

AS 4084.1:2023



STANDARDS
Australia



Steel storage racking

Part 1: Design



AS 4084.1:2023

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- Consult Australia
- Engineers Australia
- Griffith University
- National Retail Association Australia
- Queensland University of Technology
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Steel storage racking

Part 1: Design

Originated as part of AS 4084—1993.
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Preface

This Standard was prepared by the Standards Australia Committee BD-062, Steel Storage Racking, to supersede in part AS 4084—2012, *Steel storage racking*.

The objective of this document is to provide designers of steel storage racking with specifications for hot-rolled and cold-formed steel structural members used for action carrying purposes.

Part 1 applies to structural design and Part 2 applies to installation, tolerances and clearances, operation and maintenance.

The design provisions of this document are based on the limit states method and are intended to supplement AS 4100 and AS/NZS 4600.

The major changes in this edition are as follows:

- (a) The provision of further guidance on seismic design and associated structural design parameters.
- (b) The provision of further guidance in regards to the direct strength method and its application to steel storage racking.
- (c) The provision of further guidance on clad rack installations.
- (d) The provision of modified calculations of frame imperfections.

The terms “normative” and “informative” are used in Standards to define the application of the appendices to which they apply. A “normative” appendix is an integral part of a Standard, whereas an “informative” appendix is only for information and guidance.

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NOTES

Australian Standard®

Steel storage racking

Part 1: Design

Section 1 Scope and general

1.1 Scope

This document sets out minimum requirements for the analysis, design and test methods associated with steel storage racking in the limit states method.

This document applies to adjustable static pallet racking made of cold-formed or hot-rolled steel structural members. It covers racking installed within a building, outside a building, and racking that forms part of the frame of the building.

This document does not cover the following:

- (a) Drive-in and drive-through racking.
- (b) Cantilever racking.
- (c) Standalone hand loaded shelving systems up to 3.0 metres high where the unit load does not exceed 25 kg.
- (d) Mobile racking.
- (e) Racking made of materials other than steel.

NOTE 1 Refer to FEM 10.2.07 for guidance for the design of drive-in and drive-through racking. Refer to FEM 10.2.09 for guidance for the design of cantilever racking. Refer to FEM 10.2.06 for guidance for the design of standalone hand loaded shelving systems up to 3.0 metres high where the unit load does not exceed 25 kg.

NOTE 2 Refer to AS 4084.2 for details associated with operation and maintenance, dimensions and tolerances of steel storage racking.

1.2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document.

NOTE Documents referenced for informative purposes are listed in the Bibliography.

AS 1170.4, *Structural design actions, Part 4: Earthquake actions in Australia*

AS 1391, *Metallic materials — Tensile testing — Method of test at room temperature*

AS 1657, *Fixed platforms, walkways, stairways and ladders—Design, construction and installation*

AS 4100, *Steel structures*

AS 5216, *Design of post-installed and cast-in fastenings in concrete*

AS/NZS 1170.0, *Structural design actions, Part 0: General principles*

AS/NZS 1170.1, *Structural design actions, Part 1: Permanent, imposed and other actions*

AS/NZS 1170.2, *Structural design actions, Part 2: Wind actions*

AS/NZS 4600, *Cold-formed steel structures*

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

FEM 9.831-1, *Basis of calculations for storage and retrieval machines – Tolerances, deformations and clearances in the storage system, Part 1: General, single deep and double deep beam pallet racking*

FEM 9.832, *Basis of calculation for S/R machines, tolerances, deformations and clearances in automatic small parts warehouses (not silo design)*

FEM 9.841, *Storage systems with rail dependent storage and retrieval equipment*

1.3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

1.3.1

adjustable pallet racking

storage system comprising upright frames perpendicular to the aisles and independently adjustable, positive locking pallet beams parallel to the aisles, spanning between the upright frames, and designed to support unit load actions

Note 1 to entry: See [Figures 1.3.1\(a\) to \(c\)](#).

1.3.2

aisle width

space along which the unit load handling equipment operates

Note 1 to entry: See [Figure 1.3.2\(a\)](#).

1.3.3

base plate

bearing plate bolted or welded to the underside of the upright 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 loads in a racking structure

Note 1 to entry: See [Figure 1.3.2\(b\)](#).

1.3.5

bay width

see definition of pallet beam length

Note 1 to entry: See [Clause 1.3.25.4](#) and [Figure 1.3.2\(b\)](#).

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 pallet beam level and the underside of the ceiling or the support steelwork for the ceiling

Note 1 to entry: See [Figure 1.3.2\(b\)](#).

1.3.7

closed-face racking

adjustable pallet racking where the unit loads are supported by pallet beams

Note 1 to entry: See [Figure 1.3.1\(b\)](#).

1.3.8

cross-aisle

direction perpendicular to an operating aisle or parallel to an upright frame

1.3.9**diagonal frame brace**

diagonal member in the vertical plane that supplements horizontal braces to join uprights together and form a trussed upright frame designed to withstand applied design loads

Note 1 to entry: See [Figure 1.3.1\(b\)](#).

1.3.10**down-aisle**

direction parallel to an operating aisle or perpendicular to an upright frame

1.3.11**end frame extension**

protrusion of an end frame beyond the top surface of the uppermost pallet beam

Note 1 to entry: See [Figure 1.3.1\(a\) and \(b\)](#).

1.3.12**frame bracing**

system of bracing or batten members used to link a pair of uprights in the vertical plane and in the cross-aisle direction to provide frame stability in the cross-aisle direction

1.3.13**frame spacer****back tie**

horizontal member, usually bolted to upright frames to maintain distance between upright frames in a double entry (double-sided) racking layout and designed to resist applied design loads

Note 1 to entry: See [Figures 1.3.1\(a\) and 1.3.2\(a\)](#).

1.3.14**geometric non-linear analysis****GNA**

elastic analysis where the equilibrium is obtained in the deformed frame configuration

1.3.15**geometric and material non-linear analysis with imperfections — Type c****GMNIAc**

non-linear analysis where the equilibrium is obtained in the deformed frame configuration, where —

- (a) the cross-section is compact in accordance with AS 4100 and non-perforated except at connection points;
- (b) the analysis may be based on prismatic beam-elements; and
- (c) the analysis considers torsional (twist) rotations and torsional internal actions, including warping torsion, unless fully laterally restrained in accordance with AS 4100

1.3.16**geometric and material non-linear analysis with imperfections — Type s****GMNIAs**

non-linear analysis where the equilibrium is obtained in the deformed frame configuration, where —

- (a) the cross-section is non-compact in accordance with AS 4100 or cold-formed;
- (b) the analysis is based on discretization of pallet beams and uprights into shell finite elements or finite strips modelling perforations; and
- (c) the analysis incorporates local and distortional geometric imperfections

1.3.17**horizontal frame brace**

horizontal member that joins two uprights together in a frame by bolting or welding

Note 1 to entry: See [Figures 1.3.1\(a\) and \(b\)](#).

1.3.18**linear analysis****LA**

elastic analysis where the equilibrium is obtained in the original (undeformed) frame configuration (i.e, the displacements are assumed infinitesimal)

1.3.19**linear buckling analysis****LBA**

elastic analysis where the pre-buckling internal actions are obtained from a linear analysis

1.3.20**load**

value of a force appropriate for an action

1.3.21**load arm****stub arm**

short load support arm attached to the upright to support the pallet rail

Note 1 to entry: See [Figure 1.3.1\(c\)](#).

1.3.22**manual operation**

operation of machines and positioning of equipment controlled by an operator

1.3.23**may**

indicates the existence of an option

1.3.24**open-face racking**

adjustable pallet racking where the unit loads are supported by load arms attached to the uprights and rails spanning between the support arms

Note 1 to entry: See [Figure 1.3.1\(c\)](#).

1.3.25**pallet beam**

horizontal member securely locked into the upright frame by means of pallet beam connectors and designed to support vertical loads and resist horizontal loads

Note 1 to entry: See [Figures 1.3.1\(a\) and \(b\)](#).

1.3.25.1**pallet beam connector**

device at the pallet beam ends, secured to upright frames by means of boltless or bolted connections and designed to transmit forces into the upright frames and provide stability within the racking structure

Note 1 to entry: See [Figure 1.3.1\(b\)](#).

1.3.25.2**pallet beam deflection**

maximum vertical distance measured from the beam ends to the lowest point of the pallet beam in a loaded condition

1.3.25.3**pallet beam depth**

vertical distance from the top to the underside of the pallet beam

Note 1 to entry: See [Figure 1.3.2\(b\)](#).

1.3.25.4**pallet beam length**

horizontal distance between the inner faces of columns in adjacent upright frames

Note 1 to entry: See [Figure 1.3.1\(a\)](#).

Note 2 to entry: This dimension is needed to conveniently manoeuvre pallets into a bay while taking into account unit load width and minimum clearances required.

1.3.26**pallet buffer backstop**

buffering backstop which is specified as an aid for use by forklift truck drivers to deposit a unit load in the correct position in the rack

Note 1 to entry: The impact forces arising from the backstop's use as a buffer shall be quantified in the specification if this type of aid is required.

1.3.27**pallet rail
runner**

horizontal load-bearing member used to support pallets, which normally runs parallel to the pallet placement direction

Note 1 to entry: The rail may be fitted directly to the upright, a load arm or a beam.

Note 2 to entry: See [Figure 1.3.1\(c\)](#).

1.3.28**pallet safety backstop**

safety backstop used to prevent accidental damage

Note 1 to entry: The two possible types of safety backstops are as follows:

- (a) A safety device that protects against unintentional load movement within the racking and prevents unit loads from protruding or falling into an aisle or into an area accessible to people.
- (b) A safety device, usually placed at the back of a storage compartment, to prevent accidental collision of a pallet or its load with other equipment, such as sprinklers.

1.3.29**plan horizontal bracing
horizontal bracing**

horizontal bracing system which, when used with spine bracing, provides the stabilizing effect to the unbraced upright in front

Note 1 to entry: See [Figures 1.3.1\(b\) and \(c\)](#).

1.3.30**rack length
row length**

maximum horizontal length of continuously connected bays in a racking structure, equal to the sum of upright widths plus bay widths

Note 1 to entry: See [Figure 1.3.2\(b\)](#).

1.3.31**shall**

indicates a statement is mandatory

1.3.32**should**

indicates a recommendation

1.3.33**spine bracing****back bracing****vertical bracing**

bracing system providing the down-aisle stability for racking

Note 1 to entry: The bracing is normally provided in the vertical plane at the rear of the racking.

Note 2 to entry: See [Figures 1.3.1\(b\) and \(c\)](#).

1.3.34**tolerance**

permissible positive or negative variation from nominal dimension or position, resulting from either manufacture or erection, or both

1.3.35**unit load**

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

1.3.35.1**unit load action**

laden individual pallets or equivalent load action modules

1.3.35.2**unit load depth**

horizontal dimension of the unit load in the cross-aisle direction

Note 1 to entry: See [Figure 1.3.2\(a\)](#).

1.3.35.3**unit load depth clearance**

minimum horizontal distance between adjacent unit loads in the cross-aisle direction of a double entry (double-sided) racking situation

Note 1 to entry: See [Figure 1.3.2\(a\)](#).

1.3.35.4**unit load height**

maximum height measured from the underside of the pallet to the highest point of the unit load

Note 1 to entry: See [Figure 1.3.2\(a\)](#).

1.3.35.5**unit load height clearance**

minimum vertical distance between the highest point of the unit load and the underside of the pallet beam immediately above

Note 1 to entry: See [Figure 1.3.2\(b\)](#).

1.3.35.6**unit load overhang**

maximum horizontal distance the unit load protrudes beyond the outer edge of the pallet

Note 1 to entry: See [Figure 1.3.2\(a\)](#).

1.3.35.7**unit load upright clearance**

minimum horizontal distance from the inside face of the upright to the nearest part of the unit load in the down-aisle direction

Note 1 to entry: See [Figure 1.3.2\(b\)](#).

1.3.35.8**unit load width**

horizontal dimension of the unit load measured parallel to the operating aisle

Note 1 to entry: See [Figure 1.3.2\(b\)](#).

1.3.35.9**unit load width clearance**

minimum horizontal distance between adjacent unit loads on a common pallet beam in the down-aisle direction

Note 1 to entry: See [Figure 1.3.2\(b\)](#).

1.3.36**upright**

vertical members that comprise the upright frame and are subject to predominantly compressive forces parallel to their longitudinal axes and have provision for systematic attachment of pallet beams

1.3.36.1**upright frame**

vertical frame assembly composed of uprights and bracings to support design loads transmitted through pallet beams and operating equipment

1.3.36.2**upright frame height**

maximum vertical height of an upright frame assembly including, when required, base plates and packing plates

Note 1 to entry: See [Figure 1.3.2\(a\)](#).

1.3.36.3**upright protector**

component in front of an upright frame that is secured either to the floor or an upright, or both, and designed to resist minor impact loads

Note 1 to entry: See [Figure 1.3.1\(a\)](#).

Note 2 to entry: See [Section 2](#) for specifications related to upright protectors.

1.3.36.4**upright splice**

vertical member used to splice two uprights together to form a composite column and designed to support vertical loads and resist horizontal loads

Note 1 to entry: See [Figure 1.3.1\(a\)](#).

1.3.36.5**upright width**

maximum horizontal distance of an upright measured from outside face of flange to outside face of flange

1.3.37**vertical clearance**

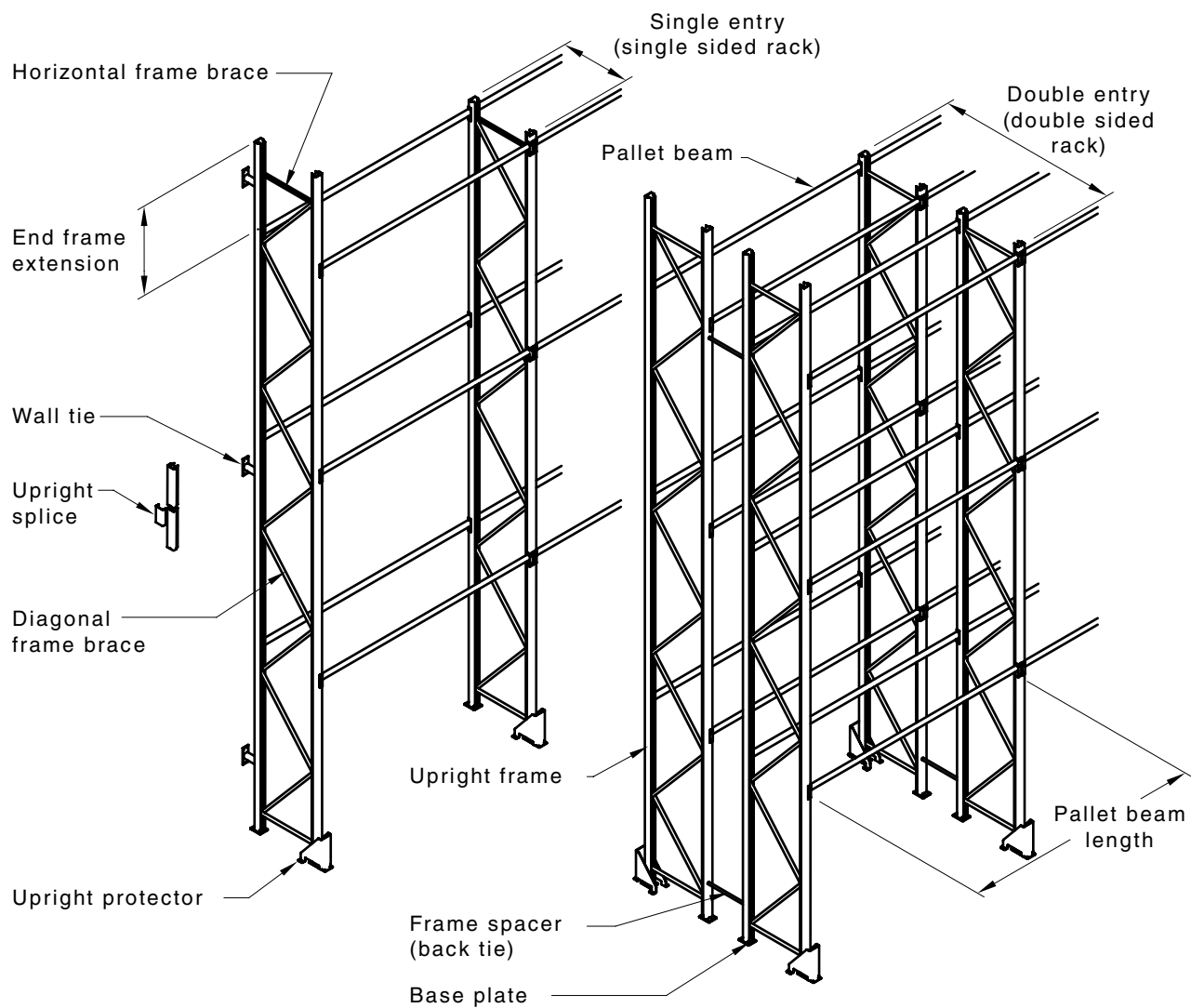
minimum vertical distance between the floor and the underside of the lowest pallet beam; or minimum vertical distance between the top of a lower pallet beam and the underside of an upper pallet beam

Note 1 to entry: See [Figure 1.3.2\(b\)](#).

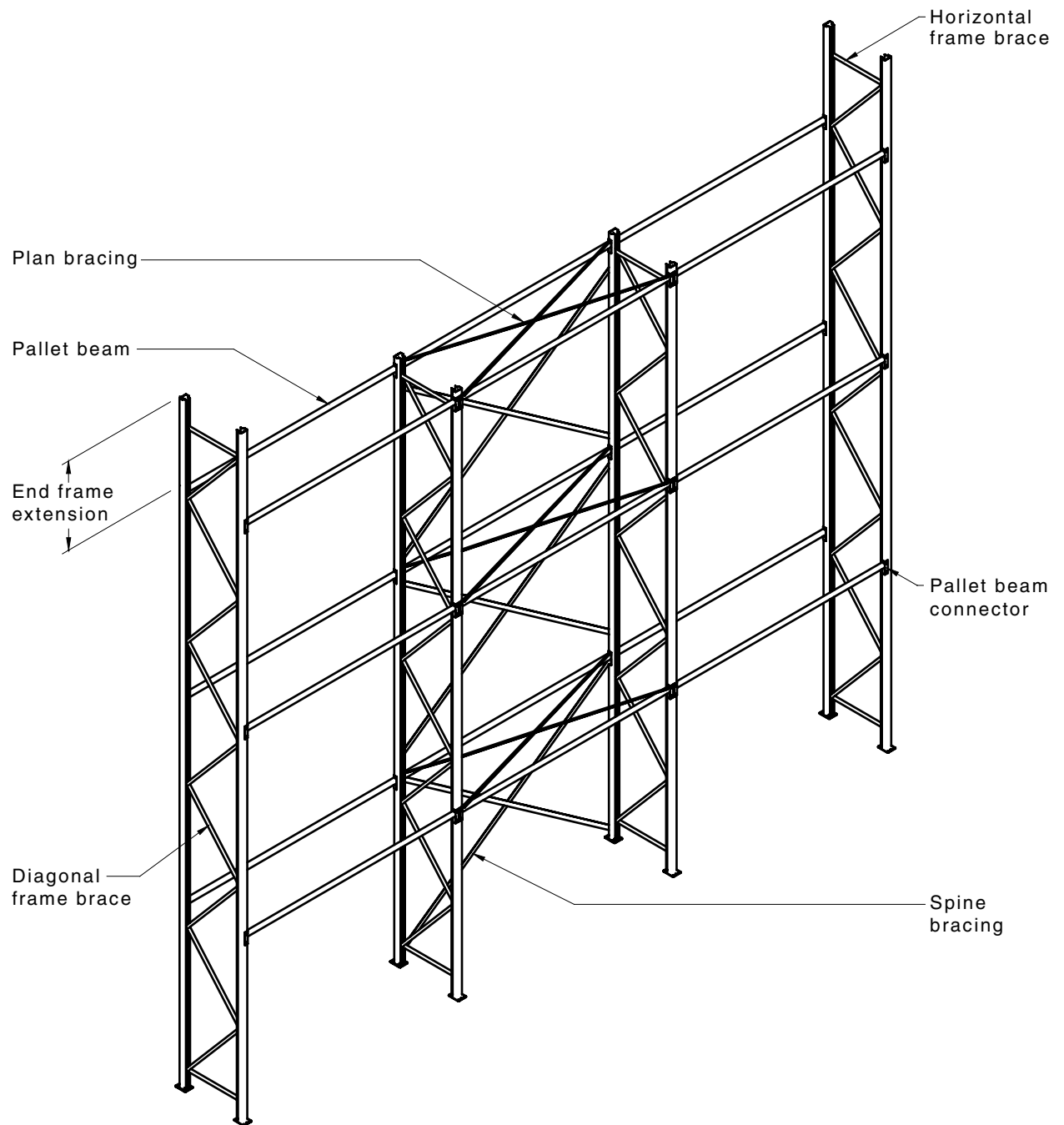
1.3.38**wall tie****ceiling tie**

horizontal or vertical member that connects the upright to a wall (or ceiling) to provide stabilizing forces and reduce overturning moments

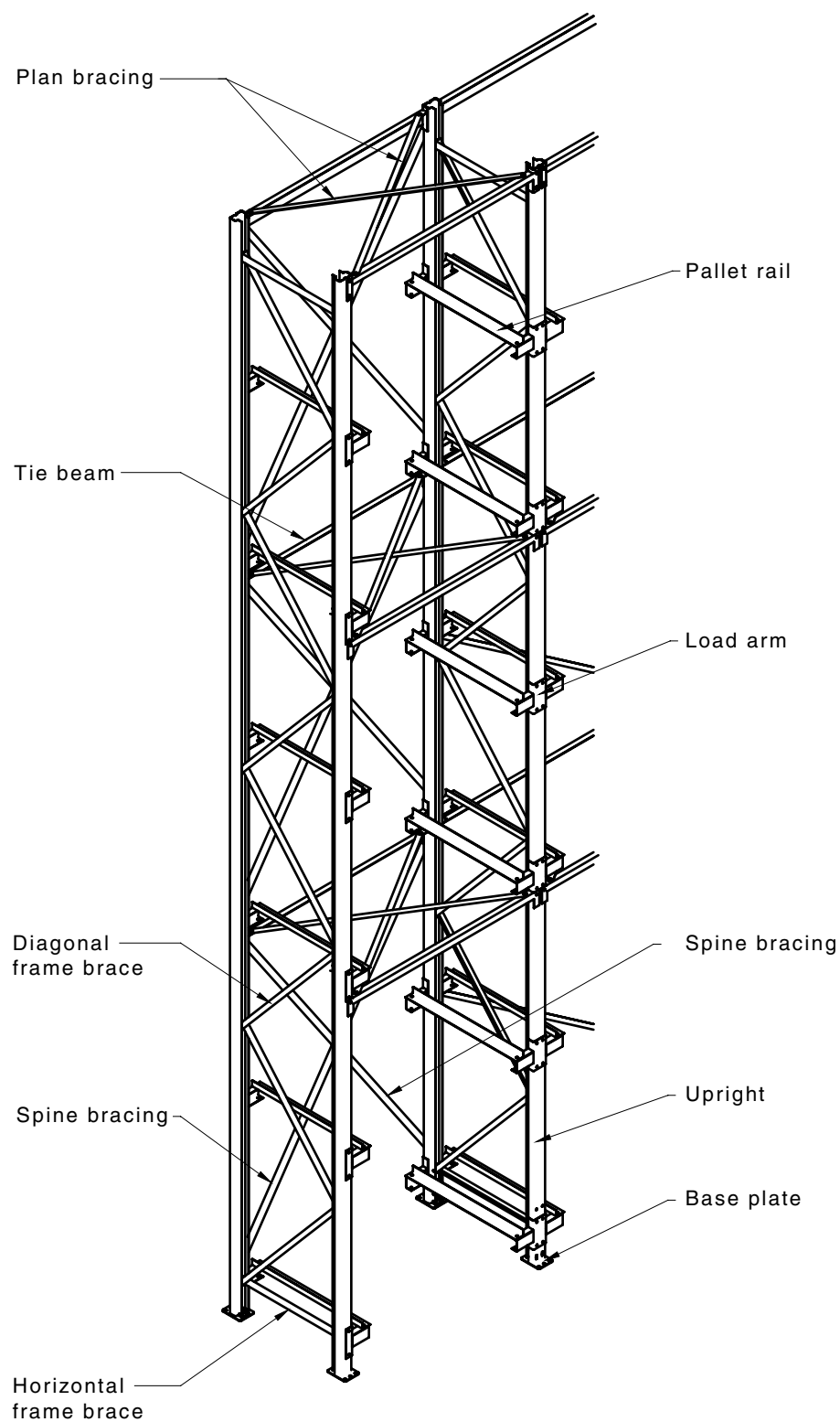
Note 1 to entry: See [Figure 1.3.1\(a\)](#).



(a) Unbraced racking

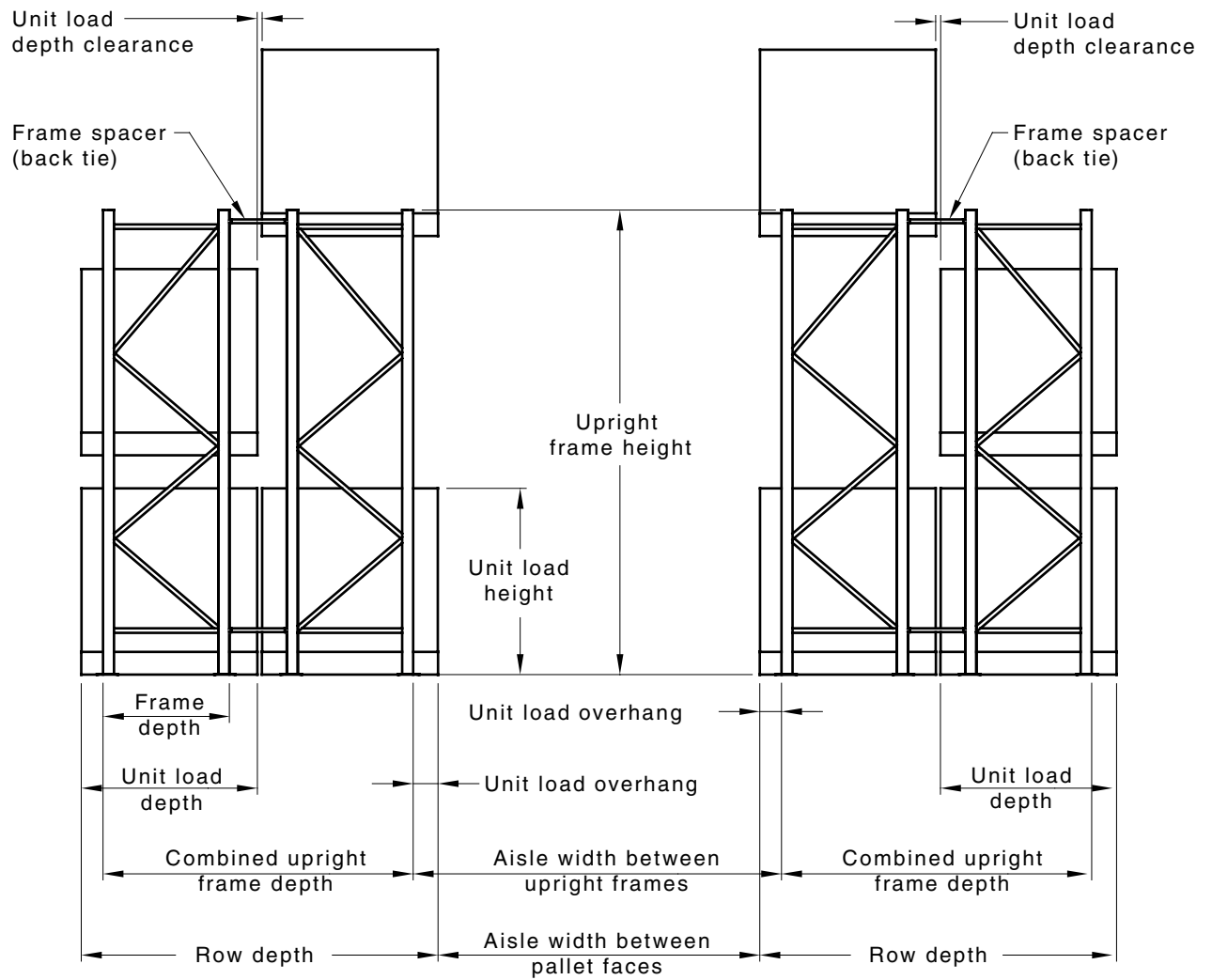


(b) Braced closed-face racking

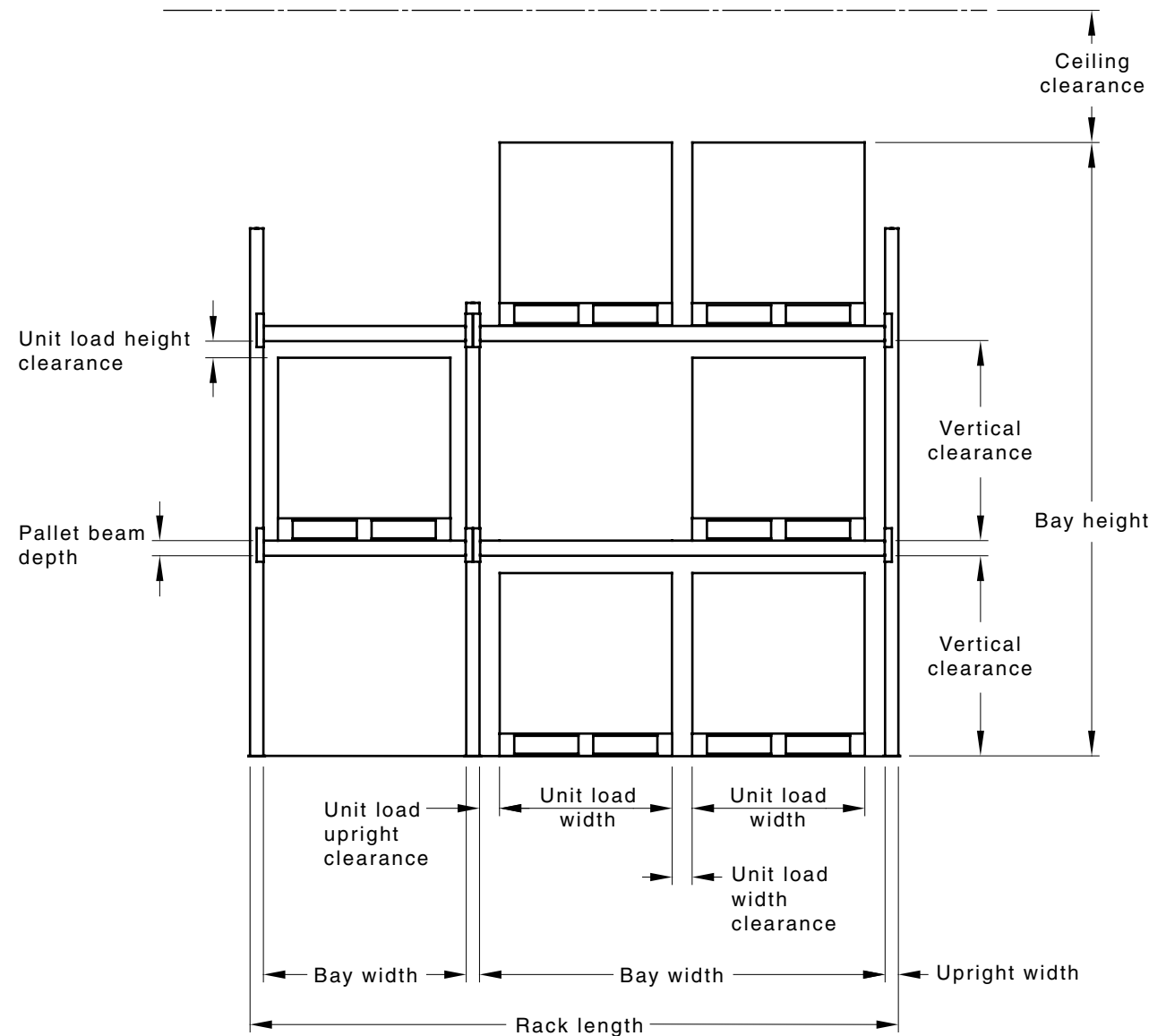


(c) Braced open-face racking

Figure 1.3.1 — Adjustable pallet racking



(a) Aisle width and related dimensions



(b) Clearance width and related dimensions

Figure 1.3.2 — Definitions

1.4 Symbols and abbreviated terms

Symbols used in the text of this document 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

=

lever arm (pallet beam to column connection cantilever test)
- or
- =

distance between measuring transducers 2 and 3 and transducers 3 and 4 (upright splice test)
- or

	=	distance from the face of the upright to the applied action F (shear test on pallet beam to column connection)
		<i>or</i>
	=	value of accidental actions
A_{CX}	=	accidental action from crane in down-aisle direction
A_{CZ}	=	accidental action from crane in cross-aisle direction
A_{VU}	=	accidental upwards vertical load (upwards)
A_e	=	effective area of the perforated cross-section at the stress f_n
A_{eff}	=	effective area of the base plate
A_{netg}	=	area for the section with reduced thicknesses
$A_{net\ min}$	=	minimum cross-sectional area obtained by passing a plane through the upright normal to the axis of the upright
A_{ph}	=	accidental horizontal action
A_{pv}	=	accidental vertical action
A_{sp}	=	net cross-sectional area of splice
B	=	upright width
b_p	=	notional plane width of plate element
B_s	=	bi-moment section capacity
C	=	coefficient equal to f_y/f_t
		<i>or</i>
	=	numerical value between 2.5 and 3 (pallet beam test)
C_m	=	correction factor (pallet beam to upright connection cantilever test)
d	=	distance between the centroidal axes of uprights (upright frame shear test)
d_1	=	distance from the anchor bolt in tension to the upright flange in compression (base plate design)
d_2	=	distance to the anchor bolt from the face of the flange of the upright of the base plate
d_3	=	flange width of upright
d_{ij}	=	distance between measuring transducers i and j (floor connection test)
d_u	=	upright depth
D	=	spacing of uprights in a frame (see Figure C.2)
E	=	eccentricity (see Clause 3.3.2.6)
		<i>or</i>

	=	modulus of elasticity (200×10^3 MPa)
e	=	effective bearing width of the base plate (see Clause 6.3.2.2)
E_{UX}	=	ultimate earthquake action in down-aisle direction
E_{UZ}	=	ultimate earthquake action in cross-aisle direction
EI^*	=	reduced flexural rigidity
f_c	=	characteristic compressive cylinder strength of concrete at 28 days
f_{cb}	=	design bearing strength of the concrete slab
f_n	=	stress value determined in accordance with AS/NZS 4600 based on the full unreduced cross-section
f_{oc}	=	elastic buckling stress in an axially-loaded compression member
f_{od}	=	elastic distortional buckling stress
f_{ol}	=	elastic local buckling stress
f_{ox}, f_{oy}, f_{oz}	=	values of f_{oc} for flexural buckling about the x and y axes, respectively, and torsional buckling about the z axis
f_t	=	measured yield stress of a specimen
f_y	=	nominal yield stress
f_{ya}	=	weighted average yield stress
F	=	applied action
F_1, F_2	=	applied axial and transverse actions, respectively
F_{sd}	=	maximum expected design action of the upright (upright splice test)
F_{ti}	=	maximum measured action for test number i (shear test on pallet beam to column connection)
g, g_1, g_2	=	eccentricities (see Clause 3.3.2.6)
G	=	value of permanent action (dead load)
h	=	total height of upright frame
	<i>or</i>	
	=	distance to the topmost beam level (AS 4084.2:2023 Figure 2.2)
	<i>or</i>	
	=	height to the first beam level (see Clause 3.3.4.3)
	<i>or</i>	
	=	storey height (see Figure 4.2.2.5)
	<i>or</i>	

	=	minimum clear distance between connecting points (pallet beam to column connection cantilever test)
		<i>or</i>
	=	distance from the floor to the top of the pallet beam (portal frame test, Clause 7.5.2)
		<i>or</i>
	=	length of the frame (upright frame shear test <i>and</i> upright frame bending and shear test)
h_c	=	distance from the top of the half round to the top of the pallet beam (portal frame test, Clause 7.5.2)
h_i	=	distance to beam level i (AS 4084.2:2023 Figure 2.2)
h_p	=	length of longest plane web element (see Figure 4.2.2.5)
H	=	horizontal action per pallet beam (portal frame test)
H_i^*	=	initial geometric imperfection horizontal action summed over all connected uprights (see Clause 3.3.2.4)
I	=	second moment of area of members for the relevant axis of buckling
I^*	=	reduced second moment of area of members when considering effects of geometric member imperfections
I_b	=	second moment of area of the pallet beam about the axis perpendicular to the plane of bending
I_c	=	second moment of area of the upright about the axis perpendicular to the plane of bending
I_w	=	cross-sectional torsion warping constant computed for the gross section
J	=	St. Venant torsion constant of the cross-section computed for the gross section
K	=	coefficient for stiffened and unstiffened elements
k_b	=	pallet beam stiffness (EI_b/L) (portal frame test)
k_c	=	upright stiffness (EI_c/h_c) (portal frame test)
k_{cti}	=	slope of test curve number i (upright frame shear and bending test)
k_d	=	design value of connection stiffness
		1.5
		<i>or</i>
	=	distortional buckling thickness coefficient (0.8)
k_m	=	average value of connection stiffness
k_{ni}	=	slope of test curve number i as defined in Clause 7.2.2.2
k_o	=	<i>initial</i> slope of moment-rotation curve (pallet beam to upright connection cantilever test)

k_s	=	coefficient based on 95 % fractile at a confidence level of 75 %
k_{ti}	=	slope of test curve number i (upright frame shear test)
L	=	length between panel points along uprights
	<i>or</i>	
	=	centre-to-centre distance (pitch) between holes in flange (see Figure 5.2.1.2)
	<i>or</i>	
	=	unsupported length of member
	<i>or</i>	
	=	distance between the centroids of the two upright frames (portal frame test, Clause 7.5.2)
	<i>or</i>	
	=	distance between pins (upright splice test)
	<i>or</i>	
	=	twice the length of an upright section (floor connection test)
l_1	=	length of plateau at constant contact pressure of the base plate
l_2	=	distance shown in Figure 6.3.2.5 of the base plate
l_e	=	effective length for flexural buckling in the down-aisle direction
	<i>or</i>	
	=	effective length for flexural buckling in the cross-aisle direction
l_{ez}	=	torsional effective length
l_i	=	length between panel points of upright number i (see Clause 3.3.2.4)
$L_{np,f}$	=	edge-to-edge length between holes in flange (see Figure 5.2.1.2)
$L_{np,w}$	=	edge-to-edge length between holes in web (see Figure 5.2.1.2)
M^*	=	moment design action
	<i>or</i>	
	=	amplified internal bending moment of the splice
M_b	=	average moment applied to the base plate (floor connection test)
M_{bd}	=	distortional buckling moment capacity
M_{be}	=	lateral-torsional buckling moment capacity
M_{blg}	=	local and global buckling moment capacity
M_c	=	design moment (pallet beam to upright connection cantilever test)

M_{ecc}^*	=	moment due to eccentricities of the splice
M_n	=	corrected moment (pallet beam to upright connection cantilever test)
M_o	=	elastic buckling moment
M_{sp}	=	moment of resistance of the splice
M_{sx}, M_{sy}	=	moment section capacity in accordance with AS 4100
M_t	=	measured moment (pallet beam to upright connection cantilever test)
M_x^*, M_y^*	=	moment design action about the x-axis and y-axis, respectively
M_y	=	yield moment
n	=	number of test results in a group
n_{fb}	=	number of upright frames connected together and acting together in the cross-aisle direction
n_{fu}	=	number of upright frames in one row of bays in the down-aisle direction
N^*	=	design value of the vertical action on the frame
	<i>or</i>	
	=	axial design action
N_c	=	compression capacity
N_{cd}	=	distortional buckling compression capacity
N_{ce}	=	flexural, torsional or flexural-torsional buckling load
N_{clg}	=	local and global buckling compression capacity
N_{cr}	=	elastic critical (buckling) value of the vertical action
N_i^*	=	design axial action in member number i
N_{od}	=	elastic distortional buckling load
N_s	=	axial section capacity in accordance with AS 4100
Q	=	action on the beam where the pallet is placed in the perfect position (variable action)
	<i>or</i>	
	=	form factor of a compression member including effect of perforations
Q_1	=	value of one of the variable actions
Q_{cx}	=	top rail placement action from crane in down-aisle direction
Q_{cz}	=	top rail placement action from crane in cross-aisle direction
Q_f	=	action acting on platforms and walkways
Q_h	=	maximum specified lateral support action per crane

Q_{ht}	=	total horizontal action at guide rail level
Q_i	=	value of typical variable action
Q_{max}	=	form factor Q for stub upright of thickness t_{max}
Q_{min}	=	form factor Q for stub upright of thickness t_{min}
Q_{ph}	=	horizontal placement action
Q_{pv}	=	vertical placement action
Q_{PX}	=	horizontal placement action acting in the down-aisle direction
Q_{PZ}	=	horizontal placement action acting in the cross-aisle direction
Q_R	=	action acting on a roof for rack clad design
Q_u	=	unit load action
r_{o1}	=	polar radius of gyration of the gross cross-section about the shear centre
r_x, r_y	=	radius of gyration of the gross cross-section about the x-axis and y-axis, respectively
R_c	=	design load or moment based on test results
R_k	=	characteristic value of the parameter being measured
R_m	=	mean value of the adjusted test results
	=	<i>or</i>
	=	mean compressive strength of stub column test
R_{ni}	=	corrected failure load or moment for test number i
R_{ti}	=	measured failure load or moment for test number i
s	=	standard deviation of the adjusted test results of the parameter being measured
s_n	=	standard deviation of the normalized test results of the parameter being measured
S	=	span of pallet beams (pallet beam test)
Sc_{ti}	=	transverse bending and shear stiffness of the frame (upright frame bending and shear test)
S_{od}	=	imperfection multiplier for distortional buckling
S_{ol}	=	imperfection multiplier for local buckling
S_{ti}	=	transverse shear stiffness of the frame (upright frame shear test)
t	=	nominal steel thickness of any element or section exclusive of coatings
t_b	=	thickness of base plate
$t_{d,w}, t_{d,f}$	=	thicknesses of the strips containing web and flange perforations for distortional buckling calculations

$t_{g,w}, t_{g,f}$	=	thicknesses of the strips containing web and flange perforations for global (overall) and local buckling calculations
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
t_t	=	measured thickness for a specimen
W_{UX}	=	ultimate wind action in down-aisle direction
W_{UZ}	=	ultimate wind action in cross-aisle direction
W_{SX}	=	serviceability wind action in down-aisle direction
W_{SZ}	=	serviceability wind action in cross-aisle direction
Z_e	=	elastic section modulus of the net section for the extreme compression fibre times $[0.5 + (Q/2)]$, where Q is the form factor of a compression member, determined in accordance with Clause 7.3.1
Z_{eff}	=	elastic section modulus of the effective area about the axis of symmetry in the plane of the base plate
Z_f	=	elastic section modulus of the full unreduced cross-section for the extreme compression fibre, determined in accordance with Clause 5.2.2.1
	<i>or</i>	
	=	elastic section modulus for the section with reduced thicknesses, determined in accordance with Clause 5.2.2.2 , direct strength method
Z_c	=	elastic section modulus of the net section for the extreme compression fibre times $\left[1 - \left(\frac{1-Q}{2} \right) \left(\frac{f_c}{f_y} \right)^Q \right]$, where Q is the form factor of a compression member, determined in accordance with Clause 7.3.1
$Z_{net\ min}$	=	elastic section modulus of minimum cross-sectional area obtained by passing a plane through the upright normal to the axis of the upright
α	=	test correction coefficient
α_{nx}, α_{ny}	=	moment amplification factors about the x-axis and y-axis, respectively
β	=	test correction coefficient
β_x, β_y	=	monosymmetry section constant about the x-axis and y-axis, respectively
χ	=	buckling stress reduction factor
χ_{cu}	=	locus of mean values of test results χ_{ni}
χ_{ni}	=	buckling stress reduction factor for test number i
Δ	=	measured side-sway displacement of the frame at the top of the pallet beam (pallet beam test)

	<i>or</i>	
	=	lateral displacement of the concrete block (floor connection test)
δ	=	horizontal deflection of the frame (upright frame shear test <i>and</i> upright frame bending and shear test)
δ_{ci}	=	deformation at the design load or moment (R_c) for test number i
δ_i	=	displacement of transducer number i
δ_o	=	scaled amplitude of the rack buckling mode
γ_A	=	partial factor for accidental actions
γ_G	=	partial factor for permanent actions
γ_{GA}	=	partial factor for permanent actions under accidental ultimate limit states
γ_Q	=	partial factor for variable actions
γ_{QA}	=	partial factor for variable actions under accidental ultimate limit states
η	=	design load amplification factor
λ	=	non-dimensional slenderness ratio
λ_d	=	distortional buckling slenderness
λ_{ni}	=	non-dimensional slenderness ratio for test number i
θ_b	=	average rotation of the base plate (floor connection test)
θ_{ni}	=	corrected value of the central rotation for test number i (pallet beam test)
θ_t	=	measured rotation of the pallet beam to column connection (pallet beam to upright connection cantilever test)
θ_{ti}	=	measured value of the central rotation in the serviceability limit state for test number i (pallet beam test)
θ_n	=	corrected rotation of the pallet beam to column connection (pallet beam to upright connection cantilever test)
θ_p	=	plastic rotation of the pallet beam to column connection (pallet beam to upright connection cantilever test)
ϕ	=	frame imperfection (out-of-plumb)
	<i>or</i>	
	=	capacity factor
$\phi_o, \phi_i, \phi_{i-1}$	=	initial imperfection angles of upright (see Clause 3.3.2.4)
ϕ_ℓ	=	looseness of pallet beam to column connection
ϕ_s	=	maximum specified out-of-plumb divided by the height, which depends on the tolerance grade of the racking given in AS 4084.2:2023 Table 2.2(A)
ϕ_t	=	capacity factor for tension

ϕ_v	=	capacity factor for shear
ϕ_x	=	global imperfection acting in the down-aisle direction
ϕ_z	=	global imperfection acting in the cross-aisle direction
ρ	=	true load amplification factor, equal to the ratio of the action on the beam arising from pallets placed with maximum misalignment, to the corresponding action on the beam arising from pallets placed in the perfect position
Ψ_A	=	average unit load factor for global static design (1.0 if unknown)
Ψ_M	=	rigid mass factor for seismic weight calculation
Ψ_{EX}	=	occupancy factor for global down-aisle design
Ψ_{EZ}	=	occupancy factor for global cross-aisle design
ω_{max}	=	maximum value of sectorial coordinate

1.5 Use of alternative materials or methods

This document assumes the use of steel of structural quality as specified in AS/NZS 4600 for the design of cold-formed steel structural members and AS 4100 for the design of hot-rolled steel structural members. This document does not prevent the use of materials, methods of assembly, procedures and the like that do not conform with the specific requirements of this document, or are not mentioned in it, provided the minimum dimensional and performance requirements specified herein are met.

1.6 Localized fires

If the sprinkler system within a rack is activated for a localized fire at the the base of an upright, the uprights shall be designed according to AS/NZS 4600:2018 Section 9 for a maximum temperature of 200 °C for the fire limit state load case combination defined in AS/NZS 1170.0.

1.7 End frame extensions

End frame extensions shall be installed where the end frame is adjacent to a trafficable aisle (trafficable by pedestrians, fork lift trucks or any other vehicles). Where required, an end frame extension shall be at least 50 % of the height of the unit loads to be stored on the uppermost pallet beam. If the usage of an aisle adjacent to an end frame changes so that it becomes trafficable, end frame extensions shall be installed.

1.8 Retrospectivity and upgrading

The requirements of this document do not apply retrospectively to racking installations designed, fabricated and installed in accordance with the previous edition of AS 4084:2012. However, if an existing racking installation has its components modified or substituted with an alternative product, has its geometry modified, has the magnitude or location of unit loads modified, or is moved from one site to another, then such racking installations shall be upgraded to the current edition of AS 4084.

Section 2 Actions

2.1 General

Racking shall be designed for the combinations of permanent, variable and accidental actions in accordance with this document and AS/NZS 1170.1.

The influence of the various types of geometric imperfections on the design actions shall be taken into account.

The term action in this document shall be as specified in AS/NZS 1170.0.

NOTE 1 The actual means by which imperfection effects are incorporated depends on the method of structural analysis adopted.

NOTE 2 Refer to AS 4084.2:2023 Table 2.2(B) to determine the tolerance grade of racking.

2.2 Permanent actions

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

Permanent actions shall be determined in accordance with AS/NZS 1170.1.

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

2.3 Variable actions

2.3.1 General

The design shall include relevant actions from the following list of variable actions:

- (a) Unit load actions (stored materials).
- (b) Vertical and horizontal placement actions.
- (c) Actions from rack guided equipment.
- (d) Floor and walkway actions.
- (e) Thrusts on handrails.
- (f) Actions from thermal effects.
- (g) Impact and accidental actions.
- (h) Actions from geometrical and action imperfections.
- (i) Actions from foundation settlement.
- (j) Seismic actions.
- (k) Wind actions.

Variable actions arising from other equipment connected to the structure shall be determined and incorporated into the design.

2.3.2 Unit loads to be stored

Unless specifically agreed and documented, the global analysis and design shall be carried out on the basis that the racking is loaded with unit load actions of maximum weight (Q_u) in each storage location. In this case, the racking shall be designed for a bay action which is equal to the sum of the maximum weight unit load actions stored in that bay.

If agreed and documented, the racking may be designed on the basis of a specified bay action calculated on the basis of an average unit load weight which is less than the sum of maximum weight unit loads stored in that bay.

The average unit load weight is termed $\Psi_A Q_u$, where Ψ_A is defined as the average unit load factor. The value of Ψ_A shall be determined based on data provided by the end user of the racking. The value of Ψ_A shall be limited to a minimum of 0.8. However, where the distribution of unit loads in the rack is managed and enforced by computerized information technology built into the warehouse management system, Ψ_A shall be limited to a minimum of 0.7.

In the case of $\Psi_A < 1$, the following conditions shall apply:

- (a) Individual storage compartments shall be designed to carry the maximum weight of unit load.
- (b) The average unit load actions shall be uniformly distributed in every bay.
- (c) In the warehouse management system, the bay action specified for global analysis and design shall never be exceeded.
- (d) In upright design, the worst case load distribution shall be considered where the maximum weight of unit load actions shall be applied to the upper storage positions up to the specified bay action.
- (e) The distribution of the unit load actions to the uprights shall be taken into account by the warehouse management system. The action in each upright shall not exceed the value corresponding to the specified bay action.

The increase in stress and deformation associated with random imperfect placement of unit load actions in the storage compartment may be ignored if it is less than or equal to 12 % compared to a storage compartment loaded with perfectly placed unit loads. When the increase is more than 12 %, the effect on the beam design shall be taken into account as follows:

$$Q'_u = \eta Q_u \quad 2.3.1$$

where

$$\begin{aligned} Q'_u &= \text{design action on the beam where the pallet is placed with the maximum misalignment} \\ \eta &= \text{design load amplification factor} \\ &= 1.0 \quad \text{if } \rho \leq 1.12 \\ &= 2\rho - 1.24 \quad \text{if } 1.12 \leq \rho \leq 1.24 \\ &= \rho \quad \text{if } \rho \geq 1.24 \\ \rho &= \text{true load amplification factor, equal to the ratio of the action on the beam arising from} \\ &\quad \text{pallets placed with maximum misalignment, to the corresponding action on the beam} \\ &\quad \text{arising from pallets placed in the perfect position} \\ &= Q_{ue}/Q_u \end{aligned}$$

Q_{ue} = theoretical action on the beam where the pallet is placed with the maximum misalignment

Q_u = action on the beam where the pallet is placed in the perfect position

2.3.3 Vertical placement actions

2.3.3.1 General

The minimum vertical placement actions specified in [Clauses 2.3.3.2](#) and [2.3.3.3](#) shall be applied in applications where unit loads are placed in position by mechanical equipment or by hand, i.e. tolerance grade I and II racking as set out in AS 4084.2:2023 Table 2.2(B).

2.3.3.2 Goods placed with mechanical equipment

Beams, supporting arms (if any), and end connections shall be designed for an additional vertical placement action (Q_{pv}), equal to 25 % of one unit load action, placed in the most unfavourable position for the particular determination (moment or shear force). When corresponding design capacities are determined by test (see [Clause 7.4](#)), due allowance shall be made for the additional placement load as specified in this section.

No placement actions need be applied when checking beam deflections (see [Clause 4.2.5](#)).

2.3.3.3 Goods placed by hand

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

2.3.4 Horizontal placement actions

2.3.4.1 General

In applications where unit loads are placed in position, the following minimum horizontal placement actions (variable actions) shall be applied in both the down-aisle and cross-aisle directions, as specified in [Clauses 2.3.4.3](#) and [2.3.4.4](#) respectively.

These horizontal forces shall be applied separately, not simultaneously, in each principal direction of the racking.

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

An accidental action in the horizontal direction (see [Clause 2.4.3](#)) shall be taken into account. However, it does not need to be accounted for at the same time as the horizontal placement action.

2.3.4.2 Effects of operational methods

The following operational methods shall be used to determine the horizontal placement action (Q_{ph}):

- (a) Where goods are placed with manually operated mechanical equipment (e.g. forklift trucks):
 - (i) For racks up to 3 m in height, Q_{ph} shall be an action of 0.5 kN applied at any height up to the top of the rack.
 - (ii) For racks over 6 m in height, Q_{ph} shall be an action of 0.25 kN applied at the top of the rack, or an action of 0.5 kN applied at any height up to 3 m.

- (iii) For racks between 3 m and 6 m, Q_{ph} shall be the worst case of an action at the top of the rack whose magnitude is determined by linear interpolation between (i) and (ii), or the action of 0.5 kN applied at any height up to 3 m.
- (b) Where goods are placed by automatic storage and retrieval equipment, Q_{ph} and its position shall be specified by the materials handling equipment supplier. The minimum value of Q_{ph} shall be 0.25 kN.
- (c) Where backstops are used, it shall be clearly defined whether these are safety backstops or buffering backstops. The value of Q_{ph} shall be defined by during the design stage. For manually operated mechanical equipment, Q_{ph} shall be subject to a minimum value of $0.25 Q_u$ where Q_u is the unit load action.

Buffer backstops and pick and deposit stations with positioning devices shall be used to give rise to variable actions. By contrast, safety backstops shall be used to give rise to accidental actions. The actions arising from both of these shall be used with the relevant action factors.

- (d) Q_{ph} shall be specified in accordance with [Clause 2.3.4.2\(c\)](#) when designing the following racking components in the direct vicinity of the backstop:
 - (i) The backstop device itself.
 - (ii) The connection of the backstop with the racking component concerned (beam or upright).
 - (iii) The part of the upright to which the backstop or the beam supporting the backstop is directly connected.
 - (iv) The upright frame bracing in the direct vicinity of this upright part.

NOTE Where damping and spreading effects are present, a reduced Q_{ph} may be considered as follows:

- (a) $Q_{ph} = 0.1Q_u$ — for frame anchoring design based on the upright being unloaded with Q_{ph} acting on one frame in the topmost position.
- (b) $Q_{ph} = 0.1Q_u$ — for overall frame design (bracing and upright) and Q_{ph} acting on one frame on the topmost pallet position.
- (e) If the goods are hand loaded, $Q_{ph} = 0.25$ kN.

2.3.4.3 Application of the horizontal placement action in the down-aisle direction

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

2.3.4.4 Application of the horizontal placement action in the cross-aisle direction

In the cross-aisle direction, the most unfavourable location for the placement action shall be one of the following:

- (a) The top of the uppermost beam level in order to maximize the forces in the bracing system.
- (b) Midway between two bracing nodes of the upright frame lattice in order to maximize the cross-aisle bending moment.

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

- (c) The mid-span of a pallet beam in the horizontal plane in order to provide the maximum minor axis bending moment. This case need not be incorporated in the global cross-aisle analysis.

An action of $0.5 Q_{ph}$ shall be carried by a single beam in the horizontal plane through the neutral axis. The interaction with the vertical action causing Q_{ph} may be ignored.

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

2.3.5 Actions from rack-guided equipment

In racking operated by rack-guided cranes, the probability of all cranes imposing horizontal actions in the same direction and at the same position in the racking simultaneously, as shown in [Figure 2.3.5](#), decreases as the number of cranes increases. Therefore, if the upright frames are joined over the aisles, the total horizontal force (Q_{ht}) at guide rail level shall be the value given in [Table 2.3.5](#).

Table 2.3.5 — Total horizontal actions at guide rail level

Number of cranes	Total horizontal force Q_{ht}
1, 2	$\sum Q_h$
3	$0.85 \sum Q_h$
4	$0.70 \sum Q_h$
5	$0.60 \sum Q_h$
≥ 6	$0.50 \sum Q_h \leq 5 Q_h$

Key

Q_h = maximum specified lateral support action per crane

Q_{ht} = reduced sum of lateral forces acting at the crane top guide rail, which is connected to a member joining all the upright frames together, as shown in [Figure 2.3.5](#)

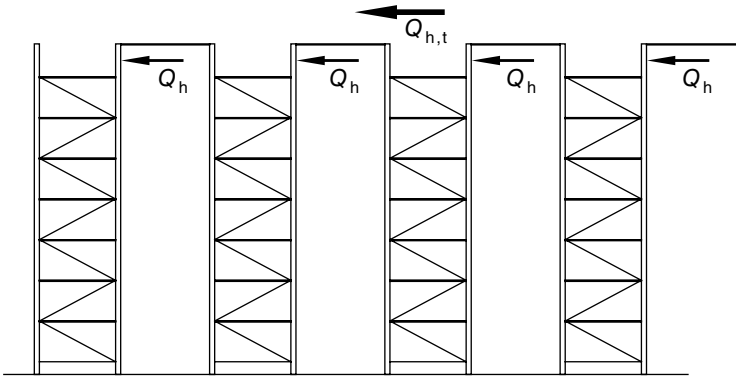


Figure 2.3.5 — Horizontal forces from rack-guided equipment

If the horizontal force (Q_h) is specified as a result of an eccentric one-sided force applied to the crane rail, then the values given in [Table 2.3.5](#) shall not be used.

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

Accidental impact forces in the down-aisle direction arising from a crane hitting a rack-mounted buffer shall be determined and accounted for in the design.

2.3.6 Floor and walkway actions

Uniformly distributed and concentrated live (variable) action requirements shall be determined in accordance with AS/NZS 1170.1 and AS 1657. If the loads arising from stored materials or racking systems supported by the floor exceed the values stated in AS/NZS 1170.1 and AS 1657, the actual

values shall be used. The concentrated actions applied by upright frames directly supported by a flooring system shall be accounted for.

Where moving equipment applies dynamic forces to the structure, these effects shall be taken into account as quasi-static actions. In order to distinguish between the effective vertical wheel actions of the different types of trucks, the relevant static forces shall be multiplied by the dynamic factors given in [Table 2.3.6](#).

Table 2.3.6 — Dynamic factor

Truck type	Dynamic factor
Pedestrian controlled truck with velocity less than 5.0 km/h	1.2
Ride-on truck with a velocity less than 7.5 km/h	1.4
Ride-on truck with a velocity less than 10.0 km/h	2.0

When repeated cycles of rolling loads are involved, fatigue design shall be taken into account.

The effects of horizontal forces applied by the equipment shall be accommodated by the structure.

2.3.7 Actions arising from installation or repair

When the installation method requires the installers to use safety harnesses, anchorage points capable of arresting an accidental fall shall be provided.

NOTE Residual deformation of the members can occur in the event of a fall.

2.4 Accidental actions

2.4.1 General

Accidental actions are defined as impact actions which are more severe than those which occur under ordinary “good practice” operating conditions.

Provision shall be made in the structural design for uses and actions that involve unusual vibration or dynamic forces.

The minimum requirements for the protection of corner uprights shall be as follows:

- (a) An upright protector with a height of not less than 400 mm shall be positioned at the end upright of each run of racking between cross-aisles.
- (b) An upright protector shall be positioned at all those uprights positioned at aisle and gangway intersections.
- (c) The upright protector shall be designed for an energy absorption of not less than 400 Nm in any direction at any height between 0.1 m and 0.4 m.
- (d) The upright protector shall be positioned in such a way that, after its deformation by absorbing an impact, the upright will not be damaged.

NOTE 1 Uprights other than corner uprights may be protected in a direction normal to the aisle, depending on the preference of the user.

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

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

2.4.2 Accidental vertical actions

Racking components directly above a unit load action shall be able to absorb an accidental vertical force (A_{pv}). In general, this force shall be applied at the end of a beam in order to verify that the connector does not disengage. Upward placement actions are accidental variable actions and shall be considered with an action factor (γ_A) (given in [Clause 2.7.4](#)) as follows:

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

$$A_{pv} = 5.0 \text{ kN}$$
- (b) If goods are placed with automatic mechanical equipment (e.g. storage and retrieval machines):

$$A_{pv} = 0.5Q_u$$

but $A_{pv} \geq 0.25 \text{ kN}$ and $A_{pv} \leq 5.0 \text{ kN}$

where

Q_u = weight of unit load action

2.4.3 Accidental horizontal actions

An accidental overload in the horizontal direction shall be calculated as follows:

- (a) For tolerance grade I racking [see AS 4084.2:2023 Table 2.2(B)] —
 From floor to 1.0 m height on the aisle side upright —

$$A_{ph} = 2.5 \text{ kN in the cross-aisle front to back direction}$$

$$A_{ph} = 1.25 \text{ kN in the down-aisle direction}$$

These actions shall be treated as occurring separately, in any position between the floor and a height of 1 m. The accidental actions may be taken by the upright itself or it may need to be reinforced or protected. Upright protectors shall be designed for the full accidental horizontal actions.

NOTE 1 Uprights do not need to be designed for accidental horizontal actions provided upright protectors are installed up to a height of 1 m, or shorter if it can be shown that shorter upright protectors prevent direct upright impact by forklift trucks.
- (b) For tolerance grades II and III racking [see AS 4084.2:2023 Table 2.2(B)] —

$$A_{ph} = 0.5 \text{ kN at any position in either the down-aisle or cross-aisle direction. If upright protectors are installed, they shall be designed to support the specified value of accidental horizontal } A_{ph}.$$

NOTE 2 The specified value of A_{ph} may not be acceptable for certain types of equipment. The machinery to be used should be checked and confirmed (i.e. during a malfunction the action can increase until the clutch on the delivery device slips).

2.5 Wind actions

Where relevant, wind actions shall be determined in accordance with AS/NZS 1170.2.

Unless specified otherwise, for calculation of wind actions racking shall be categorized as a structure of Importance Level 2 in accordance with AS/NZS 1170.0. The minimum design working life to evaluate the wind actions shall be 25 years for stand-alone racking and 50 years for racking that forms part of the frame of the building.

When racking is exposed to wind, each individual row of racking (between adjacent aisles) shall be designed to resist the full wind pressure, suction and wind friction forces. The shielding effects of fully or partially loaded racking upwind of the run in consideration shall not be used in calculating the resistance of each individual row of rack.

NOTE 1 For a clad rack installation, the assembled rows need not be capable of resisting more than the wind force calculated for the complete assembly.

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

NOTE 2 When determining the limiting deflections for the proper functioning of automatic equipment, a lower value of wind load may be used when specified by the supplier of the equipment.

2.6 Seismic actions

2.6.1 General

Provision shall be made for earthquake effects and associated lateral forces determined in accordance with AS 1170.4 and [Clauses 2.6.2 to 2.6.6](#) of this document.

Unless specified otherwise, for calculation of seismic actions, racking shall be categorized as a minimum Importance Level 2 structure. Refer to AS/NZS 1170.0 for circumstances where racking can exceed this minimum importance level. The minimum design working life to evaluate the earthquake actions shall be 25 years for stand-alone racking and 50 years for racking that forms part of the frame of the building.

2.6.2 Seismic mass

The seismic mass (W_t) shall be based on the following:

$$W_t = G + \Psi_A \Psi_E \Psi_M Q_u + 0.3Q_f$$

where

- W_t = total weight of seismic mass considered in the analysis
- G = permanent actions (see [Clause 2.2](#))
- Q_u = maximum imposed unit load action from stored goods (see [Clause 2.3.2](#))
- Q_f = imposed live load action on any floors supported by the rack (see [Clause 2.3.6](#))
- Ψ_A = specified average unit load factor for the upright frame or global down-aisle design (see [Clause 2.3.2](#))
- Ψ_E = specified storage occupancy factor (see [Clause 2.7.2](#))
- Ψ_M = the rigid mass factor accounting for energy dissipation within the unit loads and between the unit loads and the racking

The values of Ψ_M to be used in design shall be taken from [Table 2.6.2](#).

The factor Ψ_M shall be used for determining horizontal loads for seismic actions. It is not used in seismic load combinations for determining associated vertical design actions.

The product of Ψ_E and Ψ_M shall be subjected to the restriction $\Psi_E \Psi_M \geq 0.6$.

Table 2.6.2 — Rigid mass factor

Stored goods	Ψ_M	Example
Compact and constrained	1.0	Frozen goods (cold storage) Steel sheet package Coils and paper rolls
Weak	0.8	Large number of pieces stored on the pallet whose size is small in comparison to the pallet size, including goods stabilized by stretch wrapping
Loose and unconstrained	0.7	Goods that can easily move around, inside the container (e.g. granulated materials)
Liquid	1.0	Unit load containing liquid that can slosh in the container

2.6.3 Ductility

In the absence of associated test data, storage racking shall be designed for a ductility factor (μ) of 1.5 in both the cross-aisle and down-aisle directions. The ductility factor in both the cross-aisle and down-aisle directions may be increased by undertaking special studies consistent with AS/NZS 4600:2018 Clause 1.6.4.2.3(a).

NOTE When undertaking a special ductility study, guidance on representative values of ductility for storage racking can be obtained from EN 16681.

2.6.4 Structural performance factor (S_p)

The structural performance factor to be adopted shall be $S_p = 1.0$.

2.6.5 Seismic actions acting in down aisle direction

The analysis in the down aisle direction is a global analysis and the most relevant action is obtained when the rack is fully loaded with the seismic mass calculated in [Clause 2.6.2](#). Nevertheless, the mass distributions that maximize the internal forces in each element should also be considered, including for checking the uplift forces at the base of the uprights in braced racks.

When the vertical bracing subsystem is not located at the end bays of a row and also takes part in supporting storage loads, for the purposes of checking uplift, the uprights involved in the vertical bracing subsystem shall be subjected to maximum of 30 % of their average storage load. However, the seismic actions shall be determined with the rack being fully loaded.

2.6.6 Drift calculation for LA or GNA

The maximum allowable drift under ultimate earthquake loads shall be calculated based on the following:

$$\delta_{dr} = \delta_{eu} \mu k_{dm} < 0.05h$$

where

δ_{dr} = the maximum drift of the rack

δ_{eu} = the ultimate elastic displacement of the rack using either LA or GNA (see [Table 3.3.3](#))

μ = the ductility factor

k_{dm} = the drift modification factor

- = for racks analysed using LA, see [Table 2.6.6](#)
- = for racks analysed using GNA, adopt 1.0
- h = the total height of the upright frame

Table 2.6.6 — Drift modification factor

Structure height	Drift modification factor k_{dm}
$h < 15$ m	1.2
$15 \leq h \leq 30$ m	$1.2 + 0.02(h - 15)$
$h > 30$ m	1.5

The minimum separation distance between the rack and the building structure, which includes attached permanent components or elements, shall be greater than the maximum drift of the rack (δ_{dr}) limited to $0.05h$ plus allowance for any drift deflections of the adjacent building structure.

2.7 Action combinations

2.7.1 General

The weight of unit loads and global frame imperfections shall together constitute a single action. Placement actions shall constitute a separate action.

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

2.7.2 Combination of actions for ultimate limit states

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

- (a) Considering only the most unfavourable variable action:

$$\Sigma \gamma_G G + \gamma_Q Q_1$$

- (b) Considering all unfavourable variable actions that can occur simultaneously:

$$\Sigma \gamma_G G + 0.9 \Sigma \gamma_Q Q_i$$

- (c) Design for accidental actions:

$$\Sigma \gamma_{GA} G + \Sigma \gamma_{QA} Q_i + \gamma_A A$$

- (d) Design for seismic actions:

$$G + \Psi_A \Psi_E Q_u + 0.3 Q_f + E_u$$

- (e) Design for wind actions:

$$1.3 G + \Psi_A \Psi_E Q_u + 0.6 Q_f + W_u$$

$$0.9 G + W_u$$

where

G = value of permanent actions (dead loads), (see [Clause 2.2](#))

γ_G	=	partial factor for permanent actions (see Clause 2.7.4)
Q_1	=	value of one of the variable actions (see Clause 2.3)
Q_i	=	value of typical variable action (see Clause 2.3)
γ_Q	=	partial factor for variable actions (see Clause 2.7.4)
γ_{GA}	=	partial factor for permanent actions under accidental ultimate limit states (see Clause 2.7.4)
γ_{QA}	=	partial factor for variable actions under accidental ultimate limit states (see Clause 2.7.4)
A	=	value of accidental actions (see Clause 2.4)
γ_A	=	partial factor for accidental actions (see Clause 2.7.4)
Q_u	=	maximum imposed unit load action (see Clause 2.3.2)
Q_f	=	live load action on floors (see Clause 2.3.6)
Ψ_A	=	average unit load factor (see Clause 2.3.2)
Ψ_E	=	storage occupancy factor
	=	1.0 in the cross-aisle direction and 0.85 in the down-aisle direction
W_u	=	ultimate limit state wind load (see Clause 2.5)
E_u	=	ultimate limit state earthquake load (see Clause 2.6)

NOTE 1 See [Appendix D](#) for a full list of recommended action combinations.

NOTE 2 Global frame imperfections are not required to be incorporated in action combinations involving seismic loads.

2.7.3 Combination of actions for serviceability limit states

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

- (a) Considering only the most unfavourable variable action:

$$\Sigma \gamma_G G + \gamma_Q Q_1$$

- (b) Considering all unfavourable variable actions which can occur simultaneously:

$$\Sigma \gamma_G G + 0.9 \Sigma \gamma_Q Q_i$$

- (c) Considering wind load:

$$G + \Psi_A \Psi_E Q_u + W_s$$

where

W_s = serviceability limit state wind load

Placement and accidental actions need not be considered at the serviceability limit state.

NOTE 1 See [Appendix D](#) for a full list of recommended action combinations.