ASME NUM-1-20XX

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FOREWORD

The Committee on Cranes for Nuclear Power Plants was first established in 1976. In 1980, the scope of the Committee was revised, and its name was changed to the Committee on Cranes for Nuclear Facilities. In 1983, the Nuclear Underhung and Monorail (NUM) Subcommittee was established to develop a standard to cover the design, fabrication, installation, and testing of underhung and monorail equipment used in nuclear facilities. The NUM-1 Standard is the result of the Subcommittee’s work.

The first edition of ASME NUM-1 was approved by the American National Standards Institute (ANSI) on October 28, 1996. The second edition of ASME NUM-1 was approved by ANSI on May 3, 2000. The third edition of ASME NUM-1 was approved by ANSI on August 17, 2004. The fourth edition of ASME NUM-1 was approved by ANSI on December 22, 2009. The fifth edition of ASME NUM-1 was approved by ANSI on June 16, 2016.

This Standard, or portions thereof, can be applied to cranes, monorails, and hoists at facilities other than nuclear where enhanced equipment safety may be required, and can be provided by means of single failure-proof features, additional safety features, increased design factors, or a seismic design.

This reformatted and updated Standard consists of three separate Parts: NUM Part-GR, General Requirements (applicable to all equipment); NUM Part-CM, Cranes and Monorails, and NUM Part-HT, Hoists and Trolleys. The standard now applies only to the enhanced safety and seismic Type I cranes and monorails, seismic Type II cranes and monorails; and only to the enhanced safety Type I hoist and trolley units. Hoists having single failure-proof features are identified as Type IA, with those having additional safety features and increased design factors identified as Type IB. This standard now separately and more clearly addresses the criteria for powered wire rope hoists (Type IA), powered wire rope hoists (Type IB), powered chain hoists (Type IB), manual chain hoists (Type IB), and under-running trolleys (Type IB). Type III standard equipment which is not used for handling critical loads and is not required to withstand a seismic event is no longer addressed in this standard since such equipment is covered by other industry standards.

Suggestions for the improvement of this Standard are welcome. They should be addressed to the Secretary, ASME Committee on Cranes for Nuclear Facilities, The American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990. The 2023 edition of ASME NUM-1 was approved by ANSI on __________.
Committee Roster
Preparation of Technical Inquiries to the Committee on Cranes for Nuclear Facilities
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<td></td>
</tr>
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<td>GR-7.1</td>
<td>General</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
RULES FOR CONSTRUCTION OF CRANES, MONORAILS, AND HOISTS  
(WITH BRIDGE OR TROLLEY OR HOIST OF THE UNDERHUNG TYPE)  

PART GR – GENERAL REQUIREMENTS  

Section GR-1  
Introduction  

GR-1.1 GENERAL  

Design of equipment covered by this Standard shall be in accordance with the Standard’s requirements but not necessarily with its recommendations. The word shall is used to denote a requirement; the word should is used to denote a recommendation, and the word may is used to denote permission, which is neither a requirement nor a recommendation. 

This Standard is comprised of three major parts:  
(a) NUM Part GR: General Requirements applicable to all equipment  
(b) NUM Part CM: Requirements applicable to cranes and monorails  
(c) NUM Part HT: Requirements applicable to hoists and trolleys.  

NUM Part CM provides the criteria for the crane and monorail structures and is used in conjunction with NUM Part HT which provides the criteria for the hoist and trolley units. Both of these parts require inclusion of the general criteria of Part GR for the specified crane, monorail, hoist and trolley configurations.  

GR-1.2 SCOPE  

This Standard covers the following lifting and handling equipment configurations requiring enhanced safety, and/or a seismic design, used in nuclear facilities.  
(a) underhung cranes,  
(b) top-running bridge and gantry cranes with underhung trolleys,  
(c) traveling wall cranes,  
(d) jib cranes,  
(e) monorail systems,  
(f) overhead hoists,  
(g) hoists with integral trolleys  
(h) separate underhung trolleys.  

Section GR-6.2 of the Definitions section provides graphical depictions of the various crane, monorail, hoist and trolley configurations addressed in this Standard.  

The above cranes, whether single or multiple girder, are covered by this Standard. For multiple girder cranes with both top running bridge and top running trolley, refer to ASME NOG-1, “Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder).  

GR-1.2.1 Equipment Types Covered.  The handling equipment used in a nuclear facility is categorized as Type I, Type II or III. This Standard addresses Type I and II cranes and monorails and Type I hoists and trolleys. Type II hoists and trolleys shall meet the requirements of general industry standards and the additional requirements noted in GR-1.2.1.2. Type III cranes, hoists, monorails and trolleys shall meet the requirements of general industry standards. The following paragraphs define the three categories of equipment.  

GR-1.2.1.1 Type I Equipment. Type I equipment is a crane, monorail, hoist or trolley with enhanced safety designs and features for handling a critical load. Design and construction of Type I equipment shall be such that it will remain in place and support the critical load during and after a Safe-Shutdown Earthquake (SSE) event; however, Type I equipment does not have to be operational after this event.  

There are two subtypes of Type I equipment:  
(a) Type IA equipment shall incorporate single-failure-proof designs and features. The design shall be such that any credible failure of a single component will not result in the loss of capability to stop and hold the critical load.  
(b) Type IB equipment shall incorporate enhanced safety designs and features. This includes increased design factors and redundant components that minimize the potential for failure that would result in the loss of capability to stop and hold the critical load.  

Refer to Table GR-1.2.1.1-1 for the major enhanced safety design differences between various Type IA and Type IB hoist configurations addressed in this Standard.  

All trolleys addressed in this Standard, whether used with a Type IA hoist or a Type IB hoist, are Type IB trolleys with increased design factors.  

GR-1.2.1.2 Type II Equipment. Type II equipment is a crane, monorail, hoist, or trolley not used in handling a critical load. Design and construction of Type II equipment shall be such that
during or after a seismic event, no portion of the equipment will become dislodged in a way that will adversely affect any safety related system when such a system is required for unit safety; or could result in potential off-site exposure in excess of the limit determined by the purchaser. The crane or monorail need not support the load nor be operational during or after such a seismic event.

**GR-1.2.1.3 Type III Equipment.** Type III equipment is a crane, hoist, or monorail not used to handle a critical load. No seismic considerations are necessary, and no single failure-proof features are required. This Standard does not address Type III equipment. This equipment shall comply with the requirements of general industry standards.

**GR-1.3 APPLICATIONS**

This Standard applies to the design, manufacture, testing, inspection, shipment, storage, and erection of the cranes, monorails, hoists and trolleys listed herein.

This Standard provides guidance on how to identify the type of crane or monorail system configuration and identify the appropriate hoist and trolley configuration.

**GR-1.4 RESPONSIBILITY**

This Standard classifies equipment into three types as noted in Paragraph GR-1.2.1. The classification basis shall be the equipment location and usage at a nuclear facility.

The owner shall be responsible for determining and specifying the equipment type. The owner shall also be responsible for determining and specifying the environmental conditions of service, performance requirements, type and category of coatings and finishes, and degree of quality assurance.

Facilities other than nuclear may use this standard either in part or in its entirety. Determination of the extent to which it is used is the responsibility of those referencing its use.

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**Table GR-1.2.1.1-1 Major Enhanced Safety Design Differences for Various Type IA and Type IB Hoist Configurations**

<table>
<thead>
<tr>
<th>Design of:</th>
<th>Type IA Powered Wire Rope Hoists</th>
<th>Type IB Powered Wire Rope Hoists</th>
<th>Type IB Powered Chain Hoists</th>
<th>Type IB Hand Chain Hoists</th>
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<tbody>
<tr>
<td>Hoisting Machinery</td>
<td>Single-failure-proof features for hoist drive train (HT-2.2)</td>
<td>No single-failure-proof features but increased design factors (HT-3.2)</td>
<td>No single-failure-proof features but increased design factors (HT-4.2)</td>
<td>No single-failure-proof features but increased design factors (HT-5.2)</td>
</tr>
<tr>
<td>Reeling Arrangement</td>
<td>Two separate (redundant) load paths, so either path supports the load (HT-2.3.1)</td>
<td>Single load path with either single- or double-reeving (HT-3.3.1)</td>
<td>Single load path providing true vertical lift (HT-4.3.1)</td>
<td>Single load path providing true vertical lift (HT-5.3.1)</td>
</tr>
<tr>
<td>Rope or Chain Design Factor</td>
<td>4 to 1 (25% of breaking strength) each load path (HT-2.3.3(b))</td>
<td>10 to 1 (10% of breaking strength) (HT-3.3.3)</td>
<td>10 to 1 (10% of breaking strength) (HT-4.3.3)</td>
<td>10 to 1 (10% of breaking strength) (HT-5.3.3)</td>
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<tr>
<td>Two-Block Design Consideration</td>
<td>Design accommodates two-blocking (HT-2.3(a))</td>
<td>Designed to prevent two-blocking with power limit switch (3310)</td>
<td>Design accommodates two-blocking (HT-4.3.1)</td>
<td>Design accommodates two-blocking (HT-5.3.1)</td>
</tr>
<tr>
<td>Holding Brake Arrangement</td>
<td>Redundant hoist brakes: either 3 brakes or 2 brakes if 1 on drum or 2 brakes if controlled braking provided with power off (HT-2.3.6)</td>
<td>Redundant hoist holding brakes each designed for double the load (HT-3.3.6)</td>
<td>Redundant hoist brakes: 1 holding brake designed for double the load and 2nd braking means (HT-4.3.4)</td>
<td>Single brake but designed for double the load (HT-5.3.4)</td>
</tr>
</tbody>
</table>

**GENERAL NOTE:** This Standard does not address Type IA powered chain hoists or Type IA hand chain hoists. Such equipment configurations are not anticipated to be used.
NUM PART - GR

Section GR-2
Environmental Conditions of Service

GR-2.1 GENERAL

The owner shall specify environmental conditions for operation and storage in order to design the equipment to withstand the effects of those conditions.

Where the ability of the equipment to withstand the environmental conditions is limited or unknown, the manufacturer shall identify the limitations and lack of information. The manufacturer shall provide the basis for acceptance of the equipment in the specified environmental conditions.

GR-2.1.1 Clearances. The crane, monorail, hoist or trolley design shall provide clearance between the equipment and the building and surrounding obstructions.

(a) Vertical Clearance. The clearance between the highest point of a moving crane or monorail component and the lowest overhead obstruction shall be at least 3 in. after taking into account variables that affect the elevation of the overhead structure relative to the equipment, including, but not limited to, external loads such as snow, wind, etc.

(b) Horizontal Clearance. The clearance between the sides and ends of traveling cranes, jib booms, or hoist and trolley units and the building columns and other obstructions shall be at least 2 in. Measure the clearance with the crane centered on the runway rails and the hoist and trolley unit centered on the operating flange.

(c) Overall. The equipment must clear the obstructions when operational variables including, but not limited to, maximum wheel float, crane skew, rail alignment, civil installation tolerances, and thermal expansion are considered.

GR-2.1.2 Hazardous Locations. Cranes, hoists and trolleys installed in hazardous locations as defined by NFPA 70 (latest issue) or other special codes may require modifications or additional safety precautions not covered by this Standard. Design of cranes, hoists and trolleys in hazardous locations shall meet the requirements for those locations.

GR-2.2 RADIATION

(a) The owner shall specify the expected accumulated radiation dosage exposure to the crane, hoist, monorail or trolley over the life of the facility.

(b) The manufacturer shall identify components whose normal life could be reduced by the effects of the specified radiation. The manufacturer shall provide this list to the owner.

(c) For components whose failure due to specified radiation could result in loss of load, the manufacturer shall:

(1) design the components to withstand the specified radiation, or
(2) identify the replacement period for the components.

(d) The vendor shall note where insufficient data is available to determine radiation effects on components and provide recommended inspection and replacement strategies to the owner for these components.

(e) The manufacturer shall specify and provide to the owner the inspection requirements for components affected by radiation.

GR-2.3 TEMPERATURE AND HUMIDITY

(a) The owner shall specify the following temperature requirements in the area where the crane, hoist, monorail or trolley will operate:

(1) maximum operating temperature
(2) minimum operating temperature
(3) ambient temperature for motors
(4) maximum construction temperature
(5) minimum construction temperature
(6) humidity conditions

(b) The manufacturer shall design the crane, hoist, monorail or trolley to withstand the effects of the specified temperatures and humidity, or the manufacturer shall specify the limitations of the equipment's design concerning these conditions.

(c) The manufacturer shall specify the inspection requirements for components affected by temperature and humidity and shall provide this information to the owner.

GR-2.4 PRESSURE

(a) The owner shall specify the following pressure requirements in the area where the crane, hoist, monorail or trolley will operate:

(1) normal operating pressure
(2) any test or abnormal event pressures including the rate of change of pressures

(b) The manufacturer shall design the crane, hoist, monorail or trolley to withstand the effects of the specified pressures, or the manufacturer shall specify the limitations of the equipment's design concerning these pressure conditions.

(c) Where there are changes in pressure, the design shall include vented enclosures.

(d) The manufacturer shall specify the inspection requirements for components affected by pressure and shall provide this information to the owner.
GR-2.5 CHEMICAL

(a) Spray Systems
(1) Where cranes, hoists, or monorails are subject to spray systems, the owner shall specify the chemistry of the spray and any material restrictions of the hoist, crane, monorail or trolley due to the effects of the spray.
(2) Where a corrosive spray is present, the possibility of hydrogen generation exists. The manufacturer shall minimize the use of exposed aluminum, magnesium, galvanized steel, and zinc. If these materials are used, the manufacturer shall provide the owner with a list of affected components, the amounts of the material used and the location of each component.
(3) The manufacturer shall design the crane, hoist, monorail or trolley to withstand the effects of the specified spray and shall not use the specified restricted materials. Prior to construction of the equipment, the manufacturer shall specify any limitations of the design concerning the spray condition and the use of any restricted materials.
(4) The manufacturer shall specify the maintenance inspection requirements and their bases and provide this information to the owner.

(b) Liquid Immersion
(1) If the hoist load block and wire rope are to be immersed in a liquid, the owner should identify the immersion liquid, and the manufacturer should select lubricants and component materials compatible with the immersion liquid. The manufacturer should address compatibilities between lubricants used in the manufacture of wire rope and the immersion liquid.
(2) Design requirements shall address liquid entrapment in components such as sealed bearings, load blocks, and the wire rope to prevent degradation of lubricants and to protect the components from corrosion.
(3) The manufacturer shall lubricate load blocks and wire ropes that are to be immersed in liquid with a lubricant that meets the specified lubrication requirements. The manufacturer shall specify any limitations of the equipment design concerning the water chemistry and lubrication requirements.
(4) The manufacturer shall specify the inspection requirements for components that may be affected by chemical systems and provide this information to the owner.

GR-2.6 WIND

The manufacturer shall design the crane, hoist, monorail or trolley to operate under any specified operating wind conditions.

The manufacturer shall design the crane, hoist, monorail or trolley to withstand the effects of specified stored wind conditions or tornado wind conditions while stowed.

GR-2.7 SEISMIC

(a) The owner shall specify the safe shutdown earthquake (SSE) parameters for Type I and Type II equipment.
(b) The manufacturer shall design Type I and Type II equipment to withstand the effects of the specified seismic conditions specified in Part CM and Part HT of this Standard.

GR-2.8 DRAINAGE

When required by environmental conditions, box sections shall include drain holes to prevent moisture from accumulating. Where internal full-depth diaphragms extend from the top flange to the bottom flange, the compartment formed by a pair of diaphragms shall include drain holes. The design shall include holes provided in the bottom flange of the box girder for draining the whole box girder of each compartment formed by the diaphragms.
Section GR-3
Performance Requirements

GR-3.1 GENERAL

(a) This Section addresses performance requirements for Type I and Type II equipment. The owner may supplement these requirements to define special performance requirements of the specific nuclear facility.

(b) The owner shall specify the service class, capacity, speeds, and dimensional requirements.

GR-3.2 SERVICE CLASS

The owner shall specify the crane, monorail, or hoist service class necessary to meet the application. The owner shall state any specific requirements deviating from the selected service class description.

---

Table GR-3.2.1-1  Service Classes for Cranes and Monorails

<table>
<thead>
<tr>
<th>Class</th>
<th>Service Class</th>
<th>Lift Frequency</th>
<th>Average Lift Height</th>
<th>Service Conditions</th>
<th>Avg Load Capacity</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Infrequent or Standby</td>
<td>1 or fewer</td>
<td>Full Range</td>
<td>No restriction</td>
<td>Precision handling at slow speed; long idle periods</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Light</td>
<td>2-5 per hour</td>
<td>10'</td>
<td>No restriction</td>
<td>Generally slow operation</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Moderate</td>
<td>5-10 per hour</td>
<td>15'</td>
<td>Not more than 50%</td>
<td>No more than half the lifts at rated capacity</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Heavy</td>
<td>10-20 per hour</td>
<td>15'</td>
<td>50%-75%</td>
<td>General fast operation; no more than 65% at rated capacity</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Severe</td>
<td>20 or more per hour</td>
<td>No restriction</td>
<td>75-90%</td>
<td>Service conditions are severe; May include custom-designed specialty cranes for critical tasks</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Continuous Severe</td>
<td>20 or more per hour</td>
<td>No restriction</td>
<td>No restriction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Table GR-3.2.2-1  Service Classes for Electrically Operated Hoists

<table>
<thead>
<tr>
<th>Class</th>
<th>Service Conditions</th>
<th>Uniformly Distributed Work Periods</th>
<th>Infrequent Work Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>Construction and maintenance use; frequent rated load; idle for 1-6 months between periods of operation</td>
<td>Max. On Time min (% hour)</td>
<td>Max. # of Starts per hour</td>
</tr>
<tr>
<td>H2</td>
<td>Random load distribution; rated loads infrequent</td>
<td>7.5</td>
<td>75</td>
</tr>
<tr>
<td>H3</td>
<td>Random load distribution</td>
<td>(12.5)</td>
<td>75</td>
</tr>
<tr>
<td>H4</td>
<td>High volume of heavy loads; manual or automatic cycling of lighter loads; infrequent near capacity loads</td>
<td>15</td>
<td>150</td>
</tr>
<tr>
<td>H5</td>
<td>Approaches continuous operations; user shall specify exact details of operation including weight of attachments</td>
<td>30</td>
<td>300</td>
</tr>
</tbody>
</table>

Note (1) N/A = Not applicable since there are no infrequent work periods in Class H5 service.

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Table GR-3.2.3-1  Service Classes for Air-Operated Wire Rope and Chain Hoists

<table>
<thead>
<tr>
<th>Class</th>
<th>Service Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A4</td>
<td>&lt;50% rated load up to continuous runtime OR &gt;50% rated load up to 50% runtime</td>
</tr>
<tr>
<td>A5</td>
<td>Typically &gt;50% rated load with &gt;50% runtime</td>
</tr>
</tbody>
</table>

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GR-3.3 CAPACITY

(a) Equipment capacity is the maximum rated load that the equipment handles. The owner shall specify the equipment capacity.

(b) In the case where more than one trolley hoist will or may operate on a crane bridge or monorail, then the owner shall specify the crane bridge or monorail that will handle the most severe loading conditions.
NUM PART - GR

GR-3.4 OPERATIONAL CHARACTERISTICS

GR-3.4.1 Speeds. The owner shall specify the operational speeds of the crane, trolley, and electric and air-operated hoists. These speeds depend on the nature of the load, load clearances, weight of load, position of the operator, load positioning accuracy, and type of drive. Selected speeds shall allow for controlled handling of the equipment and the load.

(a) Table GR-3.4.1-1 provides suggested maximum operating speeds for Electric Wire-Rope Hoists.

(b) Table GR-3.4.1-2 provides suggested maximum speeds for Air Hoists.

(c) Table GR-3.4.1-3 provides suggested operating speeds for Crane Bridges and Trolleys.

(d) Table GR-3.4.1-4 provides suggested operating speeds for Electric Chain Hoists.

(e) The suggested maximum jib rotation speed is 0.5 rpm to 1.0 rpm.

GR-3.4.2 Hoist Hand-Chain Pull and Overhaul Characteristics. Table GR-3.4.2-1 provides the typical hoist hand-chain pull and overhaul characteristics. The owner shall verify that the characteristics for the hoist selected are suitable for the application.

GR-3.5 VERTICAL LIFT CONSIDERATIONS

The owner shall determine and specify if true vertical lift is required.

Table GR-3.4.1-1 Recommended Electric Wire Rope Hoist Speeds

<table>
<thead>
<tr>
<th>Rated Load, ton [Note (1)]</th>
<th>Hoist Duty Class and Hoist Speed, ft/min</th>
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<tr>
<td></td>
<td>H1 and H2</td>
</tr>
<tr>
<td>&lt;3</td>
<td>10-15</td>
</tr>
<tr>
<td>3-5</td>
<td>10-15</td>
</tr>
<tr>
<td>&gt;5-7.5</td>
<td>10-15</td>
</tr>
<tr>
<td>&gt;7.5-10</td>
<td>7-10</td>
</tr>
<tr>
<td>&gt;10-15</td>
<td>7-10</td>
</tr>
<tr>
<td>&gt;15-20</td>
<td>5-10</td>
</tr>
<tr>
<td>&gt;20-30</td>
<td>5-10</td>
</tr>
<tr>
<td>&gt;30-40</td>
<td>4-8</td>
</tr>
<tr>
<td>&gt;40</td>
<td>4-8</td>
</tr>
</tbody>
</table>

GENERAL NOTES:
(a) For class H5 units, speeds can only be determined after the quantity of material to be handled and the time allotted to complete the work have been established.
(b) For trolleys of an I-beam hoist unit, recommended trolley in Table GR-3.4.1-3, where hoist classes H1, H2, H3, H4, and H5 are basically equivalent to the crane and monorail classes, A, B, C D, and E.

NOTE: (1) Tons of 2,000 lbs.
### TABLE GR-3.4.2-1  Typical Hoist Hand-Chain Pull and Overhaul Characteristics

<table>
<thead>
<tr>
<th>Rated Load, ton [Note (1)]</th>
<th>Hand-Chain Pull Force [Note (2)]</th>
<th>Hand-Chain Overhaul to Lift Load 1 ft [Note (3)]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Separate From Trolley, lbs</td>
<td>Integral With Trolley, lbs</td>
</tr>
<tr>
<td>Up to 0.25</td>
<td>15-50</td>
<td>15-25</td>
</tr>
<tr>
<td>&gt;0.25 to 0.5</td>
<td>20-65</td>
<td>25-50</td>
</tr>
<tr>
<td>&gt;0.5 to 1</td>
<td>45-85</td>
<td>45-70</td>
</tr>
<tr>
<td>&gt;1 to 1.50</td>
<td>40-105</td>
<td>40-80</td>
</tr>
<tr>
<td>&gt;1.5 to 2</td>
<td>55-115</td>
<td>55-95</td>
</tr>
<tr>
<td>&gt;2 to 3</td>
<td>40-110</td>
<td>40-85</td>
</tr>
<tr>
<td>&gt;3 to 4</td>
<td>55-140</td>
<td>55-95</td>
</tr>
<tr>
<td>&gt;4 to 5</td>
<td>45-105</td>
<td>50-80</td>
</tr>
<tr>
<td>&gt;5 to 6</td>
<td>55-140</td>
<td>60-95</td>
</tr>
<tr>
<td>&gt;6 to 8</td>
<td>45-165</td>
<td>45-90</td>
</tr>
<tr>
<td>&gt;8 to 10</td>
<td>55-135</td>
<td>55-100</td>
</tr>
<tr>
<td>&gt;10 to 12</td>
<td>60-175</td>
<td>65-105</td>
</tr>
<tr>
<td>&gt;12 to 16</td>
<td>70-180</td>
<td>65-95</td>
</tr>
<tr>
<td>&gt;16 to 20</td>
<td>70-190</td>
<td>89-90</td>
</tr>
<tr>
<td>&gt;20 to 24</td>
<td>100-205</td>
<td>100-110</td>
</tr>
<tr>
<td>&gt;24 to 25</td>
<td>90-165</td>
<td>...</td>
</tr>
<tr>
<td>&gt;25 to 30</td>
<td>90-120</td>
<td>...</td>
</tr>
<tr>
<td>&gt;30 to 40</td>
<td>85-135</td>
<td>...</td>
</tr>
<tr>
<td>&gt;40</td>
<td>110-135</td>
<td>...</td>
</tr>
</tbody>
</table>

**GENERAL NOTE:** This table indicates the characteristics of hoists generally available. Those values including a dash (e.g., 15-50) denote typical ranges.

**NOTES:**

1. Tons of 2,000 lbs.
2. Standard lifts are 8 ft, 0 in. Weights predicated on standard lifts. Other lifts are available. Corresponding hand-chain drop is normally 2 ft, 0 in. less than the reach.
3. Values refer to each hand chain where two or more hand chains are required.

GR-8
Section GR-4
Coatings and Finishes

GR-4.1 COATING SERVICE LEVELS

The owner shall specify coating service Level I or Level II as defined below.

(a) Coating Service Level I is for use in areas where coating failure could adversely affect the operation of post-accident fluid systems and thereby impair safe shutdown. With few exceptions, coating service Level I applies to coatings inside a nuclear power plant’s primary containment.

(b) Coating Service Level II is for use in areas where coating failure could impair, but not prevent, normal operating performance. The function of coating service Level II coatings is to provide corrosion protection and facilitate decontamination in those areas outside primary containment subject to radiation exposure and radionuclide contamination. Coating service Level II also applies to coatings in non-radiation areas.

GR-4.2 SPECIFIC REQUIREMENTS FOR COATING SERVICE LEVELS

GR-4.2.1 Requirements for Coating Service Level I

(a) Coating requirements for coating service Level I shall be in accordance with ASTM D5144 which requires a quality assurance program.

(b) Inspection and testing of coatings for coating service Level I shall be in accordance with ASTM D5144.

(c) The owner shall specify specific coating inspections dependent upon the coating system used. Refer to ASTM D5161 for selecting and specifying appropriate inspection requirements.

GR-4.2.2 Requirements for Coating Service Level II

(a) The owner shall specify coating requirements for coating service Level II. The owner may invoke applicable sections of ASTM D5144.

(b) Quality assurance requirements for coating service Level II shall only apply as specified by the owner.

(c) Inspection and testing requirements for coating service Level II shall only apply as specified by the owner.

GR-4.2.3 Additional Requirements Applicable to All Coatings. Paragraphs (a) through (m) below list additional requirements for coatings and finishes.

(a) If not specified by the owner, the manufacturer shall determine the type of coating to meet the specified environmental conditions of service and coating service level. Specifically, the selected coatings shall be suitable for any specified radiation, temperature, and chemical immersion or chemical spray environment.

(b) Welding through coatings shall not be allowed unless:

(1) the coating system is specifically designed and formulated as a weldable system; and

(2) the coating manufacturer provides documentation to attest to this capability.

The owner shall approve the use of these coatings.

(c) Prior to assembly, the manufacturer shall coat surfaces exposed to the environment that will be inaccessible after assembly, such as wheel wells and hubs.

(d) Coating of interior or enclosed surfaces of the equipment, such as inside a welded box section, is not required unless specified by the owner.

(e) The manufacturer shall not apply the specified coating system to friction-type joints joined by high-strength bolts. The manufacturer may coat these surfaces with organic or inorganic zinc coating systems not prohibited by GR-2.5.

(f) For shipping and/or storage, the manufacturer shall protect machined mating surfaces and other surfaces not normally protected by the specified coating system (such as hooks, hook nuts, wheel treads, rails, gears, shafts, pinions, couplings, drum grooves, sheave grooves, and brake wheels) with an appropriate preservative.

(1) The manufacturer shall specify which preservatives the owner must remove for proper operation of the equipment.

(2) The owner may remove other preservatives after installation of the equipment.

(g) The manufacturer shall not force-cure or force-dry the coating system unless recommended by the coating manufacturer.

(h) Fillers, sealants, and caulking compounds shall be compatible with the coating system.

(i) The manufacturer may furnish finished components with conventional coatings unless otherwise specified by the owner. Examples of such finished components are: motors, brakes, gear reducers, limit switches, electrical dials and gauges, control enclosures, brake rectifier cabinets, control masters, safety switches, auxiliary heaters, push-button stations, transformers, manual magnetic disconnects, light fixtures, reactors, resistor banks, protective guards, cross-shaft bearing blocks, utilized hoists, interior of control cabinets, festoon trolley cable spacer systems, cab interiors, and radio control equipment.

(j) For coating service Level I applications, the equipment manufacturer shall supply the estimated
surface area of exposed parts provided with conventional coatings.

(k) The manufacturer shall prevent all labels and nameplates affixed to components from being obscured during the coating process.

(l) The manufacturer shall supply items such as fasteners and conduits with the specified coating system, galvanized or plated. Galvanizing or plating shall be subject to the requirements of GR-2.5. When specifically requested by the owner, the manufacturer shall provide a list of galvanized or plated parts.

(m) The manufacturer shall remove surface contaminants such as grease and oil detected after blasting to produce the surface conditions required by the appropriate Steel Structures Painting Council (SSPC) surface preparation.

(1) If there is visible deterioration of the surface beyond the specified SSPC preparation, the manufacturer shall prepare the surface again.

(2) The manufacturer shall prepare surfaces by the methods originally used, except that small areas requiring repair or touch up where conventional blasting is not desirable may be prepared the second time by one of the following methods, listed in descending order of effectiveness:

(-a) Vacuum blast to clean an abrasive finish with a minimum 2.0-mm profile. The minimum blasting air pressure shall be 50 psi at the blasting nozzle.

(-b) Power tool clean using grinding wheels, sanding disks, or other devices to provide a minimum 2.0-mm profile in accordance with SSPC SP-3. The manufacturer should use a needle gun to roughen the surface after grinding.

(-c) Hand sand to obtain as clean a surface as possible in accordance with SSPC SP-2, or wire brushing in accordance with SSPC SP-2.
Section GR-5
Quality Assurance

GR-5.1 REQUIREMENTS

GR-5.1.1 Type I Equipment

(a) The quality assurance program of the manufacturer of Type I equipment shall meet ASME NQA-1 or shall meet the quality assurance requirements specified by the owner.

(b) The owner may require quality assurance measures from suppliers of structural, mechanical, and electrical components used on Type I equipment in addition to those listed in Table CM-2.1.5.1-2 and the applicable table of Part HT as noted below.

1. Table HT-2.9.1-1 for Type IA Powered Wire Rope Hoists
2. Table HT-3.8.1-1 for Type IB Powered Wire Rope Hoists
3. Table HT-4.8.1-1 for Type IB Powered Chain Hoists
4. Table HT-5.6.1-1 for Type IB Hand Chain Hoists
5. Table HT-6.6.1-1 for Type IB Independent or Integral Under-Running Trolleys

GR-5.1.2 Type II Equipment

(a) The quality assurance program of the manufacturer of Type II equipment shall meet ASME NQA-1 or shall meet the quality assurance requirements specified by the owner.

(b) The owner may require quality assurance measures from suppliers of structural components used on Type II cranes and monorails in addition to those listed in Table CM-2.1.5.1-2.

(c) The owner may also require quality assurance measures from suppliers of electrical and mechanical components used on Type II equipment.

GR-5.2 DOCUMENTATION

The owner shall define, in its purchase documents, the requirements for the collection, storage and maintenance of documentation applicable to procurement, design, manufacture, shipment, receipt, storage, installation, and startup of cranes covered by this standard. The owner’s quality assurance program shall define which of these quality assurance documents are permanent records.

Paragraph GR-5.2.2 provides additional recommendations for quality documentation the owner may require.

(a) As a minimum, design and manufacturing documentation to be specified in the owner’s purchase documents for all cranes shall include the following:

1. Assembly and outline drawings
2. Electrical schematics and wiring diagrams
3. System Calculations (mechanical, electrical, structural)
4. Acceptance test plans and procedures
5. Software test plans for controls
6. Operating instructions
7. Maintenance instructions
8. Software programs

(b) Minimum installation documentation for all cranes shall include the following:

1. Records of high-strength bolt torquing
2. Data sheets or logs on equipment installation, inspection and alignment
3. Lubrication records
4. Documentation of testing performed after installation and prior to equipment acceptance
5. Results of end-to-end electrical tests
6. Final system adjustment data
7. Acceptance test plan, procedures and results
8. Load test
9. Load summary reports

GR-5.2.1 Recommendation for the Manufacturer. The manufacturer should establish a system for the collection and temporary storage of records received and generated during the design, manufacture, and shipment of the equipment. The manufacturer should submit these records to the owner or to the owner’s designated representative.

GR-5.2.2 Recommendation for Additional Records Submitted to the Owner for Design and Manufacture. In addition to the minimum documentation listed in GR-5.2, the owner may request the following additional records from the manufacturer:

(a) As-built drawings including a complete list of equipment and material
(b) Supplier deviation requests and approvals
(c) Shop no-load test report for crane or hoist
(d) Software test plans for controls
(e) Control logic diagrams
(f) Hard copy and soft copy with license of installed Programmable Logic Controller (PLC) software and programs.

(g) NEMA routine test reports for hoist motors


(k) Certificates of Conformance per Table CM-2.1.5.1-1

(l) Welding Procedures and Welder Certificates
(m) Weld filler material Certificates of Conformance including heat or lot numbers
(n) Fastener material for structural connection material test reports
(o) Breaking strength report(s) for hoist wire rope(s)
(p) Breaking strength report(s) for hoist load chain(s)
(q) Hook load test reports
(r) Operating instructions outlining the step-by-step procedures for system start-up, operation, and shutdown. Instructions should include a brief description of all equipment and its basic operating features and control philosophy.
(s) Maintenance instructions listing procedures, possible breakdowns, repairs and troubleshooting guides
(t) Training manuals for operations and/or maintenance

GR-5.2.3 Recommendation When Using an Intermediate Storage Facility. The owner may specify that an intermediate storage facility establish a system for the collection, storage and submittal of quality assurance records to the owner in accordance with ASME NQA-1.

GR-5.2.4 Recommendation for the Constructor and Erector. The owner may specify that the constructor organization and erector organization establish a system for the collection, storage and submittal of quality assurance records to the owner. The owner may specify submittal of the following records:
(a) Records of high-strength bolt torqueing
(b) NDE reports and procedures
(c) Weld repair procedures and results
(d) Weld fit-up reports
(e) Weld location diagrams
(f) Welding procedures
(g) Welding procedure qualification
(h) Welding filler material reports, including heat and lot numbers
(i) Welding material control procedures
(j) Welder qualification
(k) Data sheets or logs on equipment installation, inspection and alignment
(l) Erection procedures
(m) Lubrication records
(n) Documentation of testing performed after installation and prior to equipment acceptance
(o) Results of end-to-end electrical tests
(p) Instrument calibration results, including test equipment
(q) As-built drawings approved by the owner
(r) Field audit reports
(s) Field quality assurance manuals and daily reports
(t) Final inspection reports
(u) Nonconformance reports
(v) Final system adjustment data
(w) Acceptance test procedures and results
(x) Load test
Section GR-6
Definitions

GR-6.1 DEFINITIONS (WRITTEN)

acceptance criteria: specified limits placed on characteristics of an item, process, or service defined in codes, standards, or other required documents.

auxiliary girder: a girder arranged parallel to the main girder for supporting the platform motor base, operator’s cab, control panels, etc., to reduce the torsional forces such load would otherwise impose on the main girder.

block, load: the assembly of hook or shackle, swivel, bearing, sheaves, sprockets, pins, and frame suspended by the hoist rope or load chain. This shall include any appurtenances reeved in the hoisting rope or load chain.

brake: a device, other than a motor, used for retarding or stopping motion by means of friction or power.

brake, holding: a friction brake for a hoist that is automatically applied and prevents motion when power is off.

brake, mechanical load: an automatic type of friction brake used for controlling loads in a lowering direction. This unidirectional device requires torque from the motor or hand chain wheel to lower a load but does not impose any additional load on the motor or hand chain wheel when lifting a load. This may also be used as a holding brake if designed as such by the manufacturer.

braking, control: a method of controlling speed by removing energy from the moving body or by imparting energy in the opposite direction.

brake, parking: a brake for bridge and trolley automatically or manually applied in an attempt to prevent horizontal motion by restraining wheel rotation.

braking, dynamic: a method of controlling speed by using the motor as a generator, with the energy dissipated in resistors.

braking torque: torque on a drive system created by the application of a brake and by dynamic motor braking.

camber: the slight upward vertical curve given to bridge and/or runway girders to compensate partially for deflection due to hook load and weight of the crane.

Capacity, rated: the maximum rated load that an item of lifting equipment is designed to handle.

carrier: (also known as trolley) a unit that travels on the bottom flange of a monorail track, jib boom, or bridge girder to transport a load.

chain, hand: the chain grasped by a person to apply force required for lifting or lowering motion.

chain, load: the load-bearing chain in a hoist.

certification: the act of determining, verifying, and attesting in writing to the qualifications of personnel, processes, procedures, or items in accordance with specified requirements.

clearance: the distance from any part of the crane to a point of the nearest obstruction.

controller, spring-return: a controller that, when released, will return automatically to a neutral position.

crane: a machine for lifting and lowering a load and moving it horizontally, with the hoisting mechanism an integral part of the machine. Cranes, whether fixed or mobile, are driven manually or by power, or by a combination of both.

crane, gantry: a crane similar to an overhead crane that rigidly supports the bridge that carries the trolley on two or more legs running on fixed rails or other runway.

crane, jib: a fixed crane, usually mounted on a wall or building column, consisting of a rotating horizontal boom (either cantilevered or supported by tie rods) carrying a trolley or hoist.

crane, jib, free-standing pillar: a jib crane that may be Base-Mounted or Insert-Mounted. The jib boom may be fixed or have partial or full 360-deg rotation (specified degree of overlap or continuous) and can be manually or power operated (see Fig. GR-6.2.4-2).

crane, jib, mast-type: a jib crane that may be Top-Braced, Under-Braced, or Fully-Cantilevered. The jib boom may be fixed or have partial or full 360-deg rotation (specified degree of overlap or continuous) and can be manually or power operated (see Fig. GR-6.2.4-3).

crane, jib, wall-mounted: a jib crane that may be top-braced, under-braced, or full-cantilever type. The jib boom may be fixed or have partial rotation and can be manually or power operated and may be a patent, a structural shape, a reinforced patented or structural shape, or a fabricated section. (see Fig. GR-6.2.4-1).

crane, top-running, double-girder with top-running trolley: a crane that has end trucks that operate on fixed rails or tracks attached to the top flange or surface of runway girders and that use a trolley hoist unit(s) that operate on fixed rails or tracks attached to the top.
flange or surface of the bridge girders. (See ASME NOG-1 for requirements.)

crane, top-running, double-girder with underhung trolley: a crane that has end trucks that operate on fixed rails or tracks attached to the top flange or surface of runway girders, and that use an underhung, trolley-suspended hoist. Overhead hoists of the underhung type may be rigidly suspended or trolley suspended from the bridge girders. The trolley operates on the bottom flange of the bridge girders, which may be a patented shape, a structural shape, a reinforced patented or structural shape, or a fabricated section (see Fig. GR-6.2.2-2).

crane, top-running, single-girder: a crane with end trucks that operate on fixed rails or tracks attached to the top flange or surface of runway girders. (see Fig. GR-6.2.2-1).

crane, top-running, single-girder, gantry: a crane with both ends of the bridge rigidly supported on legs, with the legs supported on end trucks operating on fixed rails or tracks. (see Fig. GR-6.2.2-4).

crane, top-running, single-girder, semi-gantry: a crane with one end of the bridge supported by an end truck operating on a fixed rail or track attached to the top flange or surface of a runway girder and the other end of the bridge rigidly supported on a leg with the leg supported on an end truck operating on a fixed rail or track at a different level (see Fig. GR-6.2.2-3).

crane, travelling wall: a crane with a vertical frame supported on trucks that operate on tracks or rails by manual or powered operation. It also has a jib boom that can be single girder or multiple girder, top-braced, under-braced, or full cantilever; and is usually fixed (non-rotating) to the vertical frame. The jib may be a patented shape, a structural shape, a reinforced patented or structural shape or a fabricated section (see Fig. GR-6.2.3-1).

crane, underhung: a crane with a single- or multiple-girder movable bridge carrying a movable or fixed hoisting mechanism and traveling on the lower flanges of an overhead runway (see Figs. GR-6.2.1-1 through GR-6.2.1-3).

crane, underhung, semi-gantry: a crane with one end of the bridge supported by wheels operating on the bottom flange of a runway track and having one end of the bridge rigidly supported on a leg, with the leg supported on a top running end truck operating on a fixed rail or track (see Fig. GR-6.2.1-4).

cross shaft: the shaft extending across the bridge, used to transmit torque from motor to bridge drive wheels.

deflection: displacement due to bending or twisting in a vertical or lateral plane caused by the imposed live and dead loads.

drop section: (also known as lift section) a mechanism that will permit a section of track(s) to be lifted or lowered out of alignment with the stationary track(s).

drum: a cylindrical member around which the rope is wound for lifting or lowering the load.

electric baffle: conductors wired to cut off electric power to approaching motor-driven equipment if track switches, drop sections, and other movable track devices are not properly set for passage of equipment.

end stop: a device located at the end of the track to prevent the carrier from running off the end of the track.

drum: an assembly consisting of the frame and wheels that supports the crane girder(s) and allow movement along the runway.

equalizer: a device that compensates for unequal length or stretch of a rope or chain.

fork: a mechanical device for use on interlocking transfer equipment to mechanically prevent passage of a trolley or carrier when the elements are not securely locked.

gantry leg: the structural member that supports a bridge girder or end tie from the sill.

girder: the principal horizontal beam of the crane bridge supporting the trolley and supported by the end trucks.

hand-chain drop: the distance to the lowest point of the hand chain measured from a known reference.

hand-chain overhaul: the number of feet the hand chain must travel to raise the load hook 1 foot

hand-chain pull: the average force measured in pounds exerted by the operator on the hoist hand chain to lift the rated load.

hanger rod: steel rods that together with other fittings used to suspend the track from the supporting structure.

hazardous (classified) locations: locations where fire or explosion hazards may exist. Locations are classified depending on the properties of the flammable vapors, liquids, or gases, or combustible dusts or fibers present, and the likelihood that a flammable or combustible concentration or quantity is present (see ANSI/NFPA 70)

headroom: the distance measured with the load hook at its upper limit of travel from the saddle of the load hook to the position listed in (a) through (e) as appropriate.

(a) saddle of the top hook on hook-suspended hoists
(b) centerline of the suspension holes on lug-suspended hoists
(c) bottom of the beam on trolley-suspended hoists
(d) supporting surface on base-mounted and deck-mounted hoists
(e) uppermost point of hoist on wall-mounted and ceiling-mounted hoists

hoist, auxiliary: supplemental hoisting unit usually of lighter capacity and higher speed than the main hoist.

hoist: a machinery unit that is used for lifting or lowering a freely suspended (unguided) load.

hoist, air-operated chain: An air-powered hoist using chain as the lifting medium (see Fig. GR-6.2.7-5)

hoist, air-operated wire rope: an air-powered hoist using wire rope as the lifting medium (see Fig. GR-6.2.7-4).

hoist, electric chain: An electric-powered hoist using chain as the lifting medium (see Fig. GR-6.2.7-3)

hoist, electric wire-rope: an electric-powered hoist using wire rope as the lifting medium (see Fig. GR-6.2.7-1).

hoist, hand-chain: a suspended machinery unit used for lifting or lowering a freely suspended (unguided) load by use of a hand-chain manual operation (see Fig. GR-6.2.7-2).

hoist, underhung: trolley hoists or hoists suspended from trolleys traveling on the lower flanges of beams or similar hoists that are hook- or lug-suspended.

hook approach: the minimum horizontal distance between the center of the runway rail and the hook.

hook latch: a mechanical device to close (bridge) the throat opening of a hook.

inspection: examination or measurement to verify that an item or activity conforms to specified requirements.

interlocking mechanism: a mechanical device to lock together the adjacent ends of two cranes or a crane to a fixed transfer section or spur track to permit the transfer of carriers from one crane or track to the other.

L10 bearing life: the minimum expected life, in hours, of 90% of a group of bearings that are operated at a given speed and loading.

lift: the maximum safe vertical distance through which the hook, magnet, or bucket can move between its upper and lower limits of travel.

lift section: see drop section

lift, true vertical: lift in which the load hook travels in a vertical path with no horizontal displacement between the lower limit of lift and the upper limit of lift.

load: the total superimposed weight on the load block or hook.

load-carrying part(s): any part(s) of the equipment for which the load on the hook influences induced stress.

load chain: the load suspension chain in the hoist consisting of a series of interwoven links formed and welded.

load, credible critical: combinations of lifted loads and plant seismic events that have probabilities of occurrence equal to or more than 10−7 times per calendar year. The critical loads handled by the crane and their durations of lifts shall be used in the calculations to determine the credible critical load to be considered for the crane in the crane design load combinations that include seismic loadings. The owner shall specify the credible critical load.

load, critical: any lifted load whose uncontrolled movement or release could adversely affect any safety-related system when such a system is required for unit safety or could result in potential off-site exposure in excess of the limit determined by the owner.

load, dead (DL): the weight of all effective parts of the bridge structure, the machinery parts, and the fixed equipment supported by the structure

load hang-up: the event in which the load block and/or load stops during hoisting (or traversing) due to snagging or entanglement with heavy or fixed objects, creating a sudden and potentially severe overload.

load hook: the hook used to connect the load to the hoist.

load, lifted: the combination of the weight of the load and the lifting devices used for handling and holding the load and the lifting devices used for handling and holding the load, such as the load block, lifting beam, bucket, magnet, grab and other supplemental devices.

load, live: a load that moves relative to the structure under consideration.

load, rated (capacity): the maximum load designated by the manufacturer or qualified person, for which the equipment is designed and built

load, seismic lifted: the maximum lifted load under the evaluated seismic conditions where the crane or monorail structure and hoist and trolley unit must remain in place. This lifted load is not a critical load;
therefore, retaining the load itself is not required during the seismic event.

load, trolley: the weight of the trolley and the equipment attached to the trolley

load, wheel: the load, without impact, on any wheel with the trolley and lifted load (rated capacity) positioned on the bridge to give maximum loading.

manufacturer: one who constructs or fabricates an item to meet prescribed design requirements.

monorail: a single run of overhead track on which trolleys travel, including curves, switches, transfer devices, and lift and drop sections.

monorail system: a machine for lifting and lowering a load and moving it horizontally, suspended from a single track (see Figs. GR-6.2.5-1 through GR-6.2.5-6).

non-coasting mechanical drive: a drive that results in decelerating a trolley or bridge when power is not available. The braking effort will be established automatically when power to the drive is interrupted.

nondestructive examination: methods for determining the integrity of structural materials without physically damaging the material; methods of inspection include visual, radiographic, ultrasonic, magnetic particle, and liquid penetrant.

normal walking speed: a walking speed assumed to be 150 ft/min.

overload: any load greater than the rated load.

owner: the organization legally responsible for the construction and/or operation of a nuclear facility including, but not limited to, one who has applied for or been granted a construction permit or operating license by the regulatory authority having lawful jurisdiction.

parts (lines): number of lines of hoisting rope or chain supporting the load block or hook.

pushbutton station: an electrical control device consisting of push-button operated contacts, in an enclosure used by the operator for control of the powered motions of the crane, carrier, hoist, and other auxiliary equipment.

qualified person: a person who, by possession of a recognized degree in an applicable field or certificate of professional standing, or by extensive knowledge, training, and experience, has successfully demonstrated the ability to solve or resolve problems relating to the subject matter and work.

quality assurance: all those planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service.

rail sweep: a device attached to the crane and located in front of the crane’s leading wheels to push aside loose obstructions.

reach: the distance from the saddle of the load hook at its lower limit of lift to the upper point of the headroom measurement. Reach is equal to lift plus headroom.

reeving: a system in which a rope or chain travels around drums, sheaves, or sprockets.

runway: an assembly of rails, beams, girders, brackets, and framework on which the crane travels.

runway conductors: the main conductors mounted on or parallel to the runway that supply current to the crane.

safety lug: a mechanical device fixed securely to the end truck or trolley yoke that will limit the fall of the crane or carrier in case of wheel or axle failure.

shall: a word indicating a requirement

sheave: a wheel or pulley used with a rope or chain to change direction and point of application of a pulling force

sheave, running: a sheave that rotates as the load block raises or lowers.

should: a word indicating a recommendation.

single failure-proof features: those features that are included in the crane design such that any credible failure of a single component will not result in the loss of capability to stop and hold the critical load within facility-acceptable excursion limits.

slew drive: the mechanism (including motor and gearing) used to rotate a jib boom about a vertical axis.

span: the horizontal distance, center-to-center, between runway rails.

sprocket, load: a hoist component that transmits motion to the load chain. Other names for this component are load wheel, load sheave, pocket wheel, or chain wheel.

static control: a method of switching electrical circuits without the use of contacts.

switch: a device for making, breaking, or changing connections in an electric or pneumatic circuit (valve).

switch, cross-track: a track switch containing one straight section of track, pivoted at the center that can be rotated to align it with other crossing tracks to allow
passage of the carrier through the junction without changing the direction of the carrier motion.

*switch, track:* a device with a moving section of track that can be moved to permit passage of a carrier from an incoming fixed track(s) to outgoing fixed track(s).

*track opener:* a section of monorail track arranged to lift or swing out of line to make an opening through which a door may pass.

*tractor drive:* a motor-driven unit supported by wheels and propelled by drive wheel or wheels, bearing on the underside of the track.

*trolley:* the unit carrying the hoisting mechanism that travels on the bridge rails or bottom flange of a monorail track or bridge girder to transport the load.

*trolley (carrier):* the unit that travels on the lower or upper flange of the bridge girder and carries the hoist.

*trolley, underrunning:* a trolley that is suspended from the underside of one or more girders; it may be integral to a hoist or furnished as a separate unit to which a hoist or load could be attached.

*truck:* the unit consisting of a crane, wheels, bearings, and axles that supports the bridge girders, the end ties of an overhead crane, or the sill of a gantry crane.

*two-blocking:* the act of hoisting beyond the intended upper limit in which the load block comes into physical contact with the head-block (upper block) or its supporting structure, preventing further upward movement of the load block and creating a sudden and potentially severe overload.

*Type I equipment:* a crane, monorail, or hoist used to handle a critical load. The design and construction of Type I equipment is such that it will remain in place and support the critical load during and after a seismic event, but does not have to be operational after this event. The design of Type I equipment shall include either single failure-proof features (Type IA) or enhanced safety features (Type IB).

*Type IA equipment:* a Type I crane, monorail, or hoist that includes single failure-proof features so that any credible failure of a single component will not result in the loss of capability to stop and hold the critical load.

*Type IB equipment:* a Type I crane, monorail, or hoist with enhanced safety features, including increased design factors and redundant components that minimize the potential for failure that would result in the loss of capability to stop and hold the critical load.

*Type II equipment:* a crane, hoist, or monorail not used to handle a critical load. The design and construction of Type II equipment is such that it will remain in place during a seismic event; however, the crane need not support the load nor be operational during and after such an event. Single failure-proof features are not required.

*Type III equipment:* a crane, hoist, or monorail not used to handle a critical load; no seismic considerations are necessary, and no single failure-proof features are required.

*upper block:* a fixed block located on a trolley that, through a system of sheaves, bearings, pins, and frames, supports the load block and its load.

**GR-6.2 GRAPHICAL DEPICTIONS OF CRANES**

**GR-6.2.1 Underhung Cranes.** These cranes may be single or multiple girder.

(a) Underhung, single-girder crane (see Fig. GR-6.2.1-1)

(b) Underhung, multiple-girder crane (see Figs. GR-6.2.1-2 and GR-6.2.1-3)

(c) Underhung, semi-gantry crane (see Fig. GR-6.2.1-4)
GR-6.2.2 Top-Running Cranes. These cranes have overhead hoists of the underhung type that may be rigidly suspended or trolley suspended from the bridge girders. The trolley operates on the bottom flange of the bridge girders, which may be a patented shape, a structural shape, a reinforced patented or structural shape, or a fabricated section:

(a) Top-running, single-girder crane (see Fig. GR-6.2.2-1).
(b) Top-running, double-girder crane (see Fig. GR-6.2.2-2).
(c) Top-running, single-girder semi-gantry crane (see Fig. GR-6.2.2-3).
(d) Top-running, single-girder gantry crane (see Fig. GR-6.2.2-4).

GR-6.2.3 Travelling Wall Cranes. These cranes may have single or multiple girder booms.

On single-girder booms, overhead hoists of the underhung type may be rigidly-suspended or trolley-suspended from the jib boom. If the trolley is suspended, the trolley will operate on the bottom flange of the jib boom.

On multiple girder booms, overhead hoists of the underhung type may be rigidly suspended or trolley suspended from the jib boom girders. If the trolley is suspended, the trolley may operate on the bottom flange of the boom girders or on fixed rails or track attached to the top flange or surface of the boom girders (see Fig. GR-6.2.3-1).
**Figure GR-6.2.4-1** Wall-Mounted Jib Cranes

**GR-6.2.4 Jib Cranes.** These cranes may have overhead hoists of the underhung type that may be rigidly suspended or trolley suspended from the jib boom. If trolley suspended, the trolley will operate on the bottom flange of the jib boom:

- (a) Wall-Mounted Jib Cranes (see Fig. GR-6.2.4-1)
- (b) Freestanding Pillar Jib Cranes (see Fig. GR-6.2.4-2)
- (c) Mast-Type Jib Cranes (see Fig. GR-6.2.4-3)
Figure GR-6.2.4-2 Free-Standing Pillar Jib Cranes

(b) Under-Braced Wall-Mounted Jib Crane

(a) Base-Mounted Pillar Jib Crane

(c) Full-Cantilevered Wall-Mounted Jib Crane

(b) Insert-Mounted Pillar Jib Crane

Figure GR-6.2.4-3 Mast-Type Jib Cranes
GR-6.2.5 Monorail Systems. These systems incorporate single-track monorails and include curves, switches, transfer devices, lift and drop sections and associated equipment (see Figs. GR-6.2.5-1 through GR-6.2.5-6). Equipment installed on these monorails may be manually-operated, power-operated or operate automatically. Operation may be controlled from the floor, a cab, a pulpit, or remotely. For monorail systems, the trolley operates on the bottom flange of the track. The monorail track may be a patented shape, a structural shape, a reinforced patented or structural shape, or a fabricated section.
**Figure GR-6.2.5-5** [FL17] Interlocking Mechanism Monorail System

**Figure GR-6.2.5-6** [FL18] Monorail System with Lift/Drop Sections

**GR-6.2.6 Under-Running Trolleys.** These trolleys may be suspended from multiple girders or from a single girder. Trolleys may be either integral with a hoist or furnished as separate units to which a hoist or load could be attached (see Fig. GR-6.2.6-1.)

- (a) Plain (Push) Type.
- (b) Hand-Chain Operated.
- (c) Motor-Operated.
GR-6.2.7 Overhead Hoists. Overhead hoists fall into one of the following 5 categories:

(a) Electric Wire-Rope Hoist (see Fig. GR-6.2.7-1)
(b) Hand-Chain Hoist (see Fig. GR-6.2.7-2)
(c) Electric-Chain Hoist (see Fig. GR-6.2.7-3)
(d) Air-Operated Wire-Rope Hoist (see Fig. GR-6.2.7-4).
(e) Air-Operated Chain Hoist (see Fig. GR-6.2.7-5).

GR-6.2.7.1 Hoist Suspension Types.
Hoists suspension varies based on type of hoist and the application. The suspension types listed below are typical for the application listed.

(a) Both electric- and air-operated wire-rope hoists use one of the following suspension types. See Fig. GR-6.2.7.1-1.

- (1) lug
- (2) hook
- (3) trolley
- (4) base- or deck-mounted
- (5) wall-mounted
- (6) ceiling-mounted

(b) Hand Chain Hoists use one of the following suspension types. See Fig. GR-6.2.7.1-2
- (1) clevis
- (2) hook
- (3) trolley

(c) Both electric and air-operated chain hoists use one of the following suspension types. See Fig. GR-6.2.7.1-3.
- (1) hook or clevis
- (2) lug
- (3) trolley
Figure GR-6.2.7.1-1 Electric and Air-Operated Wire-Rope Hoist Suspension Types

- (a) Lug Suspended
- (b) Hook Suspended
- (c) Trolley Suspended
- (d) Base or Deck Mounted
- (e) Wall Mounted
- (f) Ceiling Mounted

GENERAL NOTE: Illustrations shown are not intended to confine the use of single or double reeving. Each of the mountings may be used with either type of reeving.
Figure GR-6.2.7.1-2  [FL26] Hand-Chain Hoist Suspension Types

(a) Hook or Clevis Suspended  
(b) Trolley Suspended  
(c) Trolley Suspended (Integral)

Figure GR-6.2.7.1-3  [FL27] Electric and Air-Operated Chain Hoist Suspension Types

(a) Hook or Clevis Suspended  
(b) Lug Suspended  
(c) Trolley Suspended  
(d) Trolley Suspended (Integral)
Section GR-7
Referenced Codes and Standards

GR-7.1 GENERAL

This Standard references portions of other specifications. Where conflict occurs, this Standard shall prevail. The following is a list of publications referenced in this Standard:


ASTM A388/A388M-1049. Standard Practice for Ultrasonic Examination of Steel Forgings. ASTM International.


## Section CM-1 Introduction

- **CM-1.1** General

## Section CM-2 Structural

- **CM-2.1** General Requirements for All Cranes and Monorails
- **CM-2.2** Additional Requirements Specific to Underhung Cranes
- **CM-2.3** Additional Requirements Specific to Top-Running Bridge and Gantry Cranes
- **CM-2.4** Additional Requirements Specific to Traveling Wall Cranes
- **CM-2.5** Additional Requirements Specific to Jib Cranes
- **CM-2.6** Additional Requirements Specific to Monorail Systems

## Section CM-3 Mechanical

- **CM-3.1** General
- **CM-3.2** Additional Requirements Specific to Underhung Cranes
- **CM-3.3** Additional Requirements Specific to Top-Running Bridge and Gantry Cranes
- **CM-3.4** Additional Requirements Specific to Traveling Wall Cranes
- **CM-3.5** Additional Requirements Specific to Jib Cranes
- **CM-3.6** Additional Requirements Specific to Monorail Systems

## Section CM-4 Electrical

- **CM-4.1** General
- **CM-4.2** Additional Requirements Specific to Jib Cranes
- **CM-4.3** Additional Requirements Specific to Monorail Systems

## Section CM-5 Pneumatic

- **CM-5.1** General
- **CM-5.2** Air supply
- **CM-5.3** Air Motors
- **CM-5.4** Additional Air Equipment
- **CM-5.5** Air Motor Controls

## Section CM-6 Marking Cranes & Monorails

- **CM-6.1** Crane and Monorail Marking

## Section CM-7 Inspection and Testing

- **CM-7.1** General
- **CM-7.2** Additional Requirements Specific to Underhung Cranes
- **CM-7.3** Additional Requirements Specific to Top-Running Bridge and Gantry Cranes
- **CM-7.4** Additional Requirements Specific to Traveling Wall Cranes
- **CM-7.5** Additional Requirements Specific to Jib Cranes
- **CM-7.6** Additional Requirements Specific to Monorail Systems
**RULES FOR CONSTRUCTION OF CRANES, MONORAILS, AND HOISTS**  
(*WITH BRIDGE OR TROLLEY OR HOIST OF THE UNDERHUNG TYPE*)

**NUM PART CM – CRANES AND MONORAILS**

Section CM-1  
Introduction, Cranes & Monorails (Type I & II)

**CM-1.1 GENERAL**

As stated in Section GR-1 of NUM Part-GR, this Standard provides the criteria for Type I and Type II cranes and monorails.

The Type I crane or monorail has enhanced safety designs and features for handling a critical load. Hoists installed on a Type I crane or monorail shall be Type IA or Type IB as addressed under NUM Part-HT. All sections of NUM Part-CM apply to Type I cranes and monorails.

The Type II crane or monorail is not used to handle a critical load but is designed and constructed to remain in place during a seismic event. The mechanical, electrical and pneumatic components of a Type II crane or monorail shall be designed in accordance with general industry standards but shall remain in place during a seismic event. Hoisting equipment used on a Type II crane or monorail shall be designed in accordance with general industry standards but shall also remain in place during a seismic event. Only the following sections of NUM Part-CM apply to Type II cranes and monorails:

- CM-2 Structural
- CM-6 Marking
- CM-7 Inspection and Tests

This Standard does not cover Type III cranes and monorails. Type III cranes and monorails shall comply with general industry standards.

The specific Type I and Type II crane and monorail configurations addressed in NUM Part-CM are as follows:

- (a) underhung cranes
- (b) top-running bridge and gantry cranes with underhung trolleys
- (c) traveling wall cranes
- (d) jib cranes
- (e) monorail systems

The requirements of NUM Part-CM apply to all of the above equipment configurations unless a requirement is indicated as applying to one or more specific equipment configurations.

The cranes and monorails of NUM Part-CM shall also comply with the following general requirements of NUM Part-GR.

- GR-2 Environmental Conditions of Service
- GR-3 Performance Requirements
- GR-4 Coatings and Finishes
- GR-5 Quality Assurance

Additional information and criteria are provided in Section GR-1, with definitions provided in Section GR-6, and a list of referenced codes and standards provided in Section Section GR-7.
Section CM-2
Structural, Cranes & Monorails (Type I & II)

CM-2.1 GENERAL REQUIREMENTS FOR ALL CRANES AND MONORAILS

This section covers the design, design criteria, materials, and fabrication procedures for the structural components that apply for all Type I & II cranes and monorails.

CM-2.1.1 Load Categories

Loads acting on the structure are divided into the following six categories and shall be considered during design:

(a) principal loads including dead loads, lifted loads, and inertia forces
(b) additional loads including operating wind loads and skewing
(c) extraordinary loads including stored wind loads and collision forces
(d) extreme loads including tornado wind loads, earthquake safe shutdown load, seismic lifted loads, and extreme overload
(e) torsional forces and moments
(f) abnormal event load

Test loads are specified in CM-7.1.7.4.

CM-2.1.1.1 Principal Loads

(a) Dead Load (DL). The dead load is the weight of all effective parts of the bridge structure, the machinery parts, and the fixed equipment supported by the structure.

(b) Trolley Load (TL). The trolley load is the weight of the trolley and the equipment attached to the trolley.

(c) Lifted Load (LL). The lifted load is the combination of the weight of the load and the lifting devices used for handling and holding the load, such as the load block, lifting beam, bucket, magnet, grab, and other supplemental devices.

(d) Vertical Inertia Forces for Motorized Cranes and Hoists. Vertical inertia forces include forces due to the motion of the crane and crane components (dead load forces) and forces due to raising or lowering of a load (hoist load forces). These forces shall be included by multiplication of the simplified factors defined below with the applicable dead loads and lifted loads.

(1) Dead Load Factor (DLF). This factor covers only the dead loads of the crane, trolley, and their associated equipment. The dead load factor is between 10%-20% based on the travel speed of the crane or monorail as determined using the following:

\[ DLF = 1.1 \leq 1.05 + \frac{\text{travel speed, ft/min}}{2,000} \leq 1.2 \]

(2) Hoist Load Factor (HLF). This factor applies to the motion of the lifted load in the vertical direction and covers inertia forces, the mass forces due to the sudden lifting of the load, and the uncertainties in allowing for other influences. The hoist load factor is 0.5% of the hoisting speed in feet per minute, but not less than 15% or more than 50%, except for bucket and magnet cranes for which the impact value shall be taken as 50% of the rated capacity of the bucket or magnet hoist.

\[ HLF = 0.15 \leq 0.005 \times \text{hoist speed} \leq 0.5 \]

(e) Inertia Forces from Motorized Drives (IFD). The inertia forces occur during acceleration or deceleration of horizontal drive motions and depend on the driving and braking torques applied by the drive units and brakes during each cycle. The IFD shall be 7.8% of the acceleration or deceleration rate (ft/sec\(^2\)) but not less than 2.5%. The resulting drive inertia force is based on 250% of the nominal acceleration or deceleration rate produced by either the drive motor or brake. This percentage shall be applied to both the live and dead loads, exclusive of the end trucks. The live load shall be located in the same position as when calculating the vertical moment. The moment of inertia of the entire girder section about its vertical axis shall be used to determine the stresses due to lateral forces. The inertia forces during acceleration and deceleration shall be calculated in each case with the trolley in the worst position for the component being analyzed.

\[ IFD = (2.50/32.2) \times \text{accel. or decel. rate (ft/sec}\(^2\)) \geq 0.025 \]

\[ = 0.078 \times \text{accel. or decel. rate (ft/sec}\(^2\)) \geq 0.025 \]

CM-2.1.1.2 Additional Loads

(a) Operating Wind Load (WLO). Lateral load due to wind shall be considered as an operating load of 5 lb/ft\(^2\) of effective area. Where multiple surfaces are exposed to the wind, such as crane girder and auxiliary girder, and the horizontal distance between surfaces is greater than the depth of the member on the windward side, consideration shall be given to increasing the effective area exposed to the wind. For single surfaces, such as cabs, the effective area shall be considered to be 1.2 times the projected area to account for negative pressure on the far side of the enclosure.

(b) Forces due to Skewing (SK). When wheels roll along a rail, the horizontal forces normal to the rail and those tending to skew the structure shall be taken into consideration. The horizontal forces shall be obtained by multiplying the vertical load exerted on each wheel...
by coefficient $S_{sk}$, which depends on the ratio of the span to the wheel base (see Fig. CM-2.1.2.1). The wheel base is the distance between the outermost wheels.

Figure CM-2.1.2.1 Wheel-Skewing Forces (from CMAA 74)

CM-2.1.3 Extraordinary Loads

(a) Stored Wind Load (WLS). This is the maximum wind that a crane is designed to withstand during out-of-service condition. The speed and test pressure vary with the height of the crane above the surrounding ground level, geographical location, and degree of exposure to prevailing winds (see ASCE/SEI 7-10).

(b) Collision Forces (CF). Special loading of the crane structure resulting from the bumper stops shall be calculated with the crane at 0.4 times the rated speed, assuming the bumper system is capable of absorbing the energy within its design scope. Load suspended from lifting equipment and free oscillating load need not be taken into consideration. Where the load cannot swing, the bumper effect shall be calculated in the same manner, taking into account the value of the load. The kinetic energy $(KE)$ released on the collision of two cranes with the moving masses of $M_1$ and $M_2$ and a 40% maximum traveling speed of $V_{T1}$ and $V_{T2}$ shall be determined from the following equation:

$$KE = \frac{M_1M_2(0.4V_{T1} + 0.4V_{T2})^2}{2(M_1 + M_2)}$$  \hspace{1cm} (1)

The bumper forces shall be distributed in accordance with the bumper characteristics and the freedom of the motion of the structure with the trolley in its worst position. Should the crane application require that maximum deceleration rates and/or stopping forces be limited due to suspended load or building structure considerations, or if bumper impact velocities greater than 40% of maximum crane velocity are to be provided for, such conditions shall be defined at the time of the crane purchase.

CM-2.1.4 Extreme Loads.

(a) Tornado wind loads (WLT). Tornado wind loads are not applicable to cranes and monorails unless specifically required by the owner. The wind speed varies with the height of the crane above the surrounding ground level, geographical location, and degree of exposure. Additional tornado-generated loads that should be considered are pressure drop and tornado missiles.

(b) Earthquake Safe Shutdown load (Es). The site Safe Shutdown Earthquake (SSE) parameters shall be used in the seismic analysis of the crane or monorail to determine the Earthquake Safe Shutdown load following the guidance of CM-2.1.3.

(c) Seismic Lifted Load SSE (LL ES). For cranes and monorails, the seismic lifted load for an SSE is the maximum lifted load under the evaluated seismic conditions where the crane or monorail structure must remain in place. The owner shall specify the seismic lifted load.

1. For Type I equipment, the seismic lifted load shall be equal to the maximum critical load.
2. Depending upon the facility-specific application, the requirement that Type II equipment remain in place during a seismic event may not require consideration of a seismic lifted load. The owner shall specify the seismic lifted load, if any, that shall be required.

(d) Extreme Overload (EOL). Overloads that could be imposed on a crane or monorail structure from a Type IB Hoist whose overload limiting device cannot be set below 150% of the MCL rating. The owner shall specify the extreme overload, if any, that shall be required.

CM-2.1.5 Torsional Forces and Moments

(a) Due to the Starting and Stopping of the Bridge Motors. The twisting moment due to the starting and stopping of bridge motors shall be considered as the starting torque of the bridge motor at 200% of full-load torque multiplied by the gear ratio between the motor and cross shaft.

(b) Due to Vertical Loads. The torsional moment due to vertical forces acting eccentric to the vertical neutral axis of the girder shall be considered as those vertical forces multiplied by the horizontal distance between the centerline of the forces and the shear center of the girder.

(c) Due to Lateral Loads. The torsional moment due to the lateral forces acting eccentric to the horizontal neutral axis of the girder shall be considered as those horizontal forces multiplied by the vertical distance between the centerline of the forces and the shear center of the girder.

CM-2.1.6 Abnormal Event Load, $A_e$. An abnormal event load is a load caused by failure of plant equipment that impose jet or missile loads on the
crane. The owner shall be responsible for the effects of, and shall establish the criteria for, these loads.

**CM-2.1.2 Loading Conditions**

The loads described in CM-2.1.1 are listed in Table CM-2.1.2-1. The various load combinations, using the load designations shown, shall be calculated for the design cases listed herein.

<table>
<thead>
<tr>
<th>Load</th>
<th>Load Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trolley dead load</td>
<td>TL</td>
</tr>
<tr>
<td>Bridge dead load</td>
<td>DL</td>
</tr>
<tr>
<td>Lifted load</td>
<td>LL</td>
</tr>
<tr>
<td>Inertia forces from drives</td>
<td>IFD</td>
</tr>
<tr>
<td>Forces due to skewing</td>
<td>SK</td>
</tr>
<tr>
<td>Operating wind</td>
<td>WLO</td>
</tr>
<tr>
<td>Stored wind load</td>
<td>WLS</td>
</tr>
<tr>
<td>Tornado wind load</td>
<td>WLT</td>
</tr>
<tr>
<td>Collision Forces</td>
<td>CF</td>
</tr>
<tr>
<td>Safe Shutdown Earthquake load</td>
<td>$E_s$</td>
</tr>
<tr>
<td>Maximum Seismic Lifted Load</td>
<td>$LL_{ES}$</td>
</tr>
<tr>
<td>Extreme Overload</td>
<td>$EOL$</td>
</tr>
</tbody>
</table>

(a) Case 1: Principal Loads: A crane or monorail in regular use under principal loading (stress level 1)

$$DL (DL_F_B) + TL (DL_F_T) + LL (1 + HLF) + IFD$$

where $DL_F_B$ refers to the bridge load factors, and $DL_F_T$ refers to the trolley load factors.

(b) Case 2: Additional Loads: A crane or monorail in regular use under principal loading and additional loading.

$$DL (DL_F_B) + TL (DL_F_T) + LL (1 + HLF) + IFD + WLO + SK$$

(c) Case 3: Extraordinary Loads:

(1) A crane or monorail subjected to out-of-service wind:

$$DL + TL + WLS$$

(2) A crane or monorail in collision:

$$DL + TL + LL + CF$$

(d) Case 4: Extreme Loads:

(1) A crane or monorail subjected to tornado wind load:

$$DL + TL + WLT$$

(2) A crane or monorail subjected to an SSE is subject to the following loads:

$$DL + (TL + LL_{ES}) + E_s + WLO$$

(3) A crane or monorail whose structure could be subjected to an extreme overload as a result of a substantially higher overload limit setting of a Type IB hoist:

$$DL + TL + EOL$$

**CM-2.1.3 Seismic Analysis for Cranes and Monorails**

**CM-2.1.3.1 Methods of Analysis.** A dynamic analysis method (e.g., response-spectrum or time-history method) or an equivalent static analysis shall be used to establish the response of the equipment to a seismic event.

**CM-2.1.3.2 Seismic Input Data.** The seismic input data for the equipment seismic analysis shall be provided by the owner. The seismic input shall be specified as broadened floor response spectra or time histories of acceleration, displacements, or velocities defined at an appropriate level in the structure supporting the crane or monorail.

**CM-2.1.3.3 Load Pendulum Effects.** Pendulum effects of the suspended load shall be considered. (In most facilities, the horizontal load due to pendulum effects will be negligible because the load displacement is small. Where displacement is significant, consider obstacle-avoidance measures.)

**CM-2.1.3.4 Dynamic Analysis**

**CM-2.1.3.4.1 Response-Spectrum Method.** The crane or monorail shall be considered to respond as a linear elastic system when using the response spectrum-method. The undamped natural modes and frequencies shall be computed using a model acceptable under the requirements of this section. These outputs shall serve as the basis for mode-by-mode computation of the response of the crane or monorail to each of the three components of seismic input.

**CM-2.1.3.4.2 Time-History Analysis.** Time histories of structural response at the appropriate level may be used for analysis of the crane or monorail. The time histories shall be provided by the owner. Procedures for assembling the mathematical model shall be in accordance with this section. The effects of the three components of ground motion shall be combined in accordance with the following requirements:

(a) The representative maximum values of the structural responses to each of the three components of earthquake motion shall be combined by taking the square root of the sum of the squares of the maximum representative values of the codirectional responses caused by each of the three components of earthquake.
Dynamic degrees of freedom.  

(b) The maximum value of a particular response of interest for design of a given element may be obtained through a step-by-step method. The time-history responses from each of the three components of the earthquake motions may be obtained separately and then combined algebraically at each time step, or the response at each time step may be calculated directly, owing to the simultaneous action of the three components. The maximum response is determined by scanning the combined time-history solution. When this method is used, the earthquake motions specified in the three different directions shall be statistically independent.

CM-2.1.3.4.3 Mathematical Model

(a) The crane or monorail shall be represented by a generalized three-dimensional system of nodes. The model’s geometry shall reflect the overall size, length, connectivity, and stiffness of the various structural members. An appropriate element representation of each member shall be used to describe all components that contribute significantly to the stiffness of the equipment.

(b) For cranes using pin-connected wheel trucks, pinned connections shall be specified for line elements that represent the attachment of the end trucks to the bridge girders or gantry legs. Where various connected structural members of the crane do not have intersecting centroidal axes, stiff line elements shall be used to represent the offset. These elements shall have stiffness values that are an order of magnitude higher than the stiffest structural member of the crane.

(c) A simplified finite element representation of the trolley structure using stiff line elements may be used for the crane or monorail dynamic model, provided it can be shown by rational analyses that the actual trolley structure responding as an uncoupled system has natural frequencies above 33 Hz. The model used for seismic analysis should be evaluated and revised if required to account for higher frequencies if plant operations induce such frequencies.

CM-2.1.3.4.4 Location and Number of Dynamic Degrees of Freedom. Dynamic degrees of freedom shall be assigned to a sufficient number of node points in such locations that the real mass and stiffness distribution of the equipment are simulated. Structural members subject to concentrated loads shall be provided with additional nodes at the points where a concentrated load or its equivalent mass is positioned. Crane or monorail components to be modeled as mass points (concentrated loads) shall include, but not be limited to, upper and lower blocks, gear cases, motors, brakes, heavy electrical control cabinets, cab, wheel assemblies, and trunnion pins. The total number of masses or degrees of freedom selected shall be considered adequate when additional degrees of freedom do not result in more than a 10% increase in responses. Dynamic coupling shall be accounted for.

CM-2.1.3.4.5 Decoupling Criteria for the Runway. The crane or monorail and runway shall be evaluated to determine if the equipment should be represented as a separate model or as a model coupled with the runway. For the equipment to be considered decoupled from the runway, the criteria of (a) or (b) below shall be met

(a) If \( R_m < 0.01 \), decoupling can be done for an \( R_f \).

(b) If \( 0.01 \leq R_m \leq 0.1 \), decoupling can be done if \( R_f \leq 0.8 \) or if \( R_f \geq 1.25 \).

(c) If \( R_m \geq 0.2 \), or \( 0.8 \leq R_f \leq 1.25 \), an approximate model of the runway system shall be included with the model.

\[ R_m = \frac{\text{total mass of the crane}}{\text{mass of the runway system}} \]  

\[ R_f = \frac{\text{fundamental frequency of the crane}}{\text{frequency of the dominant runway motion}} \]

The owner shall determine the mass and frequency characteristics of the runway.

CM-2.1.3.4.6 Boundary Conditions

(a) The crane or monorail shall be provided with devices so that they remain on their respective runways during and after a seismic event. Characteristics of these devices that influence the dynamic behavior of the crane or monorail shall be included as boundary conditions in the model of the equipment. The restraint devices shall be considered to be in contact with the resisting structure in establishing boundary conditions used in the analysis for the crane or monorail. The restraint device and resisting structure shall be designed for the maximum load resulting from the boundary condition considered. The crane or monorail shall be modeled with the wheel-to-rail boundary conditions specified in Fig. CM-2.1.3.4.6-1, unless additional restraining, driving, or holding mechanisms exist. The configurations shown in Table CM-2.1.3.4.6-1 were developed to show standard configurations. Other configurations are also acceptable.

(b) The crane or monorail boundary conditions at pivot points (such as hinges at jib crane connections) need to be modeled in computer analysis as rotationally fixed about the rotation of the hinge. If left free to rotate, the crane or monorail will be unstable and the results of the analyses will be unrealistic. By fixing the rotation around the pin, the stresses in the crane or monorail will be conservative. During an actual seismic event, however, the crane or monorail will tend to rotate about these pivot points. It is the responsibility of the owner to determine if uncontrolled movement about the pivot point is acceptable (i.e., the
crane or monorail movement will not impact and damage equipment). If uncontrolled movement is not acceptable, the owner shall specify that restraint devices be provided that will limit or dampen the movement.

(c) The crane or monorail boundary conditions at the point of interface with the building structure shall be determined by the person performing the crane or monorail analysis. The boundary conditions shall take into consideration the method of attachment and flexibility of connections.

**Figure CM-2.1.3.4.6-1 Boundary Conditions for Wheel-to-Rail Interface**

**GENERAL NOTES:**
(a) The hoist is modeled as a lumped mass at its centroid.
(b) The members are modeled at their centroidal axis.
(c) The nodes shown illustrate wheel-to-rail boundary conditions. Additional nodes are required to complete the mathematical model.
CM-2.1.3.4.7 Trolley Positions and Hoist Positions. The crane or monorail shall be analyzed under the following loading conditions.

(a) Seismic lifted load on hook (if specified)

(b) no load on hook

The analysis procedure shall use the bridge, jib, trolley, and hoist in as many different positions as necessary to envelope the worst-case loading situation. Since this Standard encompasses many different cranes and monorails, which may be fabricated and installed in many different configurations, it is the responsibility of the manufacturer to determine the worst-case configurations.

CM-2.1.3.4.8 Crane or Monorail Damping Values. The response of each mode shall be determined from the amplified response spectra for the appropriate values of structural damping. A damping value of 7% of critical damping shall be used for the crane or monorail when the SSE is used in the analysis.

CM-2.1.3.4.9 Number of Modes Required for Seismic Analysis. It is not generally necessary to include the contributions of all modes to the seismic response of the crane or monorail. A modal participation factor shall be used with the modal frequencies to select significant modes. Since high-frequency modes may respond strongly in some cases, it is not sufficient to limit the modal analysis to the first several modes computed. Additional modes shall be computed until the inclusion of additional modes does not result in more than a 10% increase in response.

CM-2.1.3.4.10 Combination of Modal Responses. In combining the dynamic responses, it shall be assumed that the dynamic responses have the sign that yields the worst case for the combination being considered.

(a) With No Closely Spaced Modes. When the results of the modal dynamic analysis show that some or all of the modes are closely spaced (two consecutive modes are defined as closely spaced if their frequencies differ from each other by 10% or less of the lower frequency), modal responses for each of the three components for seismic input shall be combined using one of the following three methods:

1) Grouping Method. Closely spaced modes shall be divided into groups that include all modes having frequencies within the range of the group and a frequency 10% higher [see Note (1)]. The representative maximum value of a particular response of interest for the design of a given element of a nuclear power plant structure, system, or the crane or monorail attributed to each such group of modes shall first be obtained by taking the sum of the absolute values of the corresponding peak values of the response of the element attributed to individual modes in that group. The representative maximum value of this particular response attributed to all the significant modes of the structure, system, or the crane or monorail shall then be obtained by taking the square root of the sum of the squares of corresponding representative maximum values of the response of the element attributed to each closely spaced group of modes and the remaining modal responses for the modes that are not closely spaced. Mathematically, this is expressed as follows:

\[ R = \left( \sum_{k=1}^{N} R_k^2 + \sum_{q=1}^{P} \sum_{i=1}^{j} \sum_{m=1}^{j} |R_{iq}R_{mq}| \right)^{1/2} \]  

where \( i \neq m \); \( R_{iq} \) and \( R_{mq} \) are modal responses; \( R_i \) and \( R_m \) are within the \( q \)th group; \( i \) is the number of the mode where a group starts; \( j \) is the number of the mode where the group ends; \( R \), \( R_i \), and \( N \) are as defined in Note (2); and \( P \) is the number of groups of closely spaced modes, excluding individual, separated modes.

(2) 10% Method

\[ R = \left( \sum_{k=1}^{N} R_k^2 + 2 \sum |R_i^*R_j^| \right)^{1/2} \]
where \( i \neq j \); and \( R, R_k, \) and \( N \) are as defined in Note (2). The second summation shall be done on all \( i \) and \( j \) modes whose frequencies are closely spaced to each other. Let \( \omega_i \) and \( \omega_j \) be the frequencies of the \( i \)th and \( j \)th modes. To verify which modes are closely spaced, the following equation shall be applied:

\[
\omega_j - \omega_i \leq 0.1 \tag{6}
\]

where

\[1 \leq i < j \leq N \tag{7}\]

(3) Double-Sum Method

\[
R = \left( \sum_{k=1}^{N} \sum_{s=1}^{N} |R_k R_s| \epsilon_{ks} \right)^{1/2} \tag{8}
\]

where \( R, R_k, \) and \( N \) are as defined in Note (2); \( R_s \) is the peak value of the response of the element attributed to the \( s \)th mode; and \( \omega_{ks} \) is a correlation coefficient between modes \( k \) and \( s \).

\[
\epsilon_{ks} = \left\{ 1 + \left[ \frac{\omega_k - \omega_s}{\beta_k \omega_k + \beta_s \omega_s} \right]^{2} \right\}^{-1} \tag{9}
\]

where

\[
\omega'_k = \omega_k \left( 1 - \beta_k^2 \right)^{1/2} \tag{10}
\]

\[
\beta_k = \beta_k + \frac{2}{t_d \omega_k} \tag{11}
\]

where \( \omega_k \) and \( \beta_k \) are the modal frequency and the damping ratio in the \( k \)th mode, respectively, and \( t_d \) is the time duration of the earthquake.

NOTES:

(1) Groups shall be formed starting from the lowest frequency and working toward successively higher frequencies. No one frequency shall be in more than one group.

(2) \( R \) is the representative maximum value of a particular response of a given element to a given component of an earthquake; \( R_k \) is the peak value of the response of the element due to the \( k \)th mode; and \( N \) is the number of significant modes considered in the modal response combination.

(c) Combination of Three Components of Earthquake Motion. The representative maximum values of the structural responses of each of the three directional components of earthquake motion shall be combined by taking the square root of the sum of the squares of the maximum \( m \) representative values of the codirectional responses caused by each of the three components of earthquake motion at each node of the crane or monorail mathematical model.

CM-2.1.3.5 Equivalent Static Analysis. In cases where a dynamic analysis is not necessary because the crane or monorail model is very simple (as in the case of a single-span monorail or simple jib crane), an equivalent static analysis can be performed.

CM-2.1.3.5.1 Mathematical Model. The crane or monorail shall be represented by a generalized three-dimensional system of nodes. The model’s geometry shall reflect the overall size, length, connectivity, and stiffness of the various structural members. An appropriate element representation of each member shall be used to describe all components that contribute significantly to the stiffness of the crane or monorail.

CM-2.1.3.5.2 Decoupling Criteria for the Runway. Refer to CM-2.1.3.4.5.

CM-2.1.3.5.3 Trolley Locations and Hoist Positions. Refer to CM-2.1.3.4.7.

CM-2.1.3.5.4 Crane or Monorail Damping Values. Refer to CM-2.1.3.4.8.

CM-2.1.3.6 Number of Modes Required for Seismic Analysis. Only the fundamental frequency of the crane or monorail in each direction of earthquake is used. For fundamental frequencies less than or equal to the frequency at which the maximum spectral acceleration occurs, the maximum spectral acceleration shall be used. For fundamental frequencies greater than the frequency at which the maximum spectral acceleration occurs, the actual spectral acceleration depicted on the response spectra curve shall be used. The maximum spectral acceleration may conservatively be used without calculation of the fundamental frequency.

CM-2.1.3.7 Combination of Modal Responses. Since only one mode is calculated in each direction, an increase factor of 1.5 shall be used on the acceleration to account for other modes.

CM-2.1.3.8 Combination of Three Components of Earthquake Motion. The representative maximum values of the structural responses of each of the three directional components of earthquake motion shall be combined by taking the square root of the sum of the squares of the maximum representative values of the codirectional responses caused by each of the three components of earthquake motion at each node of the crane or monorail mathematical model.

CM-2.1.4 Tolerances

Dimensions on the clearance drawings are the maximum dimensions of the crane and shall not be
exceeded by the manufacturer. Height and end dimensions shall be shown in relationship to the operating surface and centerline of the beam or rail. Cumulative measurements of crane components are permitted. The runway shall be straight, parallel, level, and at the same elevation within the tolerances given in Fig. CM-2.1.4-1 or Fig. CM-2.1.4-2. The crane manufacturer shall design the crane to operate properly within the runway tolerances given in Figs. CM-2.1.4-1 and CM-2.1.4-2.

**Figure CM-2.1.4-1** Building Runway Alignment Tolerance for Patent Track

<table>
<thead>
<tr>
<th>Item</th>
<th>Figure</th>
<th>Overall Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crane span ( (L) ) measured at crane wheel contact surface</td>
<td><img src="image" alt="Crane Span Diagram" /></td>
<td>( A = \frac{1}{2} ) in. in any support span</td>
</tr>
<tr>
<td>Span ( (3 \text{ or more runways}) )</td>
<td><img src="image" alt="Span Diagram" /></td>
<td>( B = \frac{1}{2} ) in. in any support span</td>
</tr>
<tr>
<td>Straightness</td>
<td><img src="image" alt="Straightness Diagram" /></td>
<td>( C = \frac{1}{2} ) in. in any support span</td>
</tr>
<tr>
<td>Elevation</td>
<td><img src="image" alt="Elevation Diagram" /></td>
<td>( D = \frac{1}{2} ) in. in any support span</td>
</tr>
<tr>
<td>Rail-to-rail elevation</td>
<td><img src="image" alt="Rail-to-rail Diagram" /></td>
<td>( E = \frac{1}{16} ) in. between adjacent rails</td>
</tr>
</tbody>
</table>

"Figure CM-2.1.4-1 [FL32] Building Runway Alignment Tolerance for Patent Track"
CM-2.1.5 Materials and Connections

**CM-2.1.5.1 Base Materials.** The base materials listed in Table CM-2.1.5.1-1 are considered acceptable for the structural components. The manufacturer shall list all structural materials used for the owner and shall provide the material tests and certifications as required in Table CM-2.1.5.1-2. Structural materials not listed in Table CM-2.1.5.1-1 may be acceptable with approval by the owner.
### Table CM-2.1.5.1-1 Acceptable Materials and Reference Properties for Structural Components

<table>
<thead>
<tr>
<th>ASTM Specification</th>
<th>Grade or Class</th>
<th>Form</th>
<th>Size [Note (1)]</th>
<th>Yield Strength, ksi</th>
<th>Tensile Strength, ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>A36</td>
<td>...</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars &lt; 8 in. and shapes (for shapes, see Note (2))</td>
<td>36 min.</td>
<td>58-80</td>
</tr>
<tr>
<td>A53</td>
<td>B</td>
<td>Pipe</td>
<td>Diameter ≤ 26 in.</td>
<td>35 min.</td>
<td>60 min.</td>
</tr>
<tr>
<td>A42</td>
<td>...</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars ≤ 5/8 in.; and shapes with flange or leg thickness ≤ 1 1/16 in.</td>
<td>50 min.</td>
<td>70 min.</td>
</tr>
<tr>
<td>A42</td>
<td>...</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars &gt; 5/8 in. and ≤ 1 1/4 in.; and shapes with flange thickness &gt; 1 1/16 in. and ≤ 2 in.</td>
<td>46 min.</td>
<td>67 min.</td>
</tr>
<tr>
<td>A42</td>
<td>...</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars &gt; 1 1/4 in. and ≤ 4 in.; and shapes with flange thickness &gt; 2 in.</td>
<td>42 min.</td>
<td>63 min.</td>
</tr>
<tr>
<td>A33</td>
<td>3 and 7</td>
<td>Pipe</td>
<td>Diameter ≤ 26 in.</td>
<td>35 min.</td>
<td>65 min.</td>
</tr>
<tr>
<td>A33</td>
<td>4 and 6</td>
<td>Pipe</td>
<td>Diameter ≤ 26 in.</td>
<td>35 min.</td>
<td>60 min.</td>
</tr>
<tr>
<td>A500</td>
<td>B</td>
<td>Rectangular tubing</td>
<td>Wall ≤ 5/8 in. and periphery ≤ 64 in. (Note (3))</td>
<td>46 min.</td>
<td>58 min.</td>
</tr>
<tr>
<td>A501</td>
<td>...</td>
<td>Tubing</td>
<td>Square and rectangular with sides ≤ 10 in. and wall ≤ 1 in.; and round ≤ 24 in. diameter and wall ≤ 1 in.</td>
<td>36 min.</td>
<td>58 min.</td>
</tr>
<tr>
<td>A516</td>
<td>65</td>
<td>Plates</td>
<td>Thickness ≤ 8 in.</td>
<td>35 min.</td>
<td>65-85</td>
</tr>
<tr>
<td>A516</td>
<td>70</td>
<td>Plates</td>
<td>Thickness ≤ 8 in.</td>
<td>38 min.</td>
<td>70-90</td>
</tr>
<tr>
<td>A537</td>
<td>1</td>
<td>Plates</td>
<td>Thickness ≤ 3/4 in.</td>
<td>50 min.</td>
<td>70-90</td>
</tr>
<tr>
<td>A537</td>
<td>2</td>
<td>Plates</td>
<td>Thickness &gt; 3/4 in. and ≤ 4 in.</td>
<td>45 min.</td>
<td>65-85</td>
</tr>
<tr>
<td>A537</td>
<td>2</td>
<td>Plates</td>
<td>Thickness ≤ 3/4 in.</td>
<td>60 min.</td>
<td>80-100</td>
</tr>
<tr>
<td>A537</td>
<td>2</td>
<td>Plates</td>
<td>Thickness &gt; 3/4 in. and ≤ 4 in.</td>
<td>55 min.</td>
<td>75-95</td>
</tr>
<tr>
<td>A537</td>
<td>3</td>
<td>Plates</td>
<td>Thickness ≤ 3/4 in.</td>
<td>46 min.</td>
<td>70-90</td>
</tr>
<tr>
<td>A537</td>
<td>3</td>
<td>Plates</td>
<td>Thickness ≤ 3/4 in.</td>
<td>55 min.</td>
<td>80-100</td>
</tr>
<tr>
<td>A572</td>
<td>42</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars ≤ 6 in.; and shapes</td>
<td>42 min.</td>
<td>60 min.</td>
</tr>
<tr>
<td>A572</td>
<td>50</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars ≤ 4; and shapes</td>
<td>50 min.</td>
<td>65 min.</td>
</tr>
<tr>
<td>A572</td>
<td>55</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars ≤ 2; and shapes</td>
<td>55 min.</td>
<td>70 min.</td>
</tr>
<tr>
<td>A572</td>
<td>60</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars ≤ 1 1/2 in.; and shapes with flange or leg thickness ≤ 2 in.</td>
<td>60 min.</td>
<td>70 min.</td>
</tr>
<tr>
<td>A572</td>
<td>65</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars ≤ 1 1/2 in.; and shapes with flange or leg thickness ≤ 2 in.</td>
<td>65 min.</td>
<td>80 min.</td>
</tr>
<tr>
<td>A588</td>
<td>...</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars ≤ 4 in; and shapes</td>
<td>50 min.</td>
<td>70 min.</td>
</tr>
<tr>
<td>A588</td>
<td>...</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars &gt; 4 in. and ≤ 5 in.</td>
<td>46 min.</td>
<td>67 min.</td>
</tr>
<tr>
<td>A588</td>
<td>...</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars &gt; 5 in. and ≤ 6 in.</td>
<td>42 min.</td>
<td>63 min.</td>
</tr>
<tr>
<td>A618</td>
<td>EA, IB, and II</td>
<td>Tubing</td>
<td>Wall ≤ 3/4 in.</td>
<td>50 min.</td>
<td>70 min.</td>
</tr>
<tr>
<td>A618</td>
<td>IA, IB, and II</td>
<td>Tubing</td>
<td>Wall &gt; 3/4 in. and ≤ 1 1/4 in.</td>
<td>46 min.</td>
<td>67 min.</td>
</tr>
<tr>
<td>A618</td>
<td>III</td>
<td>Tubing</td>
<td>All tubing</td>
<td>50 min.</td>
<td>65 min.</td>
</tr>
<tr>
<td>A633</td>
<td>A</td>
<td>Plates</td>
<td>Thickness ≤ 4 in.</td>
<td>42 min.</td>
<td>63-83</td>
</tr>
<tr>
<td>A633</td>
<td>C and D</td>
<td>Plates</td>
<td>Thickness ≤ 2 1/2 in.</td>
<td>50 min.</td>
<td>70-90</td>
</tr>
<tr>
<td>A633</td>
<td>C and D</td>
<td>Plates</td>
<td>Thickness &gt; 2 1/2 in. and ≤ 4 in.</td>
<td>46 min.</td>
<td>65-85</td>
</tr>
<tr>
<td>A633</td>
<td>E</td>
<td>Plates</td>
<td>Thickness ≤ 4 in.</td>
<td>60 min.</td>
<td>80-100</td>
</tr>
<tr>
<td>A633</td>
<td>E</td>
<td>Plates</td>
<td>Thickness &gt; 4 in. and ≤ 6 in.</td>
<td>55 min.</td>
<td>75-85</td>
</tr>
<tr>
<td>A709</td>
<td>36</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars ≤ 4 in.; and shapes for shapes, see Note (2)</td>
<td>36 min.</td>
<td>58-80</td>
</tr>
<tr>
<td>A709</td>
<td>50</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars ≤ 4 in.; and shapes</td>
<td>50 min.</td>
<td>65 min.</td>
</tr>
<tr>
<td>A709</td>
<td>50W</td>
<td>Plates, shapes, and bars</td>
<td>Plates and bars ≤ 4 in.; and shapes</td>
<td>50 min.</td>
<td>70 min.</td>
</tr>
<tr>
<td>A737</td>
<td>B</td>
<td>Plates</td>
<td>Thickness ≤ 3/4 in.</td>
<td>50 min.</td>
<td>70-90</td>
</tr>
<tr>
<td>A737</td>
<td>C</td>
<td>Plates</td>
<td>Thickness &gt; 3/4 in. and ≤ 4 in.</td>
<td>60 min.</td>
<td>80-100</td>
</tr>
<tr>
<td>A913</td>
<td>50</td>
<td>Shapes</td>
<td>All shapes</td>
<td>50 min.</td>
<td>65 min.</td>
</tr>
<tr>
<td>A913</td>
<td>60</td>
<td>Shapes</td>
<td>All shapes</td>
<td>60 min.</td>
<td>75 min.</td>
</tr>
<tr>
<td>A913</td>
<td>65</td>
<td>Shapes</td>
<td>All shapes</td>
<td>65 min.</td>
<td>80 min.</td>
</tr>
<tr>
<td>A913</td>
<td>70</td>
<td>Shapes</td>
<td>All shapes</td>
<td>70 min.</td>
<td>90 min.</td>
</tr>
<tr>
<td>A992</td>
<td>...</td>
<td>Shapes</td>
<td>All shapes [Note (5)]</td>
<td>50-65</td>
<td>65 min.</td>
</tr>
</tbody>
</table>

**GENERAL NOTE:** The above data was obtained from the ASTM 2007 publication.

**NOTES:**

1. For additional material information, see the referenced ASTM specification.
2. For wide flange shapes with flange thickness over 3 in., the 80 ksi maximum tensile strength does not apply.
3. The exception from fracture toughness requirements in Table CM-2.1.5.1-2, Note (3) does not apply to this material.
4. Mechanical properties, standard sizes, and design/selection criteria or patented shape track are under the auspices of the individual manufacturers.
5. Patented shape track is comprised of an upper T-section (compression member) of standard structural steel and a lower load-carrying T-section (tension member) of high-strength alloy steel. The two sections are welded continuously from both sides, web-to-web. Patented shape track is also used for crane bridge girders and jib crane booms with under-running trolleys or hoists with integral trolleys.

5. The yield strength to tensile strength ratio shall not exceed 0.85.
### Table CM-2.1.5.1-2 \[FL35\] Required Inspection or Tests

<table>
<thead>
<tr>
<th>Items</th>
<th>Material Test Reports</th>
<th>Certificate of Conformance From Item Manufacturer</th>
<th>NDE of Welds (Note (1))</th>
<th>UT (Note (2))</th>
<th>Surface MP or PT</th>
<th>Impact Test (Note (3))</th>
<th>Weld Filler Material C.C. Typical Value</th>
<th>Welder Certs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary load-bearing structural welds</td>
<td>...</td>
<td>...</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Fastener material for structural interconnections (including seismic restraints and safety lugs)</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Crane or monorail structure</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>X</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Bridge seismic restraints</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Safety lugs</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Hinges or pins on jib cranes (Note (4))</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Tension rods for jibs or monorails (Note (4))</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

**NOTES:**
1. See CM-7.1.2.1.1.
2. See CM-7.1.2.1.3.
3. Impact testing required for materials greater than 5/8 in. thickness. See CM-7.1.2.1.2.
4. If the item is designed with double a design margin, material test reports are not required.

---

**CM-2.1.5.2 Fastener Materials**

(a) The bolts used for joining structural components shall be in accordance with CM-2.1.6.1.5.

(b) The fastener finish and tolerances shall be suitable for the type of connection in which they are employed.

**CM-2.1.5.3 Welding Materials.** All welding materials shall be in compliance with the requirements of AWS D1.1 or AWS D14.1 as applicable.

**CM-2.1.5.4 Connections**

**CM-2.1.5.4.1 Welded Connections:**

Welded connections shall comply with the requirements of AWS D1.1 or AWS D14.1 as applicable.

**CM-2.1.5.4.2 Bolted Connections**

**CM-2.1.5.4.2.1 Structural Joints Using ASTM A325 or A490 Bolts.** Structural joints using ASTM A325 or A490 bolts shall be designed and installed in accordance with the Specification for Structural Joints Using ASTM A325 and A490 Bolts, as included in The AISC Manual of Steel Construction: Allowable Stress Design. Bolt holes shall not be burned. Standard holes shall have a maximum diameter 1/16 in. in excess of the nominal bolt diameter. Holes for alignment (bound) bolts shall be reamed to close tolerances as required. Slotted bolt holes shall not be used for connections of end trucks.

**CM-2.1.5.4.2.2 Structural Joints Using Bolts Other than ASTM A325 or A490.** Structural joints using bolts other than ASTM A325 or A490 shall be bearing type, and shall comply with the requirement for non-high-strength bolts specified in the Specification for Structural Steel for Buildings — Allowable Stress Design and Plastic Design, as included in the AISC Manual of Steel Construction: Allowable Stress Design. All bolts shall be torqued to a pre-tension load on the bolt of 60% to 70% of the minimum yield strength of the bolt materials. Standard holes shall have a maximum diameter 1/6 in. in excess of the nominal bolt diameter. Holes for alignment (bound) bolts shall be reamed to close tolerances as required.

**CM-2.1.5.4.3 Gauge and Edge Distances.** The minimum gauge between centers of bolt holes and minimum and maximum edge distances from the center of a bolt hole to any edge shall be as stipulated in the Specification for Structural Steel for Buildings — Allowable Stress Design and Plastic Design, as included in The AISC Manual of Steel Construction: Allowable Stress Design.

**CM-2.1.5.4.4 Field Connections.** All field connections of structural components shall be bolted unless otherwise approved by the owner. The manufacturer shall provide sufficient information on drawings or in installation manuals on the requirements for all field connections.

**CM-2.1.6 Design Criteria**

**CM-2.1.6.1 Basic Allowable Stresses for Structural Steel Members**

**CM-2.1.6.1.1 Members Not Controlled by Buckling.** For members not controlled by buckling, the basic allowable stresses in structural steel members of the crane shall not exceed the values in Table CM-2.1.6.1.1-1.
## CM-2.1.6.1.2 Compression Members Controlled by Buckling.

(a) For compression members with an equivalent slenderness ratio

\[
\frac{kl}{r} < C_c \tag{12}
\]

where

\[
C_c = \frac{2\pi^2E}{\sigma_y r} \tag{13}
\]

and

- \( C_c \) = column slenderness ratio separating elastic and inelastic buckling
- \( E \) = modulus of elasticity, psi
- \( k \) = effective length factor
- \( l \) = unbraced length of compression member, in.
- \( r \) = radius of gyration of member, in.
- \( \sigma \) = yield point, psi

The allowable axial compression stress, \( \sigma_a \), is:

\[
\sigma_a = \left[ 1 - \left( \frac{kl}{2rC_c} \right)^2 \right] \left( \frac{\sigma_y}{DF} \right) \tag{14}
\]

where

- \( DF \) = design factor

The required design factor shall be equal to:

\[
DF = N \left\{ \frac{5}{3} + \frac{3}{8} \left[ \frac{kl}{C_c r^3} \right] - \frac{1}{8} \left[ \frac{kl}{C_c r^3} \right]^3 \right\} \tag{15}\]

The allowable axial compression stress shall not exceed the value

\[
\sigma_a = \frac{12\pi^2E}{23N \left( \frac{kl}{r} \right)^2} \tag{16}
\]

## CM-2.1.6.1.3 Bending Stress

The allowable bending stress shall be determined per AISC Part 5, Chapter F, Beams and Other Flexural Members, divided by 1.12 (where \( N \) is defined in Table CM-2.1.6.1.2-1) for the different loading conditions.

## CM-2.1.6.1.4 Welds

Basic allowable stresses in welds shall be as specified in AWS D14.1. Allowable stresses for all types of welds may be increased for extraordinary load combinations by a factor of 1.33 and increased for extreme load combinations by a factor of 1.50.

## CM-2.1.6.1.5 Bolts

(a) ASTM A325 or A490 Bolts. Allowable working stresses for operational (Principal Load case) or construction loads (Additional Load case) shall be in accordance with the Specification for Structural Joints Using ASTM A325 and A490 Bolts, as included in The AISC Manual of Steel Construction: Allowable Stress Design. Allowable working stresses for other loadings shall be as follows:

(1) Bearing-Type Joints. Allowable working stresses for bearing-type joints may be increased by a factor of 1.33 for extraordinary loadings and by a factor of 1.50 for extreme loadings.

(2) Friction-Type Joints. Allowable working stresses for friction-type joints shall not be increased for extraordinary loadings or extreme loadings.

(b) Bolts Other Than ASTM A325 or A490. Allowable stresses shall be in accordance with Table CM-2.1.6.1.5-1.
### Table CM-2.1.6.1.5-1 Bolt Allowable Stresses

<table>
<thead>
<tr>
<th>Loading Condition (Expressed in Terms of Ultimate Strength)</th>
<th>Stress Type</th>
<th>Tension</th>
<th>Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal</td>
<td></td>
<td>0.33</td>
<td>0.17</td>
</tr>
<tr>
<td>Additional</td>
<td></td>
<td>0.33</td>
<td>0.17</td>
</tr>
<tr>
<td>Extraordinary</td>
<td></td>
<td>0.44</td>
<td>0.23</td>
</tr>
<tr>
<td>Extreme</td>
<td></td>
<td>0.50</td>
<td>0.26</td>
</tr>
</tbody>
</table>

### CM-2.1.6.2 Combined Stresses

#### CM-2.1.6.2.1 Axial Compression and Bending.

Members subjected to both axial compression and bending stresses shall satisfy the following requirements:

$$\frac{\sigma}{\sigma_a} + \frac{C_m \sigma_{bx}}{(1 - \frac{\sigma}{\sigma_{ax}}) \sigma_{abx}} + \frac{C_m \sigma_{by}}{(1 - \frac{\sigma}{\sigma_{ay}}) \sigma_{aby}} \leq 1.0 \quad (17)$$

$$\frac{\sigma}{\sigma_a} + \frac{\sigma_{bx}}{\sigma_{abx}} + \frac{\sigma_{by}}{\sigma_{aby}} \leq 1.0 \quad (18)$$

When \( \frac{\sigma}{\sigma_a} \leq 0.15 \), the following equation may be used in lieu of equations (17) and (18):

$$\frac{\sigma}{\sigma_a} + \frac{\sigma_{bx}}{\sigma_{abx}} + \frac{\sigma_{by}}{\sigma_{aby}} \leq 1.0 \quad (19)$$

In equations (17), (18), and (19), the subscripts \( x \) and \( y \), combined with subscripts \( b, m, \) and \( e \), indicate the axis of bending about which a particular stress or design property applies, and

\( \sigma, \sigma_{ab} = \) allowable axial and bending stresses, respectively (See CM-2.1.6.1.1.)

It is to be noted that

\( \sigma_a = \sigma_{ab} \) in paragraphs CM-2.1.6.1.1 and CM-2.1.6.1.2

\( \sigma_{ab} = \sigma_a \) as given in CM-2.1.6.1.1 only

$$\sigma_e = \frac{12 \pi^2 E}{23N \left( \frac{kr^2}{l} \right)^2} \quad (20)$$

where

\( C_m = \) a coefficient whose value shall be given in (a), (b) and (c) below
\( k = \) the effective length factor in the plane of bending
\( l = \) the actual unbraced length in the plane of bending, in.
\( N = \) a loading condition factor given in Table CM-2.1.6.1.2-1
\( r = \) the corresponding radius of gyration, in.
\( \sigma = \) computed axial stress, psi

\( \sigma_b = \) computed compressive bending stress at the section under consideration, psi

(a) For compression members in frames subject to joint translation, \( C_m = 0.85 \).

(b) For rotationally restrained compression members in frames braced against joint translation and not subject to transverse loading between their supports in the plane of bending

$$C_m = 0.6 - 0.4 \left( \frac{M_1}{M_2} \right) \geq 0.4 \quad (21)$$

where \( M_1 / M_2 \) is the ratio of the smaller to larger moments at the ends of that portion of the member unbraced in the plane of bending under consideration. \( M_1 / M_2 \) is positive when the member is bent in reverse curvature and negative when it is bent in a single curvature.

(c) For compression members in frames braced against joint translation in the plane of loading and subjected to transverse loading between their supports, the value of \( C_m \) may be determined by analysis; however, in lieu of such analysis, the following values may be used:

(1) for members whose ends are restrained against rotation in the plane of bending, \( C_m = 0.85 \).

(2) for members whose ends are unrestrained against rotation in the plane of bending, \( C_m = 1.0 \).

#### CM-2.1.6.2.2 Axial Tension and Bending.

Members subject to both axial tension and bending stresses shall be proportioned at all points along their length to satisfy the following equation:

$$\frac{\sigma_t}{\sigma_{at}} + \frac{\sigma_{bx}}{\sigma_{abx}} + \frac{\sigma_{by}}{\sigma_{aby}} \leq 1.0 \quad (22)$$

where

\( \sigma_{abx} = \) the allowable bending stress about the member's \( x \)-axis, psi
\( \sigma_{aby} = \) the allowable bending stress about the member's \( y \)-axis, psi
\( \sigma_{at} = \) the allowable axial tension stress as determined from Table CM-2.1.6.1.1-1, psi
\( \sigma_{bx} = \) the computed bending stress about the member's \( x \)-axis, psi
\( \sigma_{by} = \) the computed bending stress about the member's \( y \)-axis, psi
\( \sigma_t = \) the computed axial tension stress, psi

The computed bending compressive stress arising from an independent load source relative to the axial tension, taken above, shall not exceed the applicable value required in CM-2.1.6.1.3.
CM-2.1.6.2.3 Local Bending of Flanges due to Wheel Loads

(a) Each wheel load shall be considered as a concentrated load applied at the center of the wheel contact area with the flange [see Fig. CM-2.1.6.2.3-1].

(b) Local flange bending stresses in the lateral (x) and longitudinal (y) directions at certain critical points may be calculated from formulas 23 - 41. Other suitable formulas/analysis in lieu of formulas 23 - 41 may be adopted to address the local flange bending stresses.

(1) Underside of flange at flange-to-web transition, Point 0

\[ \sigma_x^0 = C_{x0} \frac{P}{t_a^2} \]  
\[ \sigma_y^0 = C_{y0} \frac{P}{t_a^2} \]  

(2) Underside of flange directly beneath wheel contact point, Point 1

\[ \sigma_x^1 = C_{x1} \frac{P}{t_a} \]  
\[ \sigma_y^1 = C_{y1} \frac{P}{t_a} \]  

(3) Topside of flange at flange-to-web transition, Point 2

\[ \sigma_x^2 = -\sigma_x^0 \]  
\[ \sigma_y^2 = -\sigma_y^0 \]  

(4) For tapered flange sections [see Fig. CM-2.1.6.2.3-2]

\[ C_{x0} = -1.096 + 1.095\lambda + 0.192e^{-6.01} \]  
\[ C_{x1} = 3.965 - 4.835\lambda - 3.965e^{-2.673\lambda} \]  
\[ C_{y0} = -0.981 - 1.479\lambda + 1.120e^{1.322\lambda} \]  
\[ C_{y1} = 1.810 - 1.150\lambda + 1.060e^{-7.70\lambda} \]  

for standard “S” section,

\[ t_a = t_f - \left( \frac{b'}{2} \right) + \left( \frac{a}{6} \right) \]  

(5) For parallel flange [see Figs. CM-2.1.6.2.3-3 and CM-2.1.6.2.3-4]

\[ C_{x0} = -2.110 + 1.977\lambda + 0.0076e^{6.53\lambda} \]  
\[ C_{x1} = 10.108 - 7.408\lambda - 10.108e^{-1.364\lambda} \]  
\[ C_{y0} = 0.050 - 0.580\lambda + 0.148e^{3.015\lambda} \]  
\[ C_{y1} = 2.230 - 1.490\lambda + 1.390e^{-18.333\lambda} \]  

(6) For single-web symmetrical sections [see Figs. CM-2.1.6.2.3-2 and CM-2.1.6.2.3-3]

\[ \lambda = \frac{2a}{b - t_w} \]  

(7) For other cases [see Fig. CM-2.1.6.2.3-4]

\[ \lambda = \frac{a}{b' - \left( \frac{b}{2} \right)} \]  

where

- a = distance from edge of flange to point of wheel load application, in. (center of wheel contact)
- b = Overall length of flange (from edge of flange to edge of flange), in.
- b' = distance from centerline of web to edge of flange, in.
- P = load per wheel including HLF, lb.
- ta = flange thickness at point of load application, in.
- tr = published flange thickness for standard “S” section, in.
- tw = web thickness, in.

NOTE: If \( \frac{1}{2} b - a < \) centerline distance between adjacent wheels, then the load P is equal to the maximum single wheel load without considering the effect of the adjacent wheel. Conversely, if \( \frac{1}{2} b - a \geq \) centerline distance between adjacent wheels, then the loading of the two adjacent wheels shall be combined into a single load.

(c) The localized stresses due to local bending effects imposed by wheel loads calculated at Points 0 and 1 are to be combined with the stresses due to Case 2 loading specified in CM-2.1.2 of this specification.

When calculating the combined stress, the flange bending stresses shall be diminished to 75% of the value calculated per (b) above.

The combined stress value (\( \sigma_t \)) obtained by the method prescribed in (g) below shall not exceed the allowable Case 2 stress level of 0.66\( \sigma_y \), where \( \sigma_y \) = yield strength of the material.

(d) Additionally, in the case of welded plate girders only, the localized stresses on the top side of the flange at the flange-to-web transition (Point 2) shall be combined with the stresses due to the Case 2 loading specified in CM-2.1.2 of this specification.

The combined stress value (\( \sigma_v \)) in the weld at Point 2 obtained by the method prescribed in (g) below shall not exceed the allowable weld stress specified in CM-2.1.5.4.1, nor shall the stress range in the weld exceed the value specified in Table CM-2.1.6.4.1-1 for joint category E.
(e) The local flange bending criteria per CM-2.1.6.2.3 shall be met in addition to the general criteria of CM-2.1.2 and CM-2.1.6.1.

(f) At transfer points, consideration should be given to lower flange stresses that are not calculable by the formulae presented in CM-2.1.6.2.3.

(g) Combined Stresses. Where a state of combined plane stresses exists, the reference stress, $\sigma_t$, can be calculated from the following formula:

$$\sigma_t = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \sigma_y + 3 \tau_{xy}^2} \leq \sigma_{all} \quad (40)$$

where

$\sigma_{all}$ = allowable stress, psi
$\sigma_x, \sigma_y$ = normal stress in respective $x$ and $y$ directions, psi
$\tau_{xy}$ = shear stress in plane, psi

For welds, the maximum combined stress, $\sigma_v$, shall be calculated as follows:

$$\sigma_v = \frac{1}{2} (\sigma_x + \sigma_y) \pm \frac{1}{2} \sqrt{(\sigma_x - \sigma_y)^2 + 4 \tau_{xy}^2} \leq \sigma_{all} \quad (41)$$

See NUM Appendix A-2 for a lower flange bending calculation example.
CM-2.1.6.2.4 Shear and Tension of Bolts

(a) Bolts subject to combined shear and tension shall be so proportioned that the tension stress, in psi, produced by forces applied to the connected parts, shall not exceed the allowable tension value, $\sigma_{at}$.

For A325 bolts in bearing-type joints:

$$\sigma_{at} = 55,000R - 1.8\tau \leq 44,000R \quad (42)$$

For A490 bolts in bearing-type joints:

$$\sigma_{at} = 68,000R - 1.8\tau \leq 54,000R \quad (43)$$

For other bolting materials in bearing-type joints:

$$\sigma_{at} = 0.6\sigma_yR - 1.6\tau \quad (44)$$

where $\tau$ (the shear stress produced by the same forces) shall not exceed the value for the shear given in CM-2.1.6.1.5. The variable $\sigma_y$ is the yield stress (the proof stress may be used). $R$ is given in Table CM-2.1.6.2.4-1.

### Table CM-2.1.6.2.4-1 Bolt Shear and Tension Factor, R

<table>
<thead>
<tr>
<th>Principal</th>
<th>Additional</th>
<th>Extraordinary</th>
<th>Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.33</td>
<td>1.50</td>
</tr>
</tbody>
</table>

(b) For bolts used in friction-type joints, the shear stress ($\tau_a$) allowed in CM-2.1.6.1.5 shall be reduced so that

For A325 bolts:

$$\tau_a \leq 15,000\left(1 - \frac{\sigma \sigma_{A_h}}{T_b}\right) \quad (45)$$

For A490 bolts in bearing-type joints:

$$\tau_a \leq 20,000\left(1 - \frac{\sigma \sigma_{A_h}}{T_b}\right) \quad (46)$$

where

$A_b = $ the tensile stress area, in$^2$

$T_b = $ the specified pre-tension load of the bolt, lb.

$\sigma = $ the average tensile stress due to a direct load applied to all of the bolts in a connection, psi

In friction-type joints, the allowable shear stress shall not be increased due to environmental conditions.

CM-2.1.6.2.5 Shear and Bending. The maximum combined shear stress due to shear, bending, and direct stresses shall not exceed the allowable values for shear as given in CM-2.1.6.1.1.

CM-2.1.6.3 Buckling

CM-2.1.6.3.1 Local Buckling or Crippling of Flat Plates. The structural design of the crane to avoid local buckling of plates shall conform to ASME NOG-1, paras. NOG-4331 through NOG-4332.1.

CM-2.1.6.3.2 Proportion for Fabricated Box Girders. The ratio of $l/h$ shall not exceed 25; the ratio of $l/b$ shall not exceed 60; and the ratio of $b/t$ shall not exceed

$$\sqrt{\frac{(2.62 \times 10^7)K_a}{\sigma_p}} \times \frac{2}{DFB} \quad (operating \ condition)$$

(where $b$ is the unsupported plate width between longitudinal stiffeners, webs, or cover plate) or

$$30.99 \sqrt{\frac{K_a}{\sigma_p}} \quad (operating \ condition \ for \ A36 \ steel)$$

where

$b = $ distance between web plates, in.

$DFB = $ design factor for buckling (See Table CM-2.1.6.3.2-1)

$h = $ depth of web, in.

$K_a = $ buckling coefficient compression (See Table CM-2.1.6.3.2-2)

$l = $ span, in.

$t = $ thickness of web plate, in.

$\sigma_p = $ proportional limit (assumed at $\sigma_y/1.32$)

### Table CM-2.1.6.3.2-1 Design Factor for Buckling, DFB

<table>
<thead>
<tr>
<th>Crane Loading Condition</th>
<th>Design Factor DFB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal</td>
<td>$2 \times 0.3(\beta - 1) \geq 1.40$</td>
</tr>
<tr>
<td>Additional</td>
<td>$2 \times 0.3(\beta - 1) \geq 1.40$</td>
</tr>
<tr>
<td>Extraordinary</td>
<td>$1.5 + 0.125(\beta - 1) \geq 1.25$</td>
</tr>
<tr>
<td>Extreme</td>
<td>$1.35 + 0.075(\beta - 1) \geq 1.20$</td>
</tr>
</tbody>
</table>
CM-2.1.6.3.3 Spacing of Transverse Stiffener. The spacing of the transverse stiffeners, \(a\), in., shall not exceed the amount given by the formula

\[
a = \frac{11.068t}{\sqrt{\tau c}}
\]  

(47)

where

- \(c\) = spacing coefficient (see Table CM-2.1.6.3.3-1 below)
- \(t\) = thickness of the web plate, in.
- \(\tau\) = shear stress in plate, psi

nor shall it exceed 72 in., or \(h\), the depth of the web whichever is greater.

<table>
<thead>
<tr>
<th>Loading Condition</th>
<th>Spacing Coefficient, (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating</td>
<td>1</td>
</tr>
<tr>
<td>Construction</td>
<td>1</td>
</tr>
<tr>
<td>Severe environment</td>
<td>0.75</td>
</tr>
<tr>
<td>Extreme</td>
<td>0.6</td>
</tr>
</tbody>
</table>

CM-2.1.6.3.4 Stiffness of Longitudinal and Transverse Stiffeners. The required stiffness of the longitudinal stiffener and the stiffness of the transverse stiffeners shall be in accordance with CMAA 74.

CM-2.1.6.3.5 Girder Deflection. The total vertical deflection of the girder during operational loading for the rated live load plus trolley \((P_{\text{at}} + P_{\text{cn}})\), and not including impact or dead load of the girder, shall not exceed \(1/600\) of the span.

The total vertical or lateral deflection of the girder during environmental loading shall be limited such that displacements do not cause the girder or any of its attachments to become dislodged or to leave the crane.

CM-2.1.6.3.6 Girder Camber. Girders shall be cambered an amount equal to the dead load deflection, plus \(1/2\) of the deflection caused by the live load, plus trolley \([\text{camber} = \Delta (P_{\text{at}}) + 0.5(P_{\text{at}} + P_{\text{cn}})]\).

CM-2.1.6.4 Fatigue Requirements. If the owner determines that more than 20,000 full-load cycles are required, the owner shall specify the cycles and load class per CM-2.1.6.4.1. The allowable stresses for the appropriate service level shall be used, but shall not exceed the basic operating stress allowables specified in CM-2.1.6.1.

CM-2.1.6.4.1 Allowable Stress Range, Repeated Loads. Members and fasteners subject to repeated loads shall be designed so that the stress range (maximum stress minus minimum stress) does not exceed allowable values for various categories as listed in Table CM-2.1.6.4.1-1. The minimum stress is considered as negative if it is opposite in sign to the maximum stress. The categories are described in Table CM-2.1.6.4.1-2 with joint configuration illustrations shown in Fig. CM-2.1.6.4.1-1. The allowable stress range shall be based on the condition most nearly approximated by the description and illustration.
### Table CM-2.1.6.3.2-2 Value of the Buckling Coefficients, $K_\sigma$ and $K_\tau$, for Plates Supported at Their Four Edges

<table>
<thead>
<tr>
<th>No.</th>
<th>Case</th>
<th>$\alpha = \frac{a}{b}$</th>
<th>$K_\sigma$ or $K_\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Simple uniform compression: $\sigma_1 = \sigma_2$</td>
<td>$\sigma \geq 1$</td>
<td>$K_\sigma = \left(\frac{1}{\alpha} + 1\right)^2$</td>
</tr>
<tr>
<td></td>
<td>$\sigma &lt; 1$</td>
<td>$K_\tau = \frac{\alpha}{\beta + 1.1}$</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Nonuniform compression: $0 &lt; \beta \leq 1$</td>
<td>$\sigma \geq 1$</td>
<td>$K_\sigma = \frac{8.4}{\beta + 1.1}$</td>
</tr>
<tr>
<td></td>
<td>$\sigma &lt; 1$</td>
<td>$K_\tau = \frac{\alpha}{\beta + 1.1} \cdot \frac{2.1}{\beta + 1.1}$</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Pure bending, $\beta = -1$ or bending with tension preponderant, $\beta &lt; -1$</td>
<td>$\alpha \geq \frac{\pi}{2}$</td>
<td>$K_\sigma = 23.9$</td>
</tr>
<tr>
<td></td>
<td>$\alpha &lt; \frac{\pi}{2}$</td>
<td>$K_\tau = 15.87 + \frac{1.87}{\alpha^2} + 8.8\alpha^2$</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Bending with compression preponderant, $-1 &lt; \beta &lt; 0$</td>
<td></td>
<td>$K_\sigma = (1 + \beta)K' - \beta K'' + 10\beta(1 + \beta)$ where $K'$ = value of $K_\sigma$ for $\beta = 0$ in Case No. 2 $K''$ = value of $K_\tau$ for pure bending (Case No. 3)</td>
</tr>
<tr>
<td>5</td>
<td>Pure shear</td>
<td>$\alpha \geq 1$</td>
<td>$K_\sigma = \frac{5.34 + \frac{4}{\alpha^2}}{\sqrt[3]{\alpha}}$</td>
</tr>
<tr>
<td></td>
<td>$\alpha &lt; 1$</td>
<td>$K_\tau = \left(\frac{5.34}{\alpha} \right)^{\frac{1}{3}}$</td>
<td></td>
</tr>
</tbody>
</table>

**GENERAL NOTE:** The definitions of $K_\sigma$ and $K_\tau$ are in this Table and depend on the ratio $\alpha = a/b$ of the two sides of the plate, the manner in which the plate is supported along its edges (simply supported), and the type of loading sustained by the plate. For other cases than those covered by this Table, further appropriate analysis should be made.

### Table CM-2.1.6.4.1-1 Allowable Stress Ranges

<table>
<thead>
<tr>
<th>CMAA Service Class</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>63</td>
<td>49</td>
<td>35</td>
<td>28</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>B</td>
<td>50</td>
<td>39</td>
<td>28</td>
<td>22</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>37</td>
<td>29</td>
<td>21</td>
<td>16</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>D</td>
<td>31</td>
<td>24</td>
<td>17</td>
<td>13</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

**GENERAL NOTE:** Allowable stress ranges from CMAA 74.

**NOTE:**
1. Stress range values are independent of material yield stress.
Table CM-2.1.6.4.1-2 Fatigue Stress Provisions – Tension (T) or Reversal (Rev) Stresses (Part 1 of 2)

<table>
<thead>
<tr>
<th>General Condition</th>
<th>Situation</th>
<th>Joint Category</th>
<th>Example of a Situation [Note (1)]</th>
<th>Kind of Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain material</td>
<td>Base metal with rolled or cleaned surfaces. Oxygen-cut edges with ANSI smoothness of 1,000 or less</td>
<td>A</td>
<td>1, 2</td>
<td>T or Rev</td>
</tr>
<tr>
<td>Built-up members</td>
<td>Base metal and weld metal in members without attachments, built up, of plates or shapes connected by continuous complete or partial joint penetration groove welds or by continuous fillet welds parallel to the direction of applied stress</td>
<td>B</td>
<td>3, 4, 5, 7</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>Calculated flexural stress at toe of transverse stiffener welds on girder webs or flanges</td>
<td>C</td>
<td>6</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>Base metal at end of partial length welded cover plates having square or tapered ends, with or without welds across the ends</td>
<td>E</td>
<td>7</td>
<td>T or Rev</td>
</tr>
<tr>
<td>Groove welds</td>
<td>Base metal and weld metal at complete joint penetration groove welded splices of rolled and welded sections having similar profiles when welds are ground and weld soundness established by UT or RT examination</td>
<td>B</td>
<td>8, 9</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>Base metal and weld metal in or adjacent to complete joint penetration groove welded splices at transitions in width or thickness, with welds ground to provide slopes no steeper than 1 to 2 ½ and weld soundness established by UT or RT examination</td>
<td>B</td>
<td>10, 11</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>Weld metal or partial penetration transverse groove welds based on effective throat area of the weld or welds</td>
<td>F</td>
<td>17</td>
<td>T or Rev</td>
</tr>
<tr>
<td>Groove welds</td>
<td>Base metal and weld metal in or adjacent to complete joint penetration groove welded splices either not requiring transition or when required with transitions having slopes no greater than 1 to 2 ½ and when in either case reinforcement is not removed and weld soundness is established by UT or RT examination</td>
<td>C</td>
<td>8, 9, 10, 11</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>Base metal and weld metal at complete joint penetration groove welded splices of sections having similar profiles or at transitions in thickness to provide slopes no steeper than 1 to 2 ½ with permanent backing bar parallel to the direction of stress when welds are ground and weld soundness established by UT or RT examination. Backing bar is to be continuous, and, if spliced, is to be joined by a full-penetration butt weld. Backing bar is to be connected to parent metal by continuous welds along both edges, except intermittent welds may be used in regions of compression stress</td>
<td>B</td>
<td>19, 20</td>
<td>...</td>
</tr>
<tr>
<td>Groove-welded connections</td>
<td>Base metal at details of any length attached by groove welds subjected to transverse or longitudinal loading, or both, when weld soundness transverse to the direction of stress is established by UT or RT examination, and the detail embodies a transition radius, R, with the weld termination ground when</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(a) for longitudinal loading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24 in. ≥ R ≥ 6 in.</td>
<td>B</td>
<td>13</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>6 in. &gt; R ≥ 2 in.</td>
<td>C</td>
<td>13</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>2 in. &gt; R ≥ 0</td>
<td>D</td>
<td>13</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>(b) for transverse loading, materials having equal or unequal thickness sloped, welds ground web connections excluded</td>
<td>E</td>
<td>12, 13</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>24 in. ≥ R ≥ 6 in.</td>
<td>B</td>
<td>13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>6 in. &gt; R ≥ 2 in.</td>
<td>C</td>
<td>13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>2 in. &gt; R ≥ 0</td>
<td>D</td>
<td>13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>(c) for transverse loading, materials having equal thickness, no ground, web connections excluded</td>
<td>E</td>
<td>12, 13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>24 in. ≥ R ≥ 6 in.</td>
<td>C</td>
<td>13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>6 in. &gt; R ≥ 2 in.</td>
<td>C</td>
<td>13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>2 in. &gt; R ≥ 0</td>
<td>D</td>
<td>13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>(d) for transverse loading, materials having unequal thickness, not sloped or ground, including web connections</td>
<td>E</td>
<td>13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>24 in. ≥ R ≥ 6 in.</td>
<td>E</td>
<td>13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>6 in. &gt; R ≥ 2 in.</td>
<td>E</td>
<td>13</td>
<td>T or Rev</td>
</tr>
</tbody>
</table>
### Table CM-2.1.6.4.1-2  Fatigue Stress Provisions – Tension (T) or Reversal (Rev) Stresses (Part 2 of 2)

<table>
<thead>
<tr>
<th>General Condition</th>
<th>Situation</th>
<th>Joint Category</th>
<th>Example of a Situation [Note (1)]</th>
<th>Kind of Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Groove-welded or fillet-welded connections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Base metal at details attached by groove or fillet welds subject to longitudinal loading where the detail embodies a transition radius, $R$, less than 2 in., and when the detail length, $L$, parallel to the line of stress is</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$L \leq 2$ in.</td>
<td>C</td>
<td>12, 14, 15, 16, 18</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>$2 \text{ in.} &lt; L \leq 4$ in.</td>
<td>D</td>
<td>12, 18</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>$L &gt; 4$ in.</td>
<td>E</td>
<td>12, 18</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td><strong>Fillet-welded connections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Base metal at details attached by fillet welds or partial penetration groove welds parallel to the direction of stress, regardless of length, when the detail embodies a transition radius, $R$, 2 in. or greater and with the weld termination ground. When</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$R \geq 24$ in.</td>
<td>B</td>
<td>13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>$24 \text{ in.} &gt; R &gt; 6$ in.</td>
<td>C</td>
<td>13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>$6 \text{ in.} \geq R &gt; 2$ in.</td>
<td>D</td>
<td>13</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>Base metal at junction of axially loaded members with fillet-welded end connections. Welds shall be disposed about the axis of the member so as to balance weld stresses</td>
<td>E</td>
<td>21, 22, 23</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td><strong>Fillet welds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shear stress on throat of fillet welds</td>
<td>F</td>
<td>21, 22, 23, 24, 25, 26, 27, 28</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Base metal at intermittent welds attaching transverse stiffeners and stud-type shear connectors</td>
<td>C</td>
<td>7, 14</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>Base metal at intermittent welds attaching longitudinal stiffeners or cover plates</td>
<td>E</td>
<td>7, 29</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td><strong>Stud welds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shear stress on nominal shear area of stud-type shear connectors</td>
<td>F</td>
<td>14</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td><strong>Plug and slot welds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Base metal adjacent to or connected by plug or slot welds</td>
<td>E</td>
<td>30</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>Shear stress on nominal shear area of plug or slot welds</td>
<td>F</td>
<td>30, 31</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td><strong>Mechanically fastened connections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Base metal at gross section of high-strength bolted friction-type connections, except connections subject to stress reversal and axially loaded joints that induce out-of-plane bending in connected material</td>
<td>B</td>
<td>32</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>Base metal at net section of other mechanically fastened joints</td>
<td>D</td>
<td>33</td>
<td>T or Rev</td>
</tr>
<tr>
<td></td>
<td>Base metal at net section of high-strength bolted bearing connections</td>
<td>B</td>
<td>32, 33</td>
<td>T or Rev</td>
</tr>
</tbody>
</table>

**NOTE:**

(1) Example numbers are from CMAA 74.
CM-2.1.6.5 Hardness. The minimum Brinell hardness (BHN) of the lower load-carrying (tension) flange shall be 195 for patented track systems. For A36 material, the normal hardness produced by normal mill processing shall be sufficient.

CM-2.1.6.6 Stability. The crane shall be stable under all loading conditions. A factor of safety of 1.5 shall be provided against the combination of loads producing maximum overturning forces.
CM-2.1.7 Component Design

CM-2.1.7.1 Footwalks, Handrails, Platforms, Stairs and Ladders

CM-2.1.7.1.1 General. Platforms and footwalks shall be provided as required for access and maintenance. Dimensions and clearances for footwalks, handrails, platforms, stairs, and ladders shall be in accordance with the latest edition of ASME B30.17.

CM-2.1.7.1.2 Design. Footwalks, handrails, platforms, stairs, and ladders shall be designed for the appropriate dead load and the live loads as specified in ASME B30.17. Structural design shall be in accordance with CM-2.1.6.

CM-2.1.7.2 Operator’s Cab (When Specified)

CM-2.1.7.2.1 General

(a) The general arrangement of the cab and the location of the control and protective equipment shall be such that all operating control devices are within convenient reach of the operator when facing the area to be served by the load block or when facing the direction of travel of the cab. The operator’s cab shall be open type for indoor service unless otherwise specified.

(b) The cab shall be clear of all fixed structures within its area of possible movement. Clearances shall be in accordance with the latest edition of ASME B30.17. The cab shall be so located as not to interfere with the hook approach.

(c) The arrangement of equipment in the cab should be approved by the owner.

(d) Cabs shall be designed for maximum operator visibility. The arrangement of the cab should allow the operator a full view of the load block in all positions. A visibility diagram shall be furnished to the owner for approval when requested.

(e) The operator’s cab shall have a clear height, with equipment installed, of not less than 7 ft, except where dimensional interferences or other design considerations require the use of a smaller cab. Cab heights of less than 7 ft shall be approved by the owner, and in no case shall be less than 5 ft.

 Provision shall be made in the operator’s cab for all necessary equipment, wiring, and fittings. All cabs should be provided with a swivelled seat unless otherwise specified.

(f) There shall be means of egress from cab-operated cranes to permit departure under emergency conditions, at any cab location.

CM-2.1.7.2.2 Materials. Materials for construction of the operator’s cab shall meet the requirements of CM-2.1.5.

CM-2.1.7.2.3 Design. The operator’s cab shall be designed for dead and live loads as specified by the owner. Structural design shall be in accordance with CM-2.1.6.

CM-2.1.7.2.4 Construction

CM-2.1.7.2.4.1 General. Cabs shall be constructed in accordance with ASME B30.17.

CM-2.1.7.2.4.2 Enclosed Cabs. Enclosed cabs shall have watertight plate roofs that slope to the rear, and shall be provided with sliding, hinged, or drop windows on the three sides, and with sliding or hinged doors. Steel plates for enclosing sides, when used, shall not be less than 1/8 in. thick. Window sash shall be equipped with clear, shatterproof glass installed from the inside so that if it is dislodged it will fall in the cab.

 Drop windows shall be protected from breakage by a 1/8-in. sheet steel guard, extending to within 2 in. of the floor, and shall be provided with handles and stops, which will prevent catching the operator’s hands or toes when operating the windows. Drop windows shall be counterweighted.

CM-2.1.7.2.4.3 Open Cabs. Open cabs shall be enclosed with panels not less than 1/8 in. thick or standard railing 42 in. high. Railing enclosures shall be provided with midrail and steel toe plate. Where the top rail, or top panel, interferes with the operator’s vision, it may be lowered, with the owner’s approval.

CM-2.2 ADDITIONAL REQUIREMENTS SPECIFIC TO UNDERHUNG CRANES

CM-2.2.1 Allowable Deflections and Cambers

CM-2.2.1.1 Miscellaneous Structure Deflection. Deflections of components such as end ties, end trucks, trolley load bars, and auxiliary beams shall not impair the functions for which they were designed or cause any attachments to the crane to become dislodged or leave the crane.

CM-2.2.1.2 Girder Deflection. The maximum vertical deflection of the girder produced by the bridge dead load, trolley dead load (including hoist dead weight) and design rated load shall not exceed 1/600th of the span. Impact need not be considered in determining deflection. For interlocking cranes, the deflection shall not exceed 1/1000 of the span.

CM-2.2.1.3 Girder Camber. Where girders are cambered, the recommended amount of camber is equal to the bridge dead load deflection, plus ½ of the deflection caused by the trolley dead load (including hoist dead weight), plus ½ of the deflection caused by the design rated load. Girder camber and deflection...
shall be considered when determining vertical clearances.

**CM-2.2.2 Component Design**

**CM-2.2.2.1 Girders, Beams, or Tracks.**
Girders may be standard rolled beams, patented shape track, or plate girders. Where necessary, auxiliary girders shall be used to support overhanging loads to
minimize torsional moments on and lateral deflections of the girder. The analysis required for girders shall be in accordance with CM-2.1. On spans longer than 16 ft, the ratio of span to top flange width shall not exceed 60 to 1.

**CM-2.2.2.2 End Trucks.** The crane bridge shall be carried on end trucks designed to carry the rated loads when lifted at one end of the crane bridge (closest approach). Load combinations and basic allowable stresses shall be in accordance with CM-2.1.2 and CM-2.1.6.1. The wheel base of the outermost wheels shall be 1/8 of the span or greater.
End trucks may be of the rotating-axle or fixed-axle type. Provisions shall be made to prevent a drop of the crane not more than 1 in. in the case of axle failure. When appropriate, equalizer bridge trucks shall be incorporated to promote sharing of the bridge wheel loads. Equalizer pins shall be provided between equalizer truck and equalizer beams and/or rigid bridge structures. A rail sweep shall be provided in front of each outside wheel. End trucks shall be in accordance with applicable sections of CM-2.1.

**CM-2.3 ADDITIONAL REQUIREMENTS SPECIFIC TO TOP-RUNNING BRIDGE AND GANTRY CRANES**

**CM-2.3.1 Allowable Deflections and Cambers**

**CM-2.3.1.1 Structure Deflection.**
Deflections of components such as end ties, end trucks, trolley load bars and auxiliary beams shall not impair the functions for which they were designed or cause any attachments of the crane to become dislodged or leave the crane.

**CM-2.3.1.2 Girder Deflection.** The maximum vertical deflection of the girder produced by the bridge dead load, trolley dead load (including hoist dead weight), and the design rated load shall not exceed 1/600 of the span. Vertical inertia forces need not be considered in determining deflection. For interlocking cranes, the deflection shall not exceed 1/1000th of the span.

**CM-2.3.1.3 Girder Camber.** Where girders are cambered, the recommended amount is equal to the bridge dead load deflection, plus ½ of the deflection caused by the trolley dead load (including hoist dead weight), plus ½ of the deflection caused by the design rated load. Girder camber and deflection shall be considered when determining vertical clearance.

**CM-2.3.2 Component Design**

**CM-2.3.2.1 Girders, Beams or Tracks.**
Girders may be standard rolled beams, patented shape track, or plate girders. Where necessary, auxiliary girders shall be used to support overhanging loads to
minimize torsional moments on and lateral deflections of the girder. The analysis required for girders shall be in accordance with CM-2.1. On spans longer than 16 ft, the ratio of span to top flange width shall not exceed 60 to 1.

**CM-2.3.2.2 End Trucks.** The crane bridge shall be carried on end trucks designed to carry the rated load when lifted at one end of the crane bridge (closest approach). Load combinations and basic allowable stresses shall be in accordance with CM-2.1.2 and CM-2.1.6.1. The wheel base of the outermost wheels shall be 1/8 of the span or greater.
End trucks may be of the rotating-axle or fixed-axle type. Provisions shall be made to prevent a drop of the crane not more than 1 in. in the case of axle failure. When appropriate, equalizer bridge trucks shall be incorporated to promote sharing of the bridge wheel loads. Equalizing pins shall be provided between equalizer truck and equalizer beams and/or rigid bridge structures. A rail sweep shall be provided in front of each outside wheel and shall project below the top of the runway rail. End trucks shall also be in accordance with applicable sections of CM-2.1.

**CM-2.3.3 Wind Loads.** Gantry structures shall be designed to withstand wind-loading conditions as specified by the owner. If loads are not specified, a load of 30 lb/ft$^2$ on the projected area, under nonoperating conditions, is to be used. For through-leg gantries, a check is to be made using a 5-lb/ft$^2$ wind loading with the lifted load at the end of the bridge.

**CM-2.4 ADDITIONAL REQUIREMENTS SPECIFIC TO TRAVELLING WALL CRANES**

**CM-2.4.1 Allowable Boom Deflections.**
The maximum vertical deflection of the boom and its end tie structure produced by the boom dead load, the trolley dead load (including the hoist dead weight), and the design rated load shall not exceed 1/600 of the span. When a motorized trolley is specified, the allowable vertical deflection may be increased up to 1/225 of the span. Impact shall not be considered in determining deflection.

**CM-2.4.2 Component Design**

**CM-2.4.2.1 Booms.** Crane booms may be fabricated with standard rolled beams and reinforced
with angles, channels or plates as necessary. Auxiliary members may be of standard shapes, structural tube, or fabricated plates. Structural analysis shall be in accordance with Section CM-2.

CM-2.4.2.2 End Tie Structure.

(a) End tie structural may be fabricated with standard rolled shapes, structural tube, or plate and reinforced with the same. Structural analysis shall be consistent with the requirements of Section CM-2.

(b) Loads induced from drive mechanisms, acceleration and braking, motor stall, bumper stops, and varying loads from a swinging boom, where used, shall be considered.

CM-2.4.2.3 Braces and Secondary Members. Braces and secondary members may be fabricated of standard rolled beams, angles, tees, rods, structural tube, or other structural shapes. They shall be analyzed in accordance with Section CM-2.

CM-2.5 ADDITIONAL REQUIREMENTS SPECIFIC TO JIB CRANES.

CM-2.5.1 Allowable Deflections and Cambers

CM-2.5.1.1 Jib Boom Deflection. The maximum vertical deflection of the boom produced by the boom dead load, the trolley dead load (including the hoist dead weight), and the design rated load shall not exceed 1/600 of the span. When a motorized trolley is specified, the allowable vertical deflection may be increased up to 1/225 of the span. Impact shall not be considered in determining deflection.

CM-2.5.1.2 Miscellaneous Structure Deflection. In the case of jib cranes that are self-supporting (such as freestanding or mast-type) the entire structure shall not produce a deflection greater than that given in CM-2.5.1.1.

CM-2.5.2 Component Design.

CM-2.5.2.1 Jib Booms, Beams or Tracks. Jib booms may be standard rolled beams and reinforced with angles, channels, or plates. Where necessary, auxiliary members shall be used to act as bracing when a full cantilever is not used.

CM-2.5.2.2 Columns, Posts, or Masts. Columns may be standard rolled beams, plate girders, structural tube, or structural pipe, and reinforced with angles, channels or plates. Structural analysis shall be consistent with the requirements of CM-2.1.

CM-2.5.2.3 Braces and Secondary Members. Braces and secondary members may be fabricated of standard rolled beams, angles, tees, rods and structural tube, or other structure shapes. They shall be analyzed in accordance with CM-2.1.

CM-2.6 ADDITIONAL REQUIREMENTS SPECIFIC TO MONORAIL SYSTEMS.

CM-2.6.1 Allowable Deflections and Cambers

CM-2.6.1.1 Miscellaneous Structure Deflection. Deflections of components such as end ties, end trucks, and auxiliary beams shall not impair the functions for which they were designed or cause any attachments to the crane to become dislodged or leave the crane.

CM-2.6.1.2 Monorail Beam Deflection. The maximum vertical deflection of the monorail beam produced by the beam dead load, the trolley dead load (including the hoist dead weight), and the design rated load shall not exceed 1/600th of the span between supports. Impact need not be considered in determining deflection.

CM-2.6.1.3 Monorail Camber. Where monorail beams are cambered, the recommended amount of camber is equal to the beam dead load deflection, plus ½ of the deflection caused by the trolley dead load (including hoist dead weight), plus ½ of the...
deflection caused by the design rated load. Monorail beam camber and deflection shall be considered when determining vertical clearance.

CM-2.6.2 Component Design.

CM-2.6.2.1 Girders, Beams, or Tracks. Girders may be standard rolled beams, patented shape track or plate girders. Where necessary, auxiliary girders shall be used to support overhanging loads to minimize torsional moments on and lateral deflections of the girder. The analysis required for girders shall be in accordance with Section CM-2. On spans longer than 16 ft., the ratio of span to top flange width shall not exceed 60 to 1.

CM-2.6.2.2 Track Joints. Web-type or other suitable couplings shall be provided at all track joints. The maximum gap between ends of the load carrying flange shall not exceed 1/16 in.

CM-2.6.2.3 Monorail Curves. Monorail curves shall be of such radius as to permit operation of the carrier without binding.

CM-2.6.2.4 Building Expansion Joints. Where a track system crosses building expansion joints, provision shall be made to accommodate for differential expansion of the building and track.

CM-2.6.3 Inertia Forces from Drives. The inertia forces occur during acceleration or deceleration of trolley motion and depend on the driving and braking torques applied by the drive units and brakes during each cycle. These loads are longitudinal to the monorail only. This load shall be taken as 10% of the combined trolley dead load and the rated load.

CM-2.6.4 Allowable Stresses and Wheel Loads.

CM-2.6.4.1 Lower Load-Carrying (Tension) Flange. The allowable stress in the lower load-carrying (tension) flange shall be 20% of the minimum ultimate strength of the material used.

CM-2.6.4.2 Compression Flange. The allowable stress in the compression flange shall be determined per Section CM-2.

CM-2.6.4.3 Allowable Wheel Loads. Allowable wheel loads shall take into account the stress imposed on the lower load-carrying flange when a carrier transfers from one track to another. Where track sections are diagonally cut at transfers, the wheel loads shall be limited by the stress imposed on the lower carrying flange.

CM-2.6.5 Monorail Supports

(a) Monorail beams shall be fastened to a supporting structure.
(b) All clamps, hanger roads, bolts or other suspension fittings and supporting structures shall be designed to withstand the loads and forces imposed by the cranes or carriers.
(c) Where multiple hanger rods are used at a suspension point, consideration shall be given to the unequal load induced in the rods.
(d) Means shall be provided to restrain the track against damaging lateral and longitudinal movement.
(e) Where the track is suspended from hanger rod assemblies, restraining means shall be provided to prevent the hanger rod nuts from backing off the hanger rods.
(f) All monorail beam supports shall conform to the minimum design parameters as specified in Section CM-2 and the AISC Manual of Steel Construction.
CM-3.1 GENERAL

This section covers the mechanical requirements and criteria common to all Type I cranes and monorails. Requirements for hoists and trolleys are covered under NUM Part-HT.

CM-3.1.1 Lubrication Subject to Radiation. If the crane is subjected to radiation, the lubricants shall resist the effects of gamma or neutron radiation or provisions shall be made for changing the lubricants. If lubricants cannot be conveniently replaced, then lubricants shall be National Lubrication and Grease Institute (NLGI) Grade 0 oil containing molybdenum disulfate or NLGI Grade 1.5 grease with sodium aluminate thickener. Lubricants shall be oxidation and rust inhibited with the exception of lubricants for wire rope.

CM-3.1.2 Design and Performance Criteria

CM-3.1.2.1 Allowable Stresses. Load-carrying parts, except structural members and gears, shall be designed such that the calculated static stress in the material, based on rated load, shall not exceed 20% of the published average ultimate strength of the material. Castings, forgings, stampings, and fasteners shall be designed with allowable stress not to exceed 20% of the minimum ultimate strength of the material.

CM-3.1.2.2 Service Factors. All load combinations and factors including stress concentrations shall have service factors as stated for the design of specific mechanical components, as indicated in CM-3.1.4.

CM-3.1.2.3 Seismic Analysis

CM-3.1.2.3.1 Criteria. Analyses shall be performed to ensure retention of the load during a seismic event. In addition, analysis shall confirm that those mechanical components that, if dislodged, would damage safety-related equipment shall remain in place during the seismic event.

CM-3.1.2.3.2 Component Analysis (>33 Hz). Components whose major resonant frequency is greater than 33 Hz may be modeled as a lumped mass.

(a) Analysis shall consist of the determination of the stress level of the mounts when applying maximum dynamic forces to the center of gravity of the item.

(b) Loads due to vertical and horizontal motions shall act together and shall be combined in accordance with CM-2.1.3.

CM-3.1.2.3.3 Component Analysis (<33 Hz). Components whose major resonant frequency is less than 33 Hz shall be analyzed dynamically. The component shall be represented by a generalized three-dimensional system of nodes. The model’s geometry shall reflect the overall size, length, connectivity, and stiffness of the various structural members. An appropriate element representation of each member shall be used to describe all components that contribute significantly to the stiffness.

CM-3.1.2.3.4 Allowable Stresses for Fasteners. Seismic loads shall induce stresses that, when combined with appropriate dead and live loads, do not exceed 90% of the yield strength of the fastener.

CM-3.1.3 Component Design

CM-3.1.3.1 Bridge Drives. Single failure-proof features are generally not required for bridge travel systems. However, in those cases where failure of a component could result in an owner-specified facility unacceptable motion, the design shall incorporate single failure-proof features to ensure that the bridge is brought to a safe stop.

Reference specific bridge sections (Sections CM-3.2 through CM-3.6) for acceptable bridge drive arrangements. Where required, bridge drive motors shall be selected in accordance with Section CM-4.

CM-3.1.3.2 Brakes

CM-3.1.3.2.1 Bridge and Jib Brakes. On all powered cranes, one of the following braking means with a thermal capacity suitable for the frequency of operation shall be provided for bridge or jib.

(a) A spring-set, friction-type brake with the following characteristics:

(1) Brakes shall be provided with adjustment to compensate for wear.

(2) If holding brakes are provided, they shall have a torque rating of at least 50% of the rated motor torque and be adjustable to a minimum of 25% of the rated motor torque.

(b) A noncoasting mechanical drive that is capable of stopping the motion of the bridge within a distance in feet equal to 10% of full-load speed in feet per minute when traveling at full speed with full load.

CM-3.1.3.2.2 Emergency and Parking Brakes. Emergency and parking brakes shall be provided for bridge drives and for jib crane slew drives. Any combination of service, emergency, and parking functions may be performed by a single friction brake, provided the emergency and parking
functions can be obtained without having power available.

**CM-3.1.3.3 Bumpers and Stops**

**CM-3.1.3.3.1 Bumper Design**

(a) Bridge bumpers shall be provided.
(b) Bumpers shall be designed and installed to minimize parts falling from the crane in case of breakage.
(c) For two cranes on the same runway, bumpers shall be designed and installed so that no other part of either crane will come in contact when the two cranes come together.
(d) Bumpers shall have the energy-absorbing (or energy-dissipating) capacity to stop the crane when traveling with power off in either direction at a speed of at least 40% of the rated-load speed. The bumpers shall also be capable of stopping the crane (not including the lifted load) at a rate of deceleration not to exceed an average of 3 ft/sec when traveling with power off in either direction at 20% of rated-load speed.

**CM-3.1.3.3.2 Stop Design**

(a) Runway stops shall be provided and shall be located at the limits of the bridge travel, such that no part of the crane (with bumper fully compressed) will encroach upon the required clearance specified in GR-2.1.1.
(b) Runway stops shall be attached to withstand the force applied when contacted.
(c) Runway stops engaging the tread of the wheel shall not be used for motorized cranes.

**CM-3.1.3.4 Couplings.** Couplings shall be selected for the torque and alignment requirements at the point of application. Solid couplings shall be steel or minimum ASTM A48, Class 40 cast iron or equal material.

**CM-3.1.3.5 Mounting of Bridge Drive Components**

(a) Drive components, such as motors and gear reducers, shall not be mounted on multiple support structures, which can deflect relative to each other, unless the design specifically allows for this deformation.
(b) Drive components whose alignment is important to their operation shall not depend on friction, but shall use positive means, such as dowel pins, shear bars, or fitted bolts, to maintain alignment.
(c) Mechanical component connections shall be designed to accommodate all dynamic forces, such as those induced by motor starting and braking applications.

**CM-3.1.3.6 Guards**

(a) Exposed moving parts, such as couplings, gears, setscrews, projecting keys, chains, chain sprockets, and reciprocating components, that may constitute a hazard under normal operating conditions shall be guarded.
(b) Guards shall be securely fastened.
(c) Each guard shall be capable of supporting, without permanent deformation, a weight of 200 lb, unless the guard is located where it is not probable for a person to step on it.

**CM-3.1.4 General Mechanical Components**

**CM-3.1.4.1 Gearing.** Gearing shall be designed and manufactured in accordance with the procedures presented by the American Gear Manufacturers Association (AGMA).

When worm gearing is specified, it shall be rated with appropriate service factors. Consideration shall be given to lock up when selecting gear ratios for travel drives.

**CM-3.1.4.1.1 Materials.** All gears and pinions shall be constructed of steel or other material of adequate strength and durability to meet the requirements for the intended class of service and manufactured to AGMA quality class 5 or better.

**CM-3.1.4.1.2 Allowable Strength and Durability Horsepower.** The horsepower rating for all spur, helical, and herringbone gearing shall be based on ANSI/AGMA 2001-D04C95. For the purpose of this Standard, the horsepower formulas are as follows:

\[
P_{at} = \frac{N_p d}{126,000} \times \frac{FS_{at}}{K_p K_m P_{d} J_{fr} F_{r}} \quad (48)
\]

\[
P_{ac} = \frac{N_p F I}{126,000K_p K_m I_{fr} F_{r}} \times \left(\frac{S_{ac} d C_h}{C_p}\right)^2 \quad (49)
\]

where

- $C_h$ = hardness factor (durability)
- $C_p$ = elastic coefficient
- $d$ = pitch diameter of pinion, in.
- $F$ = net face width of the narrowest of the mating gears, in.
- $I$ = geometry factor (durability)
- $J$ = geometry factor (strength)
- $K_B$ = rim thickness factor
- $K_m$ = load distribution factor
- $K_d$ = dynamic factor
- $N_p$ = pinion speed, rpm
- $P_{ac}$ = allowable durability horsepower
- $P_{at}$ = allowable strength horsepower
- $P_t$ = transverse diametral pitch, 1/in.
- $S_{at}$ = allowable bending stress for material, psi (strength)
- $S_{ts}$ = crane service factor (strength)
The values for $K_v$, $K_m$, $K_B$, $C_p$, $J$, $I$, $S_{ac}$, and $S_{af}$ can be determined from the tables and curves in ANSI/AGMA 2001-D-04C95, $S_r$ from Table CM-3.1.4.1.2-1; and the remaining values will be physical characteristics pertaining to the gears for their operation characteristics.

Crane service factor $S_{fd}$ shall be determined from the formula $S_{fd} = C_d \times K_w$. For values of specific $K_w$, refer to eq (50), and for $C_d$, which is the machinery service factor, refer to Table CM-3.1.4.1.2-2.

$$K_w = \frac{2(\text{maximum load}) + (\text{minimum load})}{3(\text{maximum load})} \quad (50)$$

### Table CM-3.1.4.1.2-1 Crane Class Factors for Strength Horsepower Rating, $S_{fs}$

<table>
<thead>
<tr>
<th>Crane Class</th>
<th>$S_{fs}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.75</td>
</tr>
<tr>
<td>B</td>
<td>0.85</td>
</tr>
<tr>
<td>C</td>
<td>0.90</td>
</tr>
<tr>
<td>D</td>
<td>0.95</td>
</tr>
</tbody>
</table>

**GENERAL NOTE:** Crane Class Factors for Strength Horsepower Rating, $S_{fs}$, from CMAA 74.

### Table CM-3.1.4.1.2-2 Machinery Service Factor, $C_d$

<table>
<thead>
<tr>
<th>Class of Service</th>
<th>$C_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.64</td>
</tr>
<tr>
<td>B</td>
<td>0.72</td>
</tr>
<tr>
<td>C</td>
<td>0.80</td>
</tr>
<tr>
<td>D</td>
<td>0.90</td>
</tr>
</tbody>
</table>

**GENERAL NOTE:** Machinery service factor, $C_d$, from CMAA 74.

### CM-3.1.4.3 Bridge Drive Shafts

#### CM-3.1.4.3.1 General

Drive shafting shall be designed for the maximum wheel load in combination with the maximum torque load.

#### CM-3.1.4.3.2 Material

All shafts, except the bridge cross-shaft sections, that do not carry gears, shall be of cold-rolled shafting quality or equivalent.

#### CM-3.1.4.3.3 Bearing Spacing for Rotating Shafts

The bearing spacing for rotating shafts less than 400 rpm shall not exceed that calculated per the following equation:

$$L = \sqrt{432,000D^2} \quad (51)$$

where

- $D = \text{shaft diameter, in.}$
- $L = \text{distance between bearing centers, in.}$

When the shaft speed exceeds 400 rpm, the bearing spacing shall not exceed that determined by the following formula or the preceding formula, whichever is less, in order to avoid objectionable vibration at critical shaft speeds.

$$L = \sqrt{\frac{4,760,000D^{1.2}}{N}} \quad (52)$$

where

- $N = \text{maximum shaft speed, rpm}$
of brake torque. When significant stresses are produced by other forces, these forces shall be positioned to provide the maximum stresses at the section under consideration. Impact shall not be included.

(a) Static Stress Check for Operating Conditions

(1) For shafting subjected to axial loads, the stress shall be calculated as follows (for shafting not limited by buckling):

\[ \sigma = \frac{P}{A} \]  \(53\)

where

- \(A\) = cross-sectional area of shaft, in.\(^2\)
- \(P\) = total axial load, lb.

This axial stress shall not exceed \(S_u/5\).

(2) For shafting loaded in bending, the stress shall be calculated as follows:

\[ \sigma = \frac{Mr}{I} \]  \(54\)

where

- \(I\) = bending moment of inertia at point of examination
- \(M\) = bending moment at point of examination, in.-lb.
- \(r\) = outside radius of shaft at point of examination, in.

This bending stress shall not exceed \(S_u/5\).

(3) For shafting loaded in torque, the shear stress shall be calculated as follows:

\[ \tau = \frac{T_r}{J} \]  \(55\)

where

- \(J\) = polar moment of inertia of shaft at point of examination
- \(T\) = torque at point of examination, in.-lb.

This shear stress shall not exceed \(S_u/(5\sqrt{3})\).

(4) Transverse shear stress in shafting shall be calculated as follows:

For solid shaft:

\[ \tau = \frac{1.33V}{A} \]  \(56\)

where

- \(A\) = cross-sectional area at point of examination, in.\(^2\)
- \(V\) = shear load at point of examination, lb.

For hollow shafts

\[ \tau = \frac{2V}{A} \]  \(57\)

These shear stresses shall not exceed \(S_u/(5\sqrt{3})\).

(5) When combinations of stresses are present on the same element, they shall be combined as follows:

For axial and bending stresses:

\[ \sigma = \sigma_1 + \sigma_2 + \sigma_3 \ldots + \sigma_n \]

and shall not exceed \(S_u/5\).

For shear stresses:

\[ \tau = \tau_1 + \tau_2 + \tau_3 \ldots + \tau_n \]

and shall not exceed \(S_u/(5\sqrt{3})\).

For axial and bending with shear

\[ \sigma_t = \sqrt{\sigma^2 + 3\tau^2} \]  \(58\)

and shall not exceed \(S_u/5\).

Note that bending and torsional stresses are maximum on the outer fibers of the shaft and must be combined. The transverse shear stresses are maximum at the center of the shaft and do not combine with bending or torsional stresses.

(b) Fatigue Stress Check for Fluctuating, Operating Stresses. Any shafting subjected to fluctuating stresses, such as bending in rotating shafts or the torsion in reversing drives, shall be checked for fatigue. This check shall be performed at points of geometric discontinuity where stress concentrations exist, such as fillets, holts, keys, press fits, etc. Pure stresses shall be calculated using appropriate stress...
multiplication factors. The allowable stresses are as follows:

(1) Tensile and bending stress
\[ \sigma K_t \leq \frac{S_e}{K_c} \quad (59) \]

(2) Shear and combined shear
\[ \tau K_s \leq \frac{S_e}{K_c \sqrt{3}} \quad (60) \]

(3) For combined stresses, where all of the shear and bending are fluctuating
\[ \sigma_t = \sqrt{(K_s \sigma)^2 + 3(K_s \tau)^2} \leq \frac{S_e}{K_c} \quad (61) \]

(4) For combined shear and bending, where only part of the stresses are fluctuating
\[ \sigma_t = \left[ \left( \frac{K_s \sigma}{S_e} \right)^2 + 3 \left( \frac{K_s \tau}{S_e} \right)^2 \right] \leq \frac{S_{yp}}{K_c} \quad (62) \]

where
- \( K_c \): crane class factor (see Table CM-3.1.4.3.5-1)
- \( K_s \): stress amplification factor
- \( K_{sc} \): surface condition factor (see Table CM-3.1.4.3.5-2)
- \( K_t \): stress amplification factor for tension or bending
- \( S_e \): endurance strength of shaft material = 0.36 \( Su'K_{sc} \), psi
- \( Su' \): minimum ultimate tensile strength of shaft material, psi
- \( S_{yp} \): minimum yield strength of shaft material, psi
- \( \sigma_{av} \): that part of the bending stress not due to fluctuating loads, psi
- \( \sigma_r \): that part of the bending stress due to fluctuating loads, psi
- \( \tau_{av} \): that part of the shear stress not due to fluctuating loads, psi
- \( \tau_r \): that part of the shear stress due to fluctuating loads, psi

<table>
<thead>
<tr>
<th>Table CM-3.1.4.3.5-1, Crane Class Factor ( K_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crane Class</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
</tbody>
</table>

GENERAL NOTE: Crane class factor, \( K_c \), from CMAA 74.

(c) Bearing Stress in Shafts. Shafting in bearings shall be checked for operating conditions. The bearing stress is calculated by dividing the radial load by the projected area
\[ P / (dL) \]

where
- \( d \): the shaft diameter, in.
- \( L \): the length in bearing, in.

This bearing stress shall not exceed 50% of the minimum yield for non-rotating shafting.
This bearing stress shall not exceed 20% of the minimum yield for oscillating shafting when not limited by the bushing material.

CM-3.1.4.4 Wheel Assembly

CM-3.1.4.4.1 Top-Running Bridge Wheel Design

(a) Unless other means of restricting lateral movement are provided (such as side rollers), wheels shall be double flanged with treads accurately machined. Bridge wheels may have either straight treads or tapered treads assembled with the large diameter toward the center of the span. Drive wheels shall be machined in pairs within 0.001 in./in. of diameter with a maximum of 0.010 in. on the diameter, whichever case is smaller.

(b) Sizing of Wheels and Rails. Wheels shall be designed to carry the maximum wheel load under normal conditions without undue wear. The maximum wheel load is that wheel load produced with the trolley handling the rated load in the position to produce the maximum reaction at the wheel, not including impact. When sizing wheels and rails, the following parameters shall be considered:

- \( D \): wheel diameter, in.
- \( K \): hardness coefficient of the wheel
  - \( = BHN \times 5 \) (for wheels with \( BHN < 260 \))
  - \( = 1300(BHN/260)^{0.33} \) (for wheels with \( BHN > 260 \))
- \( W \): effective rail head width, in.

The bridge and trolley durability wheel loadings for different wheel hardnesses and sizes in combination with different rail sizes are shown in Table CM-3.1.4.4.1-1. The values in the table are established by the product of \( KDW \).
(c) To use Table CM-3.1.4.4.1-1, first determine the equivalent durability wheel load $P_e$.

$$P_e = \text{maximum wheel load} \times K_{rw}$$

$$K_{rw} = K_{sw} C_S S_m$$

(d) Load factor $K_{bw}$ can be determined as follows:

$$K_{bw} = \frac{0.75(BW) + f(LL) + 0.5(TW) - 0.5f(TW)}{0.75(BW) + 1.5f(LL)}$$  \hspace{1cm} (63)

where

- $BW$ = bridge weight, lb.
- $f$ = X/span (see Fig. CM-3.1.4.4.1-1)
- $LL$ = trolley weight + rated load, lb.
- $TW$ = trolley weight, lb.

See Table CM-3.1.4.4.1-2

(e) The speed factor, $C_S$, depends on the rotational speed of the wheel and is listed in Table CM-3.1.4.4.1-3. These factors are obtained from the following formulas:

For rpm $\leq 31.5$

$$C_S = \left[1 + \left(\frac{rpm - 31.5}{360}\right)^2\right]$$  \hspace{1cm} (64)

For rpm > 31.5

$$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$$  \hspace{1cm} (65)

(f) The wheel service factor, $S_m$, is equal to 1.25 times the machinery service factor, $C_S$, and is shown in table CM-3.1.4.4.1-4. This factor recognizes that the interaction between rail and wheel is more demanding in terms of durability than well-aligned and lubricated interaction of machined parts.

(g) The wheel load service coefficient is

$$K_{wl} = K_{bw} C_S S_m$$

and $K_{wl}$ may not be smaller than the $K_{wl}$ minimum shown in Table CM-3.1.4.4.1-4.

(h) The equivalent durability wheel load, $P_e$, shall not exceed the wheel load in Table CM-3.1.4.4.1-1.

(i) Proper Clearance for Bridge Wheels. A total of approximately ¾ in. to 1 in. wider than the rail head is the proper clearance. Tapered tread wheels may have a clearance over the rail head of 150% of the clearance provided for straight tread wheels.

(j) When rotating axles are used, wheels shall be mounted on the axle with press fit alone, press fit and keys, or keys alone.

Table CM-3.1.4.4.1-1  Bridge Wheel Loadings, lb; P: KDW

<table>
<thead>
<tr>
<th>Wheel BHN</th>
<th>Wheel Diameter, D. in.</th>
<th>ASCE 20 lb</th>
<th>ASCE 25 lb</th>
<th>ASCE 30 lb</th>
<th>ASCE 40 lb</th>
<th>ASCE 40 lb</th>
<th>ASCE 60 lb</th>
<th>ASCE 70 lb</th>
<th>ASCE 80 lb</th>
<th>ASCE 80 lb</th>
<th>ASCE 80 lb</th>
<th>ASCE 80 lb</th>
<th>BETH 100 lb</th>
<th>BETH 100 lb</th>
<th>BETH 100 lb</th>
<th>BETH and USS 135 lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td></td>
<td>4,200</td>
<td>5,000</td>
<td>5,300</td>
<td>...</td>
<td>...</td>
<td>...</td>
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<td></td>
<td>5,500</td>
<td>6,500</td>
<td>6,900</td>
<td>...</td>
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<td>...</td>
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<td>58 RC</td>
<td></td>
<td>7,300</td>
<td>8,650</td>
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</tr>
<tr>
<td>615 BHN</td>
<td></td>
<td>8,750</td>
<td>10,350</td>
<td>11,000</td>
<td>12,950</td>
<td>...</td>
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<td>...</td>
</tr>
</tbody>
</table>

GENERAL NOTE: Bridge wheel loadings, lb: P, KDW from CMAA 74.

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)

For rpm > 31.5

$C_S = 1 + \left(\frac{rpm - 31.5}{328.5}\right)$  \hspace{1cm} (65)
Table CM-3.1.4.4.1-2 Bridge Load Factor, $K_{bw}$

<table>
<thead>
<tr>
<th>Bridge Span, ft</th>
<th>Capacity, ton</th>
<th>3</th>
<th>5</th>
<th>7.5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td></td>
<td>0.812</td>
<td>0.782</td>
<td>0.762</td>
<td>0.747</td>
<td>0.732</td>
<td>0.722</td>
<td>0.716</td>
<td>0.716</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>0.817</td>
<td>0.785</td>
<td>0.767</td>
<td>0.750</td>
<td>0.736</td>
<td>0.725</td>
<td>0.718</td>
<td>0.718</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>0.827</td>
<td>0.794</td>
<td>0.777</td>
<td>0.760</td>
<td>0.744</td>
<td>0.732</td>
<td>0.723</td>
<td>0.723</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>0.842</td>
<td>0.809</td>
<td>0.791</td>
<td>0.771</td>
<td>0.758</td>
<td>0.740</td>
<td>0.738</td>
<td>0.731</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>0.861</td>
<td>0.830</td>
<td>0.807</td>
<td>0.790</td>
<td>0.773</td>
<td>0.754</td>
<td>0.747</td>
<td>0.741</td>
</tr>
<tr>
<td>70</td>
<td></td>
<td>0.877</td>
<td>0.844</td>
<td>0.825</td>
<td>0.807</td>
<td>0.789</td>
<td>0.768</td>
<td>0.760</td>
<td>0.752</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>0.888</td>
<td>0.857</td>
<td>0.835</td>
<td>0.818</td>
<td>0.802</td>
<td>0.779</td>
<td>0.770</td>
<td>0.761</td>
</tr>
</tbody>
</table>

GENERAL NOTES:
(a) $K_{bw}$ based on worst case with trolley against stop.
(b) Bridge load factor, $K_{bw}$, from CMAA 74.

Table CM-3.1.4.4.1-3 Speed Factor, $C_s$

<table>
<thead>
<tr>
<th>Wheel Diameter, in.</th>
<th>Speed, ft/min</th>
<th>30</th>
<th>50</th>
<th>75</th>
<th>100</th>
<th>125</th>
<th>150</th>
<th>175</th>
<th>200</th>
<th>250</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td>0.952</td>
<td>1.020</td>
<td>1.078</td>
<td>1.136</td>
<td>1.194</td>
<td>1.252</td>
<td>1.310</td>
<td>1.368</td>
<td>1.485</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>0.932</td>
<td>1.001</td>
<td>1.049</td>
<td>1.089</td>
<td>1.146</td>
<td>1.194</td>
<td>1.243</td>
<td>1.291</td>
<td>1.388</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>0.907</td>
<td>0.958</td>
<td>1.013</td>
<td>1.049</td>
<td>1.086</td>
<td>1.122</td>
<td>1.158</td>
<td>1.195</td>
<td>1.267</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>0.898</td>
<td>0.944</td>
<td>1.001</td>
<td>1.033</td>
<td>1.066</td>
<td>1.098</td>
<td>1.130</td>
<td>1.163</td>
<td>1.227</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>0.892</td>
<td>0.932</td>
<td>0.984</td>
<td>1.020</td>
<td>1.049</td>
<td>1.079</td>
<td>1.108</td>
<td>1.137</td>
<td>1.195</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>0.882</td>
<td>0.915</td>
<td>0.958</td>
<td>1.001</td>
<td>1.025</td>
<td>1.049</td>
<td>1.074</td>
<td>1.098</td>
<td>1.146</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>0.872</td>
<td>0.898</td>
<td>0.932</td>
<td>0.967</td>
<td>1.001</td>
<td>1.020</td>
<td>1.040</td>
<td>1.059</td>
<td>1.098</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>0.865</td>
<td>0.887</td>
<td>0.915</td>
<td>0.944</td>
<td>0.973</td>
<td>1.001</td>
<td>1.017</td>
<td>1.033</td>
<td>1.066</td>
</tr>
</tbody>
</table>

GENERAL NOTE: Speed factor, $C_s$, from CMAA 74.

Table CM-3.1.4.4.1-4 Wheel Service Factor, $S_m$, and Minimum Service Factor, $K_{wt}$

<table>
<thead>
<tr>
<th>Class of Crane Service</th>
<th>$K_{wt}$ min.</th>
<th>$S_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.75</td>
<td>0.80</td>
</tr>
<tr>
<td>B</td>
<td>0.75</td>
<td>0.90</td>
</tr>
<tr>
<td>C</td>
<td>0.80</td>
<td>1.00</td>
</tr>
<tr>
<td>D</td>
<td>0.85</td>
<td>1.12</td>
</tr>
</tbody>
</table>

GENERAL NOTE: Wheel service factor, $S_m$, and minimum load service factor, $K_{wt}$, from CMAA 74.

**CM-3.1.4.4.2 Under-Running Bridge Wheel Design**

(a) All under-running bridge truck wheels shall be designed to suit the surface on which they run. Drive wheels shall be the same diameter within a tolerance of 0.010 in.
(b) When flangeless wheels are used, they shall be provided with a side roller arrangement.
Wheels shall be designed to carry the maximum wheel load under normal conditions. The wheel load shown in Table CM-3.1.4.4.2-1 is that load produced with the trolley handling the rated load, in a position to exert the maximum load, not including impact. NOTE: A reduction in the allowable wheel load may be necessary to satisfy the runway lower flange stress requirements.

<table>
<thead>
<tr>
<th>Wheel Diameter, D, in.</th>
<th>Contour Tread, in [Note (1)]</th>
<th>Convex Tread, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W = ½</td>
<td>W = ¾</td>
</tr>
<tr>
<td></td>
<td>W = 1</td>
<td>W = 1 ½</td>
</tr>
<tr>
<td></td>
<td>W = 2</td>
<td>W = 2</td>
</tr>
<tr>
<td>4</td>
<td>2,000</td>
<td>2,400</td>
</tr>
<tr>
<td></td>
<td>4,000</td>
<td>3,600</td>
</tr>
<tr>
<td></td>
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<td>4,800</td>
</tr>
<tr>
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<td>2,500</td>
<td>3,000</td>
</tr>
<tr>
<td></td>
<td>5,000</td>
<td>4,500</td>
</tr>
<tr>
<td></td>
<td>10,000</td>
<td>6,000</td>
</tr>
<tr>
<td>6</td>
<td>3,000</td>
<td>3,600</td>
</tr>
<tr>
<td></td>
<td>6,000</td>
<td>5,400</td>
</tr>
<tr>
<td></td>
<td>12,000</td>
<td>7,200</td>
</tr>
<tr>
<td>7</td>
<td>3,500</td>
<td>4,200</td>
</tr>
<tr>
<td></td>
<td>7,000</td>
<td>6,300</td>
</tr>
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<td></td>
<td>14,000</td>
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<td></td>
<td>8,000</td>
<td>7,200</td>
</tr>
<tr>
<td></td>
<td>16,000</td>
<td>9,600</td>
</tr>
<tr>
<td>9</td>
<td>4,500</td>
<td>5,400</td>
</tr>
<tr>
<td></td>
<td>9,000</td>
<td>8,100</td>
</tr>
<tr>
<td></td>
<td>18,000</td>
<td>10,800</td>
</tr>
<tr>
<td>10</td>
<td>5,000</td>
<td>6,000</td>
</tr>
<tr>
<td></td>
<td>10,000</td>
<td>9,000</td>
</tr>
<tr>
<td></td>
<td>20,000</td>
<td>12,000</td>
</tr>
</tbody>
</table>

GENERAL NOTES:
(a) For contour tread, P (wheel load) = 1,000 WD, lb.
(b) For convex tread, P (wheel load) = 600 WD, lb.
(c) W = width of wheel tread exclusive of flange, in.; D = diameter of wheel, in.
(d) Charted values are based on wheels with BHN of 200. Larger wheel loads are obtainable with suitable material and with higher BHN.
(e) Maximum wheel loads/I beams and wide flange beams from CMAA 74.
NOTE: (1) Where wheel tread matches the rolling surface of the lower flange of the track beam.

CM-3.1.4.4.3 Material. Wheels shall be cast iron or rolled, forged, or cast steel with a minimum hardness of 200 BHN. For special applications, other materials may be used with permission of the owner and with consideration of hardness, impact strength, and brittleness.

CM-3.1.4.4.4 Bearings. Wheel bearings shall be single or double row, combination radial and thrust, anti-friction precision type. Bearings shall be prelubricated and sealed or provided with fittings and seals for pressure lubrication.

CM-3.1.4.4.5 Safety Lugs. All wheel sets shall have drop plates limiting the movement of the immediate structure to 1 in. in the event of axle or bearing failure.

CM-3.1.5 Miscellaneous

CM-3.1.5.1 Hand-Chain Wheels

(a) Hand-chain wheels shall have pockets formed to allow proper engagement of the hand chain.
(b) The wheels shall be equipped with a chain guide that will permit operation of the hand chain from an angle 10 deg out from either side of the chain wheel without slipping or jumping the wheel rim.
(c) All hand chains shall be guided to guard against disengagement from the hand-chain wheel.

CM-3.1.5.2 Hand Chains

(a) Hand chains shall be of the link-chain type. Each link shall be of uniform size and shape and have an accurate pitch to reliably pass over and around the hand-chain wheels.
(b) Hand chains shall be endless-link chain and shall have a drop that is approximately 2 ft above the operator’s floor level.
(c) Hand chains on booms without motorized rotation shall withstand, without permanent distortion, a force of three times the pull required to rotate the boom with a capacity load on the boom.

CM-3.2 ADDITIONAL DESIGN REQUIREMENTS SPECIFIC TO UNDERHUNG CRANES

CM-3.2.1 Bridge Drive. The bridge drive arrangements normally used with underhung bridge cranes are illustrated in Figs. CM-3.2.1-1 and CM-3.2.1-2. An underhung bridge has a minimum of four pairs of wheels and shall use a drive arrangement where at least one pair of wheels is driven on each end truck. Underhung bridges running on multiple runways may be driven by wheel pairs on two or more end trucks. End trucks may be driven by more than one wheel pair.

CM-3.2.1.1 Bridge Drive Arrangements

(a) A-2 Drive
(1) The motor is connected to a self-contained gear reducer unit located near the center of the bridge. The gear reducer is connected to a set of squaring shafts that in turn are connected to the end truck drive pinions. The pinions drive the geared section of the wheels.
(2) The motor is connected by chain and sprockets or through a self-contained reducer to a
squeezing shaft that in turn is connected to the axle of the rubber wheels at each bridge end truck. The rubber drive wheels are arranged to provide spring-loaded contact to the underside of the runway rail for traction drive.

**Figure CM-3.2.1-1** Arrangement of Crane Bridge Drives (A-2 Drive)

(b) A-4 Drive
(1) A mechanically independent drive is provided at each bridge end truck. The drive motor is directly connected to the integral self-contained gear reduction unit that in turn is connected to the drive pinion that drives the geared section of the bridge wheels.

(2) A mechanically independent drive is provided at each bridge end truck. The drive motor is directly connected to the integral self-contained gear reduction unit that in turn is connected to the axle of the rubber wheel. The rubber drive wheel is arranged to provide spring-loaded contact to the underside of the runway rail for traction drive.
CM-3.2.2 Bridge Interlocking Mechanisms

(a) Interlock mechanisms for underhung cranes shall maintain alignment between mating track sections and shall provide smooth trolley transfer across sections.

(b) Stops or forks shall be part of the interlock mechanisms to prevent the trolley from rolling off open track ends. When girders and spur tracks or transfer sections are aligned and interlock mechanisms are engaged, stops or forks shall be in the open position and permit transfer of the trolley. When girders and spurs or transfer tracks are not aligned and the interlock mechanisms are not engaged, stops or forks shall be in the closed position.
(c) Interlock mechanisms shall be designed to limit vertical misalignment to less than 1/8 in.

(d) Interlocking cranes and mating tracks shall have a gap of less than 1/4 in. between adjacent ends of the load-carrying flange.

CM-3.3 ADDITIONAL REQUIREMENTS SPECIFIC TO TOP-RUNNING BRIDGE AND GANTRY CRANES

CM-3.3.1 Bridge Drives for Top-Running Cranes. A top-running bridge has a minimum of four wheels and shall use a drive arrangement where at least one wheel is driven on each end truck.

CM-3.3.1.1 Bridge Drive Arrangements. Bridge drive arrangements normally used with top-running bridge cranes are illustrated in Figs. CM-3.3.1.1-1. CM-3.3.1.1-2 and CM-3.3.1.1-3.

(a) A-1 Drive (Figure CM-3.3.1.1-1). The motor is located near the center of the bridge span and is connected to a self-contained gear reduction unit, also located near the span center, that in turn is connected to a set of line shafts by solid or semiflexible couplings. Each line shaft is connected to a pinion at the end truck that meshes with the drive gear. Connecting couplings between line shaft and pinion are semiflexible. All other couplings, if required, are of the solid type.

(b) A-2 Drive (Figure CM-3.3.1.1-2). The motor is located near the center of the bridge span and connected by a flexible coupling to a self-contained gear reduction unit, also located near the span center, that in turn is connected to a set of line shafts by solid or semiflexible couplings. Each line shaft is connected to a pinion at the end truck that meshes with the drive gear. Connecting couplings between line shaft and pinion are semiflexible. All other couplings, if required, are of the solid type.

(c) A-4 Drive (Figure CM-3.3.1.1-3). Two mechanically independent drive arrangements are provided, one unit at each end truck of the bridge. Motors are connected to the gear reduction units that in turn are connected to the wheel axles.

CM-3.3.2 Bridge Drives for Gantry Cranes. For bridge drives on gantry cranes, the number of driven wheels shall be selected based on crane acceleration rates to prevent wheel skidding.

CM-3.3.3 Gantry Crane Drive Brakes. Each motorized drive on gantry cranes shall be provided with a suitable brake and sized as described in Section CM-3.
CM-3.4 ADDITIONAL DESIGN REQUIREMENTS SPECIFIC TO TRAVELLING WALL CRANES

CM-3.4.1 Wall Crane End Truck Configuration. The wall crane shall have vertical and horizontal end trucks and a cantilevered girder. The driven vertical truck may be top running with wheels on standard rails or underhung from the lower flange of an I-beam or patented track. The horizontal reaction idler trucks may be constructed similar to the vertical truck, top running or under running (see Fig. GR-6.2.3-1).

CM-3.4.2 End Truck Assembly. For the truck assembly drive, if the vertical wheels are top running, a minimum of two wheels shall be driven. If the vertical wheels are under running, a minimum of two pairs of wheels shall be driven.

CM-3.4.3 Wall Crane Drive Brakes. Each motorized drive shall be provided with a suitable brake, sized as described in Section CM-3.

CM-3.5 ADDITIONAL REQUIREMENTS SPECIFIC TO JIB CRANES

CM-3.5.1 Considerations for the Boom

(a) If the jib crane is subject to damage due to wind loading, a means shall be provided to tie down or restrain the boom during storage.

(b) If the jib crane’s boom is located 16 ft or more above the operating floor, or if the jib crane is subject to wind loading, the jib boom’s rotation should be hand-gear powered or motorized.

(c) If a jib rotation allows the boom to move into an area of facility unacceptable excursion, positive means to tie down or restrain the boom for storage shall be provided.

CM-3.5.2 Wall-Bracket-Type Jib Cranes. Rotational stops for the jib boom shall be specified by the owner, if required.

CM-3.5.3 Freestanding or Mast-Type Jib Cranes. Jib boom rotation shall be limited unless the power service connection provides for continuous rotation.

CM-3.6 ADDITIONAL REQUIREMENTS SPECIFIC TO MONORAIL SYSTEMS.

CM-3.6.1 Track

CM-3.6.1.1 Track Switch Types. Track switches shall be of the tongue, rotary, cross-track, or sliding type. Track switches shall maintain alignment of the incoming tracks and switch tracks with a maximum gap of 3/16 in. between adjacent ends of the load-carrying flanges. Switches may be operated by pull chains or ropes, manually, or by electric, pneumatic, or hydraulic operated devices.

CM-3.6.1.2 Track Switch Stops. Stops shall be provided as an integral part of the switch to protect the end of an incoming track when the switch track is not aligned with the incoming track. Stops shall resist the impact forces of a fully loaded carrier traveling at a speed of 150 ft/min or 50% of the full-load speed if the carrier is motor propelled. Guards shall also be provided to prevent a carrier on the movable track from running off the movable track when it is not engaged with an incoming track.

CM-3.6.1.3 Track Switch Holding. Means shall be provided to hold the movable frame in alignment during passage of carriers through the track switch.

CM-3.6.1.2 Track Openers. Track openers, when required, shall be specified by the owner. The gap between the adjacent track and the track opener shall be not more than 3/16 in. Forks or stops shall be provided to prevent a carrier from running off either of the open ends of the track when the movable section is not in alignment with the track.

CM-3.6.1.3 Vertical Drop or Lift Sections. Type I vertical drop or lift sections shall have structural, mechanical, and electrical components meeting the...
Type I requirements. The drop or lift section hoist shall be either a Type IA or Type IB hoist.

**CM-3.6.1.3.1 Alignment**

(a) Vertical drop or lift sections shall maintain alignment of the stationary tracks and the movable tracks with a maximum gap of 3/16 in. between adjacent ends of the load-carrying flanges.

(b) When sections are operated by electric, pneumatic, or hydraulic power, means shall be provided to limit the vertical travel for alignment of the movable track with the stationary tracks. Vertical misalignment between the movable track and stationary tracks shall not exceed 1/16 in.

**CM-3.6.1.3.2 Stops.** Stops shall be an integral part of the movable and stationary track and shall prevent a carrier from running off the open ends of the movable or stationary track when the movable track is not in alignment with the stationary tracks.
Section CM-4
Electrical, Cranes & Monorails (Type I)

CM-4.1 GENERAL

This section covers the electrical requirements and criteria common to all Type I cranes and monorails. Requirements for hoists and trolleys are covered under NUM Part-HT.

CM-4.1.1 Electrical Components

CM-4.1.1.1 Crane Controls. The type of control supplied for a traverse drive shall result in operation complying with the specified performance as defined in Section GR-3.

CM-4.1.1.1.1 Types of Control

(a) Common control systems may be one of the following:
   (1) Single-speed AC magnetic reversing, which uses an AC squirrel-cage induction motor (also see CM-4.1.1.1.2)
   (2) Two-speed AC magnetic reversing, which uses a dual-wound AC squirrel-cage induction motor. Speed ratios under any load are normally 3 to 1, but may also be furnished in other ratios, such as 2 to 1 or 4 to 1 (see also CM-4.1.1.1.2).
   (3) Variable-speed AC magnetic reversing, which is a type of constant potential AC control that uses resistance in the secondary of an AC wound rotor induction motor. Three to five speed steps are normally provided, with the speed at each step varying depending on the load.
   (4) AC variable-frequency control, which uses an AC squirrel-cage induction motor and provides either stepped or stepless speed control by varying the motor frequency (see CM-4.1.1.1.6).

(b) Other Control Systems. Other control systems, such as adjustable-voltage DC and adjustable voltage AC, may be required depending on the specific application or owner specifications.

CM-4.1.1.1.2 Cushioned Start Devices

(a) Cushioned start devices are used with single-speed and two-speed AC magnetic-reversing controls in order to control the rate of acceleration by limiting the starting voltage of the AC squirrel-cage induction motor.
(b) A cushioned start device should be used on single-speed and two-speed applications that require load swing to be minimized.
(c) Crane controls for a motorized boom shall have a cushioned start device or other controlled acceleration means.
(d) A cushioned start device shall be used for the following applications:
   (1) Single-speed drives greater than 100 ft/min
   (2) Two-speed drives greater than 100 ft/min that do not use a time delay between the two speeds.
   (e) Standard cushioned start devices are as follows:
      (1) Solid-state reduced-torque starters, which provide for the adjustment of the initial torque upon starting and adjustment of the time for reaching full motor torque
      (2) Ballast resistors, which limit the initial torque upon starting when the resistor is in the unheated condition
      (f) A nonelectrical cushioned start device, such as a fluid coupling, may also be used to minimize load swing.

CM-4.1.1.3 Time Delays

(a) All two-speed AC magnetic controls without cushioned starting should be provided with a time delay between the speed steps.
(b) All variable-speed AC magnetic controls shall be provided with time delays between the speed steps as follows:
   (1) For a three-step control, a time delay shall be provided between the last two speed steps.
   (2) For either a four-step or five-step control, two time delays shall be provided between the last three speed steps.

CM-4.1.1.4 Contactors

(a) Reversing and Speed Stepping Contactors. The minimum NEMA size of magnetic contactors shall be in accordance with Table CM-4.1.1.1.4-1 for AC wound rotor motors, Table CM-4.1.1.1.4-2 for AC squirrel-cage motors and Table CM-4.1.1.1.4-3 for DC motors.

Wound rotor primary contactors shall be selected to be not less than the current and horsepower ratings. Wound rotor secondary contactors shall be selected to be not less than the motor full-load secondary current, using contactor intermittent rating. The ampere intermittent rating of a three-pole secondary contactor with poles in delta shall be 1-1/2 times its wound rotor intermittent rating.

(b) Mainline Magnetic Contactors. When required, mainline magnetic contactors shall be sized in accordance with Table CM-4.1.1.1.4-4 for AC contactors and Table CM-4.1.1.1.4-5 for DC contactors. The size shall not be less than the rating of the largest primary contactor used on any one motion.

(c) Unless noted otherwise by the owner, definite purpose contactors, in lieu of NEMA-rated contactors, specifically rated for crane and hoist duty service may be used for service classes, A, B, and C provided the
application does not exceed the contactor manufacturers' published ratings.

### Table CM-4.1.1.4-1 AC Contactor Ratings for AC Wound Rotor Motors

<table>
<thead>
<tr>
<th>Size of Contactor</th>
<th>8-hr Open Rating, A</th>
<th>460 V and 575 V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A 250 V</td>
<td>A 200 V</td>
</tr>
<tr>
<td>0</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>30</td>
<td>7 ½</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>7 ½</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>133</td>
</tr>
</tbody>
</table>

GENERAL NOTE: AC contactor ratings for AC wound rotor motors from CMAA 74.

### Table CM-4.1.1.4-2 AC Contactor Ratings for AC Squirrel-Cage Motors (Maximum Intermittent Horsepower Rating)

<table>
<thead>
<tr>
<th>Size of Contactor</th>
<th>230 V</th>
<th>460 V and 575 V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>7 ½</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>[Note (1)] 25</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>[Note (1)] 50</td>
</tr>
</tbody>
</table>

GENERAL NOTE: AC contactor ratings for AC squirrel-cage motors from CMAA 74.

NOTE:
(1) Squirrel-cage motors over 20 hp are not normally used for crane motions.

### Table CM-4.1.1.4-3 DC Contactor Ratings for DC Motors (230V to 250VDC)

<table>
<thead>
<tr>
<th>Size of Contactor</th>
<th>8-hr Open Rating, A</th>
<th>Maximum Intermittent Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A hp</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>25</td>
<td>7 ½</td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>35</td>
</tr>
</tbody>
</table>

GENERAL NOTE: DC contactor ratings for DC motors from CMAA 74.

### Table CM-4.1.1.4-4 AC Contactor Ratings for Mainline Service

<table>
<thead>
<tr>
<th>Size of Contactor</th>
<th>8-hr Open Rating, A</th>
<th>Maximum Intermittent Duty Rating, A</th>
<th>Maximum Total Motor Horsepower</th>
<th>Maximum Horsepower for Any Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>230 V</td>
<td>460 V and 575 V</td>
<td>230 V</td>
<td>460 V and 575 V</td>
</tr>
<tr>
<td>0</td>
<td>20</td>
<td>20</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>1</td>
<td>30</td>
<td>30</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>67</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>133</td>
<td>63</td>
<td>125</td>
</tr>
</tbody>
</table>

GENERAL NOTE: AC contactor ratings for mainline service from CMAA 74.

### Table CM-4.1.1.4-5 DC Contactor Ratings for Mainline Service (230V to 250VDC)

<table>
<thead>
<tr>
<th>Size of Contactor</th>
<th>8-hr Open Rating, A</th>
<th>Maximum Intermittent Duty Rating, A</th>
<th>Maximum Total Motor Horsepower</th>
<th>Maximum Horsepower for Any Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>230 V</td>
<td>460 V and 575 V</td>
<td>230 V</td>
<td>460 V and 575 V</td>
</tr>
<tr>
<td>0</td>
<td>25</td>
<td>30</td>
<td>10</td>
<td>7 ½</td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>67</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>133</td>
<td>55</td>
<td>35</td>
</tr>
</tbody>
</table>

GENERAL NOTE: DC contactor ratings for mainline service from CMAA 74.
CM-4.1.1.1.5 Resistors

(a) Variable-speed AC magnetic controls that require use of resistors in the secondary circuit of the wound rotor motor shall be as follows:
(1) Not less than NEMA Class 150 Series for service classes A, B, and C.
(2) Not less than NEMA Class 160 Series for service classes D, E, and F.
(b) Additional considerations for increasing the resistor class are operating conditions such as sustained slow-speed operation.

(c) Secondary resistors are rated and classified according to the amount of time they can be in use and the percent of full-load current in the secondary circuit when on the first point of the variable-speed control. Table CM-4.1.1.1.5-1 shows the standard NEMA crane service resistor classifications based on current, torque, and duty cycle.
(d) All resistors shall be guarded to prevent inadvertent contact.
(e) All resistor enclosures shall be ventilated or sized to dissipate heat.

Table CM-4.1.1.1.5-1 NEMA Resistor Classification

<table>
<thead>
<tr>
<th>Approx. Percentage of Full Load Current on First Point</th>
<th>Starting Torque in Percentage of Full Load Torque</th>
<th>Class Number According to Duty Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 Phase Starting</td>
<td>3 Phase Starting</td>
</tr>
<tr>
<td>25</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>50</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>70</td>
<td>40</td>
<td>70</td>
</tr>
<tr>
<td>100</td>
<td>55</td>
<td>100</td>
</tr>
</tbody>
</table>

CM-4.1.1.1.6 AC Variable-Frequency Drives. The general requirements are as follows:
(a) Control shall consist of a variable-frequency drive (VFD) with a full load ampere (FLA) rating equal to, or greater than, the FLAs of the corresponding motor(s).
(b) Control shall include, as a minimum, the following protective features:
(1) output phase loss
(2) undervoltage
(3) overvoltage
(4) motor thermal overload
(5) VFD overheat
(c) Control shall provide a control braking means using dynamic braking or line regeneration.
(d) Control shall have a minimum of 150% overload capability for 1 min.
(e) The crane/jib power supply and electronic equipment shall be protected from detrimental effects due to harmonic and electromagnetic interference/radio frequency interference (EMI/RFI) emissions produced by inverters.

CM-4.1.1.2 Motors

CM-4.1.1.2.1 General

(a) Direct-Current Motors. DC motors shall be in accordance with either NEMA MG-1 or AISE Standard No.1.
(b) Alternating-Current Motors
(1) Definite-Purpose Inverter-Fed Motors. AC squirrel-cage motors applied to VFDs shall be specifically designed for inverter duty and shall conform to NEMA MG-1, Part 31, or other standard as approved by the owner.
(2) Definite-Purpose Wound Rotor Induction Motors. AC wound rotor motors shall conform to NEMA MG-1, Parts 18.501 through 18.520.
(3) Other AC Motors. All other AC motors not already described shall conform to NEMA MG-1.
(c) All AC or DC motors shall have enclosures and time ratings as required for the duty and environmental conditions.

CM-4.1.1.2.2 Motor Voltage

(a) Rated Voltage
(1) Standard rated motor voltage and the corresponding nominal system voltage shall be in accordance with Table CM-4.1.1.2.2-1.
(2) For nominal system voltage other than shown in Table CM-4.1.1.2.2-1, the rated motor voltage should not be less than 95% nor more than 100% of the nominal system voltage.
(b) Variation from Rated Voltage
(1) All AC induction motors with rated frequency and balanced voltage applied shall be capable of accelerating and running with the rated hook load at ±10% of rated motor voltage, but not necessarily at rated voltage performance values.
(2) Operation at reduced voltage may result in unsatisfactory drive performance with rated hook load, such as reduced speed, slower acceleration, increased motor current, noise, and heating.
(3) Operation at elevated voltages may result in unsatisfactory operation, such as excessive torques.
(c) Voltage Unbalance. AC polyphase motors shall be capable of accelerating and running with rated hook load when the voltage unbalance at the motor terminals does not exceed 1%. Performance will not necessarily be the same as when the motor is operating with a balanced voltage at the motor terminals.
### Table CM-4.1.1.2.2-1 Standard Rated Motor Voltages

<table>
<thead>
<tr>
<th>Power Supply</th>
<th>Nominal System, V</th>
<th>Rated Motor Voltages, V</th>
<th>Permissible Motor Operating Range, V</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC, single phase, 60 Hz</td>
<td>120</td>
<td>115</td>
<td>104 to 126</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>230</td>
<td>207 to 253</td>
</tr>
<tr>
<td>AC, polyphase, 60 Hz</td>
<td>208</td>
<td>200</td>
<td>180 to 220</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>230</td>
<td>207 to 253</td>
</tr>
<tr>
<td></td>
<td>480</td>
<td>460</td>
<td>414 to 506</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>575</td>
<td>518 to 632</td>
</tr>
<tr>
<td>AC, polyphase, 50 Hz</td>
<td>208</td>
<td>200</td>
<td>180 to 220</td>
</tr>
<tr>
<td></td>
<td>230</td>
<td>220</td>
<td>198 to 242</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>380</td>
<td>342 to 418</td>
</tr>
<tr>
<td>DC</td>
<td>125</td>
<td>115</td>
<td>104 to 126</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>230</td>
<td>207 to 253</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>240</td>
<td>216 to 264</td>
</tr>
</tbody>
</table>

#### CM-4.1.1.2.3 Motor Time Ratings.

The motor time rating shall result in operation complying with the specified performance as defined in Section GR-3, taking into consideration any supplemental requirements specified by the owner.

**Minimum Time Ratings.** Single-speed, two-speed and variable-speed motors shall be rated on no less than a 30-min basis under rated load, with the temperature rise in accordance with the class of insulation and enclosure used. The low-speed winding of a two-speed motor may be rated less than 30 min, and the lower stepping speeds of a variable-speed control will have a substantially lower operating time.

(b) Under unusual conditions, such as abnormal inching or jogging requirements, short repeated travel drive movements, altitudes more than 3,300 ft above sea level, abnormal ambient temperatures, etc., the motor time rating shall be increased accordingly.

#### CM-4.1.1.2.4 Traverse Motor Size Selection.

The traverse motor rating is basically the mechanical horsepower with considerations for the effect of control and ambient temperature.

**Required Motor Horsepower, Indoor Cranes**

(1) The bridge motor shall be selected so that the horsepower rating is not less than that given by the following formula:

\[
HP = K_a W V K_s
\]  

(66)

Where

- \( K_a \) = acceleration factor for type of motor used
- \( K_s \) = service factor, which accounts for the type of drive and duty cycle shall be as follows:
  - 1.0 (A, B, or C Crane Classes) for AC inverter, AC magnetic and DC adjustable-voltage controls
  - 1.1 (D Crane) for AC inverter, AC magnetic, and DC adjustable-voltage controls

**NOTE:** For other types of controls, consult control manufacturer.

\( V \) = rated drive speed, ft/min

\( W \) = total weight to be moved including all dead and live loads, ton

\[
K_a = \frac{f + 2000aC_r}{33,000K_t} \times \frac{N_r}{N_f} \quad (67)
\]

\[
C_r = 1.05 + \frac{a}{7.5} \quad (68)
\]

Where

- \( a \) = average or equivalent uniform acceleration rate, ft/sec² up to rated motor rpm (for guidance see Table CM-4.1.1.2.4-1 and CM-4.1.1.2.4-2)
- \( C_r \) = rotational inertia factor, for equipment governed by this standard.
- \( E \) = mechanical efficiency of drive machinery expressed as a per unit decimal (for guidance see Table CM-4.1.1.2.4-3)
- \( f \) = rolling friction of drive (including transmission losses, lb/ton; see Table CM-4.1.1.2.4-4)
- \( g = 32.2 \text{ ft/sec}^2 \)
- \( K_t \) = equivalent steady-state torque relative to rated motor torque, which results in accelerating up to rated motor rpm, \( N_r \), in the same time as the actual variable-torque speed characteristic used (see Table CM-4.1.1.2.4-5 for standard values of \( K_t \))
- \( N_f \) = free-running rpm of motor when driving at speed \( V \)
- \( N_r \) = rated speed of motor at full load, rpm

(2) Latitude is permitted in selecting the nearest rated motor horsepower over or 5% under the required horsepower to use commercially available motors. In either case, consideration shall be given to proper performance of the drive.

**Required Motor Horsepower, Outdoor Cranes**

(1) Compute the free-running bridge motor horsepower, \( HPF \), at rated load and rated speed, neglecting any wind load, using the following formula:

\[
HPF = \frac{W V f}{33,000} \quad (69)
\]

where

\( W \) = total weight to be moved including all dead and live loads, ton

\( V \) = rated drive speed, ft/min

\( f \) = rolling friction of drive (including transmission losses, lb/ton; see Table CM-4.1.1.2.4-4)
\( f \) = friction factor, lb/ton (per Table CM-4.1.1.2.4-4)  
\( V \) = full-load speed, ft/min  
\( W \) = full-load weight to be accelerated, ton

(2) Compute the free-running bridge motor horsepower due to wind force only \((HP_w)\) using the following formula:

\[
HP_w = \frac{P \times \text{wind area} \times V}{33,000E}
\]  
(70)

where  
\( E \) = bridge drive mechanical efficiency  
\( P \) = wind pressure, lb/ft\(^2\) [computed from the formula \( P = 0.00256(V_w)^2\), where \( V_w \) is the wind velocity, mph; when \( V_w \) is unspecified, \( P = 5\) lb/ft\(^2\) shall be used]  
wind area = effective crane surface area exposed to wind, ft\(^2\) (as computed in Section CM-2)

(3) The bridge drive motor shall be selected so that its horsepower rating is not less than the indoor horsepower rating required by (a)(1) above, or as given by the following formula, whichever is greater:

Required motor horsepower = 0.75\((HPF + HPw)K_s\)

(4) The following items shall be considered in the overall bridge drive design to ensure proper operation under all specified load and wind conditions:

-(-a) proper speed control, acceleration, and braking without wind

-(-b) ability of control to reach full-speed mode of operation against wind

-(-c) bridge speed, on any control point, when traveling with the wind, not to exceed the amount resulting in the maximum safe speed of the bridge drive machinery

-(-d) avoidance of wheel skidding that could likely occur under no load, low-percent driven wheels, and wind conditions.

-(-e) sufficient braking means to maintain the bridge braking requirements.

(c) Motor Selection Versus Drive Gear Ratio

(1) The drive gear ratio is computed by the following formula:

\[
\text{Bridge drive gear ratio} = \frac{N_f D_w \pi 12}{V}
\]  
(71)

where  
\( D_w \) = wheel tread diameter, in.  
\( N_f \) = free-running rpm of the motor, after the drive has accelerated, with rated load to the steady-state speed, \( V \) (the value of \( N_f \) is established from the motor control speed-torque curves at the free-running horsepower, \( HP FR \) )  
\( V \) = specified full-load travel drive speed, ft/min

(2) Variations from the calculated gear ratio are permissible to facilitate the use of standard available ratios, provided that motor heating and operational performance are not adversely affected.

The actual full-load drive speed may vary a maximum of +/- 10% from the specified full-load speed.

### Table CM-4.1.1.2.4-1 Standard Maximum Acceleration Rate to Prevent Wheel Skidding

<table>
<thead>
<tr>
<th>Percent of Driven Wheels</th>
<th>Maximum Acceleration Rate, Dry Rails, ft/sec(^2) (Based on 0.2 Coefficient of Friction)</th>
<th>Acceleration Rate, Wet Rails, ft/sec(^2) (Based on 0.12 Coefficient of Friction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>4.8</td>
<td>2.9</td>
</tr>
<tr>
<td>50</td>
<td>2.4</td>
<td>1.5</td>
</tr>
<tr>
<td>33.33</td>
<td>1.6</td>
<td>1.0</td>
</tr>
<tr>
<td>25</td>
<td>1.2</td>
<td>0.7</td>
</tr>
<tr>
<td>16.67</td>
<td>0.8</td>
<td>0.5</td>
</tr>
</tbody>
</table>

GENERAL NOTES:

- (a) Standard maximum acceleration rate to prevent wheel skidding from CMAA 74.
- (b) The values given above are based on the peak acceleration torque being equal to 1.33 times the average acceleration torque.

### Table CM-4.1.1.2.4-2 Standard Bridge Motion Acceleration Rates

<table>
<thead>
<tr>
<th>Free-Running Full-Load Speed</th>
<th>Acceleration Rate for AC or DC Motors, ( a ), ft/sec(^2) [Note (1)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft/min</td>
<td>ft/sec</td>
</tr>
<tr>
<td>60</td>
<td>1.0</td>
</tr>
<tr>
<td>120</td>
<td>2.0</td>
</tr>
<tr>
<td>180</td>
<td>3.0</td>
</tr>
<tr>
<td>240</td>
<td>4.0</td>
</tr>
<tr>
<td>300</td>
<td>5.0</td>
</tr>
</tbody>
</table>

GENERAL NOTES:

- (a) Standard bridge motion acceleration rates from CMAA 74.
- (b) The actual acceleration rates shall be selected to account for proper performance, including such items as acceleration time, free-running time, motor and resistor heating, duty cycle, load-spotting capability, and hook swing. (The acceleration rates shall not exceed the values shown in Table CM-4.1.1.2.4-3.) To avoid wheel skidding, the acceleration rate should not exceed the values shown in Table CM-4.1.1.2.4-1.

**NOTE:**

(1) For DC series motors, the acceleration rate, \( a \), is the value occurring while on series resistors. This would be in the range of 50% to 80% of the free-running speed (\( N \)).

### Table CM-4.1.1.2.4-3 Mechanical Efficiency, \( E \), of Drive Machinery

<table>
<thead>
<tr>
<th>Bearings</th>
<th>( E ) [Note (1)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antifriction</td>
<td>0.97</td>
</tr>
<tr>
<td>Sleeve</td>
<td>0.93</td>
</tr>
</tbody>
</table>

GENERAL NOTE: Mechanical efficiency, \( E \), of drive machinery from CMAA 74.

**NOTE:**

(1) The values of gear efficiency shown apply primarily to spur, herringbone, and helical gearing, and are not intended for special cases such as worm gearing, friction drives, chain drives, etc.
Table CM-4.1.1.2.4-4 Standard Values for Friction, $f$ (for Bridges with Metallic Wheels and Antifriction Bearings)

<table>
<thead>
<tr>
<th>Wheel Diameter, in.</th>
<th>$f$ to Running</th>
<th>Under Running</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>15</td>
<td>...</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>22</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>24</td>
</tr>
</tbody>
</table>

**GENERAL NOTES:**

(a) Standard values for friction factor, $f$, from CMAA 74.

(b) For crane equipped with sleeve bearings of normal proportions, a friction factor of 24 lb/ton may be used.

(c) The above friction factors may require modification for other variables, such as low-efficiency worm gearing, nonmetallic wheels, special bearings, and unusual rail conditions.

Table CM-4.1.1.2.4-5 Standard Values of Accelerating Torque Factor, $K_t$

<table>
<thead>
<tr>
<th>Type of Motor</th>
<th>Type of Control</th>
<th>$K_t$, [Note 1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC wound rotor</td>
<td>Contactor – resistor</td>
<td>1.3 – 1.5</td>
</tr>
<tr>
<td>AC wound rotor</td>
<td>Static stepless</td>
<td>1.3 – 1.5</td>
</tr>
<tr>
<td>AC squirrel cage</td>
<td>Ballast resistor</td>
<td>1.3</td>
</tr>
<tr>
<td>AC inverter</td>
<td>Inverter</td>
<td>1.5</td>
</tr>
<tr>
<td>DC shunt wound</td>
<td>Adjustable voltage</td>
<td>1.5</td>
</tr>
<tr>
<td>DC series wound</td>
<td>Contactor-resistor</td>
<td>1.35</td>
</tr>
</tbody>
</table>

**GENERAL NOTE:** Standard values of accelerating torque factor, $K_t$, from CMAA 74.

**NOTES:**

(1) $K_t$ is a function of control and/or resistor design.

(2) Low end of range should be used for applications with permanent slip resistance.

**CM-4.1.1.3 Brakes.** When electric brakes are used, brake selection, sizing and design shall be in accordance with the brake requirements of ASME B30.17, as applicable. The requirements of CM-3.1.3.2 shall also be met.

**CM-4.1.1.3.1 Electrical Operating and Excitation Systems.**

(a) The electrical operating and excitation systems shall have a thermal rating for the frequency and duration of the specified operations and the thermal time rating shall equal or exceed the corresponding drive-motor time rating.

(b) Any electrical traverse-drive brake used only for emergency stop on power loss, or set by operator choice, shall have a coil thermal rating for continuous duty.

(c) Brakes with DC shunt coils shall release at 80% and operate without overheating at 110% of the rated excitation system voltage.

(d) Brakes with AC coils shall release at 85% and operate without overheating at 110% of the rated excitation system voltage.

**CM-4.1.1.3.2 Parking Brakes.** Parking brakes shall be automatically applied. When two friction brakes are used on a single drive, a time delay means shall be provided to prevent simultaneous application of both brakes.

**CM-4.1.1.4 Disconnect and Protective Devices**

**CM-4.1.1.4.1 Disconnects.** All disconnects shall be in accordance with the requirements of NFPA 70, Article 610.

(a) Crane Overcurrent Protection. The crane shall be protected by a main overcurrent device in accordance with NFPA 70, Article 610. In many cases, the main manual disconnect and crane overcurrent devices are furnished as a single unit, being either a circuit breaker or fused disconnect.

(b) Branch Circuit Overcurrent Protection. Motor branch circuits shall be protected by fuses or inverse-time circuit breakers in accordance with NFPA 70, Article 610.

(c) Branch Circuit Overload Protection. Each motor, motor control, and branch circuit conductor shall be protected from overload in accordance with NFPA 70, Article 610.

(d) Undervoltage Protection. Undervoltage protection shall be provided as a function of each motor
controller, or an enclosed protective panel, or a magnetic mainline contactor, or a manual magnetic disconnect switch.

(e) Control circuits shall be protected in accordance with NFPA 70, Article 610.

CM-4.1.1.4.3 Control. Control shall include a separate disconnecting means for each crane/jib motion.

CM-4.1.1.5 Operator Stations and Controllers. The operator station shall use pendant push-button controllers, cab-operated master-switch controllers, or radio-transmitter lever-switch controllers. One or more operator stations may be provided, using either the same type or different types of controller, as required by the owner. The control station shall be clearly marked to indicate the function of the control device and indicator. The type of operator station and its location shall be specified by the owner.

CM-4.1.1.5.1 Pendant Pushbutton Controllers. Pendant pushbutton controllers shall meet the following requirements:

(a) The arrangement of the pendant pushbuttons shall conform to Fig. CM-4.1.1.5.1-1, unless otherwise required by the owner. The relative arrangements of the pushbuttons should be standardized at each facility.

(b) Pushbuttons shall return to the OFF position when pressure is released by the crane operator.

(c) Pendant stations shall have a grounding conductor between a ground terminal in the station and the crane.

(d) The maximum voltage in the pendant pushbutton stations shall be 150 VAC or 300VDC.

(e) Pushbuttons shall be guarded or shrouded to prevent accidental actual of crane motions.

(f) Pendant pushbutton stations shall be supported in a manner that will protect the electrical conductors against strain.

(g) Minimum wire size of multiconductor flexible cords for pendant push-button stations shall be #16 AWG unless otherwise permitted by NFPA 70, Article 610.

(h) Pendant control stations shall be constructed to prevent electrical shock.

(i) The location of the pendant push-button station controllers shall be one of the following:

(1) suspended from the hoist and trolley when the bridge, jib or monorail control is shared

(2) suspended from a festooned messenger track system

(3) suspended from a single point off the structure

(4) remote-mounted off the crane

CM-4.1.1.5.2 Cab-Operated Master-Switch Controllers. Cab-operated master-switch controllers shall meet the following requirements:

(a) The arrangement of cab master-switches shall conform to Fig. CM-4.1.1.5.2-1 unless otherwise required by the owner. Inappropriate controllers shall be deleted. The relative arrangement of the master-switches should be standardized at each owner’s location.

(b) Master-switches shall be within reach of the operator.

(c) Cab master-switches shall be provided with a notch or spring-return arrangement latch that in the OFF position prevents the handle from being inadvertently moved to the ON position.

(d) The movement of each switch handle should be in the same direction as the resultant movement of the load.

(e) Cranes furnished with skeleton (dummy) cabs are operated by either a pendant pushbutton station or
radio transmitter, and therefore do not require master-switches unless otherwise required by the owner.

**Figure CM-4.1.1.5.2-1** [FL51] Arrangement of Cab Master-switch Controllers

CM-4.1.1.5.3 Radio Transmitter Lever-Switch Controllers. Radio transmitter lever switch controllers shall meet the following requirements:

(a) The arrangement of the radio transmitter lever switches shall conform to Fig CM-4.1.1.5.3-1 unless otherwise required by the owner. The relative arrangements of the lever switches should be standardized at each owner’s location.

(b) In order for a radio transmitter lever-switch controller to start and maintain a crane motion, there must be a permissive radio signal in addition to a crane motion signal.

**Figure CM-4.1.1.5.3-1** [FL52] Arrangement of Radio-Transmitter Lever-Switch Controllers

CM-4.1.1.6 Electrical Enclosures. Control enclosures, unless otherwise specified by the owner, shall be suitable for the owner specified environmental conditions of service. Enclosure types, as defined by NEMA, include, but are not limited to the following:

(a) NEMA Type 1: general purpose for indoor applications

(b) NEMA Type 3: watertight, dust-tight, and sleet (ice) resistant; outdoor

(c) NEMA Type 3R: rainproof and sleet resistant; outdoor

(d) NEMA Type 4: watertight and dust-tight; indoor and outdoor

(e) NEMA Type 4X: watertight, dust-tight, and corrosion resistant; indoor and outdoor

(f) NEMA Type 7: Class I, Groups A, B, C and D; indoor hazardous locations (explosive atmosphere)

(g) NEMA Type 9: Class II, Groups E, F and G; indoor hazardous locations (explosive atmosphere)

(h) NEMA Type 12: industrial use, dust-tight and drip-tight, indoor

CM-4.1.1.7 Current Conductor Systems

CM-4.1.1.7.1 Categories of Conductor Systems. Conductor systems shall be considered in the following three general categories:

(a) Runway Systems. Conductor power from the building supply to the crane.

(b) Bridge Systems: Conductor power and control between the bridge and trolley portions of the crane.

(c) Auxiliary Systems. These include pendant pushbutton, communication, remote control, and instrumentation cables.

CM-4.1.1.7.2 Conductor System Types

(a) When AC variable frequency controls are used, the runway and the bridge conductor systems shall include a grounding conductor.
(b) Standard types of conductor systems are as follows, with examples of the various styles of these types shown in Fig. CM-4.1.1.7.2-1.

1. **Contact Conductor.** These systems may consist of either a rigid bar or taut wire, with a sliding or rolling collector. To ensure continuous contact on systems that use AC variable-frequency drives or DC motor drives, there shall be at least two spring-loaded contact shoes per phase on the mainline systems, in the primary circuit of AC motors, and in any DC motor armature circuit that does not supply current to a series brake. Adequate expansion means shall be incorporated to allow for building expansions and contractions as specified. Where low-contact resistance is required for low-current or low-voltage pilot devices, such as tachometer generators, a combination of conductor and collector materials shall be suitable for that usage.

   NOTE: While taut wire arrangements are present on many existing systems, the use of an insulated taut wire system is not recommended on new applications due to inherent safety issues.

2. **Brush-Type Cable Reel.** These systems consist of a cable that is played out off a reel and uses a slip-ring and brush arrangement to maintain electrical contact. Where low-contact resistance is required for low-current or low-voltage pilot devises, such as tachometer generators, a combination of slip-ring and brush materials shall be suitable for that usage.

3. **Flexible Continuous Conductor:** These systems consist of a continuous flexible cable, either flat or round, which is suspended in a festooned arrangement from a trolley and track system, or in a cable carrier.
CM-4.1.1.7.3 Conductor System Design

(a) Current conductors shall have sufficient ampacity to carry the required current to the crane or cranes when operating with rated load. The conductor ratings shall be selected in accordance with NFPA 70, Article 610. For manufactured conductor systems with published ampacities, the intermittent ratings may be used. The ampacities of fixed loads, such as heating, lighting, and air conditioning may be computed as 2.25 times their sum total, which will permit the application of intermittent ampacity ratings for use with continuous fixed loads.

(b) The type of runway conductor system shall be suitable for the application and environmental conditions, and shall be approved by the owner since it interfaces with the building structure. See also criteria of CM-4.1.2.

(c) The type of bridge conductor and auxiliary conductor systems shall be suitable for the application and environment.

(d) Bridge and runway conductors shall use a separate ground conductor.

(e) Runway contact conductors shall be enclosed or guarded.

(f) Bridge contact conductors shall be enclosed, guarded, or located in a manner such that persons cannot inadvertently touch energized current-carrying parts.

(g) Bridge and runway contact conductors shall use tandem collectors.

(h) All sections of contact conductors shall be mechanically joined to provide a continuous electrical connection, except for the use of required expansion joints and jumper cables.

(i) The type and location of runway system conductors shall be specified by the owner.

CM-4.1.1.8 Warning Devices

(a) On cab-operated cranes and remote-operated cranes, a gong or other warning means shall be provided for each crane equipped with a power-traveling mechanism.

(b) On pendant pushbutton controlled cranes, a gong or other warning means shall be provided if required by the owner.

CM-4.1.1.9 Auxiliary Electrical Equipment

When required by the owner, the following auxiliary equipment shall be provided.

(a) Travel Limit Switches.

(b) Heating, Ventilating and Air Conditioning.

(c) Convenience Outlets.

CM-4.1.2 Wiring Materials and Methods

(a) The wiring system shall meet the requirements of NFPA 70, Article 610, as supplemented by this section.

(b) The provisions of this section apply to interconnecting wiring both within and external to control panel enclosures. It does not apply to wiring that forms an integral part of equipment, such as motors, individual control components (e.g., contactors, transformers and relays), and electronic control subassemblies.

(c) The complete raceway system including wire shall be assembled on the crane at the crane manufacturer’s facility. Where disassembly is necessary for shipment, components shall be marked for each of field erection. Where any portion of a raceway run must be disconnected or dismantled to permit shipment, the wire shall not be pulled through that raceway during shop assembly. Wire not pulled shall be cut to approximately length and bound in coils marked for the circuit to which it applies.

CM-4.1.2.1 Wiring Materials

CM-4.1.2.1.1 Conductors

(a) Individual conductors, including those in multiconductor cables, shall have a maximum operating temperature rating not less than 75 C.

(b) Multiconductor cable shall be permitted in wiring the crane. The cable used shall comply with the requirements of NFPA 70. Flexible service cable shall be used when required for the application, such as a festooned flexible continuous conductor system.

(c) Minimum sizes of conductors (excluding electronics) shall be as follows:

(1) Number 14 AWG for power and lighting circuits

(2) Number 16 AWG for control circuits

(d) Conductors shall be annealed copper with minimum stranding as follows:

(1) ASTM B8 Class B for non-flexing service.

(2) ASTM B174 Class K for flexing service.

(e) Color coding, if required by the owner, shall be in accordance with NEMA ICS 1.

(f) All control conductors and cables used with AC inverter-type controls and having operating voltages less than 110V shall be of shielded type.

CM-4.1.2.1.2 Raceways

(a) Wiring external to control panel enclosures or assemblies of control panels with integral raceways shall be installed in rigid metal conduit, except as otherwise permitted in this section or as approved by the owner.

(b) Short lengths of open conductors shall be permitted at collectors and within enclosures or guards for resistors and transformers.

(c) Conduit smaller than ¾ in. diameter trade size shall not be used.

(d) Flexible metal conduit may be used to enclose conductors to stationary or infrequently moved devices, such as motors, brakes, master switches, and limit switches, or to equipment subject to vibration.
(e) Connections to moving parts (bridge to trolley, bridge or trolley to pendant pushbutton station) may be made by flexible cable not enclosed in conduit. Where flexible cable is used, some form of strain relief shall be provided.

(f) Conduit shall be rigidly attached to the crane by conduit supports.

**CM-4.1.2.2 Wiring Methods**

(a) All conductors shall be identified at each termination by a marking that corresponds to the schematic diagram.

(b) Conductors shall be run from terminal to terminal without splices except at devices with integral leads or within junction boxes.

(c) Pressure-type connectors shall be provided on all wires connected to terminals not equipped with a means for retaining conductor strands.

(d) All external conductors for control circuits shall be routed through terminal blocks with no more than two conductors terminated at each connection point, provided the termination point is designed to accept two connections.

(e) Panel wiring shall be routed in a manner that will not interfere with inspection and maintenance of devices.

(f) Control conductors external to AC inverter controls that connect to components subject to detrimental effects due to electromagnetic interference induced in the conductor for other conductors or electrical equipment shall be of a design or installed in such a manner that prevents such effects. Examples include the following:

(1) Use individually shielded twisted-pair conductors for tachometers or encoder connections.

(2) Route such conductors through a separate conduit.

(3) Refrain from splicing connections.

**CM-4.1.3 Seismic.** Analyses shall be performed to confirm that those electrical components that, if dislodged, would damage safety-related equipment shall remain in place during the seismic event.

**CM-4.1.4 Allowable stresses for Fasteners.** Fasteners for mounting electrical components, such as control enclosures, shall comply with the requirements of CM-3.1.2.3.4.

**CM-4.2 ADDITIONAL DESIGN REQUIREMENTS SPECIFIC TO JIB CRANES**

**CM-4.2.1 General**

(a) Except as noted under (b) below, the following information applies to jib cranes that have motor-operated boom rotation.

(b) For jib cranes that do not have a motor-operated boom but use either an electrically operated hoist or electrically operated trolley, the information listed in the following sections will still apply: CM-4.1.1.4, CM-4.1.1.5, CM-4.1.1.7, CM-4.1.2.1, and CM-4.1.2.2.

**CM-4.2.2 Electrical Components**

**CM-4.2.2.1 Motors.** A jib slew drive motor for a motorized boom shall meet the criteria of CM-4.1.1.2, except that the motor rating, which is basically the mechanical horsepower with consideration for the effect of control, shall be sized as follows for indoor and outdoor applications:
Figure CM-4.2.2.1-1 Slew Drive Motor -Size Selection

(a) Slew Drive Motor-Size Selection, Indoor Cranes. The jib slew drive motor shall be selected so that the horsepower rating is not less than that given by the following formula:

$$ HP = \frac{I_0(N^2)}{(7 \times 10^6)E K_t} \quad (72) $$

where, referring to Fig. CM-4.2.2.1-1

- $E$ = system efficiency
- $I_0$ = load moment of inertia
  \[ = WL \times RL^2 \]
- $K_t$ = torque factor, which is the equivalent steady-state torque relative to rated motor torque that results in accelerating up to rated motor rpm in the same time as the actual variable-torque speed characteristic of the motor and control characteristic used (see Table CM-4.1.1.2.4-5 for standard values of $K_t$)
- $N$ = rotational speed, rpm
- $RL$ = maximum load radius, ft.
- $WL$ = rated load plus the hoist weight, lb.

(b) Slew Drive Motor-Size Selection, Outdoor Cranes. The jib slew drive motor shall be selected so that the horsepower rating is not less than that given by the following formula:

$$ HP_{\text{wind}} = \frac{TN}{5,250 E K_t} \quad (73) $$

and where, referring to Fig. CM-4.2.2.1-1

$$ HP_{\text{wind}} = \text{horsepower required to overcome wind load} $$

$$ T = PSF \left( (A_{\text{boom}})(RB) + (A_{\text{load}})(RL) \right)SF $$

where

- $A_{\text{boom}}$ = projected area of boom, ft.$^2$
- $A_{\text{load}}$ = projected area of load, ft.$^2$
- $HB$ = height of boom, ft.
- $HL$ = height of load, ft.
- $LB$ = length of boom, ft.
- $LL$ = length of load, ft.
- $PSF$ = operating wind load, lb/ft.$^2$ (use 5 lb/ft.$^2$ if not otherwise specified by the owner)
RB = radius to centroid of projected area of boom, ft.
RL, N, E and K are defined in (a) above.

SF = Shape Factor (typically 1.2 for a single girder crane)

(c) See NUM Part-B2 for a jib slew drive sample calculation and a derivation of the simplified horsepower formula.

CM-4.3 ADDITIONAL DESIGN REQUIREMENTS SPECIFIC TO MONORAIL SYSTEMS

CM-4.3.1 General

The following information applies to monorail systems that use either an electrically operated hoist or electrically operated trolley, or that use electrically operated track devices.

CM-4.3.2 Electrical Components

CM-4.3.2.1 Electrically Operated Track Devices

(a) The owner shall specify if track devices are to be electrically operated.

(b) Standard track devices that are electrically operated are as follows:
   (1) Track switches and turntables
   (2) Track interlocks
   (3) Vertical track lift and drop sections
   (4) Electric baffles

(c) Electric baffles shall be provided as required by ASME B30.17.

CM-4.3.2.2 Motors. Motors for electrically operated track devices shall meet the criteria of CM-4.1.1.2, except that time rating and size selection shall be as required for the specific track device and application.

CM-4.3.2.3 Brakes

(a) Vertical track lift and drop sections shall be furnished with a spring-set, friction-type brake having a torque rating of at least 125% of the rated motor torque of the track device hoisting motor.

(b) Spring-set, friction-type brakes shall be in accordance with CM-4.1.1.3.
Section CM-5
Pneumatic, Cranes & Monorails (Type I)

CM-5.1 GENERAL
This section covers the pneumatic requirements and criteria common to all Type I cranes and monorails. Requirements for hoists are covered under NUM Part-HT.

CM-5.2 AIR SUPPLY
Air operated cranes and monorails shall operate on an air supply which is essentially clean and dry with the pressure being 90 psi (6.3 bar), although air systems at 105 psi (7.3 bar) may be used if accepted by both the owner and hoist manufacturer. Unless specified otherwise, the maximum moisture content of the air is to be 0.002 lb. of water per pound of dry air at 60° F and 90 psi absolute, with the maximum solid particulate contamination limited to 25 microns. The owner’s main air supply shall be sufficient to accommodate the total air consumption of all air motors, with this consumption rate (cfm) provided by the manufacturer. The owner’s main air supply shall include a building mounted shutoff valve and an adjustable air pressure regulator in the area of the crane or monorail. Additionally, the owner shall provide a relief valve system to prevent excessive air pressure from damaging the crane or monorail.

CM-5.3 AIR MOTORS
Air motors shall be air-driven piston or rotary vane type and shall be provided with an air inlet connection fitted for the use of air hose assemblies. Also, the air motor shall be provided with an oiler and air filter between the motor and the air inlet connection. The motor shall have the required horsepower to accelerate and traverse the rated load at the specified speed. The motor shall have the capacity to traverse 125% of the rated load. Air motor performance curves shall be furnished.

CM-5.4 ADDITIONAL AIR EQUIPMENT
Air motors shall be furnished with the necessary directional valves, a dump valve operated by a power off or emergency stop button, and a crane or monorail mounted regulator and pressure gauge to confirm the pressure at the motor. The air motor exhausts should include an exhaust filter and muffler as determined necessary by the manufacturer or shall be provided as specified by the owner. Mufflers shall be required for indoor applications and shall be such that the motor sound level for each motor shall be 80 db or less, 3 feet from the muffler, unless specified otherwise by the owner.

CM-5.5 AIR MOTOR CONTROLS
Air operated cranes and monorails shall have pendant, pull, or rod control as specified by the owner. Control actuators shall automatically return to the OFF position when released. Unless otherwise specified by the owner, the control station shall be 3 ft to 5 ft above the specified operating level. Criteria for the various types of air motor controls are listed in the following paragraphs:

CM-5.5.1 Pendant Control. The pendant control station shall be supported to protect the pneumatic hoses and connections against strain. The pendant control station shall be clearly marked to indicate the function of each actuator. The control motion actuators may be either pushbuttons or levers.

CM-5.5.2 Pull Control. Pull control shall consist of two pull chains or cords with suitable handle(s) clearly marked for direction.

CM-5.5.3 Rod Control. Rod control shall permit control of crane or monorail (air operated) motion by linear or rotary movement of the rod handle, or a combination of both. Rod handle shall be clearly marked for direction of motion.
Section CM-6
Marking, Cranes & Monorails (Type I & II)

CM-6.1 CRANE AND MONORAIL MARKING

CM-6.1.1 General

(a) The rated load shall be marked on each side of the crane bridge, jib boom, and monorail with monorail markings being at intervals so as to always be visible from the operating floor.

(b) Top-running bridge and gantry cranes including wall cranes shall have additional markings in accordance with ASME B30.17.

(c) Monorails, underhung cranes, and bridge cranes shall have additional markings in accordance with ASME B30.17.

(d) Hoists used on any bridge crane, wall crane, jib crane, or monorail shall be marked in accordance with NUM Part-HT.

CM-6.1.2 Type I Cranes and Monorails

(a) For Type I bridge cranes, wall cranes, jib cranes, and monorails, the maximum critical load rating (MCL) shall be marked on the bridge beam, jib boom, or monorail in lieu of the rated load using the terminology MCL as part of the marking.

(b) For Type I bridge cranes, wall cranes, jib cranes, and monorails that lift loads in excess of the MCL, the terminology DRL (design rated load) shall be used and shall also be marked on the bridge beam, jib boom, or monorail.
Section CM-7
Inspection and Testing, Cranes & Monorails (Type I & II)

CM-7.1 GENERAL

The requirements and criteria in Section CM-7 are applicable to all Type I & II cranes and monorails unless specifically stated elsewhere.

CM-7.1.1 Scope and Responsibility

CM-7.1.1.1 Scope. This section describes the general inspection and testing requirements for all cranes and monorails beginning prior to manufacture and continuing through delivery, erection, acceptance load testing, and inspection at the erection site. Each crane and monorail shall be examined for compliance with the requirements specified and with the approved drawings. This element of inspection shall include a visual examination and dimensional checks.

CM-7.1.1.2 Responsibility. Unless otherwise specified by the owner, the manufacturer is responsible for the performance of all inspection and test requirements as specified herein. The owner shall be permitted to witness inspections and tests as well as any inspections and tests to be performed at the erection site.

CM-7.1.1.3 Documentation. All inspections and tests performed on the crane or monorail, both at the plant and at the site, shall be fully documented in reports with copies furnished to the owner.

CM-7.1.2 Inspection by Seller Prior to and During Manufacture. The following identifies the specific criteria for the inspections and tests specified by Table CM-2.1.5.1-2:

CM-7.1.2.1 Structural. Structural components shall be visually and dimensionally inspected for conformance with drawing requirements and specifications.

CM-7.1.2.1.1 Welding

(a) All structural welds shall be visually inspected over their entire lengths. Acceptance criteria of welds and repairs shall be in accordance with AWS D1.1 or AWS D14.1. Nondestructive testing of groove welds shall be in accordance with Table CM-2.1.5.1-2.

(b) Welds whose failure during a seismic event could cause the crane or monorail to fall shall be nondestructively tested.

(1) For butt welds, 100% radiographic testing (RT) or ultrasonic testing (UT) in accordance with AWS D1.1 or AWS D14.1. Acceptance criteria shall be in accordance with AWS D1.1 or AWS D14.1.
(2) For other welds, 100% magnetic particle testing (MT) or dye penetrant testing (PT) of each weld 10 in. or less in length; 10% MT or PT of each weld that exceeds 10 in. in length. Technique and acceptance criteria shall be in accordance with AWS D1.1 or AWS D14.1.

(c) Welders and welding procedures shall be qualified or prequalified in accordance with AWS D1.1 or AWS D14.1.

CM-7.1.2.1.2 Drop Weight Testing. Drop weight test shall be per ASTM E208 or Charpy impact test shall be per ASTM A370.

CM-7.1.2.1.3 UT Volumetric Testing

(a) UT volumetric testing and acceptance criteria shall be in accordance with ASTM A435 for plate material.

(b) UT volumetric testing shall be in accordance with ASTM E114 and ASTM A388 for wrought or forged material.

(1) Acceptance criteria for forged material shall be in accordance with the following:

(\(a\)) Straight Beam. A forging or bar shall be unacceptable if the results of straight beam examinations show one or more reflectors that produce indications accompanied by a complete loss of back reflection not associated with or attributable to geometric configurations. Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.

(\(b\)) Angle-Beam Rule. A forging or bar shall be unacceptable if the results of angle-beam examinations show one or more reflectors that produce indications exceeding the amplitude reference line from the appropriate calibration notches.

(2) Acceptance criteria for material without parallel surfaces shall be as follows:

(\(a\)) Discontinuity indications in excess of the response from a \(\frac{1}{8}\)-in.-diameter flat-bottomed hole at the estimated discontinuity depth shall not be acceptable.

(\(b\)) Discontinuity indications in excess of the response from a \(\frac{3}{32}\)-in.-diameter flat-bottomed hole at the estimated discontinuity depth shall not have their indicated centers closer than 1 in.

(\(c\)) Elongated (stringer) type defects in excess of 1 in. in length shall not be acceptable if at any point along the length the discontinuity indication is equal to or greater than the response from a \(\frac{3}{32}\)-in.-diameter flat-bottomed hole.

CM-7.1.2.1.4 Component Fit-Up. Structural components shall be inspected to ensure
that they are properly aligned and fitted without inducing built-in stresses.

**CM-7.1.2.1.5 Structural Materials.** Material test reports shall be required on structural materials, including seismic restraints, whose failure during a seismic event would cause the crane or monorail to fall.

**CM-7.1.2.1.6 Fasteners.** Material test reports shall be required on fasteners, including those of a seismic restraint, whose failure during a seismic event would cause the crane or monorail to fall.

**CM-7.1.2.2 Mechanical.** Mechanical components shall be inspected as specified by the owner.

**CM-7.1.2.3 Electrical**

**CM-7.1.2.3.1 Visual.** Inspections shall be performed at the crane or monorail manufacturer’s plant (or during field erection if not feasible to perform at the plant) to verify the following:

(a) terminal connections for tightness  
(b) panels and resistors are properly placed  
(c) required fuses are installed  
(d) panels, switches, resistors, and other parts and materials are in accordance with drawings and are properly identified  
(e) raceways are properly supported and installed, and raceways to be removed for shipment are properly marked and fitted for field reinstallation  
(f) no interferences involving electrical items exist when trolley moves through its full range  
(g) electrical items do not protrude beyond the confines of the crane or monorail as established by the drawings  
(h) electrical items requiring routine maintenance are accessible  
(i) no wiring is touching resistor heating parts  
(j) portions of conductor systems that are designed to move in order to accommodate crane or monorail move freely  
(k) pendant and festoon cable strain relief is properly installed  
(l) overload relay current sensing elements are in accordance with drawings  
(m) motor connections are properly made  
(n) contactors and electromechanical relays whose armatures are accessible operate freely by hand  
(o) electrical enclosures are correct NEMA type, and panel door operates properly  
(p) motor brushes are properly seated  
(q) electrical holding brakes are adjusted to correct torque settings  
(r) conductors are identified at each termination and correspond to the schematic diagrams

**CM-7.1.2.3.2 Control Software.** Desk audits, peer reviews, and static analysis tools/techniques shall be used throughout the development process to verify implementation of design requirements in the source code, with particular attention paid to the implementation of identified safety-critical functions such as fault detection and safing or correcting logic.

**CM-7.1.2.3.3 Operation.** Electrical components shall be checked out prior to and/or during shop tests to ensure that they operate as designed.

**CM-7.1.3 Shop Operational Tests.** A shop no-load test shall be performed at the crane or monorail manufacturer’s facility. Procedures shall be prepared and used by the manufacturer in conducting the test. If subsequent manufacturing or associated activities affect the validity of this test or portions thereof, the appropriate portions of the test shall be repeated. Non-conformances found during the testing shall be treated as required by the test procedure.

**CM-7.1.3.1 Prerequisites.** Prior to conducting the shop no-load test, the lifting equipment or applicable portions to be tested shall be assembled and wired subject to the following:

(a) The equipment or its applicable portions need not be completely assembled, wired or painted at time of testing if subsequent work will not influence or alter the results of the test.

(b) Temporary electrical connections for test purposes are acceptable for normally installed field wiring.

(c) When testing the operations of mechanical portions of the crane or monorail the use of a temporary controller is acceptable unless otherwise specified by the owner.

(d) When testing electrical portions of the crane or monorail they shall be tested with the actual equipment controls unless specifically excepted by the owner.

(e) The assembled crane or monorail shall be square and in alignment with parts fitted and adjusted properly.

**CM-7.1.3.2 Testing**

**CM-7.1.3.2.1 Mechanical Requirements.** As a minimum, the following mechanical functions shall be verified:

(a) Traverse the trolley on the bridge, boom, or monorail, verify interfaces of auxiliary equipment (powered operation is preferred).  
(b) Operation of mechanical components shall be verified to meet design criteria.

**CM-7.1.3.2.2 Electrical Requirements.** A test of the crane or monorail electrical system shall be made to verify proper operation of the controls. For
remote-controlled cranes or monorails, the transmitter–receiver system shall be used for this test.

**CM-7.1.3.2.3 Software Requirements.** For programmable logic controller (PLC) controlled cranes or monorails, the PLC software shall be installed and used during the test. Software testing (either breadboard or as part of the crane or monorail testing) shall include the following, as a minimum:

(a) hardware, software, and operator input failure mode testing
(b) boundary, out-of-bounds, and boundary-crossing test conditions
(c) input values of zero, zero crossing, and approaching zero from either direction
(d) minimum and maximum input data rates in worst-case configurations to determine system capabilities and responses to these environments

**CM-7.1.4 Preparation For Shipment**

**CM-7.1.4.1 Disassembly.** Equipment that has been assembled for shop testing shall be disassembled only as required for shipment to the erection site or specified storage facility.

**CM-7.1.4.2 Marking and Tagging.** Each item or subassembly shall be marked and/or tagged with its name and drawing, assembly, and item or subassembly identification. Items disconnected for handling and shipping shall be match-marked for reassembly at the erection site. Marking shall be accomplished using a method that is not detrimental to the material, e.g., sharp bottom stamps shall not be used for marking structural components that will be subjected to high stresses.

**CM-7.1.4.3 Inspection.** Prior to shipment, all items, assemblies, or subassemblies shall be inspected to ensure that they are complete, undamaged, properly identified and properly packaged.

**CM-7.1.4.4 Packaging.** Packaging of items to be shipped shall be as required to provide protection from handling and/or shipping damage, which could occur during such shipment. All items, assemblies, or subassemblies shall be accurately identified and listed in the bill of lading as necessary for performance of receipt inspection at the erection site or storage facility.

**CM-7.1.4.5 Receipt Inspection by Owner**

**CM-7.1.4.5.1 Verification.** All items, subassemblies, and assemblies shall be checked against the bill of lading for proper identification and verification of receipt. Discrepancies shall be reported to the transporter and to the shipper.

**CM-7.1.4.5.2 Condition.** All items, subassemblies, and assemblies shall be inspected for corrosion, contamination, deterioration, or physical damage resulting from their being shipped. Damage shall be reported to the shipper.

**CM-7.1.5 Storage by Owner Prior to Erection**

**CM-7.1.5.1 Preparation for Storage.** When receipt inspection of an item has been completed, the item shall be in satisfactory condition for storage. Ensure that pipe caps or covers removed for receipt inspection are replaced, machined surfaces are protected, and crated items have been re-crated (if applicable) in accordance with the owner’s requirements governing preparation for shipment and storage.

**CM-7.1.5.2 Storage Requirements.** Items, assemblies and subassemblies should be stored in an atmosphere that will provide protection from damage or deterioration from other work or traffic, adverse weather conditions, fires, flooding, etc.

**CM-7.1.6 Inspection by Owner at Erection**

**CM-7.1.6.1 Prerequisites**

(a) Inspections or checks, as appropriate, shall be performed to verify that conditions of the installation area conform to specified requirements and that precautions have been taken to prevent conditions that will adversely affect the quality of the item during installation.

(b) Permanent crane runway supports and mountings that will properly interface with the crane shall have been installed

**CM-7.1.6.2 Inspection During Assembly.** Inspections of the work areas and the work in progress shall be performed to verify that the crane components are being located, installed, assembled, or connected in compliance with the latest approved-for-construction drawings, this Standard, installation instructions and procedures.

Inspections performed shall include, as appropriate, the following:

(a) Identification
(b) Location and orientation of components
(c) Leveling and alignment
(d) Clearances and tolerances
(e) Tightness of connections and fasteners
(f) Fluid levels and pressures
(g) Cleanliness
(h) Welding operations, including materials and process controls
(i) Adequacy of housekeeping, barriers, and protective equipment to ensure that items will not be
damaged or contaminated as a result of adjacent construction activities.

**CM-7.1.6.3 Assembled Inspection.** Checks shall be performed to verify that all components have been correctly installed. If construction or associated activities affect the results of these checks, the checks shall be repeated, if necessary, to ensure that the quality has not been adversely affected.

Checkout procedures to verify correctness of installation and ability to function shall include the following mechanical elements:

(a) Mating parts, such as couplings, are properly positioned
(b) Proper greasing or lubrication has been completed
(c) Casings, reservoirs, etc., are primed, vented and filled
(d) Control of specified bolting method and the following electrical elements:
   (1) Electrical connections inspected for good contact and conformance with the wiring diagram
   (2) Bridge conductor-collector system inspected for proper alignment

**CM-7.1.7 Site Load Testing**

**CM-7.1.7.1 Preoperational Testing and Inspection.** A preoperational testing and inspection program shall be established to demonstrate that the equipment will perform satisfactorily in service. The preoperational testing shall be performed in accordance with written test procedures that incorporate acceptance criteria. Unless otherwise specified by the owner, the owner or representative(s) designated by the owner shall:

(a) Witness the preoperational tests called for this these procedures.
(b) Furnish all facilities necessary for the performance of such tests
(c) Ensure that proper communications are established for control of testing

These testing requirements shall be completed after the equipment has been installed and prior to construction/operational use of the crane or monorail.

**CM-7.1.7.2 No-Load Test**

**CM-7.1.7.2.1 Testing.** A no-load test shall be performed after the power supply has been verified to be in accordance with equipment specifications to verify the following:

(a) Motor rotation is correct.
(b) Lubrication and cooling systems are in service.
(c) Limit switches, interlocks, and stops are properly adjusted and set.
(d) Instrumentation is calibrated and in service as required.
(e) Controls are adjusted properly for drives, as applicable, through their respective speed ranges.

**CM-7.1.7.2.2 Additional Requirements.** While the no-load testing is being performed, the following information shall be recorded or observed:

(a) Electrical (full-speed conditions)
   (1) motor volts
   (2) motor amps
   (3) motor rpm
(b) Mechanical
   (1) noise levels
   (2) oil leaks
   (3) excessive vibration
   (4) clearances per drawings and specifications
   (5) gear alignment and engagement
   (6) wire rope or chain condition
(c) Structural
   (1) overall building clearances
   (2) bridge and trolley end approaches
(d) All software faults
(e) Components, systems, and features having single failure-proof functions related to retaining the load in event of failure in the primary load path are functioning correctly and are properly adjusted and calibrated

**CM-7.1.7.3 Full-Load Test.** The crane or monorail shall be statically loaded at bridge midspan (or end of boom) to 100% (+5%, −0%) of manufacturer’s rating. With this load, the crane or monorail shall be operated through all drives for bridge or boom, and through all speed ranges to demonstrate speed controls and proper function of limit switches, locking, and safety devices as practical with full load. Hoist shall be verified to stop and hold 100% load while lowering at maximum speed upon loss of power. Opening the mainline magnetic contactor by means of the E-Stop may be used to simulate a loss of power condition. Manually operated load-lowering devices, if supplied, shall be tested.

**CM-7.1.7.4 Rated Load Test.** After the no-load and full-load tests are completed and prior to use for handling loads, the equipment shall be rated load tested.

(a) The crane or monorail shall receive a rated-load test of 125% (+5%, −0%) of the rated capacity.
(b) The rated load test shall consist of the following operations as a minimum:
   (1) Lift the test load approximately 2 ft and hold the load for a minimum of 5 min to verify no test weight drift.
   (2) Transport the test load by means of the trolley (carrier) from one end of the crane bridge, jib, or monorail to the other. The trolley motion shall be smooth and regular. The trolley shall approach the limits of travel as close as practical if use area restrictions are imposed and based on the test load configuration.
   (3) For bridge and gantry cranes, transport the test load by means of the bridge or gantry for the
full length of the runway in one direction with the trolley as close to the extreme right-hand end of the crane as practical, and in the other direction with the trolley as close to the extreme left-hand end of the crane as practical if use area restrictions are imposed and based upon the test load configuration.

When cranes operate on more than two runways (multiple-track cranes), the crane shall transport the test load for the full length of the runway with the test load under each of the intermediate tracks.

(4) Verify that the nameplate reflects the load rating per (a) above.

(5) For jib cranes, verify that there is jib boom motion with the trolley located at each end and at the center of the boom.

CM-7.1.7.5 Certification. A written report confirming the equipment has successfully passed the rated-load testing shall be furnished. This report shall be signed by representatives of all parties participating in the test.

CM-7.2 ADDITIONAL INSPECTION AND TESTING REQUIREMENTS SPECIFIC TO UNDERHUNG CRANES

CM-7.2.1 General. There are no additional inspection and testing requirements.

CM-7.3 ADDITIONAL INSPECTION AND TESTING REQUIREMENTS SPECIFIC TO TOP-RUNNING BRIDGE AND GANTRY CRANES

CM-7.3.1 General. There are no additional inspection and testing requirements.

CM-7.4 ADDITIONAL INSPECTION AND TESTING REQUIREMENTS SPECIFIC TO TRAVELLING WALL CRANES

CM-7.4.1 General. The requirements of CM-7.1 shall be followed where applicable.

CM-7.4.2 Performance. The following is to be performed after installation at the site:

(a) Check the levelness and alignment of the wall crane, without load.

(b) Check deflection of the boom with crane loaded to rated capacity and load positioned at maximum distance from support rails/flanges. Deflection shall not exceed the maximum specified in CM-2.4 or by the owner. Verify that the trolley does not drift along the boom at rated load.

(c) Verify proper alignment and engagement of all wheels with support rails/flanges and proper operation through all modes of travel during rated-load and no-load conditions.

CM-7.5 ADDITIONAL INSPECTION AND TESTING REQUIREMENTS SPECIFIC TO JIB CRANES

CM-7.5.1 General. The requirements of CM-7.1 shall be followed where applicable.

CM-7.5.2 Performance. The following is to be performed after installation at the site:

(a) Check the levelness and alignment of the boom or jib, without load.

(b) Check deflection of the boom with rated load applied at maximum distance from wall, mast, or column support. Deflection shall not exceed the maximum specified in CM-2.5. Verify that the trolley does not drift along the boom at rated load.

(c) Verify proper rotation of the jib throughout its full range of travel with the rated load applied at the maximum distance from the wall, mast, or column support as permitted by the test load configuration. Verify that the amount of boom drift under these conditions is acceptable.

CM-7.6 ADDITIONAL INSPECTION AND TESTING REQUIREMENTS SPECIFIC TO MONORAIL SYSTEMS

CM-7.6.1 General. The requirements of CM-7.1 shall be followed where applicable.

CM-7.6.2 Performance. The following site inspection shall be performed as applicable to verify installation:

(a) Tracks. Check the following for compliance with the drawings and with CM-2.6:

(1) Track levelness

(2) Proper location and installation of supports (e.g. hanger rods)

(3) Bracing to prevent excessive sway

(4) Rail couplings (splice plates)

(5) Rail spacing (gaps)

(6) Track radii

(7) Proper clearances

(8) End stops

(b) Track Switches. Check track switches for

(1) Proper alignment and operation

(2) Spacing (gaps)

(3) Stops or guards on open ends of track and on movable track.

(4) Means of holding movable track when carrier (trolley) is being moved on it.

(5) Electric baffles (if provided to prevent load path from interfering with load path of adjacent track)

NOTE: Track switches shall only operate with an unloaded carrier unless otherwise specified and designed for.
(c) **Track Openers.** Check track openers, if provided for:
   (1) Proper alignment and operation
   (2) Spacing (gaps)
   (3) Proper installation of forks or stops to prevent carrier (trolley) from running off open ends of track when movable section is not aligned with the track.

(d) **Vertical Drop and Lift Sections.** Check vertical drop and lift sections for:
   (1) Proper alignment
   (2) Spacing (gaps)
   (3) End stops
   (4) Clearances
   (5) Electric baffles (if provided for cab-operated carriers or automatic-dispatch carriers)

(e) **Clearances.** Check clearances of lateral or overhead obstructions for compliance with GR-2.1.1.

(f) **Locking and Safety Devices.** During no-load operational testing, check all locking and safety devices for interlocking mechanisms, track switches, drop sections, and lift sections.

(g) **Deflection.** Check deflection of track and track components at rated load for compliance with CM-2.6.

(h) **Rated-Load Testing.** During rated-load testing, check the trolley for smooth motion in all directions, around all curves, across all rail splices, and through all switch configurations and travel directions. Check for proper structural bracing to prevent excessive sway and

(i) **Track Splices and Switches.** Check for proper alignment of track splices and switches under load.
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Section HT-1
Introduction

HT-1.1 GENERAL

As stated in Section GR-1 of NUM Part-GR, General Requirements, Type I enhanced safety hoisting equipment is divided into two subtypes: Type IA and Type IB. NUM Part-HT specifies the requirements for the subtypes of the following specific hoisting equipment configurations:

- Powered Wire Rope Hoists (Type IA)
- Powered Wire Rope Hoists (Type IB)
- Powered Chain Hoists (Type IB)
- Hand Chain Hoists (Type IB)

This Standard does not anticipate the use of chain hoists in a Type IA application. If the owner desires a Type IA chain hoist, it shall be provided with safety features and designs equivalent to those of a Type IA wire rope hoist.

This Part of the Standard also covers Under-Running Trolleys (Type IB), either as an independent unit or integral with a hoist. All trolleys are categorized as Type IB and have increased design factors.

Common NDE criteria applicable to the hoists and trolleys of NUM Part-HT are addressed under Section HT-7.

Although the Type IA and IB hoist and trolley equipment of NUM Part-HT is typically suspended from a Type I crane or monorail as specified under NUM Part-CM, this hoist and trolley equipment may also have independent applications including the mounting of a hoist unit to a stationary structure.

Standard hoist and trolley units, such as those used on a Type II or Type III crane or monorail, are not covered under this Standard. However, standard hoisting equipment used on a Type II crane or monorail shall remain in place during a seismic event and have restraints that ensure that requirement.

The hoists and under-running trolleys of NUM Part-HT shall also comply with the following general requirements of NUM Part-GR.

- GR-2 Environmental Conditions of Service
- GR-3 Performance Requirements
- GR-4 Coatings and Finishes
- GR-5 Quality Assurance

Additional information and criteria are provided in Section GR-1, with definitions provided in Section GR-6, and a list of referenced codes and standards provided in Section GR-7.
Section HT-2
Powered Wire Rope Hoists (Type IA)

HT-2.1 GENERAL

This section provides the requirements for powered (electric or air) operated Type IA hoists for enhanced safety vertical lifting of freely suspended unguided loads using wire rope as a lifting medium.

A Type IA powered wire rope hoist shall be of a unique design with single-failure-proof features for the hoisting machinery and for the hoist reeving.

HT-2.2 EQUIPMENT CONFIGURATIONS (Type IA)

(a) The hoisting machinery from the motor to the drum shall be designed to provide assurance that a failure of a single component would not result in the uncontrolled movement of the lifted load. The wire rope drum shell is exempted from this requirement.

(b) Load motion due to failure of one load path of a redundant load path hoist shall be evaluated as to facility acceptability.

(c) Figures HT-2.2-1, HT-2.2-2, and HT-2.2-3 provide some block diagrams illustrating examples of Type IA wire rope hoist equipment configurations. These block diagrams show conceptual layouts only. The machinery together with a redundant reeving arrangement shall comply with the vertical alignment requirements for a Type IA hoist. These block diagrams are not meant to show actual configurations and may be rearranged as needed to meet the specific application. These diagrams are only a few of many acceptable configurations.
HT-2.3 MECHANICAL (Type IA)

(a) The hoisting machinery and wire rope reeving system, in addition to other affected components, shall be designed to withstand the most severe potential overload, including two-blocking and load hang-up.

(1) Motor stall torque shall be considered, as well as all other factors contributing to maximum loading of the equipment components.

(2) The system or components (which may include torque-limiting or energy-absorbing components or systems) used to mitigate the effects of two-blocking and load hang-up shall permit the hoisting machinery to be returned to service without need for repair or replacement of components. Should any device in the hoist drivetrain such as a clutch or torque limiter fail to hold the load, the emergency brake (or other secondary/redundant load path) shall engage (or remain engaged) and safely retain the load.

(b) Allowable stresses for hoisting machinery components during these events shall be limited to 75% of the yield strength.

(c) Design calculations and component sizing shall take into consideration the maximum forces resulting from the kinetic energy of the hoisting machinery operating at maximum normal full-load or unloaded operating speed at the onset of the overload condition.

(d) Design calculations demonstrating the capability of the crane system to withstand severe overloads including two-blocking and load hang-up shall be submitted to the owner.

HT-2.3.1 Reeving. The reeving system shall be divided into two separate (redundant) load paths so that either path will support the load and maintain vertical alignment in the event of rope breakage or failure in the rope system. See Figs. HT-2.3.1-1, HT-2.3.1-2, and HT-2.3.1-3 for examples of Type IA reeving systems. These figures show three of many acceptable configurations.

(a) In each load path, multiple parts of rope in the reeving system shall be equalized.

(b) Each load path in the reeving system shall be balanced with the others.
Figure HT-2.3.1-1 Type IA Redundant Reeving with Single Drum (With Upper Equalizer Sheaves) [FL55]

GENERAL NOTE: Relative position of sheaves is extended and angle of view is distorted to clarify reeving paths. An equalizer system between the two ropes is required but is not shown for clarity.

Figure HT-2.3.1-2 [FL56]Type IA Redundant Reeving with Single Drum (With Equalizer Bar)

GENERAL NOTE: Relative position of sheaves is extended and angle of view is distorted to clarify reeving paths.

Figure HT-2.3.1-3 [FL57]Type IA Redundant Reeving with Dual Drum

GENERAL NOTE: Relative position of sheaves is extended and angle of view is distorted to clarify reeving paths.

HT-2.3.2 Hooks and Load Blocks

HT-2.3.2.1 Hooks. Hook(s) shall be designed for twice the rated load (e.g., for a 5-ton MCL rating, the design load shall be 10 tons) or shall be of single-failure-proof design.

(a) If the hooks are of the swiveling type, they shall be capable of rotating through 360 deg when supporting the rated load, unless otherwise specified by the owner.

(b) Hook latches shall be provided, unless the application makes use of the latch impractical. When required, a hook latch shall be provided to bridge the throat opening of the hook for the purpose of retaining slings, chains, etc., under slack conditions. Depending on the conditions of service, consideration shall be given to the use of hook latches constructed of corrosion-resistant materials.

(c) All hooks and latches shall comply with ASME B30.10.

HT-2.3.2.2 Load Blocks. Load blocks shall have double the normal design factors (e.g., for a 5-ton MCL rating, the design load shall be 10 tons) or shall be of a single-failure-proof design. Load blocks shall be of the guarded/enclosed type and shall guard against rope jamming under normal operating conditions.

HT-2.3.2.3 Upper Blocks. The upper block (or upper sheave nest) shall have double the normal design factors or shall be of single-failure-proof design.
HT-2.3.3 Wire Rope

(a) Wire rope shall be of a type and construction suitable for hoist service.

(b) Selection of Ropes. Hoisting ropes shall be selected based on the more stringent of the following requirements.

1. The maximum critical load (without impact), plus the weight of the load block divided by the total number of parts of rope, shall not exceed 12½ % of the manufacturer’s published breaking strength on the total system or 25% on each of the dual systems.

2. The impact load in the transfer of the maximum critical load from one of the dual hoisting rope systems to the other, in the event of rope failure, shall not exceed 40% of the manufacturer’s published breaking strength.

3. The seismic load with all parts of rope intact shall not exceed 40% of the manufacturer’s published breaking strength.

4. The load resulting from the maximum possible overload of the hoisting machinery, including two-blocking and load hang-up, shall not exceed 40% of the manufacturer’s published breaking strength.

(c) The rope ends shall be attached to the hoist in such a manner as to prevent disengagement throughout rated hook travel.

(d) End terminations shall be in accordance with the Wire Rope Users-Manual and shall be equal to the required rope strength. Wire rope clips shall not be used as the primary end terminations.

(e) Rope fleet angle to the drum grooves shall be limited to 3½ deg, except the last 3 ft of the maximum lift elevation, which shall be limited to 4 deg. Refer to Fig. HT-2.3.3-1 for fleet angle measurement to the drum grooves.

(f) Rope fleet angle for sheaves shall be limited to 3½ deg, except the last 3 ft of maximum lift elevation, which shall be limited to 4½ deg. Refer to Fig. HT-2.3.3-2 for fleet angle measurement to the sheaves.

Figure HT-2.3.3-1 Drum Fleet Angle

Figure HT-2.3.3-2 Sheave Fleet Angle

HT-2.3.4 Sheaves

(a) Sheave grooves shall be smooth and free from surface irregularities that could cause rope damage. The cross-sectional radius at the bottom of the groove should be such as to form a close-fitting saddle for the size of the rope used, and the sides of the groove should be tapered outwardly to facilitate entrance of the rope into the groove. Flanges shall be rounded, and the rims shall run true about the axis of rotation.

(b) Sheaves shall be mounted and guarded to protect against the entrance of foreign objects, wire-rope jamming, and wire-rope displacement during normal operation.

(c) All running sheaves shall use antifriction bearings. All running sheave bearings, except permanently lubricated bearings, shall be equipped with means for lubrication.

(d) Equalizer sheaves shall be provided with bronze bushings, oil-impregnated bearings, antifriction bearings with grease fittings, or other means to ensure that the sheave bearing remains lubricated, ensuring its capability to provide the rotation required to equalize the reeving.

(e) Equalizer systems shall be able to withstand the dynamic forces from load transfer upon failure of one wire rope and shall not load the remaining intact reeving system more than 40% of the breaking strength of the wire rope.

(f) The pitch diameter of running sheaves shall not be less than that indicated in Table HT-2.3.4-1.

(g) The pitch diameter of nonrunning sheaves (equalizers) shall not be less than 12 times the rope diameter.
Table HT-2.3.4-1 Minimum Pitch Diameter of Running Sheaves

<table>
<thead>
<tr>
<th>Hoist Duty Class</th>
<th>6X37 Class Rope</th>
<th>6X19 Class Rope</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1 and H2</td>
<td>16d</td>
<td>20d</td>
</tr>
<tr>
<td>H3</td>
<td>18d</td>
<td>24d</td>
</tr>
<tr>
<td>H4</td>
<td>20d</td>
<td>24d</td>
</tr>
<tr>
<td>H5</td>
<td>24d</td>
<td>30d</td>
</tr>
</tbody>
</table>

GENERAL NOTE: \( d = \) rope diameter

HT-2.3.5 Drums

(a) Provisions shall be made to retain the drum and the load in the event of drum shaft or bearing failure.

(b) Rope drums shall be grooved and the grooves shall be smooth and free from surface irregularities that could cause rope damage. The cross-sectional radius at the bottom of the groove should form a close-fitting saddle for the size of the rope used. The top edge of the grooves shall be rounded to minimize rope damage and wear.

(c) Rope drums shall be flanged to guard against ropes sliding over the ends of the drum. Drums that are mounted in the hoist structure such that the rope cannot slip over the drum ends do not require flanges.

(d) All rope drums shall have only one layer of rope and the drum shall be designed to store the entire length of rope for the rated lift with the load block in its upper-most position.

(e) No less than two wraps of rope shall remain on each anchorage of the hoist drum when the hook is in its lowest position unless a lower limit device is provided, in which case no less than one wrap shall remain on each anchorage of the hoist drum.

(f) Minimum drum groove depth shall be 0.5 times the rope diameter.

(g) The minimum drum groove pitch is either 1.14 times the rope diameter or the rope diameter plus \( \frac{1}{8} \) in., whichever is smaller.

(h) The rope drum pitch diameter shall not be less than that indicated in Table HT-2.3.5-1.

Table HT-2.3.5-1 Minimum Pitch Diameter of Drums

<table>
<thead>
<tr>
<th>Hoist Duty Class</th>
<th>6X37 Class Rope</th>
<th>6X19 Class Rope</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1 and H2</td>
<td>16d</td>
<td>20d</td>
</tr>
<tr>
<td>H3</td>
<td>18d</td>
<td>24d</td>
</tr>
<tr>
<td>H4</td>
<td>20d</td>
<td>24d</td>
</tr>
<tr>
<td>H5</td>
<td>24d</td>
<td>30d</td>
</tr>
</tbody>
</table>

GENERAL NOTE: \( d = \) rope diameter

Table HT-2.3.6.1-1 Bearing Life Expectancy

<table>
<thead>
<tr>
<th>Hoist Duty Class</th>
<th>Minimum Life Expectancy, hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>1,250</td>
</tr>
<tr>
<td>H2</td>
<td>2,500</td>
</tr>
<tr>
<td>H3</td>
<td>5,000</td>
</tr>
<tr>
<td>H4</td>
<td>10,000</td>
</tr>
<tr>
<td>H5</td>
<td>20,000</td>
</tr>
</tbody>
</table>

HT-2.3.6 Bearings, Rotating Shafts and Keys

HT-2.3.6.1 Bearings

(a) Shaft bushings or bearings shall be enclosed against entry of dirt, dust, and other foreign material.

(b) All bearings and bushings shall be provided with means of lubrication.

(c) Hoist bearings shall be selected to give a minimum B10 life expectancy based on full rated speed from Table HT-2.3.6.1-1.

(d) Bearing loads, for life computation purposes, shall be determined using a mean effective load factor of 0.65.

Table HT-2.3.6.2 Rotating Shafts. Rotating shafts shall be supported by antifriction, lubricated, or self-lubricated bearings or bushings. All sliding surfaces shall be lubricated.

HT-2.3.6.3 Hoist Keys. Keys used in hoist drives shall only be of a parallel, square or rectangular shape, not precluding the use of a splined shaft for power transmission.

HT-2.3.7 Hoist Gearing

(a) Gearing and associated shafts and couplings or other connection means shall be redundant (i.e., provide two separate load paths from the hoist brakes to the wire rope drum) with each independent gear train rated at full hoisting horsepower. As an alternative, a single hoist gear train may be provided in conjunction with two holding brakes, one of which shall act directly on the wire rope drum and set automatically upon failure or overspeed of the hoist drivetrain.

(b) Gears shall be constructed of steel or other material of adequate strength and durability to meet the requirements for the intended class of service. For the purpose of this standard, the strength and durability shall be based on the torque required to lift the rated load.

(c) Means shall be provided to ensure adequate and proper lubrication on all gearing.

(d) All gearing not enclosed in gear cases shall be guarded with provision for lubrication and inspection.
(e) Due consideration shall be given to the maximum brake torque that can be applied to the drive.

(f) The horsepower rating for all spur, helical, and herringbone gearing shall be based on ANSI/AGMA 2001-D04C95 and manufactured to AGMA quality class 6 or better. For the purpose of this standard, the power formula is as follows:

\[
P_{at} = \frac{n_p d}{126,000 K_v} \left( \frac{F_{sat}}{K_m P_d S_{fs} K_B} \right)
\]

Allowable Durability Horsepower

\[
P_{ac} = \frac{n_p I}{126,000 K_v K_m S_{fs} K_B} \left( \frac{S_{ac} d C_H}{C_p} \right)^2
\]

where

- \(C_d\) = machinery service factor; see Table HT-2.3.7-2
- \(C_h\) = hardness factor (durability)
- \(C_p\) = elastic coefficient
- \(d\) = pitch diameter of pinion, in.
- \(F\) = net face width of the narrowest of the mating gears
- \(I\) = geometry factor (durability)
- \(J\) = geometry factor (strength)
- \(K_B\) = rim thickness factor
- \(K_m\) = load distribution factor
- \(K_v\) = dynamic factor
- \(K_w\) = mean effective load factor that equals 0.667
- \(n_p\) = pinion speed, rpm
- \(P_{ac}\) = allowable durability, horsepower
- \(P_{at}\) = allowable strength, horsepower
- \(P_d\) = transverse diametral pitch, 1/in.
- \(S_{ac}\) = allowable contact stress number (durability)
- \(S_{at}\) = allowable bending stress for material, psi (strength)
- \(S_{fs}\) = hoist duty class factor (strength); see Table HT-2.3.7-1
- \(S_{fd}\) = hoist duty class factor (durability) = \(C_d \times K_w\)

The values for \(I, J, C_h, C_p, K_B, K_m, K_v, S_{ac},\) and \(S_{at}\) can be determined from the tables and curves in the appropriate AGMA specification; \(S_f\) is in Table HT-2.3.7-2; and the remaining values are physical characteristics pertaining to the gears for their operational characteristics.

(g) When worm gearing is called for, it shall be rated with appropriate service factors.

### Table HT-2.3.7-1 Hoist Duty Class Factor (strength) \(S_{fs}\)

<table>
<thead>
<tr>
<th>Hoist Duty Class</th>
<th>(S_{fs})</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>0.75</td>
</tr>
<tr>
<td>H2</td>
<td>0.85</td>
</tr>
<tr>
<td>H3</td>
<td>0.90</td>
</tr>
<tr>
<td>H4</td>
<td>0.95</td>
</tr>
<tr>
<td>H5</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Table HT-2.3.7-2 Machinery Service Factor \(C_d\)

<table>
<thead>
<tr>
<th>Hoist Duty Class</th>
<th>(C_d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>0.64</td>
</tr>
<tr>
<td>H2</td>
<td>0.72</td>
</tr>
<tr>
<td>H3</td>
<td>0.80</td>
</tr>
<tr>
<td>H4</td>
<td>0.90</td>
</tr>
<tr>
<td>H5</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### HT-2.3.8 Hoist Brakes

(a) The braking system shall consist of at least two holding brakes and a control braking means and shall perform the following functions:

1. Stop hook motion and hold the load when the controls are released
2. Limit the speed of the load during lowering to a maximum speed of 120% of rated lowering speed for the rated load
3. Stop and hold the load hook in the event of a complete power failure

(b) Each hoist holding brake shall have a torque rating not less than 125% of the full (rated) load hoisting torque at the point of brake application, and shall be capable of stopping the lowering movement within amounts of motion wherein damage to load or facility would not occur. A maximum lowering distance of 3 in. is recommended. Under normal operating conditions, the brakes shall apply automatically on power removal. The application of the second (and any other additional) brake(s) shall be delayed to minimize shock to the hoist drivetrain.

(c) The braking system shall have thermal capacity for the frequency of operation required by the hoist duty service classification.

(d) The hoist holding brakes shall have provision for adjustment to compensate for lining wear.

(e) The Type IA hoist braking system shall comply with at least one of the following:

1. Three or more holding brakes shall be provided for stopping and holding the load, such that after failure of any one holding brake or hoist machinery component, at least two holding brakes remain available for emergency load lowering.
2. Two brakes, each capable of stopping and holding the load, may be provided if one of them acts directly on the wire rope drum shell or a flange or disk attached thereto, is not the primary stopping and holding brake, and does not set prior to the wire rope drum coming to a complete stop during normal
operation. The brake acting on the drum shall have sufficient thermal capability to permit emergency lowering of rated load from normal high hook position to normal low hook position at maximum design full-load lowering speed in one continuous operation, and shall have a torque-modulating method of manual release.

(3) Two brakes, each capable of stopping and holding the load, may be provided if the hoist also has a mechanical or electrical control braking means that prevents the rated load from lowering faster than design maximum lowering speed with power off. The control braking system shall be capable thermally and in all respects of lowering the rated load from normal high hook position to normal low hook position in one continuous operation. One of the two stopping and holding brakes and the control braking means shall remain effectively connected to the hoist drivetrain after failure of the other brake or any component of the hoist machinery. The design of the brakes and the arrangement of the braking system shall enable recovery from an inoperable brake by repair of the brake in place or replacement of the brake, with rated load on the hoist, or by an alternative recovery means acceptable to the purchaser.

HT-2.4 ELECTRICAL (Type IA)

HT-2.4.1 General. All electrical equipment furnished shall conform to the applicable sections of the latest issue of NFPA 70. The owner shall specify the voltage, frequency, and phase of the power supply. The supply voltage shall be maintained within ±10% of the rated motor voltage of the hoist with motor operating at rated load.

HT-2.4.2 Controllers

HT-2.4.2.1 Types of Control. The type of control supplied for a hoist shall result in operation complying with the performance as defined in Section GR-3.

(a) Common control systems may be one of the following:

(1) single-speed AC magnetic reversing, which uses an AC squirrel-cage induction motor.

(2) two-speed AC magnetic reversing, which uses a dual-wound AC squirrel-cage induction motor. Speed ratios under any load are normally 3 to 1, but may also be furnished in other ratios, such as 2 to 1 or 4 to 1.

(3) variable-speed AC magnetic reversing, which is a type of constant potential AC control that uses resistance in the secondary of an AC wound rotor induction motor. Three to five speed steps are normally provided, with the speed at each step varying depending on the load.

(4) AC variable-frequency control, which uses an AC squirrel-cage induction motor and provides either stepped or stepless speed control by varying the motor frequency (see HT-2.4.2.2).

(b) Other Control Systems. Other control systems, such as adjustable-voltage DC and adjustable-voltage AC, may be required depending on the specific application or owner specifications.

HT-2.4.2.2 Variable-Frequency Drive (VFD) Hoist Controls. The general requirements are as follows:

(a) Control shall consist of a variable-frequency drive (VFD) with a full load ampere (FLA) rating equal to, or greater than, the FLAs of the corresponding motor(s).

(b) Control shall include, as a minimum, the following protective features:

(1) output phase loss
(2) undervoltage
(3) overvoltage
(4) motor thermal overload
(5) VFD overheat

(c) Control shall provide a control braking means using dynamic braking or line regeneration.

(d) Control shall have a minimum of 150% overload capability for 1 min.

(e) The power supply and electronic equipment shall be protected from detrimental effects due to harmonic and electromagnetic interference/radio frequency interference (EMI/RFI) emissions produced by inverters.

(f) For VFDs used in hoisting applications that do not use a mechanical load brake, speed feedback shall be incorporated.

HT-2.4.2.3 Contactors. Each magnetic control shall have contactors sized for the specified service. Reversing contactors shall be interlocked to guard against line-to-line faults.

HT-2.4.3 Motors

HT-2.4.3.1 General

(a) Alternating-Current Motors

(1) Definite-Purpose Inverter-Fed Motors. AC squirrel-cage motors applied to VFDs shall be specifically designed for inverter duty and shall conform to NEMA MG-1, Part 31, or other standard as approved by the owner.

(2) Definite-Purpose Wound Rotor Induction Motors. AC wound rotor motors shall conform to NEMA MG-1, Parts 18.501 through 18.520.

(3) Other AC Motors. All other AC motors not already described shall conform to NEMA MG-1.

(b) Direct-Current Motors. DC motors shall be in accordance with either NEMA MG-1 or AISE Standard No. 1.

(c) All AC or DC motors shall have enclosures and time ratings as required for the duty and environmental conditions.

(d) Motors shall be reversible, with torque characteristics suitable for hoist or trolley service, and
capable of operation at rated loads and speeds in accordance with the class of service specified.  
(e) Temperature rise of motors shall be in accordance with the latest NEMA standards for the class of insulation and enclosure used. The hoist manufacturer will assume 104°F (40°C) ambient temperature unless otherwise specified by the owner.  
(f) Hoist motors shall have phase loss and phase reversal protection.  

HT-2.4.3.2 Motor Voltage  
(a) All AC motors at rated frequency and all DC motors shall be capable of operation within ±10% of rated motor voltage, but not necessarily at rated voltage performance.  
(b) Standard rated motor voltage shall be in accordance with Table HT-2.4.3-1.  
(c) For nominal system voltages other than shown in Table HT-2.4.3-1, the rated motor voltage should not be less than 95% or more than 100% of the nominal system voltage.  

<table>
<thead>
<tr>
<th>Power Supply</th>
<th>Nominal System, V</th>
<th>Rated Motor, V</th>
<th>Permissible Motor Operating Range, V</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC, Single Phase 60 Hz</td>
<td>120</td>
<td>115</td>
<td>104 to 126</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>230</td>
<td>207 to 253</td>
</tr>
<tr>
<td>AC, Polyphase 60 Hz</td>
<td>208</td>
<td>200</td>
<td>180 to 220</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>230</td>
<td>207 to 253</td>
</tr>
<tr>
<td>AC, Polyphase 50 Hz</td>
<td>480</td>
<td>460</td>
<td>414 to 506</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>575</td>
<td>518 to 632</td>
</tr>
<tr>
<td>DC</td>
<td>208</td>
<td>200</td>
<td>180 to 220</td>
</tr>
<tr>
<td></td>
<td>230</td>
<td>220</td>
<td>198 to 242</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>380</td>
<td>342 to 418</td>
</tr>
<tr>
<td>DC</td>
<td>125</td>
<td>115</td>
<td>104 to 126</td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>120</td>
<td>108 to 132</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>230</td>
<td>207 to 253</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>240</td>
<td>216 to 264</td>
</tr>
</tbody>
</table>

(b) The use of 60-min or continuous duty motors shall be considered for use with long lift hoists.  
(c) Under unusual conditions, such as abnormal inching or jogging requirements, cyclical hoist movements, altitudes more than 3,300 ft above sea level, abnormal ambient temperatures, etc., the motor time rating shall be increased as appropriate.  

HT-2.4.3.3 Motor Time Rating. The motor time rating shall result in operation complying with the specified performance as defined in Section GR-3, taking into consideration any supplemental requirements specified by the owner.  
(a) Minimum Time Ratings. Single-speed, two-speed, variable-speed and inverter-fed motors shall be rated on no less than a 30-min basis under rated load, with the temperature rise in accordance with the class of insulation and enclosure used. The low-speed winding of a two-speed motor may be rated less than 30 min, and the lower stepping speeds of a variable-speed control will have a substantially lower operating time.  

HT-2.4.3.4 Hoist Motor Size Selection. Electric motors shall have a required rated motor horsepower not less than that given by the following formula:

\[ HP_{\text{required}} = HP_{\text{mechanical}} \times K_c \]

Where

\[ HP_{\text{mechanical}} = \frac{WV}{33,000E} \]

and

\[ E = \text{mechanical efficiency between the load and the motor, expressed in decimal form, where} \]

\[ E = E_g^n \times E_s^m \]

\( E_g \) = efficiency per gear reduction  
= 0.97 for spur, herringbone, and helical gearing supported on antifriction bearings  
= 0.93 for spur, herringbone, and helical gearing supported on sleeve bearings (for worm gearing, consult the gear and hoist manufacturer)  
\( E_s \) = rope system efficiency per rotating sheave  
= 0.99 for rotating sheaves supported on antifriction bearings  
= 0.98 for rotating sheaves supported on sleeve bearings  
\( K_c \) = control factor, which is a correction value that accounts for the effects the control has on motor torque and speed  
= 1 for the majority of controls, such as AC wound rotor magnetic, inverter, or static systems where there are no secondary permanent slip resistors, systems for squirrel-cage motors, and constant potential magnetic systems with DC power supplies  
\( m \) = the number of rotating sheaves between the drum and equalizer passed over by each part of moving rope attached to the drum  
\( n \) = the number of gear reductions  
\( V \) = specified speed when lifting weight \( W, \) ft/min  
\( W \) = total weight to be lifted, lb. (rated load plus the weight of the load block)
For AC wound rotor systems, magnetic or static control with secondary permanent slip resistors, \( K_c \) shall be as follows:

\[
K_c = \frac{\text{motor-rated full load, rpm}}{\text{motor rated rpm, when hoisting}}
\]

\( K_c \) values for power supplies rectified on the hoist shall be determined by consulting with the motor and control manufacturers.

**HT-2.4.4 Limit Devices**

**HT-2.4.4.1 General.** A limit device is defined as a switch or sensing system to provide control functions on the crane. This subsection includes requirements for control limit devices that activate when the normal operating envelope has been reached and safety-critical limit devices that indicate malfunction, failure, or inadvertent operator action. Additional limit device requirements not addressed in this section shall be incorporated in the specifications.

**HT-2.4.4.2 Type IA Hoist Safety-Critical Limit Devices**

(a) This paragraph includes additional requirements for the following safety-critical limit devices:

1. Final high hoist overtravel
2. Overload limit
3. Hoist drum wire rope mis-spooling
4. Hoist overspeed
5. Equalizer travel error

(b) Manual Reset. When a safety-critical limit device is activated, a manual reset is required. This may be accomplished by means of a key switch on the crane or some other administrative control that will prevent the crane operator from resetting the affected function before a person knowledgeable in the crane control system determines and corrects the cause of device activation.

(c) Safety-Critical Limit Devices. Safety-critical limit devices shall be in addition to and separate from the limiting means or control devices provided for operation unless independently monitored.

**HT-2.4.4.3 Overtravel Protection.** Hoists shall have the following:

(a) First High Hoist Overtravel Limit. The first upper hoisting limit shall be a control circuit device such as a geared-type, weight-operated, or paddle-operated switch. Actuation of this switch shall result in the removal of power from the motor and setting the hoist brakes. The operator may lower or back out of this tripped switch without further assistance.

(b) Final Hoist High Overtravel Limit. In addition to the first upper limit switch, a final power circuit hoisting limit switch shall directly remove power from the hoist motor and set the hoist brakes.

(c) If the hoist is designed to withstand two-blocking, only the first high hoist overtravel limit switch is required. In this case, the ropes shall not be cut or crushed, nor the hoist damaged in the event of load block overtravel.

(d) Low Hoist Overtravel Limit. The hoist shall include an overtravel low limit switch. This switch may be of the control circuit type. Actuation of this switch shall stop the lowering motion and set the hoist brakes. The operation of this switch shall not prevent hoisting.

**HT-2.4.4.4 Overload Limiting Devices.**

(a) An overload-limiting device, when furnished, shall be designed to permit operation of the hoist within its rated load and to limit the amount of overload that can be lifted by a properly maintained hoist, under normal operating conditions.

(b) The overload-limiting device may allow the lifting of an overload, but shall be designed to prevent the lifting of an overload that could cause damage to the hoist. This does not imply that any overload is to be intentionally applied to the hoist.

**HT-2.4.4.5 Hoist Drum Wire Rope Spooling Monitor.** Hoists shall include a wire rope spooling device to detect improper threading of the hoist rope in the hoist drum grooves. Actuation of this device shall result in removal of power from the hoist motor and the setting of hoist holding brakes. Actuation of this limit device shall prevent further hoisting. A mechanical rope guide that encompasses the circumference of the drum and provides spooling of the wire rope onto the drum may be used in lieu of a spooling device.

**HT-2.4.4.6 Hoist Overspeed Limits.**

(a) Electrically operated hoists that handle critical loads shall include an overspeed limit device (switch or sensing system). When handling a critical load, hook speeds greater than 115% of the design critical load- lowering speed shall actuate this device, causing all holding brakes to set without intentional time delay. Operation of this device may also initiate any control braking means normally used for stopping of the load. It shall be necessary to position the hoist motion master switch in the neutral or OFF position and to manually reset the overspeed limit device (or the overspeed circuit) before operation can be resumed.

(b) The overspeed device for wire rope hoists shall be located so that it monitors drum rotation irrespective of a single failure in the drivetrain.

(c) On hoists that provide high-speed, light load features, provisions may be made to permit override of this overspeed limit device when handling noncritical loads.

**HT-2.4.4.7 Equalizer Travel Error Indication Device.** A sensing and signaling
means shall be provided to automatically shut down the hoist and provide indication to the operator if displacement between the separate reeving systems exceeds design operating limits.

**HT-2.4.5 Control Enclosures.** Control enclosures, unless otherwise specified by the owner, shall be in accordance with NEMA ICS 6. Enclosure types, as defined by NEMA, include, but are not limited to:

(a) NEMA Type 1: general purpose for indoor applications
(b) NEMA Type 3: watertight, dust-tight, and sleet (ice) resistant; outdoor
(c) NEMA Type 3R: rainproof and sleet resistant; outdoor
(d) NEMA Type 4: watertight and dust-tight; indoor and outdoor
(e) NEMA Type 4X: watertight, dust-tight, and corrosion resistant; indoor and outdoor
(f) NEMA Type 7: Class I, Groups A, B, C, and D; indoor hazardous locations (explosive atmosphere)
(g) NEMA Type 9: Class II, Groups E, F, and G; indoor hazardous locations (explosive atmosphere)
(h) NEMA Type 12: industrial use; dust-tight and drip-tight; indoor

**HT-2.4.6 Additional Electric Equipment.** Additionally, each Type IA electric operated wire rope hoist shall have the following:

(a) Phase Loss Protection
(b) Phase Reversal Protection
(c) Mainline magnetic contactor operated by a power off or emergency stop button
(d) Motor thermal detectors

**HT-2.4.7 Resistors.** Resistors, when furnished, shall have sufficient thermal capacity for the class of service specified. Enclosures for resistors shall provide means for heat dissipation and shall be installed to minimize the accumulation of combustible matter. Provision shall be made to contain broken resistor parts or molten metal.

**HT-2.4.8 Current Conductor Systems.** Current conductor systems are not normally supplied with electric wire-rope hoists. When required, they shall be specified by the owner. Standard systems include the following:

(a) flexible cable
(b) coiled cord
(c) festooned cable arrangement
(d) cable reel
(e) rigid conductor
(f) energy chain

**HT-2.5 PNEUMATIC (Type IA)**

**HT-2.5.1 Air Supply.** Hoists shall operate on an air supply which is essentially clean and dry with the pressure being 90 psi (6.3 bar), although air systems at 105 psi (7.3 bar) may be used if accepted by both the owner and hoist manufacturer. Unless specified otherwise, the maximum moisture content of the air is to be 0.002 lb. of water per pound of dry air at 60°F and 90 psi absolute, with the maximum solid particulate contamination limited to 25 microns. The owner’s main air supply shall be sufficient to accommodate the total air consumption of all air motors, with this consumption rate (cfm) provided by the manufacturer. The owner’s main air supply shall include a building mounted shutoff valve and an air regulator valve in the area of the hoist or crane. Additionally, the owner shall provide a relief valve system to prevent excessive air pressure from damaging the hoist as could be developed by the owner’s air compressor system.

**HT-2.5.2 Air Motors.** The air motor shall be an air-driven piston or rotary vane type and shall be provided with an air inlet connection fitted for the use of air hose assemblies. Also, the air motor shall be provided with an oiler and air filter between the motor and the air inlet connection. The motor shall have adequate capacity to lift 125% of the rated load. The air motor shall have a required rated motor horsepower not less than that given by the following formula:

\[ H_{\text{required}} = \frac{WV}{33,000E} \]

Where \( V, W \) and \( E \) are defined under HT-2.4.3.4.

**HT-2.5.3 Additional Air Hoist Equipment.** Air hoist motors shall be furnished with the necessary directional valves, a dump valve operated by a power off or emergency stop button, and a hoist mounted regulator and pressure gauge to confirm the pressure at the hoist. The air motor exhausts shall include as necessary an exhaust filter and muffler. Mufflers are required for indoor service and shall be such that the motor sound level for each hoist shall be 80 db or less, 3 feet from the muffler, unless specified otherwise by the owner.

**HT-2.5.4 Limiting Devices for Air Operated Hoists.** Limiting devices for a Type IA air operated wire rope hoist shall be the same as those for a Type IA electric wire rope hoist, with the requirement for these devices listed under HT-2.4.4. However, for an air operated hoist some of these devices may need to be electrically operated where the device would then fall into the category of an “electric-over-air” operated device.

**HT-2.6 OPERATOR CONTROL STATION (Type IA)**

The hoist’s operator control station type and location, with inclusion of any other motions (i.e., trolley,
bridge and jib) shall be as specified by the owner. Examples of various operator control stations are as follows:

(a) Floor Operated, where the equipment motion is controlled by an operator on the floor, or on an independent platform, through use of a suspended pendant station.

(b) Remote Operated, where the equipment motion is controlled by an operator though use of controllers contained in a remote operating station not attached to the hoist, trolley or crane, or by means of a radio transmitter.

(c) Cab Operated, where the equipment motion is controlled by an operator through use of controllers located in an enclosed or open cab attached to the hoist, trolley or crane.

(d) Pulpit Operated, where the equipment motion is controlled by an operator though use of suspended self-centering nonconducting pull cords with handles.

All operator control stations shall meet the criteria as addressed in the ASME B30.16 and B30.17, safety standards. Arrangement of the control station’s controllers or master switches are provided under CM-4.1.1.5.

HT-2.7 SEISMIC (Type IA)

The Type IA hoist unit, being of a compact design and suspended from a crane or monorail, shall be considered a lumped mass for input into the crane or monorail seismic analysis as addressed in Section CM-2. However, the hoist unit itself shall be analyzed to ensure that the hoist unit, and the trolley to which it is connected, remain in place during and after a seismic event. As required, seismic restraints shall be provided for this purpose. Allowable stresses of mechanical fasteners of hoist and trolley connections under seismic loads shall not exceed 90% of the yield strength of the fastener.

HT-2.8 HOIST MARKING (Type IA)

(a) For Type IA hoists, the maximum critical load rating (MCL) shall be marked on the hoist or load block, using the terminology MCL as part of the marking.

(b) For Type IA hoists that lift loads in excess of the MCL, the terminology DRL (design rated load) shall be used and shall also be marked on either the hoist or hoist load block.

HT-2.9 INSPECTIONS & TESTS FOR POWERED WIRE ROPE HOISTS (Type IA)

HT-2.9.1 Hoist Component Inspections or Tests. The required component inspections and tests for a Type IA powered wire rope hoist shall be as listed in Table HT-2.9.1-1, with the specific criteria for these inspections and tests being as follows:

(a) Material Test Reports shall include both chemical analysis and physical properties on the actual component materials of those items listed on Table HT-2.9.1-1.

(b) Surface Magnetic Particle Testing (MT) or Penetrant Testing (PT) shall be performed on the hoist hook(s) and hook-nut(s) or attachment devices after performing the hook proof load test of HT-2.9.1-1. Other components as listed on Table HT-2.9.1-1 which require surface MT or PT shall require these tests on the finished component part. The MT and PT procedures and acceptance criteria shall be in accordance with Section HT-7.

(c) Impact Testing, either Charpy-V or Drop Weight, shall be performed on the actual component material of those items listed on Table HT-2.9.1-1, unless the component material has a thickness of 5/8” or less. The Charpy-V or Drop Weight testing criteria shall be in accordance with Section HT-7.

(d) Breaking Strength Test for the hoist wire rope shall be performed on the actual hoist rope, or on the actual rope lot used on the hoist, and shall require the wire rope to be pulled to the breaking load. Additionally, where rope end fittings are used in direct tension in the load path, at least one identical fitting shall be tested with the rope sample being pulled to failure, confirming that failure occurs in the rope and not at the fitting.

(e) The welds as listed on Table HT-2.9.1-1 shall require NDE, consisting of visual examination and either magnetic particle testing (MT) or liquid penetrant testing (PT), with procedures and acceptance criteria in accordance with Section HT-7. Such welds shall also require weld filler metals to have an actual certificate of conformance for the specific production batch providing operating parameters, mechanical properties and chemical composition. Additionally, all such welds shall be performed by welders who have been AWS certified for the specific welding process that was used, with these certificates provided as part of the documentation package.

(f) A Certificate of Conformance shall be furnished specifically for the hoist wire rope, separate from any other Certificates of Conformance. This wire rope certificate, which may be provided as part of the documentation on the wire rope breaking strength test, shall specify the safe working load limit and the breaking load. This certificate shall also identify the wire rope’s diameter, rope lay, manufacturer’s designation of the rope grade, and all construction details of the rope strands, individual wires and rope core. Any limitations or restrictions on the use of the rope with regard to sheave diameters or fleet angles shall be identified in this certificate.

(g) A Certificate of Conformance shall be furnished specifically for any wire rope end fittings (such as eyes and sockets), separate from any other Certificates of Conformance. This wire rope end fitting certificate, which may be provided as part of the documentation on the wire rope end fitting proof test,
shall specify the type of end fitting, the terminations efficiency and any limitations on this efficiency due to the rope’s construction or grade.

(h) A Certificate of Conformance shall be furnished for each different hoist sheave by the sheave manufacturer, separate from any other Certificates of Conformance. This sheave certificate shall identify the sheave manufacturer, sheave part or stock number, sheave pitch diameter, wire rope size to be accommodated, groove depth, capacity rating, and sheave material.

(i) The components as listed on Table HT-2.9.1-1 shall require ultrasonic testing (UT) of the finished item, with procedures and acceptance criteria in accordance with Section HT-7.

(j) Hooks shall be proof load tested in accordance with the criteria of ASME B30.10, with throat opening dimensions taken before and after this test. This test shall also include the proof testing of the hook nut or hook attachment device.

(k) The proof load test of any wire rope end fitting shall be performed at 40% of the rope’s published breaking strength.

(l) Documentation on the above listed component inspections, tests and certificates of conformance shall be furnished as part of the Seller’s documentation package to qualify the hoist as NUM Type IA.

Table HT-2.9.1-1 Required Hoist Component Inspections or Tests (Type IA Powered Wire Rope Hoists)

<table>
<thead>
<tr>
<th>Material</th>
<th>Test Report (Note 1)</th>
<th>C of C (Note 2)</th>
<th>NDE of Welds (Note 3)</th>
<th>UT (Note 4)</th>
<th>Surface MT or PT (Note 5)</th>
<th>Impact Test (Note 6)</th>
<th>Proof Load Test (Note 7)</th>
<th>Breaking Strength Test (Note 8)</th>
<th>Weld Filler Material C.C. (Note 3)</th>
<th>Welder Certs (Note 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hook</td>
<td>X</td>
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<td>Hook nut or attachment device</td>
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<td>Hook trunnion cross head &amp; load block structure (cast or forged)</td>
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<tr>
<td>Hook trunnion cross head &amp; load block structure (rolled)</td>
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<td>Load block structure welds</td>
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<td>Load block sheave pin</td>
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<td>Wire rope end fittings (such as eyes &amp; sockets)</td>
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<td>Hoist drum</td>
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<td>Hoist drum shell &amp; hub welds</td>
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<td>Hoist drum shaft</td>
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<td>Upper block sheave pin</td>
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<td>Upper block load structure (cast or forged)</td>
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<td>Upper block load structure (rolled)</td>
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<td>Upper block structural welds</td>
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<td>Sheaves</td>
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<tr>
<td>Gears, pinions &amp; shafts</td>
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</tbody>
</table>

NOTES:

(1) Material Test Reports shall be per HT-2.9.1(a).
(2) Certificate of Conformance (C of C) criteria are to be per HT-2.9.1(f) for hooks, HT-2.9.1(g) for hook nuts, and HT-2.9.1(h) for sheaves.
(3) Specific criteria for NDE of Welds, and criteria for Weld Filler Material C of C, and Welder Certs are to be per HT-2.9.1(e).
(4) Specific criteria for the UT of components are to be per HT-2.9.1(i).
(5) Specific criteria for Surface MT or PT are to be per HT-2.9.1(b).
(6) Specific criteria for Impact Tests are to be per HT-2.9.1(c).
(7) Proof Load Test criteria are to be per HT-2.9.1(j) for Hooks and Hook Nut or attachment device, and per HT-2.9.1(k) for Wire Rope End Fittings.
(8) Specific criteria for Breaking Strength Test of wire rope and rope end fittings are to be per HT-2.9.1(d).
HT-2.9.2 Hoist Shop Performance and Shop Load Tests. Each Type IA power operated wire rope hoist shall require the following shop performance and shop load tests:

**HT-2.9.2.1 No-Load Performance Test.** A no-load shop performance test shall be conducted through all speeds utilizing the operator control station. If the actual control station is not available, a duplicate control station may be used for test purposes. The maximum no-load speed shall be documented. This performance test shall also verify the operation of all upper and lower limit devices with these initial limit device tests being at the lower hoist speeds.

**HT-2.9.2.2 Two-Block Test.** With all high hoist overtravel limit switches bypassed, the hoist shall be two-blocked to demonstrate that the equipment is capable of being two-blocked without damage, and specifically confirming that the wire rope is not cut or damaged. It is recommended that the two-block test be conducted at the highest hoisting speed produced by normal operations. However, the owner and supplier may agree on alternate speeds for this test or alternative methods for demonstrating the capability of the equipment to withstand two-blocking.

**HT-2.9.2.3 Rated Load Test (125% of MCL).** A hoist rated load test of at least 125% of the MCL rating shall be performed.

**HT-2.9.2.4 Overload Limit Test.** A load shall be applied above the hoist’s MCL rating to confirm and document the overload setting. Air operated hoists which adjust the air pressure lower to set an inherent overload limiting capability of the hoist, shall require documentation of the no-load speed at this lower air pressure to supplement the original no-load performance test.

**HT-2.9.2.5 Performance Test (100% of MCL).** A hoist performance test at 100% of the MCL rating shall be performed, documenting the maximum hoist raising and lowering speeds for the MCL rating.

**HT-2.9.2.6 Redundant Holding Brake Test.** The redundant hoist holding brakes shall be verified to confirm that each braking system can independently hold the 100% MCL rating.

**HT-2.9.2.7 Loss of Power Test.** While raising and lowering 100% of the MCL rating the main power, electric or air, shall be interrupted to confirm that the holding brake systems engage to hold the MCL. Manually operated load-lowering devices, if supplied, shall be tested.

**HT-2.9.2.8 Shop Test Documentation.** Documentation on the above listed shop tests shall be furnished as part of the Seller’s documentation package to qualify the hoist as NUM Type IA.

**HT-2.9.3 Site Load Tests.** Hoists suspended from a crane or monorail shall be site load tested as stated under section CM-7.1.7 of NUM Part-CM.
Section HT-3
Powered Wire Rope Hoists (Type IB)

HT-3.1 GENERAL

This section provides the requirements for powered (electric or air) operated Type IB hoists for enhanced safety vertical lifting of freely suspended, unguided loads using wire rope as a lifting medium.

A Type IB powered wire rope hoist shall be a standard hoist meeting the criteria of ASME B30.16, and either ASME HST-4 for electric operation or ASME HST-6 for pneumatic (air) operation, with its maximum critical load (MCL) rating being no more than \(\frac{1}{2}\) of its original design capacity per these standards. However, to qualify for this Type IB classification, the hoist must also meet the additional design, inspection, testing and documentation requirements of this section.

NOTE: As an example, for a hoist to qualify as a 2-ton MCL rated Type IB hoist, its original design rating would have to be 4 ton or greater, but if it did not meet the additional design, inspection, testing and documentation requirements of this section, it would not be qualified as a Type IB hoist.

HT-3.2 EQUIPMENT CONFIGURATIONS (Type IB)

(a) The hoisting machinery from the motor to the drum is not designed to tolerate a single component failure. Instead, increased design factors are applied to reduce the probability of a component failure such that it is no longer considered to be a credible failure.

(b) The equipment configurations are similar to those of a standard wire rope hoist noting that a Type IB hoist must have a secondary means of holding the load, or retarding the lowering speed of the load to an evaluated facility acceptable limit.

(c) Figures HT-3.2-1 and HT-3.2-2, provide block diagrams illustrating examples of Type IB wire rope hoist equipment configurations. These block diagrams show conceptual layouts only. These block diagrams may be rearranged as needed to meet the specific application. These diagrams are only a few of many acceptable configurations.
HT-3.3 MECHANICAL (Type IB)

All load suspension parts shall be designed so that the static stress calculated for the MCL rating shall not exceed 10% of the minimum tensile strength.

NOTE: This equates to all load suspension parts being designed to a static stress on the hoist’s original design rating of 20% of the minimum tensile strength.

HT-3.3.1 Reeving. Hoist reeving may be either single or double and may be one part or multiple parts. Since such standard reeving systems are not single failure proof and cannot safely accommodate a two-blocked condition, a limiting device is required to prevent two-blocking. (See Section HT-3.3.7.)

(a) On single-reeved hoists, one end of the rope is attached to the drum. Continuous drum grooving runs in one direction. The load block moves laterally in the direction of the axis of the drum as the rope winds onto or off of the drum. Refer to Fig. HT-3.3.1-1.

(b) On double-reeved hoists, both ends of the rope are attached to the drum. The drum is grooved with left-hand and right-hand grooves beginning at both ends of the drum, then grooving toward the center of the drum. The load block will follow a true vertical path (true vertical lift) as the ropes wind toward or away from each other onto or off of the drum. Refer to Fig. HT-3.3.1-2.

Figure HT-3.3.1-1 Single-Reeved Hoist

Figure HT-3.3.1-2 Double-Reeved Hoist

HT-3.3.2 Hooks. Hooks shall have a design factor of at least 10 to 1 on the hoist’s MCL rating, based upon the average ultimate load or force at which the hook fails or no longer supports the load. Hooks shall be proof load tested based upon the hook’s original working load limit, before being derated for use on an MCL hoist, as specified under section HT-3.8.1.

HT-3.3.3 Wire Rope. Wire ropes shall have a multi-strand construction for a powered hoisting application. Ropes shall meet the criteria of ASME B30.16 except that they shall have a design factor of at least 10 to 1 on the hoist’s MCL rating based upon the rope’s minimum breaking force. Wire ropes shall be pull tested to their breaking load as required under HT-3.8.1.

HT-3.3.4 Sheaves

(a) The pitch diameter of running sheaves shall not be less than 16 times the rope diameter.

(b) The pitch diameter of nonrunning sheaves shall not be less than 12 times the rope diameter

HT-3.3.5 Drums

(a) Drums shall be grooved for a single layer of rope, and shall have a grooved depth of at least 40% of the rope diameter. Hoist designs utilizing multi layers of rope are not covered by this standard.
(b) Drums shall have a pitch diameter of not less than 18 times the rope diameter.

HT-3.3.6 Hoist Brakes. A Type IB powered wire rope hoist shall have a primary disc type holding brake, as well as a backup braking means to hold the load consisting of either an additional holding brake, or a gearcase mounted mechanical load brake. Each holding brake shall have a torque rating of at least 125% of the motor torque and shall be capable of holding 125% of the hoist’s original design rated load. A mechanical load brake (if used) shall be capable of holding 125% of the hoist’s original design rated load. Each brake’s holding capability shall be confirmed during shop testing as specified under section HT-3.8.2.

HT-3.3.7 Limit Devices. A Type IB powered wire rope hoist shall have the following limit devices:

(a) High Hoist Overtravel Limit Device. To prevent two-blocking, two upper limit devices shall be provided, with the first to trip being of the rotary type based on drum rotation, and with the second and final to trip being a load block actuated device. The second and final block actuated device shall remove power directly to the motor and set the holding brake(s). This final high hoist overtravel limit device shall require a manual reset.

(b) Lower Limit Device. A lower limit device shall be furnished to prevent the wire rope from being disengaged at the hoist’s lowest limit.

(c) Overload Limit Device. A positive hoist overload limiting means independent of the hoist controls shall be furnished for all Type IB powered wire rope hoists. This means shall be provided by either incorporating an overload limiting device, or for air operated hoists by the inherent overload limiting capability of the air motor. The following are acceptable configurations:

1. A separate overload limiting device as provided in the hoist’s suspension system to stop hoist lifting operations.

2. A gearcase mounted overload clutch as located in the hoist drive train.

3. An air motor providing an inherent overload capability in that air just passes through the motor when its designed lifting capacity is reached.

All of the above overload limiting features, shall allow the operator to lower the overload.

Note, in that a Type IB powered wire rope hoist is rated at ½ the capacity of the hoist’s original design load, an overload clutch, or air motor overload limiting capability, will have been designed for this higher original design load. These original overload limiting capabilities can be lowered some by adjusting the clutch setting or by regulating the air pressure, however the limiting capability may still be about 200-250% of the MCL rating. High overload settings such as these require that the crane and its supporting structure be analyzed for this extreme overload condition.

HT-3.4 ELECTRICAL (Type IB)

HT-3.4.1 Electrical Supply. Electric operated hoists shall operate on the Owner specified power supply with regard to voltage, frequency and phase. The supply voltage shall be maintained within ±10% of rated motor voltage at the hoist with the motor operating at the design rated load. The rated motor voltage should not be less than 95% or more than 100% of the nominal system voltage. See Table HT-2.4.3-1 under the Type IA wire rope hoist requirements for a listing of various nominal system voltages and rated motor voltages.

HT-3.4.2 Electric Motors. The electric motor shall be reversible alternating current (AC) squirrel-cage (single or dual wound) induction motor, definite purpose inverter-fed induction motor, or definite purpose wound rotor induction motor. Other AC motors or direct current (DC) motors which are not listed may be used, but being less common are not listed. The motor shall have capacity to lift 125% of the design rated load, which is at least twice the maximum critical load (MCL). The electric motor shall have a rated motor horsepower on the design rated load not less than that given by the following formula:

\[
HP_{\text{required}} = HP_{\text{mechanical}} \times K_c
\]

Where

\[
HP_{\text{mechanical}} = \frac{WV}{33 \times 1000 E}
\]

and

\[V = \text{specified speed when lifting weight } W, \text{ ft/min} \]
\[W = \text{total weight to be lifted, lb. (design rated load plus the weight of the hook & load block)} \]
\[E = \text{mechanical efficiency between the load and the motor, expressed in decimal form} \]
\[K_c = \text{control factor, which is a correction value that accounts for the effects the control has on motor torque and speed} \]

For values and computations of \(E\) and \(K_c\) see Section HT-2.4.3.4 under the Type IA wire rope hoist requirements.

HT-3.4.3 Controllers. Controllers for Type IB electric operated hoists shall be in accordance with the Type IA criteria of section HT-2.4.2.

HT-3.4.4 Additional Electric Equipment. Additionally, each Type IB electric operated wire rope hoist shall have the following:
(a) Phase Loss Protection
(b) Phase Reversal Protection
(c) Mainline magnetic contactor operated by a power off or emergency stop button
(d) Motor thermal detectors

HT-3.5 PNEUMATIC (Type IB)

HT-3.5.1 Air Supply. Pneumatic hoists shall operate on an air supply which is clean and dry with the pressure being 90 psi (6.3 bar), although air systems at 105 psi (7.3 bar) may be used if accepted by both the owner and hoist manufacturer. Unless specified otherwise, the maximum moisture content of the air is 0.002 lb. of water per pound of dry air at 60°F and 90 psi absolute, with the maximum solid particulate contamination limited to 25 microns. The owner’s main air supply shall be sufficient to accommodate the total air consumption of all air motors, with this consumption rate (cfm) provided by the manufacturer. The owner’s main air supply shall include a building mounted shutoff valve and air regulator valve in the area of the hoist or crane. Additionally, the owner shall provide a relief valve system to prevent excessive air pressure from damaging the hoist.

HT-3.5.2 Air Motors. The air motor shall be an air-driven piston or rotary vane type and shall be provided with an air inlet connection fitted for the use of air hose assemblies. Also, the air motor shall be provided with an oiler and air filter between the motor and the air inlet connection. The motor shall have adequate capacity to lift 125% of the design rated load, which is at least twice the maximum critical load (MCL). The air motor shall have a required rated motor horsepower on the design rated load of not less than that given by the following formula:

\[ HP_{\text{required}} = \frac{WV}{33,000E} \]

where

- \( V \) = specified speed when lifting weight \( W \), ft/min
- \( W \) = total weight to be lifted, lb. (design rated load plus the weight of the hook & load block)
- \( E \) = mechanical efficiency between the load and the motor, expressed in decimal form

For values and computations of \( E \) see Section HT-2.4.3.4 under the Type IA wire rope hoist requirements.

HT-3.5.3 Additional Air Equipment. Air hoist motors shall be furnished with the necessary directional valves, a dump valve operated by a power off or emergency stop button, and a hoist mounted regulator and pressure gauge to confirm the pressure at the hoist. The air motor exhausts shall include an exhaust filter and muffler. Mufflers are required for indoor service and shall be such that the motor sound level for each hoist shall be 80 dB or less, 3 feet from the muffler, unless specified otherwise by the owner.

The limiting devices for a Type IB air operated wire rope hoist shall be as stated under HT-3.3.7, noting that if a separate overload limiting device is used in lieu of adjusting the air flow, that this separate device may need to be electrically operated where the device would then fall into the category of an “electric-over-air” operated device.

HT-3.6 SEISMIC (Type IB)

The Type IB hoist unit, being based upon a standard compact hoist design and suspended from a crane or monorail, shall be considered a lumped mass for input into the crane or monorail seismic analysis. The hoist unit itself, with double the normal design factors, will not require a specific seismic analysis if the accelerations as imparted from the crane or monorail to the hoist are less than 1.0g. A loading of 1.0g or less will ensure that normal design stresses are not exceeded and that uplift will not occur. Should the hoist accelerations exceed 1.0g then additional analysis shall be required utilizing analysis methods and modeling techniques as addressed under the seismic analysis criteria of CM-7.1.7, Cranes and Monorails.

HT-3.7 HOIST MARKING (Type IB)

(a) For Type IB hoists, the maximum critical load rating (MCL) shall be marked on the hoist or load block, using the terminology MCL as part of the marking.

(b) For Type IB hoists that lift loads in excess of the MCL, the terminology DRL (design rated load) shall be used and shall also be marked on either the hoist or load block.

HT-3.8 INSPECTIONS AND TESTS (Type IB)

HT-3.8.1 Hoist Component Inspections and Tests. The required component inspections and tests for a Type IB powered wire rope hoist shall be as listed in Table HT-3.8.1-1, with the specific criteria for these inspections and tests being as follows:

(a) Material Test Reports shall include both chemical analysis and physical properties. If such test reports are not available on the actual component, then these tests may be obtained from identical spare part components or from components of a duplicate hoist where such components meet the “like-for-like” criteria of Section 402 of ASME NQA-1, Subpart 2.14.

(b) Surface Magnetic Particle Testing (MT) or Liquid Penetrant Testing (PT) shall be performed on the hoist hook(s), hook-nut(s) and any wire rope end fitting connecting pins before performing the 250% MCL shop load test as required by HT-3.8.2.3. After this load test the hoist hook(s) shall require a surface MT or PT of all exposed external areas of the hook. The hoist is not to be disassembled to inspect other
parts of the hook in that this would invalidate the 250% MCL test. The MT and PT procedures and acceptance criteria shall be in accordance with Section HT-7.

(c) Impact Testing, either Charpy-V or Drop Weight, shall be performed on the material of the hoist suspension shafts or pins having a diameter 2 inches or greater. If such tests are not available on the actual component material, then such tests shall be performed on identical spare part components or from components of a duplicate hoist where such components meet the "like-for-like" criteria of Section 402 of ASME NQA-1, Subpart 2.14. The Charpy-V or Drop Weight testing criteria shall be in accordance with Section HT-7.

(d) Breaking Strength Test for the hoist wire rope shall be performed on the actual hoist rope, or on the actual rope lot used on the hoist, and shall require the wire rope to be pulled to the breaking load.

(e) A Certificate of Conformance shall be furnished for all hooks by the hook manufacturer, (separate from any other Certificates of Conformance), identifying the hook’s working load limit, proof load and straightening load.

(f) A Certificate of Conformance shall be furnished specifically for the hoist wire rope, separate from any other Certificates of Conformance. This wire rope certificate, which may be provided as part of the documentation on the wire rope breaking strength test, shall specify the safe working load limit and the breaking load. This certificate shall also identify the wire rope’s diameter, rope lay, manufacturer’s designation of the rope grade, and all construction details of the rope strands, individual wires and rope core. Any limitations or restrictions on the use of the rope with regard to sheave diameters or fleet angles shall be identified in this certificate.

(g) A Certificate of Conformance shall be furnished specifically for any wire rope end fittings, separate from any other Certificates of Conformance. This wire rope end fitting certificate, which may be provided as part of the documentation on the wire rope end fitting proof test, shall specify the type of end fitting, the terminations efficiency and any limitations on this efficiency due to the rope’s construction or grade.

(h) A Certificate of Conformance shall be furnished for each hoist holding brake, (separate from any other Certificates of Conformance), by the brake manufacturer documenting the brake’s torque rating.

(i) A proof test of any wire rope end fitting shall be performed at 200% of the rope’s working load limit.

(j) Documentation on the above listed component inspections, tests and certificates of conformance shall be furnished as part of the Seller’s documentation package to qualify the hoist as NUM Type IB.
Table HT-3.8.1-1  Required Hoist Component Inspections or Tests (Type IB) Powered Wire Rope Hoists

<table>
<thead>
<tr>
<th>Item</th>
<th>Material Test Reports (Note 1)</th>
<th>Surface MT or PT (Note 2)</th>
<th>Impact Test (Note 3)</th>
<th>Certificate of Conformance (Note 4)</th>
<th>Breaking Strength Test (Note 5)</th>
<th>Proof Test (Note 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hook, for bottom block</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>...</td>
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<tr>
<td>Hook Nut, for bottom block</td>
<td>X</td>
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<td>...</td>
<td>...</td>
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<td>...</td>
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<td>Load Block Plates or Bolted Component Plates</td>
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<tr>
<td>Wire Ropes</td>
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<td>Wire Rope end fittings</td>
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<td>...</td>
<td>...</td>
<td>X</td>
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<td>...</td>
</tr>
<tr>
<td>Wire Rope End Connecting Pins (single reeved hoists)</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Wire Rope End Connecting Pins to an equalizer bar (double reeved hoists)</td>
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<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
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<td>Running Sheaves</td>
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<tr>
<td>Nonrunning (Equalizer) Sheaves</td>
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<tr>
<td>Sheave Pins</td>
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<td>...</td>
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<td>...</td>
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<tr>
<td>Hoist Holding Brakes</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>X</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Top Hook (for hook suspended hoists)</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Top Hook Nut (for hook suspended hoists)</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Hoist Suspension Shafts or Pins (for lug mounted hoists) (Note 7)</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

NOTES:
(1) Material Test Reports if not available on the actual hoist components, may be obtained from identical spare part components, or from components of a duplicate hoist. Criteria for these test reports are to be per HT-3.8.1(a).
(2) Specific requirements regarding MT and PT testing either before or after load testing are to be per HT-3.8.1(b).
(3) Impact Tests are required for hoist suspension shafts or pins 2 inches or larger in diameter. See HT-3.8.1(c).
(4) Certificate of Conformance criteria are to be per HT-3.8.1(e), (f), (g) and (h).
(5) Breaking Strength Test criteria are to be per HT-3.8.1(d).
(6) Proof Test criteria are to be per HT-3.8.1(i).
(7) Hoist Suspension Shafts of an Integral Hoist & Trolley Unit are addressed under Section HT-6, Underrunning Trolleys (Type IB).
HT-3.8.2 Hoist Shop Performance and Shop Load Tests. Each Type IB power operated wire rope hoist shall require the following shop performance and load tests:

**HT-3.8.2.1 No-Load Performance Test.** A no-load shop performance test shall be conducted through all speeds utilizing the operator control station. If the actual control station is not available, a duplicate control station may be used for test purposes. The maximum no-load speed shall be documented. This performance test shall also verify the operation of all upper and lower limit devices with these initial limit device tests being be at the lower hoist speeds.

**HT-3.8.2.2 Two-Block Prevention Test.** With the hoist rotary type high hoist overtravel limit device bypassed, the hoist shall be raised at maximum speed so as to trip the block actuated high hoist overtravel limit device, confirming that power is removed from the hoist motor with two-blocking prevented. Clearance of the load block from the underside of the hoist shall be confirmed, along with an inspection of the rope to verify that no damage has occurred. The separate reset function of the block actuated high hoist overtravel limit device shall also be confirmed.

**HT-3.8.2.3 Design Load Test (250% of MCL).** A hoist design load test of at least 250% of the MCL rating shall be performed, with this test also serving as a 125% proof test of the design rating of hoist hooks. Note hooks, hook nuts, and any wire rope end fitting connecting pins, are to be MT or PT examined before this test, with a baseline measurement taken of the hook’s throat opening. After this Design Load Test, the exposed accessible areas of the hooks are to be reexamined by MT or PT, with an additional measurement taken on the hook throat openings.

**HT-3.8.2.4 Overload Limit Test.** A load shall be applied above the hoist’s MCL rating to confirm and document the overload setting. Air operated hoists which adjust the air pressure lower to set an inherent overload limiting capability of the hoist, shall require documentation of the no-load speed at this lower air pressure to supplement the original no-load performance test.

**HT-3.8.2.5 Performance Test (100% of MCL).** A hoist performance test at 100% of the MCL rating shall be performed, documenting the maximum hoist raising and lowering speeds for the MCL rating.

**HT-3.8.2.6 Redundant Holding Brake System Test.** The redundant hoist holding brake systems shall be verified to confirm that each braking system can independently hold the 100% MCL rating.

**HT-3.8.2.7 Loss of Power Test.** While raising and lowering 100% of the MCL rating the main power, electric or air, shall be interrupted to confirm that the holding brake systems engage to hold the MCL. Manually operated load-lowering devices, if supplied, shall be tested.

**HT-3.8.2.8 Shop Test Documentation.** Documentation on the above listed shop tests shall be furnished as part of the Seller’s documentation package to qualify the hoist as NUM Type IB.

**HT-3.8.3 Site Load Tests.** Hoists suspended from a crane or monorail shall be site load tested as stated under section CM-7.1.7.
Section HT-4
Powered Chain Hoists (Type IB)

HT-4.1 GENERAL

This section provides the requirements for powered (electric or air) operated Type IB hoists for enhanced safety vertical lifting of freely suspended, unguided loads using chain as a lifting medium.

A Type IB powered chain hoist shall be a standard hoist meeting the criteria of ASME B30.16, and either ASME HST-1 for electric operation or ASME HST-5 for pneumatic (air) operation, with its maximum critical load (MCL) rating being no more than ½ of its original design capacity per these standards. Additionally, to qualify for this Type IB classification, the hoist must also meet the additional design, inspection, testing and documentation requirements of this section.

NOTE: As an example, for a hoist to qualify as a 2-ton MCL rated Type IB hoist, its original design rating would have to be 4 ton or greater, but if it did not meet the additional design, inspection, testing and documentation requirements of this section, it would not be qualified as a Type IB hoist.

HT-4.2 EQUIPMENT CONFIGURATIONS (Type IB)

(a) The hoisting machinery from the motor to the load chain drive sprocket is not designed to tolerate a single component failure. Instead, increased design factors are applied to reduce the probability of a component failure such that it is no longer considered to be a credible failure.

(b) The equipment configurations are similar to those of a standard powered chain hoist noting that a Type IB hoist must have a secondary means of holding the load, or retarding the lowering speed of the load to an evaluated facility acceptable limit.

(c) Figures HT-4.2-1 and HT-4.2-2, illustrate examples of Type IB powered chain hoist equipment configurations. These block diagrams show conceptual layouts only. These blocks in the diagrams may be rearranged as needed to meet the specific application. These diagrams are only a few of many acceptable configurations.

HT-4.3 MECHANICAL (Type IB)

All load suspension parts shall be designed so that the static stress calculated for the MCL rating shall not exceed 10% of the minimum tensile strength.

NOTE: This equates to all load suspension parts being designed to a static stress on the hoist’s original design rating of 20% of the minimum tensile strength.
**HT-4.3.1 Reieving.** The chain hoist reeving system, consisting of one or more parts of load chain, shall provide for a true vertical lift and shall be designed in a manner to accommodate a two blocked condition with the high hoist overtravel limit switch being bypassed. See Figs. HT-4.3.1-1 and HT-4.3.1-2 for examples of chain hoist reeving systems. Note, these figures show just two of many configurations.

**Figure HT-4.3.1-1** Powered Chain Hoist With, Two-Part Reieving

**Figure HT-4.3.1-2** Powered Chain Hoist With, Single-Part Reieving and Idler Sheaves to Obtain a Low Headroom

**HT-4.3.2 Hooks.** Hooks shall have a design factor of at least 10 to 1 on the hoist’s MCL rating, based upon the average ultimate load or force at which the hook fails or no longer supports the load. Hooks shall be proof load tested based upon the hook’s original working load limit, before being derated for use on an MCL hoist, as specified under section HT-4.8.2.3.

**HT-4.3.3 Load Chains.** Load chains shall be of the welded link type for powered hoisting applications, except that they shall have a design factor of at least 10 to 1 on the hoist’s MCL rating based upon chain’s breaking strength. Powered chain hoists using roller type load chains are not anticipated for Type IB hoists, and are not addressed in this standard. The load chains shall be pull tested to their breaking strength as required under HT-4.8.1(d).

**HT-4.3.4 Hoist Brakes.** A Type IB powered chain hoist shall have a primary disc type holding brake, as well as a backup braking means to either hold the load, or retard the load’s lowering speed to a facility acceptable limit. The holding brake shall have a torque rating of at least 125% of the motor torque for an electrically operated hoist and 150% of the motor torque for an air operated hoist. A gear case mounted mechanical load brake meets the criteria of a backup means to hold the load for either an electric or air operated hoist. Retarding the hoist lowering speed to a facility acceptable limit to meet the backup braking means may be accomplished by use of an air motor such as a rotary piston motor along with the other retarding forces of the chain hoist reeving system. Note, the inherent dynamic braking of an electric motor does provide the same degree of braking as an air motor, and therefore that configuration is not addressed in this standard.

**HT-4.3.5 Limit Devices.** A Type IB powered chain hoist shall have the following limit devices:

(a) **High Hoist Overtravel Limit Device.** Due to the design to accommodate two-blocking, only a single block operated upper limit device is required to remove power and set the holding brake when the hoist has reached its high hook position.

(b) **Lower Limit Device.** A lower limit device shall be furnished to prevent the load chain from being disengaged at the hoist’s lowest limit. This may be a lower limit switch, a chain stopper, or fixed chain end connection. If the lower limit device does not remove power, then the hoist shall be designed to accommodate the forces imposed when the end of travel is reached.

(c) **Overload Limit Device.** A positive hoist overload limiting means independent of the hoist controls shall be furnished for all Type IB powered chain hoists. This means shall be provided by either incorporating an overload limiting device, or by the inherent overload limiting capability of the hoist motor. The following are acceptable configurations:

(1) A separate overload limiting device as provided in the hoist’s suspension system to stop hoist lifting operations.
(2) A gearcase mounted overload clutch as located in the hoist drive train.
(3) An air motor providing an inherent overload capability in that air just passes through the motor when its designed lifting capacity is reached.

All of the above overload limiting features, shall allow the operator to lower the overload.

Note, in that a Type IB powered chain hoist is rated at \( \frac{1}{2} \) the capacity of the hoist's original design load, an overload clutch, or air motor overload limiting capability, will have been designed for this higher original design load. These original overload limiting capabilities can be lowered some by adjusting the clutch setting or by regulating the air pressure, however the limiting capability may still be about 200-250\% of the MCL rating. Use of a Type IB powered chain hoist with a high overload setting shall require verification of the acceptability of this higher loading on the crane or monorail from which it is suspended. See NUM Part-CM for the design requirements of the crane or monorail to accommodate a high hoist overload limit setting as an Extreme Load Case.

**HT-4.4 ELECTRICAL (Type IB)**

**HT-4.4.1 Electrical Supply.** Electric operated hoists shall operate on the Owner specified power supply with regard to voltage, frequency and phase. The supply voltage shall be maintained within \( \pm 10\% \) of rated motor voltage at the hoist with the motor operating at the design rated load. The rated motor voltage should not be less than 95\% or more than 100\% of the nominal system voltage. See Table HT-2.4.3-1 under the Type IA wire rope hoist requirements for a listing of various nominal system voltages and rated motor voltages.

**HT-4.4.2 Electric Motors.** The electric motor shall be reversible alternating current (AC) squirrel-cage (single or dual wound) induction motor, definite purpose inverter-fed induction motor, or definite purpose wound rotor induction motor. Other AC motors or direct current (DC) motors which are not listed may be used, but being less common are not listed. The motor shall have adequate capacity to lift 125\% of the design rated load, which is at least twice the maximum critical load (MCL). The electric motor shall have a required rated motor horsepower on the design rated load not less than that given by the following formula:

\[
H_{\text{required}} = H_{\text{mechanical}} \times K_c
\]

where

\[
H_{\text{mechanical}} = \frac{WV}{33,000E}
\]

and

\[
V = \text{specified speed when lifting weight } W, \text{ ft/min}
\]

\[
W = \text{total weight to be lifted, lb. (design rated load plus the weight of the hook & load block)}
\]

\[
E = \text{mechanical efficiency between the load and the motor, expressed in decimal form}
\]

\[
K_c = \text{control factor, which is a correction value that accounts for the effects the control has on motor torque and speed}
\]

For values and computations of \( E \) and \( K_c \) see section HT-2.4.3.4 under the Type IA wire rope hoist requirements.

**HT-4.4.3 Controllers.** Controllers for Type IB electric operated hoists shall be in accordance with the Type IA criteria of section HT-2.4.2.

**HT-4.4.4 Additional Electric Equipment.** Additionally, each Type IB electric operated chain hoist shall have the following:

(a) Phase Loss Protection
(b) Phase Reversal Protection
(c) Mainline magnetic contactor operated by a power off or emergency stop button
(d) Motor thermal detectors

**HT-4.5 PNEUMATIC (Type IB)**

**HT-4.5.1 Air Supply.** Pneumatic hoists shall operate on an air supply which is clean and dry with the pressure being 90 psi (6.3 bar), although air systems at 105 psi (7.3 bar) may be used if accepted by both the owner and hoist manufacturer. Unless specified otherwise, the maximum moisture content of the air is to be 0.002 lb. of water per pound of dry air at 60° F and 90 psi absolute, with the maximum solid particulate contamination limited to 25 microns. The owner’s main air supply shall be sufficient to accommodate the total air consumption of all air motors, with this consumption rate (cfm) provided by the manufacturer. The owner’s main air supply shall include a building mounted shutoff valve and air regulator valve in the area of the hoist or crane. Additionally, the owner shall provide a relief valve system to prevent excessive air pressure from damaging the hoist.

**HT-4.5.2 Air Motors.** The air motor shall be an air-driven piston or rotary vane type and shall be provided with an air inlet connection fitted for the use of air hose assemblies. Also, the air motor shall be provided with an oiler and air filter between the motor and the air inlet connection. The motor shall have adequate capacity to lift 125\% of the design rated load, which is at least twice the maximum critical load (MCL). The air motor shall have a required rated motor horsepower on the design rated load not less than that given by the following formula:
**HT-4.5.3 Additional Air Equipment.** Air hoist motors shall be furnished with the necessary directional valves, a dump valve operated by a power off or emergency stop button, and a hoist mounted regulator and pressure gauge to confirm the pressure at the hoist. The air motor exhausts shall include as necessary an exhaust filter and muffler. Mufflers are required for indoor service and shall be such that the sound motor level for each hoist shall be 80 dB or less, 3 feet from the muffler, unless specified otherwise by the owner.

The limiting devices for a Type IB air operated chain hoist shall be as stated under HT-4.3.5, noting that if a separate overload limiting device is used in lieu of adjusting the air flow, that this separate device may need to be electrically operated where the device would then fall into the category of an “electric-over-air” operated device.

**HT-4.6 SEISMIC (Type IB)**

The Type IB hoist unit, being based upon a standard compact hoist design and suspended from a crane or monorail, shall be considered a lumped mass for input into the crane or monorail seismic analysis. The hoist unit itself, with double the normal design factors, will not require a specific seismic analysis if the accelerations as imparted from the crane or monorail to the hoist are less than 1.0g. A loading of 1.0g or less will ensure that normal design stresses are not exceeded and that uplift will not occur. Should the hoist accelerations exceed 1.0g then additional analysis shall be required utilizing analysis methods and modeling techniques as addressed under the seismic analysis criteria of Section CM-2, Cranes and Monorails.

**HT-4.7 HOIST MARKING (Type IB)**

(a) For Type IB hoists, the maximum critical load rating (MCL) shall be marked on the hoist or load block, using the terminology MCL as part of the marking.

(b) For Type IB hoists that lift loads in excess of the MCL, the terminology DRL (design rated load) shall be used and shall also be marked on either the hoist or hoist load block.

\[
HP_{\text{required}} = \frac{WV}{33,000E}
\]

where
- \(V\) = specified speed when lifting weight \(W\), ft/min
- \(W\) = total weight to be lifted, lb. (design rated load plus the weight of the hook & load block)
- \(E\) = mechanical efficiency of the chain sprockets and gears between the load and the motor, expressed in decimal form.

**HT-4.8 INSPECTIONS AND TESTS (Type IB)**

**HT-4.8.1 Hoist Component Inspections and Tests.** The required component inspections and tests for a Type IB powered chain hoist shall be as listed in Table HT-4.8.1-1, with the specific criteria for these inspections and tests being as follows:

(a) Material Test Reports shall include both chemical analysis and physical properties. If such test reports are not available on the actual component, then these tests may be obtained from identical spare part components or from components of a duplicate hoist where such components meet the “like-for-like” criteria of Section 402 of ASME NQA-1, Subpart 2.14.

(b) Surface Magnetic Particle Testing (MT) or Liquid Penetrant Testing (PT) shall be performed on the hoist hook(s), hook-nut(s) and load chain connecting pins or components before performing the 250% MCL shop load test as required by HT-4.8.2.3. After this load test the hoist hook shall require a surface MT or Pt of all exposed external areas of the hook. The hoist is not to be disassembled to inspect other parts of the hook in that this would invalidate the 250% MCL test. The MT and PT procedures and acceptance criteria shall be in accordance with Section HT-7.

(c) Impact Testing, either Charpy-V or Drop Weight, shall be performed on the material of the hoist suspension shafts or pins having a diameter 2 inches or greater. If such tests are not available on the actual component material, then such tests shall be performed on identical spare part components or from components of a duplicate hoist where such components meet the “like-for-like” criteria of Section 402 of ASME NQA-1, Subpart 2.14. The Charpy-V or Drop Weight testing criteria shall be in accordance with Section HT-7.

(d) Breaking Strength Test for the hoist load chain shall be performed on the actual hoist chain, or on the actual chain lot used on the hoist, and shall require the chain to be pulled to the breaking load.

(e) A Certificate of Conformance shall be furnished for all hooks by the hook manufacturer, (separate from any other Certificates of Conformance), identifying the hook’s working load limit, design factor on this working load limit, proof load and straightening load.

(f) A Certificate of Conformance shall be furnished specifically for the hoist load chain, separate from any other Certificates of Conformance. This load chain certificate which may be provided as part of the documentation on the load chain breaking strength test, shall specify the safe working load limit, proof load and breaking load. This certificate shall also identify the load chain’s dimensions, tolerances, grade and hardness either directly, or indirectly if traceable to a chain product specification document or drawing.

(g) A Certificate of Conformance shall be furnished for each hoist holding brake, separate from any other Certificates of Conformance, by the brake manufacturer documenting the brake’s torque rating.
(h) Documentation on the above listed component inspections, tests and certificates of conformance shall be furnished as part of the Seller’s documentation package to qualify the hoist as NUM Type IB.

**Table HT-4.8.1-1 Required Hoist Component Inspections or Tests (Type IB Powered Chain Hoists)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Material Test Reports (Note 1)</th>
<th>Surface MT or PT (Note 2)</th>
<th>Impact Test (Note 3)</th>
<th>Certificate of Conformance (Note 4)</th>
<th>Breaking Strength Test (Note 5)</th>
</tr>
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<tbody>
<tr>
<td>Hook, for bottom block</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>...</td>
</tr>
<tr>
<td>Hook Nut, for bottom block</td>
<td>X</td>
<td>X</td>
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<td>...</td>
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</tr>
<tr>
<td>Load Block Plates or Bolted Component Halves</td>
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<td>Load Chains</td>
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<tr>
<td>Load Chain Connecting Pins or Components</td>
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<td>X</td>
<td>...</td>
</tr>
<tr>
<td>Top Hook (for hook suspended hoists)</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>...</td>
</tr>
<tr>
<td>Top Hook Nut (for hook suspended hoists)</td>
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<td>...</td>
<td>...</td>
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</tr>
<tr>
<td>Hoist Suspension Shafts or Pins (for lug mounted hoists) <em>(Note 6)</em></td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Material Test Reports if not available on the actual hoist components, may be obtained from identical spare part components, or from components of a duplicate hoist. Criteria for these test reports can be per HT-4.8.1(a).
2. Specific requirements regarding MT and PT testing either before or after load testing are to be per HT-4.8.1(b).
3. Impact Tests are required for hoist suspension shafts or pins 2 inches or larger in diameter. See HT-4.8.1(c).
4. Certificate of Conformance criteria are to be per HT-4.8.1(e), (f) and (g).
5. Breaking Strength Test criteria are to be per HT-4.8.1(d).
6. Hoist Suspension Shafts of an Integral Hoist & Trolley Unit are addressed under Section HT-6, Underrunning Trolleys (Type IB)
HT-4.8.2 Hoist Shop Performance and Shop Load Tests. Each power operated chain hoist shall require the following shop performance tests and shop load test:

HT-4.8.2.1 No-Load Performance Test. A no-load shop performance test shall be conducted through all speeds utilizing the operator control station. If the actual control station is not available, a duplicate control station may be used for test purposes. This test shall also verify the operation of all hoist limit switches, and shall document the maximum no-load speed.

HT-4.8.2.2 Two-Block Test. With all high hoist overtravel limit switches bypassed, the hoist shall be raised to a two-blocked condition confirming that the chain is not cut or damaged.

HT-4.8.2.3 Design Load Test (250% of MCL). A hoist design load test of at least 250% of the MCL rating shall be performed, with this test also serving as a 125% proof test of the design rating of hoist hooks. Note hooks and hook nuts are to be MT or PT examined before this test, with a baseline measurement taken of the hook’s throat opening. After this Design Load Test, the exposed accessible areas of the hooks are to be reexamined by MT or PT, with an additional measurement taken on the hook throat openings.

HT-4.8.2.4 Overload Limit Test. A load shall be applied to hoist above the MCL rating to confirm and document the overload setting. Air operated hoists which adjust the air pressure lower to set an inherent overload limiting capability of the hoist, shall require documentation of the no-load speed at this lower air pressure to supplement the original no-load performance test.

HT-4.8.2.5 Performance Test (100% of MCL). A hoist performance test at 100% of the MCL rating shall be performed, documenting the maximum hoist raising and lowering speeds for the MCL rating.

HT-4.8.2.6 Redundant Holding Brake System Test. The redundant hoist holding brake systems shall be verified to confirm that each braking system can independently hold the 100% MCL rating. For air hoists which utilize the inherent backup braking of the air motor and chain reeving system to retard the MCL lowering speed to a facility acceptable limit, this test shall confirm and document this lowering speed limit.

HT-4.8.2.7 Loss of Power Test. While raising and lowering 100% of the MCL rating the main power, electric or air, shall be interrupted to confirm that the holding brake systems engage to hold the MCL. Manually operated load-lowering devices, if supplied, shall be tested.

HT-4.8.2.8 Shop Test Documentation. Documentation on the above listed shop tests shall be furnished as part of the Seller’s documentation package to qualify the hoist as NUM Type IB.

HT-4.8.3 Site Load Tests. Hoists as suspended from a crane or monorail shall be site load tested as stated under section CM-7.1.7 of NUM Part-CM.
Section HT-5
Hand Chain Hoists (Type IB)

HT-5.1 GENERAL

This section provides the requirements for hand operated Type IB hoists for enhanced safety vertical lifting service involving the handling of freely suspended, unguided loads using chain as a lifting medium.

A Type IB hand chain hoist shall be a standard hoist meeting the criteria of ASME B30.16, and ASME HST-2 for a hand chain manually operated chain hoist, with its maximum critical load (MCL) rating being no more than ½ of its original design capacity per these standards. Additionally, to qualify for this Type IB classification, the hoist must also meet the additional design, inspection, testing and documentation requirements of this section.

NOTE: As an example, for a hoist to qualify as a 2-ton MCL rated Type IB hoist, its original design rating would have to be 4 ton or greater, but if it did not meet the additional design, inspection, testing and documentation requirements of this section, it would not be qualified as a Type IB hoist.

HT-5.2 EQUIPMENT CONFIGURATIONS (Type IB)

(a) The hoisting machinery from the hand wheel operated by the hand chain to the load sheave which operates the load chain is not designed to tolerate a single component failure. Instead, increased design factors are applied to reduce the probability of a component failure such that it is no longer considered to be a credible failure.

(b) The equipment configurations are identical to those of a standard hand chain hoist where there is only a single load brake.

(c) Figure HT-5.2-1 provides a block diagram illustration of a Type IB hand chain hoist identifying some of the major hoist drive components. This block diagram is a conceptual layout only. Other configurations, or arrangement of components meeting the criteria of this standard are acceptable.

Figure HT-5.2-1 Type IB Hand Chain Hoist Major Drive Components

HT-5.3 MECHANICAL (Type IB)

All load suspension parts shall be designed so that the static stress calculated for the MCL rating shall not exceed 10% of the minimum tensile strength.

NOTE: This equates to all load suspension parts being designed to a static stress on the hoist’s original design rating of 20% of the minimum tensile strength.

HT-5.3.1 Reeing. The chain hoist reeving system, consisting of one or more parts of load chain, shall provide for a true vertical lift and must be designed in a manner to accommodate a two blocked condition. See Fig. HT-5.3.1-1 and Fig. HT-5.3.1-2 for examples of chain hoist reeving systems. Note, these figures show just two of many possible configurations.

Figure HT-5.3.1-1 Hand Chain Hoist With, Single-Part Reeing

Hand Chain not shown, only the Load Chain
Figure HT-5.3.1-2 | Hand Chain Hoist With, Two-Part Reeving

Hand Chains not shown, only the Load Chain

**HT-5.3.2 Hooks.** Hooks shall have a design factor of at least 10 to 1 on the hoist’s MCL rating, based upon the average ultimate load or force at which the hook fails or no longer supports the load. Hooks shall be proof load tested based upon the hook’s original working load limit, before being derated for use on an MCL hoist. Note, the 250% Design Load Test specified under section HT-5.6.2.3, may also serve as the hook’s proof load test.

**HT-5.3.3 Load Chains.** Load chains shall be of the welded link type for manual hoisting applications except that they shall have a design factor of at least 10 to 1 on the hoist’s MCL rating based upon chain’s breaking strength. Hand chain hoists using roller type load chains are not anticipated for Type IB hoists, and are not addressed in this standard. The load chains shall be pull tested to their breaking strength as required under HT-5.6.1(d).

**HT-5.3.4 Hoist Brake.** A Type IB hand chain hoist shall have an automatic acting Weston-type mechanical load brake with ratchet and pawl and associated brake discs. The brake shall be self-adjusting for the service life of the brake disc lining. The brake shall provide smooth controlled lowering of a load when manual power is applied to the hand chain, and shall be capable of stopping and holding up to 125% of the hoist’s original design rated load.

**HT-5.3.5 Hoist Limiting Provisions.** A Type IB hand chain hoist shall have the following hoist limiting provisions:

(a) Hoist Upper Limit. In the fully raised position, the hoist is required to be designed such that it can be two-blocked without the chain becoming wedged or damaged.

(b) Hoist Lower Limit. The hoist is required to have a lower limit anchor that will prevent the load chain from jamming at the lowest hook position, and will prevent the accidental disengagement of the load chain.

(c) Hoist Overload Limit Device. The hoist overload limiting device shall be a handwheel mounted unit that limits the torque that can be manually imparted to the load sheave for load lifting. When the preset overload limit is reached, the handwheel rotates without lifting the load. For a type IB hand chain hoist this handwheel mounted limiting device must meet the following criteria:

1. For overload limiting devices that rely on friction to cause the handwheel to rotate without lifting, the device shall be set as low as possible to provide repeatability of the overload setting. Note, since such limiting devices are normally designed for the hoist’s original design rated load, this may result in a setting range as high as 260% to 320% of the MCL rating.
2. For overload limiting devices that do not rely on friction to cause the handwheel to rotate without lifting, the device shall be set as low as possible to provide repeatability of the overload setting, with this setting being in the range of 130% to 160% of the MCL rating.

3. The setting of all overload limiting devices must be such that they will repeatedly be able to prevent lifting within the specified overload range without requiring the device to be reset. This repeatability of the overload setting range shall be confirmed by an Overload Limit Test as specified under HT-5.6.2.4.
4. All overload limiting devices, shall allow the operator to lower the overload by pulling the hoist hand chain in the opposite direction.

Note, since a hand chain hoist’s overload limiting device, (especially one relying on friction), has an overload limit substantially above the MCL rating, the acceptability of the use of a Type IB hand chain hoist on a crane or monorail shall require verification of the acceptability of this higher loading on the crane or monorail structure. See NUM Part-CM for the design requirements of a crane or monorail to accommodate a hoist overload limit setting as an Extreme Load Case.

**HT-5.4 SEISMIC (Type IB)**

The Type IB hoist unit, being based upon a standard compact hoist design and suspended from a crane or monorail, shall be considered a lumped mass for input into the crane or monorail seismic analysis. The hoist unit itself, with double the normal design factors, will not require a specific seismic analysis if the accelerations as imparted from the crane or monorail to the hoist are less than 1.0g. A loading of 1.0g or less will ensure that normal design stresses are not exceeded and that uplift will not occur. Should the hoist accelerations exceed 1.0g then additional analysis shall be required utilizing analysis methods and
modeling techniques as addressed under the seismic analysis criteria of Section CM-2, Cranes and Monorails.

**HT-5.5 HOIST MARKING (Type IB)**

(a) For Type IB hoists, the maximum critical load rating (MCL) shall be marked on the hoist or load block, using the terminology MCL as part of the marking.

(b) For Type IB hoists that lift loads in excess of the MCL, the terminology DRL (design rated load) shall be used and shall also be marked on either the hoist or hoist load block.

**HT-5.6 INSPECTIONS AND TESTS (Type IB)**

**HT-5.6.1 Hoist Component Inspections and Tests.** The required component inspections and tests for a Type IB hand chain hoist shall be as listed in Table HT-5.6.1-1. (Note, trolley component inspections and tests including those pertaining to the trolley portion of an integral hoist & trolley unit are specified under Section HT-6.) Specific criteria for the hoist component inspections and tests listed under Table HT-5.6.1-1 are as follows:

(a) Material Test Reports shall include both chemical analysis and physical properties. If such test reports are not available on the actual component, then these tests may be obtained from identical spare part components or from components of a duplicate hoist where such components meet the “like-for-like” criteria of Section 402 of ASME NQA-1, Subpart 2.14.

(b) Surface Magnetic Particle Testing (MT) or Liquid Penetrant Testing (PT) shall be performed on all hoist hooks or suspension lugs, hook nuts or suspension lug nuts, load chain connecting pins or components, and suspension shafts or pins of a lug mounted hoist before performing the 250% MCL shop load test as required by HT-5.6.2. After this load test all hoist hooks or suspension lugs shall require a surface MT or PT of all exposed external areas of the hook or lug. The hoist is not to be disassembled to inspect other parts of the hook in that this would invalidate the 250% MCL test. The MT and PT procedures and acceptance criteria shall be in accordance with Section HT-7.

(c) Impact Testing, either Charpy-V or Drop Weight, shall be performed on the material of the hoist suspension shafts or pins having a diameter 2 inches or greater. If such tests are not available on the actual component material, then such tests shall be performed on identical spare part components or from components of a duplicate hoist where such components meet the “like-for-like” criteria of Section 402 of ASME NQA-1, Subpart 2.14. The Charpy-V or Drop Weight testing criteria shall be in accordance with Section HT-7.

(d) Breaking Strength Test for the hoist load chain shall be performed on the actual hoist chain, or on the actual chain lot used on the hoist, and shall require the chain to be pulled to the breaking load.

(e) A Certificate of Conformance shall be furnished for all hooks by the hook manufacturer, separate from any other Certificates of Conformance, identifying the hook’s working load limit, design factor on this working load limit, proof load and straightening load.

(f) A Certificate of Conformance shall be furnished specifically for the load chain, separate from any other Certificates of Conformance. This load chain certificate which may be provided as part of the documentation on the load chain breaking strength test, shall specify the safe working load limit, proof load and breaking load. This certificate shall also identify the load chain’s dimensions, tolerances, grade and hardness either directly, or indirectly if traceable to a chain product specification document or drawing.

(g) Documentation on the above listed component inspections, tests and certificates of conformance shall be furnished as part of the Seller’s documentation package to qualify the hoist as NUM Type IB.
<table>
<thead>
<tr>
<th>Item</th>
<th>Material Test Reports (Note 1)</th>
<th>Surface MT or PT (Note 2)</th>
<th>Impact Test (Note 3)</th>
<th>Certificate of Conformance (Note 4)</th>
<th>Breaking Strength Test (Note 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hook, for bottom block</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>...</td>
</tr>
<tr>
<td>Hook Nut, for bottom block</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Load Block Plates or Bolted Component Halves (supporting bottom hook)</td>
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<td>...</td>
<td>...</td>
<td>...</td>
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<tr>
<td>Load Chains</td>
<td>...</td>
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<td>...</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Load Chain Connecting Pins or Components</td>
<td>X</td>
<td>X</td>
<td>...</td>
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<td>...</td>
</tr>
<tr>
<td>Sheave Pins, Axles, or Sheave Retaining Bosses</td>
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<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Top Hook / Lug (for hook / lug suspended hoists)</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>...</td>
</tr>
<tr>
<td>Top Hook Nut (for hook suspended hoists)</td>
<td>X</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Top Block / Crosshead (supporting top hook or lug)</td>
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<td>...</td>
</tr>
<tr>
<td>Hoist Suspension Shafts or Pins (for lug mounted hoists) (Note 6)</td>
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<td>X</td>
<td>X</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

NOTES:

(1) Material Test Reports if not available on the actual hoist components, may be obtained from identical spare part components, or from components of a duplicate hoist. Criteria for these test reports are to be per HT-5.6.1(a).
(2) Specific requirements regarding MT and PT testing either before or after load testing are to be per HT-5.6.1(b).
(3) Impact Tests are required for hoist suspension shafts or pins 2 inches or larger in diameter. See HT-5.6.1(c).
(4) Certificate of Conformance criteria are to be per HT-5.6.1(e) and (f).
(5) Breaking Strength Test criteria are to be per HT-5.6.1(d).
(6) Hoist Suspension Shafts of an Integral Hoist & Trolley Unit are addressed under Section HT-6, Underrunning Trolleys (Type IB)
NUM PART - HT

HT-5.6.2 Hoist Shop Performance and Shop Load Tests. Each hand operated chain hoist shall require the following shop performance tests and shop load test:

**HT-5.6.2.1 No-Load Performance Test.** A no-load shop performance test shall be conducted to verify smooth lifting and lowering.

**HT-5.6.2.2 Two-Block Test.** The hoist bottom hook shall be raised to a two-blocked condition confirming that the chain is not cut or damaged.

**HT-5.6.2.3 Design Load Test (250% of MCL).** A hoist design load test of at least 250% of the MCL rating shall be performed, with this test also serving as a 125% proof test of the design rating of hoist hooks or suspension lugs. Note, as required by HT-5.6.1(b), specific components require NDE before this test. Additionally, a baseline measurement of each hook’s throat opening is also to be taken before this test. After this Design Load Test, the exposed accessible areas of the hooks and suspension lugs are to be reexamined by MT or PT, with an additional measurement taken on the hook’s throat opening.

**HT-5.6.2.4 Overload Limit Test.** Upon setting the handwheel mounted load limiter, a load shall be applied to hoist above the MCL rating to confirm and document the overload setting. The overload limit shall be tripped at least three (3) separate times to confirm repeatability and ensure that the overload limit remains within the specified range. Note, if the load at which lifting device prevents lifting increases with each successive test, indicating that future tripping would not be within the specified range, then the trip setting shall be increased.

**HT-5.6.2.5 Performance Test (100% of MCL).** A hoist performance test at 100% of the MCL rating shall be performed after the overload limit test, confirming proper hoist operation while supporting the MCL rating.

**HT-5.6.2.6 Shop Test Documentation.** Documentation on the above listed shop performance and load tests shall be furnished as part of the Seller’s documentation package to qualify the hoist as NUM Type IB.

**HT-5.6.3 Site Load Tests.** Hoists as suspended from a crane or monorail shall be site load tested as stated under section CM-7.1.7 of NUM Part-CM.
Section HT-6
Under-Running Trolleys (Type IB)

HT-6.1 GENERAL

This section provides the requirements for under-running trolleys used for the enhanced safety supporting the following hoisting equipment addressed in this standard:

Type IA Powered Wire Rope Hoists
Type IB Powered Wire Rope Hoists
Type IB Powered Chain Hoists
Type IB Hand Chain Hoists

The under-running trolleys as addressed in this section are all identified as Type IB and are not designed to tolerate all single failures. Instead, increased design factors are applied to reduce the probability of a component failure such that it is no longer considered to be a credible failure.

A Type IB under-running trolley shall be a standard manufactured and cataloged product meeting the applicable trolley safety criteria of ASME B30.17, Cranes and Monorails (With Underhung Trolley or Bridge), but derated to provide increased design factors. However, to qualify for the Type IB classification, the trolley must also meet the additional design, inspection, testing and documentation requirements of this section. This derating of an under-running trolley’s original design rating provides the trolley’s maximum critical load (MCL) rating.

Under-running trolleys for use with a powered wire rope hoist, shall comply with the trolley criteria as provided in ASME HST-4, Performance Standard for Overhead Electric Wire Rope Hoists, or ASME HST-6, Performance Standard for Air Wire Rope Hoists.

Under-running trolleys for use with a powered chain hoist, shall comply with the trolley criteria as provided in ASME HST-1, Performance Standard for Electric Chain Hoists, or ASME HST-5, Performance Standard for Air Chain Hoists.

Under-running trolleys for use with a hand chain hoist, shall comply with the trolley criteria as provided in ASME HST-2, Performance Standard for Hand Chain Manually Operated Chain Hoists.

Top running trolleys are not covered by this standard, but if furnished for use with the hoist units covered by this standard, they shall be in accordance with ASME NOG-1.

HT-6.2 TROLLEY CONFIGURATIONS (Type IB)

(a) Standard manufactured and cataloged under-running trolleys covered by this standard shall be one of the following general configurations:

(1) An independent trolley unit for the hook or lug suspension of a hoist unit. A typical independent trolley unit is depicted in Figure HT-6.2-1.

(b) Multiple, standard manufactured and cataloged under-running trolley units may be used to support the hoist unit, but such arrangements shall incorporate load bars or members to distribute the load.

(c) An independent trolley unit or integral trolley unit may utilize more than two sets of 2-wheels, where each wheel operates on opposite sides of the beams operating flange.

(d) Non-standard and non-cataloged under-running trolley configurations may be used, but their design, inspection and testing would then be required to comply with the Type I criteria of NUM PART-CM, as if they were an integral part of the crane or monorail.
HT-6.3 TROLLEY DESIGN CRITERIA (Type IB)

HT-6.3.1 Design Factors

(a) Design factors on a trolley’s MCL rating for all load suspension parts shall be as listed in Table HT-6.3.1-1 for under-running independent trolleys, and shall be as listed in Table HT-6.3.1-2 for under-running integral trolleys.

Table HT-6.3.1-1 Under-Running Type IB Design Factors for Independent Trolleys

<table>
<thead>
<tr>
<th>Type of Hoist</th>
<th>Under-Running Trolley Design Factor on the Ultimate Material Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powered Hoist</td>
<td>10 to 1</td>
</tr>
<tr>
<td>Manual Hoist</td>
<td>7.5 to 1</td>
</tr>
</tbody>
</table>

NOTES:
1. For example, a 2-ton MCL rated trolley suspending a “powered hoist” requires at least a 4-ton capacity trolley with load suspension parts designed to a static stress on its original design rating of 20% of the minimum tensile strength, in order to provide the 10 to 1 design factor.
2. For example, a 2-ton MCL rated trolley suspending a “manual hoist” requires at least a 3-ton capacity trolley with load suspension parts designed to a static stress on its original design rating of 20% of the minimum tensile strength, in order to provide the 7.5 to 1 design factor.

(b) The dead weight of the hoist unit need not be included in determining the design factor for an under-running independent trolley provided the weight of the hoist does not exceed 10 percent of the MCL rating. This hoist dead weight is accommodated by the increased design factor of an MCL rated trolley. Note, some long lift hoists may not meet this 10 percent weight limitation.

(c) An independent under-running trolley supporting a powered hoist with an extremely fast hoisting speed should consider increasing the trolley’s MCL design factor.

(d) The dead weight of any intervening component between an under-running independent trolley and the suspended hoist, such as a load cell or insulating link, need not be included in determining the design factor for the independent trolley provided the combined dead weight of the intervening component and the hoist does not exceed 10 percent of the hoist’s MCL rating.

(e) To ensure that the increased design factors are provided for an MCL Type IB rated trolley, the following documentation shall be provided:

(1) Catalog literature or other written information from the trolley manufacturer stating the design factor of the trolley’s original design rated load. Note, not all standard trolleys have a 5 to 1 design factor, with some being 4 to 1.

(2) Catalog literature or other written information from the hoist manufacturer to confirm if the dead weight of hoist exceeds 10% of the hoist’s MCL rating, and would need to be included when verifying the design factor for an MCL rated independent trolley.

(3) Catalog literature or other written information from the intervening component manufacturer to confirm if the dead weight of the intervening component when added to the dead weight of the hoist exceeds 10% of the hoist’s MCL rating. Such weight would then need to be included when verifying the design factor for an MCL rated independent trolley.

Table HT-6.3.1-2 Under-Running Type IB Design Factors for Integral Trolleys

<table>
<thead>
<tr>
<th>Type of Hoist</th>
<th>Under-Running Trolley Design Factor on the Ultimate Material Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Trolley that is Integral with the Trolley</td>
<td></td>
</tr>
<tr>
<td>Powered Hoist</td>
<td>10 to 1</td>
</tr>
<tr>
<td>Manual Hoist</td>
<td>10 to 1</td>
</tr>
</tbody>
</table>

NOTES:
1. For under-running integral trolleys, the design factors on the MCL rating of load suspension parts are identical to the design factors of the hoist unit it is part of. This is regardless of the type of hoist, powered or manual, wire rope or chain.

HT-6.3.2 Drop Protection. Means shall be provided to limit the drop of the trolley to 1 inch (25.4 mm) or less should a wheel or axle fail. Note, such drop protection may serve as a seismic restraint, or part of a seismic restraint system. See section HT-6.4.

HT-6.3.3 Trolley Propulsion. Trolleys shall be either plain (with manual push-pull propulsion), hand chain-operated (with geared or sprocket driven wheels), or motor-operated (for electric or pneumatic operation), with the selection of the type of trolley propulsion being by the owner. Note, separate under-rail tractor drives may also be provided as a means of motorized trolley propulsion.

HT-6.3.4 Trolley Brakes. Motor-operated trolleys (for electric or pneumatic operation) shall be furnished with friction type trolley brakes that engage when power is removed. Trolley brakes shall be in accordance with ANSI B30.17, with this B30 standard specifying the brake’s minimum torque capability for stopping and holding functions.

HT-6.3.5 Trolley Bumpers. Motor-operated trolleys (for electric or pneumatic operation) shall have trolley bumpers in accordance with ANSI B30.17, noting that these bumpers may be physically located on the crane or monorail, rather than on the trolley.

HT-6.4 SEISMIC (Type IB)

The Type IB trolley unit, being based upon a standard under-running trolley design and suspended from a crane or monorail, shall be considered a lumped mass along with the hoist unit for input into the crane or monorail seismic analysis. The trolley unit itself, with increased design factors of 1½ to 2 times the normal design factors, will not require a specific seismic analysis if the accelerations as imparted from the crane or monorail to the trolley and hoist are less than 1.0g.
A loading of 1.0g or less will ensure that normal design stresses are not exceeded or only marginally exceeded, and that uplift will not occur. Should the accelerations at the trolley and hoist exceed 1.0g then additional analysis shall be required utilizing analysis methods and modeling techniques as addressed under the seismic analysis criteria of Section NUM-CM, Cranes and Monorails.

**HT-6.5 TROLLEY MARKING (Type IB)**

(a) For Type IB trolleys, the maximum critical load rating (MCL) shall be marked on the trolley using the terminology MCL as part of the marking.

(b) For Type IB trolleys that support loads in excess of the MCL, the terminology DRL (design rated load) shall be used and shall also be marked on the trolley.

**HT-6.6 INSPECTIONS AND TESTS (Type IB)**

**HT-6.6.1 Trolley Component Inspections and Tests.** The required component inspections and tests for a Type IB trolley, whether an independent trolley or integral trolley, shall be as listed in Table HT-6.6.1-1. Specific criteria for the trolley component inspections and tests listed under Table HT-6.6.1-1 are as follows:

(a) Material Test Reports shall include both chemical analysis and physical properties. If such test reports are not available on the actual component, then these tests may be obtained from identical spare part components or from components of a duplicate hoist where such components meet the “like-for-like” criteria of Section 402 of ASME NQA-1, Subpart 2.14.

(b) NDE of Welds of the trolley drop lugs of either an independent trolley or integral trolley shall be performed if such welds exist. Note, some trolleys do not have welded drop lugs, in that they are part of the trolley side plate, or they are bolted to the trolley side plates. The NDE of such welds may be performed either before or after the trolley’s 250% MCL load test. The NDE procedure and acceptance criteria for welds shall be in accordance with Section HT-7.

(c) Surface Magnetic Particle Testing (MT) or Liquid Penetrant Testing (PT) shall be performed on the connecting shafts or pins of the trolley side plates for independent trolleys, and for integral trolleys, provided the integral design accommodates their removal without disassembling the hoist. These surface examinations shall be performed after the trolley’s 250% MCL shop load test. The MT and PT procedures and acceptance criteria shall be in accordance with Section HT-7.

(d) Surface Magnetic Particle Testing (MT) or Liquid Penetrant Testing (PT) shall be performed on the hoist suspension shaft or pin of an independent trolley designed for a hook or lug suspended hoist. This surface examination shall be performed after the trolley’s 250% MCL shop load test. The MT and PT procedures and acceptance criteria shall be in accordance with Section HT-7.

(e) Impact Testing, either Charpy-V or Drop Weight, shall be performed on the clevis of an independent trolley designed for a hook or lug suspended hoist should such a component be provided between the trolley and the hoist. This surface examination shall be performed after the trolley’s 250% MCL shop load test. The MT and PT procedures and acceptance criteria shall be in accordance with Section HT-7.

(f) A Certificate of Conformance shall be furnished for all bolting materials of a trolley drop lug, should such bolts exist. This certificate shall identify the specific bolt grade and include material properties.

(g) Documentation on the above listed component inspections, tests and certificates of conformance shall be furnished as part of the Seller’s documentation package to qualify the trolley as NUM Type IB.
### Table HT-6.6.1-1 Required Under-Running Trolley Component Inspections or Tests

**(Type IB Independent or Integral trolleys)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Material Test Reports (Note 1)</th>
<th>NDE of Welds (Note 2)</th>
<th>Surface MT or PT (Note 3)</th>
<th>Impact Test (Note 4)</th>
<th>Certificate of Conformance (Note 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trolley Side Plates</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Trolley Wheel Axles or Shafts</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Trolley Drop Lugs (note 6)</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Welds of Trolley Drop Lugs (note 6)</td>
<td>...</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Bolts of Trolley Drop Lugs (note 6)</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>X</td>
</tr>
<tr>
<td>Connecting Shafts or Pins of the Trolley Side Plates (Note 7)</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>X</td>
<td>...</td>
</tr>
<tr>
<td>Hoist Suspension Shafts or Pins of an independent trolley (Note 7)</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>X</td>
<td>...</td>
</tr>
<tr>
<td>Hoist Suspension Shafts of an Integral Trolley (Note 7)</td>
<td>X</td>
<td>...</td>
<td>...</td>
<td>X</td>
<td>...</td>
</tr>
<tr>
<td>Clevis for Hook / Lug Suspended Hoists (for independent trolleys utilizing a clevis)</td>
<td>X</td>
<td>...</td>
<td>X</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Material Test Reports if not available on the actual trolley components, may be obtained from identical spare part components, or from components of a duplicate trolley. Criteria for these test reports are to be per HT-6.6.1(a).
2. Specific requirements regarding NDE of welds, and the requirement to perform this NDE either before or after load testing, are to be per HT-6.6.1(b).
3. Specific requirements regarding surface MT and PT testing of trolley components, and the requirement to perform these tests either before or after load testing, are to be per HT-6.6.1(c), (d) and (e).
4. Impact Tests are required for suspension/connecting shafts or pins 2 inches or larger in diameter, on either the original material stock, or on an identical spare part component or from a duplicate hoist, with the criteria per HT-6.6.1(f).
5. Certificate of Conformance criteria are to be per HT-6.6.1(g).
6. Some trolley designs are such that the trolley drop lugs are part of the trolley side plate itself, and welds or bolts will not exist.
7. Some trolley designs are such that the shaft or pin connecting the trolley side plates also serves as the hoist suspension shaft or pin.
HT-6.6.2 Trolley Shop Performance and Shop Load Tests. Integral trolleys shall be tested with its hoist unit, but independent trolleys may be tested either with the hoist or independently. Each trolley shall require the following shop performance tests and shop load tests:

**HT-6.6.2.1 No-Load Performance Test.** A no-load shop performance test shall be conducted to verify the designed operation of the trolley propulsion system, whether it be manual push-pull operated, hand chain-operated or motor-operated. Motor-operated trolleys shall require verification of the operation of the trolley brake(s).

**HT-6.6.2.2 Design Load Test (250% of MCL).** A trolley design load test of at least 250% of the trolley MCL rating shall be performed. Note, as required by HT-6.6.1(c), (d) and (e), specific components require surface NDE after this test.

**HT-6.6.2.3 Full Load Performance Test (100% of MCL).** A trolley performance test at 100% of the trolley MCL rating shall be performed after the design load test, and after setting of the hoist overload limit test for trolleys tested with the hoist. This test shall verify the designed operation of the trolley propulsion system while supporting the MCL rating, including verification of the operation of the trolley brake(s) for motor-operated trolleys.

**HT-6.6.2.4 Shop Test Documentation.** Documentation on the above listed shop performance and load tests shall be furnished as part of the Seller’s documentation package to qualify the trolley as NUM Type IB.

**HT-6.6.3 Site Load Tests.** Trolleys as suspended from a crane or monorail shall be site load tested as stated under section CM-7.1.7 of NUM Part-CM.
Section HT-7
Common NDE Criteria for Hoists & Trolleys

HT-7.1 GENERAL

This section provides the common nondestructive examination (NDE) criteria for performing the inspections and tests as required for a Type IA and Type IB hoist, and for a Type IB trolley. Note, this criterion only applies to the required component NDE as listed in the following inspection and testing sections for a particular hoist or trolley addressed in this standard:

| HT-2.8 for Powered Wire Rope Hoists (Type IA) |
| HT-3.8 for Powered Wire Rope Hoists (Type IB) |
| HT-4.8 for Powered Chain Hoists (Type IB)      |
| HT-5.6 for Hand Chain Hoists (Type IB)         |
| HT-6.6 for Under-Running Trolleys (Type IB)    |

HT-7.2 SURFACE MAGNETIC PARTICLE TESTING OR LIQUID PENETRANT TESTING CRITERIA

Magnetic Particle Testing (MT) for surface defects shall be performed in accordance with ASTM A275 and/or ASTM E709, with Liquid Penetrant Testing (PT) for surface defects being in accordance with ASTM E165. For both MT and PT, the acceptance criteria are that the following relevant indications are unacceptable:

(a) linear indications greater than 1/16 in. long in material under 5/8 in. thick, greater than 1/8 in. long in material from 5/8 in. thick to under 2 in. thick, and greater than 3/16 in. long in material 2 in. thick and over;

(b) rounded indications with any dimension greater than 1/8 in. in material under 5/8 in. thick, and greater than 3/16 in. in material 5/8 in. thick and over;

(c) in any thickness of material, four or more relevant indications separated by 1/16 in. or less, edge-to-edge;

(d) in any thickness of material, ten or more relevant indications in any 6 in.² of surface with the major dimension of the area not to exceed 6 in., with the area taken in the most unfavorable orientation relative to the indications being evaluated.

Relevant indications are those that result from mechanical discontinuities and have a major dimension greater than 1/16 in. Indications may be explored to determine if they are the result of material discontinuities, material properties, or part geometry. Linear indications are those whose length is more than three times the width. Rounded indications are those that are circular or elliptical with the length less than three times the width.

HT-7.3 NDE WELD CRITERIA

Welds shall be visually examined in accordance with AWS D14.1 or AWS D1.1. Welds shall then require either magnetic particle testing (MT) or liquid penetrant testing (PT) in accordance with AWS D14.1 or AWS D1.1. Based upon the short weld lengths on this type of equipment, 100% of the weld length shall be examined. The acceptance criteria for these weld examinations shall be in accordance with AWS D14.1 or AWS D1.1, unless exceptions to this criterion, as provided by the manufacturer or testing organization, are approved by the Owner.

HT-7.4 CHARPY-V OR DROP WEIGHT IMPACT TESTING CRITERIA

Charpy-V impact testing shall be in accordance with ASTM A370 or ASTM E23, with Drop Weight impact testing being in accordance with ASTM A208. The acceptance criteria for either test shall be in accordance with the manufacturer’s or testing organization’s standards, but shall be approved by the Owner.

HT-7.5 ULTRASONIC (UT) VOLUMETRIC TESTING CRITERIA

The following criteria is only applicable to Type IA Powered Wire Rope Hoists as stated in HT-2.8.

(a) Plate Materials. UT volumetric tests shall be performed in accordance with ASTM A435. Any area where one or more discontinuities produce a continuous loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. or one-half of the plate thickness, whichever is greater, is unacceptable.

(b) Bar and Forged Material. Ultrasonic volumetric tests shall be performed in accordance with the applicable sections of ASTM A388 after forging and heat treatment, but before any machining that would render the ultrasonic test results indeterminate.

(c) Additional requirements and acceptance criteria

(1) Solid shafts, bars, and forgings with parallel surfaces (i.e., providing an adequate back reflection to conduct the test) shall be ultrasonic tested using the straight-beam back-reflection technique. The test results shall be unacceptable if one or more reflectors produce indications accompanied by a complete loss of back reflection not associated or attributable to geometric configurations. Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.
(2) Solid shapes and forgings with nonparallel surfaces, including hooks, shall be ultrasonically tested using flat-bottomed hole reference standards and distance–amplitude correction curves. Discontinuity indications in excess of the response from a 1/8-in. flat-bottomed hole at the estimated discontinuity depth shall be unacceptable.

(3) Rings and hollow forgings shall be tested using the angle beam examination technique when a valid test using the back reflection technique through the axial direction cannot be performed. One or more reflectors that produce indications exceeding the amplitude reference line from the appropriate calibration notches shall be unacceptable.
MANDATORY APPENDIX I
SI CONVERSION FACTORS

I-1 SI CONVERSION FACTORS

See Tables I-1-1 and I-1-2 for conversion information relative to this Standard.

Table I-1-1  SI Conversion Factors

<table>
<thead>
<tr>
<th>Quantity</th>
<th>English to SI</th>
<th>SI to English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 in.</td>
<td>2.54 cm</td>
<td>1 cm = 0.3937008 in.</td>
</tr>
<tr>
<td>1 ft</td>
<td>0.3048 m</td>
<td>1 m = 3.2808399 ft</td>
</tr>
<tr>
<td>1 mil</td>
<td>25.4 µm</td>
<td>1 µm = 0.00003937008 mil</td>
</tr>
<tr>
<td>Area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 in.²</td>
<td>6.4516 cm²</td>
<td>1 cm² = 0.1550003 in²</td>
</tr>
<tr>
<td>1 ft²</td>
<td>0.09290304 m²</td>
<td>1 m² = 10.76391 ft²</td>
</tr>
<tr>
<td>Volume</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 in.³</td>
<td>16.387064 cm³</td>
<td>1 cm³ = 0.06102374 in³</td>
</tr>
<tr>
<td>1 ft³</td>
<td>0.028316847 m³</td>
<td>1 m³ = 35.31467 ft³</td>
</tr>
<tr>
<td>1 gal</td>
<td>3.785412 L</td>
<td>1 L = 0.26417205 gal</td>
</tr>
<tr>
<td>Velocity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 ft/s</td>
<td>0.3048 m/s</td>
<td>1 m/s = 3.280839 ft/s</td>
</tr>
<tr>
<td>1 ft/min</td>
<td>0.00508 m/s</td>
<td>1 m/s = 196.8504 ft/min</td>
</tr>
<tr>
<td>1 rpm</td>
<td>0.01047197 rad/s</td>
<td>1 rad/s = 0.0540197 rpm</td>
</tr>
<tr>
<td>Mass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 lb</td>
<td>0.45359237 kg</td>
<td>1 kg = 2.204622 lb</td>
</tr>
<tr>
<td>1 ton (long)</td>
<td>1016.0469088 kg</td>
<td>1 kg = 0.0009842065 ton (long)</td>
</tr>
<tr>
<td>1 ton (long)</td>
<td>1.016047 ton</td>
<td>1 ton = 0.9842065 ton (long)</td>
</tr>
<tr>
<td>Acceleration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 ft/s²</td>
<td>0.3048 m/s²</td>
<td>1 m/s² = 3.280840 ft/s²</td>
</tr>
<tr>
<td>Force</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 lbf</td>
<td>4.44822 N</td>
<td>1 N = 0.224809 lbf</td>
</tr>
<tr>
<td>Bending, torque</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 ft-lbf</td>
<td>1.35582 N-m</td>
<td>1 N-m = 0.737562 ft-lbf</td>
</tr>
<tr>
<td>Pressure, stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 lbf/in.²</td>
<td>6894.76 Pa (N/m²)</td>
<td>1 Pa = 0.000145038 lbf/in.²</td>
</tr>
<tr>
<td>1 kPa/in.²</td>
<td>6.89476 Mpa</td>
<td>1 Mpa = 0.145038 kPa/in.²</td>
</tr>
<tr>
<td>1 lbf/in.²</td>
<td>0.0703070 kg/cm²</td>
<td>1 kg/cm² = 14.22334 lbf/in.²</td>
</tr>
<tr>
<td>Energy, work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Btu</td>
<td>1055.056 J (N·m)</td>
<td>1 J = 0.000947817 Btu</td>
</tr>
<tr>
<td>1 ft-lbf</td>
<td>1.35582 J</td>
<td>1 J = 0.737562 ft-lbf</td>
</tr>
<tr>
<td>Power</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 hp</td>
<td>745.7 W (J/s)</td>
<td>1 W = 0.00134102 hp</td>
</tr>
</tbody>
</table>

Temperature

\[ t_c = \frac{t_f - 32}{1.8} \]
\[ t_f = (t_c \times 1.8) + 32 \]

GENERAL NOTE: For others, see ASTM E380

Table I-1-2  Conversion Factors for Weight, ton

<table>
<thead>
<tr>
<th>English to Metric</th>
<th>Metric to English</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ton (long)</td>
<td>1.0160469 ton</td>
</tr>
<tr>
<td>1 ton (short)</td>
<td>0.9071847 ton</td>
</tr>
</tbody>
</table>

U.S. Customary to Metric

<table>
<thead>
<tr>
<th>English to U.S. Customary</th>
<th>Metric to U.S. Customary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ton (long)</td>
<td>0.9842065 ton (long)</td>
</tr>
<tr>
<td>1 ton (short)</td>
<td>0.8928571 ton (long)</td>
</tr>
</tbody>
</table>

GENERAL NOTE: For others, see ASTM E380.
A-1 JIB SLEW DRIVE SAMPLE CALCULATION

The following examples illustrate determination of horsepower for slew drive motors for indoor and outdoor jib cranes.

Assumed example values

\[ E = 0.9 \]
\[ HB = 1.5 \text{ ft} \]
\[ HL = 5 \text{ ft} \]
\[ l = \text{moment of inertia of load} = WL \times RL^2 = (22,000)(10)^2 = 22 \times 10^5 \text{ lb-ft}^2 \]
\[ K_i = 1.3 \]
\[ LB = 12 \text{ ft}, \text{ book length} \]
\[ LL = 5 \text{ ft} \]
\[ N = 1.5 \text{ rpm} \]
\[ PSF = 5 \text{ lb/ft}^2 \]
\[ RB = 6 \text{ ft}, \text{ the radius to centroid of projected area of the boom} \]
\[ RL = 10 \text{ ft}, \text{ maximum load radius} \]
\[ WL = 22,000 \text{ lb} (10\text{-ton rated load plus 2,000-lb hoist weight}) \]

Formulae and Calculations

Indoor crane

\[ \text{Required HP} = \frac{IN^3}{7 \times 10^6 EK_t} = \frac{22 \times 10^5 (1.5)^3}{7 \times 10^6 (0.9)(1.3)} = 0.91 \text{ HP} \]

Outdoor crane

\[ \text{Total required motor horsepower} = \text{HP} + \text{HP}_{\text{wind}} \]
\[ \text{HP}_{\text{wind}} = \frac{PSF \left( A_{\text{boom}} \times RB + A_{\text{load}} \times RL \right) N}{5,250 EK_t} \]
\[ (A_{\text{boom}} \times RB) + (A_{\text{load}} \times RL) = (LB \times HB \times RB) + (LL \times HL \times RL) \]
\[ = (12 \times 1.5 \times 6) + (5 \times 5 \times 10) \]
\[ = 358 \]
\[ \text{HP}_{\text{wind}} = \frac{1.5 \times 358 \times 5}{5,250 \times 0.9 \times 1.3} = 0.44 \text{ HP} \]

\[ \text{HP (from indoor crane calculation)} = 0.91 \text{ HP} \]

\[ \text{Total required motor horsepower} = 0.91 + 0.44 = 1.35 \text{ HP} \]

A-1.1 Examples

A 6-ton jib crane has a boom length of 38 ft, a drivetrain overall ratio of 2,400:1, and a motor \( W/K^2 \) of 0.2 lb/ft².
\[ T = \frac{l_T \omega}{t} = \frac{l_T (N) \left( \frac{2\pi}{60} \right)}{t} \]

\[ t = \frac{6.67}{N} \text{ and } l_T = 1.35 \frac{w}{g} (RL)^2 \]

Therefore

\[ T = \frac{1.35 (\frac{w}{g} (RL)^2 (\frac{2\pi}{60}) (N))}{1519} ; \quad g = 32.2 \]

\[ T = \frac{W (RL)^2 (N^2)}{1519} \]

\[ HP = \frac{TN}{5250EK_t} = \frac{W (RL)^2 (N^3)}{5250(1519)EK_t} \]

Conservatively rounding downward

\[ HP = \frac{W (RL)^2 N^3}{7 \times 10^6 EK_t} \]

### A-2 LOWER FLANGE BENDING CALCULATION

#### A-2.1 Example

Calculation for local bending of lower flanges due to wheel loads (see Fig. A-2.1-1). Span 37 ft 6 in., crane capacity 5 tons with a maximum static trolley load \((TL + LL)\) of 11.04 kips. Girder S18 x 54.7 with C15 x 33.9 cap. Bridge and trolley speed is 100 ft/min. Assume A36 steel.

(a) Check for Case 2 loading (see CM-2.1.2; bridge speed \(\leq 200\) ft/min). Assume the following:

1. \(DLF_g = 1.1\) [see CM-2.1.1.1(d)(1)]
2. \(DLF_s = 1.1\), trolley speed \(\leq 200\) ft/min
3. \(HLF = 0.15\) [see CM-2.1.1.1 (d)(2)]
4. \(IFD\) and \(SK\) are negligible and ignored
5. \(WLO = 0\), indoor crane

\[ DL(DLF_g) = [(54.7 + 33.9)37.5]1.1 = 3.65 \text{ kips} \]

\[ TL(DLF_s) = (1.04)1.1 = 1.14 \text{ kips} \]

\[ LL(1 + HLF) = (10.00)(1 + 0.15) = 11.50 \text{ kips} \]

Consider Load Case 2

\[ DL(DLF_g) + TL(DLF_s) + LL(1 + HLF) + IFD + WLO + SK \]

\[ M_{vertical} = \left( \frac{3.65}{6} \right) + (1.14 + 11.5) \left( \frac{3.65}{4} \right) = 135.61 \text{ kips/ft} \]

\( IFD\) and \(WLO\) are ignored in this condition.

\[ d_{Flange(ten)} = \frac{(135.61)12}{103.2} = 15.76 \text{ ksi} \]

\[ d_{Flange(comp)} = \frac{(135.61)12}{207.7} = 7.83 \text{ ksi} \]

\[ \tau_{xy(in-web)} = \frac{1/2(3.65 + 11.4 + 11.5)}{(0.461)(6.10 + 12.30 - 0.40 - 1.38)} = \frac{8.145}{7.66} = 1.06 \text{ ksi} \]

(b) Compute coefficients and stress girder section properties.

\[ I_{xx} = 1,269 \]

\[ I_{yy} = 335.8 \text{ in.}^4 \]

\[ S_{xx(ten)} = 103.2 \text{ in.}^3 \]

\[ S_{yy(ten-comp)} = 44.7 \text{ in.}^3 \]

\[ S_{xx(comp)} = 207.7 \text{ in.}^3 \]

\[ A = 26.06 \text{ in.}^2 \]

\[ t_w = 0.461 \text{ in.} \]

\[ t_f = 0.691 \text{ in., } b = 6.00 \text{ in.} \]

\[ a = 0.75 \text{ in.} \]

\[ t_a = 0.691 - \left( \frac{a}{2a} \right) + \left( \frac{a}{6} \right) = 0.566 \text{ in.} \]

For single-web symmetrical section

\[ \lambda = \frac{2a}{b-t_w} = \frac{(2)(0.75)}{6-0.461} = 0.271 \text{ in.} \]

Coefficients (for tapered flange sections)

\[ C_{x0} = -1.096 + 1.095(0.271) + 0.192e^{-6.0(0.271)} \]

\[ C_{x0} = -0.762 \]

\[ C_{x1} = 3.965 - 4.835(0.271) - 3.965e^{-2.675(0.271)} \]

\[ C_{x1} = 0.734 \]

\[ C_{y0} = -0.981 - 1.479(0.271) + 1.120e^{1.322(0.271)} \]

\[ C_{y0} = 0.221 \]

\[ C_{y1} = 1.810 - 1.150(0.271) + 1.060e^{-7.70(0.271)} \]

\[ C_{y1} = 1.63 \]

lateral \((x)\) and longitudinal \((y)\) flange bending stress (Point 0 and Point 1)
\[ \sigma_{x0} = \frac{C_{x0} P}{(t_a)^2} = -0.762 \frac{(3.175)}{0.567^2} = -7.53 \text{ ksi} \]

where

\[ \frac{P}{(t_a)^2} = \frac{3.16}{0.566^2} = 9.86 \]

\[ \sigma_{x1} = \frac{C_{x1} P}{(t_a)^2} = 0.734(9.86) = 7.24 \text{ ksi} \]

\[ \sigma_{x2} = -\sigma_{x0} = 7.52 \text{ ksi} \]

\[ \sigma_{y0} = \frac{C_{y0} P}{(t_a)^2} = 0.221(9.86) = 2.18 \text{ ksi} \]

\[ \sigma_{y1} = \frac{C_{y1} P}{(t_a)^2} = 1.622(9.86) = 16.00 \text{ ksi} \]

\[ \sigma_{y2} = -\sigma_{y0} = -2.18 \text{ ksi} \]

(c) Reduce flange bending stresses to 75% and combine with Case 2 loading [see CM-2.1.6.2.3(b)].

Point 0

\[ \sigma_y = \sigma_{long} + 0.75\sigma_{y0} \]

\[ \sigma_y = 15.76 + 0.75(2.18) = 17.40 \text{ ksi} \]

\[ \sigma_x = \sigma_{lat} + 0.75\sigma_{x0} \]

\[ \sigma_x = 0 + 0.75(-7.52) = -5.64 \text{ ksi} \]

\[ \tau_{xy} = 0 \text{ ksi} \]

Point 1

\[ \sigma_y = \sigma_{long} + 0.75\sigma_{y1} \]

\[ \sigma_y = 15.76 + 0.75(16.00) = 27.76 \text{ ksi} \]

\[ \sigma_x = \sigma_{lat} + 0.75\sigma_{x1} \]

\[ \sigma_x = 0 + 0.75(7.24) = 5.43 \text{ ksi} \]

\[ \tau_{xy} = 0 \text{ ksi} \]

Point 2

\[ \sigma_y = \sigma_{long} + 0.75\sigma_{y2} \]

\[ \sigma_y = \frac{(12.31-1.38)15.76}{12.31} + 0.75(-2.18) = 13.31 \text{ ksi} \]

\[ \sigma_x = \sigma_{lat} + 0.75\sigma_{x2} \]

\[ \sigma_x = 0 + 0.75(7.52) = 5.64 \text{ ksi} \]

\[ \tau_{xy} = 1.06 \text{ ksi} \]

(d) Combine stresses [see CM-2.1.6.2.3(g)].

\[ \sigma_t = \sqrt{(\sigma_x)^2 + (\sigma_y)^2 - \sigma_x\sigma_y + 3(\tau_{xy})^2} < \sigma_{\text{allowable}} \]

\[ \sigma_{\text{allow}} \text{ for Case 2) = 0.66}\sigma_y = 0.66(36) = 23.76 \text{ ksi} \]

where

\[ \sigma_y \text{ for A36 steel} = 36 \text{ ksi} \]

Point 0

\[ \sigma_t = \sqrt{(-5.64)^2 + (17.40)^2 - (-5.64)(17.40) + 3(0.24)^2} < 20.80 \text{ ksi} \]

Point 1

\[ \sigma_t = \sqrt{(5.43)^2 + (27.76)^2 - (5.43)(27.76)} \]

\[ \sigma_t = 25.48 \text{ ksi} > 23.76 \text{ ksi} \] (not good)

Point 2

\[ \sigma_t = \sqrt{(5.64)^2 + (12.36)^2 - (5.64)(12.36) + 3(1.06)^2} \]

\[ \sigma_t = 10.71 \text{ ksi} \leq 23.76 \text{ ksi} \] (okay)