:

 (i) Racking manufacturer's name and trademark.

 (ii) Safe working unit load.

 (iii) Safe working unit load for each shelf beam level.

 (iv) Safe working total unit load for each bay.

(b) Load application, racking configuration drawings and specification shall be furnished with each racking installation. A notice shall be included on the drawings that deviations from the drawings may impair the safety of the racking installation.

(c) If the racking is required to be used in more than one configuration, drawings shall include each required configuration.

(d) If the maximum damage assumed in the design differs from that given in Figure 7 then values for maximum damage shall be specified in the drawings and specification.

(e) For installations not exceeding 4.5 m in height to the highest shelf beam, covering a floor area less than 300 m^2, not including aisles, and having a unit load not exceeding 10 kN, the requirements of Items (a) to (c) may be waived.

1.6.2 Resistance to minor impact For resistance to minor impacts, the bottom portions of those frames which are exposed to possible impact or collision by forklift trucks or other moving equipment shall either—

(a) include collision protection devices; or

(b) be designed to resist without exceeding the permissible stresses factored by 1.25, a static horizontal force as specified in Item (ii).

In addition, the racking shall be maintained so that all upright sections, whose visible damage exceeds that in Figure 7, shall be immediately unloaded and the damaged portion replaced.

Protection devices shall comply with the following:

(i) Extend from the floor to a level of 300 mm above the floor.

(ii) Resist, without exceeding the permissible stresses and without permanent deformation, a static horizontal force of 10 kN (a minor impact), acting at a level of 250 mm above the floor and in the following non-concurrent directions:

(A) Perpendicular to the aisle from the aisle side of the upright frame.

(B) Parallel to the aisle.

(C) At 45° to the aisle from the aisle side of the upright frame.

(iii) If the protector is connected to the upright by welding or other means, it shall resist the forces in Item (ii) without increasing the stresses in the upright and upright frame above the permissible stresses when the upright frame is supporting the design load.

(iv) Withstand, without structural damage to the upright, the minor impact specified in this Clause as shown by test.

1.6.3 Bracing to building structures If the racking is braced to the building structure, the building structure shall be designed to include the maximum possible horizontal and vertical forces, based on the strength of the attachment, imposed by the racking on the building, calculated for the effects of effective length factors as specified in Clause 5.1.

SECTION 2 LOADS

2.1 DESIGN LOADS Racking shall be designed for the combinations of dead loads, live loads, vertical impact loads, horizontal loads, and wind or earthquake-induced loads, as applicable.

2.2 VERTICAL IMPACT LOADS Beams, supporting arms (if any), and end connections shall be designed for an additional vertical impact load of 25% of one unit load, placed in the most unfavourable position for the particular determination (moment or shear). Such impacts shall not cause stresses greater than the permissible stresses. When permissible loads are determined by test (see Clause 8.3), due allowance shall be made for the additional impact load as specified in this Section. No impact loads need be applied when checking beam deflections (see Clause 8.3) and no impact loads need be considered in designing upright frames, uprights, and other vertical components.

2.3 HORIZONTAL LOADS

2.3.1 General In addition to specific horizontal loads which may be applied to the racking by unit load handling equipment, racking shall be designed to resist the greater of—

(a) horizontal forces due to loading and off-loading, as specified in Clause 2.3.2; and

(b) horizontal forces caused by the eccentricity of the gravity loads resulting from the initial out-of-plumb of the frame, as specified in Clause 2.3.3.

These horizontal forces shall be applied separately, not simultaneously, in each principal direction of the racking in addition to the full vertical load and dead load.

2.3.2 Loading and off-loading (placement loads) Horizontal forces due to loading and off-loading of unit loads and minor impact are given in Table 1. The horizontal force shall be applied at the most unfavourable location.

TABLE 1

HORIZONTAL FORCE DUE TO LOADING AND OFF-LOADING

Manually operated equipment guided by operator	Greater of $\frac{\text{unit load}}{15}$ or 0.50 kN
Manually operated equipment guided by electrical or mechanical devices	Greater of $\frac{\text{unit load}}{20}$ or 0.35 kN
Fully automatic operated equipment guided by electrical or mechanical devices	Greater of $\frac{\text{unit load}}{30}$ or 0.25 kN

2.3.3 Initial out-of-plumb The sum of all horizontal forces at each beam level for the design of the upright frame bracing shall be equal to $\psi_o W_{fb}$, where W_{fb} is the total of all superimposed gravity loads supported by the upright frame at that beam level.

The sum of all horizontal forces for the design of the upright frame bracing shall not be less than 0.5 kN for each braced frame.

The sum of all horizontal forces at each beam level for the design of the racking in the plane of the beams shall be equal to θW_{tb}, where θ is the initial out-of-plumb and W_{tb} is the total of all superimposed gravity loads supported by the racking at that beam level.

The sum of all horizontal forces for the design of the racking in the plane of the beams shall not be less than 1.0 kN on the racking as a whole.

The number of bays or frames which are interconnected, averages the total value of these horizontal forces. This average effect shall be determined from Equation 2.3 for calculating initial out-of-plumb (θ) in radians:

$$\theta = \frac{1}{2}\psi_o\left(1 + \frac{1}{n}\right) + \phi_1 \qquad \ldots\ldots 2.3$$

where

ψ_o = design value for maximum initial out-of-plumb (deviation from vertical), in radians (see Table 2)

n = number of bays which are interconnected

ϕ_1 = angular rotation caused by looseness of the beam upright connector or looseness of bracing members due to oversize bolt holes, in radians

If the bracing connections or the connection between upright and beam show looseness, the angular rotation (ϕ_1) caused by such looseness shall be taken into account as an additional initial out-of-plumb.

In the absence of tests of connector looseness, ϕ_1 shall be taken as 0.01 when calculating the initial out-of-plumb in the plane of the beams. In the absence of tests of connector looseness, ϕ_1 shall be taken as 0.01 when calculating the initial out-of-plumb in the plane of the bracing, unless standard size holes are used for the connections between the uprights and frame bracing, in which case ϕ_1 may be taken as zero.

TABLE 2

DESIGN VALUE FOR MAXIMUM INITIAL OUT-OF-PLUMB (ψ_o)

Radians

Tolerance grade (see Note)	Unbraced	Braced
I	0.01	0.007
II	0.007	0.005
III	0.005	0.0035

NOTE: Tolerance grades are specified in Table 3.

2.4 WIND LOADS Outdoor racking exposed to wind shall be designed for the wind loads acting on the racking plus loaded pallets determined in accordance with AS 1170.2. For stability, consideration shall be given to loading conditions which result in large wind loads combined with small stabilizing gravity loads.

Forces described in Clause 2.3 shall be assumed to act concurrently with wind loads.

2.5 EARTHQUAKE LOADS If required, provisions shall be made for earthquake effects and associated lateral forces determined in accordance with AS 2121. For each such installation, the storage racking shall be designed, manufactured, and installed in accordance with such provisions.

SECTION 3 DESIGN PROCEDURES

3.1 GENERAL All computations for safe loads, stresses, deflections and the like shall be made in accordance with conventional methods of structural design and provisions as specified in AS 1538 for cold-formed steel components and structural systems and AS 1250 for hot-rolled steel components and structural systems, as applicable, except as modified or supplemented by this Standard. In cases where adequate methods of design calculations are not available, calculations shall be substituted by test results obtained in accordance with Section 8 or AS 1538.

The effect of perforations (slots) on the load carrying capacity of compression members is accounted for by the modification of the definition in AS 1538 and the use of the minimum net area instead of the gross area in the relevant calculations described in Section 4. Distortional buckling is accounted for as specified in Clause 4.2.3.4.

3.2 METHODS OF STRUCTURAL ANALYSIS

3.2.1 Upright-frame design Upright frames shall include designs for the critical combinations of vertical and horizontal loads for the most unfavourable positions as specified in Section 2. All moments and forces induced in the uprights by the beams shall be considered. In lieu of the calculation, frame capacity may be established by test according to Clause 8.5.

Connections that cannot be readily analysed shall be capable of withstanding the moments and forces in proper combination as shown by test.

Two methods of analysis of pallet racking structures are presented in this Standard. One of the two shall be used in the design of a pallet racking. The two methods of structural analysis are as follows:

(a) *Linear elastic* The structure shall be analysed in its undeformed configuration using the full section properties of the members and assuming rigid joints. The loads specified in Section 2 shall be used in the analysis. Instability in the direction perpendicular to the upright frames shall be accounted for in the design using the effective lengths set out for flexural buckling in Clause 5.1.2 and for torsional buckling in Clause 5.1.4. Instability in the plane of the upright frame shall be accounted for using the effective lengths set out for flexural buckling in the plane of the upright frames in Clauses 5.1.3 and 5.2. In the calculation of the effective lengths for instability in the direction perpendicular to the upright frames, the flexibility of the joints determined in accordance with Clause 8.4.2 shall be used.

    Adequate stiffness of the racking structure in the direction perpendicular to the upright frames shall be determined accounting for the flexibility of the joints.

    The horizontal deflection of the structure shall be calculated using the joint flexibility determined from Clause 8.4.2.

    The total deflection shall not exceed $h/200$.

(b) *Non-linear (second order) elastic* The structure shall be analysed in its deformed configuration accounting for the deformations of the joints. The full section properties of the members shall be used in the analysis. The flexibility of the beam-to-upright connections, determined in accordance with Clause 8.4.2 with a load factor of 1.67, shall be used in the analysis. The flexibility of the base plate connections determined by test or a rational analysis shall be used in the analysis. The loads set out in Section 2 shall be used but factored by 1.67.

The uprights shall be designed in accordance with the provisions of this Standard except that effective length factors greater than 1.0 need not be used and the moments, shears and axial forces derived from the second-order analysis shall be divided by 1.67. The moments in the beam-to-upright connections shall not exceed the values determined from test as specified in Clause 8.4.1.

3.2.2 Beams Beams shall be analysed as simply supported, or by rational analysis when partial end-fixity is considered.

Where the shape of the beam cross-section and the end connection details permit, permissible loads of pallet-carrying beams shall be determined by conventional methods of calculation according to AS 1538 or AS 1250, as applicable.

At working load (excluding impact), the deflections shall not exceed 1/180 of the span measured with respect to the ends of the beam.

3.3 OVERTURNING The safety factor against overturning of the racking structure in any direction shall be not less than 1.5. Overturning shall be considered for the most unfavourable combination of vertical and horizontal loads. Stabilizing forces provided by the anchors to the floor are not considered in checking overturning, unless anchors and floor are specifically designed and installed to resist these uplift forces.

SECTION 4 DESIGN OF COLD-FORMED STEEL ELEMENTS AND MEMBERS

4.1 ELEMENTS Effective width calculated for a compression element in accordance with AS 1538 shall not exceed the total net width of the element. Net effective section properties shall be calculated as specified in Clause 4.2.

4.2 MEMBERS

4.2.1 Section properties Exceptions to the provisions of AS 1538 for computing the section properties are given in Clauses 4.2.2 and 4.2.3.

4.2.2 Flexural members The maximum permissible bending stress (F_b) specified in AS 1538 shall be modified to $F_{b,net\ min.}$ as follows:

$$F_{b,net\ min.} = F_b \left(\frac{Z_{x,net\ min.}}{Z_{x\ min.}} \right) \quad \ldots\ 4.2.2$$

where

$F_{b,net\ min.}$ = maximum permissible bending stress to be applied to the full unreduced gross section

$Z_{x,net\ min.}$ = elastic section modulus of the net effective section calculated with the extreme compression or tension fibre at F_Y

$Z_{x\ min.}$ = elastic section modulus of the full unreduced gross section

The modified maximum permissible bending stress ($F_{b,net\ min.}$) shall be applied to the full unreduced gross section. In the calculation of the elastic flexural or torsional buckling stress (F_o) in accordance with AS 1538, the section properties shall be based on the full unreduced gross section considering round corners except for J, b_x, r_{o1} and I_w which shall be based on the full unreduced gross section and computed assuming sharp corners.

Inelastic reserve capacity (see AS 1538) shall not be considered for perforated members.

4.2.3 Axially-loaded compression members

4.2.3.1 *General* The maximum permissible average axial compression stress (F_a) specified in AS 1538 shall be modified to $F_{a,net\ min.}$ as follows:

$$F_{a,net\ min.} = F_a \left(\frac{A_{net\ min.}}{A} \right) \quad \ldots\ 4.2.3.1(1)$$

where

$F_{a,net\ min.}$ = maximum permissible axial compression stress to be applied to the full unreduced gross section

$A_{net\ min.}$ = minimum cross-sectional area obtained by passing a plane through the upright normal to the axis of the upright

A = gross area of cross-section

The modified maximum permissible axial compression stress ($F_{a,net\ min.}$) shall be applied to the full unreduced gross section. The Q factor specified in AS 1538 shall be determined experimentally in accordance with Clause 8.2.

The imperfection parameter (η) specified in AS 1538 may be reduced to:

$$\eta = 0.5\,(1.25 - Q)\,QF_y / F_{oc} \qquad \ldots\ 4.2.3.1(2)$$

where

Q = form factor of a compression member including effects of slots for perforation

F_Y = yield stress of the steel taking into account any variation due to manufacturing processes

F_{oc} = elastic buckling stress in an axially-loaded compression member

4.2.3.2 *Sections not subject to torsional or torsional-flexural buckling* In the calculation of F_{ox}, F_{oy} in AS 1538, the following applies:

$$r_x = \sqrt{(I_{x\ min}/A_{x\ corr})} \qquad \ldots\ 4.2.3.2(1)$$

$$r_y = \sqrt{(I_{min.}/A_{y\ corr})} \qquad \ldots\ 4.2.3.2(2)$$

where

$I_{x\ min.}$, $I_{y\ min.}$ = second moment of area of that net section which results in the minimum second moment of area about the x and y axes, respectively

$A_{x\ corr}$, $A_{y\ corr}$ = net cross-sectional area corresponding to that net section used in calculating $I_{x\ min.}$, $I_{y\ min.}$, respectively

4.2.3.3 *Doubly symmetric or monosymmetric sections subject to torsional-flexural buckling* In the calculation of F_{ox}, F_{oy}, F_{oz} in AS 1538, the section properties shall be based on the full unreduced gross section considering round corners except for J, x_o, y_o, r_{o1} and I_w which shall be based on the full unreduced gross section and computed assuming sharp corners.

4.2.3.4 *Monosymmetric sections subject to distortional buckling* For monosymmetric sections subject to distortional buckling, such as lipped channel uprights with additional rear flanges (with or without stiffeners), the value of F_a in AS 1538 shall be the lesser of—

(a) F_a calculated in accordance with AS 1538; or

(b) $$F_a = \frac{F_{od}}{\Omega} \quad \text{for} \quad F_{od} \le \frac{F_Y}{2} \qquad \ldots\ 4.2.3.4(1)$$

$$F_a = \frac{F_Y}{\Omega}\left(1 - \frac{F_Y}{4F_{od}}\right) \quad \text{for} \quad F_{od} > \frac{F_Y}{2} \qquad \ldots\ 4.2.3.4(2)$$

where

F_{od} = elastic distortional buckling stress of the gross section

Ω = load factor for compression members
= 1/0.6

F_{od} may be calculated using either of the following methods:

(i) $$F_{od} = \frac{K_d \pi^2 E}{12(1 - \nu^2)\left(\frac{B^*}{t}\right)^2} \quad \text{. . . . 4.2.3.4(3)}$$

where

K_d = buckling coefficient computed for elastic buckling in the distortional mode (a typical case is shown in Figure 3(b))

E = modulus of elasticity (200 x 10^3 MPa)

ν = Poisson's ratio (0.25)

B^* = full width of flange elements, parallel with the flange, including stiffeners (see Figure 3)

t = nominal steel thickness of any element or section exclusive of coatings, in millimetres

(ii) A rational elastic buckling analysis of the gross section accounting for rounded corners.

NOTE: Guidance in using such a buckling analysis to calculate the elastic distortional buckling stress (F_{od}) may be found in the following references:

1 HANCOCK, G.J., Distortional buckling of steel storage rack columns, *Journal of Structural Engineering*, ASCE, Vol. 111, No. 12, December 1985, p. 2770-2783.

2 LAU, S.C.W. and HANCOCK, G.J., Distortional buckling formulas for channel columns, *Journal of Structural Engineering*, ASCE, Vol. 113, No. 5, May 1987, p. 1063-1078.

4.3 COMBINED BENDING AND COMPRESSION All the parameters in the interaction equations (see AS 1538) shall be determined with the modifications specified below.

f_a = calculated axial stress in a member, equal to the axial force divided by the full cross-sectional area of the member

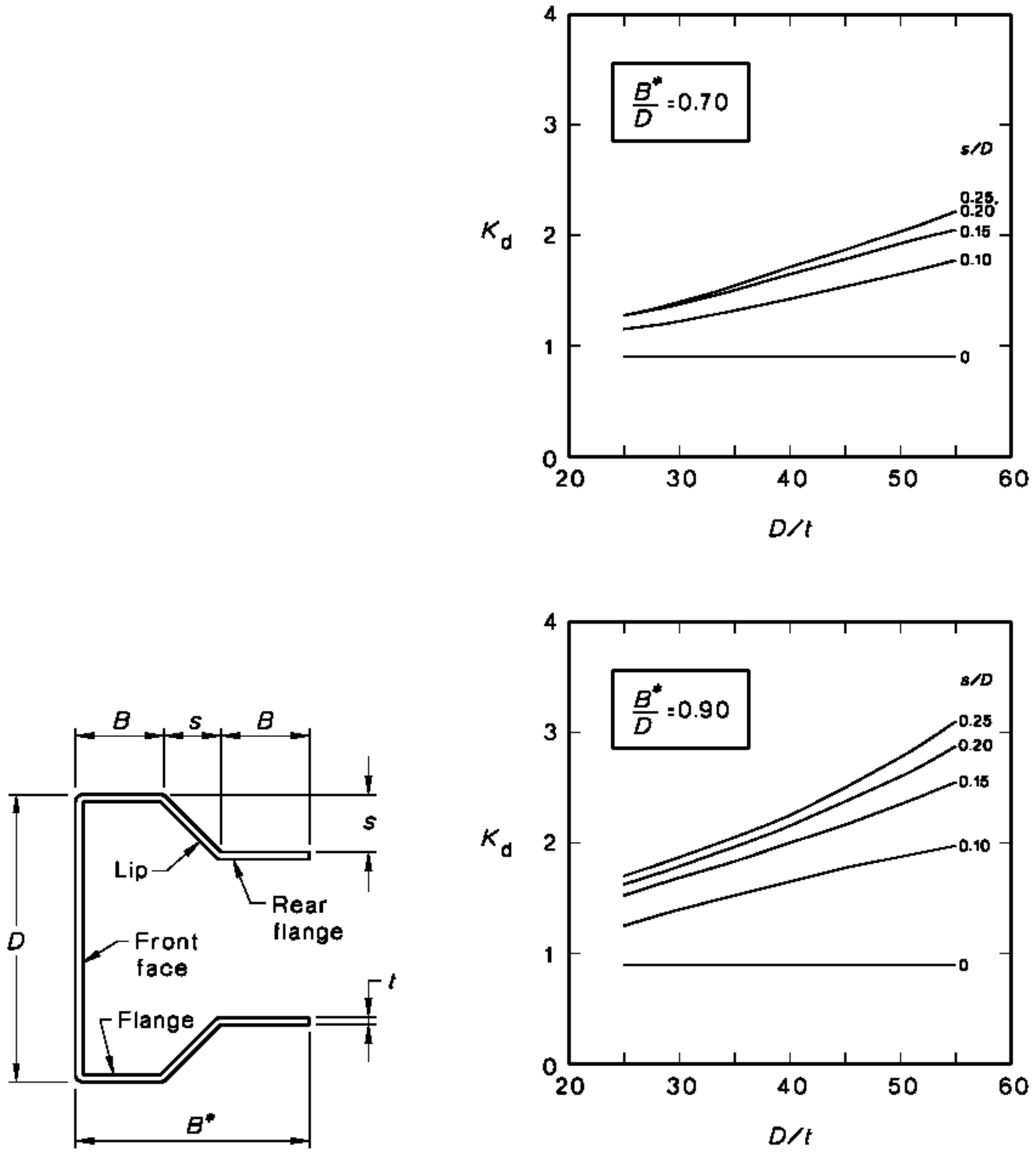
f_{by} = calculated maximum tensile or compressive stress in a member bent about the *x* and *y* axes. They shall be based on the section moduli about the *x* and *y* axes of the full unreduced gross section

F_a = $F_{a,\text{net min.}}$ specified in Clause 4.2.3.1

F_{bx}, F_{by} = $F_{b,\text{net min.}}$ specified in Clause 4.2.2 about the *x* and *y* axes, respectively

F_{ox}, F_{oy} = elastic flexural buckling stresses specified in AS 1538 with r_x, r_y determined in accordance with Clause 4.2.3.2

F_{bxo}, F_{byo} = $F_{b,\text{net min.}}$ specified in Clause 4.2.2 with F_b equal to $0.60F_Y$



(a) Section geometry

(b) Distortional buckling coefficient (K_d)

FIGURE 3 TYPICAL SECTION GEOMETRY AND DESIGN CHART

SECTION 5 UPRIGHT FRAME STABILITY

5.1 EFFECTIVE LENGTH FACTORS

5.1.1 General Effective length factors for uprights are those specified in Clauses 5.1.2 to 5.2 or as determined by a rational analysis or tests.

5.1.2 Flexural buckling in the direction perpendicular to the upright frames

5.1.2.1 *Racking not braced against side-sway* For adjustable pallet racking and for the portion of the upright between the bottom beam and the floor as well as between the beam levels, the effective length factor (K_x) shall be equal to 1.7 or as otherwise determined by rational analysis or tests.

5.1.2.2 *Racking braced against side-sway* The effective length factor (K_x) for adjustable pallet racking is equal to 1.0 provided that racking have diagonal bracing in the vertical plane and have either a rigid and fixed top shelf, or diagonal bracing in the horizontal plane of the top fixed shelf. Increased upright capacity may be achieved by any additional rigid and fixed shelves or bracing in the horizontal plane. The unsupported length (L) is defined as the distance from the floor to affixed shelves or braced shelves. The effective length is K_xL. If there is no bracing in the vertical plane of the racking, the K_x values shall be the same as for racking not braced against side-sway (see Clause 5.1.2.1).

5.1.3 Flexural buckling in the plane of the upright frames

5.1.3.1 *Upright frames with non-intersecting diagonal and horizontal braces* For upright frames having diagonal braces or a combination of diagonal and horizontal braces that intersect the uprights, the effective length factor (K_y) for the portion of the upright between braced points is equal to 1.0, provided that the maximum value of the ratio of L_{short} to L_{long} does not exceed 0.15.

L_{short} or L_{long} is defined as the distance between the intersection of the neutral axis of the upright with the neutral axis of either two adjacent diagonals, or a diagonal and a horizontal.

In an upright frame with diagonals and horizontals, L_{short} and L_{long} refer to the minimum and maximum distances between two adjacent segments and between two adjacent horizontals. In an upright with only diagonals, L_{short} and L_{long} refer to two adjacent segments. All distances are measured along the neutral axis of the upright (see Figure 4(a)).

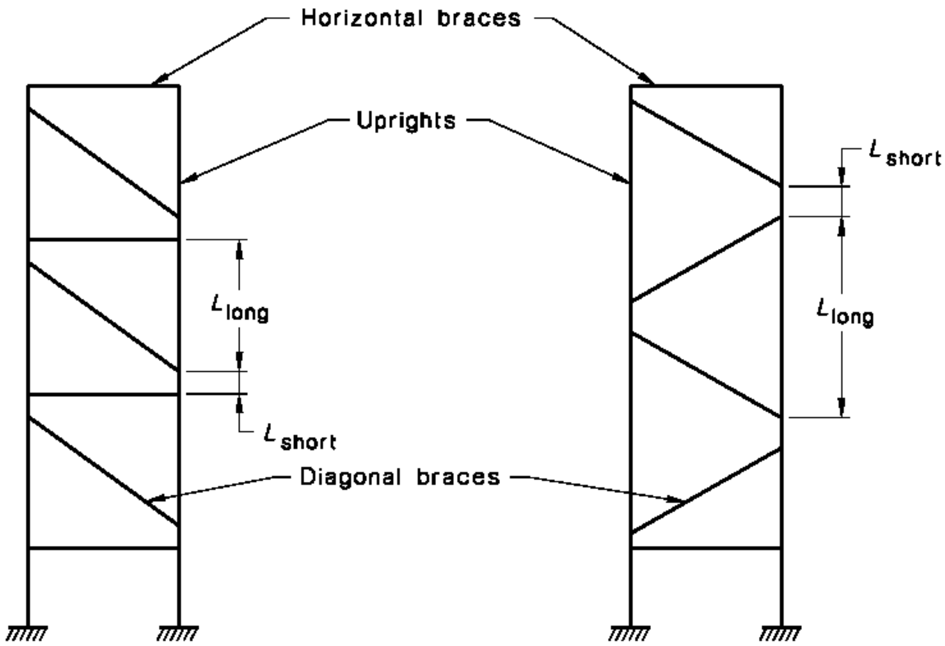
5.1.3.2 *Upright frames with intersecting diagonal and horizontal braces* For upright frames having diagonal braces that intersect the horizontal braces, the effective length factor (K_y) for the portion of the upright between braced points is equal to 1.0 provided that the ratio of L_{short} to L_{long} does not exceed 0.12.

L_{short} is defined as the shortest distance between the intersection of the neutral axis of one of the two diagonal braces with the neutral axis of the horizontal brace, or the shortest distance between the intersection of one diagonal brace with the neutral axis of the horizontal brace to the intersection of the neutral axis of the horizontal brace with the neutral axis of the upright (see Figures 4(a) and 4(b)).

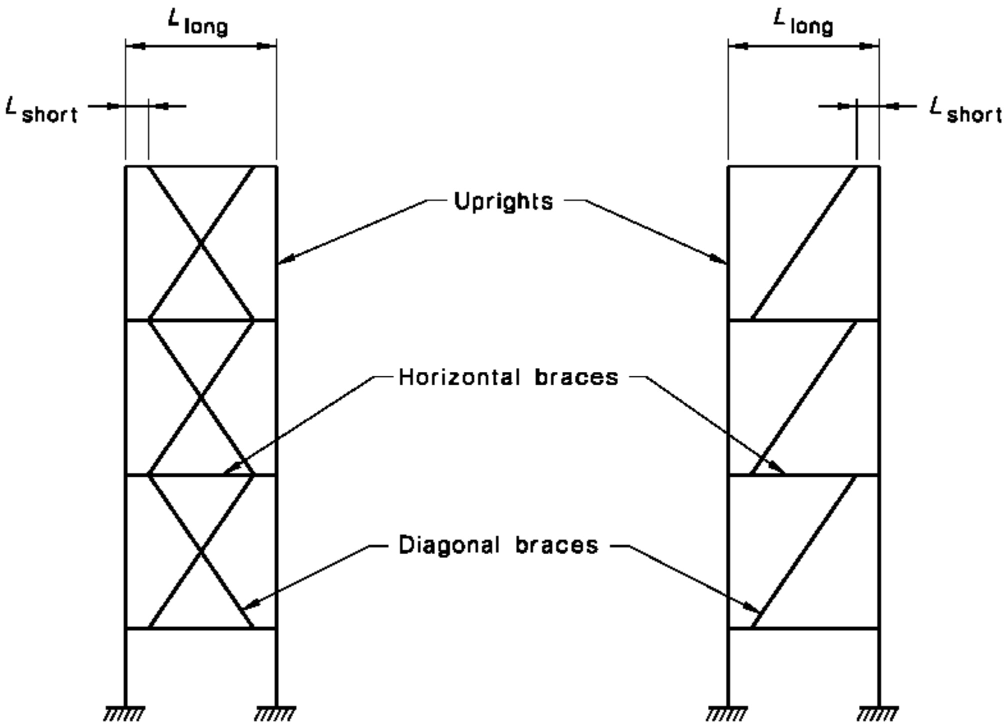
L_{long} is defined as the length of the horizontal brace measured between the neutral axis of the uprights (see Figures 4(a) and 4(b)).

All measurements are along the neutral axis of the horizontal brace.

For upright frames having bracing patterns not included in this Clause, the effective length factor (K_y) of the upright shall be determined by rational analysis or by upright frame test.



(a) Non-intersecting diagonal and horizontal braces



(b) Intersecting diagonal and horizontal braces

FIGURE 4 UPRIGHT FRAME WITH DIAGONAL AND HORIZONTAL BRACES

5.1.4 Torsional buckling The effective length factor for torsional buckling (K_z) can be taken as 0.8 provided that the connection details between the uprights and the braces are such that the twisting of the upright is prevented at the brace points. If the connection details are not appropriate, K_z can be larger and shall be determined by rational analysis or test.

5.1.5 Compression diagonals and horizontals For compression diagonals and horizontal members of trussed-braced upright frames, the effective length factor for torsional buckling (K_z) shall be taken as 1.0.

5.2 STABILITY OF TRUSSED-BRACED UPRIGHT FRAMES To prevent tall and narrow trussed-braced upright frames from becoming unstable and buckling in their own plane, the maximum permissible compression stress in the upright of such upright frames shall be determined from the appropriate provisions of AS 1538 or AS 1250 for a value l_y/r_y or l/r, respectively, calculated as follows:

$$\frac{l_y}{r_y} \text{ or } \frac{l}{r} = \sqrt{\left(\frac{\pi^2 E A_f}{P_{cr}}\right)}$$

For upright frames braced with diagonals and horizontals—

$$P_{cr} = \frac{\pi^2 EI}{k^2 h^2}\left[\frac{1}{1 + \frac{\pi^2 I}{k^2 h^2}\left(\frac{1}{A_d \sin\phi \cos^2\phi} + \frac{b}{a A_b}\right)}\right] \quad \text{.... 5.2(1)}$$

For upright frames braced with diagonals only—

$$P_{cr} = \frac{\pi^2 EI}{k^2 h^2}\left[\frac{1}{1 + \left(\frac{\pi^2 I}{k^2 h^2}\ \frac{1}{A_d \sin\phi \cos^2\phi}\right)}\right] \quad \text{.... 5.2(2)}$$

For upright frames braced with horizontals only, and with fully rigid connections—

$$P_{cr} = \frac{\pi^2 EI}{k^2 h^2}\left[\frac{1}{1 + \frac{\pi^2 I}{k^2 h^2}\left(\frac{ab}{12 I_{bx}} + \frac{a^2}{24 I_c}\right)}\right] \quad \text{.... 5.2(3)}$$

where

k = factor reflecting the effects of vertical load distribution on an upright frame

= 1.1 if the centre of gravity of the loads along the upright frame is below midheight

= 1.6 if the centre of gravity is below the upper third-point of the height

= 2.0 if the centre of gravity is above the upper third-point of the height

SECTION 6 CONNECTIONS AND BEARING PLATES

6.1 GENERAL Adequate strength of connections to withstand the calculated resultant forces and moments, and adequate rigidity where required, shall be established by test or, where possible, by calculation. Test procedures for various connections are specified in Section 8.

6.2 BEAM SUPPORT CONNECTIONS Beams shall have connection locking devices (or bolts) capable of withstanding an upward force of 5 kN per connection without failure or disengagement.

6.3 BASE PLATES The bottom of all uprights shall be furnished with base (bearing) plates to transfer upright loads and moments into the floor. These forces and moments shall be consistent in magnitude and direction with the racking analysis.

Unless otherwise specified, the maximum permissible bearing stress (F'_p) on the bottom of the plate shall be determined as follows:

$$F'_p = 0.7f'_c \qquad \text{. . . . 6.3}$$

where f'_c is the characteristic compressive cylinder strength of the concrete floor at 28 days which shall be assumed to be 20 MPa unless otherwise determined.

Once the required bearing area has been determined from the permissible bearing stress (F'_p), the minimum thickness of the base plate shall be determined by a rational analysis or by an appropriate test using a test load 1.5 times the design load.

6.4 CONNECTIONS TO BUILDINGS Connections of racking to buildings, if any, shall be such that reactions or displacements of the buildings will not damage the racking (see also Clause 1.6.3).

6.5 UPRIGHT SPLICES In any type of compression joint where the ends of the members are square cut for bearing over the whole of the cut area, upright sections shall be spliced to hold the connected members accurately in place and in alignment, and to resist any tension where bending occurs.

Where such members are not in bearing over the whole of the cut area, the joint shall be designed to transmit all the forces and moments.

An upright section shall not be spliced below the lowest beam level on the front face of a racking.

SECTION 7 TOLERANCES AND CLEARANCES

7.1 FINISHED TOLERANCES IN UNLOADED CONDITION The finished tolerances of pallet racking in unloaded condition shall be as specified in Table 4 for the tolerance grades specified in Table 3.

NOTE: Tolerance grades are governed by the type of unit.

TABLE 3

TOLERANCE GRADE

Tolerance grade	Type of unit load handling equipment
I	Manually operated equipment guided by operator
II	Manually operated equipment guided by electrical or mechanical devices
III	Fully automatic operated equipment guided by electrical or mechanical devices

TABLE 4

FINISHED TOLERANCES

Type of tolerance (see Figure 5)	Description	Tolerance, mm		
		Tolerance, grade		
		I	II	III
A	Maximum variation in individual bays. Total cumulative deviation in racking length (nA = total deviation, where n is the number of bays)	±3 ±3	±3 ±3	±3 ±3
B	Maximum out-of-plumb upright perpendicular to the plane of the upright frames	1/500	1/750	1/1000
C	Racking depth (single or multiple frames)	±5	±5	±5
D	String depth	±5	±5	±5
E	Rail positioning with regard to the pallet racking measured as the difference between the values at the top and bottom of the upright frames	±5	±5	±5
F	Maximum form imperfection of upright with regard to the theoretical longitudinal upright *x* or *y* axis	1/1000	1/1000	1/1000
G	Maximum out-of-plumb of upright in the plane of the upright frame	1/500	1/750	1/1000
H	Distance between top of base plate and lowest beam level	±15	±10	±5
I	Maximum deviation of beam level or portal level with regard to the lowest beam level or crane rail level	± 1/250	± 1/500	± 1/1000

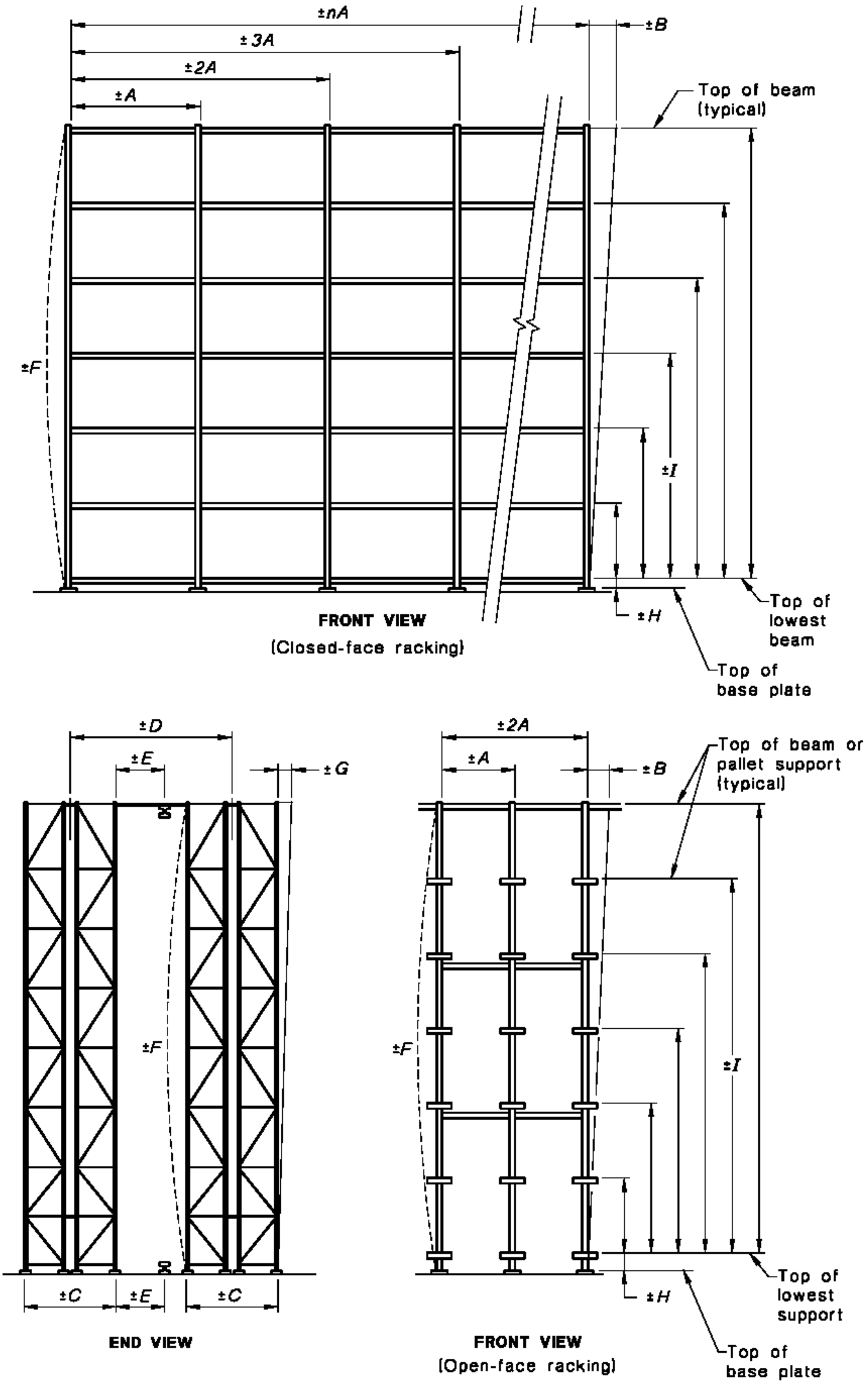
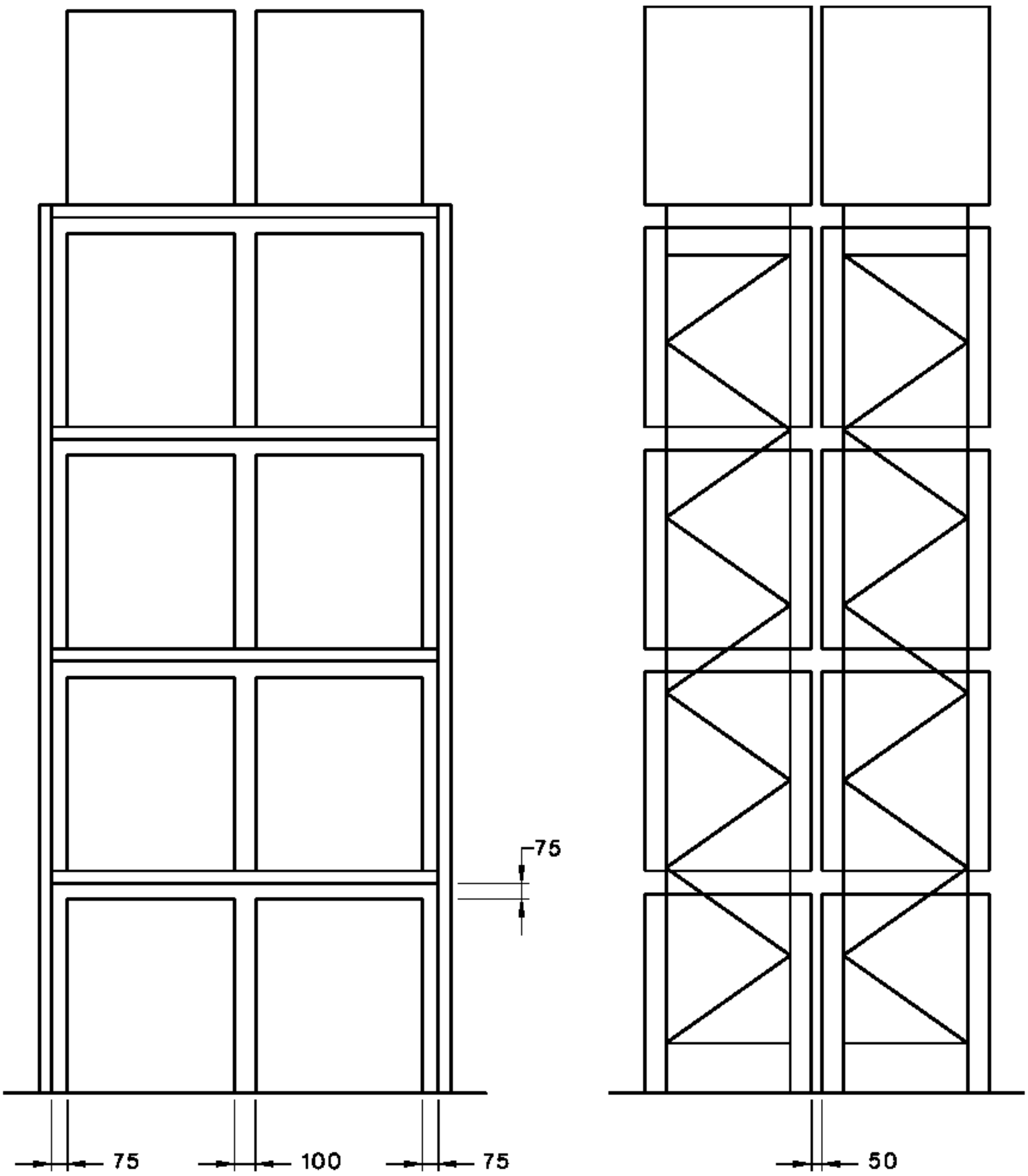


FIGURE 5 TYPES OF TOLERANCES

7.2 UNIT LOAD CLEARANCES Unit load clearances shall be as shown in Figure 6.

NOTE: Clearance (vertically and horizontally) may be reduced in installations utilizing automatic unit load handling equipment.



DIMENSIONS IN MILLIMETRES

FIGURE 6 UNIT LOAD CLEARANCES

SECTION 8 TEST METHODS

8.1 INTRODUCTION

8.1.1 General Material properties as determined in accordance with applicable test procedures in AS 1250 apply. For this purpose, tensile coupons are taken, after the completion of testing, from flat portions of the specimen at regions of low moment and shear.

If the effect of cold-work and finishing cure schedules are to be accurately accounted for by test, the test specimens shall be formed and subjected to the same curing procedure as is used or contemplated in the prototype. This is essential because different manufacturing methods and finishing processes produce different amounts of cold working and thermal exposure (e.g. cold working of a specimen by brake-pressing is less than in a cold-roll formed prototype).

Test specimens shall be fully described prior to testing and any dents or other defects shall be noted and the condition of welds, if any, inspected and described. All cross-sectional dimensions of each specimen shall be measured prior to testing at several points along the length and photographs of specimens shall be taken prior to, during, and after testing.

NOTE: The purpose of these tests is for design and not for purchase acceptance tests.

8.1.2 Testing apparatus and fixtures The tests shall be carried out in a testing machine or by means of hydraulic jacks in a test frame or by application of measured weights. The testing machine or load-measuring apparatus shall comply with the requirements of AS 1250 and AS 1538.

The mass of load distribution beams and other fixtures shall be measured and included in evaluating the test data.

8.1.3 Instrumentation Dial gauges or other deflection measuring devices are required at appropriate points to obtain proper alignment and to measure load-deflection behaviour accurately. The deflections shall be measured and reported to an accuracy of 1 mm.

Strain gauges may be used if behaviour characteristics other than ultimate loads and load-deflection relations are desired. Extensometers shall be used for coupon tests.

For members subject to twisting (such as channels and zeds), the twist angle shall be measured.

8.1.4 Reduction and presentation of test data For each test, the report shall include the following:

(a) A sketch of the specimen with all dimensions.

(b) A sketch of the test set-up with all dimensions, including locations and kinds of gauges, loading and support arrangements and an identification of the loading apparatus, such as testing machine, jacks, with information on the range used and the smallest increment readable for that range.

(c) The results of the coupon tension tests shall be presented in the form of a table of elongation versus load or, alternatively, strain versus stress. Yield stress and ultimate strength shall be determined by any of the methods prescribed in AS 1250 and AS 1538.

NOTE: It is desirable to include stress-strain curves in the data presentation.

(d) For presentation of the results of the test, all load, deflection and other recorded data shall be reduced to actual values by correcting, where appropriate, for initial readings, weights of loading apparatus, e.g. loading beams.

These reduced measurements shall be presented in tables showing load versus the particular measured quantity, e.g. deflection, strain. In these same tables, observations of special events, such as flange buckling, connection failure, shall be noted at the particular load at which they occurred.

NOTE: Graphic presentation of load deformation curves is advisable, at least for the mid-span deflections. Depending upon observations made during the test and on inspection of tabulated data, graphic presentation of selected or all other load deformation data is desirable.

8.1.5 Evaluation of test for determining structural performance Tests shall be evaluated in accordance with AS 1538 except as otherwise noted.

8.2 STUB COLUMN TESTS

8.2.1 Test specimen and procedure The form factor (Q) of perforated compression members shall be determined by stub upright tests as described in AS 1538. The ends of the stub upright shall be milled flat (to tolerance of +0.025 mm) and perpendicular to the longitudinal axis of the upright. The axial load shall be applied by flat plates bearing (not welded or otherwise connected) against the milled ends. For the purposes of determining Q, only the ultimate strength of the stub upright needs to be determined.

8.2.2 Evaluation of test results The form factor (Q) shall be calculated as follows:

$$Q = \frac{\text{Ultimate compressive strength of stub upright by test}}{F_Y A_{\text{net min.}}} \quad \ldots . \; 8.2.2.1(1)$$

where

F_Y = actual yield stress of the upright material if no cold work effects are to be considered; or the weighted average yield point F_{Ya}, calculated in accordance with AS 1538, if cold work effects are to be considered, in megapascals

$A_{\text{net min.}}$ = minimum cross-sectional area obtained by passing a plane through the upright normal to the axis of the upright, in square millimetres

In no case shall the form factor (Q) be greater than 1.0.

Where a series of sections with identical cross-sectional dimensions and identical hole dimensions and locations are produced in a variety of thicknesses, stub upright tests need to be made only for the largest and the smallest thicknesses ($t_{\text{max.}}$ and $t_{\text{min.}}$). Q values for intermediate thicknesses shall then be determined by interpolation according to the following equation:

$$Q = Q_{\text{min.}} + \frac{(Q_{\text{max.}} - Q_{\text{min.}})(t - t_{\text{min.}})}{(t_{\text{max.}} - t_{\text{min.}})} \quad \ldots . \; 8.2.2(2)$$

where

Q = form factor for the intermediate thickness t

$Q_{\text{min.}}$, $Q_{\text{max.}}$ = form factors obtained by test in accordance with this Clause for the smallest ($t_{\text{min.}}$) and largest ($t_{\text{max.}}$) thicknesses, respectively

This interpolation is permissible only if the yield stresses of the two test specimens do not differ by more than 25% and if the yield points of the intermediate thicknesses fall between or below those of the test specimens.

8.3 PALLET BEAM TESTS

8.3.1 Simply supported pallet beam tests

8.3.1.1 *General* These tests are acceptable only for beams that are not subject to significant torsional stresses or distortions.

The simply supported pallet beam test shall be made if only the flexural behaviour parameters such as yield moment, ultimate moment and the effective rigidity (*EI*) are to be determined. For the latter parameter, tests shall be conducted on two identical specimens unless a third test is required as specified in Clause 8.3.1.4. If lateral restraints are required, the beams shall be tested in pairs as they would be used in completed assemblies.

8.3.1.2 *Test set-up* The test set-up consists of a beam test specimen simply supported at each end (not connected to uprights). The test load is applied to a load distribution beam which in turn imposes a load at two points on the beam specimen. Each load point on the beam test specimen is set at a distance of *S/C* from the support, where *S* is the span, in millimetres, and *C* is a numerical value between 2.5 and 3.

Plates shall be used to prevent local failure at supports or at load points.

8.3.1.3 *Test procedure* After alignment, a small initial load of about 5% of the expected ultimate load shall be applied to the test assembly to ensure firm contact between the specimen and all loading and support components. At this load, initial readings shall be taken from all gauges. Loads shall then be applied in increments no larger than about one fifth of the expected design load. Readings shall be taken for all load increments.

NOTE: It is good practice to plot load versus mid-span deflection readings at each load increment during testing.

Noticeable deviation from straightness of such a plot will indicate incipient inelastic behaviour or local buckling or crippling. When such is the case, load increments shall be reduced to no more than half the initial increments.

NOTE: It is good practice to measure permanent set for loads within the interval of 25% of the expected design load by reducing, within this interval, the ratio of the applied load to the initial load after each increment. Appropriate gauge readings are to be taken at this reduced load to determine permanent set.

When deflection increments for given load increments increase rapidly, this indicates the approach of ultimate failure load. If sudden failure is possible because of the nature of the specimen, and if such sudden failure may damage the gauges, they shall be removed.

On the other hand, if a gradual failure is expected, such as by simple yielding, it is desirable to measure at least centre-line deflections right up to and past the maximum or ultimate load, to obtain some part of the descending portion of the load deflection curve.

All specific events noticeable by visual inspection, such as local buckling, crippling or failure of connections, shall be recorded at the loads at which they occur.

8.3.1.4 *Evaluation of test results* The parameters investigated shall be determined from the test results by conventional methods.

The flexural rigidity shall be calculated on the basis of the results of two tests of identical specimens provided that the deviation from the average value does not exceed 10%. If the deviation from the average value exceeds 10%, then a third identical specimen shall be tested. The average of the two lower values obtained from the tests shall be the result of the series of tests.

8.3.2 Pallet beam in upright frames assembly tests

8.3.2.1 *General* This test is intended to simulate the conditions in the actual racking as closely as possible to determine the permissible load.

8.3.2.2 *Test set-up* The test assembly shall consist of two upright frames not bolted to the floor and two levels of pallet beams with front-to-back ties when specified.

The upright frame may be as high as desired. However, the bottom-level beams shall be tested and shall be located so there will not be less than 610 mm clear between the test beams and the floor or between the test beams and the top-level beams.

The end connections shall be those used in the prototype.

The location of the test loads perpendicular to the beams shall simulate the actual loading.

If loads are to be applied by pallets or other devices resting on beams, it is important that friction between pallet and beam be reduced to the minimum possible amount by greasing or other means.

NOTE: This is recommended because new dry pallets on new dry beams when used in the test could provide considerably more bracing than pallets and beams worn smooth in use and possibly covered with a film of oil.

The minimum instrumentation for such tests consists of devices for measuring the deflections of both beams at mid-span relative to the ends of the beams. One way of doing this is to attach a scale graduated to 0.25 mm at mid-span of each beam and to stretch a tight string (usually a string with a rubber band at one end) attached to each end of the beam. Another way is to use dial gauges at mid-span and at each end of the beams. Surveyor levels may also be used to read scales located at mid-span and at the ends of the beams.

Additional instrumentation, such as strain gauges or additional dial gauges at the ends of the beam, is needed only if special problems are to be considered. For highly unsymmetrical beams, e.g. deep channels or C-sections, it may be advisable to measure rotation under load. This is most easily done by rigidly attaching a protractor of sufficient size to the beam at or close to mid-span. A vertical string weighted at the end and acting as a plumb is then read against the protractor at every load increment.

8.3.2.3 *Test procedure* The test procedures specified in Clause 8.3.1.3 shall be used.

8.3.2.4 *Evaluation of test results* The permissible load shall be the lowest of the following:

(a) One-half of the ultimate test load carried by the beam.

(b) Two-thirds of the load at which harmful or objectionable local distortions are observed in the connections or elsewhere. These distortions include rotations of such magnitude as to render the beam unserviceable.

(c) The load (not including impact) at which maximum vertical deflections attain 1/180 of the span, measured with respect to the ends of the beams.

The number of tests for determining design loads shall be as specified in AS 1538.

Once the design load has been determined as specified in Clauses 8.3.1.1 to 8.3.2.4, any additional tests shall be made using a new set of specimens. An initial load equal to the design load shall be applied, reduced to zero and the deflection read. This deflection reading shall be the zero reference reading. A load equal to 1.5 times the design load shall then be applied and the deflection read. The load shall then be held constant for 15 minutes and the deflection read again. This deflection reading shall not exceed the previous reading by more than 5%. The load shall then be reduced to zero and the residual or permanent deflection read. The net residual deflection of the beam shall not exceed 15% of the final deflection measured at 1.5 times the design load. If these limitations are not met, the design load shall be reduced accordingly or the source of residual deflections determined and remedied, and the test repeated with new specimens.

8.4 PALLET BEAM TO COLUMN CONNECTION TESTS

8.4.1 Cantilever test

8.4.1.1 *General* This test is for determining the connection moment capacity.

8.4.1.2 *Test set-up* The test set-up shall consist of a pallet beam at least 660 mm in length connected to the centre of an upright at least 760 mm in length. Both ends of the upright shall be rigidly connected to rigid supports. The load shall be applied to the pallet beam at 610 mm from the face of the upright. At this load application point, a dial gauge shall be mounted to measure deflections.

8.4.1.3 *Test procedure* The test procedure specified in Clause 8.3.1.3 shall be used.

8.4.1.4 *Evaluation of test results* The permissible moment shall be determined in a manner similar to that specified in Items (a) and (b) of Clause 8.3.2.4.

8.4.2 Portal test

8.4.2.1 *General* This test shall be used to obtain a joint spring constant needed for a semirigid frame analysis.

8.4.2.2 *Test set-up* The test set-up shall consist of two upright frames supported on four half-round bars, one under the base of each upright, two beams the top of which are installed at a distance of 610 mm from the floor, and including front-to-back ties when specified. The half-round bars shall be located on the centroidal axes of the uprights perpendicular to the beams. Extra plates shall be placed between the base plates and the half-round bars, if necessary. The bases of the uprights shall be held against lateral displacement but not against rotation.

8.4.2.3 *Test procedure* After the racking is assembled, a load equal to the design load of the beams shall be placed on the beams, simulating usual loading. Horizontal forces equal to the load up to twice the horizontal design load corresponding to the vertical load on the assembly shall be applied to the assembly in increments, equally distributed between the two uprights on one side, at the level of the top of the beams, and in the direction of the beams. Deflection due to the horizontal loading shall be measured at the level of the top of the beams.

8.4.2.4 *Evaluation of test results* The spring constant and looseness shall be determined by rational analysis.

8.5 UPRIGHT FRAME TEST

8.5.1 General The upright frame tests are intended to simulate the conditions in the actual racking as closely as possible. The purpose of the test is to determine the permissible upright frame loads for an expected upright failure that takes place between the floor and the bottom beam or between the two lower beams in a three beam-level test set-up. The test shall account for vertical and horizontal loads as specified in Clause 2.3 as well as the effects of semirigid connections. This procedure is also applicable to Clauses 2.4 and 2.5 with adjustments to take into account modified loads and increased permissible stresses.

8.5.2 Horizontal load in the direction perpendicular to the upright frame

8.5.2.1 *Test set-up for symmetrical loading condition* The test assembly shall consist of three upright frames not bolted to the floor, and at least two levels of beams connecting the frames together to make two bays of pallet racking. When the distance from the floor to the first beam is smaller than the distance between beams, then three levels of beams shall be used.

The vertical spacing of the beams shall be the same as in the actual application. The upright frame may be as high as desired. However, its construction consisting of upright and truss web members shall be of the same cross-section, pattern and spacing as in the actual application. The top beam level and its upright connection shall be heavier or reinforced to the degree necessary to carry the test load to the point where the frame fails. The remaining beams and their connections shall be as in the actual application. This test load represents the loading from two or more beam levels.

Horizontal loads shall be applied perpendicular to one outside upright frame at the centre-line of the beam connection by means of either hydraulic cylinders or by ropes and pulleys with hanging weights attached. The load at each beam level shall be applied equally to each upright of the upright frame.

To measure horizontal displacements, one scale shall be located at the centre-line of each beam level, one scale mid-height between each beam level, and another scale mid-height between the bottom beam level and the floor. All scales shall be placed on one upright.

8.5.2.2 *Test procedure for symmetrical loading condition* The test procedure for upright frames shall be determined as follows:

(a) Align the racking structure so that it is level and plumb, and that all components are properly seated.

(b) Take initial scale readings.

(c) Place a vertical load equal to 1.5 times the beam design load on each of the lower beam levels.

(d) Take scale readings for horizontal movement.

(e) Apply a horizontal load to the upright frame at each level of beams. The horizontal load shall be determined in accordance with Clause 2.3.

(f) Take scale readings for horizontal movement.

(g) Apply one additional unit of vertical load to the reinforced top level beams only and take scale readings for horizontal movement.

(h) Apply one additional unit of horizontal load to the reinforced top level beams only. Take scale readings for the horizontal movement. If hydraulic cylinders are used, be sure the hydraulic cylinder at the bottom beam level is always applying the proper force to the upright frame.

(i) Repeat Steps (g) and (h) until failure occurs in the upright frame.

8.5.2.3 *Evaluation of test results for symmetrical loading condition* The permissible vertical load for an upright frame based on combined vertical and horizontal loads shall be the tested ultimate load divided by 2. The tested ultimate load shall be the last set of test data which has an equal number of both vertical and horizontal load increments.

The tested ultimate load shall be the lowest of the three tested conditions, namely symmetrical loading as specified in Clause 8.5.2.1, unsymmetrical loading as specified in Clause 8.5.2.4, or for the horizontal load in the direction parallel to the upright frame as specified in Clause 8.5.3.

8.5.2.4 *Test set-up and test procedure for unsymmetrical loading condition* The test set-up and test procedure for unsymmetrical loading condition shall be as specified in Clauses 8.5.2.1 and 8.5.2.2, except that no load shall be placed on one beam-level in one bay directly adjacent to the expected upright failure location. The direction of the horizontal load shall be in the direction of the side-sway.

8.5.3 Horizontal load in the direction parallel to the plane of upright frame

8.5.3.1 *Test set-up* The test set-up shall be as specified in Clause 8.5.2.1 except that the locations of horizontal loads and scales shall be changed so that the horizontal loads and displacements are in the plane of the upright.

8.5.3.2 *Test procedure* The test procedure shall be as specified in Clause 8.5.2.2, except that in Step (e), the distribution of the horizontal load on each beam level on each upright frame shall be determined in accordance with Clause 2.3.

8.5.3.3 *Evaluation of test results* Test results are evaluated as specified in Clause 8.5.2.3.

SECTION 9 OPERATION AND MAINTENANCE OF ADJUSTABLE PALLET RACKING

9.1 GENERAL

9.1.1 Safe working loads The safe working unit load or the safe working total load per bay for the racking installation shall not be exceeded.

9.1.2 Alteration of the racking installation The racking installation shall not be altered to deviate from the load application and configuration furnished for the racking installation.

Physical alterations to uprights, bracings, beams or components, such as welding on additional cleats or bearers, shall not be made.

In addition, change of use, such as from timber pallets to post pallets, shall not be permitted.

9.1.3 Operating instructions Operating instructions, including but not limited to the following shall be provided:

(a) The correct application and use of the equipment.

(b) The safe working loads to be adhered to.

(c) Prohibitions on unauthorized alterations.

(d) The requirement to report any damage incurred due to impact so that its effect can be assessed in accordance with Clauses 9.3 and 9.4.

9.1.4 Hazardous situations Any hazardous situations which may exist in relation to the operation or maintenance of the racking installation shall be reported.

9.1.5 Damage report Any damage incurred, however minor, shall be reported so that its effect on safety can be immediately assessed.

9.2 INSPECTIONS Inspections shall be carried out on a regular basis, and at least once every twelve months to—

(a) ensure the correct application and use of equipment;

(b) ensure that the safe working loads are adhered to;

(c) ensure that the racking installation has not been altered. A copy of the load application and configuration drawings shall be retained for this purpose;

(d) examine the extent of damage due to impact in the racking installation;

(e) examine the out-of-plumb of the racking;

(f) examine for any dislocation and deformation of sections and connections for uprights and beams; and

(g) examine connectors for deformation or signs of cracking of the welds.

9.3 DAMAGE DUE TO IMPACT

9.3.1 General The extent of damage due to impact in the racking installation determined from regular inspections and reports of damage incurred shall be assessed in accordance with Clauses 9.3.2 to 9.3.5.

Where damage due to impact exceeds that specified in Clauses 9.3.2 to 9.3.5, the damaged member shall be immediately unloaded and replaced. All members subject to tears and splits shall be replaced.

9.3.2 Uprights For uprights, the visible damage shall not exceed that shown in Figure 7.

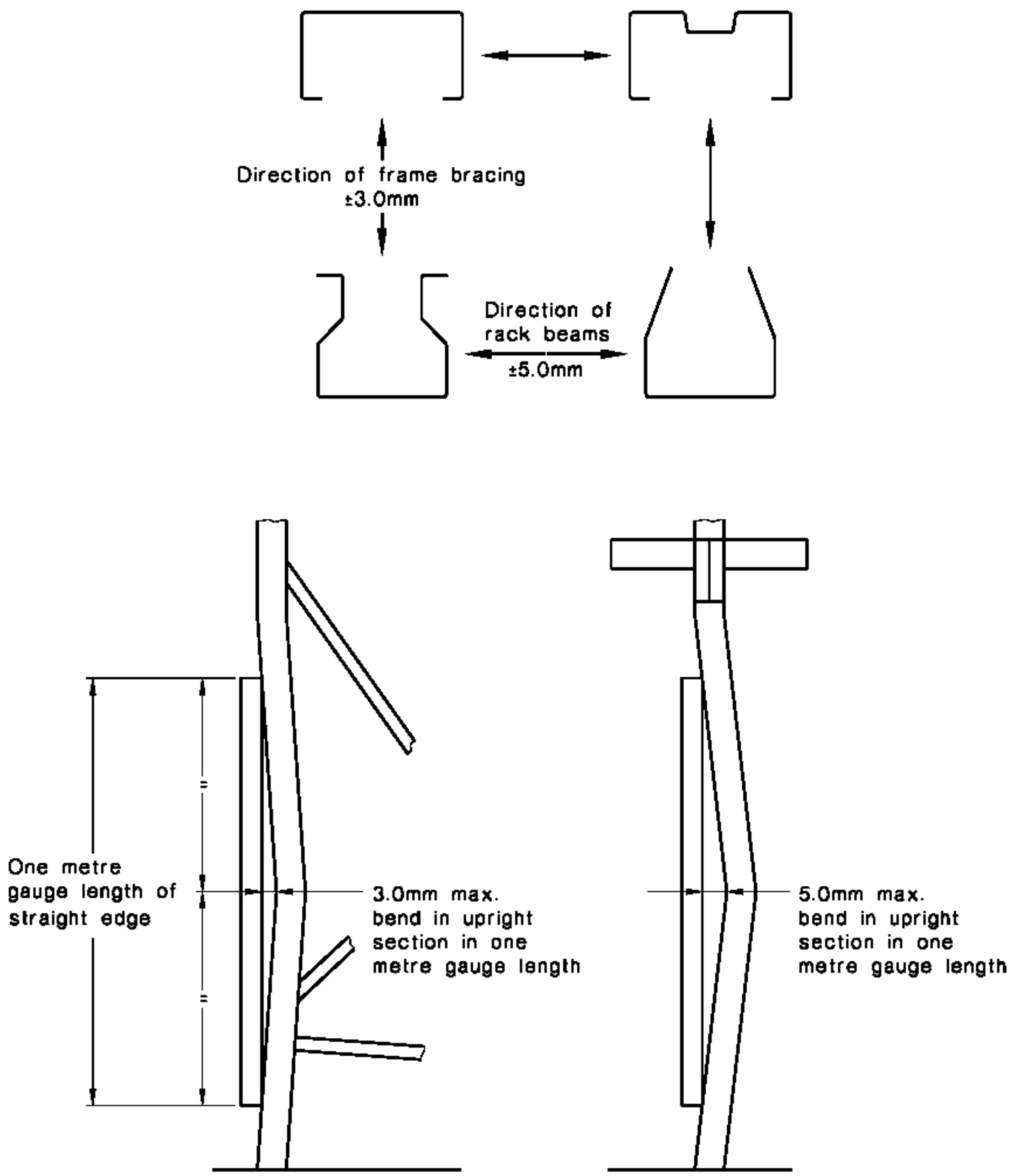


FIGURE 7 TYPICAL UPRIGHT SECTIONS AND METHOD OF MEASUREMENT

9.3.3 Bracing For bracing, the member deviation from a 1 m long straight edge in either plane shall not exceed 10 mm.

9.3.4 Beams For beams, the permanent vertical deformation when unloaded shall not exceed $L/800$ and the permanent horizontal deformation shall not exceed $L/500$.

9.3.5 Connectors Connectors shall not show visible permanent deformation or signs of cracking of welds.

9.4 OUT-OF-PLUMB OF RACKING The out-of-plumb of unloaded racking caused by impact shall not exceed the finished tolerances given in Table 4, factored by 1.5.

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