MH16.1: 2008
(a revision of MH16.1: 2004)

Specification for the Design, Testing and Utilization of Industrial Steel Storage Racks

An Affiliated Trade Association of Material Handling Industry of America
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American National Standard

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American National Standards Institute, Inc.

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Foreword (This foreword is not part of American National Standard MH16.1:2008)

RACK MANUFACTURERS INSTITUTE

The Rack Manufacturers Institute (RMI) is an independent incorporated trade association affiliated with the Material Handling Industry. The membership of RMI is made up of companies which produce the preponderance of industrial steel storage racks. This specification is the result of RMI's recognition of the need to develop a comprehensive safety specification and establish minimum design and performance criteria to ensure the safe application and utilization of racking, and was formulated under American National Standards Institute (ANSI) procedures.

At the date of approval of this specification, RMI consisted of the following member companies:

Adrian Fabricators, Inc./Cargotainer
Advance Storage Products, Div. of J.C.M. Industries Inc.
Atlas Material Handling, Inc.
AWP Industries, Inc./American Wire Products
Base Manufacturing
BITO Lagertechnik Bittmann GmbH
Bulldog Rack Company
Engineered Products
Excel Storage Products, LP
Frazier Industrial
Hannibal Material Handling, Inc.
ITC
J&L Wire Cloth LLC
Konstant
Lodi Metal Tech, Inc.
Mecalux USA, Inc.
Morgan Marshall Division, A Leggett & Platt Company
Nashville Wire Products Manufacturing Co., Inc.
Nedcon USA Inc.
Ridg-U-Rak, Inc.
SpaceRak, Division of Tarpon
Speedrack Products Group, Ltd.
Steel King Industries, Inc.
Unarco Material Handling, Inc.
United Fixtures Interlake
Wireway Husky Corporation

RMI maintains a public website at www.MHIA.org/RMI that has information about storage racks and the RMI members including ordering information for literature and a section for frequently asked questions. All inquiries concerning the Specification should be directed in writing to the RMI Engineering Committee, 8720 Red Oak Boulevard, Suite 201, Charlotte, NC 28217

MATERIAL HANDLING INDUSTRY

The Material Handling Industry (Industry) provides RMI with certain services and, in connection with this Specification, arranges for its production and distribution. Neither the Material Handling Industry nor its officers, directors, or employees have any other participation in the development and preparation of the information contained in the Specification.

SPECIFICATION - HISTORY

In the interest of improved uniformity of rack performance and enhanced public safety, the RMI published in 1964 its first “Minimum Engineering Standards for Industrial Storage Racks.” and now publishes this Specification. It was developed and promulgated by the RMI with the sole intent of offering information to the parties engaged in the engineering, manufacturing, marketing, purchasing, installation or use of such racks.

Since 1964, mechanized storage systems have grown very rapidly both in size and height with new and modified types of racks having been developed. To reflect this rapid development and to assure adequate safety and performance of modern rack structures, the RMI decided early in 1971 to replace its original standards by a more detailed and comprehensive specification. Professors George Winter and Teoman Pekoz of Cornell University were retained to assist the Rack Standard Development Project Committee in producing such a document. The members of the Material Handling Institute, Inc. were the sponsors.

In 1972, the “Interim Specification for the Design, Testing and Utilization of Industrial Steel Storage Racks” was adopted by the Rack Manufacturers Institute at their annual fall meeting. The specification was then submitted to the American National Standards Institute for their review and acceptance. In 1974, the Interim Specification with minor changes was accepted as American National Standard ANSI MH 16.1: 1974.

The Rack Manufacturers Institute together with its sponsors from the Material Handling Institute, Inc., retained Professors Winter and Pekoz to continue testing rack components plus perform full scale tests on typical storage rack structures. A number of the test results have been analyzed, and it was considered necessary to rewrite the 1972 Interim Specification to include the knowledge gained from the analysis of those tests. The 1972 Interim Specification was rewritten by the Rack Standards Subcommittee with the assistance of Professors Winter and Pekoz. Design parameters relating to drive-in and drive-through racks have been removed from the Specification until drive-in and drive-through rack test results could be analyzed more thoroughly; perhaps more testing would be required. Movable-shelf racks were added to the Specification.

As a result of additional testing and analytical research, the RMI revised the 1972 Specification. The ANSI MH 16.1: 1974 was withdrawn in deference to the 1979 Specification. More additions and revisions prompted the RMI to publish the 1985 Specification.

Subsequent testing and research by Dr. Pekoz was the basis of the changes resulting in the 1990 Specification.

From 1990 to 1997, due to continuing changes, specifically as they relate to seismic analysis and other model building code issues, the Specification Advisory Committee, the Seismology Committee and the RMI Engineering Committee working again with Dr. Pekoz and several highly regarded members of the code community and various other members of similar groups throughout the world, conducted extensive testing and parametric analysis. Findings resulted in the 1997 Specification.

In addition to the state-of-the-art benefit from the ongoing testing and analysis, the 1997 Specification was expanded to include complete treatment of seismic design considerations so that the Specification could be more easily incorporated by reference into various model building and design codes.

In 1999, the Membership of RMI acted to create a Voluntary Certification Program known as the R-MARK. The R-Mark is a license earned by a manufacturer following a rigorous review by Independent Professional Engineers of tests and load capacity calculations performed by the manufacturer consistent with the RMI/ANSI Specification.

Continued testing and parametric studies resulted in the 2002 Specification. In 2004 the 2002 RMI Specification and Commentary were adopted as American National Standard ANSI MH 16.1-2004

SPECIFICATION - 2008 EDITION

The use of this Specification is permissive, not mandatory. Voluntary use is within the control and discretion of the user and is not intended to, and does not in any way limit the ingenuity, responsibility or prerogative of individual manufacturers to design or produce industrial steel storage racks that do not comply with this Specification. RMI has no legal authority to require or enforce compliance with the Specification. This advisory Specification provides technical guidelines to the user for his specific application. Following the Specification does not assure compliance with applicable federal, state, or local regulations and codes. This Specification is not binding on any person and does not have the effect of law.

The RMI and the Material Handling Industry do not take any position regarding any patent rights or copyrights which could be asserted with regard to this Specification and does not undertake to insure anyone using this Specification against liability, nor assume any such liability. Users of this Specification are expressly advised that determination of the validity of any such copyrights, patent rights, and risk of infringement of such rights is entirely their own responsibility.

In the interest of safety, all users of storage racks are advised to regularly inspect and properly maintain the structural integrity of their storage rack systems by assuring proper operational, housekeeping and maintenance procedures

Users of the Specification must rely on competent advice to specify, test and/or design the storage rack system for their particular application. This Specification is offered as a guideline. If a user refers to, or otherwise employs, all or any part of the Specification, the user is agreeing to follow the terms of indemnity, warranty disclaimer, and disclaimer of liability.

Table of Contents

SYMBOLS

a	Vertical distance between the horizontal brace axes
A	Sum of the minimum net area (Anet min.) of the columns of the upright frame
A_b	Cross-sectional area of a horizontal brace
A_d	Cross-sectional area of a diagonal brace
A_e	Effective area at the stress F_n
$A_{net\ min}$	Minimum cross-sectional area obtained by passing a plane through the column normal to the axis of the column
b	Horizontal distance between neutral axes of the columns
C_s	Seismic response coefficient
DL	Dead Load
E	Modulus of elasticity of steel
EL	Earthquake (seismic) Load
f'_c	Minimum 28-day compression strength of the concrete
F_1	Lateral force at the first shelf level
F_a	Site coefficient defined in Table 2.6.3.2 (2). If site class is unknown, use site class D
F_c	Critical buckling stress
F_n	Nominal buckling stress
F_v	Site coefficient defined in Table 2.6.3.2 (3). If site class is unknown, use site class D
F_x	Lateral force at any level
F_y	Yield point used for design
h_i or h_x	Height from the base to level i or x
I	Minimum net moment of inertia of the columns about the gravity axis of the upright frame perpendicular to the plane of the upright frame
I_{br}	Moment of inertia of the horizontal brace about its own axis perpendicular to the plane of the upright frame
I_c	Minimum net moment of inertia of one column about its own major axis perpendicular to the plane of the upright frame
IL	Impact loading on a shelf
I_p	System importance factor that varies from 1.00 to 1.50
k	Upright stability coefficient based on location of the center of load
l	Total height of the upright frame
LL	Live Load other than the pallets or products stored on the racks

Lr	Roof Live Load
L_{short}, L_{long}	Distance between column brace points
L_x, L_y, L_t	Unbraced lengths for column design, for bending about x- and y-axes and torsion
PL	Maximum Load from pallets or products stored on the racks
PL_{app}	Portion of pallet or product load that is used to compute the seismic base shear
$PL_{Average}$	Maximum total weight of product expected on the beam levels in any row divided by the number of beam levels in that row
$PL_{Maximum}$	Maximum weight of product that will be placed on any one beam level in that row
PL_{RF}	Product Load reduction factor ($PL_{Average}$ / $PL_{Maximum}$)
P_n	Nominal axial strength
Q	Capacity reduction factor for compressive members
R	Seismic response modification factor (Section 2.6.3)
RL	Load from rain including ponding
S_1	Mapped spectral accelerations for a 1-second period as determined per USGS
S_c	Elastic section modulus of the net section for the extreme compression fiber times $1-0.5(1-Q)(Fc/Fy)^Q$
S_{D1}	Design spectral response acceleration parameter for 1-second period (2/3) S_{M1}
S_{DS}	Design spectral response acceleration parameter for short period (2/3) S_M
S_e	Elastic section modulus of the net section for the extreme compression fiber times (0.5+Q/2)
S_f	Elastic section modulus of the full unreduced gross section for the extreme compression fiber
SL	Snow Load
S_{M1}	Maximum considered earthquake spectral response accelerations for 1-second period
S_{MS}	Maximum considered earthquake spectral response accelerations for short period
S_s	Mapped spectral accelerations for short periods as determined per USGS
T	Fundamental period of the rack structure in each direction under consideration
V	Seismic base shear
w_i or w_x	Portion of the total gravity load of the rack, located or assigned to the bottom shelf level, level i or x
WL	Wind Load

W_s	Loads on the structure that are used to compute the horizontal base shear. $(0.67 x PL_{RF} x PL) + DL + 0.25 x LL$
α	Second-order load amplification factor used in the column check
α_s	Second-order amplification factor from FEMA 460 calculated using Ws as the vertical load.
θ_{Max}	Maximum rotation sustained by the beam to column connection over at least 2 cycles during testing
θ_D	Rotational seismic demand of the beam to column connection
σ_{ex}, σ_{ey}, σ_t	Compressive stresses calculated per AISI
ϕ	Angle between horizontal and diagonal braces
ϕ_c	Resistance factor for concentrically loaded compression member
$\phi_c P_n$	Design strength
Ω	Factor of safety for ASD

NOMENCLATURE

Note: Terms designated with † are common with AISI-AISC terms that are coordinated between the standards developers.

Automated Storage and Retrieval Systems (ASRS) - A rack structure in which loading and unloading of the racks is accomplished by a stacker crane, or similar vehicle, without the aid of an on-board operator.

Allowable strength† - Nominal strength divided by the safety factor

Allowable stress. - Allowable strength divided by the appropriate section property, such as section modulus or cross-section area.

Applicable code† - Code (enforced by the local building department)under which the structure is designed.

ASD (Allowable Strength Design)† - Method of proportioning structural components such that the allowable strength equals or exceeds the required strength of the component under the action of the ASD load combinations.

ASD load combination† - Load combination in the applicable building code intended for allowable strength design (allowable stress design).

Beam – Typically, a horizontal structural member that has the primary function of resisting bending moments.

Beam locking device - A pin, bolt, or other mechanism that resists disengagement of the beam connector from the column.

Braced frame† - An essentially vertical truss system that provides resistance to lateral forces and provides stability for the structural system.

Buckling - Limit state of sudden change in the geometry of a structure or any of its elements under a critical loading condition.

Buckling strength - Nominal strength for buckling or instability limit states.

Cantilever rack - A rack structure comprised primarily of vertical columns, extended bases, horizontal arms projecting from the face of the columns, and down-aisle bracing between columns. There can be shelf beams between arms depending on the product being stored. Cantilever columns may be free-standing or overhead tied.

Cantilever test - A test designed and conducted to determine the connection moment-resisting capacity and the rotational rigidity, F, of a beam-to-column connection. The test set-up employs one column segment and one beam segment connected to one another with a beam-to-column connector, with a load applied downwardly in the plane of the frame at the cantilever end of the beam segment.

Case flow rack - A specialized pallet rack structure in which either the horizontal shelf beams support case-flow lanes or case-flow shelf assemblies are supported by the upright frames. The case-flow lanes or shelves are installed at a slight pitch

permitting multiple-depth case or box storage with loading from one service aisle and unloading or picking from another service aisle.

Cladding - Exterior covering of structure.

Cold-formed steel structural member† - Shape manufactured by press-braking blanks sheared from sheets, cut lengths of coils or plates, or by roll forming cold- or hot-rolled coils or sheets; both forming operations being performed at ambient room temperature; that is, without manifest addition of heat such as would be required for hot forming.

Column - Structural member that has the primary function of resisting axial force.

Concrete crushing - Limit state of compressive failure in concrete having reached the ultimate strain.

Concurrent forces - Two or more forces acting in conjunction with one another at a single location.

Connection† - Combination of structural elements and joints used to transmit forces between two or more members.

Cyclic tests - A test designed and conducted to determine the connection moment-resisting capacity and rotational rigidity, along with energy-dissipation properties, of beam-to-column connections when those connections are subjected to cyclic loading conditions. The test set-up employs one column segment and two beam segments connected to one another, using two beam-to-column connectors, as a double cantilever. Two parallel loads are applied, in opposing reversing cyclic fashion, in the plane of the frame at the ends of, and normal to, the cantilevered beam elements.

Design load† - Applied load determined in accordance with either LRFD load combinations or ASD load combinations, whichever is applicable.

Design strength† - Resistance factor multiplied by the nominal strength, [F R_n].

Design stress - Design strength divided by the appropriate section property, such as section modulus or cross section area.

Diagonal bracing - Inclined structural member carrying primarily axial force in a braced frame.

Distortional buckling. - A mode of buckling involving change in cross-sectional shape, excluding local buckling.

Double-stacking - When a shelf is loaded with loads stacked one on top of another in a pallet position.

Drive-in rack - A rack structure comprised primarily of vertical upright frames, horizontal support arms, and horizontal load rails typically used for one-wide by multiple-depth storage. This structure includes an 'anchor section' with horizontal beams supporting the load rails. Loading and unloading within a bay must be done from the same aisle. A two-way drive-in rack is a special case where back-to-back rows of drive-in racks are combined into a single entity with a common rear post.

Drive-through rack - A rack structure comprised primarily of vertical upright frames, horizontal support arms, and horizontal load rails typically used for one-wide by multiple-depth storage. This structure lacks the 'anchor section' found in drive-in racks; therefore, loading and unloading can be accomplished from both ends of a bay.

Effective length - Length of an otherwise identical column with the same strength when analyzed with pinned end conditions.

Effective length factor - Ratio between the effective length and the unbraced length of the member.

Effective section modulus - Section modulus reduced to account for buckling of slender compression elements.

Effective width - Reduced width of a plate or slab with an assumed uniform stress distribution which produces the same effect on the behavior of a structural member as the actual plate or slab width with its nonuniform stress distribution.

Factored load† - Product of a load factor and the nominal load.

Flexural buckling - Buckling mode in which a compression member deflects laterally without twist or change in cross-sectional shape.

Flexural-torsional buckling† - Buckling mode in which a compression member bends and twists simultaneously without change in cross-sectional shape.

Force - Resultant of distribution of stress over a prescribed area.

Gravity load - Load such as that produced by dead and live loads, acting in the downward direction.

Kick-plate - A vertical plate (angle or barrier) that is installed at the edge of an elevated floor that is intended to prevent loose items from sliding off the edge of the floor. (Section 8.4.3.3).

Load factor† - Factor that accounts for deviations of the nominal load from the actual load, for uncertainties in the analysis that transforms the load into a load effect and for the probability that more than one extreme load will occur simultaneously.

Local buckling - Limit state of buckling of a compression element within a cross section.

LRFD (Load and Resistance Factor Design)† - Method of proportioning structural components such that the design strength equals or exceeds the required strength of the component under the action of the LRFD load combinations.

LRFD load combination† - Load combination in the applicable building code intended for strength design (load and resistance factor design).

Movable-shelf rack - A rack structure comprised primarily of vertical upright frames and horizontal shelf beams and typically used for one-deep pallet or hand-stack storage. Typically, the locations of a couple of shelf levels are 'fixed' with the location of the in-fill shelves being flexible.

Net area - Gross area reduced to account for removed material.

Nominal strength† - Strength of a structure or component (without the resistance factor or safety factor applied) to resist load effects, as determined in accordance with this Specification.

Out-of-plumb ratio - Maximum horizontal distance (in.) from the centerline of the column at the floor to a plumb line that extends downward from the centerline of the column at the top shelf elevation divided by the vertical distance (ft.) from the floor to the top shelf elevation.

Out-of-straight ratio – Maximum horizontal distance (in.) from the centerline at any point on the column to a plumb line from any other point on the column divided by the vertical distance (ft.) between the two points.

Overturning moment - An applied force that causes a structure to turn over.

Pallet beam - The front and back shelf members that bear the weight of the load and transfer the load to the upright frames.

Pallet flow rack - A specialized pallet rack structure in which the horizontal shelf beams support pallet-flow lanes. The pallet-flow lanes are typically installed on a slight pitch permitting multiple-depth pallet storage with loading from one service aisle and unloading from another service aisle.

Pallet load support member - Any load bearing member with the long axis on the horizontal plane and intended for use as support of unit loads in direct contact. (pallet and shelf supports and beams, not bracing).

Pallet rack - A rack structure comprised primarily of vertical upright frames and horizontal shelf beams and typically used for one and two-deep pallet storage.

Pick modules - A rack structure comprised primarily of vertical frames and horizontal beams typically having one or more platform levels of selective, case-flow, or pallet-flow bays feeding into a central pick aisle(s) [work platform(s)] supported by the rack structure.

Plaque – Signage permanently and prominently displayed depicting the permissible loading of the rack.

Portable rack (stacking frames) - An assembly, typically with four corner columns, that permits stacking of one assembly on top of another without applying any additional load to the product being stored on each assembly.

Portal test - A test designed and conducted to determine the connection moment-resisting capacity and the rotational rigidity, F, of a beam-to-column connection. The test set-up employs two column segments and one beam segment connected to one another using two beam-to-column connectors forming a portal frame, with the load applied laterally in the plane of, and to the corner of, the portal frame in the direction parallel to the beam segment.

Product load - The weight of the item(s) placed on the rack.

Push-back rack - A specialized pallet rack structure in which the horizontal shelf beams support push-back lanes comprised of tracks and carts. The push-back lanes are installed on a slight pitch permitting multiple-depth pallet storage. Loading and unloading are done from the same service aisle by pushing the pallets back.

Rack supported platforms - A decked working surface supported by a rack structure.

Rack supported structure - A rack structure similar to other rack structures; however, this structure also includes wall girts and roof purlins or equivalent components used to support wall and roof cladding. This structure is designed to carry, wind, snow, and rain loads in addition to the normal storage rack loads.

Resistance factor† - Factor that accounts for unavoidable deviations of the nominal strength from the actual strength and for the manner and consequences of failure.

Safety factor† - Factor that accounts for deviations of the actual strength from the nominal strength, deviations of the actual load from the nominal load, uncertainties in the analysis that transforms the load into a load effect, and for the manner and consequences of failure.
The nominal load divided by the safety factor results in the allowable load for an Allowable Strength Design.

Safety flooring - A surface that is provided in areas where order picking personnel may need to step off the normal walking area or pick module walkway to dislodge loads that may not have properly flowed to their correct position.

Seismic response modification coefficient - Factor that reduces seismic load effects to strength level.

Sidesway buckling - Limit state of lateral buckling of the tension flange opposite the location of a concentrated compression force.

Simple lip – Single plate elements used to stiffen a compression flange.

Site class definition - A classification assigned to a location based on the types of soils present.

Stability - Condition reached in the loading of a structural component, frame or structure in which a slight disturbance in the loads or geometry does not produce large displacements.

Stacking rack – See Portable rack.

Stacker rack - A rack structure similar to one of the other rack structures; that is serviced by an automated storage and retrieval machine.

Stiffness - Resistance to deformation of a member or structure, measured by the ratio of the applied force (or moment) to the corresponding displacement (or rotation).

Stress - Force per unit area caused by axial force, moment, shear or torsion.

Structural system - An assemblage of load-carrying components that are joined together to provide interaction or interdependence.

Stub column test – Concentric compression testing of members not affected by column buckling used to determine the column effectiveness.

Torsional buckling - Buckling mode in which a compression member twists about its shear center axis.

Torsional-flexural buckling. - Buckling mode in which compression members bend and twist simultaneously without change in cross section shape.

Trussed-braced upright frame – Upright frames having two columns similar to the chords of a truss and diagonal and horizontal bracing attached to and located between the columns. The diagonals and horizontals become the web members of the truss. (It is referred to as a vertical truss.).

Unbraced length - Distance between braced points of a member, measured between the centers of gravity of the bracing members.

Unit load - The total weight expected to be positioned in the rack consisting of the product load and pallet weight.

Upright frame – The main members that carry the vertical and horizontal loads to the floor. They are usually made up of two columns and bracing members between the columns. The beams of the rack are attached to the columns of the frames and carry the loads to the columns.

Vertical impact load - Additional downward force added to the beams produced during loading of the rack.

Yield point† - First stress in a material at which an increase in strain occurs without an increase in stress as defined by ASTM.

Yield strength† - Stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain as defined by ASTM.

SPECIFICATION FOR THE DESIGN, TESTING AND UTILIZATION OF INDUSTRIAL STEEL STORAGE RACKS

1. GENERAL

1.1 SCOPE

This Specification and companion Commentary (hereinafter referred to as the Specification) applies to industrial pallet racks, movable shelf racks, rack supported systems and stacker racks made of cold-formed or hot-rolled steel structural members. Such rack types also include push back rack, pallet flow rack, case flow rack pick modules and rack supported platforms. This Specification is intended to be applied to the design of the storage rack portion of any rack structure that acts as support for the exterior walls and roof, except as noted. It does not apply to other types of racks, such as drive-in or drive-through racks, cantilever racks, portable racks, or to racks made of material other than steel.

1.2 MATERIALS

This Specification assumes the use of steel of structural quality as defined in general by the specifications of the American Society for Testing and Materials (ASTM) that are listed in the American Iron and Steel Institute (AISI) North American Specification for the Design of Cold-Formed Steel Structural Members [1][1], and the American Institute of Steel Construction (AISC) Specification for Structural Steel Buildings [2].

Steels not listed in the above specifications are not excluded provided they conform to the chemical and mechanical requirements of either reference [1] or [2], or other published specifications which establish their properties and structural suitability, and provided they are subjected either by the producer or the purchaser to analyses, tests, and other controls in the manner prescribed by either reference [1] or [2] as applicable.

1.3 APPLICABLE DESIGN SPECIFICATIONS

Except as modified or supplemented in this Specification, the AISI (2001) [1] and the AISC (2005) [2], as respectively applicable, are used in the determination of the available strength of industrial steel storage racks.

1.4 INTEGRITY OF RACK INSTALLATIONS

1.4.1 Owner Maintenance

The owner shall maintain the structural integrity of the installed rack system by assuring proper operational, housekeeping, and maintenance procedures including, but not limited to, the following:

(1) Prohibit any overloading of any pallet positions and of the overall rack system.

(2) Regularly inspect for damage. If damage is found, immediately unload the affected area and replace or repair any damaged columns, beams, or other structural components.

[1] Numbers in brackets refer to corresponding numbers in Section 10, References to the Text.