ASME NOG-1–2004
(Revision of ASME NOG-1–2002)

Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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Three Park Avenue • New York, NY 10016

Date of Issuance: May 16, 2005

The next edition of this Standard is scheduled for publication in 2008. There will be no addenda or written interpretations of the requirements of this Standard issued to this edition.

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment that provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

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The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

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FOREWORD

The Committee on Cranes for Nuclear Power Plants was first established in 1976. In 1980 the name and scope of the Committee were revised from the Committee on Cranes for Nuclear Power Plants to the Committee on Cranes for Nuclear Facilities. This Standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards committee that approved the Standard was balanced to ensure that individuals from competent and concerned interests have had an opportunity to participate.

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

Suggestions for improvement as gained in the use of this Standard are welcome. They should be sent to the Secretary, ASME Committee on Cranes for Nuclear Facilities, The American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990.

The first edition of NOG-1 was approved in 1983; the second edition was approved in 1989; the fourth edition was approved in 1998; and the fifth edition was approved in 2002. This 2004 edition is a compilation of revisions made since the 2002 edition. ASME NOG-1–2004 received ANSI approval on December 9, 2004.

ASME COMMITTEE ON CRANES FOR NUCLEAR FACILITIES

(The following is the roster of the Committee at the time of approval of this Standard.)

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PREPARATION OF TECHNICAL INQUIRIES TO THE COMMITTEE ON CRANES FOR NUCLEAR FACILITIES

INTRODUCTION

The ASME Committee on Cranes for Nuclear Facilities (CNF) will consider written requests for interpretations and revisions to CNF Standards and develop new requirements if dictated by technological development. The Committee's activities in this regard are limited strictly to interpretations of the requirements or to the consideration of revisions to the present Standard on the basis of new data or technology. As a matter of published policy, ASME does not ''approve,'' ''certify,'' ''rate,'' or ''endorse'' any item, construction, proprietary device, or activity and, accordingly, inquiries requiring such consideration will be returned. Moreover, ASME does not act as a consultant on specific engineering problems or on the general application or understanding of the Standard requirements. If, based on the inquiry information submitted, it is the opinion of the Committee that the inquirer should seek assistance, the inquiry will be returned with the recommendation that such assistance be obtained.

All inquiries that do not provide the information needed for the Committee's full understanding will be returned.

INQUIRY FORMAT

Inquiries shall be limited strictly to interpretations of the requirements or to the consideration of revisions to the present Standard on the basis of new data or technology.

Inquiries shall be submitted in the following format.

(a) *Scope.* The inquiry shall involve a single requirement or closely related requirements. An inquiry letter concerning unrelated subjects will be returned.

(b) *Background.* State the purpose of the inquiry, which would be either to obtain an interpretation of the Standard or to propose consideration of a revision to the present Standard. Provide concisely the information needed for the Committee's understanding of the inquiry, being sure to include reference to the applicable Standard, Edition, Addenda, Requirements, Parts, Subparts, Appendices, paragraphs, figures, and tables. If sketches are provided, they shall be limited to the scope of the inquiry.

(c) *Inquiry Structure*

(1) *Proposed Question(s).* The inquiry shall be stated in a condensed and precise question format, omitting superfluous background information, and, where appropriate, composed in such a way that ''yes'' or ''no'' (perhaps with provisos) would be an acceptable reply. The inquiry statement should be technically and editorially correct.

(2) *Proposed Reply(ies).* State what it is believed that the Standard requires. If, in the inquirer's opinion, a revision to the Standard is needed, recommended wording shall be provided.

(d) *Submittal.* The inquiry shall be submitted in typewritten form; however, legible, handwritten inquiries will be considered. It shall include the name and mailing address and telephone number of the inquirer and be mailed to the following address:

Secretary
ASME Committee on Cranes for Nuclear Facilities
Nuclear Department
Three Park Avenue
New York, NY 10016

ASME NOG-1–2004

Following approval by the ASME Committee on Cranes for Nuclear Facilities and ASME, and after public review, ASME NOG-1–2004 was approved by the American National Standards Institute on December 9, 2004.

SUMMARY OF CHANGES

ASME NOG-1–2004 consists of NOG-1–2002 as well as the following additional changes.

Changes given below are identified on the indicated pages by a margin note **(04)** placed next to the affected area. The pages not listed are the reverse sides of the listed pages and contain no changes.

Page	*Location*	*Change*
10, 11	1160	Revised
25	Table 4211-1	Revised in its entirety
33	4331	Equations corrected by errata
34	4333	Equation corrected by errata
36	4412	Revised
40	5111(b)	Cross-reference revised
46, 47	5413.1	Second paragraph added
50	5413.1(i)	Cross-reference updated
	5416.1	Editorially revised
57	5426	Revised in its entirety
	Fig. 5426-1	Revised
	Fig. 5426-2	Added
79, 80	5477(a)	Equation (35) corrected by errata
86, 87	6230(f)	Revised
90	6417	(1) Subparagraph (b) deleted (2) Former subparas. (c) through (f) re-designated (b) through (e), respectively
91	6422.1(a)	Cross-reference updated
92	6432.5	Added
95	6471(a)	Cross-reference updated
96	6472.2(c)	Cross-reference updated
98	6472.4(a)	Cross-reference updated
102	6483	Revised in its entirety

Page	*Location*	*Change*
103	7100	Cross-references updated in subparas. (d)(1), (d)(2), and (g)(1)
109	7270	Cross-reference corrected by errata
111	7341	Last cross-reference corrected by errata
114	7512	Cross-reference corrected by errata
115	7521.2(r)	Cross-reference corrected by errata

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RULES FOR CONSTRUCTION OF OVERHEAD AND GANTRY CRANES (TOP RUNNING BRIDGE, MULTIPLE GIRDER)

Section 1000
Introduction

1100 GENERAL

Cranes covered under this Standard shall be designed 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.

1110 Scope

This Standard covers electric overhead and gantry multiple girder cranes with top running bridge and trolley used at nuclear facilities and components of cranes at nuclear facilities.

1120 Applications

This Standard applies to the design, manufacture, testing, inspection, shipment, storage, and erection of the cranes covered by this Standard.

1130 Responsibility

The cranes covered by this Standard are classified into three types (see para. 1150, Definitions, *crane types*) depending upon crane location and usage of the crane at a nuclear facility.

The owner shall be responsible for determining and specifying the crane type. The owner shall also be responsible for determining and specifying the environmental conditions of service, performance requirements, type and service level of coatings and finishes, and degree of Quality Assurance.

Determining the extent to which this Standard can be used, either in part or in its entirety, at other than nuclear facilities, shall be the responsibility of those referencing the use of this Standard.

1140 Environmental Conditions (Types I, II, and III Cranes)

1141 Radiation

(a) The purchase specification shall specify the accumulated radiation dosage expected to be seen by the crane in the life of the nuclear facility.

(b) Components whose normal life could be reduced by the effects of the specified radiation shall be tabulated and submitted to the crane purchaser.

(c) Components whose failure, due to radiation, could result in loss of one of the single failure-proof features which hold the load either shall be designed to withstand the specified radiation or shall have a specific replacement period. Where state-of-the-art is such that sufficient data are not available, periodic inspections shall be made by the purchaser to determine when replacement should be made.

1142 Temperature

(a) The purchase specification shall specify the following temperature requirements in the area where the crane operates:

(1) maximum operating temperature,
(2) minimum operating temperature,
(3) ambient temperature for motors,
(4) maximum construction temperature, and
(5) minimum construction temperature.

(b) The crane shall be designed to withstand the effects of the specified temperatures, or the limitations of the crane's design concerning these temperature conditions shall be specified by the crane designer.

1143 Pressure

(a) The purchase specification shall specify the following pressure requirements in the area where the crane operates:

(1) normal operating pressure and

(2) any test or abnormal event of these pressures including the rate of change.

(b) The crane shall be designed to withstand the effects of the specified pressures, or the limitations of the crane's design concerning these pressure conditions shall be specified by the manufacturer. Specifically where there are changes in pressure, enclosures shall be vented.

1144 Humidity

(a) The purchase specification shall specify the humidity conditions in the area where the crane operates.

(b) The crane shall be designed to withstand the effects of the specified humidity, or the limitations of the crane's design concerning the humidity condition shall be specified by the manufacturer.

1145 Chemical

(a) *Spray Systems*

(1) If the crane may be subject to any spray systems, then the chemistry of the spray shall be specified in the purchase specification. Any restrictions on the use of materials due to the effects of the spray shall also be specified. Specifically, where a corrosive spray is present the possibility of H_2 generation exists and, therefore, the use of exposed aluminum, magnesium, galvanized steel, and zinc is to be minimized.

(2) The crane shall be designed to withstand the effects of the specified spray and shall not use the specified restricted materials. Any limitations of the crane's design concerning the spray condition and the use of any restricted materials shall be specified by the manufacturer prior to the manufacture of the crane.

(b) *Pools*

(1) If the crane's load block and wire rope are to be immersed, then the chemistry of the pool shall be specified in the purchase specification. Requirements for the materials and lubricants of the load block and wire rope shall also be specified to insure compatibility with the pool chemistry. In reactor and fuel pools, the lubricants shall basically be nonwater-soluble and shall be free of halogenated compounds, halogens, mercury, and other deleterious materials.

(2) Load blocks and wire ropes that are to be immersed shall be lubricated with a lubricant that meets the specified lubrication requirements. Any limitations of the crane design concerning the pool chemistry and lubrication requirements shall be specified by the manufacturer.

1150 Definitions

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

alligatoring: see *checking*.

appointed: assigned specific responsibilities by the employer or the employer's representative.

approval: an act of endorsing or authorizing, or both.

appurtenance: a part that is attached to a component that has been completed.

as-built data: documentation describing a complete item.

audit: a planned and documented activity performed to determine by investigation, examination, or evaluation of objective evidence the adequacy of and compliance with established procedures, instructions, drawings, and other applicable documents, and the effectiveness of implementation. An audit should not be confused with surveillance or inspection activities performed for the sole purpose of process control or product acceptance.

audit, external: an audit of those portions of another organization's quality assurance program not under the direct control or within the organizational structure of the auditing organization.

audit, internal: an audit of those portions of an organization's quality assurance program retained under its direct control and within its organizational structure.

authorized: appointed by a duly constituted administrative or regulatory authority.

auxiliary hoist: see *hoist, auxiliary*.

barrier: a flexible material designed to withstand the penetration of water, water vapor, grease, or harmful gases.

blisters: bubble-like protrusions formed in a cured, or nearly cured, coating film; see ASTM D 714-56 for photographic examples.

boom, gantry crane: an extension of the trolley runway, which may be raised or retracted to obtain clearance for gantry travel.

boom, overhead crane: a horizontal member mounted on the trolley to permit hoisting and lowering the load at a point other than directly under the hoist drum or trolley.

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

brake, drag: a friction brake that provides a continuous retarding force having no external control.

brake, emergency: a brake for bridge and trolley that is released during normal operation and arranged to apply a retarding force when initiated by the operator during an emergency, or to automatically apply a retarding force upon loss of power.

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 to lower a load but does not impose any additional load on the motor when hoisting a load.

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

brake, service: a brake for bridge or trolley used by the operator, during normal operation, to apply a retarding force.

bridge: that part of a crane consisting of two or more girders, trucks, end ties, footwalks, and drive mechanism, which carries the trolley or trolleys.

bridge travel: the crane movement in a direction parallel to the crane runway.

bubbles: gas pockets that rise through the wet coating film to the surface. An example of a bubble can be observed on runs shown in Fig. 10-8 of the ASTM Manual of Coating Work.

bumper (also known as *buffer*): a device for reducing impact when a moving crane or trolley reaches the end of its permitted travel, or when two moving cranes or trolleys come into contact. This device may be attached to the crane, trolley, or runway stop.

cab: the operator's compartment on a crane.

cab-operated crane: see *crane, cab-operated.*

calibration: comparison of two instruments or measuring devices, one of which is a standard of known accuracy traceable to national standards, to detect, correlate, report, or eliminate by adjustment any discrepancy in accuracy of the instrument or measuring device being compared with the standard.

cantilever frame: a structural member that supports the trolley of a wall crane.

cantilever gantry crane: see *crane, gantry, cantilever.*

carrier: the transporting agency.

certificate of conformance: a document signed or otherwise authenticated by an authorized individual certifying the degree to which items or services meet specified requirements.

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

certified test report: see *report, certified test.*

characteristic: any property or attribute of an item, process, or service that is distinct, describable, and measurable.

checking: a defect in the coating manifested by slight breaks in the coating film that do not penetrate to the underlying surface per ASTM D 660-44. Line-type checking is commonly known as alligatoring.

classification: the organization of items according to their susceptibility to damage during shipping, receiving, and storage. Classification does not relate to the function of the item in the completed system.

cleanness: a state of being clean in accordance with predetermined standards, usually implies freedom from dirt, scale, heavy rust, oil, or other contaminating impurities.

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

collector, current: a contacting device for collecting current from runway or bridge conductors.

condition adverse to quality: an all-inclusive term used in reference to any of the following: failures, malfunctions, deficiencies, defective items, and nonconformances. A significant condition adverse to quality is one which, if uncorrected, could have a serious effect on safety or operability.

conductors, bridge: the electrical conductors located along the bridge structure of a crane to provide power and control to the trolley(s).

conductors, runway (also known as *main conductors*): the electrical conductors located along a crane runway to provide power or control to the crane.

construction phase: a period that commences with receipt of items at the construction site and ends when the components and systems are accepted by the owner or the owner's designated representative.

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

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

control braking means, eddy current: a method of controlling or reducing speed by means of an electrical induction load brake.

control braking means, emergency: a method of decelerating a drive when power is not available. The braking effort may be established as a result of action by the operator or automatically when power to the drive is interrupted.

control braking means, mechanical: a method of controlling or reducing speed by friction.

controller: a device or group of devices that serves to govern in some predetermined manner the power delivered to the apparatus to which it is connected.

controller, manual: a controller having all of its basic functions performed by devices that are operated by hand.

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

control panel: an assembly of components (magnetic, static, hydraulic, pneumatic, etc.) that governs the flow of power to or from a motor or other equipment in response to signals from a master switch, pushbutton station, remote control, automatic program control, etc.

corrective action: measures taken to rectify conditions adverse to quality and, where necessary, to preclude repetition.

countertorque (also known as *plugging*): a method of control by which the power to the motor is reversed to develop torque in the direction opposite to the rotation of the motor.

cracking: a defect in the coating, manifested by a break in the coating film, that extends from the surface to substrate per ASTM D 660-44. Irregular cracking is commonly known as mud cracking.

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, cab-operated: a crane controlled by an operator in a cab attached to the bridge or trolley.

crane, floor-operated: a crane that is controlled by a means suspended from the crane by an operator on the floor or an independent platform.

crane, gantry: a crane similar to an overhead crane except that the bridge for carrying the trolley or trolleys is supported on two or more legs running on fixed rails or other runway.

crane, gantry, cantilever: a gantry or semigantry crane in which the bridge girders or trusses extend transversely beyond the crane runway on one or both sides.

crane, gantry, outdoor storage: a gantry crane of long span usually used for storage of bulk material; the bridge girders or trusses are rigidly or nonrigidly supported on one or more legs. It may have one or more fixed or hinged cantilever ends.

crane, overhead: a crane with a multiple girder movable bridge carrying a movable or fixed hoisting mechanism and traveling on an overhead fixed runway structure.

crane, polar: a bridge or gantry crane that travels on a circular runway.

crane, power-operated: a crane whose mechanism is driven by electric, air, hydraulic, or internal combustion means.

crane, pulpit-operated: a crane operated from a fixed operator station not attached to the crane.

crane, remote-operated: a crane controlled by an operator not in a pulpit or in the cab attached to the crane, by any method other than a means suspended from a crane.

crane, semigantry: a gantry crane with one end of the bridge rigidly supported on one or more legs that run on a fixed rail or runway, the other end of the bridge being supported by a truck running on an elevated rail or runway.

crane, standby: a crane that is not in regular service but that is used occasionally or intermittently as required.

crane, Type I: a crane that is used to handle a critical load. It shall be designed and constructed so 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. Single failure-proof features shall be included so that any *credible failure* of a single component will not result in the loss of capability to stop and hold the critical load.

crane, Type II: a crane that is not used to handle a critical load. It shall be designed and constructed so that it will remain in place with or without a load 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.

crane, Type III: a crane that is not used to handle a critical load; no seismic considerations are necessary, and no single failure-proof features are required.

crater: the result of bubbles that rise through the wet coating film and burst at the surface creating a bowl-like depression (see Fig. 10-13 of the ASTM Manual of Coating Work for photographic examples).

delamination: separation of one coat or layer from another coat or layer of a coating system.

design, final: approved design output documents and approved changes thereto.

designated: selected or assigned by the employer or the employer's designated representative as being qualified to perform specific duties.

designated representative: an individual or organization authorized by the purchaser or owner to perform specified functions.

design input: those criteria, parameters, bases, or other design requirements upon which the detailed final design is based.

design output: documents such as drawings, specifications, and other documents defining technical requirements of structures, systems, and components.

design process: technical and management processes that commence with identification of design input and that lead to and include the issuance of design output documents.

deviation: a departure from specified requirements.

disconnecting means: a device, or group of devices, or other means by which the conductors of a circuit can be disconnected from their source of supply.

diaphragm: a plate or partition between opposite parts of a member, serving a purpose in the structural design of the member.

document: any written or pictorial information describing, defining, specifying, reporting, or certifying activities, requirements, procedures, or results.

drift point: a point on a travel motion master switch or on a manual controller that releases the brake while the motor is not energized; this allows for coasting.

drum: the cylindrical member around which the ropes are wound for lifting or lowering the load.

end tie: a structural member that connects the ends of the bridge girders to maintain squareness of the bridge.

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

equipment, measuring and testing: devices or systems used to calibrate, measure, gage, test, or inspect in order to control or acquire data to verify conformance to specified requirements.

examination: an element of quality verification consisting of investigation of items or services to determine conformance to specified requirements.

exposed: a condition in which hazardous objects are not adequately guarded or isolated (capable of being contacted inadvertently).

fish eye: a coating film defect consisting of holes or visible depressions in the coating film (see Figs. 10-11 and 10-12 of the ASTM Manual of Coating Work for photographic examples).

flaking: a defect in the coating film manifested by actual detachment of pieces of the film either from its substrate or from coating previously applied per

ASTM D 772-47 including photographic standards. Flaking is generally preceded by cracking, checking, or blistering and is the result of loss of adhesion.

floor-operated crane: see *crane, floor-operated*.

gantry crane: see *crane, gantry.*

gantry crane boom: see *boom, gantry crane*.

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

guideline: a suggested practice that is not mandatory in programs intended to comply with a standard.

handling: an act of physically moving items by hand or mechanical machinery, not including transport modes.

hoist: a machinery unit that is used for lifting and lowering a load.

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

hoist, main: the primary hoist mechanism provided for lifting and lowering the rated load.

hoist motion: that motion which lifts or lowers a load.

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

holiday: a discontinuity in the coating film that exposes the substrate; types of holidays are pinholes, skips, or voids.

hydraulic: a method of controlling or powering drive or braking by means of displacement of a liquid.

in place: remaining on the runway and retaining its physical integrity.

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

inspector: a person who performs inspection activities to verify conformance to specific requirements.

item: an all-inclusive term used in place of any of the following: appurtenance, assembly, component, equipment, material, module, part, structure, subassembly, subsystem, system, or unit.

lifting device: a device that is not reeved onto the hoist ropes, such as hook-on buckets, magnets, grabs, and other supplemental devices used for ease of handling certain types of loads; the weight of these devices is considered part of the rated load.

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

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 at the plant of the crane installation. 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 credible critical load shall be specified by the purchaser.

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 purchaser.

load, rated: the maximum load for which a crane or individual hoist is designed and built by a manufacturer; the rated load is shown on the equipment nameplate(s).

load block: the assembly of hook or shackle, swivel, bearing, sheaves, pins, and frames suspended by the hoisting rope; this shall include any items reeved in the hoisting ropes.

main hoist: see *hoist, main*.

man trolley: see *trolley, man*.

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

material test report: see *report, material test*.

modification: a planned change accomplished in accordance with the requirements and limitations of applicable codes, standards, and specifications.

mud cracking: see *cracking*.

noncoasting mechanical drive: a drive that results in automatically decelerating a trolley or bridge when power is not available

nonconformance: a deficiency in characteristic, documentation, or procedure that renders the quality of an item or activity unacceptable or indeterminate.

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

normal operating conditions, floor-operated crane: conditions during which a crane is performing functions within the scope of the original design. Under these conditions, the operator is at the operating control devices that are attached to the crane but operated with the operator off the crane and with no other persons on the crane.

objective evidence: any documented statement of fact, other information, or record, either quantitative or qualitative, pertaining to the quality of an item, activity, or service based on observations, measurements, or tests that can be verified.

orange peel: a dimpled appearance of a dried coating film that resembles the texture and appearance of an orange peel.

outdoor storage gantry crane: see *crane, gantry, outdoor storage*.

overhead crane: see *crane, overhead*.

overhead crane boom: see *boom, overhead crane*.

overload: any load greater than the rated load.

overspray: spraying of coating on adjacent surfaces; texture can range from that of sandpaper to orange peel (see Fig. 10-5 of the ASTM Manual of Coating Work for photographic examples).

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 who has been granted a construction permit or operating license by the regulatory authority having lawful jurisdiction.

package: the shipping container plus the contents of the container.

package unit: any assembly of mechanical and/or electrical components and parts that can be disassembled without destroying the integrity of the individual parts.

peeling: separation of one or more coats or layers of a coating system from the substrate.

pinhole: a minute hole through the thickness of a coating film, allowing exposure of substrate (see Fig. 10-14 of the ASTM Manual of Coating Work for photographic examples).

plugging: a control function that provides braking by reversing the motor line voltage polarity or phase sequence so that the motor develops a countertorque that exerts a retarding force.

pneumatic: a method of controlling or powering a drive or braking by means of compressing a gas.

polar crane: see *crane, polar*.

power-operated crane: see *crane, power-operated*.

procedure: a document that specifies or describes how an activity is to be performed.

procurement document: purchase requisitions, purchase orders, drawings, contracts, specifications, or instructions used to define requirements for purchase.

pulpit-operated crane: see *crane, pulpit-operated*.

purchaser: the organization responsible for establishment of procurement requirements and for issuance or administration, or both, of procurement documents.

push-button station, pendant: means suspended from the crane for operating the controllers from the floor or other level beneath the crane.

qualification, personnel: the characteristics or abilities gained through education, training, or experience, as measured against established requirements, such as standards or tests, that qualify an individual to perform a required function.

qualified person: a person who, by possession of a recognized degree 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.

qualified procedure: an approved procedure that has been demonstrated to meet the specified requirements for its intended purpose.

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

quality assurance record: a completed document which furnishes evidence of the quality of items and/or activities affecting quality.

quality control: those quality assurance actions that provide a means to control and measure the characteristics of an item, process, or facility to established requirements.

rail sweep: a mechanical device attached to the crane but located in front of the crane leading wheels to deflect any obstructions.

receiving: taking delivery of an item at a designated location.

regenerative: a method in which the electrical energy generated by the motor is fed back into the power system.

remote-operated crane: see *crane, remote-operated*.

repair: the process of restoring a nonconforming characteristic to a condition, such that the capability of an item to function reliably and safely is unimpaired, even though that item still does not conform to the original requirement.

report, certified test: a document signed by a qualified party that contains sufficient data and information to verify the actual properties of items and the actual results of all required tests.

report, load summary: the report provided by the manufacturer that furnishes the numerical values of the crane loads at the crane-building interfaces for the load combinations of each category of loads listed for the structural design of the crane.

report, material test: a report from the material supplier that identifies the furnished material in terms of heat number, physical and chemical properties, etc., as appropriate.

rework: the process by which an item is made to conform to original requirements by completion or correction.

right of access: the right of a purchaser or designated representative to enter the premises of a supplier for the purpose of inspection, surveillance, or quality assurance audit.

rope: refers to wire rope unless otherwise specified.

run: the flow of an excessively applied coating that results in an elongated pattern of irregular coating films over a small vertical or sloped surface area such as a point or an angle (see Fig. 10-8 of the ASTM Manual of Coating Work for photographic examples).

running sheave: a sheave that rotates as the load block is raised or lowered.

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

sag: the flow of an excessively applied coating that results in a broad pattern of irregular coating films over a large vertical or sloped surface area (see Fig. 10-9 of the ASTM Manual of Coating Work for photographic examples).

scaling: detachment of coating film from substrate.

semigantry crane: see *crane, semigantry*.

service: the performance of activities such as design, fabrication, inspection, nondestructive examination, repair, or installation.

shall: indicates that which is mandatory and must be followed.

should: indicates a recommendation, the advisability of which depends on the facts in each situation.

side pull: the portion of the hoist pull acting horizontally when the hoist lines are not operated vertically.

sill: a horizontal structural member that connects the lower ends of two or more legs of a gantry crane on one runway.

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.

skip: the unintentional omission of coating from an area of the substrate.

span: the horizontal distance center-to-center of runway rails.

special process: a process, the results of which are highly dependent on the control of the process or the skill of the operators, or both, and in which the specified quality cannot be readily determined by inspection or test of the product.

specification: a concise statement of a set of requirements to be satisfied by a product, material, or process.

standby crane: see *crane, standby*.

stop: a device to limit travel of a trolley or crane bridge; this device normally is attached to a fixed structure and normally does not have energy absorbing ability.

storage: the act of holding items in a storage facility.

storage facility: area designated and prepared for holding of items.

structural weld: a weld that is directly stressed by the crane load.

substrate: the uncoated base surface to which the coating is to be applied.

supplier: any individual or organization who furnishes items or services in accordance with a procurement document; an all-inclusive term used in place of any of the following: vendor, seller, contractor, subcontractor, fabricator, consultant, and their subtier levels.

surveillance: the act of monitoring or observing to verify whether an item or activity conforms to specified requirements.

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

switch, emergency stop: a manually operated switch to cut off electric power independently of the regular operating controls.

switch, limit: a switch that is operated by some part or motion of a power-driven machine or equipment to alter or disconnect the electric circuit associated with the machine or equipment.

switch, main: a switch on the crane controlling the main power supply to the crane.

switch, master: a switch that dominates the operation of contactors, relays, or other remotely operated devices.

temperature, minimum operating: the minimum ambient temperature at which the crane is operated, either during the construction phase or plant inservice phase of use of the crane.

test, break strength: a physical test to destruction performed on a sample of an item to verify the rated strength of that item.

test, dynamic load: a test wherein designated loads are hoisted, lowered, rotated, or transported through motions and accelerations required to simulate handling of the intended item.

test, proof load: a physical load test, with magnitude to be as specified but always in excess of the design load.

testing: an element of verification for the determination of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental, or operational conditions.

traceability: the ability to trace the history, application, or location of an item and like items or activities by means of recorded identification.

transit carriers, closed: trucks, trailers, railroad cars, barges, aircraft, or ships that do provide protection of items from the environment.

transit carriers, open: trucks, trailers, railroad cars, barges, aircraft, or ships that do not provide protection of items from the environment.

transportation mode: a method identified by the conveyance used for transportation of items. It includes any motor vehicle, ship, railroad car, or aircraft; each cargo-carrying body (trailer, van, boxcar, etc.) is a separate vehicle.

trolley: the unit that travels on the bridge rails and supports the load block.

trolley, man: a trolley having an operator's cab attached to it.

trolley frame: an assembly consisting of two side frames or trucks that are connected together by one or more load girts to form a one-piece unit capable of transmitting the load to the crane bridge without undue deflection. The hoist machinery and supports for the sheaves or equalizer are assembled into and supported by the trolley frame.

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

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

use-as-is: a disposition permitted for a nonconforming item when it can be established that the item is satisfactory for its intended use.

verification: the act of reviewing, inspecting, testing, checking, auditing, or otherwise determining and documenting whether items, processes, services, or documents conform to specified requirements.

visual inspection: a macroscopic examination to determine conformance to quality requirements.

void: an area of missing coating through which the substrate or base coat is visible.

waiver: documented authorization to depart from specified requirements.

web plate: the vertical plate connection and upper and lower flanges or cover plates of a girder.

wrap: a flexible material formed around the item or package, to exclude dirt and to facilitate handling, marking, or labeling.

(04) 1160 References

The following is a list of codes and standards referenced in NOG-1. These codes and standards apply to the extent invoked at the point of reference.

The following three documents are contained in the *AISC Manual of Steel Construction (ASD), Ninth Edition:*

Code of Standard Practice for Steel Buildings and Bridges, March 7, 2000
Specification for Structural Steel Buildings Allowable Stress Design and Plastic Design, June 1, 1989
Specification for Structural Joints Using ASTM A 325 or A 490 Bolts, June 23, 2000

Publisher: American Institute of Steel Construction (AISC), One East Wacker Drive, Chicago, IL 60601-2001

AISE TR No. 1, 1991, DC Mill Motors
AISE TR No. 6, 2000, Specification for EOT Cranes for Steel Mill Service
AISE TR No. 11, 1997, Brake Standards for Mill Motors

Publisher: Association of Iron and Steel Engineers (AISE), Three Gateway Center, Pittsburgh, PA 15222-1097

SNT-TC-1A-1996, Recommended Practices for Nondestructive Testing Personnel Qualification and Certification

Publisher: American Society for Nondestructive Testing (ASNT), 1711 Arlingate Lane, Columbus, OH 43228

Systems and Specifications Steel Structures Painting Manual, Volume 2, 8th Edition, 2000

Publisher: The Society for Protective Coatings, Steel Structures Painting Council (SSPC), 40 24th Street, 6th Floor, Pittsburgh, PA 15222-4643

ANSI/AGMA 2001-C95, Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth
AGMA 9005-E02, Industrial Gear Lubrication

Publisher: American Gear Manufacturers Association (AGMA), 1500 King Street, Alexandria, VA 22314-1560

NFPA 70-1999, National Electrical Code

Publisher: National Fire Protection Association (NFPA), One Batterymarch Park, Quincy, MA 02269-9101

ASME B30.2-1996, Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist)
ASME B30.10-1999, Hooks
ASME NQA-1-2002, Quality Assurance Requirements for Nuclear Facility Applications

Publisher: American Society of Mechanical Engineers (ASME International), Three Park Avenue, New York, NY 10016-5990; Order Department: 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300

ASTM A 275/A 275M-98, Magnetic Particle Examination of Steel Forgings
ASTM A 370-02, Standard Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A 388/A 388M-01, Standard Practice for Ultrasonic Examination of Heavy Steel Forgings
ASTM A 435/A 435-82/A 435M-90, Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates for Pressure Vessels
ASTM D 5144-00, Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants
ASTM D 5161-96, Standard Guide for Specifying Inspection Requirements for Coating and Lining Work (Metal Substrates)
ASTM E 114-95 (R2001), Standard Practice for Ultrasonic Pulse-Echo Straight Beam Examination by the Contact Method
ASTM E 165-02, Standard Test Method for Liquid Penetrate Examination

ASTM E 380-93, Standard Practice for Use of the International System of Units (SI) (the Modernized Metric System)
ASTM E 709-01, Standard Guide for Magnetic Particle Examination

Publisher: American Society for Testing and Materials (ASTM International), 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

AWS D1.1/D1.1M-2002, Structural Welding Code — Steel

Publisher: American Welding Society (AWS), 550 NW Le Jeune Road, Miami, FL 33126-5671

CMAA 70-2000, Specifications for Top Running Bridge and Gantry Type Multiple Girder Electric Overhead Traveling Cranes
CMAA 74-2000, Specifications for Top Running and Under Running Single Girder Electric Overhead Traveling Cranes Utilizing Under Running Trolley Hoist

Publisher: Crane Manufacturers Association of America (CMAA), 8720 Red Oak Boulevard, Charlotte, NC 28217-3992

NEMA ICS 1-2000, Industrial Control and Systems: General Requirements
NEMA ICS 2-2002, Industrial Control and Systems: Controllers, Contactors, and Overload Relays Rated 600 Volts (Addendum/Errata 5/23/2002)
NEMA ICS 3-1993, Industrial Control and Systems: Factory Build Assemblies
NEMA ICS 6-1993 (R2001), Industrial Control and Systems Enclosures
Publisher: National Electrical Manufacturers Association (NEMA), 1300 North 17th Street, Rosslyn, VA 22209-3801

OSHA Safety and Health Standards, Title 29, Code of Federal Regulations Part 1910 (29 CFR 1910), Occupational Safety and Health Standards
Publisher: U.S. Department of Labor — Occupational Safety and Health Administration (OSHA)

1170 Nomenclature

The nomenclature used in this Standard is listed and defined in the Section in which it is used.

1180 Conversion Factors

Conversion factors, including metric equivalents, are provided in the Mandatory Appendix I.

Section 2000
Quality Assurance

2100 REQUIREMENTS

(a) The quality assurance program of the Manufacturer of Types I and II cranes shall meet the Basic and Supplemental Requirements of ASME NQA-1, or shall meet the Quality Assurance Requirements specified by the owner.

(b) A specific quality assurance program for manufacturers of Type III cranes is not required unless specified in the procurement documents.

(c) A specific quality assurance program for mechanical components for Type II cranes is not required unless specified in the procurement documents.

(d) A specific quality assurance program for suppliers of electrical components for Types I and II cranes is not required unless specified in the procurement documents.

(e) A specific quality assurance program for suppliers of Type I crane structural and mechanical components which are not listed in Table 7200-1, and for Type II crane structural components which are not listed in Table 7200-2, is not required unless specified in the procurement documents.

(f) The quality assurance program for packaging, shipping, receiving, storage, and handling of Types I and II cranes shall be in conformance with Section 8000.

Section 3000
Coatings and Finishes

3100 COATING SERVICE LEVELS

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

(a) Coating Service Level I. 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. 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 decontaminability in those areas outside primary containment subject to radiation exposure and radionuclide contamination. Coating service level II also applies to coatings in nonradiation areas.

3200 SPECIFIC REQUIREMENTS FOR COATING SERVICE LEVELS

3210 Requirements for Coating Service Level I

(a) Coating requirements for coating service level I shall be in accordance with ASTM D 5144, Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants.

(b) In accordance with ASTM D 5144, coating service level I requires a quality assurance program.

(c) Inspection and testing of coatings for coating service level I shall be in accordance with para. 7700. Specific coating inspections shall be specified by the owner, dependent upon the coating system being used. See ASTM D 5161, Standard Guide for Specifying Inspection Requirements for Coating and Lining Work (Metal Substrates), for selecting and specifying the appropriate inspection requirements.

3220 Requirements for Coating Service Level II

(a) Coating requirements for coating service level II shall be as specified by the owner. The owner may invoke applicable sections of ASTM D 5144, Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants.

(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 be in accordance with para. 7700.

3230 Additional Requirements Applicable to All Coatings

Additional requirements for coatings and finishes are listed in (a) through (o) below. Further information for coatings and finishes is provided in Nonmandatory Appendix A, Section A3240.

(a) If not specified by the owner, the type of coating will be determined by the manufacturer 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 the coating system is specifically designed and formulated as a weldable system and documentation can be provided by the coating manufacturer to attest to this capability. The use of these coatings shall be approved by the owner.

(c) Surfaces exposed to the environment, but inaccessible after assembly, such as wheel wells and hubs, shall be coated prior to assembly.

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

(e) Contact surfaces of friction-type joints to be joined by high-strength bolts shall not be coated with specified coating system except for organic or

inorganic zinc coating systems not prohibited by para. 1145.

(f) 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, shall be protected by means of an appropriate preservative for shipment and/or storage. The manufacturer shall specify which preservatives must be removed by the owner for proper operation of the equipment. Other preservatives may be removed by the owner after installation of the equipment.

(g) Forced curing or drying of the coating system shall not be performed unless recommended by the coating manufacturer.

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

(i) Finished components, such as 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, unitized hoists, interior of control cabinets, festoon trolley cable spacer systems cab interiors, and radio control equipment, may be furnished with conventional coatings unless otherwise specified by the owner.

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

(k) Nameplates and warning labels of factory finished components that are recoated shall be masked to preserve legibility.

(l) Items such as fasteners and conduits shall be supplied with the specified coating system, galvanized, or plating. Galvanizing or plating shall be subject to the requirements of para. 1145. When specifically requested by the owner, a list of galvanized or plated parts shall be provided by the equipment manufacturer.

(m) Surface contaminants, such as grease and oil, detected after blasting shall be removed to produce the surface conditions required by the appropriate Steel Structures Painting Council (SSPC) surface preparation requirement.

(n) If there is visible deterioration of the surface beyond the specified SSPC preparation, repreparation of the surface shall be required.

(o) Preparation of surface shall be accomplished by the methods originally used, except that small areas requiring repair or touchup where conventional blasting is not desirable may be reprepared by one of the following methods. These methods are listed in descending order of effectiveness.

(1) Vacuum blasting to clean an abrasive finish with a minimum 2.0 mil profile; the minimum blasting air pressure shall be 50 psi at the blasting nozzle.

(2) Power tool cleaning using grinding wheels, sanding discs, or other devices to provide a minimum 2 mil profile in accordance with SSPC SP-3; the use of a needle gun to roughen the surface after grinding is recommended.

(3) Hand sanding to obtain as clean a surface as possible in accordance with SSPC SP-2; or wire brushing in accordance with SSPC SP-2.

Section 4000
Requirements for Structural Components

4100 GENERAL

4110 Scope

Section 4000 specifies the design criteria, design, materials, and fabrication procedures for the structural components of Types I, II, and III cranes. The structural components of the crane are identified in para. 4400.

4120 Nomenclature

The nomenclature listed herein is used in the equations in 4000. For further information on nomenclature, application, and units of measurement, see the Section 4000 references noted in parentheses.

A_b = tensile stress area of bolt, sq in. (para. 4323)
C = coefficient for spacing of transverse stiffeners of web (para. 4334)
C_c = column slenderness ratio separating elastic and inelastic buckling (para. 4312)
C_m = coefficient applied to bending term in interaction formula for prismatic members, and dependent upon column curvature caused by applied moments (para. 4321)
DF = design factor (para. 4312)
DFB = design factor for buckling (paras. 4332, 4333)
E = modulus of elasticity of the materials (29,000,000 psi for carbon steel) (paras. 4312, 4321, 4331)
K = buckling coefficient (paras. 4331, 4332.1, 4333)
K_σ = effective length factor for compression (paras. 4331, 4332.1, 4333)
K_τ = buckling coefficient for shear (paras. 4331, 4332.1)
M = bending moment at end of member in plane of bending being considered
M_1 = smaller of end moments in member in plane of bending being considered (para. 4321)
M_2 = larger of end moments in member in plane of bending being considered (para. 4321)
N = modifying coefficient for loading condition (paras. 4312, 4321)
P_a = abnormal event load (paras. 4130, 4140)
P_{cn} = construction lifted load (paras. 4130, 4140)
P_{co} = credible critical load with operating basis earthquake (OBE) (paras. 4130, 4140)
P_{cs} = credible critical load with safe shutdown earthquake (SSE) (paras. 4130, 4140)
P_{db} = bridge or gantry frame dead load (paras. 4130, 4140)
P_{dt} = trolley dead load (paras. 4130, 4140)
P_e = OBE load (paras. 4130, 4140)
$P_{e'}$ = SSE load (paras. 4130, 4140)
P_{hl} = longitudinal horizontal load (paras. 4130, 4140)
P_{ht} = transverse horizontal load (paras. 4130, 4140)
P_{lc} = critical load (paras. 4130, 4140)
P_{lr} = design rated lift load (paras. 4130, 4140)
P_p = plant operations induced loads transmitted to the crane (paras. 4130, 4140)
P_{tp} = containment static test pressure load (paras. 4130, 4140)
P_v = vertical impact load (paras. 4130, 4140)
P_{wd} = plant design basis wind load (paras. 4130, 4140)
P_{wo} = crane operating wind load (paras. 4130, 4140)
P_{wt} = tornado wind load (paras. 4130, 4140)
R = multiplying factor for loading condition (para. 4323)
R_f = ratio of frequencies of crane and runway system (para. 4153.5)
R_m = ratio of masses of crane and runway system (para. 4153.5)
SR_i = structural response (Table 4153.7-1)
T_b = specified pre-tension load of the bolt, lb (para. 4323)

a = plate length for direction parallel to the direction of compression force (Table 4332.1-1); unsupported length of web plate between transverse (vertical) stiffeners, in. (para. 4334)
b = plate width for direction perpendicular to the direction of the compressive force (para. 4331); unsupported length of web plate between longitudinal stiffeners, in. (Table 4332.1-1)
b_w = distance between web plates, in. (para. 4333)
h = depth of web, in. (para. 4333)
k = effective length factor (paras. 4312, 4321, 4331, 4332.1)
l = unbraced length of member (para. 4312)
l_b = actual unbraced length in plane of bending (para. 4333)
r = radius of gyration, in. (para. 4312)
t = thickness of plate, in. (paras. 4331, 4333, 4334)
α = ratio of plate length to width (Table 4332.1-1)
β = stress ratio (Table 4332.1-1)
θ = rotation at node (Table 4144.3-1)
μ = Poisson's ratio (para. 4331)
σ = computed axial stress, psi (para. 4321)
σ_a = allowable axial stress, psi (para. 4321)
σ_{ab} = allowable bending stress in the plane of bending being considered, psi (para. 4321)
σ_{ac} = allowable compressive stress without consideration for buckling, psi (para. 4321)
σ_{at} = allowable tensile stress (para. 4323)
σ_b = computed stress in plane of bending, psi (para. 4321)
σ_c = computed compressive stress, psi (para. 4332)
σ_{ce} = equivalent compressive stress, psi (para. 4332.1)
σ_{cr} = critical comparison buckling stress, compressive stresses only, psi (para. 4331)
σ_{crc} = critical comparison buckling stress, compressive and shear stresses in combination, psi (para. 4332)
σ_e = Euler buckling stress, psi
$\sigma_{e'}$ = Euler buckling stress divided by a modifying coefficient for design factor, psi (para. 4321)
σ_p = proportional limit, psi (para. 4331)
σ_y = specified minimum yield stress of the material, psi (paras. 4311, 4323)
τ = computed shear stress, psi (para. 4333)
τ_a = allowable shear stress, psi (para. 4323)
τ_{cr} = shear critical buckling stress, psi (para. 4331)

4130 Description of Loads

The loads described herein are the loads to be used for the analysis and design of the structural components of the crane. The loads are to be combined as outlined in para. 4140. All loads described, except the crane dead loads, shall be stated by the purchaser in the purchase specification.

4131 Dead Loads

(a) Trolley P_{dt}: the total weight of the trolley including all machinery and equipment attached thereto.

(b) Bridge or Gantry Frame P_{db}: the total weight of the bridge or gantry frame structure including all machinery and equipment attached thereto, trucks, wheels, and end ties.

4132 Live Loads

(a) Rated Load P_{lr}. The design rated load to be lifted and transported by the crane which by definition is not considered as the critical load. An allowance for lifting accessories which are not part of the crane, such as yokes, spreader beams, etc., is to be included in the design rated load.

(b) Critical Load P_{lc}. For the definition of *critical load,* see para. 1150. In addition to listing each critical load, the purchaser shall furnish the duration in hours per year that each critical load is expected to be on the crane hook. An allowance for lifting accessories is to be included in each critical load.

(c) Construction Load P_{cn}. The maximum expected construction load to be lifted and transported by the crane during the plant construction phase, prior to its use as a plant operating crane.

(d) Credible Critical Load P_{co}, P_{cs}. P_{co} is the weight of lifted load which may be considered in combination with the operating basis earthquake (OBE). P_{cs} is the weight of lifted load which may be considered in combination with the safe shutdown earthquake (SSE).

Alternatively, P_{co} and P_{cs} may be defined to be lifted loads in credible combinations with seismic events other than OBE and SSE. If this alternative method is used, the appropriate substitution for P_e and $P_{e'}$ shall be made in load combinations P_{c10} and P_{c12}.

The loads and seismic events shall be specified by the Purchaser.

4133 Impact Loads

(a) Vertical Impact Load P_v. Shall be taken as 15% of the maximum lifted load.

(b) Transverse Horizontal Load P_{ht}. The horizontal load transverse to the bridge is induced by the acceleration or deceleration of the bridge crane or gantry crane along its runway and shall be taken as 5% each of the bridge or gantry frame dead load, the trolley dead load, and the maximum lifted load.

(c) Longitudinal Horizontal Load P_{hl}. The horizontal load longitudinal to the bridge is induced by the acceleration or deceleration of the trolley on the crane bridge girder rails and shall be taken as 10% of the trolley dead load and the maximum lifted load.

4134 Wind Loads. The following wind loads are to be considered to act in any direction.

(a) Operating Wind P_{wo}. The maximum wind load under which the crane will be permitted to operate. If none is stipulated by the purchaser, then the nominal wind load specified in CMAA 70 shall be used.

(b) Design Wind P_{wd}. The plant design basis wind load resulting from the 100 year recurrence, "fastest-mile of wind." Under this loading, the crane will not be operational, but be secured.

(c) Tornado Wind P_{wt}. The plant design basis tornado loads. Tornado pressure differentials associated with the plant design basis tornado shall be included in the loading. Tornado-generated missiles shall be considered. The purchaser shall be responsible for the missile parameters and method of evaluation of tornado loads and tornado-generated missiles. Under these loadings, the crane will not be operational, but be secured. Indoor cranes may be subjected to the design basis tornado if the building enclosures have been designed to fail.

4135 Normal Plant Operating Loads

(a) Plant Operation Induced Loads P_p. The loads imposed on the crane through the supporting structure due to normal operation of plant equipment. The crane is not operating.

(b) Static Test Pressure Load P_{tp}. The over-pressure imposed on the crane due to the static test pressure load for the structure enclosing the crane. This load applies only to those cranes housed within containments. The crane is not operating.

4136 Seismic and Abnormal Events Loads

(a) Safe Shutdown Earthquake $P_{e'}$. The site SSE parameters shall be used in the seismic analysis of the bridge crane or the gantry crane following the procedures outlined in para. 4140.

(b) Operating Basis Earthquake P_e. The site OBE parameters shall be used in the seismic analysis of the bridge crane or the gantry crane following the procedures outlined in para. 4140.

(c) Abnormal Event Loads P_a. Loads caused by failure of plant equipment which impose jet or missile loads on the crane. The Purchaser shall be responsible for the effects of, and shall establish the criteria for, these loads.

4140 Load Combinations

The following tabulated loads and their designations are described in para. 4120. The various load combinations, using the load designations, are listed herein. All load combinations are applicable to Types I and II cranes, whereas the Crane Operational Loads and the Construction Loads combinations are applicable to the Type III cranes.

Load	Load Designation
Trolley Dead Load	P_{dt}
Bridge/Grantry Dead Load	P_{db}
Rated Load	P_{lr}
Critical Load	P_{lc}
Credible Critical Load With OBE	P_{co}
Credible Critical Load With SSE	P_{cs}
Construction Load	P_{cn}
Vertical Impact Load	P_v
Transverse Horizontal Load	P_{ht}
Longitudinal Horizontal Load	P_{hl}
Operating Wind Load	P_{wo}
Design Wind Load	P_{wd}
Tornado Wind Load	P_{wt}
Plant Operation Induced Loads	P_p, P_{tp}
SSE Loads	$P_{e'}$
OBE Loads	P_e
Abnormal Event Loads	P_a

(a) Crane Operational Loads[1]

$$P_{C1} = P_{db} + (P_{dt} + P_{lr})$$

$$P_{C2} = P_{db} + (P_{dt} + P_{lr}) + P_v + P_{wo}$$

$$P_{C3} = P_{db} + (P_{dt} + P_{lr}) + P_{ht} + P_{wo}$$

[1] In the event that simultaneous operation of motions is permitted, the appropriate combinations of impact loads shall be used.

$$P_{C4} = P_{db} + (P_{dt} + P_{lr}) + P_{hl} + P_{wo}$$

$$P_{C5} = P_{db} + P_{dt} + (P_p \text{ or } P_{tp})$$

(b) Construction Loads[1]

$$P_{C6} = P_{db} + (P_{dt} + P_{cn}) + P_v + P_{wo}$$

$$P_{C7} = P_{db} + (P_{dt} + P_{cn}) + P_{ht} + P_{wo}$$

$$P_{C8} = P_{db} + (P_{dt} + P_{cn}) + P_{hl} + P_{wo}$$

(c) Severe Environmental Loads

$$P_{C9} = P_{db} + P_{dt} + P_{wd}$$

(d) Extreme Environmental Loads

$$P_{C10} = P_{db} + (P_{dt} + P_{cs}) + P_{e'} + P_{wo}$$

$$P_{C11} = P_{db} + P_{dt} + P_{e'} + P_{wo}$$

$$P_{C12} = P_{db} + (P_{dt} + P_{co}) + P_e + P_{wo}$$

$$P_{C13} = P_{db} + P_{dt} + P_e + P_{wo}$$

$$P_{C14} = P_{db} + P_{dt} + P_{wt}$$

(e) Abnormal Event Loads

$$P_{C15} = P_{db} + P_{dt} + P_a + P_{wo}$$

4150 Seismic Analysis for Types I and II Cranes

4151 Methods of Analysis. A dynamic analysis method (e.g., response spectrum or time-history method) shall be used to establish the response of the crane to a seismic event.

4152 Seismic Input Data. The seismic input data for the crane seismic analysis shall be provided in the specification for the crane. 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.

For analysis of a crane with a suspended critical load, the specification for the crane shall provide the credible critical load. The basis for determining the credible critical load will be studies of site seismicity and expected crane usage (see para. 4132).

4153 Linear Analysis

4153.1 Response Spectrum Method. The crane 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 rules of this Section. These outputs shall serve as the basis for mode-by-mode computation of the response of the crane to each of the three components of seismic input.

4153.2 Time-History Analysis. Time histories of structural response at the appropriate level may be used for analysis of the crane. The time histories shall be provided by the purchaser, and shall account for parametric variation in the supporting structure. 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 co-directional responses caused by each of the three components of earthquake motion at a particular point of the structure or of the mathematical model.

(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.

4153.3 Crane Mathematical Model

(a) The crane shall be represented by a generalized three-dimensional system of nodes. The model's geometry shall reflect the overall size, length, connectivity, and stiffnesses of the various structural members. An appropriate element representation of each member shall be used to describe all components which contribute significantly to the stiffness of the crane. The elements shall include, but not

necessarily be limited to, the following structural members: bridge girders, trolley frame, gantry legs, end ties, end trucks, platform supports, and cab supports; and for cranes required to be analyzed for credible critical loads, drum, upper block supports, and hoist ropes. Line elements emanating from the end truck shall be used to represent the connectivity of the wheels of the crane to the runway rail.

(b) For cranes using bogeyed wheel trucks, pinned connections shall be specified for line elements which 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 stiffnesses which are an order of magnitude higher than the most stiff 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 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.

4153.4 Location and Number of Dynamic Degrees of Freedom. Dynamic degrees of freedom shall be assigned to a sufficient number of node points, and in such locations that the real mass and stiffness distribution of the crane 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 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.

4153.5 Decoupling Criteria for the Crane Runway. The crane and runway shall be evaluated to determine if the crane can be represented as a separate model or a model coupled with the runway. For the crane 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 any R_f.

(b) If $0.01 \le R_m \le 0.1$, decoupling can be done if $R_f \le 0.8$ or if $R_f \ge 1.25$.

(c) If $R_m \ge 0.1$, or $0.8 \le R_f \le 1.25$, an approximate model of the runway system shall be included with the crane model.

R_m and R_f are defined as:

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

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

The purchaser shall determine the mass and frequency characteristics of the crane runway.

4153.6 Boundary Conditions at Trolley and Runway Rails. The crane bridge (including gantry legs, if applicable) and trolley 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 shall be included as boundary conditions in the model of the crane. 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. The restraint device and resisting structure shall be designed for the maximum load resulting from the boundary condition considered. The crane shall be modeled with the boundary conditions specified in Fig. 4154.3-1, unless additional restraining, driving, or holding mechanisms exist. Basic boundary conditions for the crane model shall be consistent with the figure and the rational displacements, deformations, and forces in the structure under consideration.

4153.7 Trolley Locations and Hoist Positions. The crane (bridge and trolley) shall be analyzed under two separate loading conditions:

(a) credible critical load on hook

(b) no load on hook

The analysis procedure shall use three different trolley positions. These correspond to: the trolley at its extreme end positions on the bridge span; the trolley at the $^1/_4$ point of the span positions; and the trolley at mid-span. In calculating the $^1/_4$ and mid-span positions, a location on the trolley which

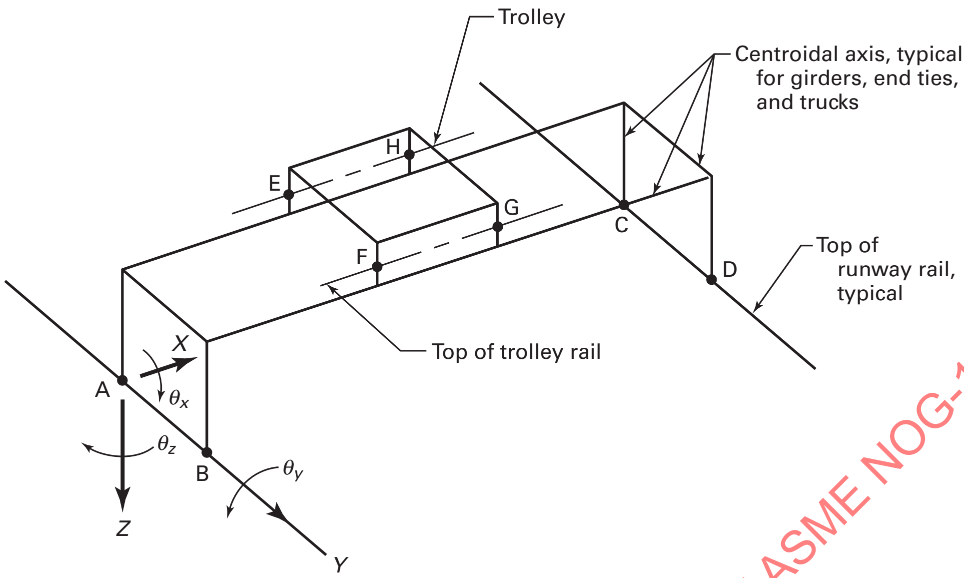


Fig. 4154.3-1 Crane Mathematical Model for Seismic Analysis

is approximately equal to the center between the closest trolley wheel to the loaded hook shall be positioned at the appropriate point on the span. Two positions of the loaded hook shall also be analyzed: hook up and hook down. The hook positions shall be specified by the purchaser. Table 4153.7-1 shows 21 independent load cases which are to be considered.

The maximum combined structural responses SR_{max} at each node, in terms of displacement, forces, moments, stresses, is

$$SR_{max} = \text{largest of } SR_{22}, SR_{23}, \ldots, SR_{29}, SR_{30}$$

4153.8 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 when the SSE is used in the analysis. A damping value of 4% of critical damping shall be used when the OBE is used in the analysis.

4153.9 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. 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.

4153.10 Combination of Modal Responses. In combining the static and dynamic responses, it shall be assumed that the dynamic responses have the sign which yields the worst case for the combination being considered. The loading conditions for the static and dynamic load cases which are required to be considered, and the corresponding structural responses (SR_1, SR_2, etc.) are listed in Table 4153.7-1.

(a) *With No Closely Spaced Modes.* When the results of the modal dynamic analysis show that the crane modes are not closely spaced, the crane's response to each of the three components of seismic input shall be combined by taking the square root of the sum of the squares (SRSS).

(b) *With 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 between the lowest frequency

Table 4153.7-1
Crane Loading Conditions for Seismic Analysis, Static and Dynamic Load Cases

Loading Condition	Trolley Position on Bridge		
	End	1/4 Span	Mid-Span
Static Load Cases			
Dead load, bridge and trolley with:			
Load on hook [Note (1)]	SR_1	SR_8	SR_{15}
No load on hook	SR_2	SR_9	SR_{16}
Dynamic Load Cases			
Horizontal direction earthquake [Note (2)]:			
Transverse	SR_3	SR_{10}	SR_{17}
Longitudinal	SR_4	SR_{11}	SR_{18}
Vertical direction earthquake:			
No load on hook	SR_5	SR_{12}	SR_{19}
Load on hook, hook up [Note (1)]	SR_6	SR_{13}	SR_{20}
Load on hook, hook down [Note (1)]	SR_7	SR_{14}	SR_{21}

GENERAL NOTES:
(a) SR denotes structural response.
(b) See Table 4153.7-2 for combining the 21 load cases listed above to obtain the maximum structural responses.

NOTES:
(1) Credible critical load.
(2) Increase in horizontal load due to pendulum effect need not be considered due to the relatively small displacement of the load.

in the group and a frequency 10% higher [see Note (1) below]. 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 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 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:

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

where $l \neq m$; R_{lq} and R_{mq} are modal responses, R_l and R_m within the qth group, respectively; i is the number of the mode where a group starts; j is the number of the mode where the group ends; R, R_k, and N are as defined in Note (2) below; P is the number of groups of closely spaced modes, excluding individual separated modes.

(2) Ten-Percent Method

$$R = \left[\sum_{k=1}^{N} R_k^2 + 2\Sigma \left| R_i R_j \right| \right]^{1/2}$$

where $i \neq j$; and R, R_k, and N are defined in Note (2) below. The second summation shall be done on all i and j modes whose frequencies are closely spaced to each other. Let ω_i and ω_j be the frequencies of the ith and jth modes. In order to verify which of the modes are closely spaced, the following equation shall be applied:

$$(\omega_j - \omega_i) / \omega_i \leq 0.1$$

Also,

$$1 \leq i \leq j \leq N$$

(3) Double-Sum Method:

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

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

$$\epsilon_{ks} = \left\{ 1 + \left[\frac{(\omega'_k - \omega'_s)}{(\beta'_k \omega_k + \beta'_s \omega_s)} \right]^2 \right\}^{-1}$$

in which

$$\omega'_k = \omega_k \left[1 - \beta_k^2 \right]^{1/2}$$

$$\beta'_k = \beta_k + 2 / t_d \, \omega_k$$

where ω_k and β_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 representative values of the co-directional responses caused by each of the three components of earthquake motion at each node of the crane mathematical model. Table 4153.7-2 lists the representative maximum values (SR_{22}, SR_{23}, etc.) for each of the three-directional components of earthquake motion which are required to be calculated.

The maximum combined structural response (SR_{max}) at each node, in terms of displacements, forces, moments, and stresses, is the largest of the representative maximum values of the structural responses of each of the three-directional components of earthquake motion, i.e.,

$$SR_{max} = \text{largest of } SR_{22}, \ldots, SR_{29}, SR_{30}$$

Table 4153.7-2
Representative Maximum Values of the Structural Responses of the Three-Directional Components of Earthquake Motion Plus Static Loads

Trolley Location
At End
$SR_{22} = SR_1 + (SR_3^2 + SR_4^2 + SR_6^2)^{1/2}$
$SR_{23} = SR_1 + (SR_3^2 + SR_4^2 + SR_7^2)^{1/2}$
$SR_{24} = SR_2 + (SR_3^2 + SR_4^2 + SR_5^2)^{1/2}$
At 1/4 Span
$SR_{25} = SR_8 + (SR_{10}^2 + SR_{11}^2 + SR_{13}^2)^{1/2}$
$SR_{26} = SR_8 + (SR_{10}^2 + SR_{11}^2 + SR_{14}^2)^{1/2}$
$SR_{27} = SR_9 + (SR_{10}^2 + SR_{11}^2 + SR_{12}^2)^{1/2}$
At Mid-Span
$SR_{28} = SR_{15} + (SR_{17}^2 + SR_{18}^2 + SR_{20}^2)^{1/2}$
$SR_{29} = SR_{15} + (SR_{17}^2 + SR_{18}^2 + SR_{21}^2)^{1/2}$
$SR_{30} = SR_{16} + (SR_{17}^2 + SR_{18}^2 + SR_{19}^2)^{1/2}$

4154 Nonlinear Time History for Slack Rope Condition. For the case when the credible critical load is being supported by the hoist ropes, and the results of the linear analysis of para. 4153 indicate a slack rope condition, that is, rope going into compression, the nonlinear time-history method of analysis shall be used to determine the maximum rope tension loads resulting from a slack rope condition. These loads shall be used for the sizing of the rope only.

Nonlinear analysis concerns the performance of a dynamic analysis of the crane, when subjected to earthquake-induced forces, taking into account the nonlinear properties (for example, tension only of the hoist ropes). To perform such an analysis, computer programs are available to solve the equations of motion via direct integration techniques at discrete time intervals over the time history of the earthquake.

4154.1 Crane Mathematical Model. The crane finite element model shall be similar to the one described in para. 4143.3 for the linear analysis,

Table 4154.3-1 Restraint Condition at Nodes

	Restraint Condition					
	Translation			Rotation		
Node	X	Y	Z	θ_x	θ_y	θ_z
A	Fixed	Fixed	Fixed		[Note (1)]	
B	Fixed	Free	Fixed			
C	Free	Fixed	Fixed			
D	Free	Free	Fixed			
E	Fixed	Fixed	Fixed			
F	Fixed	Fixed	Fixed			
G	Free	Fixed	Fixed			
H	Free	Fixed	Fixed			

NOTE:
(1) All nodes are considered to be free to rotate.

except that the crane trolley and bridge geometry may be simplified if justification can be provided that the coupling effects of those degrees of freedom that are omitted from the three-dimensional model are not significant. A nonlinear spring (tension member only) shall be used to represent the hoist ropes.

4154.2 Location and Number of Dynamic Degrees of Freedom. Dynamic degrees of freedom shall be assigned to a sufficient number of node points and in such locations that the real mass and stiffness distribution of the crane is simulated. An important consideration for modeling the crane for the nonlinear analysis is that the fundamental frequency of the crane system in its unloaded (no load on the hook) configuration approximates that determined by the linear analysis.

4154.3 Boundary Conditions at Trolley and Runway Rails. Boundary conditions for the crane model shall be consistent with those specified in para. 4153.6, Fig. 4154.3-1, and Table 4154.3-1.

4154.4 Trolley Locations and Hoist Positions. A combined trolley and loaded hook position shall be selected so as to result in a crane system frequency which produces the severest slack rope conditions. Trolley locations and hoist positions specified in para. 4153.7 shall be considered.

4154.5 Damping Values. A critical damping ratio of 7% shall be used for the rope for determining the damping parameters required to form the damping matrix. Higher values may be used with adequate justification.

4160 Tolerances

Dimensions of welded beams, girders, and built-up members shall be within the tolerances specified by AWS D1.1. All measurements shall be based on 70°F ambient temperature and be taken at the manufacturer's plant prior to shipment, unless otherwise specified. A minimum dimensional check of a member will consider straightness, camber, lateral deviation of web to flange center lines, and depth.

Overall crane dimensions shall be in accordance with the crane manufacturer's clearance drawing of the crane. 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 top of the runway rail center line. Cumulative measurements of crane components are permitted.

The accuracy of the runway rail dimensions shall be the responsibility of the purchaser. The runway rails shall be straight, parallel, level, and at the same elevation within the tolerances given in Fig. 4160-1. The crane manufacturer shall design the crane to operate properly within the runway rail tolerances given in Fig. 4160-1.

4200 MATERIALS AND CONNECTIONS

All materials of the structural components of the crane shall be an accepted type, suitable for the purpose for which the materials are to be used, and shall be in compliance with any additional requirements specified herein for the materials.

4210 Base Materials

4211 Material

(a) The base materials listed in Table 4211-1 are considered acceptable for the structural components identified in para. 4400 of Types I and II cranes when they meet the requirements of para. 4212. The manufacturer shall report the materials actually employed to the purchaser. Other suitable materials, which are in compliance with the other provisions for materials specified herein, may be acceptable subject to approval by the purchaser.

(b) The base materials for the components of cranes not included in (a) above shall be in accordance with Specification CMAA 70.

4212 Fracture Toughness

(a) Material for the structural components defined in para. 4211(a) for Types I and II cranes shall be

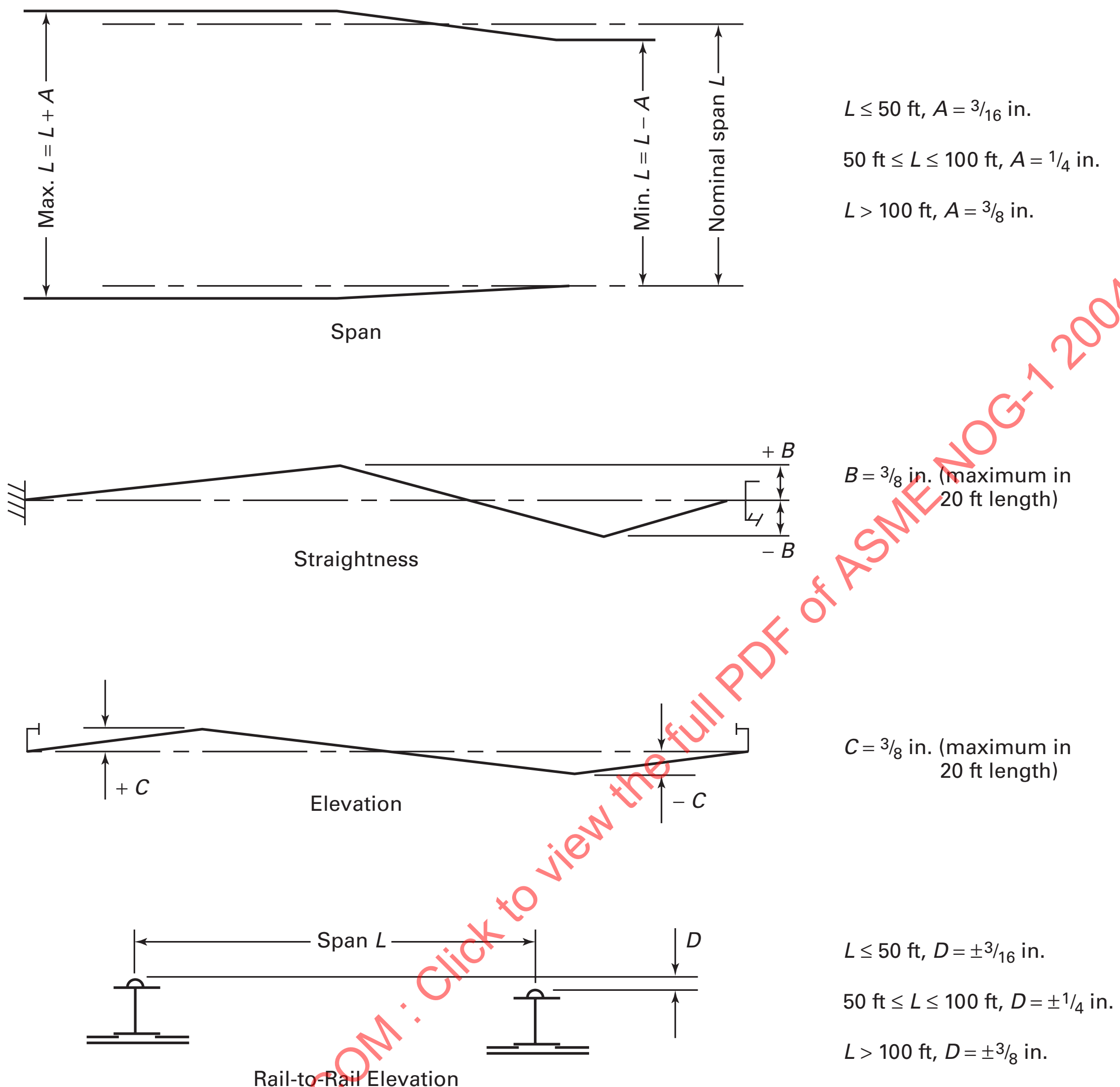


Fig. 4160-1 Runway Rail Alignment Tolerance

impact tested in accordance with (a)(1) below, except as provided in (b) below. Materials for Type III cranes shall be in accordance with Specification CMAA 70. The purchaser shall specify the minimum operating temperature as defined in para. 1150.

(1) For material greater than $^5/_8$ in. thick, Charpy V-notch tests shall be performed in accordance with (a)(3) below, or drop weight tested in accordance with (a)(2) below.

(2) The drop weight test shall be performed in accordance with ASTM E 208 using specimen type P-1, P-2, or P-3. The sampling shall be in accordance with ASTM A 20 when applicable or ASTM A 673 frequency P except for the type of specimen. The specimen depth shall be at least as far from the material surface as that specified for tensile test specimens in the material specification. The nil-ductility transition temperature shall be a minimum of 30°F below the minimum operating temperature.

(3) The Charpy V-notch test shall be performed in accordance with ASTM A 370 using full-size specimens if possible. For Type I, cranes the sampling shall be in accordance with ASTM A 673 frequency P. For Type II cranes, the sampling shall be in accordance with ASTM A 673 frequency H for specified minimum yields of 55 ksi or less, and frequency P for higher strength steels. The test temperature shall be a minimum of 30°F below the

Table 4211-1 Reference Properties of Acceptable Materials for Structural Components **(04)**

ASTM Specification	Grade or Class	Product Form	Size [Note (1)]	Yield Point/ Strength, Min., ksi	Tensile Strength, ksi
A 36	. . .	Plates, shapes, and bars	Plates to 8 in.; shapes to 426 lb/ft	36	58–80 [Note (2)]
A 53	B	Pipe	To 26 in. diameter	35	60 min.
A 242	. . .	Plates, shapes, and bars	Plates and bars to $^3/_4$ in.; shapes (Groups 1 and 2)	50	70 min.
			Plates and bars > $^3/_4$ in. to ≤ $1^1/_2$ in.; shapes (Group 3)	46	67 min.
			Plates and bars > $1^1/_2$ in. to ≤ 4 in.; shapes (Groups 4 and 5)	42	63 min.
A 333	3, 7	Pipe	To 26 in. diameter	35	65 min.
	4, 6	Pipe	To 26 in. diameter	35	60 min.
A 501	. . .	Tubing	Square and rectangular to 10 in.; round to 24 in.	36	58 min.
A 516	65	Plates	To 8 in.	35	65–85
	70	Plates	To 8 in.	38	70–90
A 537	1	Plates	To $2^1/_2$ in.	50	70–90
			> $2^1/_2$ in. to ≤ 4 in.	45	65–85
	2	Plates	To $2^1/_2$ in.	60	80–100
			> $2^1/_2$ in. to ≤ 4 in.	55	75–95
			> 4 in. to ≤ 6 in.	46	70–90
	3	Plates	To $2^1/_2$ in.	55	80–100
			> $2^1/_2$ in. to ≤ 4 in.	50	75–95
			> 4 in. to ≤ 6 in.	40	70–90
A 572	42	Plates, shapes, and bars	Plates and bars to 6 in.; shapes (all Groups)	42	60 min.
	50	Plates, shapes, and bars	Plates and bars to 4 in.; shapes (all Groups)	50	65 min.
	60	Plates, shapes, and bars	Plates and bars to $1^1/_4$ in.; shapes (Groups 1–3)	60	75 min.
	65	Plates, shapes, and bars	Plates and bars to $1^1/_4$ in.; shapes (Groups 1–3)	65	80 min.
A 588	. . .	Plate, shapes, and bars	Plates and bars ≤ 4 in.; shapes (all Groups)	50	70 min.
			Plates and bars > 4 in. to ≤ 5 in.	46	67 min.
			Plates and bars > 5 in. to ≤ 8 in.	42	63 min.
A 618	Ia, Ib, and II	Tubing	To 24 in. diameter, wall < $^3/_4$ in.	50	70 min.
			To 24 in. diameter, wall ≥ $^3/_4$ in. to ≤ $1^1/_2$ in.	46	67 min.
	III	Tubing	To 24 in. diameter, all wall thicknesses	50	65 min.
A 633	A	Plates, shapes, and bars	To 4 in.	42	63–83
	C, D	. . .	To $2^1/_2$ in.	50	70–90
			> $2^1/_2$ in. to ≤ 4 in.	46	65–85
	E	. . .	To 4 in.	60	80–100
A 709	36	Plates, shapes, and bars	Plates and bars to 4 in.; shapes to 426 lb/ft	36	58–80 [Note (2)]
	50	Plates, shapes, and bars	Plates and bars to 4 in.; shapes (all Groups)	50	65 min.
	50W	Plates, shapes, and bars	Plates and bars to 4 in.; shapes (all Groups)	50	70 min.
A 737	B	Plates	To $2^1/_2$ in.	50	70–90
	C	Plates	To $2^1/_2$ in.	60	80–100
A 913	50	Shapes	Shapes (all Groups)	50	65 min.
	60	Shapes	Shapes (all Groups)	60	75 min.
	65	Shapes	Shapes (all Groups)	65	80 min.
	70	Shapes	Shapes (all Groups)	70	90 min.

GENERAL NOTE: For additional details, see the referenced specification.

NOTES:
(1) For shape Groups, see ASTM A 6.
(2) For wide flange shapes over 426 lb/ft (634 kg/m), the 80 ksi (550 MPa) maximum tensile strength does not apply.

Table 4212-1
Required C_v Energy Values for Structural Materials (Except Bolting)
[Extracted from Table ND-2311(a)-1, Section III, Division 1, 1980 Edition, ASME Boiler and Pressure Vessel Code]

	Energy, ft-lb, for Materials of Specified Minimum Yield Strength, ksi					
	40 or Less		Over 40 to 55, Incl.		Over 55 to 105, Incl.	
Nominal Thickness, in.	Average of 3	Lowest of 3	Average of 3	Lowest of 3	Average of 3	Lowest of 3
Over $^5/_8$ to $^3/_4$, incl.	13	10	15	10	20	15
Over $^3/_4$ to 1, incl.	15	10	20	15	25	20
Over 1 to $1^1/_2$, incl.	20	15	25	20	30	25
Over $1^1/_2$ to $2^1/_2$, incl.	25	20	35	30	40	35
Over $2^1/_2$	30	25	40	35	45	40

minimum operating temperature. The acceptance criteria shall be as shown in Table 4212-1. The results obtained with sub-size Charpy V-notch specimens shall be converted to full-size specimens in accordance with ASTM A 673 Table 1 before comparison with the acceptance criteria.

(b) The base material shall be exempt from impact testing as required in (a) above provided one of the following is met:

(1) the nominal thickness is $^5/_8$ in. or less;

(2) the nominal cross-sectional area is 1 sq in. or less;

(3) the maximum tensile stress (including residual stresses if the component is not postweld heat treated) under all conditions of loading required in para. 4100 does not exceed 6000 psi;

(4) the component is fabricated from an austenitic stainless steel or a nonferrous material not subject to a ductile brittle transition;

(5) the component is fabricated from normalized ASTM A 516 Grade 70 steel and the required test temperature or the lowest service temperature is greater than 0°F;

(6) the component is fabricated from normalized ASTM A 537 Class 1 steel and the required test temperature or the lowest service temperature is greater than −30°F.

4220 Fastener Materials

4221 Material

(a) The fastener materials in Table 4221-1 are considered acceptable for the structural interconnections of Types I and II cranes. The manufacturer shall report the materials actually employed to the purchaser.

(b) The fastener materials for structural components of cranes not included in (a) above shall be in accordance with Specification CMAA 70.

(c) When not restricted by para. 1145, the fastener materials in Table 4221-2 may be galvanized or coated with zinc-rich paints. Fastener materials with a hardness higher than 320 BHN shall not be galvanized.

(d) The fastener finish and tolerances shall be suitable for the type of connection in which it is employed.

4222 Fracture Toughness

(a) Fastener materials for connections defined in 4221(a) shall be impact tested in accordance with (a)(1) below except as provided in (b) below. The purchaser shall provide the minimum operating temperature as defined in para. 1150.

(1) Charpy V-notch tests shall be performed in accordance with ASTM A 370. For bolts and studs, the sampling shall be in accordance with ASTM A 320. For nuts, the sampling shall be in accordance with ASTM A 194. The test temperature shall be equal to or less than 30°F below the minimum operating temperature as defined above. The acceptance criteria shall be as shown in Table 4222-1.

(b) Fastener materials shall be exempt from impact testing as required in (a) above, provided the nominal size of the bolt or stud is 1 in. or less.

4230 Welding Materials

4231 Material. All welding materials shall be in compliance with the requirements of AWS D1.1 and the additional requirements specified herein.

Table 4221-1 Reference Properties of Acceptable Fastener Materials for Structural Connections of Type I and Type II Cranes

ASTM Spec.	Grade Class Type	Size, in.	Proof Stress Min., ksi	Yield Strength, Min., ksi	Tensile Strength, ksi	Hardness, BHN
A 325	1, 2, 3	1/2 to 1 B	85	92	120 min.	248–331
		1 1/8 to 1 1/2 B	74	81	105 min.	223–293
		1/2 to 1 1/8 N	144	. . .	. . .	352 max.
		1 1/4 to 1 1/2 N	144	. . .	. . .	143–352
A 687	I, II	1 1/4 to 3 S	. . .	105	150 max.	. . .
A 563	D	1/4 to 3 N	150/165	. . .	. . .	163–352
A 563	DH	1/4 to 3 N	180/200	. . .	. . .	248–352
A 193	B7 B16	1/4 to 2 1/2 B, S	. . .	105	125 min.	. . .
		2 5/8 to 4 B, S	. . .	95	115 min.	. . .
		4 1/8 to 7 B, S	. . .	75	100 min.	. . .
A 320	L7	1/4 to 2 1/2 B, S	. . .	105	125 min.	. . .
A 320	L43	1/4 to 4 B, S	. . .	105	125 min.	. . .
A 194	7	1/4 to 7 N	135/150	. . .	. . .	159–352
A 194	2H	1/4 to 7 N	150/175	. . .	. . .	248–352
A 490	1, 3	1/2 to 1 1/2 B	120	130	150–170	311–352
		1/2 to 1 1/2 N	175	. . .	. . .	248–352

GENERAL NOTE: For additional requirements, see the referenced specification; N = nut; B = bolt; S = stud.

Table 4221-2 Fastener Materials That May Be Galvanized

ASTM A 307	. . .
ASTM A 325	Type 1
ASTM A 449	. . .
ASTM A 563	Grade DH
ASTM A 194	Grade 2H

(a) Matching filler metal of adequate toughness per para. 4232 shall be used. For the shielded metal arc welding (SMAW) process, low hydrogen type electrodes shall be used for the structural connections of Types I and II cranes per para. 4400.

(b) The filler metal for the structural connections of cranes not included in (a) above shall be as specified.

(c) If the SMAW process is employed for connections per (b) above but one of the base metals is on a component per para. 4211(a) that is over 2 1/2 in. thick, and is subject to applied tensile stresses in excess of 6000 psi, low hydrogen type electrodes shall be used.

4232 Fracture Toughness

(a) The filler metal defined in para. 4231(a) shall be impact tested in accordance with (a)(1) below except as provided in (b) below. The purchaser shall provide the minimum operating temperature as defined in para. 1150.

(1) Charpy V-notch tests shall be performed in accordance with the filler metal specification. The difference between the minimum operating temperature and the test temperature shall be in accordance with Table 4232-1.

(b) The filler metal shall be exempt from impact testing as required in (a) above, provided:

(1) the base materials are exempt per paras. 4212(b)(1), (2), (3) or (4); or

Table 4222-1 C_v Energy Values for Fastener Materials

Nominal Diameter, in.	Energy, ft-lb, for Materials of Specified Minimum Yield Strength, ksi [Note (1)]					
	55 or Less		Over 55 to 105, Incl. [Note (2)]		Over 105 to 145, Incl.	
	Average of 3	Lowest of 3	Average of 3	Lowest of 3	Average of 3	Lowest of 3
Over 1 to $2^1/_2$	25	20	30	25	35	30
Over $2^1/_2$ to 4	30	25	35	30	40	35
Over 4	35	30	40	35	45	40

GENERAL NOTE: For restrictions on the use of subsize specimens, see para. 4212(a)(3).

NOTES:
(1) When a minimum yield strength is not a part of the material specification, the actual yield strength shall be determined per ASTM A 370 and used to determine the required energy.
(2) Stock fasteners having an average energy of 20 ft-lb and a minimum energy of 15 ft-lb at –150°F may be used for minimum operating temperatures above –90°F without additional testing.

Table 4232-1 Test Temperature for Filler Metal — Charpy V-Notch Impact Tests With 20 ft-lb Average Energy

Specified Minimum Tensile Strength, ksi	°F Below Minimum Operating Temperature
75 or less	30
75 to 95, incl.	50
Over 95	70

(2) the effective throat of the nominal weld is $^5/_8$ in. or less.

4240 Welded Studs

Welded studs shall not be employed for the connections of the structural components defined in para. 4400. Studs welded to the structural components of the crane shall comply with the requirements for studs specified in AWS D1.1, and shall be compatible with the base material.

4250 Connections

4251 Welded Connections. Welded connections shall comply with the requirements of AWS D1.1 except as specified herein.

4251.1 Welding Procedures. All welds for Types I and II cranes shall be performed in accordance with written procedures that establish limitations of variables consistent with AWS D1.1. These welds may be either prequalified or qualified in accordance with AWS D1.1.

4251.2 Qualification Impact Tests. The weld procedure qualification shall be exempt from impact testing as required per Mandatory Appendix I, para. I4251.2, provided one of the following is met:

(a) the base materials are exempt per para. 4212(b); or

(b) the base materials are in Material Group 1 of Table 3.1 of AWS D1.1, the weld is made by shielded metal arc welding, submerged arc welding, gas metal arc welding, or flux cored arc welding, and the filler metal is exempt per para. 4232(b); or

(c) the base materials are in Material Group 1 of Table 3.1 of AWS D1.1, the weld is made by shielded metal arc welding, submerged arc welding, gas metal arc welding, or flux cored arc welding, and the weld is postweld heat treated per para. 4251.5.

4251.3 Combination of Weld Types. If two or more of the general types of welds (groove, fillet, plug, slot) are combined in a single joint, the allowable capacity of each shall be separately computed with reference to the axis of the group in order to determine the allowable capacity of the combination.

4251.4 Nondestructive Examination Requirements. All welds shall be visually inspected over their entire lengths. Additional inspection and testing of the joints of the three types of cranes shall be as stated below. Examination and acceptance criteria of welds and repairs shall be in accordance with AWS D1.1 unless otherwise stated below.

(a) Types I and II Cranes. The following inspections and tests shall be applied to welded structural

connections. Percents of welds specified for inspection are measured along each face. This doubles the length for fillet welds on both sides of a joint. The length subject to examination of other welds shall be considered as doubled when welds are made from both sides. Areas examined shall be randomly distributed along the weld length.

(1) Full penetration butt welds: 100% volumetric examination by either radiographic or ultrasonic testing unless the specification for the crane stipulates which method to use.

(2) Other welds with an effective throat over $^3/_8$ in.: dye penetrant or magnetic particle testing as follows unless the specification for the crane stipulates which method to use:

(a) 100% of each of trolley load girt welds

(b) 10% of each of the cover plate or flange to web welds of crane girders

(3) Other welds as stipulated in the crane specification.

(4) Base materials (greater than $^5/_8$ in. thick) with highly restrained welded connections subject to weld shrinkage strains in a through-thickness direction shall be ultrasonically tested per Mandatory Appendix I, para. I4251.4

(b) Types III Cranes. Nondestructive examination requirements for welds and base metal shall be in accordance with Specification CMAA 70 and the manufacturer's standards unless otherwise stated in the specification for the crane.

4251.5 Postweld Heat Treatment

(a) Types I and II Cranes. Welded connections shall be postweld heat treated (stress relieved) in accordance with AWS D1.1 except where exempted by Table 4251.5-1. However, exempted material may be postweld heat treated at the manufacturer's option. Times and temperatures per AWS D1.1 shall be employed.

When it is not practical to postweld heat treat an entire assembly, local postweld heat treatment shall be employed. Local postweld heat treatment shall be accomplished by heating a band of metal that includes the joint. Heating may be obtained by any method that will ensure sufficient uniformity without harming the material. The width of the heated band on each side of the greatest width of the finished weld shall be at least twice the effective throat of the weld. The material outside the heated band shall be protected to avoid harmful temperature gradients.

Table 4251.5-1 Exemptions to Mandatory Postweld Heat Treatment

Material Class [Note (1)]	Effective Throat of Weld, in. — Not Toughness Tested [Note (2)]	Effective Throat of Weld, in. — Toughness Tested [Notes (2) and (3)]
I	$1^1/_2$ or less	4 or less
II	$1^1/_2$ or less	4 or less
III	$1^1/_2$ or less	4 or less

NOTES:
(1) Groups are per Table 3.1 of AWS D1.1. Carbon and low alloy steels not in this table shall be exempt from postweld heat treatment for thicknesses of $^1/_2$ in. or less, provided the carbon does not exceed 0.35%.
(2) The manufacturer may test materials or procedures otherwise exempted from toughness testing in order to apply this exemption to postweld heat treating.
(3) Materials qualified by testing to para. 4212. Weld procedures qualified by testing to para. 4251.2.

When postweld heat treating is employed, the following shall be observed.

(1) All required postweld heat treating shall be covered by a written procedure.

(2) Localized postweld heat treating may be employed as stated above, when approved by the design engineer. A written procedure must address the same seven points outlined in (a)(3) below for furnace postweld heat treating.

(3) For furnace postweld heat treating, the procedure must address the following:

(a) temperature at start of thermal cycle;

(b) rate of heating;

(c) maximum allowable variation of temperature throughout the portion of the part being treated;

(d) maximum temperature tolerance at stress relief temperature;

(e) holding time at stress relief temperature;

(f) rate of cooling to temperature suitable for removal of work from the furnace; and

(g) location of thermocouples and the number required.

Vibratory conditioning to improve dimensional stability may be used at the option of the Manufacturer. The conditioning shall be done in accordance with the recommendations and procedures established by the manufacturer of the equipment.

(b) Type III Cranes. The manufacturer shall determine the need for postweld heat treatment. When used, PWHT shall comply with AWS D1.1.

4251.6 Stud Welding. The welding of studs shall be in accordance with AWS D1.1. The thickness of the base material to which studs are welded shall equal or exceed 20% of the nominal stud diameter to minimize burnthrough.

4252 Bolted Connections

4252.1 Structural Joints Using ASTM A 325 or A 490 Bolts. Structural joints for structural components identified under para. 4400 using ASTM A 325 or A 490 bolts shall be designed and installed in accordance with the AISC "Specification for Structural Joints Using ASTM A 325 or A 490 Bolts." Bolts holes shall be subpunched and reamed or drilled. Standard holes shall have a diameter nominally $^1/_{16}$ in. in excess of the nominal bolt diameter. Slotted bolt holes shall not be used except for connections which may require field adjustment for fitting the crane to the runway.

4252.2 Structural Joints Using Bolts Other Than ASTM A 325 or A 490. Structural joints using bolts other than ASTM A 325 or A 490 shall be bearing type and shall comply with the requirements for non-high-strength bolts specified in the AISC "Specification for Structural Steel Buildings, Allowable Stress Design and Plastic 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 material. Standard holes shall have a diameter nominally $^1/_{16}$ in. in excess of the nominal bolt diameter, except for bound bolts.

4252.3 Pitch and Edge Distances. The minimum pitch between centers of bolt holes and minimum edge distances from the center of a bolt hole to any edge shall be as stipulated in the AISC "Specification for Structural Steel Buildings, Allowable Stress Design and Plastic Design."

4252.4 Bolt Identification. The bolting of the structural joints of the Types I and II cranes shall be identifiable. A unique marking system shall be used to identify type and/or grade of bolts and nuts used.

4253 Field Connections. All field connections of structural components shall be bolted unless otherwise approved by the purchaser. The manufacturer shall provide sufficient information on drawings or in installation manuals on the requirements for all field connections.

4300 DESIGN CRITERIA

4310 Basic Allowable Stresses for Structural Steel Members

4311 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 values in Table 4311-1.

4312 Compression Members Controlled by Buckling. For compression members with an equivalent slenderness ratio

$$\frac{kl}{r} < C_c = \sqrt{\frac{2\pi^2 E}{\sigma_y}}$$

where
E = modulus of elasticity
σ_y = yield point

The allowable axial compression stress shall not exceed the value

$$\sigma_a = \left[1 - (kl/r)^2/2\,C_c^2\right](\sigma_y/DF)$$

where
DF = design factor
k = effective length factor
l = length of compression member
r = radius of gyration of member

The required design factor shall be equal to:

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

Value of N for each loading condition is: operating, 1.2; construction, 1.2; severe environmental, 0.9; extreme environmental, 0.67. For compression members with an equivalent slenderness ratio

$$kl/r > C_c$$

The allowable axial compression stress shall not exceed the value

Table 4311-1 Maximum Allowable Stresses in Structural Steel Members

	Stress Type (All Expressed in Terms of σ_y)			
Loading Condition	Tension	Compression [Note (1)]	Shear	Bearing
Operating	0.50	0.50	0.4	CMAA 70
Construction	0.50	0.50	0.4	CMAA 70
Severe Environmental	0.67	0.67	0.45	NA
Extreme Environmental	0.90	0.90	0.5	NA

NOTE:
(1) For gross section.

$$\sigma_a = \frac{12\pi^2 E}{23N\left(\frac{kl}{r}\right)^2}$$

In lieu of calculating the allowable stress by formula, the allowable stress listed in AISC divided by N may be used.

4313 Bending Stress. The allowable bending stress for members other than those girders conforming to the dimensional criteria outlined in para. 4333 shall conform to AISC "Specification for Structural Steel Buildings, Allowable Stress Design and Plastic Design" Chapter F divided by 1.12N for the different loading conditions.

4314 Welds. Basic allowable stresses in welds shall be as specified in AWS D1.1. Allowable stresses for all types of welds may be increased for severe environmental load combinations by a factor of 1.33, and for extreme environmental load combinations by a factor of 1.50.

4315 Bolts

(a) ASTM A 325 or A 490 Bolts. Allowable working stresses for operational or construction loads shall be in accordance with AISC "Specification for Structural Joints Using ASTM A 325 or A 490 Bolts." 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 severe environmental loadings, and by a factor of 1.50 for extreme environmental loadings.

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

Table 4315-1 Allowable Stresses for Bolts Other Than ASTM A 325 or A 490

	Stress Type (Expressed in Terms of Ultimate Strength)	
Loading Condition	Tension	Shear
Operating	0.33	0.17
Construction	0.33	0.17
Severe Environmental	0.44	0.23
Extreme Environmental	0.50	0.26

(b) Bolts Other Than ASTM A 325 or A 490. Allowable stresses shall be in accordance with Table 4315-1.

4320 Combined Stresses

4321 Axial Compression and Bending. Members subjected to both axial compression and bending stresses shall satisfy the following requirements:

$$\frac{\sigma}{\sigma_a} + \frac{C_{mx}\sigma_{bx}}{\left(1 - \frac{\sigma}{\sigma'_{ex}}\right)\sigma_{abx}} + \frac{C_{my}\sigma_{by}}{\left(1 - \frac{\sigma}{\sigma'_{ey}}\right)\sigma_{aby}} \leq 1.0 \qquad (1)$$

$$\frac{\sigma}{\sigma_{ac}} + \frac{\sigma_{bx}}{\sigma_{abx}} + \frac{\sigma_{by}}{\sigma_{aby}} \leq 1.0 \qquad (2)$$

When $\sigma/\sigma_a \leq 0.15$, the following equation may be used in lieu of the above equations:

$$\frac{\sigma}{\sigma_a} + \frac{\sigma_{bx}}{\sigma_{abx}} + \frac{\sigma_{by}}{\sigma_{aby}} \leq 1.0 \qquad (3)$$

In Eqs. (1), (2), and (3), 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 σ_a, σ_{ab} = allowable axial and bending stresses, respectively. (See paras. 4311 and 4312. Note that $\sigma_a = \sigma_{ab}$ in paras. 4311 and 4312; $\sigma_{ac} = \sigma_a$ as given in para. 4311 only.)

$$\sigma'_e = \frac{12\pi^2 E}{23N\left(\frac{kl}{r}\right)^2} \quad (4)$$

(In the expression for σ'_e, l is the actual unbraced length in the plane of bending, r is the corresponding radius of gyration, K is the effective length factor in the plane of bending, and N is the loading condition factor given in para. 4312.)

σ = computed axial stress
σ_b = computed compressive bending stress at the point under consideration
C_m = a coefficient whose value shall be as given in (a), (b), and (c) below

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

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

$$C_m = 0.6 - 0.4\left(\frac{M_1}{M_2}\right) \text{ but not less than } 0.4$$

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 rational analysis; however, in lieu of such analysis, the following values may be used.

(1) For members whose ends are restrained, $C_m = 0.85$.

(2) For members whose ends are unrestrained, $C_m = 1.0$.

4322 Axial Tension and Bending. Members subject to both axial tension and bending stresses shall satisfy the requirements of Eq. (3). The computed bending tensile stress, taken alone, shall not exceed the applicable value according to para. 4311.

4323 Shear and Tension

(a) Bolts subject to combined shear and tension shall be so proportional that the tension stress, psi, produced by forces applied to the connected parts, shall not exceed the following.

(1) For A 325 bolts in bearing-type joints:

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

(2) For A 490 bolts in bearing-type joints:

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

(3) For other bolting materials in bearing-type joints:

$$\sigma_{at} = 0.6\sigma_y R - 1.6\tau$$

where τ (the shear stress produced by the same forces) shall not exceed the value for the shear given in para. 4315. σ_y is the yield stress (the proof stress may be used). R is given as follows:

(a) Operating conditions: $R = 1$
(b) Construction conditions: $R = 1$
(c) Severe environmental conditions: $R = 1.33$
(d) Extreme environmental conditions: $R = 1.50$

(b) For bolts used in friction-type joints, the shear stress allowed in para. 4315 shall be reduced so that:

(1) For A 325 bolts:

$$\tau_a = 15{,}000\,(1 - \sigma_t A_b/T_b)$$

(2) For A 490 bolts:

$$\tau_a = 20{,}000\,(1 - \sigma_t A_b/T_b)$$

where σ_t is the average tensile stress due to a direct load applied to all of the bolts in a connection, T_b is the specified pretension load of the bolt, and A_b is the tensile stress area.

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

4324 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 para. 4311, except that in severe and extreme environmental conditions, the allowable shear stress may be increased by 20%.

4330 Buckling

(04) **4331 Local Buckling or Crippling of Flat Plates.** The structural design of the crane must guard against local buckling of plates such as webs and coverplates of girders, etc., by limiting the allowable compression stress along opposite edges and the uniformly distributed shear stress assumed to be acting around all edges of the plate or a combination of both.

The critical buckling stress σ_{cr} shall be assumed to be a multiple of the Euler stress σ_e:

$$\sigma_e = \frac{\pi^2 E}{12(1-\mu^2)}\left(\frac{t}{b}\right)^2$$

where

E = modulus of elasticity in compression (for steel, 29,000,000 psi)
t = thickness of plate, in.
b = plate width measured in the direction perpendicular to the compression force
μ = Poisson's ratio (for steel, 0.3)

The critical buckling stress in the elastic range,

$$\frac{b/t}{\sqrt{K}} \geq \sqrt{\frac{\pi^2 E}{12\,(1-\mu^2)\,0.7576\sigma_y}} \tag{5}$$

where

K = buckling coefficient (Table 4332.1-1)
= K_σ for compression
= K_τ for shear

For carbon steel:

$$\frac{b/t}{\sqrt{K}} \geq \sqrt{\frac{2.62 \times 10^7}{0.7576\sigma_y}} \tag{6}$$

For A 36 steel:

$$\frac{b/t}{\sqrt{K}} \geq 30.99$$

shall be assumed to be

$$\sigma_{cr} = \sigma_e K_\sigma \text{ (for compression)}$$

$$\tau_{cr} = \sigma_e \frac{K_\tau}{\sqrt{3}} \text{ (for shear)}$$

where

$$\frac{b/t}{\sqrt{K}} \leq \sqrt{\frac{\pi^2 E}{12\,(1-\mu^2)\,0.7576\sigma_y}} \tag{7}$$

The critical buckling stress shall be assumed to be

$$\sigma_{cr} = \frac{\sigma_y[\sigma_e K_\sigma]^2}{0.1836\,(\sigma_y)^2 + (\sigma_e K_\sigma)^2} \text{ (for compression)} \tag{8}$$

$$\tau_{cr} = \frac{\sigma_y[\sigma_e K_\tau]^2}{\sqrt{3}\,[0.1836\,(\sigma_y)^2 + (\sigma_e K_\tau)^2]} \text{ (for shear)} \tag{9}$$

These formulas assume σ_y to be 1.32 times the proportional limit σ_p.

4332 Combined Compression and Shear Buckling. Taking σ_c and τ to be the calculated compression and shear stresses, respectively, in a plate, the critical comparison stress shall be calculated as follows:

$$\sigma_{crc} = \frac{\sqrt{\sigma_c^2 + 3\tau^2}}{\left(\frac{1+\beta}{4}\right)\left(\frac{\sigma_c}{\sigma_{cr}}\right) + \left[\left(\frac{3-\beta}{4} \times \frac{\sigma_c}{\sigma_{cr}}\right)^2 + \left(\frac{\tau}{\tau_{cr}}\right)^2\right]^{1/2}} \tag{10}$$

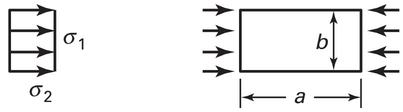
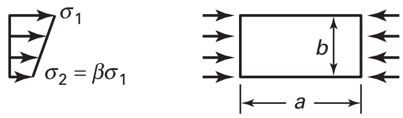
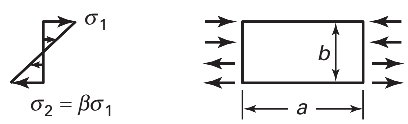
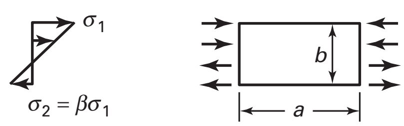
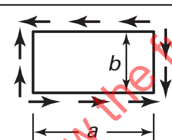
β is the stress ratio as defined in Table 4332.1-1.

4332.1 Design Factors in Plate Buckling (*DFB*). The critical comparison stress σ_{crc} for plates shall be compared with the equivalent compression stress of:

$$\sigma_{ce} = \sqrt{\sigma_c^2 + 3\tau^2}$$

Design factors *DFB* required for buckling are as follows (β is defined in Table 4332.1-1):

Table 4332.1-1 Value of the Buckling Coefficients K_σ and K_τ for Plates Supported at Their Four Edges

No.	Case		$\alpha = \frac{a}{b}$	K_σ or K_τ
1	Simple uniform compression: $\sigma_1 = \sigma_2$		$\alpha \geq 1$ $\alpha < 1$	$K_\sigma = 4$ $K_\sigma = \left(\alpha + \frac{1}{\alpha}\right)^2$
2	Non-uniform compression: $0 < \beta \leq 1$		$\alpha \geq 1$ $\alpha < 1$	$K_\sigma = \frac{8.4}{\beta + 1.1}$ $K_\sigma = \left(\alpha + \frac{1}{\alpha}\right)^2 \cdot \frac{2.1}{\beta + 1.1}$
3	Pure bending: $\beta = -1$ or bending with tension preponderant: $\beta < -1$		$\alpha \geq 2/3$ $\alpha < 2/3$	$K_\sigma = 23.9$ $K_\sigma = 15.87 + \frac{1.87}{\alpha^2} + 8.6\alpha^2$
4	Bending with compression preponderant: $-1 < \beta < 0$			$K_\sigma = (1 + \beta)K' - \beta K'' + 10\beta(1 + \beta)$ where K' = value of K_σ for $\beta = 0$ in Case No. 2 K'' = value of K_σ for pure bending (Case No. 3)
5	Pure shear		$\alpha \geq 1$ $\alpha < 1$	$K_\tau = \left(5.34 + \frac{4}{\alpha^2}\right)\sqrt{3}$ $K_\tau = \left(4 + \frac{5.34}{\alpha^2}\right)\sqrt{3}$

GENERAL NOTE: The definitions of K_σ and K_τ are in this table, and depend on the ratio $\alpha = a/b$ of the two sides of the plates, 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.

Crane Loading Condition	Design Factor *DFB*
Operating	$2 + 0.3\ (\beta - 1)$
Construction	$2 + 0.3\ (\beta - 1)$
Severe Environmental	$1.5 + 0.125\ (\beta - 1)$
Extreme Environmental	$1.35 + 0.075\ (\beta - 1)$

Therefore,

$$\sigma_{ce} \times DFB \leq \sigma_{crc}$$

(04) **4333 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:

$$\sqrt{\frac{(2.62 \times 10^7)K_\sigma}{\sigma_p}} \times \frac{2}{DFB} \text{ (operating condition)}$$

(where b is the unsupported plate width betweenlongitudinal stiffeners, webs, or coverplate) or $30.99\sqrt{K_\sigma\,(2/DFB)}$ operating condition for A 36 steel.

l = span, in.
h = depth of web, in.
b = distance between web plates, in.
t = thickness of web plate

4334 Spacing of Transverse Stiffeners. The spacing of the transverse stiffeners a, in., shall not exceed the amount given by the formula:

$$a = \frac{11{,}068t}{\sqrt{\tau c}}$$

where

c = spacing coefficient (see table below)
t = thickness of the web plate, in.
τ = shear stress in plate, psi

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

Loading Condition	Spacing Coefficient
Operating	1
Construction	1
Severe Environmental	0.75
Extreme Environmental	0.6

4335 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 Specification CMAA 70.

4340 Allowable Deflections and Cambers

4341 Girder Deflection. The total vertical deflection of the girder during operational loading for the rated live load plus trolley ($P_{dt} + P_{lr}$), and not including impact or dead load of the girder, shall not exceed $^1/_{1000}$ of the span.

The total vertical deflection of the girder during constructional loading for the construction load plus trolley ($P_{dt} + P_{cn}$), 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.

4342 Girder Camber. Girders shall be cambered an amount equal to the dead load deflection plus one-half of the deflection caused by the live load plus trolley [camber $= \Delta(P_{db}) + 0.5\Delta(P_{dt} + P_{lr})$].

4343 Trolley Frame Deflection. The trolley frame shall be of rigid construction such that lifted loads do not cause deflections that impair the proper operation of machinery.

4344 Miscellaneous Structure Deflection. Deflections of components such as end ties, end trucks, saddles, and equalizer beams shall not impair the functions for which they were designed or cause any attachments to the crane to become dislodged or to leave the crane.

4345 Gantry Frame Deflection. In addition to the preceding criteria, the following criteria shall apply to the gantry frame.

(a) The total vertical deflection of the girder shall not exceed $^1/_{1000}$ of the span between the gantry legs for the rated live load plus trolley ($P_{dt} + P_{lr}$) when the deflection is calculated as a simply supported beam.

(b) The total vertical deflection of the girder cantilever shall not exceed $^1/_{500}$ of the cantilever length for the rated live load plus trolley ($P_{dt} + P_{lr}$) when the deflection is calculated as a fixed end cantilever beam.

(c) Side thrust at the runway rail due to gantry leg spreading caused by girder span or cantilever deflection or thermal movement shall be held at an acceptable level by providing adequate clearance between the rail head and the wheel flanges, or by means of other design features incorporated into the gantry structure.

4350 Fatigue Requirements

Cranes used for nuclear power plants are normally used relatively few times during the entire life of the plant, as compared to typical structural fatigue criteria. The number of times a typical crane is cycled from no live load to full capacity load seldom exceeds 20,000 cycles during the entire life of the crane. Because of the combined effect of low full-load cycles and low allowable stresses during normal operation, the allowable stresses for the structural members, as specified in para. 4310, need not be reduced due to fatigue.

If the Purchaser determines that greater than 20,000 full-load cycles are required, the Purchaser shall then specify the cycles and load class per Specification CMAA 70. The allowable stresses for the appropriate service level in Specification CMAA 70 shall be used, but shall not exceed the basic operating stress allowables specified in para. 4310.

4400 COMPONENT DESIGN

4410 General

4411 Venting. Closed sections used in structures which are subject to changes in pressure shall be vented. If used, vent openings shall be sized to equalize the internal closed section (or compartment) pressure with its external environmental pressure. Pressure rate of change tables or graphs may be required to determine maximum flow requirements. Where internal full depth diaphragms extend from the top flange to the bottom flange, the compartment formed by a pair of diaphragms shall be vented.

(04) **4412 Drainage.** Box sections when required by environmental conditions shall be drained 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 be drained. Holes shall be provided in the bottom flange of the box girder for draining the whole box girder or each compartment formed by the diaphragms.

4413 Stress Concentrations. Consideration shall be given to points where high stresses might be encountered, such as (but not limited to) at ends of stiffeners, intermittent welds, points of attachment, cut-outs, and reentrant corners. All reentrant corners shall be shaped notch free to a radius of at least 1/2 in. Sharp corner cuts are to be avoided, as are abrupt changes in section properties. Cut-outs, where necessary, shall be made with rounded corners, and their edges shall be analyzed for reinforcement.

4420 Bridge Girders

4421 General. The crane girders (bridge girders) shall be fabricated of structural steel. Structural steel materials shall comply with the requirements of para. 4210. Construction of the crane girders can be of several types, namely, welded plates to form box sections, box sections fabricated from rolled shapes with or without plates, single-rolled shapes, or built-up single web plate girders.

4422 Loading Criteria. Bridge girders shall be designed to resist the load combinations specified in para. 4140. When bridge girders and end ties are moment-connected in the horizontal plane, the assembly shall be analyzed as a rigid frame for the transverse horizontal loads.

4423 Fabricated Box Girders

4423.1 Proportions. Proportions for fabricated box girders shall be as specified in para. 4333.

4423.2 Stiffeners. The requirements of longitudinal and vertical stiffeners are given in para. 4330. Internal full depth diaphragms are required at machinery attachment points, bridge drive supports, and line shaft bearing supports.

The diaphragms may also be considered to meet the requirements of the vertical stiffeners. External stiffeners adjacent to the diaphragms may be required to transmit forces from the attachments into the girder.

4423.3 Diaphragms. All internal diaphragms shall be fitted to bear against the top cover plate to support the trolley rail, and shall be welded to the web plates to transfer the rail load directly to the box girder webs.

4423.4 Diaphragm Spacing. Short diaphragms shall be placed between full depth diaphragms so that the maximum distance between adjacent diaphragms will limit the maximum bending stress without impact in the trolley rail to σ_{ab}:

$$\sigma_{ab} = \frac{\text{(trolley wheel load, lb)(distance between diaphragms, in.)}}{6\ \text{(minimum section modulus of rail, in.}^3\text{)}}$$

For operating and construction loading, σ_{ab} = 18,000 psi. For severe environmental loads, σ_{ab} = 24,000 psi. For extreme environmental loads, σ_{ab} = 32,400 psi.

The top cover plate of the box girder shall not be considered as contributing to the bending properties of the trolley rail.

4423.5 Diaphragm Thickness. The thickness of the diaphragm plate shall be sufficient to resist the trolley wheel load in bearing, on the assumption that the wheel load is distributed over a distance equal to the width of the rail base plus twice the distance from the rail base to the top of the diaphragm plate.

4424 Single Web Girders. Single web girders may be standard rolled beams or plate girders, reinforced with angles, channels, or plates. Where necessary, auxiliary girders shall be used to support overhanging loads to minimize torsional moments and lateral deflections on the single web girder. The analysis required for single web girders shall be the same as required for the plate box girder in para. 4423. The design shall be in accordance with the AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, but with the allowable stresses set forth in para. 4310.

4430 Trolley Frames

4431 Construction. The trolley frame shall be constructed of structural steel. If field assembly of the trolley structure is required, the connections shall be designed to ensure proper alignment of the components.

4432 Design

4432.1 Trolley Frame. The trolley frame shall be designed to resist all loading imposed by the motor, gearing, lifted load, and the load combinations specified in para. 4140.

4432.2 Load Girt. The load girt(s) shall be designed to carry the load to the side frames. Care shall be taken that the load girt deflections do not adversely affect the machinery alignment.

4433 Axle Failure. Provisions shall be made to prevent a drop of more than 1 in. in case of an axle failure.

4440 End Trucks and End Ties

4441 End Trucks

4441.1 General. The end truck is the assembly consisting of wheels, bearings, axles, and structural frame that supports the crane bridge.

4441.2 Construction. The end trucks shall be constructed of structural steel.

4441.3 Design. The end truck shall be designed to support the maximum crane end reactions for the load combinations specified in para. 4140.

4441.4 Axle Failure. Provisions shall be made to prevent a drop of more than 1 in. in case of an axle failure.

4441.5 Wheel Base. The wheel base of the end trucks of four-wheel cranes, or center-to-center of outermost wheels of multiple end trucks for cranes with more than four wheels, shall be not less than one-seventh of the girder span.

4441.6 Rail Sweeps. A rail sweep shall be provided in front of each outside wheel. The rail sweep shall project below the top of the bridge runway rail.

4442 End Ties

4442.1 Construction. The end tie shall be constructed of structural steel.

4442.2 Types. End ties for cranes with more than four bridge wheels can be either the flexible or rigid type. If equalizer bridge trucks are incorporated into the end carriage design to promote equal sharing of bridge wheel loads, and equalizer pins are provided between the equalizer trucks and equalizer beam and/or the rigid bridge frame structure, a rigid-type end tie may be used. If equalizer pins are not provided between the equalizer trucks and equalizer beam and/or the rigid bridge frame structure, a flexible end tie must be used.

4442.3 Design. End ties shall be designed to resist the loads due to crane movement and the load combinations specified in para. 4140.

A rigid frame analysis shall be used to determine the proportions of the loads resisted by the end ties and by the girders. The flexible end tie shall be designed to accommodate up to $^1/_4$ in. difference in elevation of the bridge rail between any wheels or pair of wheels without exceeding allowable stresses.

4450 Gantry Frames

4451 General. Gantry frames shall be fabricated of structural steel. The structural members assembled to form the gantry frame may include, but are not limited to, the following: girders, end ties, legs, trucks, sills, struts, saddles, and equalizer beams. Structural steel materials used in the gantry frame members shall comply with the requirements of para. 4210.

4452 Loading Criteria. Gantry frames shall be designed to resist the load combinations specified in para. 4140. The gantry frame assembly shall be analyzed as a three-dimensional structure.

4453 Gantry Legs. Gantry legs shall be designed to withstand the load combinations specified in para. 4140. The legs shall be constructed of structural steel, and their configuration may vary according to the clearance and overall crane geometry required.

Gantry legs constructed of box sections shall be provided with diaphragms to maintain the leg geometry. The legs shall be stiffened to meet the requirements of para. 4330.

4454 Struts and Sills. Struts and sills are used to connect the legs and joining members. They shall be designed to resist the load combinations specified in para. 4140. Struts and sills shall be constructed of structural steel.

4455 Saddles and Equalizer Beams. Saddles and equalizer beams are used to support the crane structure and are themselves supported by the gantry trucks. Their purpose is to distribute the loading at one corner of the crane equally to the bridge wheels at that corner. They shall be constructed of structural steel. Saddles and equalizer beams shall be designed for the load combinations specified in para. 4140.

Plates or hubs used in saddles or equalizer beams to support trunnions and rotating pins shall be designed to meet the bearing stress specified in Section 5000.

4456 Gantry Wheel Base. The wheel base of the end trucks of four-wheel gantry cranes, or center-to-center of extreme wheels of multiple end trucks for gantry cranes with more than four wheels, may be required to exceed that ratio specified in para. 4441.5. The gantry structure height may necessitate an increased wheelbase in order to gain gantry stability and to reduce gantry skewing.

4457 Gantry Stability. The gantry crane shall have a safety factor of not less than 1.5 against overturning when used in the unrestrained operating condition and subjected to the load combinations specified in para. 4140. During severe environmental, extreme environmental, or abnormal event loading, the gantry crane shall have a safety factor of not less than 1.1 against overturning. Restraints may be used to prevent overturning.

4460 Rails

4461 Requirements. All bridge and trolley rails required to transmit vertical down and horizontal loads due to normal and construction loads only shall conform to the ASCE, ARA, or AREA Specifications. When these rails are used on Types I and II cranes, secondary restraints which are not necessarily in contact under normal loading conditions shall be provided to resist the vertical up and horizontal loads due to severe environmental and extreme environmental loading conditions. Rails required to transmit vertical up and/or horizontal loads due to severe environmental and extreme environmental loading conditions shall meet all of the requirements of a structural steel member as covered in paras. 4200 and 4300.

4462 Fastening. Bridge and trolley rails shall be joined by standard joint bars or welded. For other than polar crane runway rails, provision shall be made to prevent creeping of the rails by means of a positive stop at the ends of the rail. Rails shall be securely fastened in place to maintain center-to-center distance of rails. Fastening of rails to the supporting structure shall be appropriate to transfer the calculated horizontal and vertical forces.

4470 Footwalks, Handrails, Platforms, Stairs, and Ladders

4471 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 OSHA.

4472 Materials. Materials for construction of footwalks, handrails, platforms, stairs, and ladders shall meet the requirements of para. 4200, except that the requirements of para. 4212 need not be considered. ASTM A 569 is an acceptable material for metal bar grating.

4473 Design. Footwalks, handrails, platforms, stairs, and ladders shall be designed for the appropriate dead load and the live loads as specified in the OSHA Standards. Structural design shall be in accordance with para. 4300.

4480 Operator's Cab

4481 General

(a) The standard location of the operator's cab shall be at one end of the crane bridge on the driving girder side unless otherwise specified. It shall be so located as not to interfere with the hook approach. The operator's cab shall be open type for indoor service unless otherwise specified. Dimensions and clearances shall be in accordance with the latest edition of OSHA.

(b) Cabs shall be provided with ladder or stairway leading to the bridge footwalk.

(c) The arrangement of equipment in the cab shall be approved by the purchaser.

(d) Cabs shall be designed for maximum operator visibility. A visibility diagram shall be furnished to the purchaser for approval.

(e) If specified by the purchaser, the cab shall be provided with heating, ventilating, and/or air-conditioning.

(f) The operator's cab shall have a clear height, with equipment installed, of not less than 7 ft. Provision shall be made in the operator's cab for placement of the necessary equipment, wiring, and fittings. All cabs should be provided with a swiveled seat unless otherwise specified.

4482 Materials. Materials for construction of the operator's cab shall meet the requirements of para. 4200, except that the requirements of para. 4212 need not be considered.

4483 Design. The operator's cab shall be designed for appropriate dead and live loads. Structural design shall be in accordance with para. 4300.

4484 Construction

4484.1 Enclosed Cabs. Enclosed cabs shall have watertight plate roofs which 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 be not less than $^1/_8$ in. thick. The 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 user's hands or toes when operating the windows. Drop windows shall be counter weighted.

4484.2 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 of the panel, interferes with the operator's vision, it may be lowered, with the purchaser's approval.

Section 5000 Mechanical

5100 GENERAL

5110 Load Spectrum Crane Classification

5111 Type I Cranes

(a) The design of the mechanical components of the crane is based on the loading conditions, the operating frequency, and the operating cycle in respect to the function within the facility. This specific load spectrum information, or a realistic estimate of the anticipated load spectrum, shall be conveyed to the crane manufacturer by the Purchaser.

(04) *(b)* For a crane having a specific operating cycle such as a typical polar crane, the service condition (load spectrum) can be determined by the number of operating cycles per hour, the type and magnitude of applied loads, the distance of travel motion, and the number of operating hours by given time period. The user shall also establish the service life and reliability requirements for the crane, considering such factors as technical, economic, environmental, and probability of obsolescence. This information is important so that the designer can then provide for the fatigue strength for the components of the crane to meet the requirements of the intended service. The information will provide the basis for the fatigue strength and fatigue life data criteria of the component design, which will require that a numerical documentation of the crane service requirements be in a form that will represent the duty cycle for the crane. This duty cycle or service data for each individual motion of the crane shall be recorded on the Crane Service Data Record Form 1.00 (see Fig. I-5111), and shall become part of the contract between the crane manufacturer and the Purchaser.

(c) The design for fatigue analysis shall be considered for the critical components of the crane mechanical components. The cumulative fatigue usage factors shall reflect the effects of all loads sustained from both the construction and operating periods. In absence of a complete certified crane load cycle or load spectrum, the following criteria shall govern.

(1) All mechanical components in the critical load path, or whose failure could result in uncontrolled movement of a critical load, shall be designed for infinite fatigue life.

(2) Travel drives are exempted from infinite fatigue analysis where the maximum excursions due to any postulated failure are facility acceptable.

(3) Fatigue analysis shall be based on crane maximum rated load.

(4) Design consideration shall be taken to ensure that the failure of catalog-purchased components during the projected life of the crane will not result in facility unacceptable excursion of the critical load.

5112 Types II and III Cranes. The load spectrum of Types II and III cranes shall be in accordance with Specification CMAA 70 classifications.

5120 Hoisting Units

5121 Type I Cranes

(a) The hoist components shall meet the requirements of this Standard, as applicable.

(b) The hoist drive system shall be designed to provide assurance that a failure of a single hoist mechanism component would not result in the uncontrolled movement of the lifted load. This can be accomplished by the application of a single (Fig. 5416.1-1) or dual (Figs. 5416.1-2 and 5416.1-3) hoist drive unit.

(1) The wire rope drum is exempted from this requirement.

(2) The hook, hook nut, trunnion, and load block load structure may be exempted from dual load path criteria by doubling the design service factor.

(c) Critical load excursions due to failure in the dual load path shall be determined and certified as to facility acceptability.

(d) Hooks for critical loads shall have dual attaching points.

5122 Types II and III Cranes. Hoist components of Types II and III cranes shall be in accordance with Specification CMAA 70, except as specified herein.

5130 Bridge and Trolley Drives

5131 Type I Cranes

(a) Drive components shall meet the requirements of this Standard, as applicable.

(b) In travel drives, single failure-proof features are generally not required. However, in those cases where a failure in the braking mode could result in a facility unacceptable excursion, the design shall incorporate single failure-proof features to ensure that the crane can be brought to a safe stop.

5132 Types II and III Cranes. Drive components shall be in accordance with Specification CMAA 70, except as specified herein.

5140 General Mechanical Components

5141 Type I Cranes. Couplings, wheels, axles, drive shafts, bearings, fasteners, gear cases, enclosures, guards, bumpers, stops, and limit switches shall meet the requirements of this Standard, as applicable.

5142 Types II and III Cranes. General mechanical components shall be in accordance with Specification CMAA 70, except as specified herein.

5150 Critical Items

(a) Critical items for a single failure-proof handling system on a Type I crane are those components which are located between the load and the source of energy holding the load.

(1) These components require special consideration as to material, design, control of manufacturing processes, and examination of final product.

(2) Table 7200-1 lists the tests and the inspections that are to be applied to critical items in accordance with the requirements of Section 7000.

(3) The acceptance criteria for all items listed in Tables 7200-1 and 7200-2 shall be in accordance with para. 7100.

5160 Nomenclature

The following nomenclature is used in Section 5000 and is listed according to the article heading where it appears.

5161 Drum Shell Design (Para. 5411.5)

F = out-of-roundness value
K_{SB} = service factor, bending
K_{SC} = service factor, crushing
M_{BXY} = resultant bending moment, in.-lb
P = drum groove pitch, in.
R_L = rope load, lb
S_B = bending stress, psi
S_{BA} = allowable bending stress, psi
S_{CA} = allowable crushing stress, psi
S_{comb} = combined stress on drum shell, psi
S_{CR} = crushing stress, psi
Z_B = bending section modulus, in.^{3}
t = drum shell thickness at the bottom of the groove, in.

5162 Allowable Strength Horsepower — P_{at} (Gearing) [Para. 5413.1(a)]

F = net face width of the narrowest of the mating gears, in.
J = geometry factor (AGMA 226.01, Geometry Factors for Determining the Strength of Spur, Helical, Herringbone and Bevel Gear Teeth)
K_m = load distribution factor
K_s = size factor
K_t = temperature factor
K_v = dynamic factor
N_p = pinion speed, rpm
P_{at} = allowable strength horsepower
P_d = diametral pitch, in.
S_{at} = allowable bending stress, psi
S_f = service factor reliability
S_{fl} = service factor for load application
d = pitch diameter of pinion, in.

5163 Allowable Durability Horsepower — P_{ac} (Gearing) [Para. 5413.1(b)]

C_f = surface condition factor
C_h = hardness factor
C_m = load distribution factor
C_p = elastic coefficient = 2300 for steel gears
C_s = size factor
C_t = temperature factor
C_v = dynamic factor
I = geometry factor
P_{ac} = allowable durability horsepower
S_{ac} = allowable contact stress, psi
S_{fc} = service factor, reliability
S_{flc} = service factor for application

5164 Allowable Momentary Overload — W_{tov} (Gearing) [Paras. 5413.1(c) and 5413.1(d)]

C_o = overload factor (durability)
C_{sr} = load spectra factor (durability)
K_o = overload factor (strength)
K_{sr} = load spectra factor (strength)
C_l = life factor (durability)
C_r = reliability factor (durability)
K_l = life factor (strength)
K_r = reliability factor (strength)
S_{ay} = allowable yield, psi
W_{tov} = allowable momentary overload tangential tooth load, lb

5165 Gearing Efficiencies [Para. 5413.1(g)]

E = efficiency
N = number of gear reductions

5166 Reeving Efficiency (Para. 5429)

E = overall combined efficiency
E_d = combined efficiency of ropes on drum and antifriction bearings
E_s^m = combined efficiency of rope on sheaves
E_g^n = combined efficiency of gear reductions and antifriction bearings
m = total number of rotating sheaves divided by the number of ropes off drum
n = number of gear reductions

5167 (Table 5452.3-1)

D = diameter of wheel, in.
P = allowable wheel load, lb
b = effective width rail head, in.

5168 Nomenclature (Analytical Procedures; Para. 5472)

(a) *Symbols*

A = effective cross-sectional area of critical section, in.^{2}
D = large diameter of a stepped shaft or round bar, in.
I = moment of inertia, in.^{4}
d = small diameter of a stepped shaft or round bar, in.
kip = 1000 lb
ksi = kips per sq in.

(b) *Equivalent Stress Factors*

K_{EB} = for combining bending and shear stresses
K_{EN} = for combining tension–compression and shear stresses
K_{EXY} = for combining biaxial stresses

(c) *Stress Concentration Factors*

K_{NB} = for bending
K_{NN} = for tension–compression
K_{NS} = for shear
K_{NT} = for torsion

(d) *Service Factors*

K_{SB} = for bending
K_{SN} = for tension–compression
K_{SS} = for shear
K_{ST} = for torsion

(e) *Moments and Forces*

M_B = bending moment, in.-kip
M_T = torsional moment, in.-kip
P = load (weight, force, or transverse shear load reaction), kips
Q = static moment about the neutral axis of the area of that portion of the component cross-section beyond the place where the shear is being calculated, in.^{3}
r = fillet radius, in.

(f) *Stress Fluctuation Ratios*

R_B = σ_B min./σ_B max. for bending
R_N = σ_N min./σ_N max. for tension–compression
R_S = τ_S min./τ_S max. for shear
R_T = τ_T min./τ_T max. for torsion

(g) *Dimensions and Properties*

S_B = section modulus, in.^{3}
S_T = polar section modulus, in.^{3}
t = thickness of component where stress is being calculated, in.
σ_{UT} = minimum ultimate tensile strength at midradius, ksi

(h) *Maximum Allowable Stresses*

σ_{BA} = for bending, ksi
σ_{NA} = for tension–compression, ksi
σ_{XA} = for stress about the X axis, ksi
σ_{YA} = for stress about the Y axis, ksi
τ_A = for combined (equivalent) shear, ksi
τ_{TA} = for torsional shear (equivalent torsional shear) stress

(i) *Working Stresses*

σ_B = bending stress, ksi
σ_{EB} = equivalent bending (bending and shear) stress, ksi
σ_{EBN} = equivalent bending (bending and tension-compression) stress, ksi
σ_{EN} = equivalent tension–compression (tension–compression and shear) stress, ksi

σ_{EXY} = equivalent biaxial stress, ksi
σ_{EXYT} = equivalent stress (biaxial and shear), ksi
σ_N = tension–compression stress, ksi
σ_X = normal stress about the X axis, ksi
σ_Y = normal stress about the Y axis, ksi
τ_{ET} = equivalent torsional shear stress, ksi
τ_S = shear stress, ksi
τ_T = torsional shear stress, ksi
τ_{XY} = shear stress in the X-Y plane including torsion, ksi

5169 Analytical Method for Hook of Approximate Trapezoidal Shape (Para. 5477)

A = area of cross-section, in.^{2}
K_f = factor
S_b = stress bending
S_i = stress-direct tension
S_{max} = stress maximum
S_o = stress augment
b_i = inside width of equivalent trapezoid
b_o = outside width of equivalent trapezoid
h_o = depth of equivalent trapezoid
r_i = inside radii of equivalent trapezoid
r_o = outside radii of equivalent trapezoid

5200 MATERIALS

5210 Material (Type I Crane)

Materials with less than 15% elongation shall not be used for any mechanical component except electrical motors and hydraulic components.

5220 Material (Types II and III Cranes)

Materials shall be in accordance with Specification CMAA 70.

5300 DESIGN AND PERFORMANCE CRITERIA

5310 Load Combinations

(a) The individual mechanical components of the overhead or gantry crane shall be designed to provide a design factor specified for that component to resist the forces resulting from the combination of loading specified for the component. The load combinations that must be considered for the individual components vary with the component, and frequently include maximum loadings calculated in the electrical or structural section, i.e., motor torque of a motor or live load including wind and impact.

(b) Certain components must be designed for seismic loading as a part of the load combinations. If a lump mass approach is used in the seismic design, the methods of structural design calculations within Section 4000 will provide the values of the dynamic analysis which will be determined for location, magnitude, and direction for forces to be used as equivalent static loading. The extent of seismic consideration necessary for the three types of cranes is as follows.

(1) For Type I Cranes. Seismic loading shall be only to ensure retention of the load and the prevention of any component from becoming a missile that would be detrimental to the facility's safety related equipment.

(2) For Type II Cranes. Seismic considerations shall be made to ensure that no component of the crane could become a missile that would be detrimental to the facility's safety related equipment.

(3) For Type III Cranes. Seismic analysis is not required unless specified by the purchaser.

5311 Design Loads — Hydraulic Components

(a) For Types I, II, and III Cranes. The design selection for hydraulic components shall be based on the rated load.

5320 Allowable Stresses

5321 Type I Cranes

5321.1 Normal Operating Conditions. All load combinations and factors including stress concentrations shall have a service factor of 1 or more based on the design fatigue allowable stress limit of the material, except as otherwise specified in Section 5000.

$$\text{Service Factor} \times \text{Design Stress} \leq \text{Allowable Stress}$$

5321.2 Emergency Conditions. For all emergency loads such as load hang-up, seismic loads, using the gross cross-section excluding the stress concentration factors, the service factor shall be not less than 1 based on an allowable stress equal to 75% of the yield strength, unless specifically exempted elsewhere in Section 5000.

5322 Type II Cranes

5322.1 Normal Operating Conditions. All load combinations and factors including stress concentrations shall have service factors as stated for the design of specific mechanical components.

5322.2 Emergency Conditions (if Applicable). All emergency loads such as load hang-up shall have specific factors as stated for the design of specific mechanical components.

5323 Type III Cranes

5323.1 Normal Operating Conditions. Allowable stresses shall be in accordance with the provisions of Specification CMAA 70.

5323.2 Emergency Conditions. Not applicable for this type of crane.

5324 Hydraulic Components — Allowable Stresses

5324.1 Types I, II, and III Cranes. Stresses imposed by the maximum rated load shall not exceed 20% of the average ultimate strength of the material or components.

5330 Motion Speeds

Rated load speeds for hoist, bridge, and trolley shall be such as to allow controlled handling of those loads for which the crane is designed. These speeds depend on the nature of the load, load clearances, position of operator, weight of load, positioning accuracy required, and type of drive. Design rated load speeds recommended in paras. 5331, 5332, and 5333 have been established based on typical operator reaction time and drive performance which will allow the load to be stopped and held.

5331 Hoist Speeds

5331.1 Type I Hoists

(a) The performance speed and speed tolerance of the hoist with rated load shall be specified by the purchaser. The rated load test (125% rated load or as specified by purchaser) speed criteria shall be as specified by the manufacturer.

(b) Rated load recommended hoisting speeds are given in Table 5331.1-1 for slow, medium, or fast service for various capacities. The design tolerance for rated load hoisting speed is ±10%.

(c) Hoisting speed for a critical load less than the rated load shall be limited to 125% of the rated load hoisting speed.

(d) Empty hook and light load speed-up controls are permitted. Refer to para. 6320(e).

(e) When precise positioning capability is required, and the principal control system is incapable of providing lowering speed control of 0.5 ft/min with the load as specified by the purchaser, the hoist system shall be equipped with an auxiliary system. The positioning capability speed should be0.5 ft/min. for a distance of 2 ft within the final position.

Table 5331.1-1
Rated Load Recommended Hoist Speeds

Load, tons	Hoisting Speeds, ft/min Slow	Medium	Fast
0–4	30	35	40
5–9	25	30	35
10–19	20	25	30
20–29	15	20	25
30–39	10	15	20
40–49	8	10	15
50–69	7	8	10
70–99	6	7	9
100–149	5	6	8
150–249	4	5	7
250–349	3	4	6
350–499	2	3	5
500–649	2	3	4
650–799	1	2	3
800–1000	1	1.5	2

(f) The lowering speed for any critical load shall be limited to 125% of the rated load hoisting speed.

5331.2 Types II and III Hoists. Recommended rated load speeds should be as specified in either Table 5331.1-1 or the Speed Table given in Specification CMAA 70.

5332 Trolley Speeds

5332.1 Type 1 Cranes

(a) The performance speed and speed tolerance of the trolley with rated load shall be specified by the purchaser. Rated load test speed (125% rated load) criteria shall be specified by the manufacturer.

(b) Rated load recommended trolley speeds are given in Table 5332.1-1 for various capacities. The design tolerance for a design rated load speed shall be ±10%.

(c) The trolley control shall provide an operating speed range of at least 10 to 1 under all loading conditions or be equipped with an auxiliary system to provide precise positioning capabilities.

(d) Trolley speed for a critical load less than rated load shall be limited to 125% of the rated load trolley speed.

(e) Empty hook and light load speed-up controls are permitted. Refer to para. 6340(c).

5332.2 Types II and III Cranes. Recommended rated load speeds should be as specified in either

Table 5332.1-1
Rated Load Recommended Trolley Speeds

	Trolley Speeds, ft/min		
Load, tons	Slow	Medium	Fast
0–49	100	125	150
50–99	75	100	125
100–149	50	75	100
150–199	35	50	75
200–299	25	50	75
300–499	20	40	60
500–799	15	30	45
800–1000	10	20	30

Table 5333.1-1
Rated Load Recommended Bridge Speeds

	Bridge Speeds, ft/min		
Load, tons	Slow	Medium	Fast
0–49	125	150	175
50–99	100	125	150
100–149	75	100	125
150–199	50	75	100
200–299	40	75	100
300–499	30	50	75
500–799	25	35	50
800–1000	15	20	30

Table 5332.1-1 or the Speed Table given in Specification CMAA 70.

5333 Bridge Speeds

5333.1 Type I Cranes

(a) The performance speed and speed tolerance of the bridge with rated load shall be specified by the purchaser. Rated load test speed (125% rated load) criteria shall be specified by the Manufacturer.

(b) Rated load recommended bridge speeds are given in Table 5333.1-1 for various capacities. The design tolerance for a design rated load speed shall be ±10%.

(c) The bridge control shall provide an operating speed range of at least 10 to 1 under all loading conditions, or be equipped with an auxiliary system to provide precise positioning capabilities.

(d) Bridge speed for a critical load less than rated load shall be limited to 125% of the rated load bridge speed.

(e) Empty hook and light load speed-up controls are permitted. Refer to para. 6320(c).

(f) For cranes with circular polar-type bridges, the recommended speeds shall be the tangential speeds at the runway rail.

5333.2 Types II and III Cranes. Recommended rated bridge speeds should be as specified in either Table 5332.1-1 or the Speed Table given in Specification CMAA 70.

5334 Pendant Hoist and Travel Speeds

5334.1 Traversing. Motorized travel speed for this motion should be 30 ft/min.

5334.2 Vertical Travel of Control Pendant. Motorized travel speed for this motion should be 30 ft/min.

5335 Powered Hook Rotation (Types I, II, and III Cranes)

(a) Speed of rotation shall be specified by Purchaser.

(b) Rotation limit shall be specified by Purchaser.

(c) Single failure-proof features are not required.

5400 COMPONENT DESIGN

5410 Hoist System

5411 Drum

5411.1 Description (Type I Cranes). The drum shall be of cylindrical type, varying in length and diameter, and shall be so designed as to ensure the accumulation of the entire length of rope in one single layer.

5411.2 Size (Type I Cranes). The pitch diameter of the drum shall be not less than 24 times the hoist rope diameter for 6 × 37 rope construction, or not less than 30 times the hoist rope diameter for 6 × 19 rope construction.

5411.3 Construction (Type I Cranes). The drum shell shall be of rolled or centrifugal cast steel construction with flanged ends. It shall be designed to withstand combined crushing and bending loads. Equations (1), (2), and (3) may be used to determine the stress in the drum shell. The drum gear shall be pressed on and keyed to the periphery of the shell, hub, or shaft of the drum, or be bolted with close fitting bolts (para. 5456) to the flange on the drum, in which case the bolts transmit only torque.

5411.4 Grooves (Type I Cranes). Drum grooves shall be machined to a minimum depth equal to three-eighths of the diameter of the hoist rope, and a pitch equal to 1.14 × rope diameter or rope

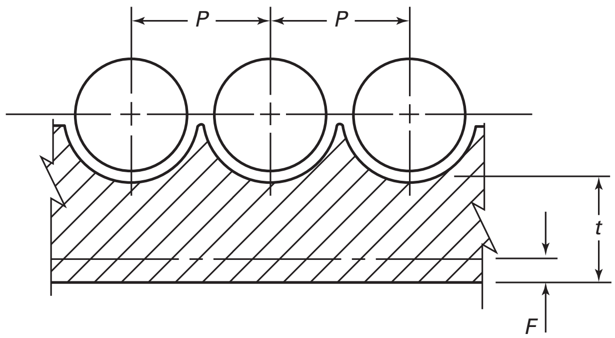


Fig. 5411.5(c)-1 Drum Shell Design

diameter + $^1/_8$ in., whichever is smaller. The groove radius shall be $^1/_{32}$ in. larger than the radius of the rope.

Rope shall be secured to the drum as follows: No less than two wraps of the rope shall remain on the drum at each anchorage to the hoisting drum when the hook is in its extreme low position. Rope end shall be anchored by a minimum of two clamps attached to the drum, or by a socket arrangement specified by the crane or rope manufacturer. The rope clamp bolts shall be tightened evenly to the manufacturer's recommended torque.

5411.5 Drum Shell Design (Type I Cranes)

(a) Crushing Stress on Drum Shell

$$S_{CR} = \left(\frac{R_L}{P\,(t - F)}\right)(K_{SC}) \leq S_{CA} \quad (1)$$

(b) Bending Stress on Drum Shell

$$S_B = \left(\frac{M_{BXY}}{Z_B}\right)(K_{SB}) \leq S_{BA} \quad (2)$$

(c) Combined Stress on Drum Shell

$$S_{\text{comb}} = (S_{CR}^2 + S_B^2)^{1/2} \quad (3)$$

F = out-of-roundness value or manufacturing tolerance (F) is subtracted from the drum shell thickness to produce net thickness, as shown in Fig. 5411.5(c)-1
K_{SB} = service factor, bending
K_{SC} = service factor, crushing
M_{BXY} = resultant bending moment, in.-lb
P = drum groove pitch, in., as shown in Fig. 5411.5(c)-1
R_L = rope load, lb
S_B = bending stress, psi
S_{BA} = allowable bending stress, psi
S_{CA} = allowable crushing stress, psi
S_{comb} = combined stress on drum shell, psi
S_{CR} = crushing stress, psi
Z_B = bending section modulus, in.^{3}
t = drum shell thickness at the bottom of the groove, in., as shown in Fig. 5411.5(c)-1

5411.6 Drum (Types II and III Cranes). The size, construction, and grooving for Types II and III crane drums shall be established in accordance with the provisions of Specification CMAA 70.

5411.7 Single Failure-Proof Features (Type I Cranes)

(a) Single failure-proof features are not required for the drum shell.

(b) In the event of failure of a drum shaft or bearing, the drum must be retained on the trolley in a manner which precludes disengagement of any gearing or brake acting on the drum and precludes disablement of the load-retaining function of these components.

(c) In the event of failure of a drum shaft or bearing, the drum must be retained on the trolley in a manner which precludes disengagement of any gearing or brake acting on the drum and precludes disablement of the load-retaining function of these components.

5411.8 Single Failure-Proof Features (Types II and III Cranes). Single failure-proof features are not required for the drum.

5412 Drive Motors

5412.1 Type I Cranes. Each hoist drive system, such as those indicated in Figs. 5416.1-1 through 5416.1-3, shall be provided with a hoist drive motor(s) for lifting and lowering loads. Motors shall be selected per para. 6470. Motor fasteners shall be per para. 5456.

5412.2 Types II and III Cranes. Motors shall be selected per para. 6470.

5413 Gearing

5413.1 Type I Cranes. Gearing shall be designed and manufactured in accordance with the procedures presented by the American Gear Manufacturers Association (AGMA) as modified by this Section. The gearing shall be designed for strength, durability, and momentary overload which includes the loads imposed during a seismic excursion. **(04)**

Unless positive control of accurate alignment under varying loads can be ensured, parallel shaft gearing, both enclosed and open, shall be straddle mounted; that is, each shaft shall be supported by two outboard bearings. (The intent is to preclude inadequately supported or inaccurately aligned overhung gears or pinions, shafts with three bearing supports, and combination gear reducer/wire rope drum shafts.)

(a) Allowable Strength Horsepower P_{at}. For helical and spur gears, AGMA 2001-C95 (Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth) applies. The allowable strength horsepower P_{at} calculated must be greater than the torque required to lift the load in hoisting applications.

$$P_{at} = \left(\frac{N_p d}{126{,}000\ K_v}\right)\left(\frac{F S_{at} J}{K_m P_d S_{fs} K_B}\right) \tag{4}$$

where

F = net face width of the narrowest of the mating gears, in.
J = geometry factor (strength)
K_B = rim thickness factor
K_m = load distribution factor (strength and durability) para. 5413 Eq. (10)
K_v = dynamic factor (strength and durability)
N_p = pinion speed, rpm
P_d = diametral pitch
S_{at} = allowable bending stress for material, psi (strength)
S_{fs} = crane class factor (strength) = 1.05
d = pitch diameter of pinion, in.

Values for K_v, J, K_B, and S_{at} can be determined from tables and curves in AGMA Standard 2001-C95.

(b) Allowable Durability Horsepower P_{ac}. For helical and spur gears, AGMA 2001-C95 (Fundamental Rating Factors and Calculations Methods for Involute Spur and Helical Gear Teeth) applies. The allowable durability horsepower P_{ac} calculated must be greater than the rated motor horsepower considering efficiency in travel drive applications and must be greater than the torque required to lift the load in hoisting applications.

$$P_{ac} = \left(\frac{N_p F I}{126{,}000\ K_v K_m S_{fd}}\right)\left(\frac{S_{ac} d C_h}{C_p}\right)^2 \tag{5}$$

where

C_h = hardness coefficient
C_p = elastic coefficient
F = net face width of the narrowest of the mating gears, in.
I = geometry factor (durability)
K_m = load distribution factor (strength and durability) para. 5413 Eq. (10)
K_v = dynamic factor (strength and durability)
N_p = pinion speed, rpm
S_{ac} = allowable contact stress for material, psi
S_{fd} = crane class factor (durability)
d = pitch diameter of pinion, in.

Values for K_v, C_h, C_p, I, and S_{ac} can be determined from tables and curves in AGMA Standard 2001-C95.

(c) Allowable Momentary Overload Tooth Load W_{tov}. Allowable momentary overload tangential tooth load shall be greater than the maximum applied tangential tooth load considering stalled motor torque or seismic hook load.

For the purpose of this Section, the allowable load in pounds can be written as:

$$W_{tov} = \frac{1.6\, F J S_{ay}}{1.1 P_d} \tag{6}$$

where

S_{ay} = allowable yield, psi

(d) Crane Class Factor S_{fd} (durability) shall be:

(1) Hoist:

$$S_{fd} = (1.16)\frac{2(\text{rated load}) + 3(\text{lower block weight})}{3(\text{rated load} + \text{lower block weight})} \tag{7}$$

(2) Trolley:

$$S_{fd} = (1.16)\frac{2(\text{rated load}) + 3(\text{trolley weight})}{3(\text{rated load} + \text{trolley weight})} \tag{8}$$

(3) Bridge:

$$S_{fd} = (1.16)\frac{2(\text{rated load}) + 3(\text{trolley weight} + \text{bridge weight})}{3(\text{rated load} + \text{trolley weight} + \text{bridge weight})} \tag{9}$$

(e) Allowable Stresses S_{at}, S_{ac}, S_{ay}

(1) The allowable stress for gear material varies with material quality, heat treatment, forging practices, and material composition. Higher allowable stress values may be permitted in some cases by careful gear design, manufacturing procedure, and various surface treatments, such as surface peening.

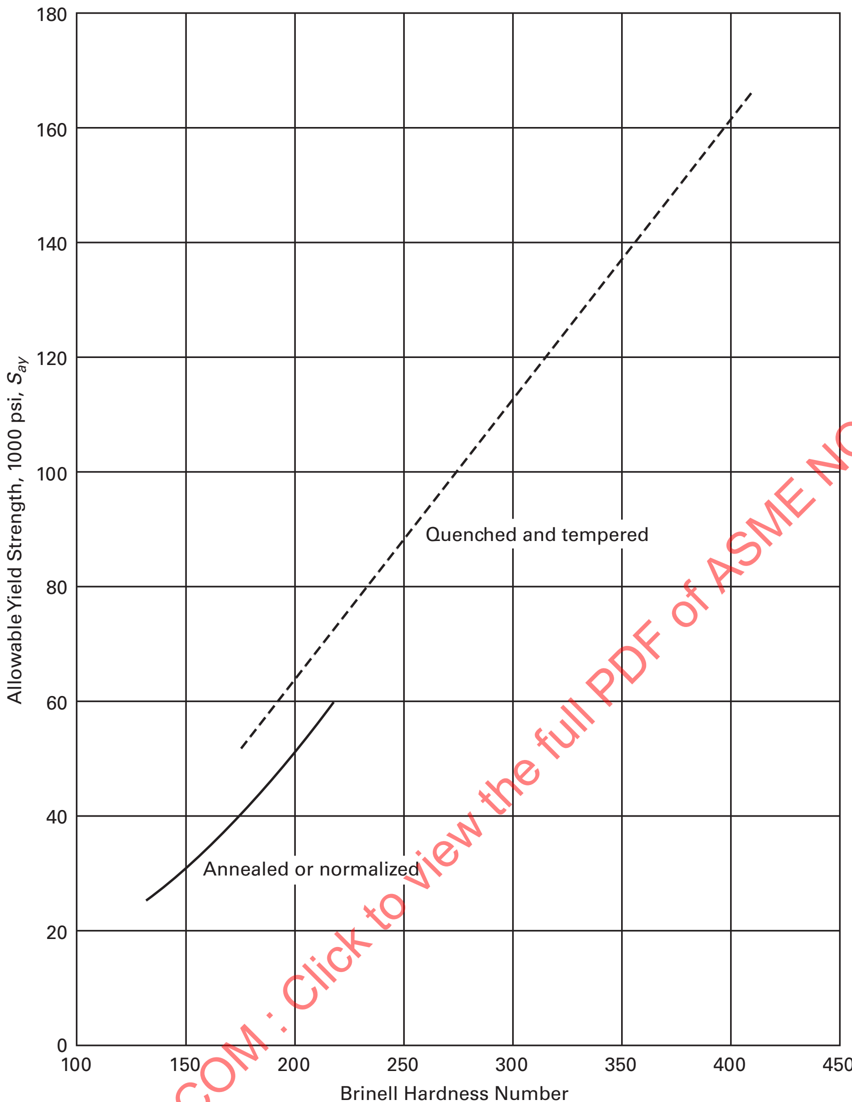


Fig. 5413.1(e)-1 Allowable Yield Strength S_{ay}

(2) The allowable design fatigue stress S_{at}, the allowable contact stress number S_{ac}, and the allowable yield stress S_{ay} are shown in Fig. 5413.1(e)-1. When the gear is subjected to infrequent momentary high overloads, the maximum allowable stress is determined by the allowable yield properties rather than the fatigue strength of the material.

(3) The allowable design bending stress and contact stress numbers are based on 10 million cycles of load application as defined by AGMA. If the life is to be varied, refer to the life factor as defined in the AGMA Standards.

(f) Load Distribution Factors K_m, C_m. All values for K (strength) and C (durability) factors, with the exception of K_m and C_m, will be taken from the appropriate AGMA Standards. The load distribution factor depends upon the combined effects of:

(1) misalignment of axis of rotation due to machining errors and bearing clearances;

(2) lead deviations;

(3) elastic deflections of shafts, bearings, and housing due to load.

The following equation should be used to determine the load distribution [see Table 5413.1(f)-1] except

Table 5413.1(e)-1 Gearing Allowable Stresses

Heat Treatment	Minimum Material Hardness	S_{at}	S_{ac}	S_{ay}
Through-hardened	180 BHN	24,500	85,000–95,000	See Fig. NOG-5413.1(e)-1
	240 BHN	30,000	105,000–115,000	
	300 BHN	36,000	120,000–135,000	
	360 BHN	40,000	145,000–160,000	
	440 BHN	43,500	160,000–170,000	
Induction or flame-hardened (full root hardness)	50 RC	45,000	170,000	. . .
	55 RC	55,000	190,000	. . .
Induction or flame-hardened (root not hardened)	50 RC	22,000	170,000	. . .
	55 RC	22,000	190,000	. . .
Case carburized	55 RC	55,000	200,000	. . .
	60 RC	60,000	210,000	. . .
	65 RC	65,000	220,000	. . .

Table 5413.1(f)-1 Load Distribution Factors

Gearing Quality Description	Precision Quality	High Quality	High Quality [Note (1)]	Minimum Quality
Minimum AGMA quality number	10–9	8	8	5–6
Minimum percent no-load face contact	90	75	60	50
Minimum percent full-load face contact	100	90	75	60
R factor [Note (2)]	1.07	1.24	1.54	1.84

NOTES:
(1) Quality of gearing being reduced due to heat treatment after cutting.
(2) Reference — AGMA Standard.

where test data may support the application of other factors.

$$K_m = C_m = 0.03\,F + R \tag{10}$$

(g) Gear Efficiencies. For the purpose of horsepower calculations, gear set efficiencies with antifriction bearings for hoist, bridge, and trolley drives using spur or helical gearing shall be assumed as 0.97 for oil lubricated gear sets, and 0.95 for grease lubricated gear sets.

The efficiency of the gear train shall be established as

$$E = (0.97)^N \text{ (oil lubricated)} \tag{11}$$

$$E = (0.95)^N \text{ (grease lubricated)}$$

where
N = number of gear reductions.

Efficiencies of other forms of gearing, such as herringbone, worm, and bevel, shall be per the gear reducer manufacturer's recommendations.

(h) Gearing Forms and Quality. Gearing forms, other than spur or helical, shall be designed in accordance with applicable procedures presented in AGMA Standards and shall be machined from forged steel blanks or rounds of certified ASTM quality.

Machining tolerance, backlash, and the inspection of gearing shall conform to the latest AGMA Standards.

Spur and helical gearing shall be hobbed to conform to a minimum AGMA quality number 8. In cases where heat treatment is done after cutting, consideration should be given to the effect of load distribution K_m. Distortion due to heat treatment can result in gear quality being reduced from 8 to 5. Surface grind, which maintains the profile, would be required to use the factors defined in Table 5413.1(f)-1, under High Quality.

(04) *(i) Lubrication.* Lubricants for gear and bearings enclosed in gear drives and gear motor drives shall be in accordance with the practices of AGMA 9005-E02, Industrial Gear Lubrication, or as recommended by the gear manufacturer.

Lubrication for bearings used that are not enclosed in speed reducers and gear motor drives shall be in accordance with the bearing manufacturer's recommendation.

Enclosed gears shall comply with the following:

(1) shall have an oil pump when vertical gearing exceeds two reductions;

(2) shall have sufficient heat radiation area to maintain lubricant at temperatures below maximum operating temperature; and

(3) shall have fill and drain connections, lubricant level indicator, and piping, and shall be piped to an accessible area on the crane.

See para. 5460 for all general lubrication requirements.

5413.2 Types II and III Cranes. Gearing for Types II and III cranes shall be established in accordance with provisions in Specification CMAA 70.

5414 Brakes — Load and Holding

5414.1 Hoist Control Braking Means (Types I, II, and III Hoists). An electrical control braking means or a mechanical braking means capable of maintaining controlled lowering speeds shall be provided. Electrically controlled braking means include regenerative, dynamic, countertorque, and eddy current. Brake sizing and design are specified in para. 6400.

Mechanical load brakes, if used as the control braking means, shall be provided with sufficient thermal capacity to accommodate lowering of the rated load at full speed through the expected operating distance.

5414.2 Hoist Holding Brakes (Type I Hoists). Two holding brakes shall be provided, mounted such that the failure of any hoist shaft or coupling will not disengage both of the hoist holding brakes. Under normal operating conditions, the brakes will be automatically applied on power removal with the application of one brake delayed to minimize shock to the hoist drive train. Brake sizing and design is specified in para. 6400.

5414.3 Hoist Holding Brakes (Types II and III Hoists). Hoist holding brakes shall be selected in accordance with para. 6420.

5415 Load Combinations — Hoist Drive Shafting (Types I, II, and III Cranes)

5415.1 Load Combinations, Allowable Stresses, and Service Factors. The hoist drive machinery shafting shall be designed to resist the following load combinations with corresponding values of allowable stresses and service factors. Combinations of the various types of loading are shown in Table 5415.1-1.

5415.2 Computation — Analysis. Analytical stress computations shall be performed according to procedures in para. 5470.

5416 Single Failure-Proof Features

5416.1 Type I Cranes. The hoist drive system shall be designed to provide assurance that a failure of a single-hoist mechanism component would not result in the loss of the lifted load. This can be accomplished in several ways. Typical applications of single- and dual-hoist drive units are shown in Figs. 5416.1-1 and 5416.1-2, respectively, and are defined below. (04)

(a) Single-Hoist Drive. The single-hoist drive may have one gear train with a single drive motor and two holding brakes. One holding brake may be located at the drive motor shaft or any intermediate shaft (including the drum shaft axis), and the second brake may be located at the drum with the drum brake to act as a back-up with a delayed setting or in cases of malfunction. The torque setting of each holding brake shall not be less than 125% of the required full-load drive torque at brake location in normal operation.

(b) Dual-Hoist Drive. The dual-hoist drive may have two gear trains with drive motor(s) and at least two holding brakes located on the cross shaft external or between the gear trains, with one of the holding brakes to act as a back-up with a delayed setting. The torque rating of each holding brake shall not be less than 125% of the full-load drive torque required at the brake location in normal operation. Each gear train shall be sized for the total full-load drive torque of the motor.

5416.2 Types II and III Cranes. Single failure-proof features are not required.

5420 Reeving System

(a) Type I Cranes. The design of the rope reeving system shall be such that a single rope failure will not result in the loss of the lifted load. A load

Table 5415.1-1 Load Combinations — Hoist Drive Shafting

		Type of Loading [Note (1)]								
Crane Type	Load Combinations	Live Load	Dead Load	Impact	Inertia	Seismic	Load Hang-up	Motor Torque	Allowable Stresses	Service Factor Minimum
Type I hoist	1	X(R)	X	X	. . .	. . .	. . .	. . .	Fatigue	1.0
	2	X(R)	X	. . .	X	. . .	. . .	. . .	Fatigue	1.0
	3	. . .	. . .	. . .	. . .	. . .	. . .	X	Fatigue	1.0
	4	. . .	. . .	. . .	X	. . .	X	. . .	0.75_y [Note (2)]	0.5 [Note (3)]
	5	X(C)	. . .	. . .	. . .	X	. . .	. . .	0.75_y [Note (2)]	0.5 [Note (3)]
Types II and III hoist	Per Specification CMAA 70									

NOTES:
(1) Type of loading:
Live Load: critical (C) or rated (R) load.
Dead Load: load block and attachments.
Impact: operational.
Inertia: rotation and linear.
Seismic: earthquake condition (refer to para. 4140).
Load Hang-up: motor pull-out torque and rotational inertia. (For design computations, 275% of motor nameplate rating shall be used. In cases of higher values than the 275% motor nameplate rating, the ratio of the actual value of percent rated motor torque divided by 275% shall be considered in relation to the calculated service factor.)
Motor torque: nameplate rating.
(2) Based on bulk section.
(3) Components that are not dual or redundant shall be designed with a service factor of 1.0.

balance shall be provided on each rope system. In the event of a hook over travel, where the lower block contacts the crane structure, the ropes shall not be cut or crushed.

The wire rope and fleet angle requirements shall be in accordance with paras. 5425.1 and 5426, respectively.

(1) Single Failure-Proof Features. Single failure-proof mechanical features for the reeving system shall consist of the following.

(a) Reeving system shall be divided into two separate 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. Figure 5420-1 shows one such reeving system. Other reeving systems that meet the above requirements are acceptable.

(b) Upper blocks and load blocks shall be designed such that each attaching point will be able to support a load of three times the load (static and dynamic) being handled without permanent deformation of any part of the block assembly. These assemblies shall be designed so that the sheaves will be contained in the event of failure of the sheave support pin.

(b) Types II and III Cranes. Reeving system components for Types II and III cranes shall be in accordance with Specification CMAA 70. Hoist reeving may be either single or double and may be one or multiple parts.

(1) On single-reeved hoists, one end of the rope is attached to the drum and the other end is dead ended on a stationary portion of the hoist. 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. 5420-2, sketch (a).

(2) On double-reeved hoists, both ends of the rope are attached to the drum. The drum is grooved with left and right 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 the drum. Refer to Fig. 5420-2, sketch (b).

(3) Single failure-proof features are not required for Type II and III cranes.

5421 Upper Block

5421.1 Type I Cranes

(a) The upper block, in conjunction with the load block, shall be designed to maintain a vertical load balance about the center of the lifted load and shall have a reeving system of dual design.

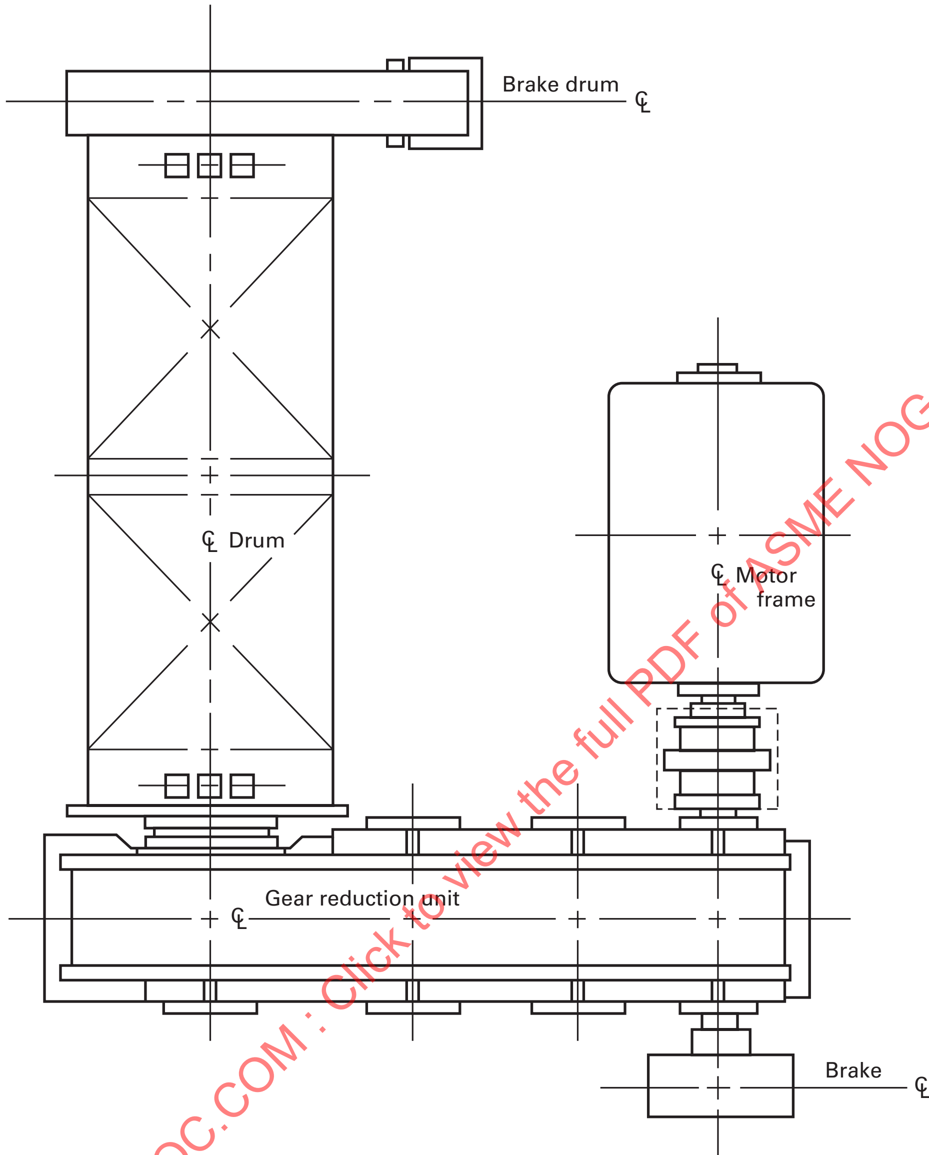


Fig. 5416.1-1 Typical Single-Hoist Drive Unit

(b) All design loads and allowable stresses for mechanical and structural components of the upper block shall be in accordance with paras. 5300 and 4310, respectively. The upper block shall be accessible from above the trolley floor.

5421.2 Types II and III Cranes. Upper blocks for Types II and III cranes shall be established in accordance with the provisions of Specification CMAA 70.

5422 Load Block

5422.1 Type I Cranes

(a) The load block frame shall be constructed of rolled steel and shall be entirely enclosed except for the rope openings. The hook(s) shall be free to swivel on antifriction or sleeve bearing so constructed as to exclude dirt and also shall be provided with a means for lubrication. Refer to para. 5460 for data relating to lubrication.

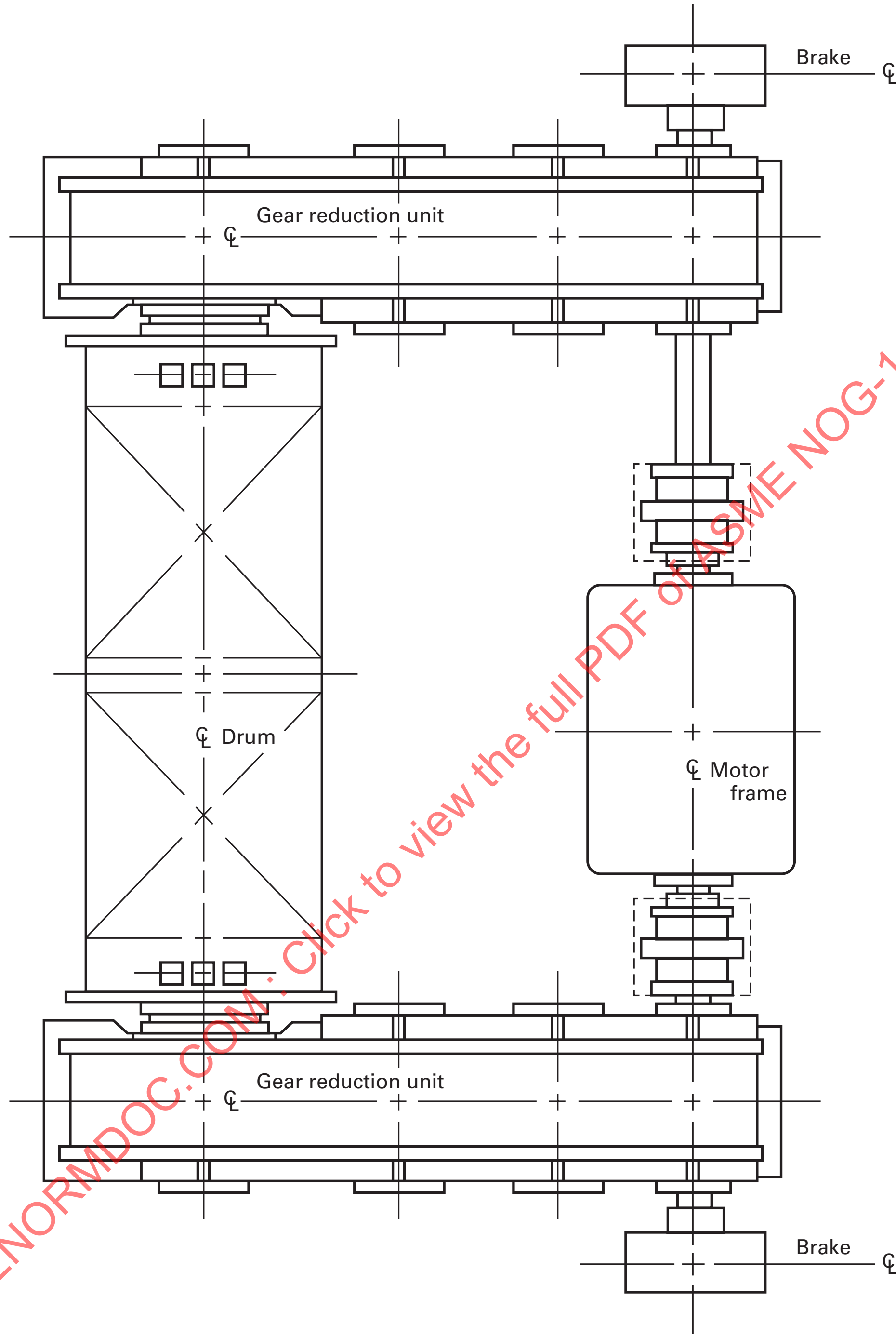


Fig. 5416.1-2 Typical Dual-Hoist Drive Units

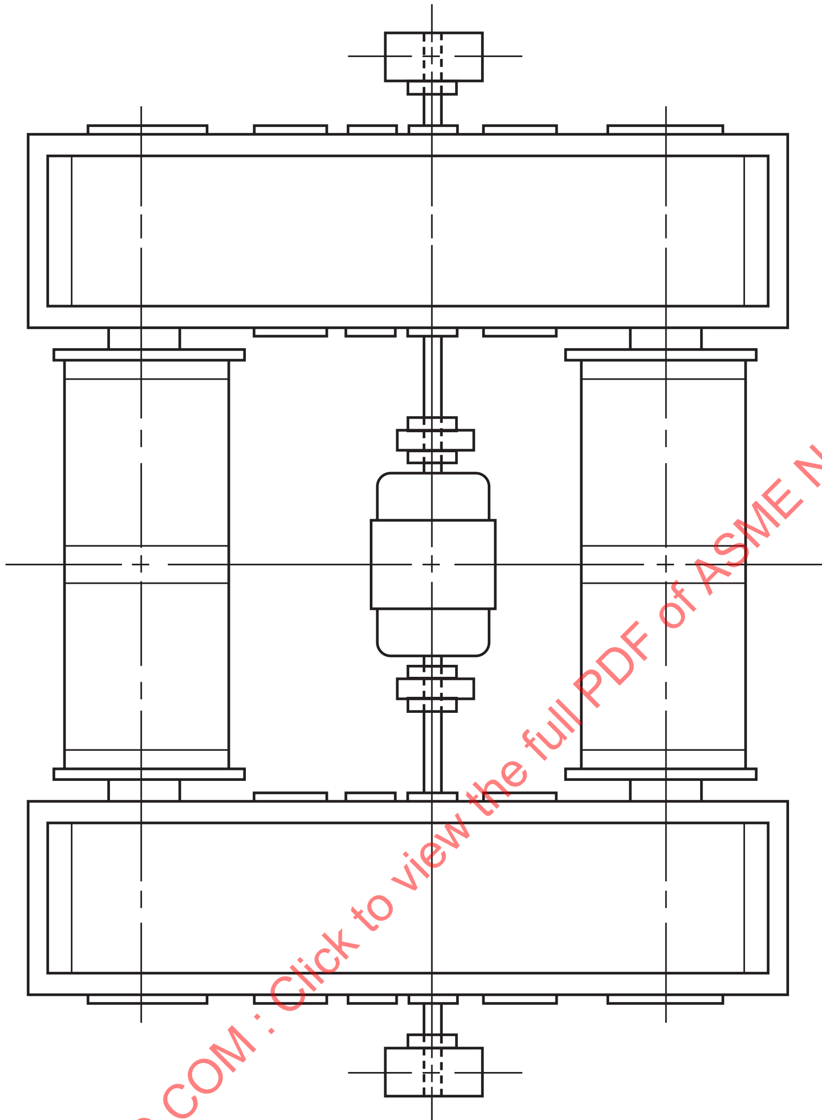


Fig. 5416.1-2 Typical Dual-Hoist Drive Units (Cont'd)

(b) Welding of trunnions for critical load handling load blocks shall not be permitted.

5422.2 Types II and III Cranes. Load blocks for Types II and III cranes shall be established in accordance with the provisions of Specification CMAA 70.

5423 Equalizer Systems

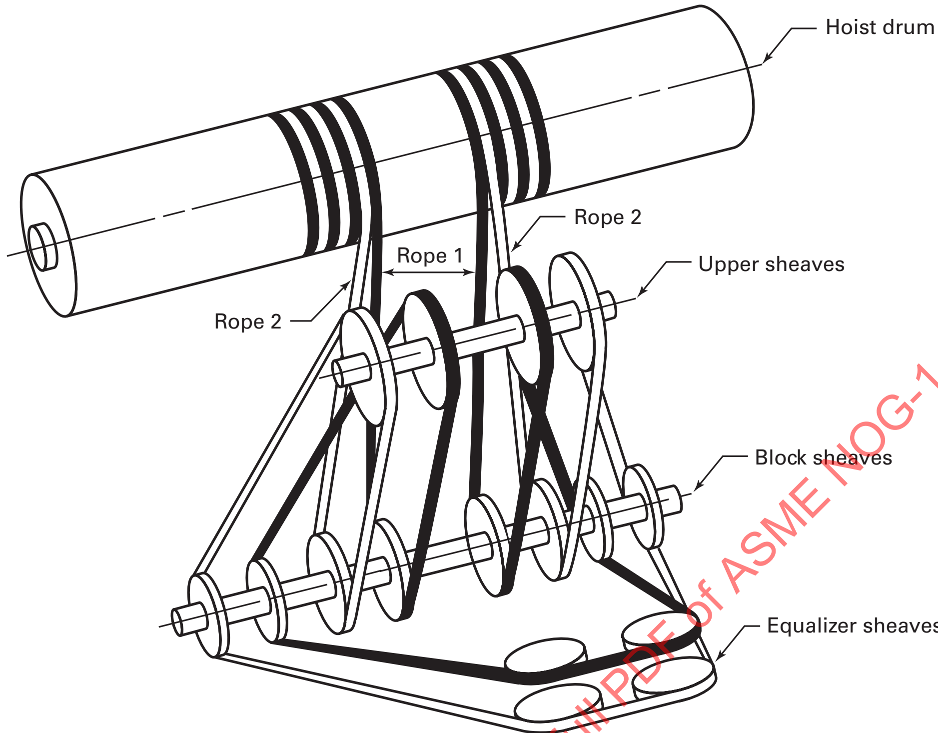
5423.1 Type I Cranes

(a) Where separate rope equalizing is required, either an equalizer bar or a sheave will be acceptable. In either case, two separate and complete reeving systems shall be provided. The equalizer, where possible, should be designed to be accessible from the floor of the trolley and be made in such a manner that it can turn or swivel to align itself with the pull of the ropes.

(b) Equalizer sheaves, when used, shall have a pitch diameter not less than one-half of the diameter of the running sheaves.

(c) Rope equalizer systems shall be designed to meet the criteria as delineated herein.

(1) Reeving equalization shall not be restricted under normal operating conditions.



GENERAL NOTES:
(a) Relative position of sheaves is extended and angle of view is distorted to clarify reeving paths.
(b) Number of parts of reeving may vary.

Fig. 5420-1 Single Failure-Proof Reeving Example

(2) Adequate free movement to compensate for operational block swing and/or normal rope stretch shall be provided.

(3) Sensing and automatic signaling of excessive rope displacement to either side shall be provided.

(4) Sensing and automatic signaling of a broken reeving shall be provided.

(5) In the event of a broken rope, the remaining intact reeving system shall not be loaded to more than 40% of the breaking strength of the wire rope, including the dynamic effects of the load transfer.

(6) The vertical displacement of the load following a rope failure shall be minimized.

(7) The vertical displacement of the load following a rope failure shall be calculated and reported to the purchaser.

(8) The effects of a broken rope on the entire system including the equalizer assembly shall be analyzed.

5423.2 Types II and III Cranes. Equalizer bars or sheaves of Types II and III cranes shall be established in accordance with the provisions of Specification CMAA 70.

5424 Sheave Pins

5424.1 Type I Cranes

(a) Sheave pins for the upper block and load block shall be designed to withstand the combined line pull of the live load, plus the dead load of the load block.

(b) Seismic effects shall be included in the analysis.

(c) Analytical stress computation shall be performed in accordance with para. 5470.

(d) Service factors shall be applied in accordance with para. 5320.

(e) Grease lubricated sheave bearings should be provided with individual lubrication fittings if the pin size is sufficiently large to provide the space for these fittings.

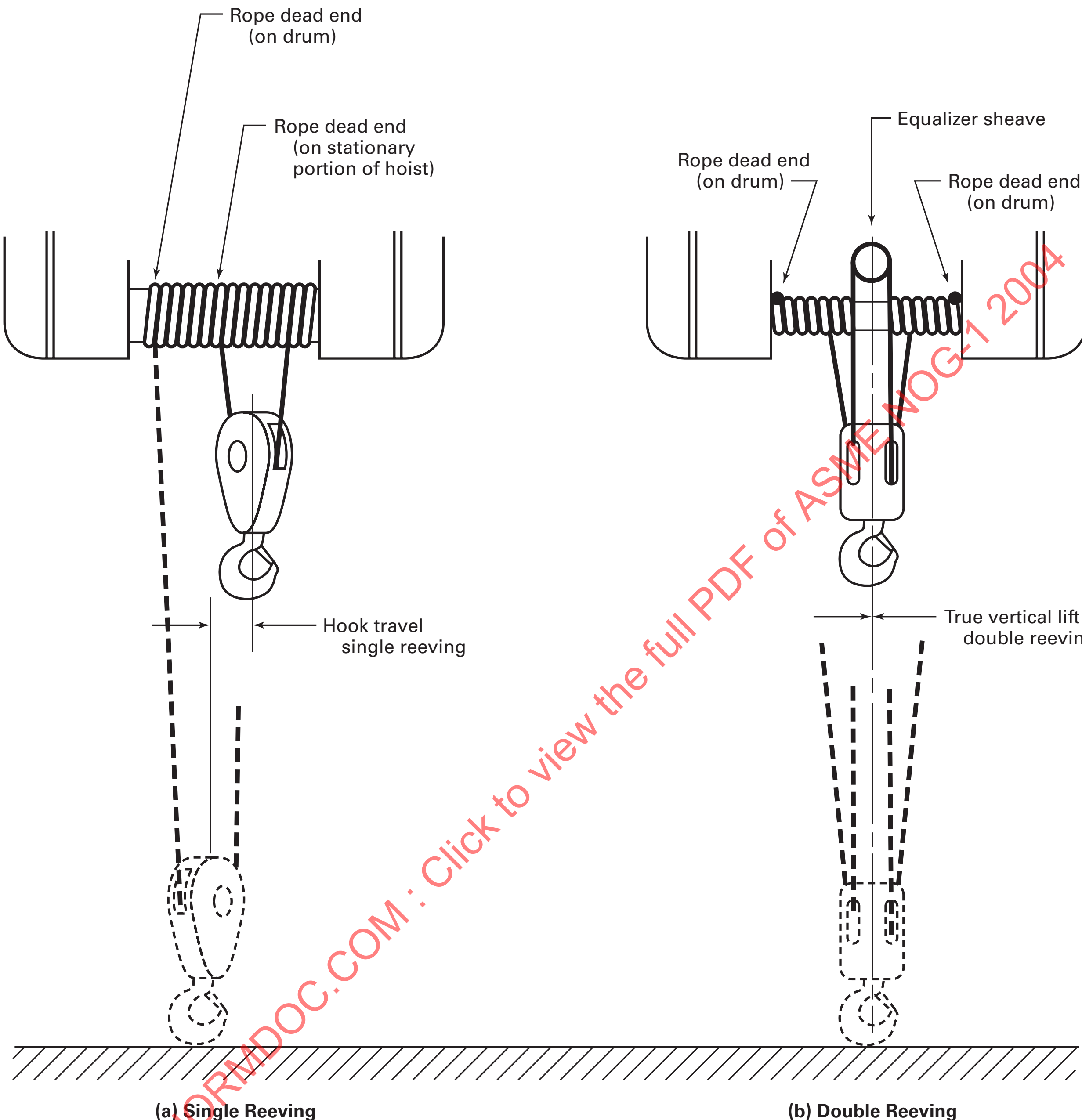


Fig. 5420-2 Single and Double Reeving

5424.2 Types II and III Cranes. Sheave pins for Types II and III cranes shall be in accordance with the provisions of Specification CMAA 70.

5425 Rope Construction, Loads, and Design Factors

5425.1 Type I Cranes

(a) Rope Construction. The hoist rope shall be of a construction for crane service, such as improved or extra-improved plow steel grades, 6 × 37 class construction (6 strand, 27 to 49 wires per strand), right regular lay with independent wire rope core. Other materials, strength grades, rope constructions, type of cores, and lay may be used where application or future development in wire rope technology indicates.

(b) Selection of Ropes. Hoisting ropes shall be selected based on the more stringent of the following requirements.

(1) The rated load (without impact), plus the weight of the load block divided by the total number of parts of rope per system, shall not exceed 20% of the manufacturer's published breaking strength.

(2) 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 10% of the manufacturer's published breaking strength on the total system or 20% on each of the dual systems.

(3) 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.

(4) The seismic load (para. 4130) with all parts of rope intact shall not exceed 40% of the manufacturer's published breaking strength.

(c) Breaking Strength of Ropes. The breaking strength of rope shall conform to the manufacturer's published values based upon the minimum values determined by actual tensile tests performed on new ropes. The theoretical strengths based upon material properties and net metal cross-section shall not be used.

5425.2 Types II and III Cranes. Rope construction, loads, and design factors for Types II and III cranes shall be established in accordance with the provisions of Specification CMAA 70.

(04) **5426 Fleet Angles**

5426.1 Type I Cranes

(a) The rope fleet angle to the drum grooves shall be limited to $3\frac{1}{2}$ deg, except at the last 3 ft of the maximum lift elevation it shall be limited to 4 deg. Refer to Fig. 5426-1 for fleet angle measurement to the drum groove.

(b) The rope fleet angle for sheaves shall be limited to $3\frac{1}{2}$ deg, except at the last 3 ft of the maximum lift elevation it shall be limited to $4\frac{1}{2}$ deg. Refer to Fig. 5426-2 for fleet angle measurement to the sheaves.

5426.2 Types II and III Cranes. The operating fleet angle for Types II and III cranes shall be in accordance with CMAA 70.

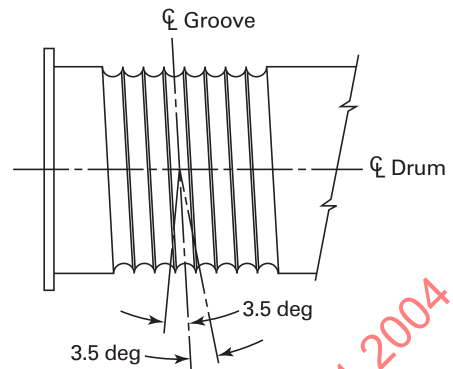


Fig. 5426-1 Drum Fleet Angle (04)

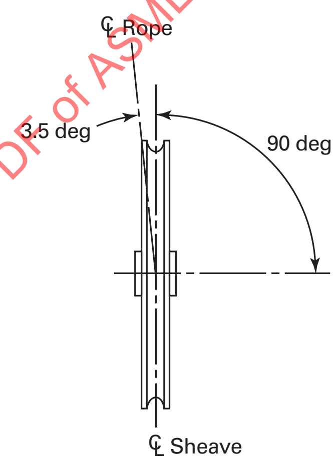
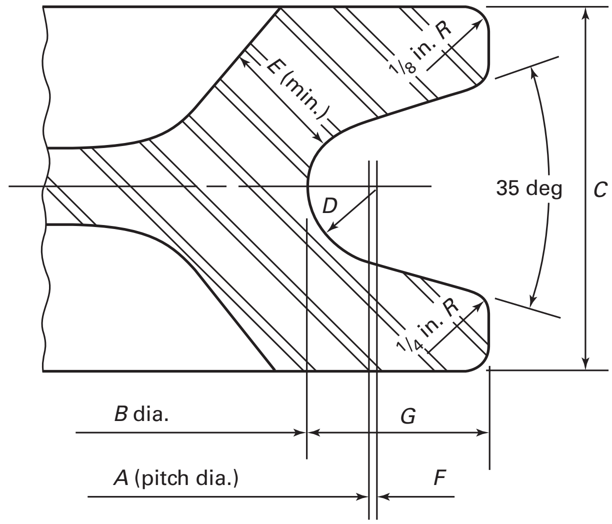


Fig. 5426-2 Sheave Fleet Angle (04)

5427 Sheaves

5427.1 Type I Cranes. Sheaves shall be of steel and provided with antifriction or sleeve bearings. Proper provision for the effects of thrust shall be made where applicable. Figures 5427.1-1 and 5427.1-2 are recommended for running sheave proportions only. The pitch diameter of all sheaves except equalizer sheaves shall be not less than 24 times the diameter of the hoist rope for 6 × 37 rope construction, or not less than 30 times the hoist rope diameter for 6 × 19 rope construction.

Sheave journals requiring external lubrication shall be provided with individual grease lines, with the fittings located such that they will be protected from damage (see para. 5460). Means shall be provided to prevent the wire rope from leaving the sheave grooves.



Sheave Wheel Contours

Rope Dia., in.	A	B	C	D	E	F	G
1/2	12	11 1/2	1 3/4	9/32	1/2	1/32	3/4
5/8	15	14 3/8	2	11/32	5/8	1/32	15/16
3/4	18	17 1/4	2 1/4	13/32	3/4	1/32	1 1/8
7/8	21	20 1/2	2 1/2	31/64	7/8	3/64	1 5/16
1	24	23	2 3/4	35/64	1	3/64	1 1/2
1 1/8	27	25 7/8	3	39/64	1 1/8	3/64	1 11/16
1 1/4	30	28 3/4	3 1/4	11/16	1 1/4	1/16	1 7/8
1 3/8	33	31 5/8	3 1/2	3/4	1 3/8	1/16	2 1/16
1 1/2	36	34 1/2	3 3/4	13/16	1 1/2	1/16	2 1/4

Fig. 5427.1-1 Proportions for 24:1 Sheave-to-Rope Ratio

5427.2 Types II and III Cranes. Sheaves for Types II and III cranes shall be established in accordance with the provisions of Specification CMAA 70.

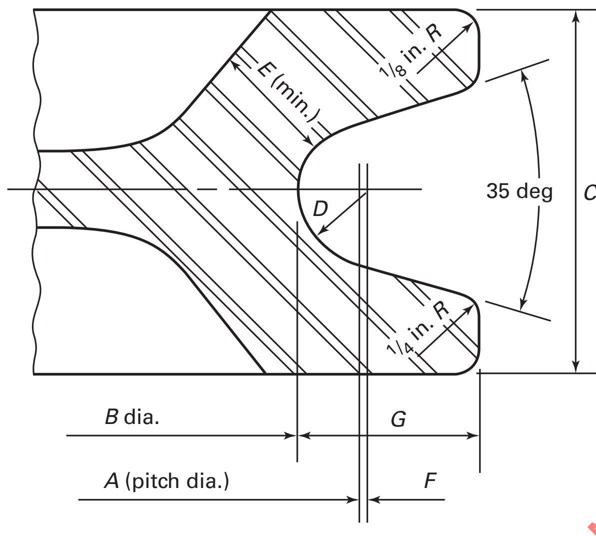
5428 Hooks

5428.1 Single Failure-Proof Features (Type I Cranes). Type I cranes shall be provided with (a) hook(s) that either:

(a) provide(s) two load-attaching points designed such that each attaching point will be able to support a load of three times the critical load (static and dynamic) being handled without permanent deformation of the hook, other than localized strain concentration in areas for which additional material has been provided for wear, or

(b) provide(s) one load-attaching point designed such that it will be able to support a load of six times the critical load (static and dynamic) being handled without permanent deformation of the hook, other than localized strain concentration in areas for which additional material has been provided for wear.

5428.2 Single Failure-Proof Features (Types II and III Cranes). Single failure-proof mechanical features are not required.



Sheave Wheel Contours

Rope Dia.	*A*	*B*	*C*	*D*	*E*	*F*	*G*
1/2	15	14 1/2	1 3/4	9/32	1/2	1/32	3/4
5/8	18 3/4	18 1/8	2	11/32	5/8	1/32	15/16
3/4	22 1/2	21 3/4	2 1/4	13/32	3/4	1/32	1 1/8
7/8	26 1/4	25 3/8	2 1/2	31/64	7/8	3/64	1 5/16
1	30	29	2 3/4	35/64	1	3/64	1 1/2
1 1/8	33 3/4	32 5/8	3	39/64	1 1/8	3/64	1 11/16
1 1/4	37 1/2	36 1/4	3 1/4	11/16	1 1/4	1/16	1 7/8
1 3/8	41 1/4	39 7/8	3 1/2	3/4	1 3/8	1/16	2 1/16
1 1/2	45	43 1/2	3 3/4	13/16	1 1/2	1/16	2 1/4

Fig. 5427.1-2 Proportions for 30:1 Sheave-to-Rope Ratio

5428.3 Analytical Procedure for Curved Beams. Hook stresses are calculated using the curved beam method described by A.M. Wahl in *The Journal of Applied Mechanics*, pp. A-239 to A-242, September 1946. For hook configuration and calculation procedures, see para. 5470.

5429 Reeving Efficiency (Types I, II, and III Cranes). The reeving efficiencies are based on the total number of ropes supporting one load block either double reeved or single reeved. The values of the reeving efficiencies are determined from Eq. (12).

For the purpose of calculation for the overall mechanical efficiency of the hoist, the efficiencies of the gearing, rope, and drum shall be established as follows.

$$E = (E_g^n)\,(E_s^m)\,(E_d) \qquad (12)$$

where

E = overall combined efficiency
E_g^n = combined efficiency of gear reductions and antifriction bearings
n = number of gear reductions

The efficiency of a gear reduction mounted on antifriction bearings for hoist drives using spur, helical, or herringbone gearing shall be assumed to be 0.97. Efficiencies of other forms of gearing such as worm and bevel shall be per the gear reducer manufacturer's recommendation.

E_s^m = combined efficiency of rope on sheaves
m = total number of rotating sheaves divided by the number of ropes off drum

The efficiency of the rope operating on a sheave that is mounted on antifriction bearing(s) shall be assumed to be 0.99 for each rotating sheave between the drum and the equalizer.

E_d = combined efficiency of ropes on drum and antifriction bearings
E_d = 0.98 for two ropes off drum or 0.99 for one rope off drum

5430 Trolley Drives

(a) *Type I Cranes.* Trolley drives shall consist of one of the following arrangements, which are shown in Fig. 5430(a)-1. Each four-wheel trolley shall use a drive arrangement that provides drive to at least 50% of the wheels. Trolleys having more than four wheels shall have at least 25% of the wheels driven.

In trolley travel drives, single failure-proof features are generally not required. However, in those cases where a failure of a component could result in a facility unacceptable excursion, the design shall incorporate single failure-proof features to ensure that the trolley can be brought to a safe stop.

(1) *A-1 Drive.* The motor is located near the center of the trolley and is connected by means of a flexible coupling to a self-contained gear reduction unit also located at the center of the trolley, which shall be connected to the line shaft by solid or half-flexible couplings. The line shaft is in turn connected to the trolley wheel axles by means of floating shafts with half-flexible couplings.

(2) *A-1A Drive.* Same as A-1 drive, except the self-contained gear reduction unit is located closer to one of the trolley wheel axles.

(3) *A-1B Drive.* Same as A-1 drive, except the self-contained gear reduction unit is located outside the trolley frame close to one of the trolley wheel axles.

(4) *A-2 Drive.* The motor is connected by means of a flexible coupling to a self-contained gear reduction unit located at the center of the trolley. The trolley wheels shall be driven through gears which are either pressed or keyed to their axles or which are attached directly to the wheel. Floating shaft couplings shall be half-flexible type at wheel and reducer connections. If splicing of floating shafts is required, couplings shall be of the solid type.

(5) *A-3 Drive.* The motor is located at the center of the trolley and is connected directly to the line shaft by half-flexible couplings. Self-contained gear reduction units located near each end of the trolley shall be connected to the trolley wheel axles by means of floating shafts with half-flexible couplings or directly with full-flexible couplings.

(6) *A-4 Drive.* The motors are located near each end of the trolley without torque shafts. The motors shall be connected to self-contained gear reduction units by means of flexible couplings. The gear reduction units shall be connected to the trolley wheel axles by means of floating shafts with half-flexible couplings or directly coupled by means of full-flexible couplings.

(7) *A-5 Drive.* The motor is located near the center of the trolley and is connected by means of a flexible coupling to a self-contained gear reduction unit located near the center of the trolley. This reduction unit shall be connected by sections of line shaft having solid or half-flexible couplings to self-contained gear reduction units located near each end of the trolley, and these in turn connect to trolley wheel axles by means of floating shafts with half-flexible couplings or directly by means of full-flexible couplings.

(8) *A-6 Drive.* The motors are located near each end of the trolley and are connected with a torque shaft. On the drive end, the motors shall be connected to self-contained gear reduction units by means of flexible couplings. Gear reduction units are to be connected to trolley wheel axles by means of floating shafts with half-flexible couplings. High-speed shafts between motors shall be connected by means of half-flexible couplings. All other couplings shall be of the solid type.

(b) *Types II and III Cranes.* Arrangement of trolley drives is the same as for Type I cranes.

5431 Motors — Trolley

5431.1 Type I Cranes. Each motor in a trolley drive arrangement (refer to para. 5430) shall connect directly or indirectly to two opposite wheels for traversing the trolley, or, if individually driven wheels are used, a motor shall be provided to drive opposite wheels. Motors are to be selected per para. 6400.

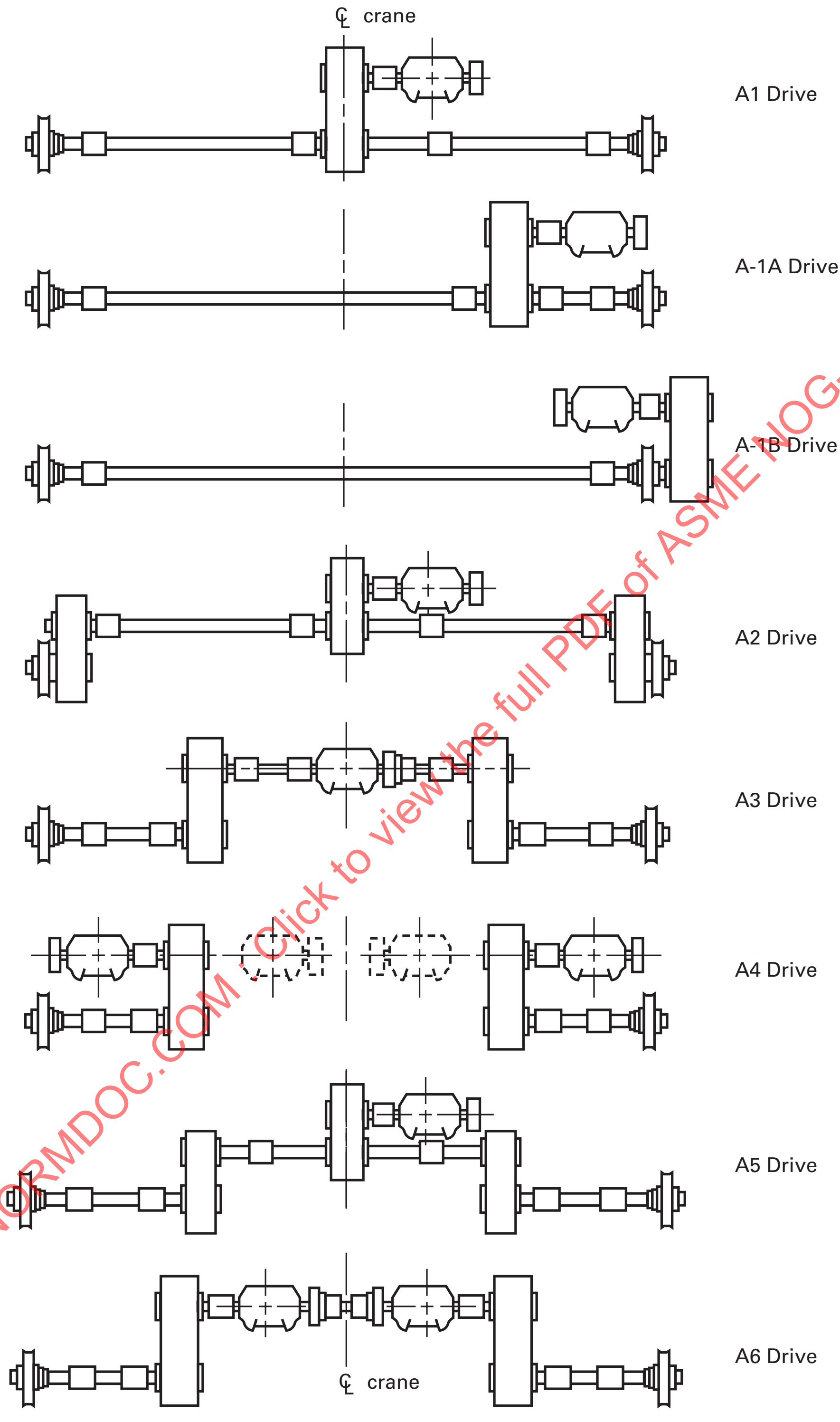


Fig. 5430(a)-1 Arrangement of Crane Trolley Drives

5431.2 Types II and III Cranes. Trolley drive motors shall be selected in accordance with para. 6400.

5432 Trolley Travel Gearing

5432.1 General — Type I Cranes. Trolley travel gearing shall be designed in accordance with para. 5413 except for the areas delineated in this Section.

The actual horsepower imposed on the gearing shall be considered as the rated motor horsepower at its normal time rating as defined in Section 6000. If 60-minute series wound motors are used, then special consideration shall be given to the short time torque ratings of such motors.

5432.2 Types II and III Cranes. Gearing for trolley travels shall be established in accordance with the provisions of Specification CMAA 70.

5433 Trolley Brakes

5433.1 Type I Cranes

(a) Service Brakes. A trolley drive system shall be provided with a service braking means which may be satisfied by the emergency brake, a separate control brake, or as part of the motor controls. Service brake requirements, brake sizes, and brake designs are specified in Section 6000.

(b) Emergency and Parking Brakes. Each primary trolley drive motor shall be provided with an emergency and a parking brake. Brake sizing and design are specified in Section 6000.

5433.2 Types II and III Cranes. Trolley brakes shall be in accordance with Specification CMAA 70.

5440 Bridge Drives

(a) Type I Cranes. Bridge drives shall consist of one of the following arrangements, which are shown in Fig. 5440(a)-1. Each four-wheel bridge shall use a drive arrangement that has at least 50% of the wheels driven. Bridges having more than four wheels, such as eight-wheel, twelve-wheel, or sixteen-wheel, shall have at least 25% of the wheels driven.

In bridge travel drives, single failure-proof features are generally not required. However, in those cases where a failure of a component could result in a facility unacceptable excursion, the design shall incorporate single failure-proof features to ensure that the bridge can be brought to a safe stop.

(1) A-1 Drive. The motor is located near the center of the bridge and is connected by means of a flexible coupling to a self-contained gear reduction unit also located at the center of the bridge, which shall be connected to the line shaft by solid or half-flexible couplings. The line shaft is in turn connected to the bridge wheel axles by means of floating shafts with half-flexible couplings [see (a)(7) below, Note].

(2) A-2 Drive. The motor is connected by means of a flexible coupling to a self-contained gear reduction unit located at the center of the bridge. The bridge wheels shall be driven through gears which either are press fitted or are attached directly to the wheel. Line shaft couplings at the center reducer shall be either solid or half-flexible. Line shaft couplings at the truck reduction pinion shall be of the half-flexible type. All other couplings shall be of the solid type [see (a)(7) below, Note].

(3) A-3 Drive. The motor is located at the center of the bridge and is connected directly to the line shaft by means of half-flexible couplings. Self-contained gear reduction units located near each end of the bridge shall be connected to the bridge wheel axles by means of floating shafts with half-flexible couplings. All other couplings shall be of the solid type.

(4) A-4 Drive. The motors are located near each end of the bridge without torque shafts. The motors shall be connected to self-contained gear reduction units by means of flexible couplings. The gear reduction units shall be connected to the bridge wheel axles by means of floating shafts with half-flexible couplings or directly coupled by means of full-flexible couplings.

(5) A-5 Drive. The motor is located near the center of the bridge and is connected by means of a flexible coupling to a self-contained gear reduction unit located near the center of the bridge. This reduction unit shall be connected by sections of line shaft having solid or half-flexible couplings to self-contained gear reduction units located near each end of the bridge, and these, in turn, shall be connected to bridge wheel axles by means of floating shafts with half-flexible couplings [see (a)(7) below, Note].

(6) A-6 Drive. The motors are located near each end of the bridge and are connected with a torque shaft. On the drive end, the motor shall be connected to a self-contained gear reduction unit by means of flexible couplings. Gear reduction units are to be connected to bridge wheel axles by means of floating shafts with half-flexible couplings. High-speed shafts between motors shall be connected by

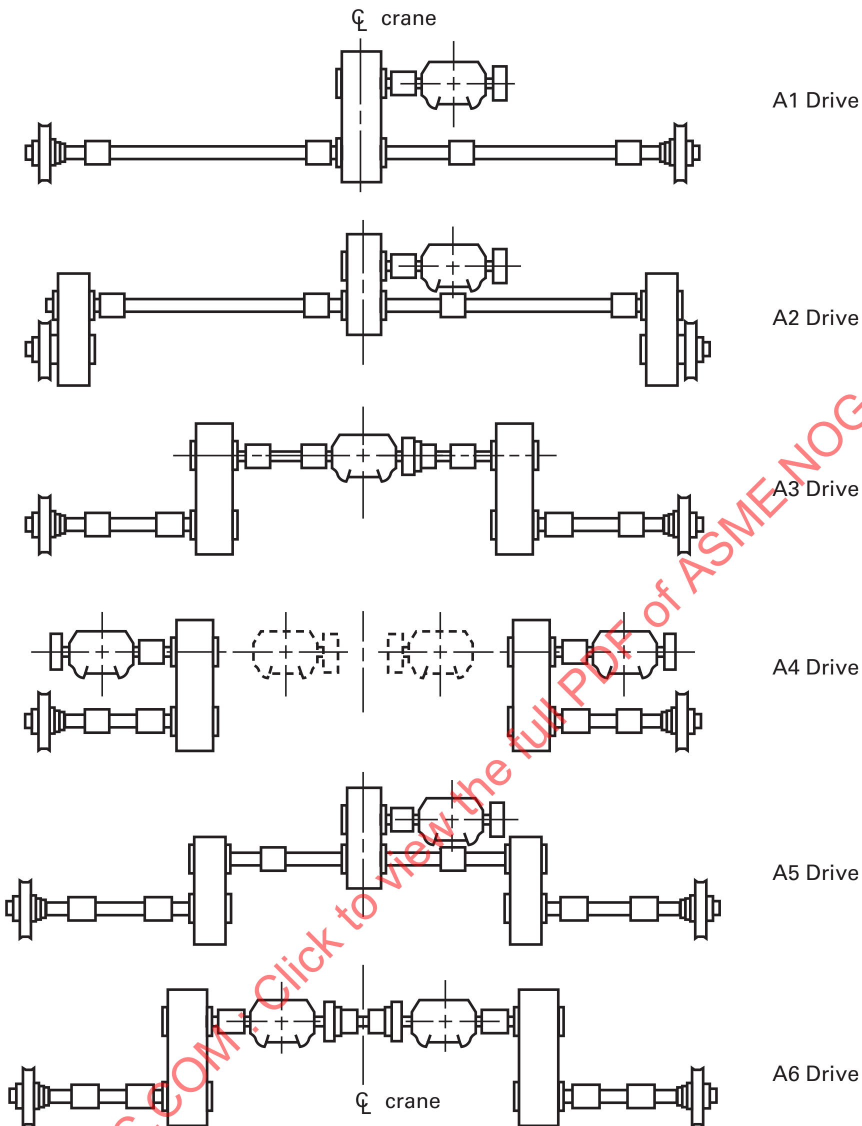


Fig. 5440(a)-1 Arrangement of Crane Bridge Drives

half-flexible couplings. All other couplings shall be of the solid type.

(7) Typical bridge drive arrangements for polar cranes are shown in Fig. 5440(a)-2. These drives use the A-4 drive arrangement with the axis of bridge wheel rotation passing through the center of the crane runway diameter.

NOTE: A-1, A-2, and A-5 drives can result in a torsionally very soft drive system if center gear ratios and/or bridge spans are of large magnitude. Natural frequency and amplitude of total torsional deflection of the drive system should be determined. Low frequencies and large total deflections are undesirable for crane operation.

(b) Types II and III Cranes. Arrangement of bridge drives is the same as for Type I cranes.

5441 Motors — Bridge

5441.1 Type I Cranes. Each bridge drive arrangement, as described in para. 5440 and shown in Figs. 5440(a)-1 and 5440(a)-2, shall use one or more motors for traversing the bridge. Motor(s) shall be selected in accordance with para. 6400.

5441.2 Types II and III Cranes. Bridge drive motors shall be in accordance with Specification CMAA 70.

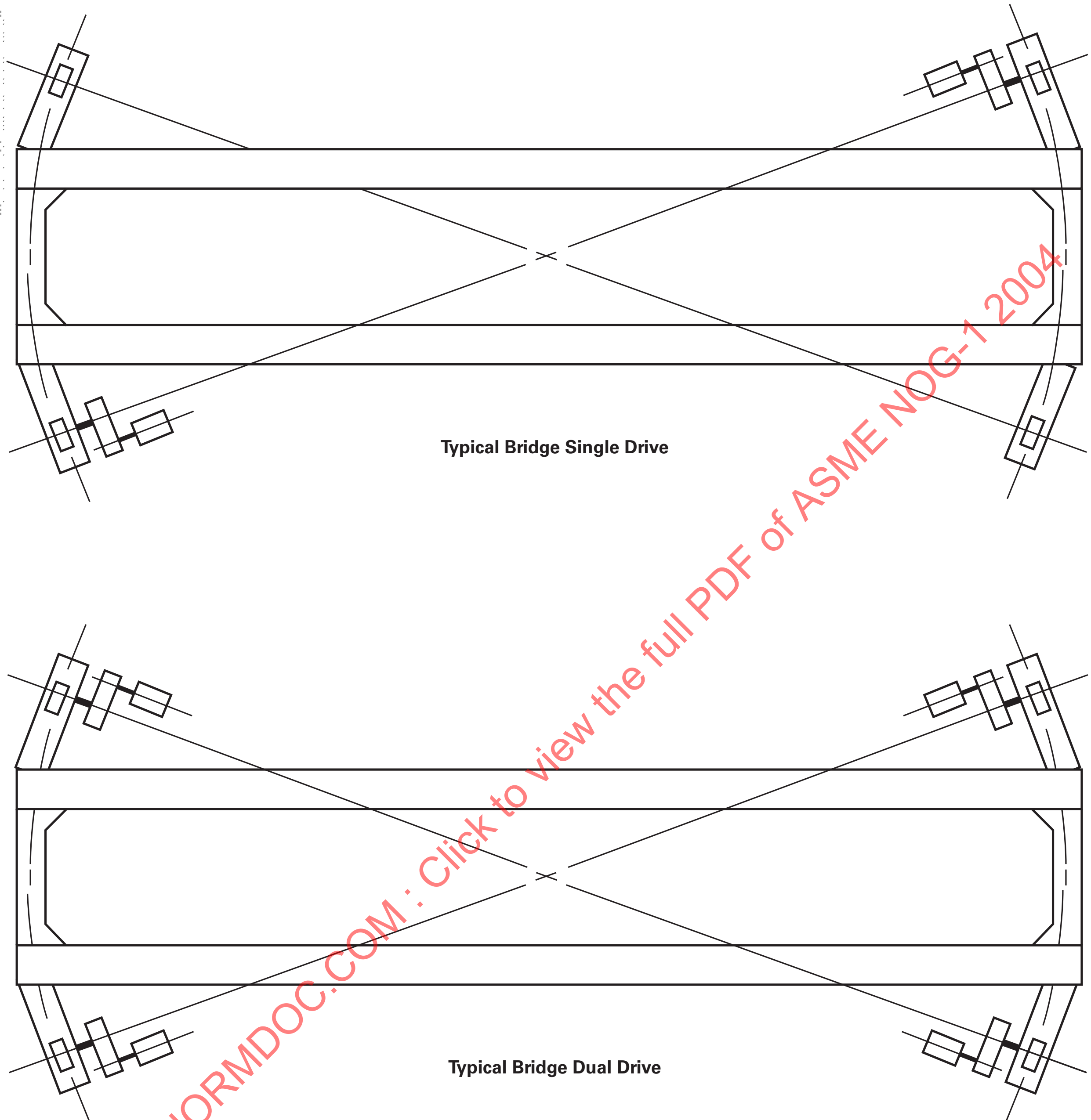


Fig. 5440(a)-2 Arrangement of Polar Cranes

5441.3 Ratings. If 60-min series wound motors are used, then special consideration shall be given to the short time torque ratings of such motors.

5442 Bridge Travel Gearing

5442.1 Type I Cranes. Bridge travel gearing shall be designed in accordance with para. 5413, except for the areas delineated in this Section. The actual horsepower imposed on the gearing shall be considered as the rated motor horsepower, at its normal time rating, unless 60-min series wound motors are used (see para. 5441.3).

5442.2 Types II and III Cranes. Gearing for bridge travels shall be established in accordance with the provisions of Specification CMAA 70.

5443 Bridge Brakes

5443.1 Type I Cranes

(a) Service Brakes. A bridge drive system shall be provided with a service braking means that may be satisfied by the parking brake, a separate control brake, or as part of the motor controls. Service brake requirements, brake sizes, and brake designs are specified under Section 6000.

(b) Emergency and Parking Brakes. Each primary bridge drive motor shall be provided with an emergency and a parking brake. Brake sizing and design are specified under Section 6000.

5443.2 Types II and III Cranes. Bridge brakes shall be in accordance with Specification CMAA 70.

5450 General Mechanical Components

5451 Couplings (Types I, II, and III Cranes)

5451.1 General

(a) Couplings connecting the motor(s) to the hoist and travel(s) shall be the flexible type. Grease lubricated couplings are preferred with gear types.

(b) Cross-shaft couplings, other than the flexible type, shall be steel as specified by the coupling manufacturer. The coupling (other than flexible) may be compression, sleeve, or flange type. Couplings shall be provided at each end truck and each side of the motor gear reducer. Additional couplings may be installed as necessary.

5451.2 Selection

(a) Coupling selection shall be based on the manufacturer's rating and applicable service factors for crane motions compared to the applied torque on the coupling, giving consideration to the following:

(1) motor output

(2) gear ratio

(3) efficiency of system

(4) wheel slippage with maximum operating wheel load (friction $= \mu = 0.2$)

(5) dynamic effects

(6) brake torque

(b) In no case do all of the loading conditions occur simultaneously, and consideration should be given to the applicable conditions, such as minimum wheel slippage or motor output torque.

5452 Wheels — Bridge and Trolley

5452.1 General. Unless other means of restricting lateral movement are provided, wheels shall be double flanged with treads accurately machined. Wheels may have either straight treads or tapered treads assembled with the large diameter toward the center of the span. Drive wheels shall be matched pairs within 0.001 in./in. of diameter, or a total of 0.010 in. on the diameter, whichever is smaller. When flangeless wheel and side roller assemblies are provided, they shall be of a type and design recommended by the crane manufacturer.

5452.2 Material. Wheels shall be rolled or forged from steel for Type I cranes. Types II and III cranes may have wheels cast of carbon or alloy steel. Wheel treads shall have a minimum surface hardness of 300 BHN.

5452.3 Loading. Wheels shall be designed to carry the maximum wheel load under normal conditions. The allowable maximum wheel load is determined by dividing the allowable wheel load in Table 5452.3-1 by the appropriate speed factor of Table 5452.3-2. The allowable wheel load shown in Table 5452.3-1 is that load produced with trolley handling the rated load in the position to produce the maximum load and shall be used for determining wheel sizes. Impact loading due to handling rated load is not included in the allowable wheel loads.

5452.4 Clearances

(a) Bridge Clearances. Wheel treads shall be a minimum of $^3/_4$ in. wider than the rail head for nontapered wheels.

(b) Trolley Clearances. Wheel treads shall be a minimum of $^3/_8$ in. wider than the rail head for nontapered wheels.

(c) Tapered Wheel Clearances. Tapered tread wheels may have a clearance over the rail head of 150% of the clearance provided for straight tread wheels, or as recommended by the crane manufacturer.

(d) Special Conditions for Wheel Clearances. Wheel tread clearances may be greater than those specified in Fig. 5452.4-1, if determined necessary to meet runway expansion requirements caused by excessive temperature and pressure. Refer to Section 1000. For guidance on wheel width and height, refer to Table 5452.4-1.

5452.5 Axle Fits. When rotating axles are used, wheels shall be mounted on the axle with a press fit alone or press fit and keys. All wheels shall have sufficient hub thickness to permit the use of keys.

5452.6 Overhung Wheels. Overhung wheels shall not be used.

Table 5452.3-1 Allowable Wheel Loads for Rim-Toughened Crane Wheels *P*, lb, for Speed Factor = 1

Wheel Diameter, in.	Rail Section						
	ASCE 30#	ASCE 40#	ASCE 60#	BETH & USS 104–105#	BETH & USS 135#	BETH & USS 175#	BETH 171#
8	11840	13930	. . .	. . .	. . .	. . .	. . .
9	13220	15670	21940	. . .	. . .	. . .	. . .
10	14800	17410	24370	. . .	. . .	. . .	. . .
12	17770	20890	29250	31340	. . .	. . .	. . .
15	22210	26110	36560	39170	. . .	. . .	. . .
18	26650	31340	43880	47010	56410	78350	87760
21	. . .	36560	51190	54850	65820	91410	102380
24	. . .	. . .	58500	62680	75220	104470	117010
27	. . .	. . .	. . .	70520	84620	117530	131640
30	. . .	. . .	. . .	78350	94020	130590	146260
36	. . .	. . .	. . .	. . .	112830	156710	175520
Effective rail width	1.063	1.250	1.750	1.875	2.250	3.125	3.500

GENERAL NOTES:

(a) allowable wheel load $P = KbD$

b = effective width rail head

D = diameter of wheel

(b) $K = 1300 \left(\dfrac{BHN}{260}\right)^{0.333} = 1393$

(c) BHN for rim-toughened wheels = 320

(d) allowable maximum wheel load $= \dfrac{\text{allowable wheel load}}{\text{speed factor}}$

Table 5452.3-2 Speed Factor for Determining Allowable Maximum Wheel Load

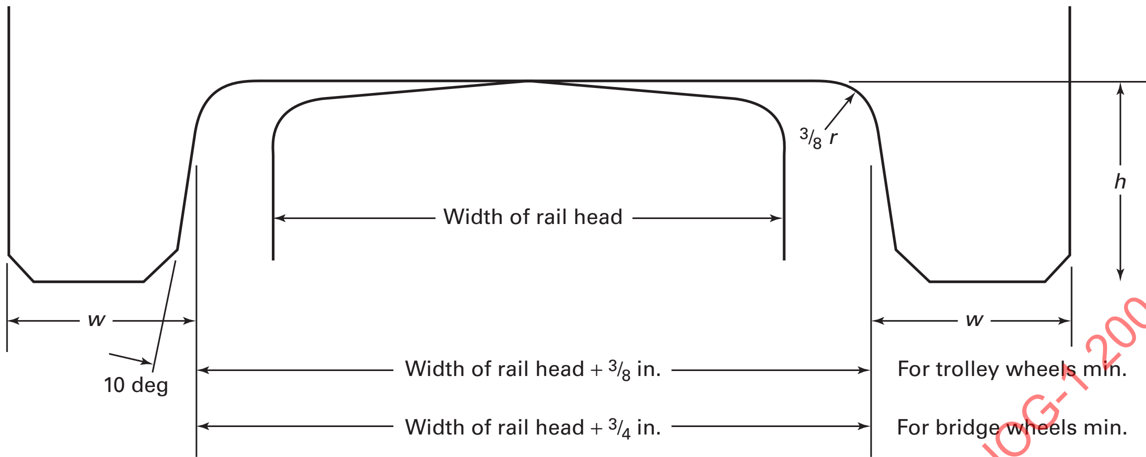
Wheel Diameter, in.	Travel Speed, ft/min												
	50	75	100	125	150	175	200	250	300	350	400	450	500
8	0.958	1.013	1.049	1.086	1.122	1.158	1.195	1.267	1.340	1.413	1.485	1.558	1.631
9	0.944	1.001	1.033	1.066	1.098	1.130	1.163	1.227	1.292	1.356	1.421	1.485	1.550
10	0.932	0.984	1.020	1.049	1.079	1.108	1.137	1.195	1.253	1.312	1.369	1.427	1.485
12	0.915	0.958	1.001	1.025	1.049	1.074	1.098	1.146	1.195	1.243	1.292	1.340	1.389
15	0.898	0.932	0.966	1.001	1.020	1.040	1.059	1.098	1.137	1.175	1.214	1.253	1.292
18	0.887	0.915	0.944	0.973	1.001	1.017	1.033	1.066	1.098	1.130	1.163	1.195	1.227
21	0.879	0.903	0.927	0.952	0.977	1.001	1.015	1.043	1.070	1.098	1.126	1.153	1.181
24	0.873	0.894	0.915	0.937	0.958	0.980	1.001	1.025	1.049	1.074	1.098	1.122	1.146
27	0.869	0.887	0.906	0.925	0.944	0.963	0.982	1.011	1.033	1.055	1.076	1.098	1.119
30	0.865	0.882	0.898	0.915	0.932	0.949	0.967	1.001	1.020	1.040	1.059	1.079	1.098
36	0.860	0.873	0.887	0.901	0.915	0.929	0.944	0.973	1.001	1.017	1.033	1.049	1.060

GENERAL NOTE:

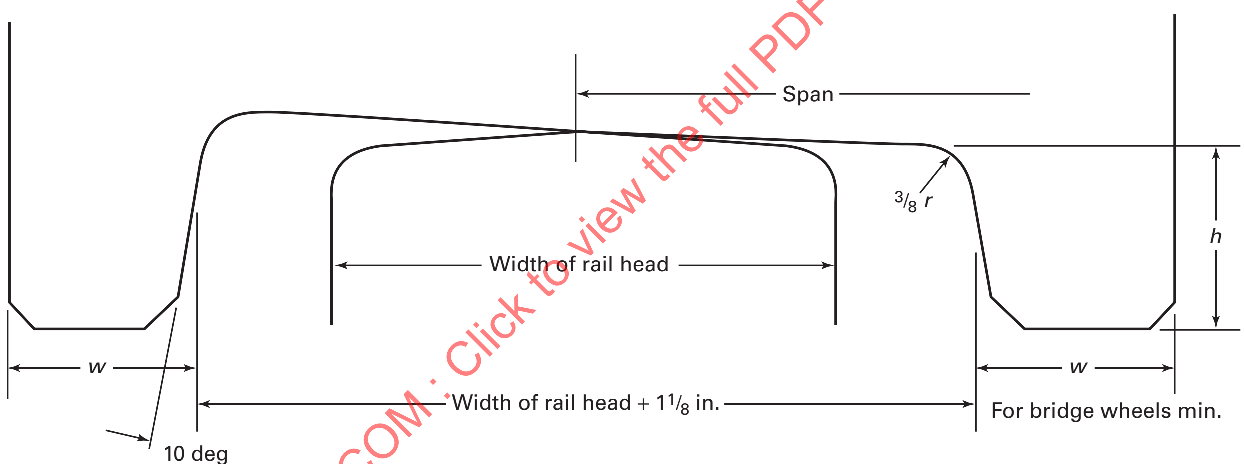
Speed factor determined by:

For rpm < 31.5: speed factor $= \left[1 + \left(\dfrac{\text{rpm} - 31.5}{360}\right)\right]^2$

For rpm ≥ 31.5: speed factor $= 1 + \left(\dfrac{\text{rpm} - 31.5}{328.5}\right)$



Straight Tread Wheels



Tapered Tread Wheels

Fig. 5452.4-1 Minimum Flange Widths and Heights

Table 5452.4-1 Guide for Wheel Flange Width and Height

Wheel Flange Width and Height	Wheel Diameter, in.										
	8	9	10	12	15	18	21	24	27	30	36
Flange width *w*, in.	5/8	5/8	5/8	3/4	3/4	7/8	7/8	1	1	1 1/8	1 1/4
Flange height *h*, in.	5/8	5/8	5/8	3/4	3/4	7/8	7/8	1	1	1	1

Table 5453.1(a)-1 Load Combinations – Bridge and Trolley Axles

Crane Type	Load Combination [Note (2)]	Type of Loading [Note (1)]: Maximum Wheel Load	Side Thrust	Output Torque	Slipping Torque	Brake Torque	Seismic	Allowable Stresses	Service Factor Minimum
Type I crane	1	X	X	X [Note (3)]	X [Note (3)]	. . .	. . .	0.2 ULT	1.0
	2	X	X	. . .	X [Note (3)]	X [Note (3)]	. . .	0.75 *Y*	1.0
	3	. . .	. . .	. . .	. . .	. . .	NA	. . .	. . .
Types II and III cranes	Per CMAA 70								

NOTES:
(1) Type of Loading:
Maximum Wheel Load: live load + dead load + impact load
Output Torque: motor rating (nameplate) x gear ratio x efficiency x factor for drive arrangement
Slipping Torque: maximum wheel load x 0.2 x diameter of wheel/2
Brake Torque: applicable percentage of rated motor torque
Side Thrust: force due to contact between wheel flange and side of rail head
Seismic: earthquake condition
Live Load: rated load
Dead Load: weight of crane (for bridge) or weight of trolley (for trolley)
(2) Load Combinations:
Load Combination 1 – normal operating.
Load Combination 2 – maximum overload-drive torque.
Load Combination 3 – seismic not applicable.
(3) Minimum value of either output, sliding, or braking torque.

5453 Axles — Bridge and Trolley

5453.1 General — Type I Cranes. Axles may be either of the fixed or rotating type.

(a) Load Combinations, Allowable Stresses, and Service Factors. The bridge and trolley axles shall be designed to resist the load combinations of Table 5453.1(a)-1 with corresponding values of allowable stresses and service factors.

(b) Computation — Analysis. Analytical stress computations shall be performed according to procedures in para. 5470.

5453.2 General — Type II Cranes. Axles shall be designed according to Specification CMAA 70.

5453.3 General — Type III Cranes. Axles shall be designed according to Specification CMAA 70.

5454 Drive Shafts — Bridge and Trolley

5454.1 General — Type I Cranes. Drive shafting shall be designed for the rated load maximum wheel load in combination with the required torque. The magnitude of the torque shall be based on the drive output torque, skid torque, or braking torque, whichever is limiting.

(a) Computation — Analysis. Analytical stress computations shall be performed according to procedures in para. 5470.

Table 5454.1(c)-1 Deflections

Type of Drive	Maximum Allowable Deflection, deg/ft	Motor Torque, %
A-1	0.080	67
A-2	0.080	50
A-3	0.080	67
A-4	0.070	100
A-5	0.080	50
A-6	0.070	100

(b) Service Factors. Service factors shall be applied according to para. 5320.

(c) Torsional Deflection. The torsional deflection of the cross-shafts and floating shafts shall not exceed the values, shown in Table 5454.1(c)-1. The types of drives referred to in this table are defined in para. 5440. The percent motor torque is the portion of the full-load torque of the drive motor(s) at its normal time rating for the service involved, increased by any gear reductions between the motor and the shaft. If 60-min series wound motors are used, short time rating torques should be considered. The allowable angular deflection is expressed in degrees per foot (deg/ft).

5454.2 General — Types II and III Cranes. Drive shafting shall be designed according to Specification CMAA 70.

5455 Bearings

5455.1 Antifriction Bearings (Type I Cranes)

(a) The type, size, and mounting of bearings shall be determined by criteria outlined in this Section. Computations confirming the adequacy of the bearing to meet the criteria shall be included as part of the crane analysis.

(b) Bearings with a calculable predicted life expectancy of a minimum of 5000 hr shall be selected.

(1) Bearing life expectancy shall be determined from the bearing manufacturer's published data or certified extension of published data.

(2) Bearing life expectancy shall be expressed as the number of hours of operation in which 90% of the bearings are expected to operate without failure.

(3) Analytical procedures may be based on L10 or B10, as defined by the AFBMA.

(4) Infrequent loads, such as impact or seismic, need not be considered in bearing life computation.

(5) Bearing life computations shall be based on the full rated speed except as exempted herein.

(a) Bearing life computations may be based on less than full rated speed only if confirmed by the load spectrum, unless otherwise specified by the purchaser.

(6) Bearing life computations shall be based on the following minimum percentages of maximum load and load combinations.

(a) Bridge drive bearings shall be computed using 75% of the maximum load, and shall be computed with no load acting against the wheel flange.

(b) Trolley drive and wheel bearings shall be computed using 65% of the maximum load, and shall be computed with no load acting against the wheel flange.

(c) Hoist bearings shall be computed using 65% of the full rated load.

(c) Bearings shall be selected to withstand the maximum forces that may be imposed.

(1) Bearing capability shall be determined from the manufacturer's published data or certified extension of published data.

(2) The basic static capacity of the bearing shall not be exceeded by load combinations as outlined herein.

(a) All bearings shall be sized to resist the maximum operating force which can be imposed by the driving motors.

(b) Wheel bearings shall be designed to resist forces due to the maximum wheel load.

(3) Loads imposed by the safe shutdown earthquake (SSE) shall not exceed 90% of the bearings' minimum fracture limit.

(d) Mounting fits and internal clearances shall be as recommended by the bearing manufacturer.

(e) All bearings shall be provided with proper lubrication or means of lubrication.

(f) Bearing enclosures shall be designed as far as practical to exclude dirt and prevent leakage of oil or grease.

(g) Assemblies shall be analyzed to confirm that deflection under load does not exceed that which the bearing can accommodate.

(h) Special consideration shall be given to bearings which operate at speeds above or below the manufacturer's published data. Certified confirmation of the bearing's capacity beyond published rating must be obtained from the manufacturer.

(i) For bearings of load blocks that are to be immersed:

(1) lubricants of these bearings shall be compatible with the chemistry of the liquid (refer to Section 1000 for special environmental conditions);

(2) provisions shall be made for relubricating the bearings once the block has been removed from the liquid.

5455.2 Antifriction Bearings (Types II and III Cranes)

(a) Refer to Specification CMAA 70.

(b) For bearings of load blocks that are to be immersed:

(1) lubricants of these bearings shall be compatible with the chemistry of the liquid (refer to section1000 for special environmental conditions);

(2) provisions shall be made for relubricating the bearings once the block has been removed from the liquid.

5455.3 Sleeve Bearings (Type I Cranes)

(a) Only bearings with published and/or certified properties shall be used.

(b) The PV (pressure velocity) rating of the bearing shall not be exceeded for any combination of operating loads.

(c) Forces induced by the SSE shall not exceed

90% of the allowable compressive strength of the bearing.

(d) All bearings shall be provided with proper lubrication or means of lubrication.

(e) Mounting fits and clearances shall be as recommended by the bearing manufacturer.

(f) Bearing enclosures shall be designed as far as practical to exclude dirt and prevent leakage of oil or grease.

5455.4 Sleeve Bearings (Types II and III Cranes). Refer to Specification CMAA 70.

5456 Fasteners — Mechanical Components

5456.1 Fastener Restraints

(a) Types I and II Cranes

(1) Fasteners shall not loosen under normal operating loads and vibration.

(2) Cranes which travel over the reactor pool or fuel pool shall use fasteners which do not depend upon lock washers unless they are so located as to be caught upon removal by drip pans or crane structure. For these cranes, when other than high-strength bolts are used, preferred locking methods are thread-upsetting fasteners, plastic insert fasteners, tack welding, cementing, or lock wire. High-strength bolts are considered restrained when torqued in accordance with the AISC method.

(b) Type III Cranes. Fasteners shall be in accordance with Specification CMAA 70.

5456.2 Allowable Stresses

(a) Types I and II Cranes. Maximum combined stresses induced in the fasteners by normal operating loads (but not including pretensioning loads) shall not exceed 20% of the ultimate strength of the fasteners. Limiting loads (such as seismic, stall torque, and load hang-up) shall induce combined stresses (not including pretensioning stresses) which do not exceed 90% of the yield strength of the fasteners.

(b) Type III Cranes. Maximum combined stresses induced in the fasteners by normal operating loads (not including pretensioning loads) shall not exceed 20% of the ultimate strength of the fasteners.

5456.3 Mounting of Machinery

(a) Types I and II Cranes

(1) Mounting surfaces for machinery (except for bridge) shall be machined for direct mounting or with allowance for shimming as dictated by the design.

(2) Single machinery elements 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.

(3) Machinery or machine parts whose alignment is important to its operation shall not depend on friction but shall use positive means such as dowel pins, shear bars, or fitted bolts to maintain alignment.

(4) Gear engagements shall be protected such that equipment deformation could not cause disengagement and drop the load.

(5) Machinery weights shall be increased by appropriate dynamic factors and analyzed by the static method to determine fastener mounting loads. Allowable stresses shall be in accordance with para. 5456.2.

(b) Type III Cranes

(1) Mounting surfaces for machinery (except for bridge cross-shafting) shall be machined for direct mounting or with allowable for shimming as dictated by the design.

(2) Single machinery elements 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.

(3) Machinery or machine parts whose alignment is important to its operation shall not depend on friction but shall use positive means such as dowel pins, shear bars, or fitted bolts to maintain alignment.

(4) Gear engagements shall be protected such that equipment deformation could not cause disengagement and drop the load.

5457 Gear Cases, Enclosures, and Guards

5457.1 Gear Cases (Type I Cranes)

(a) All gears except final reduction gears shall be completely enclosed in gear cases. All gear cases shall be oil-tight and sealed with compound or gaskets.

(b) Unless otherwise approved by the owner, the hoist motion gear case base shall be split in one plane through the bearing center lines above the oil level except in microdrives and worm drives.

(c) Openings when provided shall be provided in the top section for the inspection of gearing at mesh lines. Covers for these inspection holes shall be sealed to prevent leakage.

(d) Splash oil lubrication of bearings may be used unless otherwise specified.

(e) Oil pumps shall be used if vertical gearing exceeds two reductions. The oil level on horizontally arranged gearing shall be high enough to immerse the bottom portion of at least two gears.

(f) Solid oil seals should be selected to allow replacement with split seals, if possible.

(g) Easily accessible drain plugs and breathers shall be provided.

(h) All hoist gear cases shall be mounted on machined surfaces.

(i) Gear cases shall be provided with lugs or other means of lifting.

(j) Means for checking oil level shall be provided.

5457.2 Gear Cases (Types II and III Cranes). Gear cases shall be in accordance with Specification CMAA 70.

5457.3 Enclosures for Gears (Type I Cranes)

(a) All gears not enclosed in gear cases shall be provided with guarded enclosures. This is primarily for the final gear reduction at the hoist drum and travel motion drive wheels.

(b) All gear enclosures shall be designed to retain lubricant.

(c) Openings shall be provided in the top section for the inspection of the gearing at the mesh lines. Covers for these inspection holes shall be sealed to prevent leakage.

(d) Openings for shafts or other rotating parts such as drums shall be provided with means to retain the lubricant.

(e) Gear enclosures shall be provided with lugs or other means of lifting.

5457.4 Enclosures for Gears (Types II and III Cranes). Gear enclosures shall be in accordance with Specification CMAA 70.

5457.5 Guards for Moving Parts (Types I, II, and III Cranes)

(a) Exposed moving parts such as gears, set screws, projecting keys, chains, chain sprockets, and reciprocating components, which may constitute a hazard, shall be guarded.

(b) Guards shall be securely fastened.

(c) Each guard shall be capable of supporting the weight of a 200 lb person without permanent deformation, unless the guard is located where it is impossible for a person to step on it.

5457.6 Guards for Hoisting Ropes (Types I, II, and III Cranes)

(a) If hoisting ropes run near enough to other parts to make fouling or chafing possible under normal operating conditions, guards shall be installed to prevent this condition.

(b) A guard shall be provided to prevent contact between bridge or runway conductors and hoisting ropes if they can come into contact under normal operating conditions.

5458 Bumpers and Stops

5458.1 Bridge Bumpers (Type I Cranes)

(a) Bumpers shall be sized to limit impact and critical load excursions to facility acceptable magnitudes.

(b) A crane shall be provided with bumpers. These bumpers shall have the following minimum characteristics:

(1) energy absorbing (or dissipating) capacity to stop the crane when traveling with power off in either direction at a speed of at least 40% rated load speed (refer to para. 5459 on limit switches for limiting speed upon bumper impact);

(2) capable of stopping the crane (not including load block and lifted load unless guided vertically) at a rate of deceleration not to exceed an average of 3 ft/sec^2 when traveling with power off in either direction at 20% of rated load speed;

(3) mounted such that there is no direct shear on bolts upon impact.

(c) Bumpers shall be designed and installed to minimize parts falling from the crane in case of breakage or loosening of bolted connections.

(d) When more than one crane is located and operated on the same runway, bumpers shall be provided on their adjacent ends to meet the requirements stated above.

(e) Bumpers are not required on polar cranes unless limited rotation is desired.

5458.2 Bridge Bumpers (Types II and III Cranes). Bridge bumpers shall be in accordance with Specification CMAA 70.

5458.3 Trolley Bumpers (Type I Cranes)

(a) Bumpers shall be sized to limit impact and critical load excursions to facility acceptable magnitudes.

(b) A trolley shall be provided with bumpers. These bumpers shall have the following minimum characteristics:

(1) energy absorbing (or dissipating) capacity to stop the trolley when traveling with power off in either direction at a speed of at least 50% rated load speed (refer to para. 5459 on limit switches for limiting speed upon bumper impact);

(2) capable of stopping the trolley (not including load block and lifted load unless guided vertically) at a rate of deceleration not to exceed an average of 4.7 ft/sec^2 when traveling with power off in either direction at one-third of rated load speed;

(3) mounted such that there is no direct shear on bolts upon impact.

(c) Bumpers shall be designed and installed to minimize parts falling from the crane in case of breakage or loosening of bolted connections.

(d) When more than one trolley is located and operated on the same bridge, bumpers shall be provided on their adjacent ends to meet the requirements stated above.

5458.4 Trolley Bumpers (Types II and III Cranes). Trolley bumpers shall be in accordance with Specification CMAA 70.

5458.5 Trolley Stops (Type I Cranes)

(a) Stops shall be provided at the limits of travel of the trolley.

(b) Stops shall be designed to withstand the forces applied to the bumpers as specified in para. 5458.

(c) If a stop engages the tread of the wheel, it shall not be of a height less than the radius of the wheel. Stops engaging other parts of the crane are recommended.

(d) Stops shall be mounted such that there is no direct shear on the bolts upon impact.

5458.6 Trolley Stops (Types II and III Cranes). Trolley stops shall be in accordance with Specification CMAA 70.

5459 Limit Switches

5459.1 Limit Switches (Type I Cranes)

(a) Track type for bridge and trolley travel motion (see Section 6000 for application and function).

(b) Geared type for upper and lower travel hoist motion (see Section 6000 for application and function).

(c) Weight and paddle-operated type for upper travel hoist motion (see Section 6000 for application and function).

(d) A trolley track-type limit switch or other device shall be provided and positioned to ensure that, under operating conditions, the trolley speed cannot exceed 50% of rated load speed on engaging the trolley stops and bumpers.

(e) A bridge track-type limit switch or other device shall be provided and positioned to ensure that, under operating conditions, the bridge speed cannot exceed 40% of rated load speed on engaging the bridge stops and bumpers.

5459.2 Limit Switches (Types II and III Cranes). Limit switches shall be in accordance with Specification CMAA 70.

5459.3 Clearances. For determining clearances between the trolley structure and the load block in its high position, allowance shall be made for lift, trip, and drift as shown in Figs. 5459.3-1 and 5459.3-2.

5460 Lubrication

5461 Type I Cranes

(a) Sheave bearings shall be individually lubricated and accessible for lubrication from the trolley deck for the head block assembly and the operating floor for the load block assembly. Load blocks that are immersed in water shall have special provisions to prevent loss of lubricant to the water (refer to para. 1100).

(b) Hoisting ropes, except for stainless steel ropes (consult manufacturer), shall be lubricated. When ropes are immersed in water, the lubricant type shall be selected to reduce the loss of lubricant to the water.

(c) Lubricants for gears, bearings, and wire ropes shall resist effects of gamma or neutron radiation when such effects are present, or facilities shall be provided for changing of the lubricants.

(d) If lubricants cannot be conveniently changed, but are subjected to neutron or gamma radiation, then lubricants shall be NLGI Grade 0 oil containing molybdenum disulfate or NLGI Grade 1$^1/_2$ grease with sodium aluminate thickener. They shall be oxidation and rust inhibited with the exception of wire rope lubricants.

(e) Provisions shall be made to prevent lubricants falling from the crane.

(f) For all above paragraphs, refer to Section 1000.

5462 Types II and III Cranes. Lubrication shall be in accordance with Specification CMAA 70, unless the crane is subjected to radiation. If Types

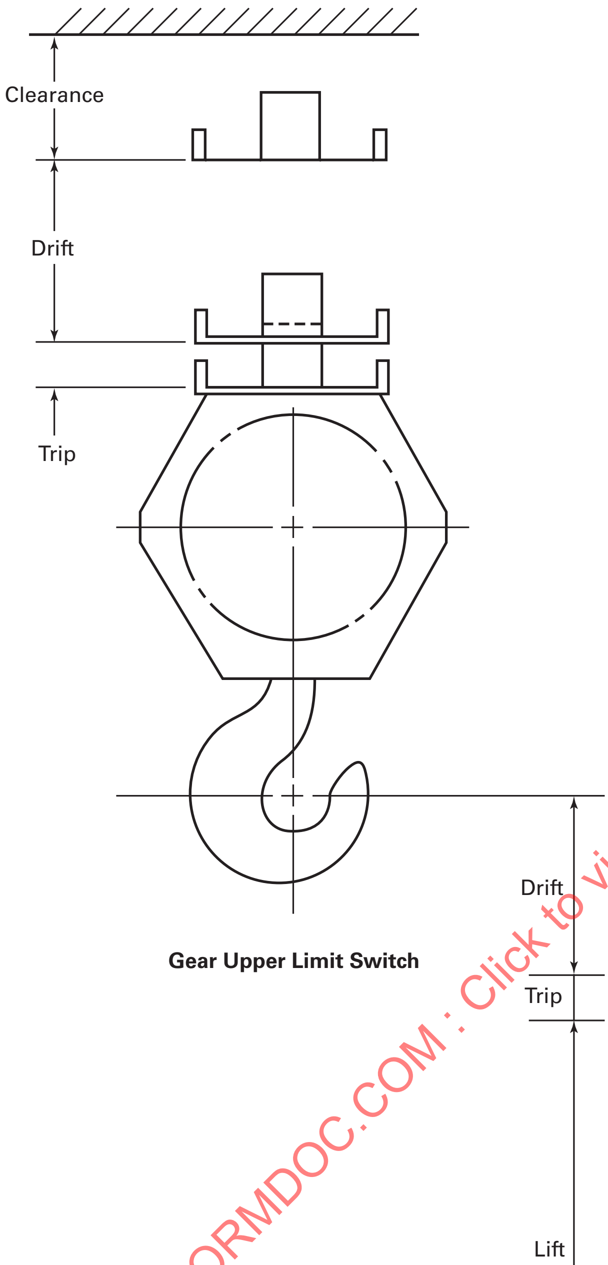


Fig. 5459.3-1
Power or Control Circuit Limit Switch With Geared Upper Limit Switch

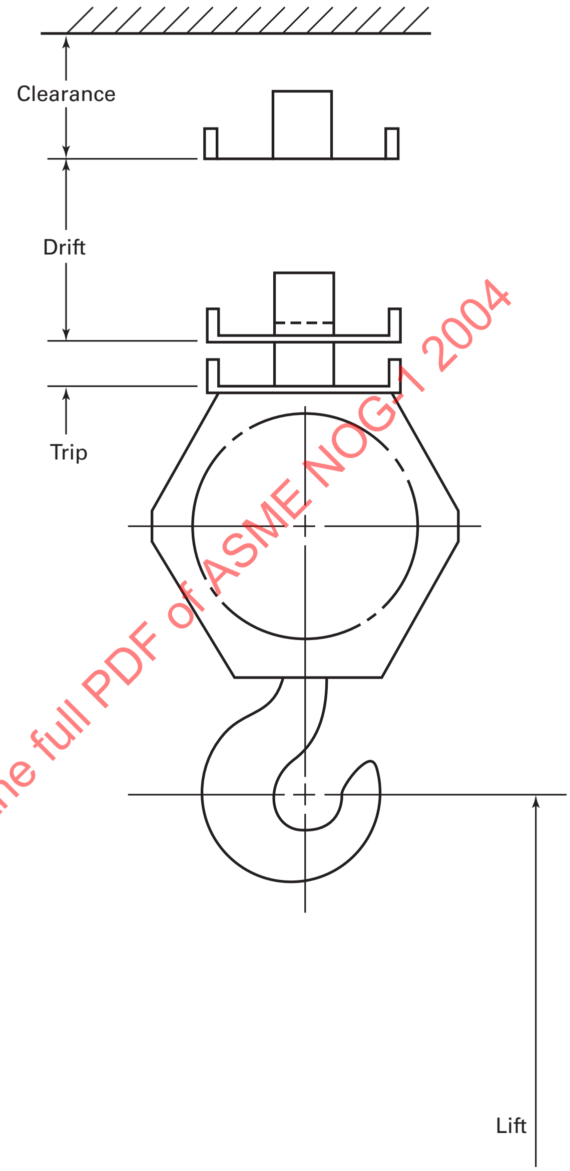


Fig. 5459.3-2
Power or Control Circuit Limit Switch

II and III cranes are subjected to radiation, then the provisions of para. 5461 apply.

5470 Analytical Procedures

It is the purpose of para. 5470 to apply common language for the terms, symbols, data, and formulas that apply most frequently in the process of mechanical crane engineering. The effects of service and stress concentrations are treated separately from the allowable stresses to conform with actual service conditions and actual design geometry.

(a) The basic stress formulas have been listed to achieve uniformity in recording and combining of design stresses throughout the industry. Where applicable, formulas and symbols shall be used as defined in this Standard. All other formulas and symbols used in design calculations shall conform as far as

possible to the method outlined and shown. The given data apply to low and medium carbon steel (usually used as hot rolled and normalized) and to heat treated alloy steel (usually used as quenched and tempered).

(b) Material strength properties have been treated on the basis of ultimate strength because it has a good relationship to the fatigue strength. No differentiation has been made between various materials because of the wide scatter of fatigue strength for each individual heat or each finished component. Heat treated alloy bar has, on the average, higher fatigue strength than medium carbon steel of the same ultimate tensile strength.

(c) Progressive fatigue failure represents the most common mode of failure in crane machinery. The design criteria of this Standard are, therefore, directed mainly to the prevention of accumulative damage to the material of mechanical crane components.

5471 Stress Concentration Factors (Type I Cranes)

(a) Stress concentration factors K_{NB}, K_{NS}, K_{NT} for shafting in bending, shear, and torsion may be obtained from Stress Concentration Factors by R. E. Peterson.[1] These factors shall give consideration to the effects on the fatigue strength of fillet radii, as well as keyways, combined with heavy press fits.

Stress concentration factors for all other forms of notches (such as lubrication holes, threads, grooves) as well as other modes of stressing must also be considered and may be obtained from *Stress Concentration Factors*.[1]

(b) A combination of stress concentration factors must take place when two or more stress concentrations superimpose in one location — for example, keyway and/or press fit extending in the critical region of a shaft fillet. The proper stress concentration factors K_{NB} or K_{NN} must be applied in calculating σ_X or σ_Y stresses, depending on whether σ_X or σ_Y are basically bending or tension–compression stresses. Stress concentration factors must be entered into calculation even if equal to 1.0.

5472 Nomenclature

(a) Symbols

A = effective cross-sectional area of critical section, in.^{2}
D = large diameter of a stepped shaft or round bar, in.
I = moment of inertia, in.^{4}
d = small diameter of a stepped shaft or round bar, in.
kip = 1000 lb.
ksi = kips per sq in.

(b) Equivalent Stress Factors

K_{EB} = for combining bending and shear stresses
K_{EN} = for combining tension–compression and shear stresses
K_{EXY} = for combining biaxial stress

(c) Stress Concentration Factors

K_{NB} = for bending
K_{NN} = for tension–compression
K_{NS} = for shear
K_{NT} = for torsion

(d) Service Factors

K_{SB} = for bending
K_{SN} = for tension–compression
K_{SS} = for shear
K_{ST} = for torsion

(e) Moments and Forces

M_B = bending moment, in.-kip
M_T = torsional moment, in.-kip
P = load (weight, force, or transverse shear load reaction), kips
Q = static moment about the neutral axis of the area of that portion of the component cross-section beyond the place where the shear stress is being calculated, in.^{3}
r = fillet radius, in.

(f) Stress Fluctuation Ratios

R_B = σ_B min./σ_B max. for bending
R_N = σ_N min./σ_N max. for tension–compression
R_S = T_S min./T_S max. for shear
R_T = T_T min./T_T max. for torsion

(g) Dimensions and Properties

S_B = section modulus, in.^{3}
S_T = polar section modulus, in.^{3}
t = thickness of component where stress is being calculated, in.
σ_{UT} = minimum ultimate tensile strength at mid-radius, ksi

[1] Peterson, R. E., Stress Concentration Factors, John Wiley & Sons, New York, NY, 1974.

(h) Maximum Allowable Stresses

σ_{BA} = for bending, ksi
σ_{NA} = for tension–compression, ksi
σ_{XA} = for stress about the X axis, ksi
σ_{YA} = for stress about the Y axis, ksi
T_A = for combined (equivalent) shear, ksi
T_{TA} = for torsional shear (equivalent torsional shear) stress

(i) Working Stresses

σ_B = bending stress, ksi
σ_{EB} = equivalent bending (bending and shear) stress, ksi
σ_{EBN} = equivalent bending (bending and tension–compression) stress, ksi
σ_{EN} = equivalent tension–compression (tension–compression and shear) stress, ksi
σ_{EXY} = equivalent biaxial stress, ksi
σ_{EXYT} = equivalent stress (biaxial and shear), ksi
σ_N = tension–compression stress, ksi
σ_X = normal stress about the X axis, ksi
σ_Y = normal stress about the Y axis, ksi
τ_{ET} = equivalent torsional shear stress, ksi
τ_{EXYT} = equivalent shear stress in X-Y plane including torsion, ksi
τ_S = shear stress, ksi
τ_T = torsional shear stress, ksi
τ_{XY} = shear stress in X-Y plane, ksi

5473 Working Stresses. The maximum working stresses in Class I crane machinery components shall not exceed the maximum allowable stresses σ_{BA}, σ_{NA}, σ_{XA}, σ_{YA}, τ_A, or τ_{TA} unless otherwise specified by the Purchaser. The working stresses (σ_B, σ_N, σ_{EBN}, σ_{EB}, σ_{EN}, σ_X, σ_Y, σ_{EXY}, σ_{EXYT}, τ_X, τ_T, τ_{ET}, τ_{XY} and σ_{EXYT}) are uniaxial, biaxial, shear, combined, or equivalent stresses, which are induced in a mechanical component by the working (operational) loads. The maximum working loads shall include dead loads, maximum live loads, and acceleration and deceleration forces which result from normal operation of the crane. The maximum calculated working stresses shall include both service and stress concentration factors.

5474 Allowable Stresses. The allowable stresses σ_{BA}, σ_{NA}, τ_A, and τ_{TA}, which shall be obtained from Figs. 5474-1 through 5474-3, vary with the minimum ultimate tensile strength σ_{UT} of the material in use, as well as with the fluctuation ratios R_B, R_N, R_S, R_T of the working stresses. σ_{XA} and σ_{YA} shall be selected from Figs. 5474-1 or Fig. 5474-2, depending upon whether σ_X or σ_Y are basically bending or tension–compression stresses. τ_{TA} shall be selected directly from Fig. 5474-3.

5475 Service Factors. Service factors K_{SB}, K_{SN}, K_{SS}, and K_{ST} are to be based on para. 5320. Not all components within a crane drive system are necessarily subjected to the same service. Service factors shall give consideration to the following:

(a) risk and consequences of potential failure;

(b) indeterminate load reactions (for example, trolley with rigid frame supported on four track wheels);

(c) unpredictability of operation conditions — for example, unexpected accidents within the building;

(d) dynamic effects — for example, impacts in hoist mechanisms and seismic effects.

5476 Basic Stress Equations

(a) Where applicable, Eqs. (13) through (27) must be used in determining basic stresses in crane machinery components. For determining size of machinery components, maximum working (operational) moments and shear loads, as well as critical section moduli, must be entered into these formulas.

(b) Sign convention must be observed when entering σ_X and σ_Y in Eqs. (25), (26), and (27). (Tension is positive, compression is negative.)

(c) Only stresses which do occur simultaneously at the location where stress is being calculated should be combined.

(d) In Eqs. (19) through (27), anisotropy and stress fluctuation have been given consideration in a simplified manner for easier use in the design engineering process.

(e) For sample calculation, refer to Nonmandatory Appendix B, para. B5476.

(f) The following are the basic stress equations:

$$\sigma_B = \left(\frac{M_B}{S_B}\right)(K_{SB})(K_{NB}) \le \sigma_{BA}, \text{ ksi} \quad (13)$$

$$\sigma_N = \left(\frac{P}{A}\right)(K_{SN})(K_{NN}) \le \sigma_{NA}, \text{ ksi} \quad (14)$$

$$\sigma_{EBN} = \sigma_B + \left[\left(\frac{\sigma_{BA}}{\sigma_{NA}}\right)(\sigma_N)\right] \le \sigma_{BA}, \text{ ksi} \quad (15)$$

$$\tau_S = \left(\frac{Q}{I}\right)\left(\frac{P}{t}\right)(K_{SS})(K_{NS}) \le \tau_{NA}, \text{ ksi} \quad (16)$$

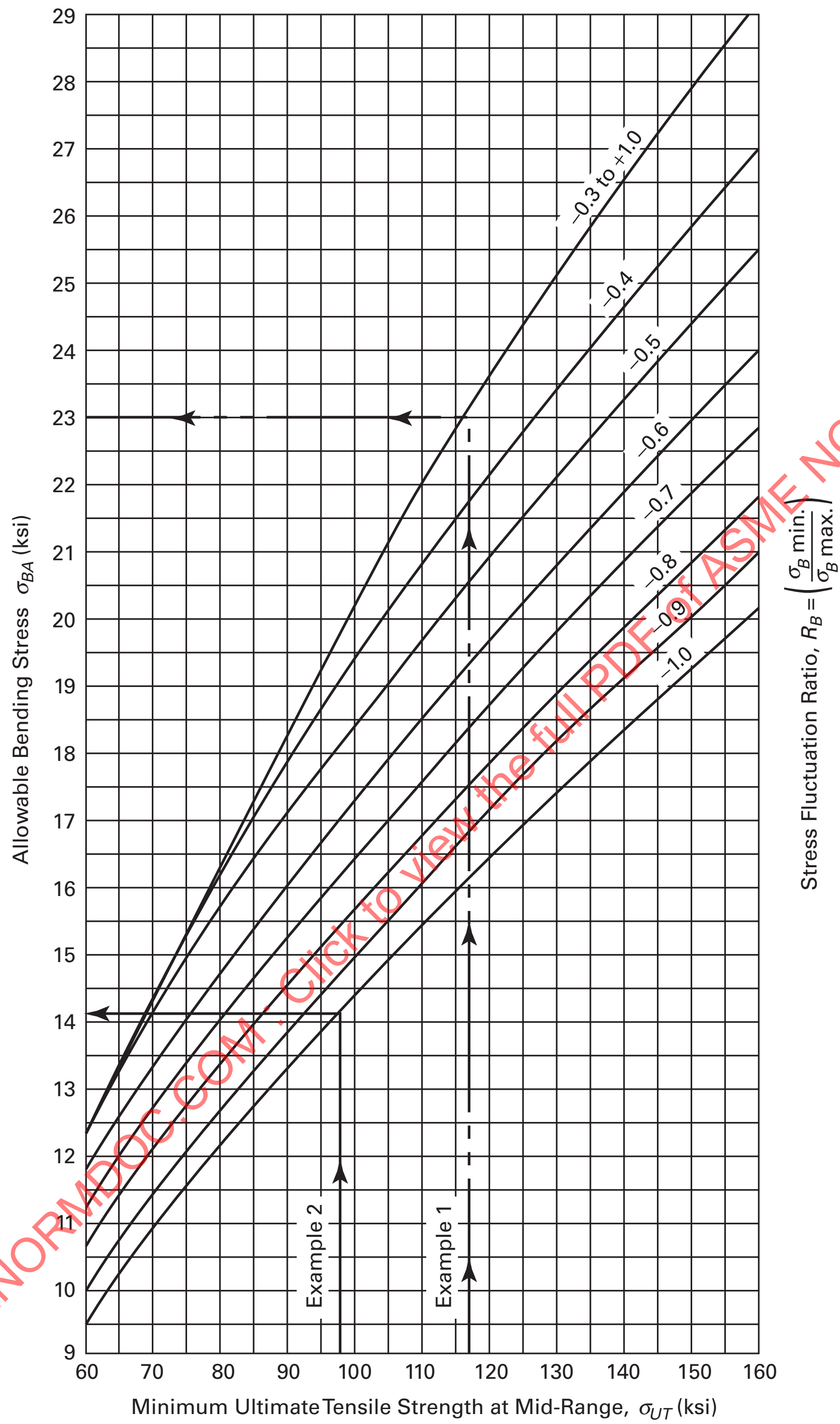


Fig. 5474-1 Allowable Bending Stress

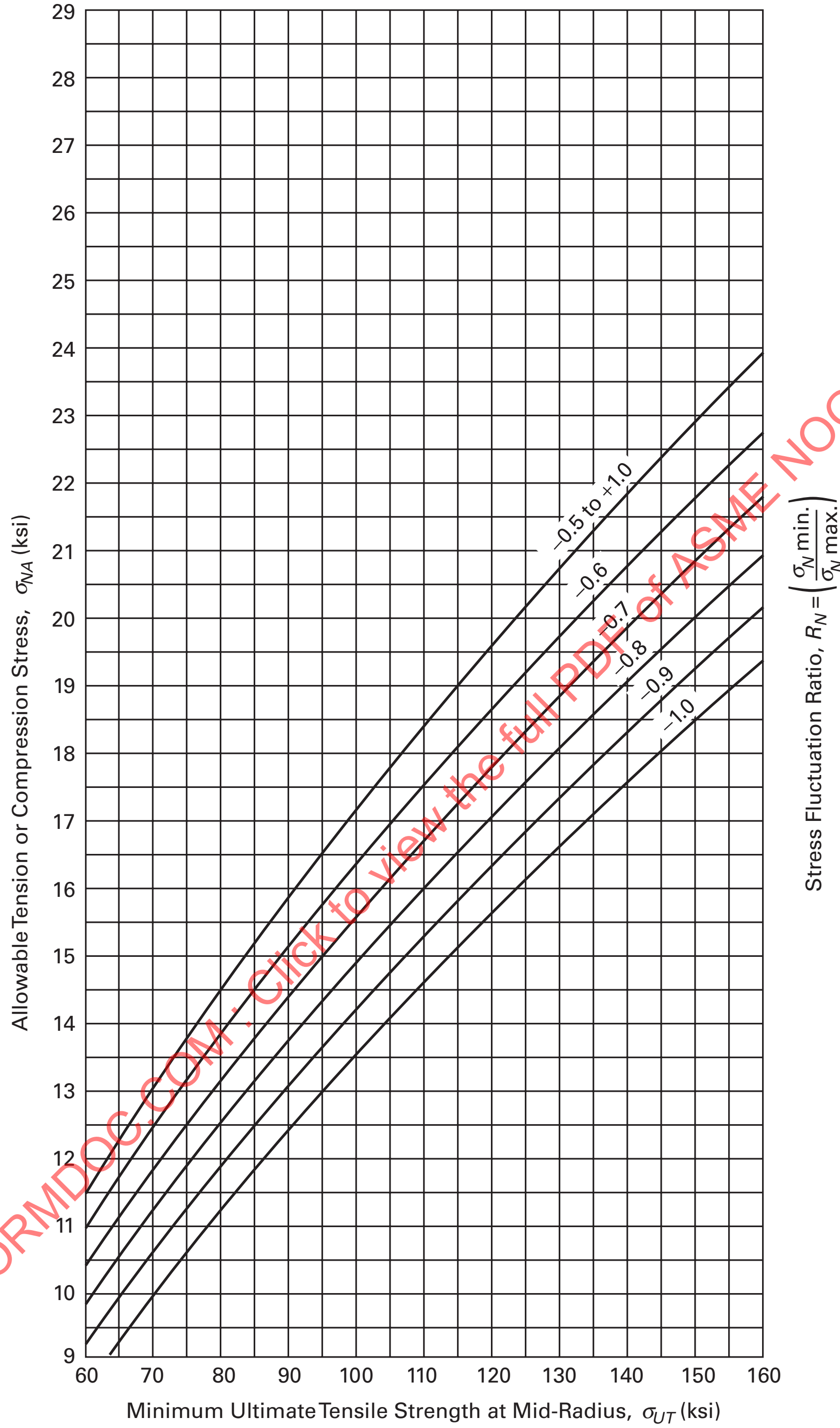


Fig. 5474-2 Allowable Tension or Compression Stress

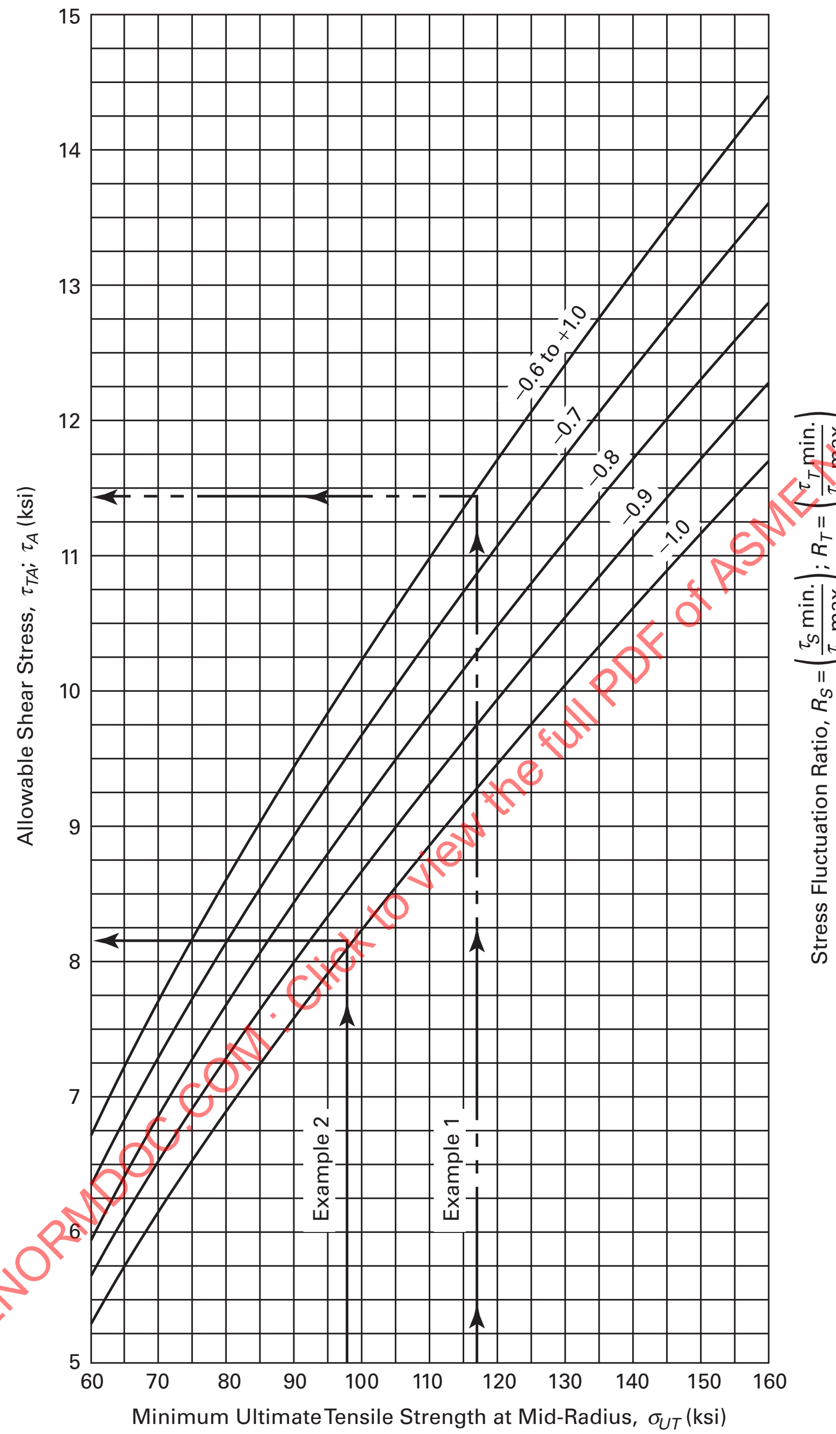


Fig. 5474-3 Allowable Shear Stress

$$\tau_S = \left(\frac{1.33P}{A}\right)(K_{SS})(K_{NS}) \le \tau_A, \text{ ksi} \qquad (17)$$[2]

$$\tau_T = \left(\frac{M_T}{S_T}\right)(K_{ST})(K_{NT}) \le \tau_{TA}, \text{ ksi} \qquad (18)$$

$$\tau_{ET} = \tau_T + \left(\frac{\tau_{TA}}{\tau_A}\right)(\tau_{XY}), \text{ ksi} \qquad (19)$$

$$\tau_{EXYT} = \tau_T + \left[\left(\frac{\tau_{TA}}{\tau_{XYA}}\right)(\tau_{XY})\right] \le \tau_{TA}, \text{ ksi} \qquad (20)$$

$$\sigma_{EB} = \left(\sigma_B^2 + \left[\left(\frac{\sigma_{BA}}{\tau_{TA}}\right)^2(\tau_{ET}^2)\right]\right)^{1/2} \qquad (21)$$

$$\sigma_{EB} = (\sigma_B)(K_{EB}) \le \tau_{BA}, \text{ ksi} \qquad (22)$$

$$\sigma_{EN} = \left(\sigma_N^2 + \left[\left(\frac{\sigma_{NA}}{\tau_{TA}}\right)^2(\tau_{ET}^2)\right]\right)^{1/2} \qquad (23)$$

$$\sigma_{EN} = \sigma_N K_{EN} = \le \sigma_{NA}, \text{ ksi} \qquad (24)$$

$$\sigma_{EXY} = \left(\sigma_x^2 + \left[(\sigma_y^2)\left(\frac{\sigma_{XA}}{\sigma_{YA}}\right)^2 - (\sigma_X)\left(\frac{\sigma_{XA}}{\sigma_{YA}}\right)(\sigma_y)\right]\right)^{1/2} \le XA, \text{ ksi} \qquad (25)$$

$$\sigma_{EXYT} = (\sigma_X)(K_{EXY}) \le \sigma_{XA}, \text{ ksi} \qquad (26)$$

$$\sigma_{EXYT} = \left(\sigma_x^2 + \left[(\sigma_y^2)\left(\frac{\sigma_{XA}}{\sigma_{YA}}\right)^2\right] - \left[(\sigma_X)\left(\frac{\sigma_{XA}}{\sigma_{YA}}\right)(\sigma_Y)\right] + \left[\left(\frac{\sigma_{XA}}{\tau_{TA}}\right)^2(\tau_{EXYT})^2\right]\right)^{1/2} \qquad (27)$$

5477 Analytical Method for Hook of Approximate Trapezoidal Shape (Types I, II, and III Cranes)

(04) *(a) Method of Analysis.* The analytical method given in this section is intended to apply to hooks with cross-sections having a shape as shown by the full line of Fig. 5477-1, which does not deviate significantly from a trapezoidal form. This includes a large number of practical crane-hook sections, such as shown in Fig. 5477-2. This method, while approximate, is much faster than the numerical integration method, and, in the cases to which it has been applied, it has given close agreement with the latter method.

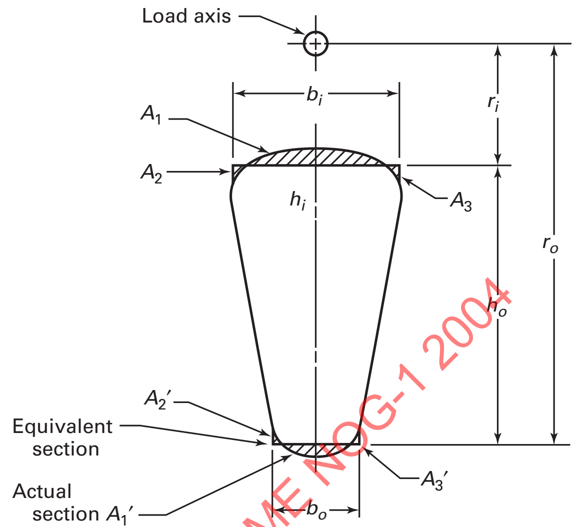


Fig. 5477-1 Typical Hook Cross-Section

Essentially, the analytical method is based on the assumption of an equivalent trapezoidal section having an area equal to that of the actual section. The stress computed in this way is then corrected for the stress increase in the neutral section resulting from the fact that the fibers nearest the center of curvature are farther from the neutral axis than in the case of the equivalent trapezoidal section. It is assumed that the resultant load on the hook passes through the center of curvature of the curved part and that the critical section is at 90 deg to the resultant load.

In Fig. 5477-1, the full lines represent the actual hook section, and the dashed lines the equivalent trapezoidal section. The equivalent section is so chosen that the shaded area A_1 is equal to the areas $A_2 + A_3$. Likewise, $A'_1 = A'_2 + A'_3$. In Fig. 5477-3, the distribution of stress over the section due to bending alone is indicated. It should be noted that the stress S_b calculated from Eq. (28) yields the bending stress at point *A* at the inside of the equivalent trapezoid. Because of its greater distance from the neutral axis, the bending stress at point *B* in

[2] Timoshenko, S., *Strength of Materials*, Second Edition, Part 2, D. Van Nostrand Co., New York, NY, 1941, p. 65.

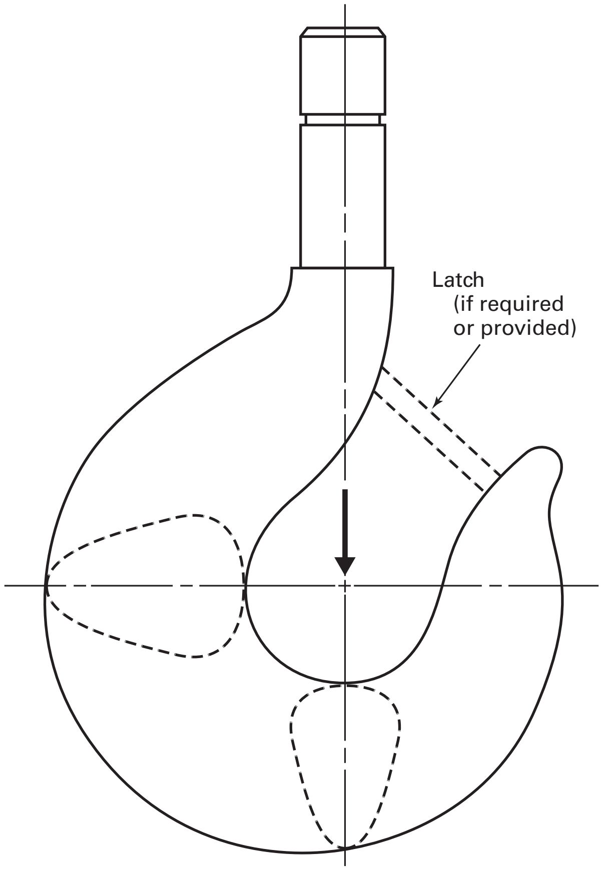


Fig. 5477-2 Fish Hook Configuration

the actual hook will be appreciably larger than that at point A by an amount S_c, as shown. If l is the distance between the points B and A, then the stress augment S_o will be given approximately by

$$S_o = (l_1)\left(\frac{ds}{dy}\right)_o \tag{28}$$

where $(ds/dy)_o$ is the value (at point A, Fig. 5477-3) of the derivative of the stress S with respect to distance y from the neutral axis. From the equations of curved-bar theory, the derivative (ds/dy) may be obtained, and by substitution in Eq. (28) using the previous notations, the stress augment S_o becomes

$$S_o = \frac{S_b K_2 l_1}{(r_i)\left(K_2 - \frac{1}{\beta - 1}\right)} \tag{29}$$

where K_2 is given by Eq. (37).

The stress due to direct tension is:

$$S_1 = P/A \tag{30}$$

where A is the area of the cross-section.

$$A = \frac{h_o\,(b_o + b_i)}{2} \tag{31}$$

where h_o = depth of equivalent trapezoid (Fig. 5477-1).

The maximum stress S_{max} in the hook at the critical section will be the sum of the bending stress S_b [Eq. (35)], the stress augment S_o [Eq. (29)], and the direct tension stress S_1 [Eq. (30)]. This gives:

$$S_{max} = S_b + S_o + S_1 \tag{32}$$

For Fig. 5477-1, let

b_i, b_o = inside and outside widths of equivalent trapezoid, respectively

r_i, r_o = inside and outside radii of equivalent trapezoid, respectively

$$\alpha = b_o/b_i \tag{33}$$

$$\beta = r_o/r_i \tag{34}$$

With these notations, the formulas for bending stress S_b at point A, Fig. 5477-3, at the inside of the trapezoidal section as derived from curved-bar theory becomes

$$S_b = \frac{2\,PK_1\left(K_2 - \frac{1}{\beta - 1}\right)}{b_i r_i\,(1 + \alpha)\,(K_1 - K_2)} \tag{35}$$

where

$$K_1 = \frac{1}{\beta - 1} + \frac{2\alpha + 1}{3\,(\alpha + 1)} \tag{36}$$

$$K_2 = \frac{(1/2)\,(1 + \alpha)}{\left[\frac{(\beta - \alpha)}{(\beta - 1)} \ln \beta\right] - (1 - \alpha)} \tag{37}$$

In general, the factors K_1 and K_2 should be calculated to at least four significant figures. For a sample calculation, see Nonmandatory Appendix B, para. B-5477.

(b) The method of analysis and design of a sister hook shall be made using the straight beam configuration for the hook.

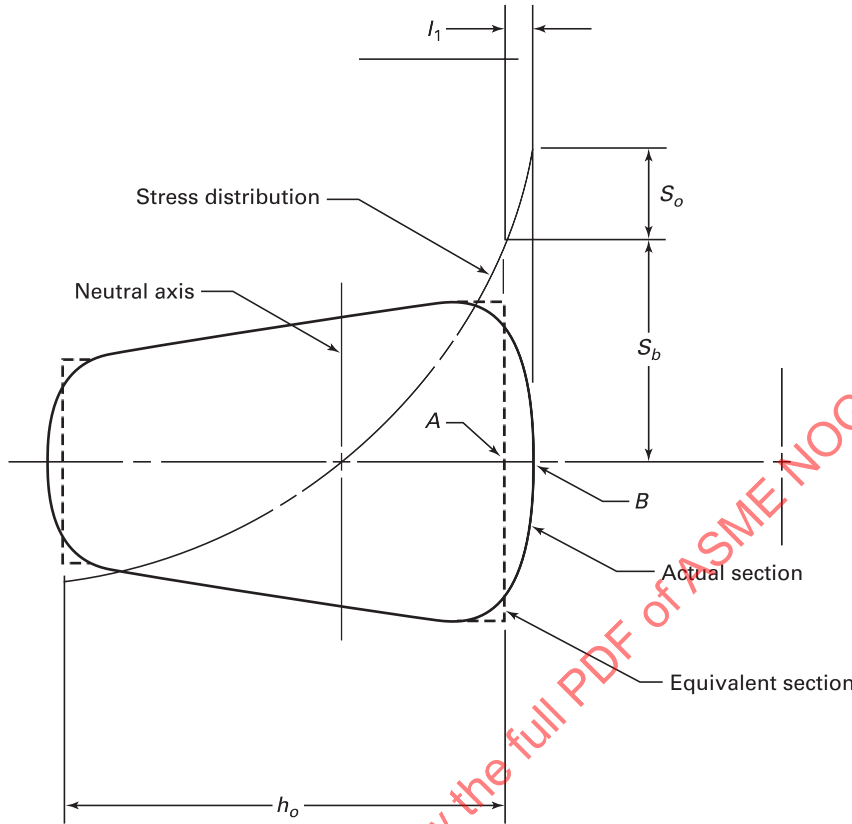


Fig. 5477-3 Equivalent Section

(1) Figure 5477-4 shows the general outline and a shade of a sister hook without a pin hole.

(2) Figure 5477-5 shows the general outline and shape of a sister hook with a pin hole.

(c) References for para. 5477

(1) Strength of Materials, S. Timoshenko, Second Edition, Part 2, D. Van Nostrand Co., New York, NY, 1941, p. 65.

(2) Stresses in Curved Bars, H. C. Perkins, Transactions of ASME, Vol. 53, 1931, p. 201.

(3) Mathematical Methods in Engineering, Thomas von Karman and M. A. Biot, McGraw-Hill Book Co., 1940, p. 5.

(4) Stress Concentration Factors, R. E. Peterson, John Wiley & Sons, New York, NY, 1974.

5480 Seismic Analysis

5481 Type I Cranes

(a) Analysis confirming that the critical load will not be dropped as a result of the forces generated by seismic events shall be performed (see Section 4000).

(1) The analysis may be static if it includes loads equivalent to those which would be imposed by the seismic event specified.

(2) Loads due to vertical and horizontal motions shall act together and shall be combined in accordance with para. 4100.

(3) All elements which support the critical load shall be analyzed as follows and should not consider material fatiguing, stress concentration factors, and infinite life criteria.

(a) The stress level at all critical points shall be determined.

(b) The gross cross-section shall be used in determining the stress level.

(c) The maximum stress level shall not exceed 90% of the yield strength of the material.

(4) All computations are to be based on the bulk cross-section of the material without consideration to any fatiguing effects of stress risers, or to the endurance limits of the material. The seismic forces according to the rules in para. 5300 are to be algebrai-

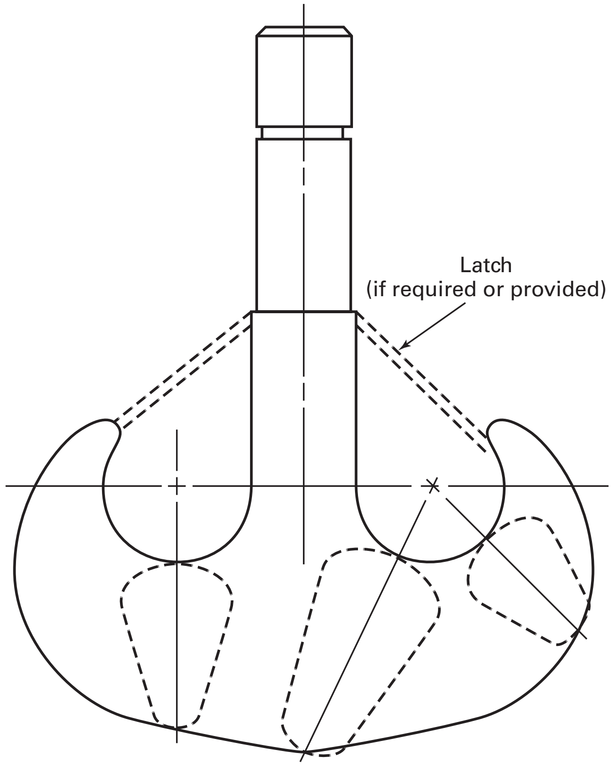


**Fig. 5477-4
Sister Hook Without a Pinhole**

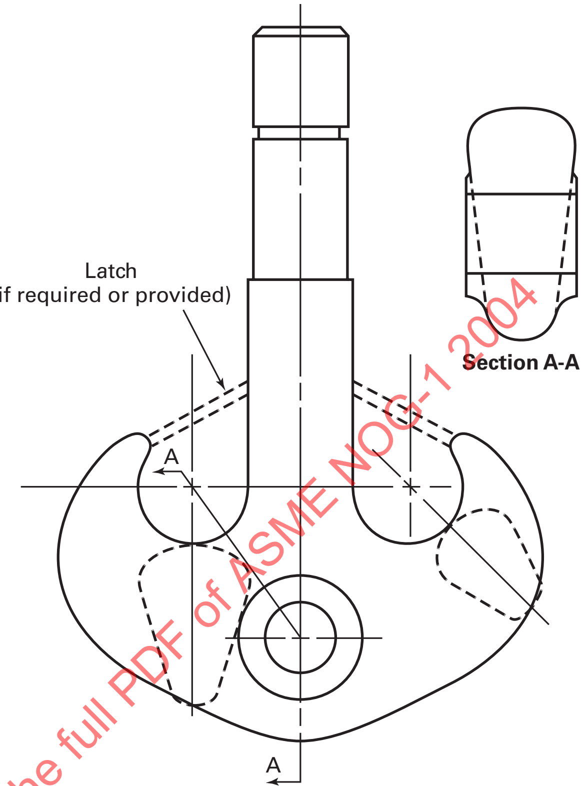


Fig. 5477-5 Sister Hook With a Pinhole

cally added to the forces and torques under normal operation.

(b) Analysis shall be performed to confirm that those components which would damage safety related equipment if dropped will remain in place during the seismic event.

(c) Components whose major resonant frequency is greater than 30 Hz may be analyzed as a lumped mass.

(1) 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.

(2) Loads shall be combined as in (a)(2) above.

(d) Components whose major resonant frequency is less than 30 Hz shall be analyzed dynamically.

5482 Type II Cranes

(a) Analysis shall be performed to confirm that those components which would damage safety related equipment if dropped will remain in place during the seismic event.

(b) Such components shall be delineated by the bidding documents.

(c) Analysis shall be as listed in para. 5481.

5483 Type III Cranes. Seismic analysis is not required unless specified by the purchaser.

5500 MISCELLANEOUS

5510 Pendant Hoist and Travel Drives (Types I, II, and III Cranes)

5511 Crane Pendant Mounting. The crane purchaser shall prescribe whether pendant control stations, if furnished, are to be mounted from the trolley frame, fixed positions on the bridge, or a messenger trace on the bridge. The purchaser shall also prescribe whether the crane is to be pendant controlled from several elevations in the building. Whenever possible, the pendant should be suspended in a manner that minimizes undue strains on the electrical conductor cable. A chain or wire rope strain relief should be provided, unless the pendant is suspended directly from a motorized cable reel.

5512 Messenger Track System

(a) The track itself should consist of a commercially available profile section, such as a rolled I-beam or an extrusion. A guide wire arrangement commonly known as a Tag-Line System shall be unacceptable for Type I cranes.

(b) Messenger trolleys shall be compatible with the track and shall be of sufficient load carrying capacity to suspend the combined weights of the pendant, cables, and accessories, as well as the pull which could be developed while maneuvering the control station. Messenger trolley rollers shall be mounted on sealed antifriction bearings and shall be provided with lubrication fittings unless bearings are lubricated for life. Individual messenger trolleys should be interconnected by strain relief chains or cables to reduce strains on the electrical control cables when traversing.

5513 Motorized Traversing. The crane purchaser shall prescribe whether pendant traversing is required. If furnished, the traversing tractor shall be controlled from the pendant station. If cable reels are suspended from a messenger track, consideration should be given to a motorized traversing system. Consideration should also be given to ensure that the pendant station is accessible to the operator after it has been lifted or lowered by a reel.

5514 Vertical Travel of Control Pendant. In cases where pendant crane control is required from several elevations, the purchaser shall specify such requirements. Methods of raising and lowering the pendant shall be determined and specified by the purchaser, depending on prevailing conditions. Commonly used and readily available lifting and lowering devices consist of spring-operated load balancing reels, or motorized cable reels. In cases where motorized cable reels are used, the pendant shall be suspended directly from the electrical cable, without a strain relief rope.

5515 Speeds. For pendant hoist and travel speeds, refer to para. 5334.

5520 Load Weighing Devices (Types I, II, and III Hoists)

(a) Load weighing devices for a hoist unit shall be provided if requested by the purchaser.

(b) Weighing accuracy, location and type of readout, and increments of the readout shall be specified by the purchaser.

(c) Refer to Section 6000 for overload devices.

5530 Welded Construction

5531 Type I Cranes. All welding design and procedures shall conform to the current issue of AWS D1.1. Where special steels or other materials are used, the manufacturer shall provide welding procedures.

5532 Types II and III Cranes. Welding shall be in accordance with Specification CMAA 70.

5540 Hydraulics (Types I, II, and III Cranes)

(a) Hydraulic components and fluids shall be selected to withstand maximum facility lifetime radiation exposure, unless a detailed maintenance program shall be supplied.

(b) Critical loads or facility equipment shall be protected from leakage.

(c) Commercial industrial hydraulic components in the critical load path shall be selected and rated to not exceed 20% of the average ultimate strength of the material.

5550 Ordering Information

Orders for cranes under this Standard shall include the following information.

(a) Load Spectrum Information. Refer to para. 5111(a).

(b) Seismic Consideration for Type III Cranes, If Required. Refer to para. 5310(b)(3).

(c) Hoist Speeds. Refer to para. 5331.1(a).

(d) Trolley Speeds. Refer to para. 5332.1(a).

(e) Bridge Speeds. Refer to para. 5333.1(a).

(f) Powered Hook Rotation. Refer to paras. 5335(a) and (b).

(g) Bearing Life Computations. Refer to para. 5455.1(b)(5)(a).

(h) Seismic Analysis for Type III Cranes, If Required. Refer to para. 5483.

(i) Crane Pendant Mounting. Refer to para. 5511.

(j) Motorized Traversing. Refer to para. 5513.

(k) Vertical Travel of Control Pendant. Refer to para. 5514.

(l) Loading Weighing Devices. Refer to paras. 5520(a) and (b).

Section 6000
Electrical Components

6100 GENERAL

(a) The specification for each crane shall state which crane classification applies (para. 1130). Types are summarized from para. 1150 as follows:

(1) Type I Cranes: single failure-proof features and seismic considerations;

(2) Type II Cranes: seismic considerations only;

(3) Type III Cranes: neither single failure-proof features nor seismic considerations.

(b) The specifications for each crane shall include any special requirements for components in accordance with the following:

(1) limiting the use of aluminum, zinc, mercury, and other specified materials (para. 6130);

(2) painting (para. 6140);

(3) life at specified values of radiation exposure (para. 6150);

(4) environmental conditions (para. 6160);

(5) quality assurance (para. 6170).

(c) Generally available equipment which conforms to industry standards, such as those of NEMA, shall be used unless special designs are necessary.

(d) The electrical equipment is not required to qualify as IEEE 323 Class 1E.

(e) The specification for each Type III crane shall state whether Section 6000 or CMAA 70 is to be invoked for electrical components.

6110 Single Failure-Proof Features (Type I Cranes)

(a) The electrical system shall be designed so that it is possible for the operator to stop and hold a critical load regardless of the failure of any single component used in normal operation.

(b) There shall be means at the operator's location that will allow him to remove power from all drive motors and brakes by opening or de-energizing a power device that is not required to close and open during normal ''run-stop'' operations.

(c) Any inadvertent short circuit or ground shall be considered a single component failure.

(d) The avoidance of two-blocking shall be accomplished by the use of single failure-proof features and shall not rely on any action by the operator. The normal hoist limit switch shall be supplemented by an independent final hoist limit switch operated by the load block to remove power from the hoist motor and brakes.

6120 Seismic Considerations (Types I, II, and III Cranes)

(a) Type I Cranes. The user shall provide the equipment that shall de-energize the crane power supply in the event of either a Safe Shutdown Earthquake (SSE) or an Operational Basis Earthquake (OBE). The hoist brakes shall be capable of holding the credible load during an SSE or OBE event, as determined in accordance with para. 6422.1(b). All electrical equipment shall remain on the crane during these seismic events.

(b) Type II Cranes. Requirements are the same as for Type I cranes, except that the brakes need not be capable of holding the load during a seismic event.

(c) Type III Cranes. Seismic considerations are not required for Type III cranes.

6130 Limiting the Use of Specified Materials (Types I, II, and III Cranes)

(a) If the crane specifications require that the content of certain specified materials for use on a crane be kept at a minimum [para. 1145(a)], but it is not practical to eliminate these specified materials completely, the electrical supplier shall tabulate their weight or surface area or the content of an alloy under the following categories:

(1) exposed, as in the head of a master switch;

(2) bare, within a ventilated enclosure, as in the shaft fan and rotor bars of a ventilated squirrel cage motor;

(3) bare, within a nonventilated enclosure, as in a totally enclosed nonventilated squirrel cage motor;

(4) covered, as in insulated windings within a

nonventilated motor, lighting transformer, reactor, etc.

(b) Galvanized conduit may be used except when specifically prohibited by the crane specifications.

6140 Painting (Types I, II, and III Cranes)

When the crane specifications include special painting requirements, the electrical items are exempt from the special painting requirements and shall be furnished with a standard industrial finish [see para. 3230(i)].

6150 Radiation Exposure [Types I, II, and III Cranes (para. 1141)]

(a) If the crane is in a location where radiation levels are likely to be a factor in the life of the electrical equipment, the maximum rate of radiation and the total accumulated exposure at the crane elevation shall be stated in the crane specifications.

(b) Insulation in rotating machines, brakes, and magnetic device coils may be required to meet an accumulated dosage of 10^7 rad in 40 years. Components, such as regulator cards, that can be removed without disconnecting wiring may be required to meet an accumulated dosage of only 10^4 rad, on the basis that such components can be removed and stored in a location where they will not be exposed to more than normal atmospheric radiation during the long time intervals in which the crane will not operate after the power plant has been placed in service. If the user prefers not to remove the components, it will be permissible to establish a routine maintenance procedure of installing new components after they have accumulated a total exposure of 10^4 rad.

(c) The electrical equipment supplier shall submit data demonstrating that the type of insulation used in the equipment being supplied meets the radiation requirements in the crane specifications.

6160 Environmental Conditions (Types I, II, and III Cranes)

(a) The electrical equipment specifications shall state environmental conditions to which that equipment may be subjected, such as:

(1) high humidity or high or low temperatures during prolonged intervals when the crane is in storage or not in use;

(2) outside service:

(a) temporary — during construction only

(b) continuous

(3) pressure (para. 1143):

(a) maximum pressure

(b) rate of change in pressure

(4) spray [para. 1145(a)];

(5) ambient temperature (para. 1142):

(a) rated

(b) short time exposure to temperatures outside rated ambient range

(6) humidity (para. 1144).

6170 Quality Assurance (Types I, II, and III Cranes)

There shall be no Quality Assurance Program requirements for activities covered by Section 6000, except for those specifically required in the electrical procurement documents (see para. 2100).

6180 Duty Cycle or Duty Class (Types I, II, and III Cranes)

The specifications shall state the duty cycle requirements in accordance with para. 6418.2 or the electrical duty class that applies to each motion as determined by Table 6472.3(b)-1. If the crane is to be used for construction purposes, the duty cycles or classes required for that service shall be specified. In addition, any requirements for prolonged operation at reduced speed shall be specified.

6200 WIRING MATERIALS AND METHODS (TYPES I, II, AND III CRANES)

6210 General

(a) Applicable Standards:

(1) National Electrical Code (NEC, Article 610, "Cranes and Hoists")

(2) American Society for Testing and Materials (ASTM) B 8 and B 174

(3) National Electrical Manufacturers Association (NEMA), Pub. No. ICS 1

(b) The provisions of this Section apply to interconnecting wiring both within and external to control panel enclosures. It does not apply to wiring which forms an integral part of equipment such as motors, individual control components — for example, contactors, transformers, and relays — and electronic control subassemblies.

(c) The complete raceway system including wire shall be assembled on the crane at the crane manu-

facturer's facility. Where disassembly is necessary for shipment, components shall be match-marked for ease 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 approximate length and bound in coils marked for the circuit for which it applies.

(d) The wiring system shall meet the applicable requirements of NEC, Article 610.

(e) For Types I and II cranes, the raceway system shall be secured and braced to withstand forces due to specified seismic events.

(f) For cranes located inside the containment, consideration shall be given to rapid pressure changes as required by the specification. Pressure relief openings in electrical enclosures shall be provided where necessary to equalize these pressures.

6220 Materials

6221 Conductors

(a) Individual conductors including those in multiconductor cables shall have a maximum operating temperature rating not less than 167°F.

(b) Multiconductor cable shall be permitted in wiring the crane. Uses of the cable shall comply with the National Electrical Code. Multiconductor cable used in flexing service shall be Type SO, Type W, or a purchaser-approved alternative.

(c) All control conductors and cables used with AC inverter type controls and having operating voltages less than 110 V shall be of a shielded type.

(d) Minimum sizes of conductors shall be as follows:

(1) No. 14 AWG for power and lighting circuits

(2) No. 16 AWG for control circuits

(3) No. 18 AWG for electronic circuits

(e) Conductors shall be annealed copper with minimum stranding as follows:

(1) ASTM B 8 Class B for nonflexing service

(2) ASTM B 174 Class K for flexing service

(f) Color coding, if specified, shall be per NEMA Part ICS 1-112.64.

6222 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 specifically approved by the purchaser.

(b) Short lengths of open conductors shall be permitted at collectors and within enclosures or guards for resistors, reactors, and transformers.

(c) Conduit smaller than $^3/_4$ in. diameter trade size shall not be used.

(d) An electrically continuous system, either liquid-tight or properly drained, shall be used. For a liquid-tight system, gaskets, bushings and seals shall be used where appropriate.

(e) 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. The length of flexible conduit shall not exceed 3 ft.

(f) Connections to moving parts (e.g., bridge to trolley, bridge or trolley to pendant push-button station) may be made by flexible cable not enclosed in conduit.

(g) Conduit shall be rigidly attached to the crane by conduit supports. Welding of conduit shall not be permitted. Conduit supports may be welded to structural members; welding shall be in accordance with para. 4230.

6230 Wiring Methods

(a) All conductors shall be identified at each termination by marking with a number to correspond 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 where connections shall be made with bolted ring-type pressure connectors.

(c) Pressure-type connectors shall be provided on all wires connected to terminals not equipped with 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.

(e) Panel wiring shall be neatly routed and supported 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 detri- **(04)**

mental effects, due to electromagnetic interference induced in the conductor from 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 tachometer or encoder connections.

(2) Route such conductors through a separate conduit.

(3) Refrain from splicing connections.

6300 PERFORMANCE SPECIFICATIONS (TYPES I, II, AND III CRANES)

6310 General

(a) The rated load speeds recommended in paras. 5331, 5332, and 5333 are normal speeds based on the rated capacity of the crane. The characteristics of drive systems can vary widely with respect to speeds at other than rated load and with respect to lowering speeds at any load. Drive systems shall be chosen to conform to any speed — load constraints stated in the specifications.

(b) If more than one control station is required — for example, cab control and radio remote control — performance criteria for each of the stations shall be specified.

6320 Hoist

(a) Hoist design rated load speed and speed load characteristics shall be in accordance with para. 5331. The corresponding rated load lowering speed shall not exceed 125% of the hoisting speed.

(b) The maximum lowering speed with 125% capacity test load shall not exceed the maximum lowering speed with rated load by more than 10%.

(c) Auxiliary hoists on Type I cranes shall meet the requirements of single failure-proof design if they handle critical loads. If, through administrative control or other means, assurance is provided that no critical load will be handled by an auxiliary hoist, it shall meet the performance requirements of hoists for Type II cranes.

(d) The hoist drive characteristics shall be such that the peak acceleration and deceleration of the load does not exceed 5 ft/sec^2.

(e) On Type I crane hoists that handle critical loads, control with a high-speed, light-load feature shall be equipped with a means of locking out this feature when handling a critical load.

(f) The stopping distance for various hoist designs is variable. On Type I crane hoists that handle critical loads, the stopping distance shall not exceed 5 in. while lowering the maximum critical load at its maximum speed unless specified otherwise by the purchaser.

6330 Bridge

(a) The bridge design rated load speed and speed load characteristics shall be in accordance with para. 5333.

(b) Bridge acceleration rates with rated loads should be limited to the values shown in Table 6472.2(b)-1. The operator should have control of deceleration to minimize load swing and avoid wheel slip. In emergency situations such as emergency stop, overspeed, and limit trips, the deceleration rate may exceed the selected acceleration rate and normal deceleration rates.

(c) Type I crane bridge control with a high-speed, light-load feature shall be equipped with a means of locking out this feature when handling a critical load.

6340 Trolley

(a) The trolley design rated load speed and speed load characteristics shall be in accordance with para. 5332.

(b) Trolley acceleration rates with rated load should be limited to the values shown in Table 6472.2(b)-1. The operator should have control of deceleration to minimize load swing or wheel slip. In emergency situations such as emergency stop, overspeed, and limit trips, the deceleration rate may exceed the selected acceleration rate and normal deceleration rates.

(c) Type I crane trolley control with a high-speed, light-load feature shall be equipped with a means of locking out this feature when handling a critical load.

6400 COMPONENT SELECTION (TYPES I, II, AND III CRANES)

6410 Controllers

6411 General

6411.1 Applicable Standards. Controllers shall conform to NEC, ASME B30.2, and NEMA Parts ICS 2-213, 3-442, 3-443, and 6-110.

6411.2 Voltage Variations. At an ambient temperature between 32°F and 100°F, the controller shall be capable of operating at a deviation not more than 10% from rated nameplate value, except that for systems using semiconductor power converters, the deviation may be limited to not more than 10% above or 5% below rated name-plate value.

6411.3 Ambient Temperature. Ambient temperature shall be above 32°F but shall not exceed 100°F. If the specifications state that the equipment is to be operated at ambient temperatures outside this range, the control manufacturer shall be consulted.

6411.4 Enclosure Requirements. The enclosures, if required, shall be in accordance with NEMA, Part ICS 6. Consideration shall be given to high humidity or washdown locations, pressure equalization requirements, and outdoor usage requirements when enclosures are selected.

6411.5 Protection Against Condensation. Unless otherwise specified, enclosed control panels in high humidity locations shall have space heaters to reduce the possibility of condensation. If heaters are used, they should be energized when the crane is to be out of service for more than 8 hr.

6411.6 Hoists

(a) All hoists shall be provided with controlled lowering capable of meeting the performance specifications in para. 6300.

(b) Hoisting shall take place only when the master switch is in a hoisting position. For all loads up to rated load, lowering shall take place only when the master switch is in a lowering position.

(c) For Type I hoists, the devices necessary to comply with the emergency stop requirements of para. 6110(b) shall be within reach of the operator in any operating position. It shall not be necessary to complete a circuit in order to implement these emergency stop provisions.

(d) In the event of an emergency stop or other emergency conditions, the two brakes required by para. 6422.1(a) shall be de-energized without intentional time delay.

(e) Both sides of shunt brake coil circuits on hoists shall be opened when the brake is de-energized.

(f) Type I hoists shall be provided with an indication at the operator's control location to confirm the selected direction of load movement. This indication shall be taken from the drive train motion and electrically separated from the control circuit.

6412 Type Selection. The type of control supplied shall result in operation complying with the performance specifications in para. 6300, taking into consideration any supplemental requirements stated in the crane specifications. Any of the following types of control that will meet those requirements shall be supplied.

6413 Constant Potential DC

6413.1 Hoist

(a) Series motors and series brake(s) shall be used. Control shall provide dynamic braking lowering and include a spring-closed off position dynamic braking contactor to provide self-excitation of the motor series field in the lowering direction.

(b) For Type I hoists, provision shall be made to comply with the maximum hoisting and lowering speed limitations when handling critical loads, as specified in paras. 5331 and 6320, with the overspeed protection specified in para. 6444. Control shall provide that the series brakes cannot be energized unless there is a path for braking current in the motor armature. These provisions are to include the following.

(1) A double set of conductors and collectors shall be provided in the part of the armature lowering circuit not connected to the series field series brake circuit.

(2) Any resistance in the armature circuit when lowering shall have a continuous rating equal to the motor rated current.

(3) If the dynamic lowering contactor in the armature circuit is not closed when the master switch is in any lowering position, the spring-closed emergency dynamic braking contactor shall remain closed.

(4) Temperature-sensitive devices in the motor shall warn the operator when the temperature approaches a value that could be injurious to the insulation.

6413.2 Travel. The travel control shall be the reversing, contactor-resistor type with controlled plugging.

6414 Constant Potential AC

6414.1 Hoist

(a) Speed control may be achieved by the following:

(1) contactors and resistance in the secondary of the wound rotor motor;

(2) static power devices such as saturable reac-

tors or thyristors in the secondary of the wound rotor motor;

(3) contactor(s), and resistance in the primary of a squirrel cage motor

(4) an electrical load brake; or

(5) a combination of these methods.

(b) Type I cranes shall be provided with the following:

(1) open and reverse phase protection;

(2) a circuit to ensure that power is applied to the hoist motor(s) before the brakes (para. 6422) are released;

(3) a circuit to de-energize the hoist motor and to set the brakes if the electrical load brake is not energized sufficiently to limit the speed when the control is in a position requiring electrical load brake torque;

(4) temperature-sensitive devices in motors and load brakes to warn the operator when the temperature of a motor or load brake approaches a value that could be injurious to the insulation or could interfere with meeting the performance specifications in para. 6300.

6414.2 Travel

(a) Speed control may be achieved by the following:

(1) contactors and resistance in the secondary of the wound rotor motor;

(2) static power devices such as saturable reactors or thyristors in the secondary of the wound rotor motor;

(3) contactor(s) and resistance in the primary of a squirrel cage motor;

(4) an electrical load brake; or

(5) a combination of these methods.

(b) Control shall include controlled plugging.

6415 Adjustable Voltage DC

(a) Control shall include a contactor that will disconnect power to any drive not in use.

(b) Control shall include controlled electrical braking and may include a feature that will keep the electrical braking circuit energized until the motor approaches zero speed when the operator wishes to stop.

(c) A contactor shall be provided in the DC motor armature circuit if a generator is the source of DC power, but the contactor can be in either the AC or DC power circuit if static power conversion is used.

(d) Motor field loss protection shall be provided.

6415.1 Hoist

(a) Hoists with static power supplies shall include means to automatically remove power from the motor and to set the brake(s) if the drive does not develop braking torque as required when lowering a load or when the operator attempts to reduce speed.

(b) In addition to (a) above, hoists handling critical loads on Type I cranes shall be provided with the following:

(1) provisions to maintain proper field excitation to comply with the speed limitation in para. 6300. Activation of this speed-limiting feature shall be the responsibility of the designated person responsible for moving critical loads [see para. 6320(e)].

(2) a protective circuit to ensure current flow in motor armature circuit before brakes can be energized (current check circuit or torque proving circuit);

(3) a temperature-sensitive device in the motor to warn the operator when temperature approaches a value that could be injurious;

(4) temperature-sensitive devices in or near the resistors that are required to absorb "pump back energy" to warn the operator when the resistors approach a value that could cause them to fail.

6415.2 Travel

(a) Field loss protection is not required on travel drives having motor field reversing and designed to permit coasting.

(b) When two or more motors connected in parallel are used, provision shall be made at the control panel to permit isolating any motor and to continue operation with the remaining motor(s) with normal protection features, if agreed to by the user, crane builder, and electrical equipment supplier(s).

6416 Adjustable Voltage AC

(a) Speed control may be achieved by static power devices such as saturable reactors or thyristors in the primary circuit.

(b) Control shall include controlled electrical braking and may include a feature that will keep the electrical braking circuit energized until the motor approaches zero speed when the operator wishes to stop.

6416.1 Hoist

(a) The secondary may have a fixed impedance, although a means may be provided to increase the resistance in the secondary of the wound rotor motor

for operation at reduced speeds for prolonged periods or if frequent deceleration is anticipated.

(b) An electrical load brake may be used with the above.

(c) Type I cranes shall have protection as required in para. 6414.

6416.2 Travel

(a) The secondary may have a fixed impedance, although a means may be provided to increase the resistance in the secondary to permit prolonged operation at reduced speed or to reduce motor heating when plugging.

(b) When two or more motors are used, provision shall be made at the control panel to permit isolating any motor and to continue operation with the remaining motor(s) with normal protection features if agreed to by the purchaser, crane builder, and electrical equipment supplier(s).

(04) **6417 AC Variable Frequency**

(a) Control shall consist of a variable frequency drive (VFD) with a full load ampere (FLA) rating equal to, or greater than, the FLA of the corresponding motor(s).

(b) Control shall include, as a minimum, the following protective features:

(1) output phase loss,

(2) under voltage,

(3) over voltage,

(4) motor thermal overload, and

(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 cable power supply and electronic equipment shall be protected from detrimental effects due to harmonic and EMI/RFI emissions produced by inverters.

6417.1 Hoist

(a) The VFD control shall incorporate a speed feedback device to sense loss of speed control during any motor operating condition. Hoists with mechanical load brakes are exempt from this requirement.

(b) Control dynamic braking shall be sized for a minimum of 150% of motor full load torque, but *shall not, under any circumstances, be less than* the torque (or corresponding current) limit setting of the VFD in the hoisting direction.

NOTE: Control dynamic braking on hoists with mechanical load brakes shall be sized such that the combined retarding torque in the lower direction of the dynamic braking and the mechanical load brake are equal to or greater than the torque (or corresponding current) limit setting of the VFD in the hoisting direction.

(c) Control shall sense sufficient motor torque (or corresponding current) before releasing holding brake(s) (i.e., torque proving). Hoists with mechanical load brakes are exempt from this requirement.

(d) In lieu of the design tolerance para. 5331.1(b), control shall maintain speed control under all motor operating conditions to within ±5% of the commanded speed.

(e) If specified by the owner, control shall be capable of operating at higher than base speed as a function of load (constant horsepower operation) for loads less than 100% rated load.

(f) Type I cranes shall have controls with the following capabilities:

(1) A warning device shall be provided to warn the operator of a pending motor overheat condition.

(2) A warning device shall be provided to warn the operator that the dynamic braking resistors have overheated.

6418 Sizing Procedure. Control ratings shall be in accordance with NEMA Standards with the following qualifications.

6418.1 Hoists That Handle Critical Loads on Type I Cranes. As a minimum, contactor, resistor, thyristor, and reactor ratings shall have a continuous rating equal to the greater of the steady state currents in those devices when hoisting or lowering rated load at full speed. Accelerating resistors, if used, shall be NEMA Class 90 (see NEMA, Part ICS 2-213).

Mechanical load brakes shall not be used as the control braking means.

6418.2 Types I, II, and III Cranes. The crane specifications shall state all required repetitive duty cycle operations or prolonged operations in terms of load, distance, speed, time, and frequency of repetition. All the control components (including the control braking means) shall be checked by the supplier to ensure that they are adequate for that specification.

6420 Friction Brakes

6421 General (Types I, II, and III Cranes). This Section covers the requirements for friction-type brakes for purposes of holding, emergency, parking, and service brakes.

6421.1 Applicable Standards. The brake selections shall be in accordance with the definitions and brake requirements of ASME B30.2, with further specific requirements as covered by this Section and para. 6100.

6421.2 Brake Operation. The brakes shall have a thermal capacity for the frequency and duration of the specified operations to prevent over-heating of the brake wheel, disks, brake linings, and other parts. Brake manual release mechanisms shall be furnished to permit drive movement during power outages, and shall be of the manual-release-self-reset type, operative only when held manually in the release position.

6421.3 Electric Brakes

(a) The electrical operating and excitation system 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) Brakes with DC shunt coils shall release at 80% and operate without overheating at 110% of the rated excitation system voltage. Whenever DC shunt coils are used on hoist brakes, the combination of the brake coil and excitation system shall result in a quick response of brake release and set.

(c) Brakes with AC coils shall release at 85% and operate without overheating at 110% of rated excitation system voltage.

6421.4 Brake Lining, Friction Material. Brake lining material shall permit brakes to maintain adequate torque for the specified environmental conditions and at the lining temperatures resulting from the frequency and duration of the specified operations. Manual or automatic means shall be provided to adjust the brake operating mechanism to compensate for the effect of lining wear.

6422 Hoist Brakes (Types I, II, and III Cranes)

6422.1 Hoists That Handle Critical Loads on Type I Cranes

(04) *(a)* A minimum of two holding brakes shall be provided. These brakes shall comply with AISE TR No. 11 or have an alternative design specifically approved by the Purchaser. Each holding brake shall have a torque rating not less than 125% of the full (rated) load hoisting torque at the point of brake application.

(b) Determination shall be made that if the holding brakes are mounted and adjusted, and linings run in properly for the torque settings required in (a) above, the brake system shall be capable of stopping and holding the credible critical load during an SSE or OBE event. The values used for this determination shall be based on the maximum acceleration forces at the brake(s) computed for the crane SSE or OBE specifications, and the total torque required on the brake system to hold the credible critical load.

(c) Provision shall be made for emergency lowering of the critical load by an alternative means of operation of the holding brakes. The alternative release mechanisms shall permit control of the braking torque and shall also provide the ability to restore the "brake set" condition promptly, thereby allowing the operators of the alternative release mechanisms to control the lowering speed. A device for indicating lowering speed shall be located at the emergency release station. Intermittent lowering shall be allowed to provide time for cooling the brake mechanism to obtain adequate heat dissipation and to prevent reduction in braking torque that can occur as the result of excessive heat.

(d) The detrimental effects of radiation exposure on the brake linings shall be determined and a routine replacement procedure established so as to maintain an adequate torque.

6422.2 Hoists on Types II and III Cranes and Hoists That Do Not Handle Critical Loads on Type I Cranes. At least one holding brake shall be provided. Each brake shall have not less than the following percentage of the rated load hoisting torque at the point where the brake(s) is applied:

(a) 125% when used with a control braking means other than mechanical;

(b) 100% when used with a mechanical control braking means;

(c) 100% if two holding brakes are provided.

6423 Trolley and Bridge Brakes (Types I, II, and III Cranes)

6423.1 Application

(a) All travel drives shall have service braking means.

(b) When a friction brake is used for service braking, the brake torque shall be sufficient to stop the drive within a distance in feet equal to 10% of the rated load speed in feet per minute when traveling at full speed with rated load.

(c) Emergency brakes shall be of the friction-type that will set automatically upon power failure and

shall be capable of stopping the drive within the distance specified in (b) above.

(1) For Type I Cranes. Emergency and parking brakes shall be provided for the travel drives. Parking brakes shall be automatically applied and shall be provided with time delay relays, if necessary, to eliminate interference with service brake operation.

(2) For Types II and III Cranes. Emergency brakes shall be provided when required by the specification.

(d) 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.

6423.2 Trolley Brake Sizing Procedures

(a) On cab-operated cranes, trolley service braking shall be provided as required by para. 6423.1(a) with sufficient torque to satisfy the deceleration requirements of para. 6423.1(b).

(b) On floor-, remote-, or pulpit-operated cranes, trolley emergency brakes with torque rating to satisfy the deceleration requirements of para. 6423.1(b) shall be provided.

6423.3 Bridge Brake Sizing Procedures

(a) On cab-operated cranes with cab on bridges, bridge service braking shall be provided with sufficient torque to satisfy the deceleration requirements of para. 6423.1(b).

(b) On cab-operated cranes with cab on trolley, bridge emergency brake(s) with torque rating to satisfy the deceleration requirements of para. 6423.1(b) shall be provided in addition to bridge service braking.

(c) On floor-, remote-, or pulpit-operated cranes, bridge emergency brake(s) shall be provided with torque rating to satisfy the deceleration requirements of para. 6423.1(b).

6430 Disconnecting Means

6431 General (Types I, II, and III Cranes)

6431.1 Applicable Standards. All crane disconnecting devices shall be selected and installed as required by NEC Article 610; ASME B30.2, Section 2-1.10.5; and NEMA Parts ICS 3-442 and 3-443.

6432 Main Disconnects

6432.1 Runway Disconnects (Types I, II, and III Cranes). A circuit breaker or motor circuit switch selected in accordance with NEC 610-31 shall be provided in the leads to the runway conductors.

6432.2 Crane Disconnect (Types I, II, and III Cranes). All cranes shall have a main line disconnect in accordance with NEC 610-32, and shall be rated in accordance with NEC 610-33 plus any additional continuous load. This disconnect shall be enclosed as required by environmental conditions. Unless overcurrent protection is provided by other means, it shall be incorporated in this main line disconnect and the user shall specify available rms symmetrical short circuit current.

6432.3 Motor Power Circuit Disconnecting Device (Type I Cranes). A device shall be furnished to open the power circuit to all crane drive motors. This device shall be capable of being opened from all operator stations. The device shall open automatically upon failure and shall be unable to reclose until a reset function is performed.

The minimum size of this device shall be not less than that required by NEC 610-33. The opening of this device shall cause the holding and emergency brakes to set.

6432.4 Motor Power Circuit Disconnecting Device (Types II and III Cranes). Unless a device (para. 6432.3) is supplied, the crane disconnect (para. 6432.2) must be accessible for opening by the operator and must be connected in a way that the functional protection required by para. 6432.3 is provided.

6432.5 Motion Power Disconnecting Devices (Type I Cranes). Control shall include a separate disconnecting means for each crane motion. (04)

6433 Auxiliary Disconnects (Types I, II, and III Cranes).

The crane manufacturer shall provide disconnecting means in the form of fused safety switches or circuit breakers as required by NEC to protect and disconnect all auxiliary equipment supplied by the manufacturer or specified by the purchaser. Auxiliary equipment may include:

(a) lighting,
(b) signal systems,
(c) heating/ventilating/air conditioning,
(d) convenience outlet, and
(e) special devices when applicable.

Ground fault circuit interrupters, if required for convenience outlets, shall be a part of the user's specifications.

6440 Limit Switches

6441 General (Types I, II, and III Cranes). A *limit switch* is defined as a switch that is operated by some part or motion of a power driven machine or equipment to alter the electric circuit associated with the machine or equipment. This Section includes the following limit switch requirements for nuclear power plant cranes:

(a) hoist overtravel,
(b) hoist overspeed,
(c) hoist overload,
(d) hoist drum rope mis-spooling, and
(e) bridge and trolley overtravel limits.

Limit switch requirements, if any in addition to the above, shall be incorporated in the specifications. AC cranes shall have phase reversal protection.

6442 High Limits

6442.1 Type I Cranes. Hoists that handle critical loads shall include two separate overhoist limit switch systems as required in paras. 6442.2 and 6442.3.

6442.2 First High Limit (Type I Cranes). 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.

6442.3 Final Overtravel High Limit (Type I Cranes). Hoists that handle critical loads shall include, in addition to the first upper limit switch as specified in para. 6442.2, a final power circuit hoisting limit switch. Actuation of this switch shall remove power from the hoist motor directly without relying on the sequencing of any devices and shall set the hoist brakes. Actuation of this limit switch shall prevent further hoisting or lowering.

6442.4 High Limits (Hoists on Types II and III Cranes and Hoists That Do Not Handle Critical Loads on Type I Cranes). One high limit switch shall be provided.

6443 Hoist Low Limits (Type I Cranes). Hoists that handle critical loads shall include two separate low limits, as required in paras. 6443.1 and 6443.2.

6443.1 First Low Limit (Type I Cranes). Each hoist that handles critical loads 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.

6443.2 Final Overtravel Low Limit (Type I Cranes). Hoists that handle critical loads shall include, in addition to a first low limit as specified in para. 6443.1, a final lowering limit switch of the control circuit type that shall be mechanically and electrically independent of the first low limit. Operation of this limit switch shall de-energize a power device other than the device operated by the first low limit to interrupt all power to the hoist motor and the hoist brakes. Actuation of this limit switch shall prevent further lowering or hoisting. When this occurs, a person knowledgeable in the hoist control system shall determine and correct the cause of tripping of the final low limit switch. That person shall direct the raising out of the final low limit after establishing a back out mode which shall prevent further lowering. The first low limit shall be tested for proper operation before making any additional lifts.

6443.3 Low Limits (Hoists on Types II and III Cranes and Hoists That Do Not Handle Critical Loads on Type I Cranes). A low limit shall be furnished:

(a) as recommended by ASME B30.2, 2-1.10.5(e), when specified in the crane specifications, or
(b) when required by ASME B30.2, 2-1.11.3(c)(1).

6444 Hoist Overspeed Limits (Type I Cranes)

(a) Hoists that handle critical loads shall include an overspeed limit switch. When handling a critical load, hook speeds over 115% of the design rated load lowering speed for any critical load shall trip this switch, causing all holding brakes to set without intentional time delay. Operation of this switch may also initiate any control braking means normally used for stopping of the load. It shall be necessary to center the master switch and to manually reset the overspeed limit switch (or the overspeed circuit) before operation can be resumed.

(b) On drives which provide high-speed, light-load features, provisions shall be made to permit override of this overspeed limit switch when handling noncritical loads.

(c) When specified, clutched-in-slow-speed hoist drives may include a bidirectional overspeed switch to shut down hoisting or lowering if drive speed exceeds 115% of the rated full load slow lowering speed.

6445 Hoist Load Limits

6445.1 Overloading (Types I, II, and III Cranes). Overloading, including load hang-up, of hoists that handle critical loads on Type I cranes shall be detected by means of a load sensing system, or the equivalent, in accordance with para. 6466. The high-load limit shall be set to prevent sustained lifting of more than rated load, but to permit lowering. Specifications shall designate any load limit requirements for Types II and III cranes.

6445.2 Unbalanced Load Limits (Type I Cranes). Dual reeved hoists that handle critical loads on Type I cranes shall include a device to detect excessive movement of the equalizer mechanism. Tripping of this device shall initiate a flashing warning light visible to the crane operator and shall shut down the hoisting motion. Means shall be provided to allow the use of hoist under administrative control. Reeving shall then be corrected before returning hoist to additional service.

6446 Hoist Drum Rope Mis-Spooling Limits

6446.1 Hoist Drum Rope Mis-Spooling Limits (Type I Cranes). Hoists that handle critical loads shall include a hoist drum rope mis-spooling limit switch to detect improper threading of hoist rope in hoist drum grooves.

Actuation of this switch shall result in removal of power from the hoist motor and setting the hoist holding brakes.

Actuation of this limit device shall prevent further hoisting or lowering until a key-operated bypass is used to enable lowering out of the mis-spooled condition, with further hoisting prevented until the mis-spooled condition is corrected. The limit shall be tested for proper operation before making any additional lifts.

6446.2 Hoist Drum Rope Level Wind Limits (Types II and III Cranes). Hoist drum rope mis-spooling limits shall be furnished in accordance with 6446.1 when so specified in the crane specifications.

6447 Bridge and Trolley Overtravel Limits (Types I, II, and III Cranes). Bridge and trolley overtravel limits shall be furnished when specified. Refer to paras. 5131(b) and 5459.1(d) and (e).

6448 Restricted Handling Path (Type I Cranes). On some Type I cranes, it may be essential that the hook follow a restricted critical load handling path. The requirements for such paths vary widely with individual nuclear plant designs. The crane specifications shall designate the required accuracy, positions where redundancy is required, and any test and signal system required.

6450 Master Switches, Pushbuttons, and Radio Controls (Types I, II, and III Cranes)

6451 General

6451.1 Applicable Standards. All such devices shall comply with ASME B30.2.

6452 Contact Ratings. Contacts in master switches, pushbuttons, and radio control interface panels should be heavy duty rated per NEMA ICS 2-125. See Table 1 or 2, for appropriate application. Multispeed pendant pushbuttons shall be rated per NEMA A150 or N300.

6453 Voltage Ratings. The voltages in pushbuttons, master switches, and similar control circuit devices shall not exceed 150 V AC or 300 V DC.

6454 Radio Controls. If radio control of cranes in the containment area has been provided for construction operation, that equipment shall be removed before the crane is certified for service in the operating plant unless the effect of radio transmission on reactor plant instrumentation has been analyzed.

6460 Auxiliary Equipment (Types I, II, and III Cranes)

6461 General. Auxiliary electrical equipment shall be provided as specified. All necessary mounting hardware, wiring, disconnecting means, and associated control means shall be included. For Types I and II cranes, all auxiliary equipment shall be mounted and secured so as not to become dislodged or to fall from the crane during a seismic event.

6462 Light Fixtures. Light fixtures shall be as specified in the crane specifications.

6463 Signal Systems. Signal systems shall be as specified in the crane specifications.

6464 Heating, Ventilating, and Air Conditioning. Heating, ventilating, and air conditioning shall be as specified in the crane specifications.

6465 Convenience Outlets. Convenience outlets shall be as specified in the crane specifications.

6466 Load Sensing Devices. Load sensing devices shall be as specified in the crane specifications. When load sensing devices provide control functions such as load limiting, as covered in para. 6445.1, they shall be powered from the control circuit of the associated drive.

6467 Power for Auxiliary Equipment. Except as stated in para. 6466 or unless otherwise specified, power for all auxiliary equipment shall be from a separate protected branch circuit(s) connected ahead of the main drive motor disconnecting means, so that power is available to auxiliary equipment when the main drives are shut down.

6468 Wiring for Auxiliary Equipment. All wiring for auxiliary equipment shall be in accordance with NEC. All equipment shall be grounded.

6470 Motors (Types I, II, and III Cranes)

6471 General

(04) *(a) Direct Current Motors.* DC motors shall be in accordance with either NEMA MG-1 or AISE TR No. 1.

(b) Alternating Current Motors

(1) Definite Purpose Inverter-Fed Motors. AC squirrel cage motors applied to variable frequency drives (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, Part 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.

6472 Motor Size Selection, AC or DC

(a) The motor size selection is determined by the duty class or duty cycle for each motion, not the Type I, II, or III crane classification. Because of the large variety of crane drives available and the difference in the effects of those drives on the thermal adequacy of the motors under consideration, any attempt to develop a procedure for selecting motor ratings becomes quite involved. Whenever possible, the specifications should indicate the most severe repetitive duty (or duties) that each motor will be required to meet, especially including intervals of slow speed operation, if any. The supplier shall be responsible for selecting ratings that will meet the specified duty with the type of control specified. In the absence of duty cycle requirements, the specifications shall clearly identify the duty class to be used for each motion in the procedure described herein. The rating of auxiliary devices (such as mechanical or electrical load brakes) must also be selected to meet the specified duty or duty class.

(b) For ambient temperatures above 100°F, the motor design (frame size, insulation class, enclosure, and ventilation) shall be selected to compensate for the increased ambient so the total insulation temperature will not exceed the value allowed by NEMA for the selected insulation class. For example, in a 140°F ambient, a motor with Class F insulation rated at Class B rise might be selected.

6472.1 Hoists. The hoist motor shall be so selected that its nameplate rating will not be less than that given by the following formula:

$$hp = K_S WV/33{,}000E \qquad (1)$$

where

E = the product of the gearing efficiency and the reeving efficiency (see para. 5413.7 for gearing efficiency and para. 5429 for reeving efficiency)
K_s = service factor from Table 6472.3(b)-1
V = rated full load hoisting speed, ft/min
W = weight of the rated load on the hook plus the weight of the block, lb
hp = horsepower

6472.2 Bridge and Trolley

(a) The force required to drive the bridge or trolley consists of that necessary to overcome rolling friction, and that necessary to accelerate the crane. The rolling friction is proportional to the total weight of the crane and is assumed to be constant at all speeds. Unless otherwise specified, a friction factor per Table 6472.2(a)-1 shall be used for anti-friction bearing cranes. Mechanical efficiencies are included in these factors.

(b) Unless otherwise specified, the acceleration rate with rated load for either AC or adjustable

Table 6472.2(a)-1
Overall Friction Factors (Antifriction Bearings)

Wheel diameter, in.	8	10	12	15	18	21	24	27	30	36
Friction, lb/ton	22	18	15	15	15	12	12	12	10	10

voltage (AV) drives is to be selected from the slow values shown in Table 6472.2(b)-1.

(04) *(c)* The size of the bridge and trolley motor shall not be less than the computed from Eq. (2):

$$hp = K_s K_a W_t V \tag{2}$$

where

K_a = a factor that includes power for both overcoming friction and accelerating the crane or trolley. Based on certain assumptions, values of K_a for either AC drives or adjustable voltage drives with constant motor field strength are given in Fig. 6472.2(c)-1. The rate of acceleration is based on the total time to accelerate from zero speed up to rated speed. The factors assume the rotating inertia to be 10% of the equivalent load inertia (based on W_t), a mechanical efficiency of 95%, and an average motor torque equal to 150% of the motor rated torque when K_s = 1.0. K_a factors for constant potential DC series motor drives are to be in accordance with AISE TR No. 6, noting that the acceleration rates may exceed those shown in Table 6472.2(b)-1 since they apply only up to the speed attained on the resistor, as explained in that standard.

K_s = a service factor to provide an allowance for motor heating resulting from repetitive operations [Table 6472.3(b)-1]

V = specified speed, ft/min

W_t = total weight of the crane or trolley plus rated load, ton

(d) After selecting an approximate motor by Eq. (2), obtain data on the Wk^2 of the motor, brake wheel, couplings, and pinion. The sum of these values is the rotating Wk_R^2. Calculate the equivalent Wk^2 of the load by the following equation.

$$Wk_L^2 = 2000 W_t (V/2\pi N_f)^2 \tag{3}$$

N_f is defined in para. 6473.1(a).

(e) If the motor is being selected for a duty class rather than a specified duty cycle, the motor rating should not be less than

$$hp = K_S [(W_t\, 2000 V)/33{,}000 T_a] \times [(f/2000 + a/32.2E + a/32.2)\, Wk_R^2/Wk_L^2] \tag{4}$$

where

E = mechanical efficiency, per unit

T_a = average per unit motor torque provided during acceleration if K_s = 1

a = average acceleration rate, ft/sec^2

f = friction factor, lb/ton

Using Eq. (4) and $K_s = 1.0$, $E = 0.95$, $T_a = 1.5$, $Wk_R^2/Wk_L^2 = 0.1$.

$$\text{rated } hp \geq 1.0\, [(W_t\, 2000\, V)/(33{,}000 \times 1.5)] \times [(f/2000) + (a/32.2 \times 0.95) + (a/32.2) \times 0.1]$$

NOTE: For constant potential DC series motor drives (or any drive where the free-running speed exceeds the motor rated speed at the applied voltage), multiply V in Eq. (4) by N_R/N_t, where N_R is the motor rated speed at the applied voltage and N_t is the free-running motor speed. If this procedure is used, a applies only up to N_R, and should be selected on that basis.

See para. B6472.3 for sample bridge motor horsepower calculations.

(f) The speed ratio for bridge and trolley drives will be determined as shown in para. 6473, computing the free-running hp from Eq. (5):

$$hp = f W_t V/33{,}000 \tag{5}$$

where f = rolling friction, lb/ton, for f = 15 lb/ton,

$$hp = 0.000455\, W_t V \tag{6}$$

(g) Polar Cranes: horsepower for bridge drives

$$hp_B = [(2/3) S_B \times W_B \times TE]/33{,}000 \tag{7}$$

$$hp_{TL} = [(X/R) S_B \times (W_T + W_L) \times TE]/33{,}000 \tag{8}$$

$$hp = hp_B + hp_{TL} \tag{9}$$

where

hp = total hp of bridge motors

hp_B = hp to drive bridge (less trolley and load)

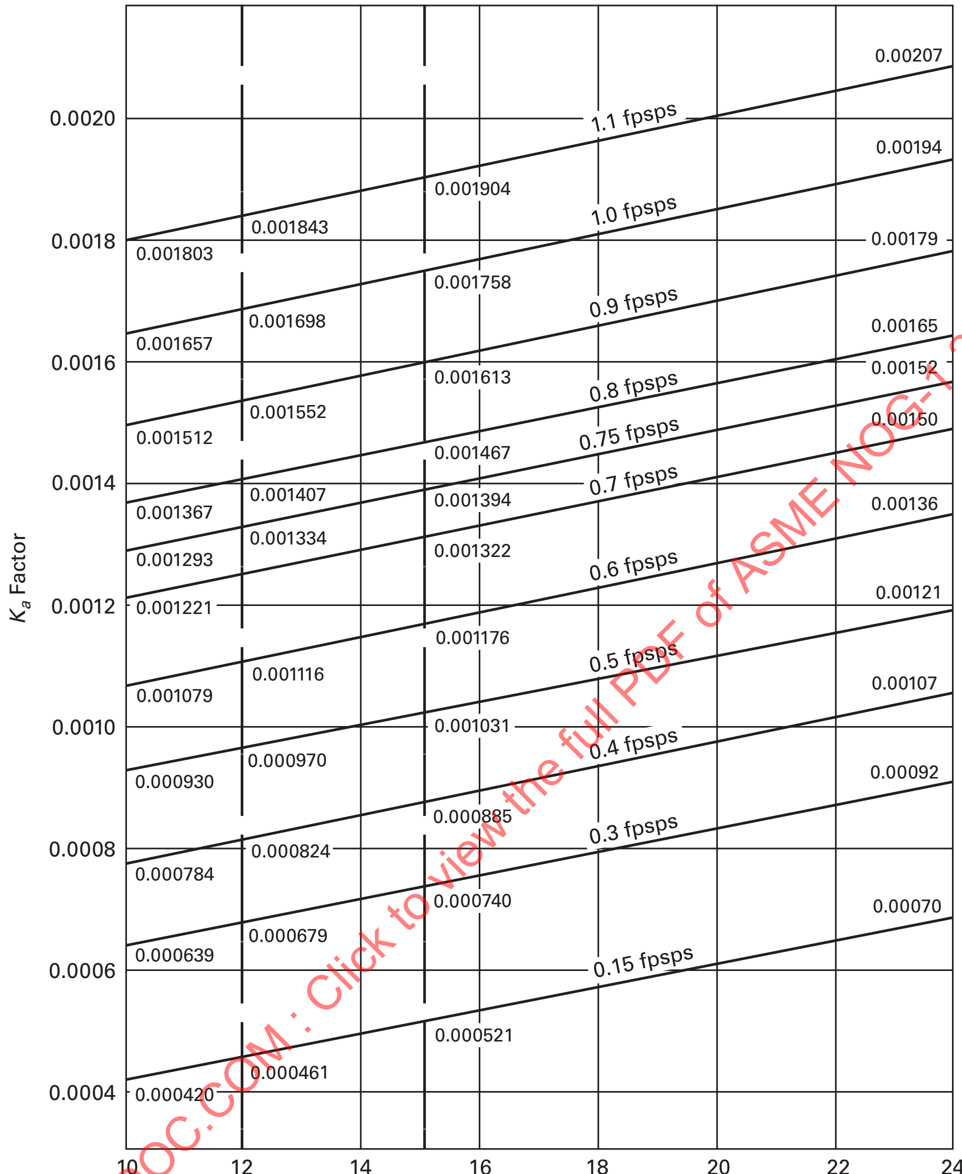


Fig. 6472.2(c)-1 K_a Factors for AC and Adjustable Voltage DC Motors (Without Field Weakening)

hp_{TL} = additional bridge motor hp to drive trolley and load

R = radius of bridge (span/2) (see Fig. 6472.2(g)-1)

S_B = speed of bridge at wheel, ft/min (see Fig. 6472.2(g)-1)

TE = tractive effort, lb/ton

W_B = weight of bridge, ton

W_L = weight of load, ton

W_T = weight of trolley, ton

X = radius from bridge center line to point of maximum hook approach (see Fig. 6472.2(g)-1)

Use tractive effort constant from

$$TE = 22.5 + S_B/20 \tag{10}$$

This value of TE gives approximately 1 ft/sec^2 acceler-

Table 6472.2(b)-1 Suggested Acceleration Rates for AC or AV Travel Drives

AC or AV Drives Rated Speed [Note (3)]		Acceleration Rate [Notes (1) and (2)]					
		Slow [Note (4)]		Medium		Fast	
ft/min	ft/sec	a, ft/sec^2	t, sec	a, ft/sec^2	t, sec	a, ft/sec^2	t, sec
30–60	0.5–1.0	0.15–0.30	3.3	0.2–0.4	2.5	0.25–0.5	2
120	2.0	0.4	5	0.6	3.33	0.8	2.5
180	3.0	0.5	6	0.75	4	1.0	3
240	4.0	0.6	6.7	0.8	5.0	1.0	4
300	5.0	0.7	7.14	0.9	5.55	1.1	4.5

NOTES:
(1) Since acceleration rates are for full-load conditions, lesser loads on the same drive will produce faster acceleration rates unless the drive has a regulator that provides controlled rate acceleration.
(2) Due to wheel slip considerations, it is suggested that the maximum acceleration rate not exceed the values in Table 6472.2(b)-2 based on a wheel to rail adhesion of 20%. If the adhesion is less than 20% or if a multi-motor drive without a line shaft is being used, the maximum rate should be reduced accordingly.
(3) 200 ft/min is considered the maximum for pendant operated cranes.
(4) Since fast acceleration may result in less precision for spotting and jogging, acceleration rates less than those shown in the slow column may be desirable where precise positioning is required.

Table 6472.2(b)-2 Suggested Maximum Acceleration Rates

Wheels Driven, %	Maximum *a*
50	2.4 ft/sec^2
$33\frac{1}{3}$	1.5
25	1.2
$16\frac{2}{3}$	0.8
$12\frac{1}{2}$	0.6

ation. For running horsepower to select the drive speed ratio, use the actual rolling friction in lb/ton in place of *TE* in the above equations.

6472.3 Service Factors

(a) As stated in para. 6472(a), the most severe requirements should be stated in the specifications whenever possible so the supplier can check the specific motor and control required.

(b) If the crane specifications do not indicate a specific duty but state the duty class for each motion, the K_s values for Eqs. (1), (2), and (4) are listed in Table 6472.3(b)-1. There is no guarantee that these values will result in the optimum motor selection, but they do indicate relative ratings.

6472.4 Calculation of Motor Heating

(04) *(a)* When definite operating requirements have been specified, the time, motor torque, and average motor speed can be calculated for each step of acceleration, running, and deceleration. The procedure for checking the thermal adequacy of the motor will vary, depending on the type of motor and motor enclosure. For totally enclosed series wound AISE TR No. 1 DC mill motors used for constant-potential DC control at 230 V, published curves may permit determining whether or not the allowable percent time-on exceeds the actual percent time-on. If the same type of motor is used at more than 230 V, the motor manufacturer shall be consulted to evaluate the effect of the increased core losses and friction and windage losses.

(b) On adjustable voltage DC drives, self- and forced-ventilated shunt motors can be checked by comparing the calculated rms current and average speed against curves of allowable rms current versus average rpm for the motors being checked. In totally enclosed motors, the losses (armature, field, core, brush, friction, windage, and stray load) shall be summarized to see if the total is below the dissipating capability of the selected motor operating over the repetitive cycle. Similarly, in AC motors, losses are divided into fixed and variable. As an approximation, the variable losses can be considered to be proportional to secondary current squared. Also, for a given value of secondary resistance, the secondary current can be calculated by

$$I = \sqrt{\text{torque} \times \text{slip/resistance}} \qquad (11)$$

all on a per unit basis. (If the calculated per unit *I* is less than the corresponding per unit *T*, use the per unit *T* value. Also, in order to take into

Table 6472.3(b)-1 Duty Classes

					K_s					
							AC — H [Note (3)]		AC — T & B	
	Maximum Time on,	Maximum [Note (1)]	Time Rating [Note (2)], min		DC AV. & CP		Includes Resistance for Counter Torque		Includes Resistance for Slow Speed	Fixed Resistance
Duty Class	%	Cycles/hr.	Hoist	T & B	H — T & B		and Slow Speed	Fixed Resistance	and Plug	[Note (4)]
1	20	15	30	30	1.0	1.1	1.0	1.1	1.1	1.3
2	30	25	30	60	1.0	1.2	1.0	1.2	1.2	1.4
3	40	35	60	60	1.0	1.3	1.1	1.3	1.3	1.5
4	50	45	60	60	1.0	1.4	1.2	1.4	1.4	1.6

GENERAL NOTE: If mechanical considerations make it desirable to keep motor rated *hp* as low as possible, and if atmospheric conditions permit ventilated motors, use duty class 1 K_s values for all duty classes above Class 1 to determine the motor 60 minute self-ventilated *hp* rating, then modify the motor by adding forced ventilation. This does not eliminate the necessity of checking the adequacy of an AC drive with a fixed secondary resistance if prolonged slow speed operation is required.

NOTES:

(1) Unless otherwise specified, a *cycle* is defined as follows:
For a hoist — Raise rated load, lower rated load, hoist empty hook, lower empty hook — same distances.
For a trolley or bridge — Carry rated load in one direction and return same distance with empty hook.

(2) For AC drives with static controls, the minimum time rating shall be 60 minutes.

(3) For a hoist, the specified full-load hoist speed must be obtained at not more than rated motor torque. To meet this requirement for an AC hoist that has some permanent secondary resistance during full-speed hoisting, and to include the selected service factor in a way that allows for the reduction in per unit slip when the service factor increases the motor rating, use the following equation instead of Eq. (1), 6000. The motor rating shall not be less than:

$$hp = [K_s - 1 = 0.97/(1.0 \text{ per unit res.})]\ (WV/33{,}000\ E)$$

Obviously, if $K_s = 1$ and the slip rings are shorted on a motor with the 3% internal resistance that is assumed on these calculations:

$$hp = WV/33{,}000\ E$$

In other words, the minimum motor rating is the mechanical *hp* required for steady-state hoisting of rated load at rated speed. See para. B6472.3(b)-1 for an illustration of the effect of permanent secondary resistance and service factor on motor rating.

(4) *Fixed Resistance* means no secondary contactors to change secondary resistance, although there may be controlled reactance.

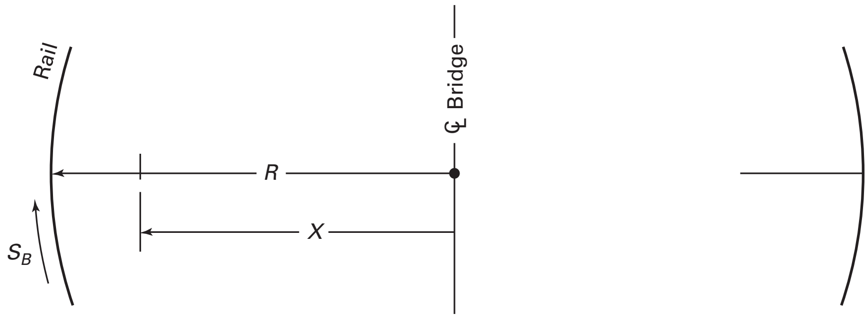


Fig. 6472.2(g)-1 Typical Polar Crane

consideration the primary copper losses at very low values of torque, the value of per unit *I* shall not be less than 0.4.)

(c) The AC motor thermal evaluation could be performed as follows. Establish a duty cycle with the time and torque for each step calculated. Convert torque to per unit current using Eq. (11) or the torque–current speed characteristics of the type of control to be used. Add the square of the per unit current × time (in seconds) × per unit variable losses to the operating time (in seconds) × per unit fixed losses. If that total is less than the sum of the seconds × the dissipation factors for each step in the cycle, the motor has adequate thermal capacity. The variable losses, fixed losses, and dissipation factors are to be obtained from the selected motor manufacturer, or the cycle summary shall be submitted to the manufacturer. See para. B6472.4 for an example of AC motor heating calculation.

6472.5 Duty in Excess of Class 4

(a) Above 50% time-on or more than 45 cycles per hour, the required duty cycle capability shall be stated by the specification writer, who should consider the possible advantages of self-ventilated, forced-ventilated, or air-over-frame motor construction, depending upon the atmospheric conditions at each installation. The acceptable type(s) shall be indicated in the specifications.

(b) If prolonged (over 30 sec) or repetitive operation at reduced speed is required, it shall be specified. Any reduced speed operations which fall below 5% speed for prolonged periods or which are repetitive shall not be evaluated by the procedures in para. 6472.4 without consulting the electrical manufacturer.

(c) Because variations in motors and controls can be appreciable, ratings selected by any duty cycle calculations shall be checked by the electrical manufacturer after an order has been placed.

6473 Drive Speed Ratios. Drive speed ratios shall be determined as follows:

$$SR = \pi D/12R \times N_f/V \quad (12)$$
$$= 0.262D/R \times N_f V$$

where

D = pitch diameter or drum for hoists or wheel diameter for traverse drives, in.

N_f = motor rpm corresponding to the free-running (i.e., steady state or developed) *hp* not including any accelerating hp, taking into consideration the voltage and control used as stated in (a) through (d) below

R = mechanical advantage of the rope system for hoists. R = 1 for traverse drives.

V = specified speed, ft/min

(a) For 230 V DC series motors, the manufacturer's characteristic curves for 230 V shall be used. At a constant-potential voltage other than 230 V, obtain an equivalent 230 V *hp* by multiplying the free-running *hp* by 230 divided by the applied voltage. From the curves, use this equivalent *hp* to obtain the motor speed at 230 V. Calculate the approximate N_f by multiplying the rpm so obtained by the applied voltage divided by 230.

(b) For AC wound rotor motors, the typical characteristic curves for wound rotor motors in Fig. 6473(b)-1 shall be used, taking into consideration the total secondary resistance at full speed. The curves are based on motors providing 3% slip at rated torque with rings shorted and with rated voltage applied to the primary,

$$hp_{pu} = T_{pu} (1 - T_{pu} \times Res._{pu})/0.97 \quad (13)$$

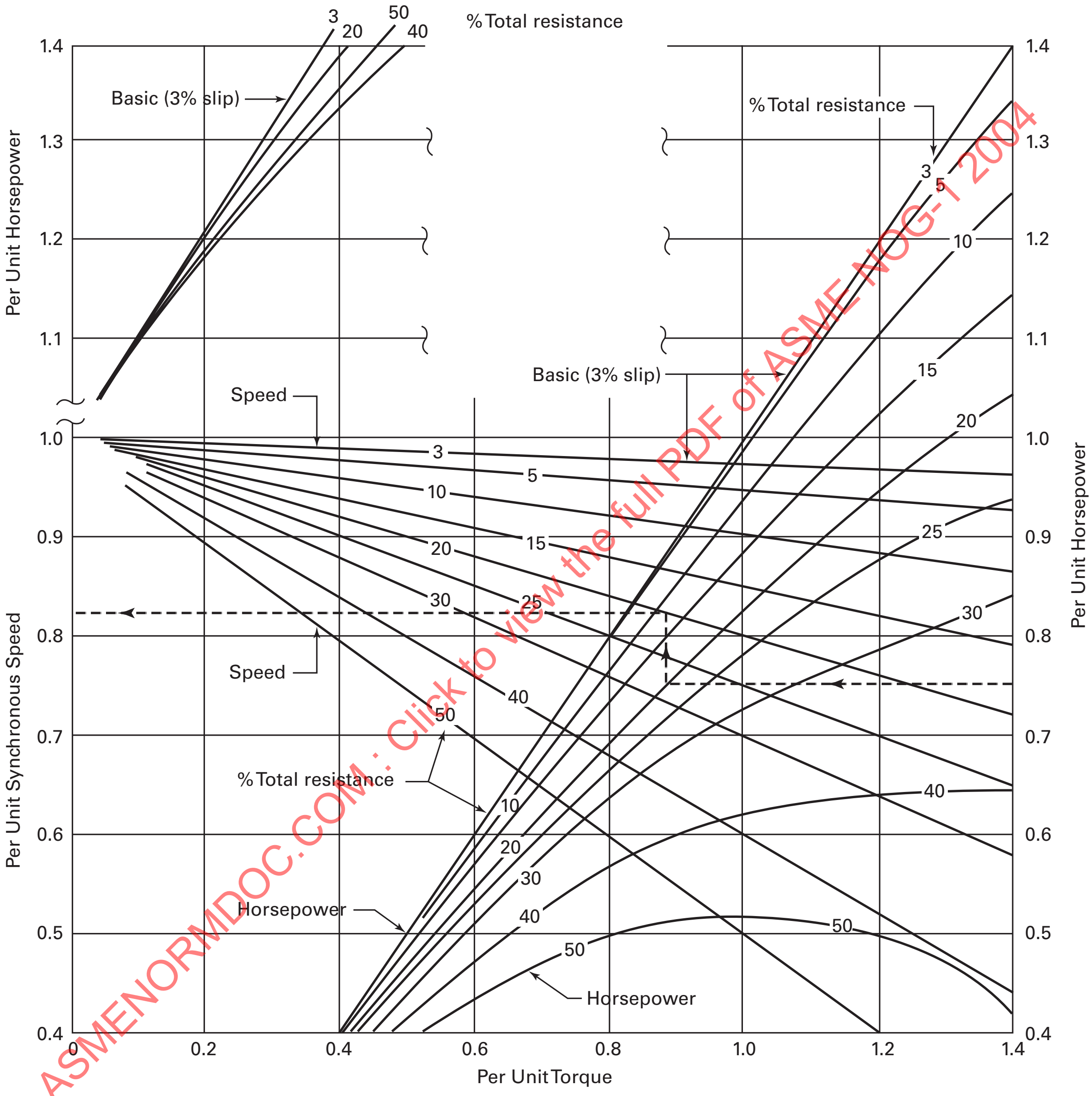


Fig. 6473(b)-1 Typical Characteristic Curves for AC Wound Rotor Motors (Examples for 0.75 Per Unit *hp* and 20% Total Resistance)

Per unit *hp* (hp_{pu}) for use of these curves

$$= \frac{\text{developed } hp \text{ (not incl. acceleration)}}{hp \text{ rating of motor}} \quad (14)$$

[The developed *hp* for a hoist is calculated by Eq. (1) with $K_s = 1$, and for a bridge or trolley by Eq. (9).]

At the calculated per unit *hp*, read per unit torque from appropriate *hp*-resistance curve and then read per unit synchronous speed at that torque on the speed curve for the same resistance. The dash line is an example at 0.75 per unit *hp* and 20% total resistance, resulting in approximately 0.88 per unit torque and 0.82 per unit synchronous speed.

(c) For DC adjustable voltage shunt motors, obtain manufacturer's rated speed for armature voltage and field strength used.

(d) For AC squirrel cage motors, use the motor's specific characteristic curves, to be supplied by the motor manufacturer.

6480 Conductor Systems (Types I, II, and III Cranes)

6481 General

(a) Conductor types and sizes shall be in accordance with NEC, taking into consideration the voltage drop limitations affecting the allowable voltage variations at the controller specified in para. 6411.2.

(b) If insulated, the insulation shall be rated for the radiation dose specified, if any.

(c) Each multiconductor control cable shall include spare conductors. The quantity of spares shall be approximately 10% of the total, but not less than two and not more than five being required.

(d) For repeated flexing service, the bending radius for the cable and the cable support system shall be not less than the minimum recommended for the cable by its manufacturer. Means shall be provided for supporting, extending, and retracting the cable to allow movement without exceeding the stress limit in the cable as stated by the cable manufacturer.

6482 Conductor System Categories. Conductor systems shall be considered in the following three general categories.

6482.1 Runway Systems. Conduct power from the building supply to the crane.

6482.2 Bridge Systems. Conduct power and control between the bridge and trolley portions of the crane.

6482.3 Auxiliary Systems. Such as pendant pushbutton, communication, remote control, and instrumentation cables.

6483 Conductor System Types (04)

(a) When AC variable frequency controls are used, the runway and bridge conductor systems shall include a grounding conductor.

(b) The following three general types of conductor systems shall be considered to meet the needs of the three categories in para. 6482.

(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 Type I, II, or III systems that use AC variable frequency drives or DC motor drives, there shall be at least two spring-loaded contact shoes per phase on main line 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 uninsulated 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, which is payed out off of 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 devices, 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, that is suspended in a festooned arrangement from a trolley and track system or in a cable carrier.

6500 ELECTRICAL EQUIPMENT TESTING REQUIREMENTS (TYPES I, II, AND III CRANES)

All electrical equipment shall be tested in accordance with Section 7000.

Section 7000
Inspection and Testing

(04) 7100 TESTS AND ACCEPTANCE CRITERIA

The following list identifies the specific tests and acceptance criteria for the inspections and tests specified by Tables 7200-1 and 7200-2.

(a) Drop weight test per ASTM E 208 or Charpy impact test per ASTM A 370. The owner or the owner's designated representative shall establish the acceptance criteria unless stated otherwise in this Standard.

(b) 100% radiographic test (RT) or ultrasonic test (UT) of buttwelds in accordance with AWS D1.1. Acceptance criteria shall be in accordance with AWS D1.1.

(c) 10% magnetic particle test (MT) or dye penetrant test (PT) of the linear feet of each weld that exceeds 10 in. in length unless stated otherwise in this Standard. Technique and acceptance criteria shall be in accordance with AWS D1.1.

(d) UT Volumetric Test

(1) UT volumetric tests are in accordance with ASTM A 435/A 435M-90 for plate material. Acceptance criteria for plate material shall be in accordance with ASTM A 435/A 435M-90.

(2) UT volumetric tests are in accordance with ASTM E 114 and ASTM A 388/A 388M-01 for wrought or forged material after forging and before machining.

(a) Acceptance criteria for forged material shall be in accordance with the following requirements:

(1) 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.

(2) 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.

(b) Acceptance criteria for the tensioned area of Type I crane hooks shall be in accordance with the following:

(1) Discontinuity indications in excess of the response from a $^5/_{64}$ in. diameter flat-bottomed hole at the estimated discontinuity depth shall not be acceptable.

(2) Discontinuity indications in excess of the response from a $^5/_{64}$ in. diameter flat-bottomed hole at the estimated discontinuity depth shall not have their indicated centers closer than 1 in.

(3) 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 $^5/_{64}$ in. diameter flat-bottomed hole.

(c) Acceptance criteria for material without parallel surfaces (such as sheave pins and shafts) shall be in accordance with (d)(2)(b) above.

(e) Proof load test of hooks including dimensional inspection as described in ASME B30.10. Acceptance criteria shall be in accordance with ASME B30.10.

(f) Wire rope breaking strength test. Breaking strength shall meet or exceed published breaking strength in accordance with Federal Specification RR-W-410 or wire rope manufacturer's published data. The sample used for the test shall be taken from the wire rope furnished.

(g) MT or PT

(1) MT or PT shall be performed in accordance with ASTM A 275/A 275M, E 709, and/or E 165.

(2) Nonrepairable transverse indications shall be in accordance with the following:

(a) Indications with any dimension of $^1/_{16}$ in. are unacceptable on material under 2 in. thick; on material 2 in. and over, indications with any dimension over $^1/_8$ in. are unacceptable.

(b) Four or more indications of any size separated by less than $^1/_{16}$ in. edge-to-edge are unacceptable on material under 2 in. thick; on

material 2 in. and over, less than $^1/_8$ in. edge-to-edge are unacceptable.

(c) Ten or more indications of any size in any 6 in.^{2} determined with the major dimension taken in the most unfavorable location relative to the indications but not exceeding 6 in. in length, are unacceptable.

(d) Indications may be explored to determine if they are the result of material discontinuities, material properties or part geometry. Only indications resulting from material discontinuities shall be considered unacceptable; however, all indications identified that exceed the criteria in (a) through (c) above shall be recorded in the test report.

(3) Nonrepairable transverse indication shall be unacceptable within the tensioned sections of the hook. Repairs by welding on the hook shall not be acceptable.

7200 MANUFACTURING

Inspections and testing of Types I and II cranes shall conform to this Standard. Assurance of implementation of the requirements of this Subsection for Types I and II cranes shall be in accordance with Section 2000. The manufacturer's standard inspection and testing program shall apply to Type III cranes if not otherwise specified in this Standard or contract document.

7210 Receipt and In-Process Inspection and Testing Requirements

(a) Receipt inspection and testing shall be performed for those items listed in Table 7200-1 for Type I cranes and Table 7200-2 for Type II cranes. In-process inspection and testing shall be performed in accordance with Table 7200-1 for Type I cranes and Table 7200-2 for Type II cranes. (See para. 7100 for definitions of inspections and tests required by tables.)

(b) Documentation required by Table 7200-1 or Table 7200-2 shall be reviewed and accepted by the crane manufacturer prior to the assembly of any item listed in these tables.

(c) All structural welds shall be visually inspected over their entire lengths for any type crane. Acceptance criteria of welds and repair shall be in accordance with AWS D1.1.

7220 Electrical Documentation

On Type I cranes, reports of standard NEMA tests shall be furnished by the electrical equipment manufacturer for hoist and travel motors and brakes.

7230 Assembly Inspection Requirements

The crane shall be sufficiently assembled to ensure that parts are properly fitted. Permanent wiring, other than that normally done at field erection, shall be complete. Control panels and rigid conduit shall be installed. It is not required to reeve the drum and blocks, to attach the cab, or to erect on gantry legs.

Inspections of the work shall be performed by the crane manufacturer. The owner or the owner's designee may verify that crane components are being installed, assembled, or connected in compliance with the latest appropriate drawings, codes, standards, and procedures.

7240 Electrical Inspection Requirements

Inspections shall be performed at the crane manufacturer's 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 job drawings and are properly identified;

(e) raceways are properly installed, and race-ways to be removed for shipment are to be properly fitted for field installation;

(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 as established by the job drawings;

(h) electrical items requiring routine maintenance are accessible;

(i) no wiring is touching resistor heating parts;

(j) portions of conductor systems which are designed to move in order to accommodate crane motion move freely;

(k) ancillary electrical items are properly installed;

(l) pendant cable strain relief is properly installed on pendant push-button station-operated cranes;

(m) overload relay current sensing elements are in accordance with job drawings;

(n) motor connections are properly made;

(o) contactors and electromechanical relays

Table 7200-1 Required Inspections or Tests — Type I

Items	Tests [Note (1)]									
	Material Test Reports	Certificate of Conformance From Item Manufacturer	RT or UT of Butt Welds [Para. 7100(b)]	MT or PT of Completed Welds [Para. 7100(c)]	UT — Base Material [Para. 7100(d)]	MT or PT of Surface [Para. 7100(g)]	Impact Test [Para. 7100(a)]	Proof Load Test (Including Dimensional) [Para. 7100(e)]	Breaking Strength Test [Para. 7100(f)]	Weld Filler Material C.C. Typical Value
Hook	x	. . .	. . .	. . .	x	x [Note (2)]	. . .	x	. . .	. . .
Hook nut or attachment device	x	. . .	. . .	. . .	x	x	. . .	x [Note (3)]	. . .	. . .
Trunnion or cross head	x	. . .	. . .	. . .	x	x	. . .	. . .	. . .	. . .
Load block load structures	x	. . .	. . .	. . .	. . .	. . .	x	. . .	. . .	. . .
Load block structural welds	. . .	. . .	. . .	x	. . .	. . .	. . .	. . .	. . .	x
Load block — sheave pin	x	. . .	. . .	. . .	x	x	. . .	. . .	. . .	. . .
Wire rope	. . .	x	. . .	. . .	. . .	. . .	. . .	. . .	x	. . .
Hoist drum	x	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Hoist drum shell and hub welds	. . .	. . .	x	x	. . .	. . .	. . .	. . .	. . .	x
Hoist drum shafts	x	. . .	. . .	. . .	x	x	. . .	. . .	. . .	. . .
Upper block sheave pin	x	. . .	. . .	. . .	x	x	. . .	. . .	. . .	. . .
Upper block load structure	x	. . .	. . .	. . .	. . .	. . .	x	. . .	. . .	. . .
Upper block structural welds	. . .	. . .	. . .	x	. . .	. . .	. . .	. . .	. . .	x
Sheaves	. . .	x	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Gears — hoist [Note (4)]	x	. . .	x	x	x	x	. . .	. . .	. . .	. . .
Pinions — hoist [Note (4)]	x	. . .	. . .	x	x	x	. . .	. . .	. . .	. . .
Shafts — hoist [Note (4)]	x	. . .	. . .	. . .	x	x	. . .	. . .	. . .	. . .
Trolley load girt structure	x	. . .	. . .	. . .	. . .	. . .	x	. . .	. . .	. . .

(continued)

Table 7200-1 Required Inspections or Tests — Type I (Cont'd)

	Tests [Note (1)]									
Items	Material Test Reports	Certificate of Conformance From Item Manufacturer	RT or UT of Butt Welds [Para. 7100(b)]	MT or PT of Completed Welds [Para. 7100(c)]	UT — Base Material [Para. 7100(d)]	MT or PT of Surface [Para. 7100(g)]	Impact Test [Para. 7100(a)]	Proof Load Test (Including Dimensional) [Para. 7100(e)]	Breaking Strength Test [Para. 7100(f)]	Weld Filler Material C.C. Typical Value
Trolley girt — structural welds [Note (5)]	. . .	. . .	. . .	x	. . .	. . .	. . .	. . .	. . .	x
Girder top and bottom plates [Note (6)]	x	. . .	. . .	. . .	. . .	. . .	x	. . .	. . .	. . .
Girder top and bottom plate but welds [Note (7)]	. . .	. . .	x	x	. . .	. . .	x	. . .	. . .	x
Fastener material for structural interconnection [Note (8)]	x	. . .	. . .	. . .	. . .	. . .	x	. . .	. . .	. . .
Girder web plates	x	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Girder web to top and bottom cover plate structural welds [Note (9)]	. . .	. . .	. . .	x	. . .	. . .	. . .	. . .	. . .	x
Girder internal stiffeners and diaphragm welds	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	x
Girder to end truck attachment	x	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Girder to end truck — structural welds	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	x
End tie — structure	x	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
End tie — structural welds	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	x
Girder end trucks — structure	x	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Girder end trucks — structural welds	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	x
Bridge and trolley seismic restraints — structural	x	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

(continued)

Table 7200-1 Required Inspections or Tests — Type I (Cont'd)

	Tests [Note (1)]									
Items	Material Test Reports	Certificate of Conformance From Item Manufacturer	RT or UT of Butt Welds [Para. 7100(b)]	MT or PT of Completed Welds [Para. 7100(c)]	UT — Base Material [Para. 7100(d)]	MT or PT of Surface [Para. 7100(g)]	Impact Test [Para. 7100(a)]	Proof Load Test (Including Dimensional) [Para. 7100(e)]	Breaking Strength Test [Para. 7100(f)]	Weld Filler Material C.C. Typical Value
Bridge and trolley seismic restraints — structural welds	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	x
Weld test plates [Note (10)]	. . .	. . .	. . .	. . .	. . .	. . .	x	. . .	. . .	. . .
$^1/_8$ in. or greater welds [Note (11)]	. . .	. . .	. . .	x	. . .	. . .	. . .	. . .	. . .	. . .
Brake drum	. . .	x	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Wire rope eyes and sockets [Note (12)]	. . .	x	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

NOTES:
(1) For test identification details, see para. 7100.
(2) After proof load test.
(3) Load tested with hook.
(4) Surface hardness shall be verified when hardness values are specifically listed on manufacturer's design documents.
(5) Throat thickness $^1/_8$ in. and greater, 100% weld inspection.
(6) As required by para. 4212.
(7) As required by para. 4232.
(8) As required by para. 4222.
(9) Throat thickness $^1/_8$ in. and greater, 10% of length.
(10) See para. 4212.
(11) See para. 4251.4.
(12) Proof tested to 40% of the published breaking strength of the wire rope.