
Load and Resistance Factor Design Specification for Safety-Related Steel Structures for Nuclear Facilities

December 17, 2003

Approved by the
AISC Committee on Specifications
and issued by the AISC Board of Directors



Documents

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PREFACE

The AISC *Load and Resistance Factor Design (LRFD) Specification for Safety-Related Steel Structures for Nuclear Facilities* addresses the design, fabrication, and erection of steel safety-related structures for nuclear facilities. This document supplements the AISC *Load and Resistance Factor Design Specification for Structural Steel Buildings* dated December 27, 1999. It also provides an alternate method of design to that given in the ANSI/AISC N690-1994, *Specification for the Design, Fabrication, and Erection of Safety-Related Steel Structures for Nuclear Facilities*, including Supplement No. 1, which is based on allowable stress design.

Safety-related steel structures in nuclear facilities, which provide support and protective functions to equipment vital to the facility, are subjected to certain unique design forces and loads resulting from postulated accidents (such as turbine generated missiles and jet forces from high energy line breaks) and from extreme natural phenomena (tornadoes and earthquakes). The relevant regulatory and jurisdictional authorities (e.g. the Nuclear Regulatory Commission, the Department of Energy) dictate special quality assurance requirements and additional design requirements associated with these structures. As such, safety related nuclear structures require special LRFD design provisions. The provisions specified herein are to be used in conjunction with the AISC *LRFD Specification for Structural Steel Buildings*. This Specification consists of modifications (additions, deletions and replacements) of the 1999 AISC *Load and Resistance Factor Design Specification for Structural Steel Buildings*, referred to as the AISC LRFD Specification.

This Specification has been developed as a consensus document to provide uniform practice in the design of steel-framed structures for nuclear facilities. The AISC Committee on Specifications, Task Committee 12—Nuclear Facilities Design, is responsible for the ongoing development of this Specification. TC 12 membership is as follows:

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A non-mandatory Commentary provides background for the Specification provisions and the user is encouraged to consult it.

The reader is cautioned that professional judgment must be exercised when data or recommendations in this Specification are applied. The publication of the material contained herein is not intended as a representation or warranty on the part of the American Institute of Steel Construction, Inc. or any other person named herein that this information is suitable for general or particular use, or freedom from infringement of any patent or patents. Anyone making use of this information assumes all liability arising from such use. The design of safety related structures for Nuclear Facilities is within the scope of expertise of a competent licensed structural engineer, architect, or other licensed professional, for the application of principles to a particular structure.

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SYMBOLS

The symbols listed below shall be used in addition to those in the AISC LRFD Specification. Where there is a duplication of symbols between this Specification and the AISC LRFD Specification the symbols herein shall take precedence. The section number in the right hand column refers to the section where the symbol is first used.

<u>Symbol</u>	<u>Definition</u>	<u>Section</u>
C	Rated capacity of crane	NA4.1
D	Dead loads due to the weight of the structural elements, fixed-position equipment, and other permanent appurtenant items; weight of crane trolley and bridge	NA4.1
E_o	Loads generated by the <i>operating basis earthquake</i>	NA4.2
E_{ss}	Loads generated by the <i>safe shutdown or design basis earthquake</i>	NA4.3
L	Live load due to occupancy and moveable equipment, including their impact	NA4.1
P_a	Maximum differential pressure load generated by the postulated accident	NA4.4
R_a	Pipe and equipment reactions generated by the postulated accident, including R_o	NA4.4
R_o	Pipe reactions during normal operating, start-up, or shutdown conditions, based on the most critical transient or steady-state condition.....	NA4.1
S	Snow load as stipulated in ASCE 7 for Category IV facilities	NA4.1
T_a	Thermal loads generated by the postulated accident, including T_o	NA4.4
T_o	Thermal effects and loads during normal operating, start-up, or shutdown conditions, based on the most critical transient or steady-state condition.....	NA4.1
W	Wind load as stipulated in ASCE 7 for Category IV facilities	NA4.2
W_t	Loads generated by the <i>specified design tornado</i> , including wind pressures, pressure differentials, and <i>tornado-borne missiles</i>	NA4.3
Y_j	<i>Jet impingement load</i> generated by the postulated accident	NA4.4
Y_r	Loads on the structure generated by the reaction of the broken high-energy pipe during the postulated accident	NA4.4
Y_m	<i>Missile impact</i> load, such as pipe whipping generated by or during the postulated accident.....	NA4.4
ϵ_{st}	Strain corresponding to the onset of strain hardening	NA5.5
ϵ_u	Strain corresponding to elongation at failure (rupture)	NA5.5
ϵ_y	Strain corresponding to yield stress	NA5.5
μ	Ductility factor	NA5.6



GLOSSARY

The terms listed below shall be used in addition to those in the AISC LRFD Specification. Where there is a duplication of terms between this Specification and the AISC LRFD Specification the definitions herein shall take precedence. Glossary terms are *italicized* where they appear in the text.

Authority having jurisdiction (AHJ). A federal government agency (or agencies), such as the Nuclear Regulatory Commission or the Department of Energy, that is empowered to issue and enforce regulations affecting the design, construction and operation of nuclear facilities.

Certificate of compliance. A document written specifically for the raw materials used. It must specifically identify the job order and component where these materials are to be used. In addition, this certification must be traceable to the applicable *certified mill test report* for the raw materials used in fabrication.

Certified mill test report (CMTR). A document identifying the actual chemical analysis, physical test data and any other testing necessary to show compliance for the actual item for which the CMTR is supplied.

Design basis earthquake (DBE). See *safe shutdown earthquake (SSE)*. (Term used in connection with DOE facilities; also used interchangeably for older nuclear power facilities.)

Ductility factor. Ratio of permitted strain or deformation to the strain or deformation at yield.

Engineer. An individual or an organization, designated by the *owner*, responsible for the preparation of the plans and specifications for the nuclear facility structures, or for the evaluation of the existing structure(s). The *engineer* as an individual or part of an organization shall be a licensed professional engineer, qualified to fulfill the assigned responsibility.

Impactive force. Time-dependent loads due to collision of masses that are associated with finite amounts of kinetic energy. The impactive load is determined by the inertia and stiffness properties of the missile and the target structure. Impactive loads include the following examples/types: *tornado-borne missiles*, whipping pipes, aircraft missiles, and other internal and external missiles.

Impulsive force. Time-dependent loads which are not associated with collision of solid masses. The loads are not dependent on the target mass or stiffness properties. Impulsive loads include the following examples/types: jet impingement, blast pressure, compartment pressurization, and *jet shield* reactions.

Jet impingement load. A force-time history depicting the forces resulting from the direct strike by a dense, high velocity jet of steam or water onto a structure, system or component.



Jet shield. A device used to protect adjacent structures, systems, or components from the effects of a dense, high velocity jet of steam or water, resulting from a rupture of a high energy pipe line.

Missile impact. The collision of a projectile (e.g. *tornado-borne missile* (see definition) or plant generated missile) with a structure, system, or component.

Operating basis earthquake, OBE. An earthquake that could reasonably be expected to occur at the plant site during the operating life of the plant considering the regional and local geology and seismology and specific characteristics of local subsurface material. It is that earthquake that produces the vibratory ground motion for which the features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional. An earthquake greater than OBE is associated with plant shutdown and inspection.

Owner. The organization responsible for the design, construction, operation, maintenance, and safety of the nuclear facility.

Pipe whip impact barrier. An energy absorbing device used to protect *safety-related* structures, systems, or components from the potentially damaging forces of a whipping, high energy pipe.

Pipe whip restraint. An energy absorbing device used to limit the potentially damaging motion of a whipping, high energy pipe, resulting from a pipe break/rupture, through the confining effects of the device.

Quality assurance program. A program identifying the planned or systematic actions necessary to provide adequate confidence that an item or facility will be designed, fabricated, and constructed in accordance with the plans and specification.

Response spectrum. A plot of the maximum responses (acceleration, velocity, or displacement) of idealized single-degree-of-freedom oscillators as a function of the natural frequencies of the oscillators for a given damping value. The *response spectrum* is calculated for a specified vibratory motion input at the oscillators' supports.

Safe shutdown earthquake, SSE. An earthquake that produces the vibratory ground motion for which certain structures, systems, and components in the nuclear power plant must be designed to remain functional.

Safety-related. A classification that applies to structures, systems, or components used in a nuclear power plant that are relied upon during or following design basis events to assure:

- The integrity of the reactor coolant pressure boundary

- The capability to shut down the reactor and maintain it in a safe shut down condition, or
- The capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the guideline exposures of 10CFR100.11.

Specified design (basis) tornado. Those combinations of translational speed, rotational speed, and prescribed pressure drop related to the environmental effects of a tornado (as defined by the licensing basis, design basis, and/or regulatory requirements (USNRC Regulatory Guide 1.76)).

Specified design (basis) wind. Combination of wind speed and exposure conditions, as defined by the facility specific document and/or other design basis documents, used to establish the forces acting on a structure from wind effects. The methodology of determining such forces should be in accordance with industry accepted practices (e.g. ASCE 7).

Tornado-borne missiles. Missiles of specific weight and velocity that are assumed to impact structures after becoming airborne as a result of tornado winds and pressures. These missiles are defined by the AHJ at the facility site.



CHAPTER NA

GENERAL PROVISIONS

Modify Chapter A of the AISC LRFD Specification as follows.

NA1. SCOPE

Replace section with the following:

This Specification contains Load and Resistance Factor Design (LRFD) criteria for the design, fabrication, and erection of steel *safety-related* structures and structural elements for nuclear facilities. It is intended to be compatible with, and a supplement to, the 1999 AISC *Load and Resistance Factor Design Specification for Structural Steel Buildings* hereafter referred to as the AISC LRFD Specification.

Unless stated otherwise, provisions of the AISC LRFD Specification are applicable. Only those sections that differ from the AISC LRFD Specification provisions are stated within this Specification. Section designations within this Specification are preceded by the letter N to denote nuclear facility design provisions.

This specification includes the list of additional symbols, the glossary of additional definitions, and the appendices.

Additional provisions for stainless steel sections are provided in Section NA5.3. Specifically excluded from this Specification are pressure retaining components, e.g., pressure vessels, valves, pumps, and piping.

In the design of members and connections of Seismic Force Resisting Systems, the AISC *Seismic Provisions for Structural Steel Buildings*, in general, are not applicable. However, the detailing requirements of Sections 6 and 7 of the provisions shall be appropriately considered when designing for plastic analysis.

Single angle members shall comply with the *Load and Resistance Factor Design Specification for Single-Angle Members* and with this Specification.

Hollow structural sections (HSS) shall comply with the *Load and Resistance Factor Design Specification for Steel Hollow Structural Sections* and with this Specification.

The sponsors of any system or construction within the scope of this Specification, the adequacy of which has been shown by successful use or by analysis or test, but which does not conform to or is not covered by this

specification, shall have the right to present the data on which their design is based to the *authority having jurisdiction* for review and approval.

Structures and structural elements subject to this Specification are those steel structures which are parts of a *safety-related* system or which support, house, or protect *safety-related* systems or components, the failure of which would impair the *safety-related* functions of these systems or components.

Safety categorization for nuclear facility steel structures and structural elements shall be the responsibility of the *owner*.

As used in this Specification, the term *structural steel* refers to the steel elements of the structural steel frame essential to the support of the required loads. Such elements are enumerated in Section 2.1 of the AISC *Code of Standard Practice for Steel Buildings and Bridges*. For the design of cold-formed steel structural members, whose profiles contain rounded corners and slender flat elements, the provisions of the American Iron and Steel Institute *North American Specification for the Design of Cold-Formed Steel Structural Members* shall be applicable.

NA3. MATERIAL

1. Structural Steel

1a. ASTM Designations

Add the following:

Seamless Carbon Steel Pipe for High-Temperature Service, ASTM A106
Stainless and Heat-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip, ASTM A167

Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels, ASTM A240/A240M

Stainless Steel Bars and Shapes, ASTM A276

Seamless and Welded Austenitic Stainless Steel Pipes, ASTM A312/A312M

Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels, ASTM A479/A479M

Pressure Vessel Plates, Carbon Steel, for Intermediate and Higher Temperature Service, ASTM A515/A515M

TABLE NA3.1

Specified Minimum Yield Strength	Charpy V-notch Energy Value	
	Avg. 3 Specimens Minimum	1 Individual Specimen Minimum
Equal to or less than 36 ksi [250 MPa]	15 ft-lbs [21 J]	10 ft-lbs [14 J]
Greater than 36 ksi [250 MPa], less than 44 ksi [300 MPa]	20 ft-lbs [27 J]	15 ft-lbs [21 J]
Equal to or greater than 44 ksi [300 MPa]	30 ft-lbs [41 J]	25 ft-lbs [34 J]

Pressure Vessel Plates, Carbon Steel, for Moderate and Lower Temperature Service, ASTM A516/A516M

Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar, ASTM A666

Exception: Types 301, 302 and 302B of ASTM A167, martensitic stainless steel grades of ASTM A276 and Class 1 stainless steel of ASTM A607 shall not be used in welded applications.

Replace the last paragraph with the following:

In addition to satisfying the appropriate ASTM specification, the specification of the material of those structures or structural components which may be subject to suddenly applied impact loads, e.g., *jet shields*, pipe restraint supports, *pipe whip impact barriers*, etc., shall be supplemented by the requirement that the material be subjected to Charpy V-notch impact tests, using the procedures described in ASTM A20/A20M. The Charpy V-notch impact test shall be conducted at a temperature not less than 30 °F (17 °C) below the lowest service metal temperature of the structural component. The acceptance criteria shall be that the material withstand not less than the energy values (average of three specimens value and individual specimen value) indicated in Table NA3.1, in addition to satisfying the appropriate ASTM specification.

Certified mill test reports or certified reports of tests made by the fabricator or a qualified testing laboratory in accordance with ASTM A6/A6M, A20/A20M, or A568/A568M, as applicable, and the governing ASTM Standards shall validate that the material meets the specification.

In lieu of the above, the material supplier or fabricator shall, if approved by the *owner*, provide a *certificate of compliance* stating that the steel furnished has been tested and conforms to the specification.



Traceability by heat is not required unless stipulated by the plans and/or specifications.

1b. Unidentified Steel

Replace with the following:

Use of unidentified steel is prohibited.

1c. Heavy Shapes

Add the following to the end of the section:

The specification covering material for structural components which, as a result of proposed welding procedures, design details, etc., may be subject to lamellar tearing (where, as determined by the *engineer*, welding high heat input/or high restraint can exist), shall include the requirement that the material shall be either ultrasonically examined in accordance with ASTM A435/A435M or tested in tension in the through-thickness direction (Z-direction). The resulting percentage reduction in area in the Z-direction shall not be less than 90 percent of that in the direction of material rolling.

2. Steel Castings and Forgings

Add the following:

Carbon-Steel Castings Suitable for Fusion Welding for High-Temperature Service, ASTM A216/A216M

Martensitic Stainless Steel and Alloy-Steel Castings for Pressure-Containment Parts Suitable for High-Temperature Service, ASTM A217/A217M

Replace the last sentence with the following:

Certified mill test reports or certified reports of tests made by the fabricator or a qualified testing laboratory shall validate that the material meets the specification.

In lieu of the above, the material supplier or fabricator shall, if approved by the *owner*, provide a *certificate of compliance* stating that the steel furnished has been tested and conforms to the specification.

Traceability by heat number is not required unless stipulated by the plans and/or specifications.

3. Bolts, Washers, and Nuts

Add the following:

Alloy Steel Bolting Materials for Low-Temperature Service, ASTM A320/A320M

Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes, ASTM A564/A564M

Replace the last sentence with the following:

Certified mill test reports or certified reports of tests made by the fabricator or a qualified testing laboratory shall validate that the material meets the specification.

In lieu of the above, the material supplier or fabricator shall, if approved by the *owner*, provide a *certificate of compliance* stating that the steel furnished has been tested and conforms to the specification.

Traceability by heat number is not required unless stipulated by the plans and/or specifications.

4. Anchor Rods and Threaded Rods

Replace the last sentence with the following:

Certified mill test reports or certified reports of tests made by the fabricator or a qualified testing laboratory shall validate that the material meets the specification.

In lieu of the above, the material supplier or fabricator shall, if approved by the *owner*, provide a *certificate of compliance* stating that the steel furnished has been tested and conforms to the specification.

Traceability by heat number is not required unless stipulated by the plans and/or specifications.

5. Filler Metal and Flux for Welding

Add the following:

Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes, AWS A5.4

Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes, AWS A5.9



Replace the last paragraph with the following:

Filler material and fluxes that are suitable for the intended application shall be selected.

The material supplier or fabricator shall, if approved by the *owner*, provide a *certificate of compliance* stating that the steel furnished has been tested and conforms to the specification.

In lieu of the above, *certified mill test reports* or certified reports of tests made by the fabricator or a qualified testing laboratory shall validate that the material meets the specification.

Traceability by heat number is not required unless stipulated by the plans and/or specifications.

NA4. LOADS AND LOAD COMBINATIONS

Replace section with the following:

1. Normal Loads

Normal loads are those loads that are encountered during normal plant start-up, operation and shutdown, and include:

D = dead loads due to the weight of the structural elements, fixed-position equipment, and other permanent appurtenant items; weight of crane trolley and bridge

L = live load due to occupancy and moveable equipment, including their impact

S = snow load as stipulated in *ASCE 7* for Category IV facilities

R_o = pipe reactions during normal operating, start-up, or shutdown conditions, based on the most critical transient or steady-state condition

T_o = thermal effects and loads during normal operating, start-up, or shutdown conditions, based on the most critical transient or steady-state condition

C = rated capacity of crane (shall include the maximum wheel loads of the crane and the vertical, lateral, and longitudinal forces induced by the moving crane)

2. Severe Environmental Loads

Severe environmental loads are those loads that may be encountered infrequently during the service life, and include: