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

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American National Standard

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Rack Manufacturers Institute (RMI)
An Industry Group of MHI

Approved October 8, 2015
American National Standards Institute, Inc.

FOREWORD This standard, which was developed under the American National Standards Institute (ANSI) Canvass method and approved by ANSI on October 8, 2015, represents suggested design practices and operational requirements for cantilevered storage racks. It was developed by MHI, along with the Rack Manufacturers Institute ("RMI"), one of its Industry Groups, and is intended to provide useful information and guidance for owners, users, designers, purchasers or specifiers of material handling equipment or systems. It is advisory only and should only be regarded as a simple tool that its intended audience may or may not choose to follow, adopt, modify, or reject. A standard may be part of, but does not constitute a comprehensive safety program that cannot guard against pitfalls in operating, selecting and purchasing cantilevered storage racks, and should not be relied upon as such. Such a program should be developed by a qualified professional.

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The **Rack Manufacturers Institute** (RMI) is comprised of companies that supply industrial steel storage racks and related structural systems. This standard is the result of RMI's recognition of the need to standardize performance, and design criteria for the proper utilization of cantilevered storage racks, and was formulated under MHI procedures approved by ANSI.

Questions or suggestions for improvement regarding of this standard are welcome. Suggestions should be sent to: MH16.3 Committee, MHI, 8720 Red Oak Blvd., Suite 201, Charlotte, NC 28217; standards@mhi.org.

ERRATA. Important corrections to the text are summarized below:

Rev.	Date	Correction
V1	Feb. 16, 2016	Eq. 2-4 changed from $C_s = \frac{S_{DS}}{TR}$ to $C_s = \frac{S_{DS}}{R}$

Table of Contents

SYMBOLS

The section or table number in the right-hand column refers to where the symbol is first used or defined.

SYMBOL	DEFINITION	SECTION
A_e	Effective area at the stress F_n	4.1.3.2
A_n	Nominal cross-sectional area	C10.1.2
$A_{net\ min}$	Minimum cross-sectional area obtained by passing a plane through the column normal to the axis of the column	10.2.2
A_t	Calculated cross-sectional area based on the weight of a length of failed component divided by the unit weight of steel times the length used for weighing	C10.1.2
C_d	Deflection amplification factor	2.7.2.3.1
C_f	Correction factor	C10.1.2
C_s	Seismic response coefficient	2.7.2.2
D	Dead load	2.1
E	Modulus of elasticity of steel	6.2.2.3
E	Earthquake (seismic) load	2.1
F_a	Site coefficient defined in Table 2.7.2.2.2 (2)	2.7.2.2.2
F_i	Lateral force at arm level, i	2.7.2.5
F_c	Critical buckling stress	4.1.2.2
F_e	Elastic buckling stress	C4.1.2.2
F_n	Nominal buckling stress	4.1.3.2
F_v	Site coefficient defined in Table 2.7.2.2.2 (3)	2.7.2.2.2
F_x	Lateral force at any arm level	2.7.2.3
F_y	Yield stress for steel used for design	10.2.2
F_{yn}	Nominal yield stress of the failed component	C10.1.2
F_{yt}	Measured yield stress of the failed component	C10.1.2
H	Height of the loaded arm level	6.3.1
I	Impact loading on an arm or shelf	2.1
I	Moment of inertia in the plane of bending	6.2.2.3
I_b	Moment of inertia of the arm about the bending axis	C10.5.4
I_p	System importance factor	2.7.2
K	Column stability coefficient based on location of the center of load	6.2.1
K_s	Top-tie stiffness (secant stiffness) at service loads	6.2.2.3
L	Live load other than the pallets or products stored on the racks	2.1
L	Height to the center of gravity of the arm loads	6.2.1
L	Distance between the column face and the load application point	C10.5.2
L_p	Limiting laterally unbraced length for plastic analysis	6.7
L_r	Roof live load	2.1
$M_{50\%}$	50 percent of the ultimate moment observed in the test	C10.5.4
MCE	Maximum Considered Earthquake event	6.3.1.3
P	Maximum load from product stored on the rack	2.1
$P_{50\%}$	Load applied at 50% of the ultimate moment observed in the test	C10.5.4
P_{app}	Portion of pallet or product load that is used to compute the seismic base shear	2.1
P_p	Bearing strength	8.3
Q	Capacity reduction factor for compressive members	10.2.2
R	Load from rain including ponding	2.1
R	Seismic response modification factor	2.7.2.2
S	Snow load	2.1

S_1	Mapped spectral accelerations for a 1-second period as determined in accordance with the USGS	2.7.2.2.2
S_c	Elastic section modulus of the net section for the extreme compression fiber times $1-0.5(1-Q)(F_c/F_y)^Q$	4.1.2.2
S_{D1}	Design spectral response acceleration parameter for 1-second period (2/3) S_{M1}	2.7.2.2
S_{DS}	Design spectral response acceleration parameter for short period (2/3) S_M	2.7.2.2
S_e	Elastic section modulus of the net section for the extreme compression fiber times (0.5+Q/2)	4.1.2.2
S_{M1}	Maximum considered earthquake spectral response accelerations for 1-second period	2.7.2.2.1
S_{MS}	Maximum considered earthquake spectral response accelerations for short period	2.7.2.2.1
S_s	Mapped spectral accelerations for short periods as determined in accordance with the USGS	2.7.2.2.2
T	Fundamental period of the cantilevered rack structure in each direction under consideration	C2.7.2.2
V	Seismic base shear	2.7.2
V_x	Seismic base shear at any level	2.7.2.5
W	Wind load	2.1
W_i	D + P (used to determine the seismic lateral forces) + 0.25L at each level *i*	C2.7.2.2
W_s	Loads on the structure that are used to compute the horizontal base shear.	2.7.2
d	Distance between the supports of the column segment	C10.5.2
f'_c	Minimum 28-day compression strength of the concrete	8.3
g	Acceleration due to gravity	C2.7.2.2
h	Height to the top of the top arm at the connection to the column	6.6.1
h	Height to the top of the column	6.6.2
h_i or h_x	Height from the base to level i or x	2.7.2.4
h_{total}	Height of the top arm level	2.7.2.3.2
k_Q	Rotational stiffness	C10.5.4
t_n	Nominal core thickness of the failed component element	C10.1.2
t_t	Measured core thickness of the failed component element	C10.1.2
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	2.7.2.4
β	Seismic product load coefficient	2.1
Δ_i	Total lateral displacement at level *i* relative to the base, as computed using F_i	C2.7.2.2
ϕ	Resistance factor for LRFD	4.1.3.1
ϕ_c	Resistance factor for bearing on concrete	8.3
Ω	Factor of safety for ASD	4.1.3.1
Ωc	Factor of safety for bearing on concrete	8.3
δ_s	Seismic drift of the top arm	2.7.2.3.1
δ_{xM}	Maximum response drift	2.7.2.3.2
δ_{xMT}	Required seismic separation between the rack and building structure	2.7.2.3.2
δ_{xM1}	Amplified seismic drift of the cantilevered storage rack	2.7.2.3.2
δ_{xM2}	Amplified seismic drift of the building structure	2.7.2.3.2
σ_{ex}, σ_{ey}, and σ_t	Compressive stresses calculated in accordance with the AISI standard	C4.1.2.2
ρ	Redundancy factor for earthquake loading	2.7.2.1

NOMENCLATURE

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

Allowable strength† - Nominal strength divided by the safety factor.

Allowable Strength Design (ASD) † - 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.

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

ASD load combination† - Load combination in Section 2.1 based on ASCE 7 [5] intended for allowable strength design (allowable stress design).

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.

Built-up member, cross section, section or shape - Member, cross section, section or shape fabricated from structural steel or cold-formed steel elements that are bolted or welded together.

Cantilevered storage 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. Cantilevered columns may be free-standing or top-tied.

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; all 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 and bending moment.

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.

Cross-aisle – One of the two principal directions of the storage rack, corresponding to the direction perpendicular to the principal handling equipment aisle. This is also referred to as the transverse direction.

Cyclic test - A test designed and conducted to determine the column-to-base connection's inelastic rotational rigidity, along with energy-dissipation properties, of the connection when the connection are subjected to cyclic loading conditions.

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

Design professional – An engineer familiar with and experienced in the design of cantilevered storage rack. Also known as the **Engineer of Record**.

Design strength† - Resistance factor multiplied by the nominal strength, $\mathbb{F}\ R_n$

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

Diagonal bracing - Inclined structural member carrying primarily axial force.

Direct analysis method – Design method for stability that captures the effects of residual stresses and initial out-of-plumbness of columns by reducing stiffness and applying notional loads in a second-order analysis.

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

Double-stacking - When an arm is loaded with loads stacked one on top of another.

Down-aisle - One of the two principal directions of the storage rack, corresponding to the direction parallel to the principal handling equipment aisle. This is also referred to as the longitudinal direction.

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 non-uniform stress distribution.

Engineer of Record – See "design professional."

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.

Free-standing (non-top tied) cantilevered columns – Columns without lateral support in the cross-aisle direction at the top.

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

Handled unit load - An individual product load weight expected to be placed into a location of the cantilevered storage rack.

Load and Resistance Factor Design (LRFD) † - 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.

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 combination† - Load combination in Section 2.2 based on ASCE 7 [5] intended for strength design (load and resistance factor design).

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.

Notional load – Virtual load applied in a structural analysis to account for destabilizing effects that are not otherwise accounted for in the design provisions.

Out-of-plumb ratio - Maximum horizontal distance 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 from the floor to the top shelf elevation.

Overturning moment – Moment resulting from an applied force or lateral displacement in the cross-aisle direction.

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

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

Rack-supported structure - A cantilevered storage 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 withstand, wind and snow or rain loads, in addition to the normal storage rack loads.

Redundancy factor – Factor that accounts for the potential of structural distress when the system has lost the carrying capacity of one load carrying element.

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.

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

Service load – The actual unfactored loads to which the member will be subjected during its lifetime.

Simple lip – A single plate element 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.

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.

Top-tied cantilevered columns – Columns with cross-aisle support members at the top of the column connected with pinned or moment-resisting connections.

Top Ties (overhead ties) – members tying the tops of the columns together in the cross-aisle direction.

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.

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

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

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

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 CANTILEVERED STORAGE RACKS

1 GENERAL

1.1 Scope

This Specification applies to free-standing and top-tied cantilevered storage racks made of cold-formed or hot-rolled structural steel members. This Specification also covers cantilevered storage racks with accessories, such as decked shelves, shed roofs and canopies.

The scope limits the applicability of this Specification to cantilevered storage racks made from either hot-rolled or cold-formed steel.

This Specification is intended to be used in conjunction with the Commentary, which serves to clarify and interpret this Specification.

1.2 Materials

This Specification requires the use of steel of structural quality that is listed in AISI S100, *North American Specification for the Design of Cold-Formed Steel Structural Members* [1][1] or the AISC 360 [2], and as defined by the specifications of the American Society of Testing and Materials (ASTM) therein.

Bolts, nuts and washers shall conform to the applicable ASTM or SAE standard. Hydrogen embrittlement shall be considered for bolts that are used in tension.

1.3 Applicable Design Specifications

Except as modified or supplemented in this Specification, the AISC 360 [2] shall apply to the design and testing of cantilevered storage rack made from hot-rolled structural steel members and AISI S100 [1] shall apply to the design and testing of cantilevered storage rack made from cold-formed structural steel members.

Capacities shall be determined using applicable standards appropriate for the structure or component. Where possible, a single standard should be used for the entirety of the rack structure. In the event of conflict between standards, the provision most specific to the component or structure shall be used.

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] Numbers in brackets refer to corresponding numbers in the References to the Text at the end of this Specification.