CHAPTER 6—MECHANICAL DESIGN

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6.1—SCOPE

The following shall supplement *A6.1*.

This chapter contains information and criteria related to the design of movable bridge projects. It sets forth the basic Louisiana Department of Transportation and Development (LADOTD) design criteria exceptions and/or additions to those specified in *AASHTO LRFD Movable Highway Bridge Design Specifications*, Second Edition, 2007, including all interim revisions.

Construction specifications shall be the latest edition of the *Louisiana Standard Specifications for Roads and Bridges (Standard Specifications)*. The *Standard Specifications* are subject to amendment whenever necessary by supplemental specifications and special provisions to specific contracts. In the absence of specific information in the *Standard Specifications*, follow the latest edition of *AASHTO LRFD Bridge Construction Specifications*.

6.2—DEFINITIONS

The following shall supplement *A6.2*.

Fully Open—The position to which a movable span opens during the normal operation of the bridge.

Past Open—Any position beyond the “fully open” position. For vertical lift span bridges, going from “fully open” to “past open” will cause the “fully open” set point for the height rotary cam limit switch to become out of sync with the movable span. This limit switch will be re-set when the span has reached the seated position. The settings of this limit switch tend to drift during normal operation, due to rope slippage/creep.

6.3—NOTATION

6.3.1—General

The following shall supplement *A6.3.1*.

W_{all} = allowable tooth load, in pounds (*D6.7.5.1*)

P_{cp} = circular pitch, in inches (*D6.7.5.1*)

S_L = allowable unit stress, in pounds per square inch, when using the formula for gear design located in *D6.7.5.1*.

N_p = number of teeth in gear (*D6.7.5.1*)

V = velocity of pitch circle, in feet per minute (*D6.7.5.1*)

np = actual number of teeth in the pinion (*D6.7.5.1*)

ng = actual number of teeth in the gear (*D6.7.5.1*)

6.4—GENERAL REQUIREMENTS

6.4.1—Machinery

6.4.1.1—Limit States and Resistance Factors

The following shall replace the 3rd paragraph in *A6.4.1.1*.

Seismic loading shall be neglected for bridge machinery located in Louisiana.

6.4.1.3—Location of Machinery

The following shall replace the 2nd sentence in *A6.4.1.3*.

Machinery is not required to be located on the stationary part of the bridge.

Machinery placement in the State of Louisiana is affected by the need to keep the machinery above known hurricane storm surge levels for a particular bridge location.

C6.4.1.3

In Louisiana, it is preferred to have the hydraulic power unit, hydraulic piping, end lifts, center live load supports, and balance wheels located on the span for swing span bridges.

6.4.2—Aligning and Locking of the Movable Span

The following shall replace the 2nd sentence in *A6.4.2*.

For swing span bridges, effective end lifting devices shall be used, and, for bascule bridges, centering devices shall be used in conjunction with span locks.

The following shall replace the 2nd paragraph in *A6.4.2*.

For vertical lift bridges, span locks shall be interlocked or designed to be driven independent of the motor brakes.

C6.4.2

Centering devices are not required for swing span bridges if the end wedges utilize tapered shoes that limit the span misalignment to less than ± 3 in. and if the wedge shoes have side rails for wedge containment.

6.4.3—Elevators

The following shall replace the 1st sentence of *A6.4.3*.

Elevators will not be employed on movable bridges unless so specified by the Bridge Design Engineer Administrator.

Only vertical lift bridges having a difference of 100 ft. or more from the bridge deck to the tower drive machinery platform shall, at the discretion of the Bridge Design Engineer Administrator, have elevators incorporated into the design.

6.6—RESISTANCE OF MACHINERY PARTS

6.6.1—Resistance at the Service Limit State

The following shall supplement *Table 6.6.1-1 – Allowable Static Stresses, psi*.

Table 6.6.1-1—Supplemental Allowable Static Stresses, psi.

Material	AASHTO	ASTM	Tension	Compression	Fixed Bearing	Shear
Structural Steel (Carbon Steel)		ASTM A 709 Gr. 50W S_y=50,000psi S_{ut}=65,000psi	16,600	16,600 – 76 $\left(\frac{L_{eff}}{k}\right)$	22,000	8,300
Structural Steel (High Strength Low Alloy)		ASTM A 588, HSLA S_y=50,000psi S_{ut}=70,000psi	16,600	16,600 – 76 $\left(\frac{L_{eff}}{k}\right)$	22,000	8,300
Forged Alloy Steel		ASTM A668 Cl. K S_y=80,000psi S_{ut}=105,000psi	25,000	25,000 - 115 $\left(\frac{L_{eff}}{k}\right)$	30,000	12,500
Forged Alloy Steel (Bottom Disc)		ASTM A514 Gr. Q 275 BHN Min.	30,000	30,000 - 138$\left(\frac{L_{eff}}{k}\right)$	35,000	15,000
Forged Alloy Steel (For Pinions, Gears, & Shafts)		ASTM A291 Gr. 4 S_y=95,000psi S_{ut}=120,000psi	30,000	30,000 – 138$\left(\frac{L_{eff}}{k}\right)$	35,000	15,000
		ASTM A291 Gr. 6 S_y=120,000psi S_{ut}=145,000psi	40,000	40,000 – 184$\left(\frac{L_{eff}}{k}\right)$	48,000	20,000
Steel Castings		ASTM A148 S_y=85,000psi S_{ut}=105,000psi	21,000	21,000 - 96 $\left(\frac{L_{eff}}{k}\right)$	25,000	10,500
Manganese Bronze		ASTM B22 Alloy UNS C86300 S_y=60,000psi S_{ut}=110,000psi	15,000	15,000 -	-	-
Stainless-Steel Bars & Shapes (For Pins)		ASTM A564, Type 630, Condition H1150 S_y=105,000psi S_{ut}=135,000psi	35,000	35,000 - 123$\left(\frac{L_{eff}}{k}\right)$	42,000	17,500
Alloy Steel for line shafts where sized for torsional deflection not strength.		ASTM A434 4140 & 4142 S_y=96,000psi S_{ut}=110,000psi	32,000	32,000 - 148$\left(\frac{L_{eff}}{k}\right)$	38,000	16,000

6.7—MECHANICAL MACHINERY DESIGN

6.7.5—Design of Open Spur Gearing

6.7.5.1—General

The following shall supplement *A6.7.5.1*.

The use of open gearing shall be limited. When used, design open gearing per AGMA specifications. Design and specify guards for all (fast and slow speed) open gearing. Provide Accuracy Grade A9 or better per *ANSI/AGMA 2015-1-A01*.

All open gears shall be 20° full-depth spur teeth. Stub teeth shall not be used unless there are compelling reasons to do so.

Open gears shall also be designed assuming a minimum of 80 percent of the teeth having 80 percent contact along the face of the teeth and no tooth shall have less than 50 percent contact.

It is important to check the gear designed by current AGMA standards against the following formula, which assumes the load to be taken as applied to only one tooth.

The following formula applies:

1. Spur Gears and Bevel Gears

For full-depth involute teeth:

$$W_{\text{all}} = FS_L p_{cp}\left(0.154 - \frac{0.912}{n}\right)\frac{600}{600+V}$$

For stub involute teeth:

$$W_{\text{all}} = FS_L p_{cp}\left(0.178 - \frac{1.033}{n}\right)\frac{600}{600+V}$$

2. Helical teeth, full depth:

$$W_{\text{all}} = 0.7\, FS_L p_{cp}\left(0.154 - \frac{0.912}{n}\right)\frac{1200}{1200+V}$$

C6.7.5.1

This supplement has been taken from *AASHTO 1988 Standard Specifications for Movable Bridges.*

The AGMA gear quality shown here and in the *AASHTO LRFD Movable Highway Bridge Design Specifications*, Second Edition, 2007 including the 2008, 2010, 2011, and 2014 interim revisions, has adopted, with respect to gear quality, the AGMA 2000-A88 specification (previously AGMA 390.03 number designation). This specification has been replaced by AGMA 2015-1 and 2015-2, with the corresponding supplements 915-1 and 915-2 respectively.

The new AGMA 2015 standard is substantially different from the previous AGMA 2000-A88 standard.

AGMA states that "the user of ANSA/AGMA 2015-1-A01 must be very careful when comparing tolerance values formerly specified using ANSI/AGMA 2000-A88." Several critical areas to be aware of are as follows:

1. Accuracy grade numbers are reversed--A smaller grade number represents a smaller tolerance value and, as such, a higher quality gear. This is directly opposite to the previous AGMA standard, ANSI/AGMA 2000-A88, but does align with the procedures used by all other world gear standards. The tolerance grades for the new standard are designated A2-A11. Also note that the letter "A" is used to designate the new AGMA standard versus "Q" for the old 2000-A88 standard.
2. The "K" chart is no longer inferred for profile and lead evaluation--Using the old AGMA gear inspection standard, a "K" chart was established by constructing two lines diagonally across the tolerance band. A key problem with the "K" chart is that any profile or lead trace within the defined

For calculating the strength of bevel teeth, the middle section of the tooth shall be taken. The number of teeth “n” in the above formulas for bevel gear teeth shall be the formative number which, for the pinion, is determined as follows:

$$n = n_p\sqrt{1}\left(\frac{n_p}{n_g}\right)^2$$

where n_p = actual number of teeth in the pinion
n_g = actual number of teeth in the gear

The allowable stresses in pounds per square inch for cut gear teeth of all types shall be:

Bronze	9,000
Bronze High Strength	20,000
Cast Steel	16,000
Class C Forged Carbon Steel AASHTO M102 (ASTM A668 Cl. C)	20,000
Class D Forged Carbon Steel AASHTO M102 (ASTM A668 Cl. D)	22,500

Forged Alloy Steels shall have allowable stress equal to 60 percent of the yield point in tension, but not more than 1/3 of the ultimate strength in tension.

The allowable stress in pounds per square inch for machine-molded teeth shall be:

Cast Steel	8,000

For racks and pinions and all other mating gears and pinions which are not supported in and shop assembled in a common frame, the allowable unit stresses shall be decreased by 20 percent. All open gearing shall be assumed to have 75 percent contact between mating surfaces.

"K" area would be an acceptable gear. In reality, this gear may or may not be a "good" gear. A second problem with the use of a "K" chart is that a nominal value is inferred such that the ideal profile or lead trace is inferred to be in the mean of the "K" area at all points.

3. Slope and form errors are now included--In addition to total helix and profile errors, slope and form errors are included for both profile and helix inspection.
4. The new AGMA 2015 gear inspection is a pure metric standard--Only a few notes are included regarding the US/Imperial system. The new AGMA standard is formula based--The AGMA tolerances for the various accuracy groups are calculated from formulas. This has been done for two reasons. First, the formulas can be computer based to provide easy and accurate calculations of the gear tolerances. Second, the tolerance calculated will reflect the actual gear parameters. Other gear inspection standards use groupings of tolerances that could allow "fudging" of the gear design to place it within a favorable position of the range
5. The new AGMA standard has an extended range. Modules (mn) from 0.5 to 50.0 mn (diametric pitch 50.8 to 0.5 DP) are now included. The new standard includes ranges of diameter (D) of 5 to 10,000mm, teeth (z) of 5 to 1000 (or 10,000/mn, whichever is less), face width (b) of 0.5 to 1000mm, and helix (β) up to 45°.

Accuracy Grade Groupings

The new AGMA 2015 standard places gears into three accuracy groups. The highest quality gears are placed in the "high accuracy" group and have designations of A2-A5. "Medium accuracy" are designated A6-A9, and "low accuracy" are designated A10-A11. Again, notice that the quality grade in the new AGMA standard is preceded by the letter "A" to distinguish it from the previous standard.

For the low accuracy gear grouping only "cumulative pitch" and "single pitch" are required. For the medium accuracy gear grouping, cumulative pitch and single pitch, as well as "total profile and lead" are required. For the high accuracy gear grouping, cumulative pitch, single pitch, lead and profile total, slope, and form are required.

The following table is taken from *Machinery's Handbook, Twenty-Eighth Edition* and shall be used for determining the backlash for open gearing used for movable bridge applications.

The backlash for open gearing shall be shown on the contract drawings.

Table 6.7.5.1-1—Recommended Backlash Range for Course-Pitch Spur, Helical, & Herringbone Gears

Center Distance (in.)	Normal Diametral Pitches					
	0.10-.049	0.50-1.99	2.00-3.49	3.50-5.99	6.00-9.99	10.00-19.99
	Backlash, Normal Plane, Inches[a]					
Up to 5		…	…	…	…	.005-.015
Over 5 to 10		…	…	…	.010-.020	.010-.020
Over 10 to 20		…	…	.020-.030	.015-.025	.010-.020
Over 20 to 30		…	.030-.040	.025-.030	.020-.030	…
Over 30 to 40		.040-.060	.035-.045	.030-.040	.025-.035	…
Over 40 to 50		.050-.070	.040-.055	.035-.050	.030-.040	…
Over 50 to 80		.060-.080	.045-.065	.040-.060	…	…
Over 80 to 100		.070-.095	.050-.080	…	…	…
Over 100 to 120 *		.080-.110	…	…	…	
Over 120 to 140 *	.145-.175	.100-.125	…	…		
Over 140 to 160 *	.165-.185	…	…			
Over 160 to 180 *	.175-.205	…				
Over 180 to 200 *	.185-.220					

a. Suggested backlash, on nominal centers, measured after rotating to the point of closest engagement. For helical and herringbone gears, divide above values by the cosine of the helix angle to obtain the transverse backlash.

*****These backlash values have been calculated using ***Equation 5.1*** from ***ANSI/AGMA 2000-A88*** and in addition contain the allowance for thermal expansion assuming temperatures up to 70° Fahrenheit from ambient. These backlash values are not part of ***Table 1-AGMA Recommended Backlash Range for Course Pitch Spur, Helical, and Herringbone Gearing*** shown in the ***Machinery's Handbook*, Twenty-Eighth Edition**. These backlash values are suggestions intended to be used for the largest rack gears on swing span bridges, bascule bridges, and large sheaves on vertical lift bridges.

The above backlash tolerances account for gear expansion, due to differential in the operating temperature of the gearing and their supporting structure and fabrication tolerances. The values may be used where the operating temperature is up to 70° Fahrenheit higher than the ambient temperature.

For most gearing applications, the recommended backlash ranges will provide proper running clearance between engaging teeth of mating gears. Deviation below the minimum or above the maximum values shown, which do not affect the operational use of the gearing, should not be cause for rejection.

6.7.5.2—AGMA Spur Gear Design Equations

6.7.5.2.2—Design for the Fatigue Limit State

The following shall replace equation *6.7.5.2.2-3* shown in *A6.7.5.2.2*.

$$K_v = \left[\frac{A + \sqrt{v_t}}{A}\right]^B$$

The following shall replace the definition of $\mathbf{K_o}$: The Overload factor shall be taken from Table C6.7.5.2.2-3, below.

$\mathbf{Q_v}$ **=** Gear Quality Number taken as an integer between 7 and 12 (dim.).

C6.7.5.2.2

$\mathbf{V_t}$ should be $\boldsymbol{v_t}$; there is a typographical error in the equation *6.7.5.2.2-3* shown in *A6.7.5.2.2*

The following shall supplement *AC6.7.5.2.2*.

Overload Factor $\mathbf{K_o}$ shall be taken from Table C6.7.5.2.2-3, below.

Table C6.7.5.2.2-3—Overload factor, K_o

Overload Factor, K_o			
	Driven Machinery		
Source of power	Uniform	Moderate Shock	Heavy Shock
Uniform	1.00	1.25	1.75
Light shock	1.25	1.50	2.00
Medium shock	1.50	1.75	2.25

The following shall supplement the 4th paragraph under *AC6.7.5.2.2*.

This commentary asks the Designer to refer to AGMA Standards for a definition of the gear quality number and goes further to say that “the accuracy of the gear increases with the increase of the gear quality number.” This is true when referring to the older *AGMA 2000-A88*, which is the gear quality number shown here (left). The current *AGMA 2015-1 and 2* has changed the definition of the gear quality number to mean “the lower the number the higher the tolerance and the higher the number the lower the tolerance”; this is opposite from what is stated in *AASHTO LRFD Movable Highway Bridge Design Specifications, Second Edition, 2007* including the 2008 interim revisions. See *D6.7.5.1* and *DC6.7.5.1*.

Size Factor K_s shall be determined by the following formula:

$$K_S = 1.192\left(\frac{F\sqrt{Y}}{P}\right)^{0.0535}$$

where:

F = Face width (in).

Y = The Lewis Form Factor.

P = Diametral Pitch.

6.7.6—Enclosed Speed Reducers

6.7.6.1—General

The following shall supplement *A6.7.6.1*.

Specify and detail gearboxes to meet the requirements of the latest edition of ANSI/AGMA 6013 Standard for Industrial Enclosed Gear Drives.

Specify and detail gearing to conform to ANSI/AGMA 2015-1-A01, Accuracy Grade A9 or better using a Service Factor of 1.0 or higher, and indicating input and output torque requirements.

Allowable contact stress numbers, "S_{ac}," must conform to the current AGMA Standard for through-hardened and for case-hardened gears.

Allowable bending stress numbers, "S_{at}," must conform to the current AGMA Standard for through-hardened and for case-hardened gears.

Include gear ratios, dimensions, construction details, and AGMA ratings on the Drawings.

For bascule bridges, provide a gearbox capable of withstanding an overload torque of 300 percent of full-load motor torque (service factor of 3.0 for strength). This torque must be greater than the maximum holding torque for the leaf under the maximum brake-loading conditions. The output shafts shall have permanent differential capability.

For vertical lift bridges, the main parallel shaft speed reducers shall be designed according to the current AGMA standards and be capable of withstanding an overload torque of 200 percent of full-load motor torque (service factor of 2.0 for strength and 1.25 for durability). In addition, the input shaft of this gearbox shall be sized to handle twice the input motor horsepower. The gearbox shall be capable of differential output, but shall also be capable of having the output shafts locked

C6.7.6.1

Please note that, because the enclosed gear reducers are specified by the Designer but the gear box manufacturer is responsible for its design and fabrication, the most current AGMA standards will apply. As a result, this section will adopt the ANSI/AGMA 2015-1-A01. The accuracy Grade in this case is preceded by the letter “A” which corresponds to the current AGMA 2015 standard. See *D6.7.5.1* and *DC6.7.5.1*.

These allowable contact and bending stress numbers are for AGMA Grade 1 materials.

It is recommended to have the differential as near the output as practical to reduce the number of moving parts within the gearbox. If the differential is placed on the input, then a wet clutch may be used.

Sizing the input shaft of the main gearbox to twice the input motor horsepower is due to having a wound rotor motor fail and therefore using one motor to open the bridge while the second motor acting as a selsyn tie driving the third motor (opposite side of the waterway). As a result, the input shaft of the gearbox may experience twice the load.

together to act as one shaft by a means of a manual clutch mechanism. The clutch mechanism shall be engaged and disengaged by pushing and pulling an external rod. It shall be capable of locking and unlocking the output shafts, regardless of whether or not the gearbox is fully loaded, and/or whether or not the gear box is turning.

Specify gears with spur, helical, or herringbone teeth. Bearings shall be anti-friction type and shall have a B-10 life of 100,000 hours, except where rehabilitation of existing boxes requires sleeve-type bearings.

Specify that the housings shall be welded steel plate or steel castings. The inside of the housings shall be sandblast-cleaned prior to assembly, completely flushed, and be protected from rusting. The housing shall have a permanent stainless-steel or aluminum nameplate stating the name of the gear box manufacturer, horsepower rating, service factors, input rpm, output rpm, gear ratio, and thermal rating.

Specify exact ratios.

Specify units with a means for filling and completely draining the case.

Specify an oil drain with a bronze or stainless-steel drain valve. The valve shall have a stainless-steel plug to prevent loss of lubricant due to accident or vandalism.

Furnish each unit with a corrosion-resistant moisture trap breather of the desiccant type with color indicator to show desiccant moisture state.

Specify inspection covers to permit viewing of all gearing (except the differential gearing, if impractical). Inspection covers shall be attached with stainless-steel hardware with seals appropriate for outdoor use.

Specify a sight oil level gauge to show the oil level. The oil level gauge must be of rugged construction and protected from breakage.

Specify that the input and output shafts shall have double FKM rubber shaft seals or those which are recommended by the bearing manufacturer and approved by the Bridge Design Engineer Administrator. All shaft seal assemblies shall have provisions to grease between the seals.

The gearbox shall be lubricated by a synthetic lubricant recommended by the gear box manufacturer.

Design and detail each gearbox with its associated brakes, motors, plugging switches, tachometer, and clutch operating machinery, if applicable, mounted on a single welded support.

Do not use vertically stacked units and components.

Detail and dimension the supports. However, leave off dimensions that are dependent on manufactured equipment. Have the shop obtain certified drawings from the manufacturer prior to producing shop drawings.

Size and locate all mounting bolts and anchor bolts.

All enclosed reducers exposed to the weather shall have the housing, seals, accessories, and the protective finish appropriate for such an application.

6.7.6.3—Worm Gear Reducers

The following shall replace the 1st sentence in *A6.7.6.3*.

Worm gear reducers shall not be used to transmit power to move the span or any high inertial loads. Worm gear reducers may be used to activate rotary cam limit switches, encoders, resolvers, tachometers, selsyn devices, or to drive end lifts and center wedges.

6.7.6.6—Mechanical Actuators

The following shall supplement *A6.7.6.6*.

Actuators shall be all stainless steel and suitable for harsh environments.

Mechanical actuators should never be used to transmit power to move high inertia loads on movable bridges.

C6.7.6.6

Mechanical actuators are commonly used to drive lock bars or actuate span lock latches, and both are considered to have no inertia loads.

6.7.7—Bearing Design

6.7.7.1—Plain Bearings

6.7.7.1.1—General

The following shall supplement *A6.7.7.1.1*.

Sleeve bearings shall be grease-lubricated bronze bushings and shall have grease grooves cut in a spiral pattern for the full length of the bearing.

C6.7.7.1.1

It is desirable to have the friction produced by sleeve bearings aid in the control of bascule bridge leafs while moving.

Provide cast-steel base and cap for bearings. Cap shall have lifting eyes with loads aligned to the plane of the eye.

6.7.7.1.4—Self-Lubricating, Low Maintenance Plain Bearings

6.7.7.1.4a—Metallic Bearings

The following shall supplement *A6.7.7.1.4a*.

These bearings shall not be used unless specified by the Bridge Design Engineer Administrator.

C6.7.7.1.4a

The LADOTD does not want to rely on self lubrication.

6.7.7.1.4b—Non Metallic Bearings

The following shall supplement *A6.7.7.1.4b*.

These bearings shall not be used unless specified by the Bridge Design Engineer Administrator.

6.7.7.2—Rolling Element Bearings

6.7.7.2.3—Roller Bearings for Heavy Loads

The following shall supplement *A6.7.7.2.3*.

Anti-friction bearing pillow block and flange-mounted roller bearings must be adaptor-mounting, self-aligning, expansion and/or non-expansion types.

1. Specify cast-steel housings capable of withstanding the design radial load in any direction, including uplift. Specify that the same supplier shall furnish the bearing and housing.
2. Specify bases to be cast and furnished with pilot holes for mounting so that, at the time of assembly with the supporting steel work, mounting holes are "drilled/reamed-to-fit" in the field. For pillow blocks used in supporting traffic barrier shafting under the roadway, slotted holes shall be used; however, chocks shall be provided at each pillow block having slotted holes.
3. Specify that triple seals shall be used. The inner seal shall be oriented such that it retains the lubricant inside of the bearing housing. The outer two seals shall be

oriented such that they prevent moisture and debris from entering the bearing housing. A provision to grease between the inner and outer seals shall be provided.

4. Specify high-strength mechanically galvanized steel cap screws on pillow blocks. The cap and cap screws must be capable of resisting the rated bearing load as an uplift force. Where clearance or slotted holes are used, the clearance space must be filled after alignment with a non-shrink grout suitable for steel to ensure satisfactory side load performance.

Fixed trunnions on bascule spans shall use bronze sleeve bearings unless specified by the Bridge Design Engineer Administrator.

See Figure 6.8.3.4.3-1 – Trunnion Spherical Roller Bearing Assembly, below, for more information.

6.7.8—Fits and Finishes

C6.7.8

The following shall replace the 2nd paragraph in *AC6.7.8.*

Fits other than those listed in *Table 6.7.8-1* may be used at the discretion of the Bridge Design Engineer Administrator.

The following shall supplement *C6.7.8*.

It has been the LADOTD's experience that if the 0.4 times hub thickness, as described in *A6.7.9.1* and *D6.7.9.1*, is followed for counterweight sheave hubs, an FN2 fit is adequate for sheave trunnions/hubs.

6.7.9—Hubs, Collars, and Couplings

6.7.9.1—Hubs

The following shall supplement the 2nd sentence of the 1st paragraph in *A6.7.9.1*.

The minimum thickness at any place on the hub of counterweight sheaves shall be not less than 0.4 of the gross section diameter of the bore.

6.7.9.3—Couplings

The following shall supplement *A6.7.9.3*.

Coupling information shall be included in the plans and shall include torque ratings, bore sizes, key sizes, and number of keys for the driver and driven sides. Provide coupling guards on all high-speed couplings. Specify low maintenance couplings: preferably the single gear type where feasible. Double gear couplings are not recommended.

All couplings associated with limit switches or other control-related equipment shall use stainless-steel double-helical flexure beam couplings with stainless-steel set screws and keys or of similar design.

C6.7.9.3

Helical flexure couplings shall only be used on shafts whose purpose is to transmit angular rotation to control devices such as rotary cam limit switches, selsyn devices, transmitters, resolvers, tachometers, or encoders. Use these couplings only for control not power transmission.

6.7.10—Keys and Keyways

6.7.10.1—General

The following shall supplement *A6.7.10.1*.

All keys for shafts 1 in. diameter and smaller shall be ASTM A276 304/316 stainless steel.

C6.7.10.1

The following shall supplement *AC6.7.10.1*.

ASTM A564 Type 630 Condition H1150 can be used if higher strength is needed

6.7.13—Motor and Machinery Brake Design

6.7.13.2—Requirements for Electrically Released Motor Brakes

The following shall supplement *A6.7.13.2*.

Use thruster-type brakes. Specify double-pole; double-throw limit switches to sense brake fully set, brake fully released, and brake manually released.

Provide a machinery brake and a motor brake. Submit calculations justifying the brake torque requirements.

Specify *AISE-NEMA* brake torque rating in the plans. Ensure that both dimensions and torque ratings are per *AISE Technical Report No. 11, September 1997*.

Show brake torque requirements on the contract drawings.

Specify the brake thruster to have an enamel powder coat finish with stainless-steel accessories suitable for harsh environments.

Specify all brake materials, with the exception of the brake wheel and the thruster, to be made from stainless steel with bronze bushings/spacers.

Carefully consider machinery layout when locating brakes. Avoid layouts that require removal of multiple pieces of equipment for maintenance of individual components.

Ensure that brakes are installed with base in the horizontal position only. For rolling lift bascule bridges where the movable bridge drive machinery is located on the movable span, orient brakes such that the hydraulic thrusters will function properly throughout the opening angle of the span.

All brakes shall use a stainless-steel NEMA 4X enclosure with the appropriate seals and stainless-steel hardware. The enclosure shall permit access to all brake adjustment points.

Where practical, locate the brake between the motor and the gearbox in order to hold the shaft while the motor is removed and/or replaced.

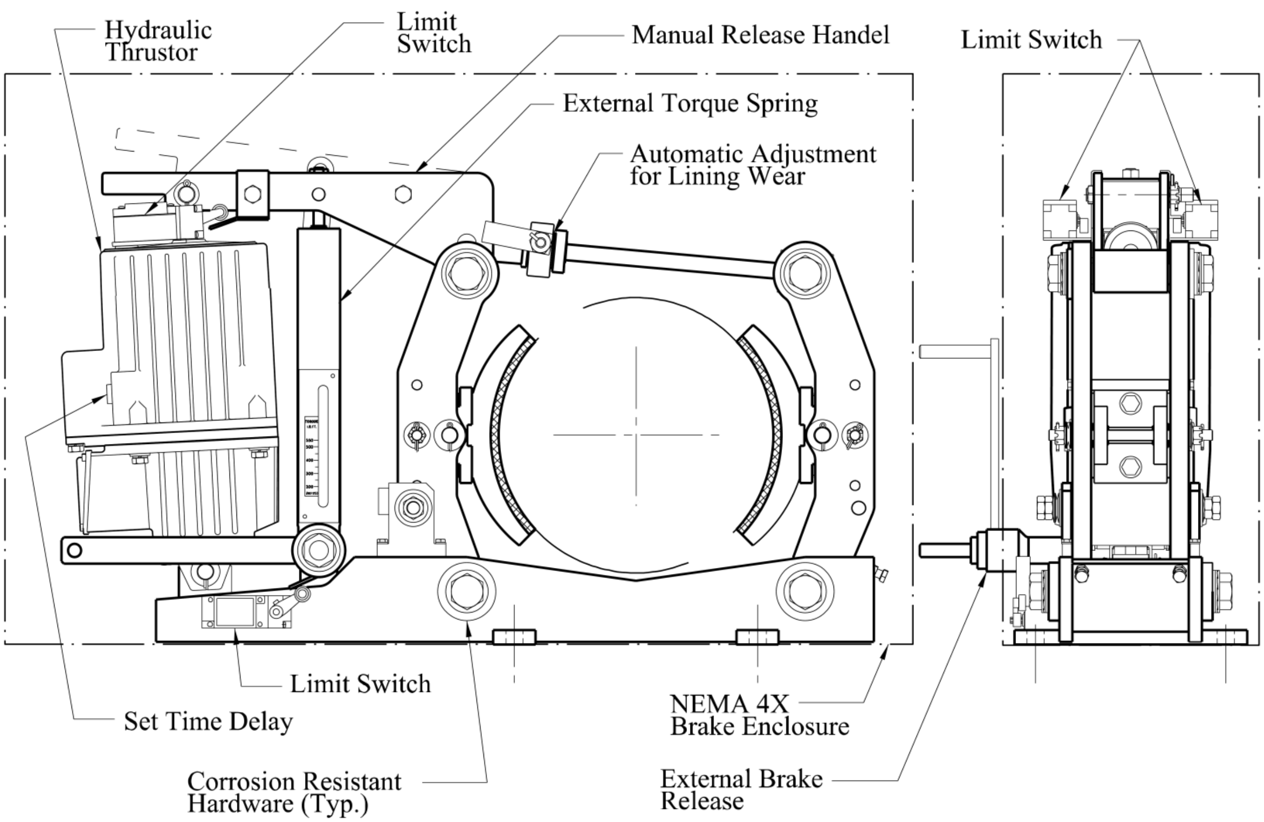


Figure 6.7.13.2-1—Thruster Type Electrically Released Shoe Brake

6.7.14—Machinery Support Members and Anchorage

6.7.14.1—Machinery Supports

The following shall supplement *A6.7.14.1*.

Provide a self-contained, welded steel support for each pair of pinion bearings and trunnion bearings. Avoid shapes and conditions that trap water and/or collect debris.

When turned bolts are to be used, specify the support to be fabricated and shipped to the field blank (with no holes). All turned bolt holes will be field drilled and reamed at assembly with their respective pillow block bearing assemblies.

Indicate or specify flatness and parallelism, position, levelness, and orientation tolerances for the supports.

Machine the mounting surface per *A6.7.8* and *DC6.7.8.*

Design to assure that the anchor bolts will be accessible for hydraulic tensioning.

Provide a reasonable clearance all around the machinery support to facilitate service access to the bearings.

Provide adjustment screws and tabs on top of the machinery support to accurately locate each bearing housing relative to its associated support.

C6.7.14.1

The following shall supplement *AC6.7.14.1*.

Care should be taken not to dimension supports based on a manufactured item. Those dimensions must be based on the submitted component. Machinery supports should not be approved before the machinery is approved.

6.7.14.2—Anchorage

The following shall supplement *A6.7.14.2*.

For machinery supports anchored to concrete, design for the maximum forces generated in starting or stopping the span plus 100 percent impact. Design hydraulic cylinder supports for 150 percent of the relief valve setting or the maximum operating loads plus 100 percent impact, whichever is greater. Detail machinery supports anchored to the concrete by preloaded anchors such that no tension occurs at the interface of the steel and concrete under any load conditions.

Mechanical devices used as anchors must be capable of developing the strength of reinforcement without damage to the concrete. Concrete anchors must be cast-in-place, drilled and epoxy-grouted, or undercut bearing

C6.7.14.2

expansion-type anchors. The bolt must consistently develop the minimum specified strength of the bolting material to provide a favorable plastic elongation stretch over the length of the bolt prior to causing high-energy failure. Require pullout testing of anchors deemed to be critical to the safe operation of the bridge machinery system. Pullout verification tests must be performed at not less than 200 percent of maximum operational force levels.

The depth and diameter of the embedment must be sufficient to assure steel failure prior concrete failure, with concrete cone shear strength greater than the strength of the bolting material.

Anchor Bolt Design:

Design anchor bolts subject to tension at 200 percent of the allowable basic stress and shown, by tests, to be capable of developing the strength of the bolt material without damage to concrete.

Specify the anchor bolts to be hot-dipped galvanized (for standard-grade bolts) or mechanically galvanized (for high-strength bolts).

Machinery anchor bolts shall be 316 stainless steel-rated for a minimum of 30ksi for saltwater environments and type 304-rated for a minimum of 30KSI if salt water is not present.

For high-strength stainless-steel anchor bolts, use ASTM F 593, alloy group 7, Condition AH, 135KSI Tensile and 105KSI Yield; or ASTM A564, Type 632, H1150, 135KSI Tensile and 105 KSI Yield for bolts greater than 1 ½ in. diameter.

The current view of the LADOTD is to move to stainless-steel anchor bolts, both for structural connections and mechanical equipment connections because of the amount anchor bolts that are failing prematurely due to corrosion.

6.7.15—Fasteners, Turned Bolts, & Nuts

The following shall supplement *A6.7.15*.

Fasteners, cap screws, turned bolts, nuts, and washers shall conform to the latest edition of the *Louisiana Standard Specifications for Roads and Bridges*.

6.8—BRIDGE TYPE-SPECIFIC MECHANICAL DESIGN

6.8.1—Bascule Spans

6.8.1.1—Drive Machinery

The following shall replace *A6.8.1.1*.

Drive machinery for bascule spans shall include: drive motor(s), main reducer, output shafts, and two pinions driving two racks mounted to two girders.

Hydraulic drive machinery shall also include a redundant hydraulic power plant powering multiple hydraulic cylinders having stop tubes and cushions. The redundant hydraulic power plant shall consist of electric motors, pumps, directional control valves, reservoir, hydraulic piping, and hydraulic hoses.

C6.8.1.1

There are exceptions, e.g., machinery to drive one pinion/rack centrally located on the span.

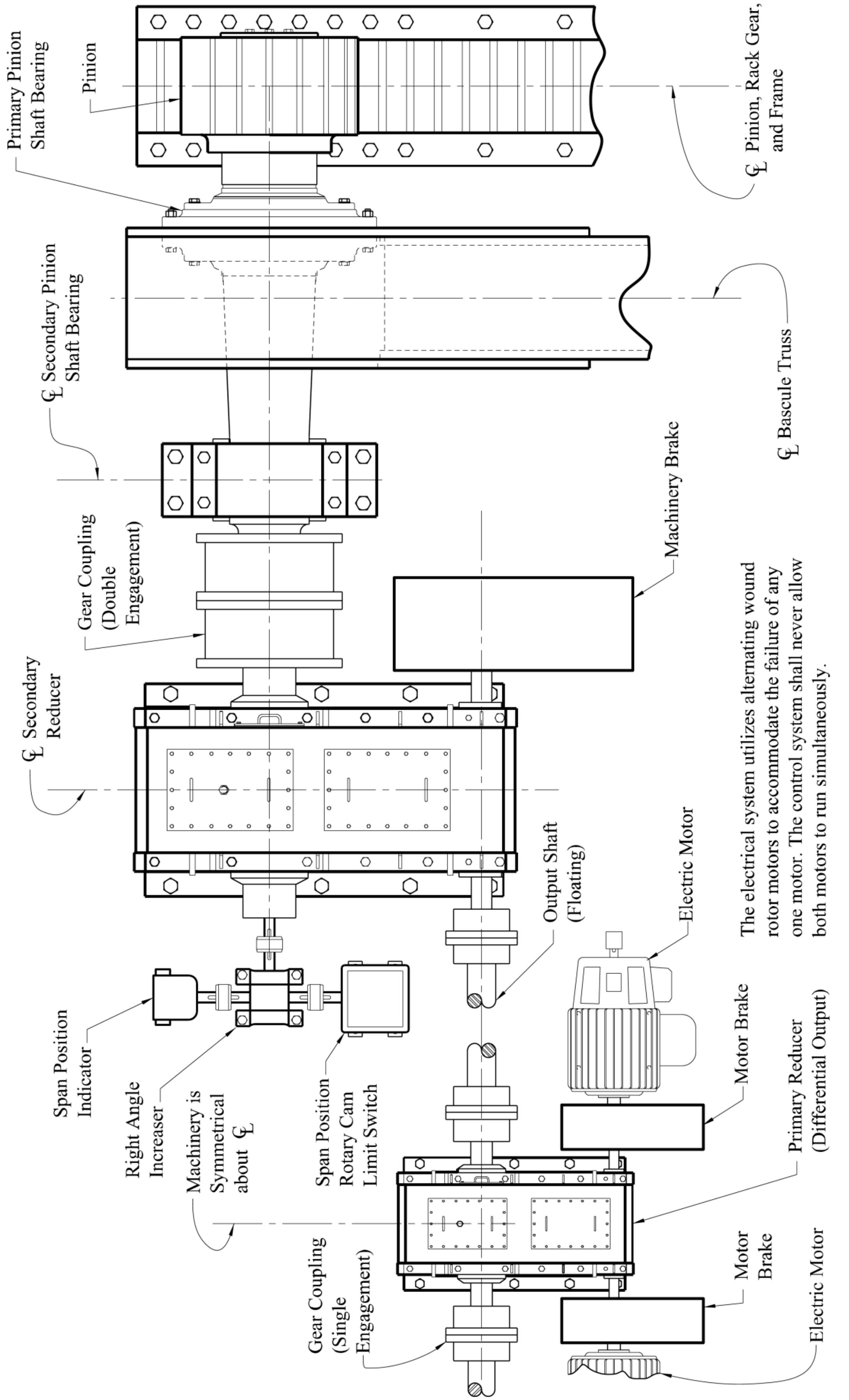


Figure 6.8.1.1-1 — Span Drive Machinery Layout for a Rolling Lift Bascule Bridge

6.8.1.2—Racks and Pinions

6.8.1.2.1—General

The following shall replace *A6.8.1.2.1*.

Where a multiple rack and pinion drive is used, there shall be a differential gear reducer on the bridge to equalize the torques at the main pinions.

C6.8.1.2.1

This main reducer shall be in differential mode at all times. A clutch mechanism used to lock or unlock the output shafts is not required.

6.8.1.2.3—Pinions

The following shall supplement *A6.8.1.2.3*.

The pinion shall be 1 in. greater (½ in. on each side) in face width than the mating rack gear.

C6.8.1.2.3

The pinion face width shall be greater than the rack face width for bascule bridges.

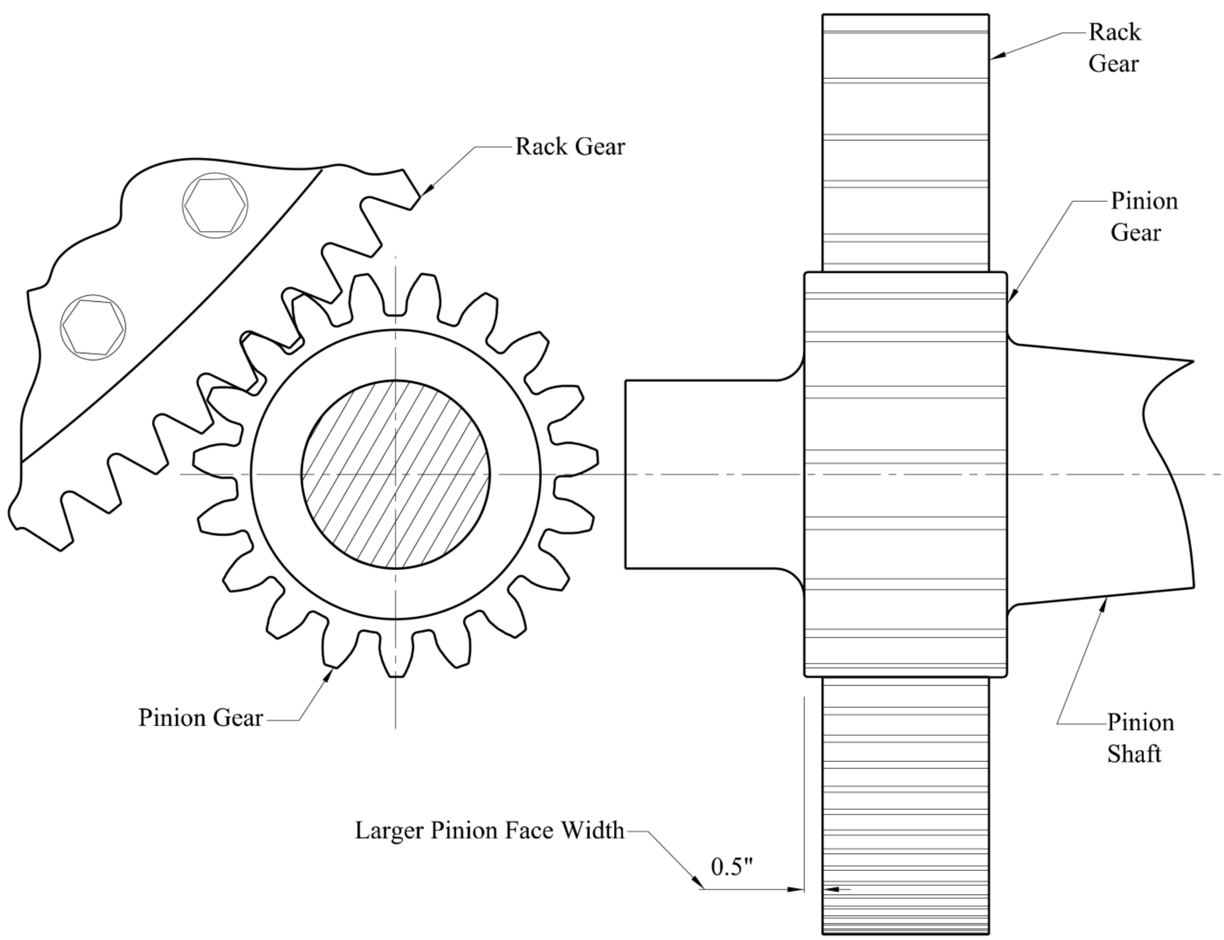


Figure 6.8.1.2.3-1—Typical Pinion and Ring Gear Assembly on a Bascule Bridge

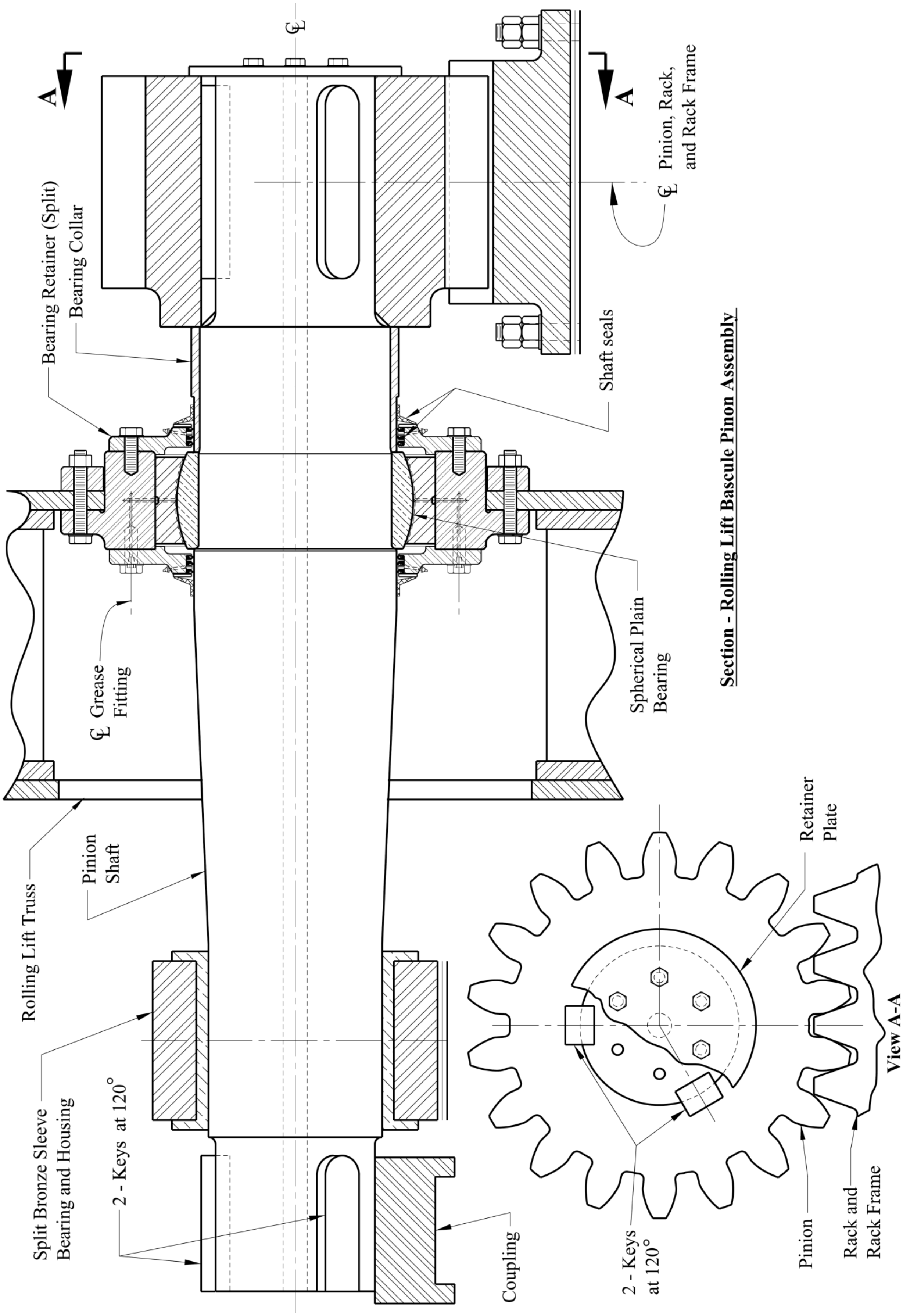


Figure 6.8.1.2.3-2—Pinion, Shaft, & Bearing Assembly for a Rolling Lift Bascule Bridge

6.8.1.3—Trunnions and Bearings

6.8.1.3.1—Trunnions

The following shall supplement *A6.8.1.3.1*.

Provide shoulders with fillets of appropriate radii.

Provide clearances for thermal expansion between shoulders and bearings.

Do not use keys between the trunnion and the hub.

For trunnions over 8 in. diameter, provide a hole 1/5 the trunnion diameter lengthwise through the center of the trunnion. Extend the trunnion at least 5/8 in. beyond the end of the trunnion bearings for bronze bushings only.

Provide a 2 in. long counter bore concentric with the trunnion journals at each of the hollow trunnion ends.

In addition to the shrink fit, drill and fit dowels of appropriate size through the hub into the trunnion after the trunnion is in place. The dowels shall have the means to vent air when they are being installed.

For rehabilitation of existing Hopkins trunnions, verify that trunnion eccentrics have capability for adjustment to accommodate required changes in trunnion alignment and are a three-piece assembly. If not, provide repair recommendations.

C6.8.1.3.1

6.8.1.3.2—Trunnion Bearings

The following shall supplement *A6.8.1.3.2*.

For bascule type bridges, trunnion bearings shall be bronze sleeve bearings. Rolling element bearings are not recommended.

C6.8.1.3.2

Sleeve bearing friction helps control the bascule span when moving.

6.8.1.4—Buffers

The following shall supplement *A6.8.1.4*.

Buffers are not necessary on hydraulic bascule bridges. Mechanical bascule bridges will most likely still need air buffers because LADOTD currently does not allow PLC control systems. See Figure 6.8.1.5.1-1 – Typical Lock Bar and Air Buffer Layout for a Single Leaf Bascule Bridge,

C6.8.1.4

Most bascule bridges in Louisiana do not have air buffers; in fact, the Causeway bascule bridges had their buffers removed. These buffers were causing maintenance problems and were eventually taken out of the system before they were permanently removed from the bridge. It below.

shall be noted that these bridges have PLC control systems which provide the soft positive seating. The Causeway bascule bridges are not owned by the LADOTD.

6.8.1.5—Span and Tail Locks, Centering Devices

6.8.1.5.1—Locking Devices

The following shall supplement *A6.8.1.5.1*.

For double leaf bascule bridges:

1. Design span locks attached to the main bascule girders. Provide maintenance access. Do not use tail locks or side locks on new bridge designs.
2. Specify a 4 in. x 6 in. minimum rectangular lock bar, unless analysis shows need for a larger size. Submit design calculations and the selection criteria for review and approval.
3. Install the bar in the guides and receivers with bronze wear fittings top and bottom, properly guided and shimmed. Provide lubrication at the sliding surfaces. Both the front and rear guides are to have a "U" shaped wear-plate that restrains the bar horizontally as well as vertically. The receiver is to have a flat wear-plate to give freedom horizontally to easily insert the lock bar in the opposite leaf. The total vertical clearance between the bar and the wear-shoes must be 0.010 in. to 0.025 in. When specifying the total horizontal clearance, the designer shall account for the thermal expansion of the movable span.
4. Provide adequate stiffening behind the web for support of guides and receivers.
5. Mount guides and receivers with ½ in. minimum shims for adjusting. Slot wear-plate shims for insertion and removal. Consider the ease of field replacing or adjusting shims in the span lock design.
6. Specify alignment and acceptance criteria for complete lock bar machinery, for the bar itself in both horizontal and vertical, and for the bar with the cylinder.

C6.8.1.5.1

Single leaf bascule bridges may not need a 4 in. x 6 in. lock bar, or they may not employ a lock bar at all. They may instead employ a hook lock.

7. Provide lubrication fittings at locations that are convenient for routine maintenance.
8. Mount actuation elements on the lock to activate limit switches controlling each end of the stroke. Incorporate a means to adjust the limit-switch actuation. Taper the receiver end of the lock bar to facilitate insertion into the receivers of the opposite leaf.
9. Connection of the lock bar to the hydraulic cylinder must allow for the continual vibration due to traffic on the leaf. This may be accomplished by providing self-aligning rod-end couplers or cylinders with elongated pinholes on male clevises. Mount limit switches for safety interlocks to sense lock bar position. Mount limit switches for span lock operator controls to sense rod position.
10. Span locks for hydraulically powered assemblies shall utilize a reversing motor-driven pump or a uni-directional pump with 4-way directional valve, and associated valves, piping, and accessories. Specify relief valves to prevent over-pressure should the lock bar jam. Specify pilot-operated check valves in the lines to the cylinder to lock the cylinder piston in place when pressure is removed. Provide a hydraulic hand pump and quick-disconnect fittings on the piping to allow pulling or driving of the lock bar on loss of power. Specify the time of driving or pulling the bar to be under 10 seconds.
11. Design and specify access platforms with access hatches located out of the travel lanes.

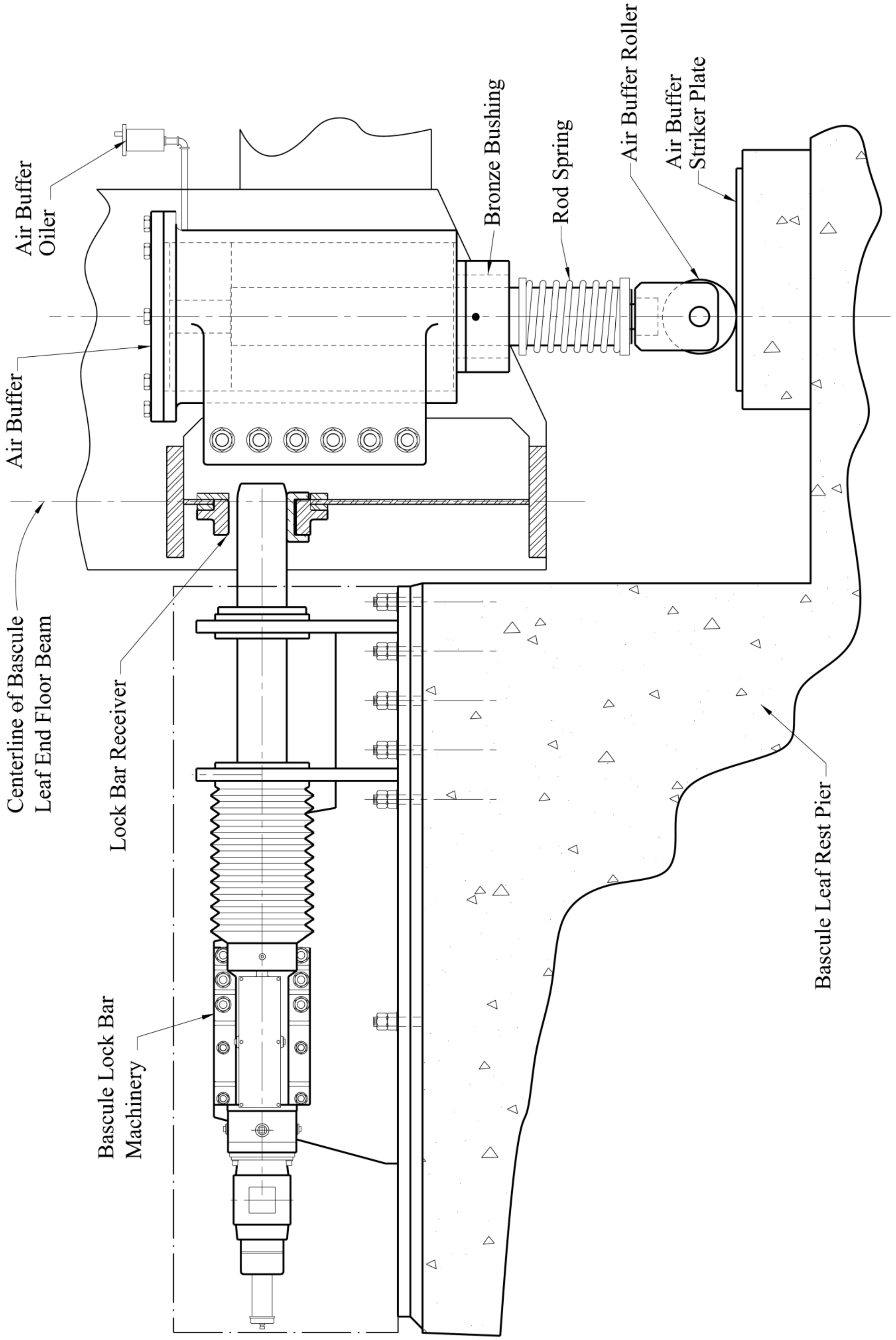


Figure 6.8.1.5.1-1—Lock Bar and Air Buffer Layout for a Single Leaf Bascule Bridge

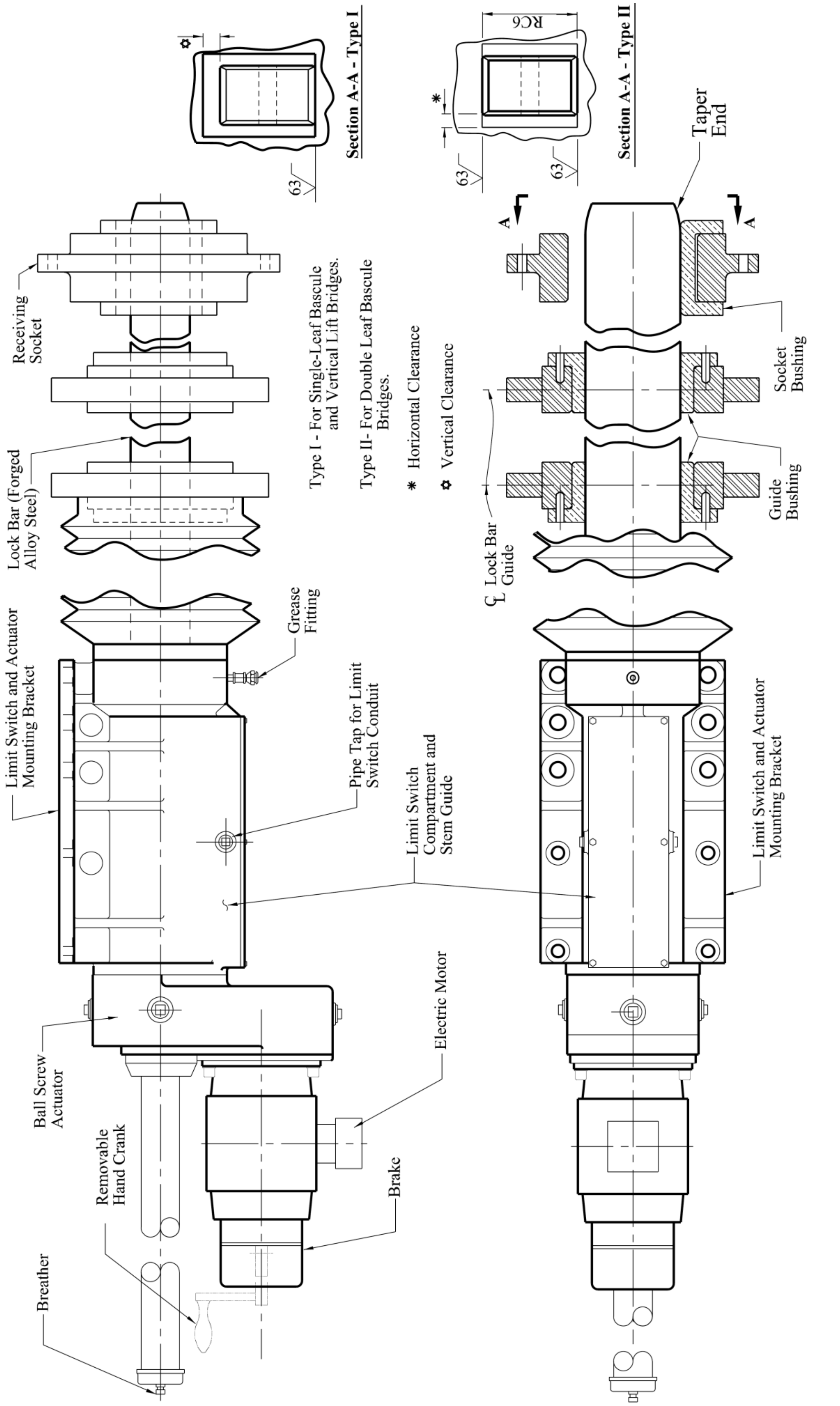


Figure 6.8.1.5.1-2—Lock Bar Assembly

6.8.2—Swing Spans

6.8.2.1—Drive Machinery

The following shall replace the 1st paragraph in *A6.8.2.1*.

Drive machinery for swing spans shall normally include drive motor(s), main reducer, output shafts, and pinions/gears driving the operating rack. There shall be a minimum of two pinions, diametrically opposite, providing equal torque to rotate the span. Either the main gear reducer shall be of the differential type, or equalization of torque shall be provided by another method acceptable to the Bridge Design Engineer Administrator.

The following shall supplement *A6.8.2.1*.

Swing span designs employing a single pinion engaging a rack gear shall be acceptable if the span weighs under 700 kips and the maximum pinion-imposed rack torque force being resisted by the center pivot bearing is less than 2.5 percent of the swing span dead weight.

6.8.2.2—Racks and Pinions

The following shall supplement *A6.8.2.2*.

For rack and pinion swing span bridges, the overhung load on the pinion shaft shall be taken as the radial load produced by the maximum holding load in *A5.5.2* and *D5.5.2*. When the pinion is keyed on to a gear motor, gearbox output shaft, or hydraulic motor output shaft, the Designer must ensure that the manufactured product is capable of taking the overhung load produced by the maximum holding requirements.

The pinion shall be 1 in. lesser (½ in. on each side) in face width than the mating rack gear.

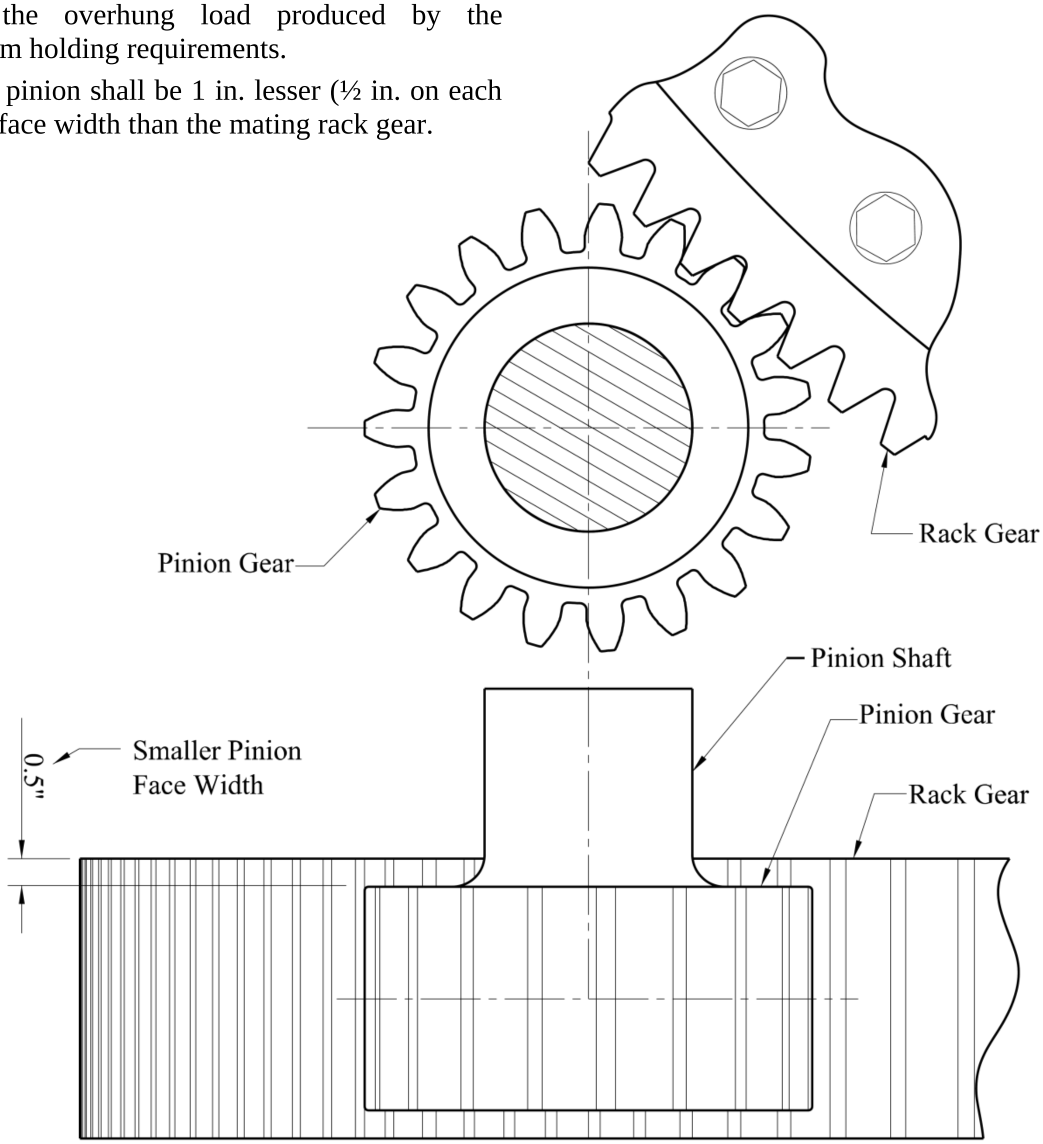


Figure 6.8.2.2-1—Typical Pinion and Rack Gear Assembly for a Mechanical Swing Span Bridge

6.8.2.3—Pivot Bearing

The following shall supplement *A6.8.2.3*.

Spherical roller thrust bearings are not to be used for this application unless requested by LADOTD.

Disc bearing assemblies shall be used for swing span bridges.

Housing shall come complete with oil level sight glass, oil fill port, oil drain port, air vent plug, seals, and non-corrosive metallic nameplates.

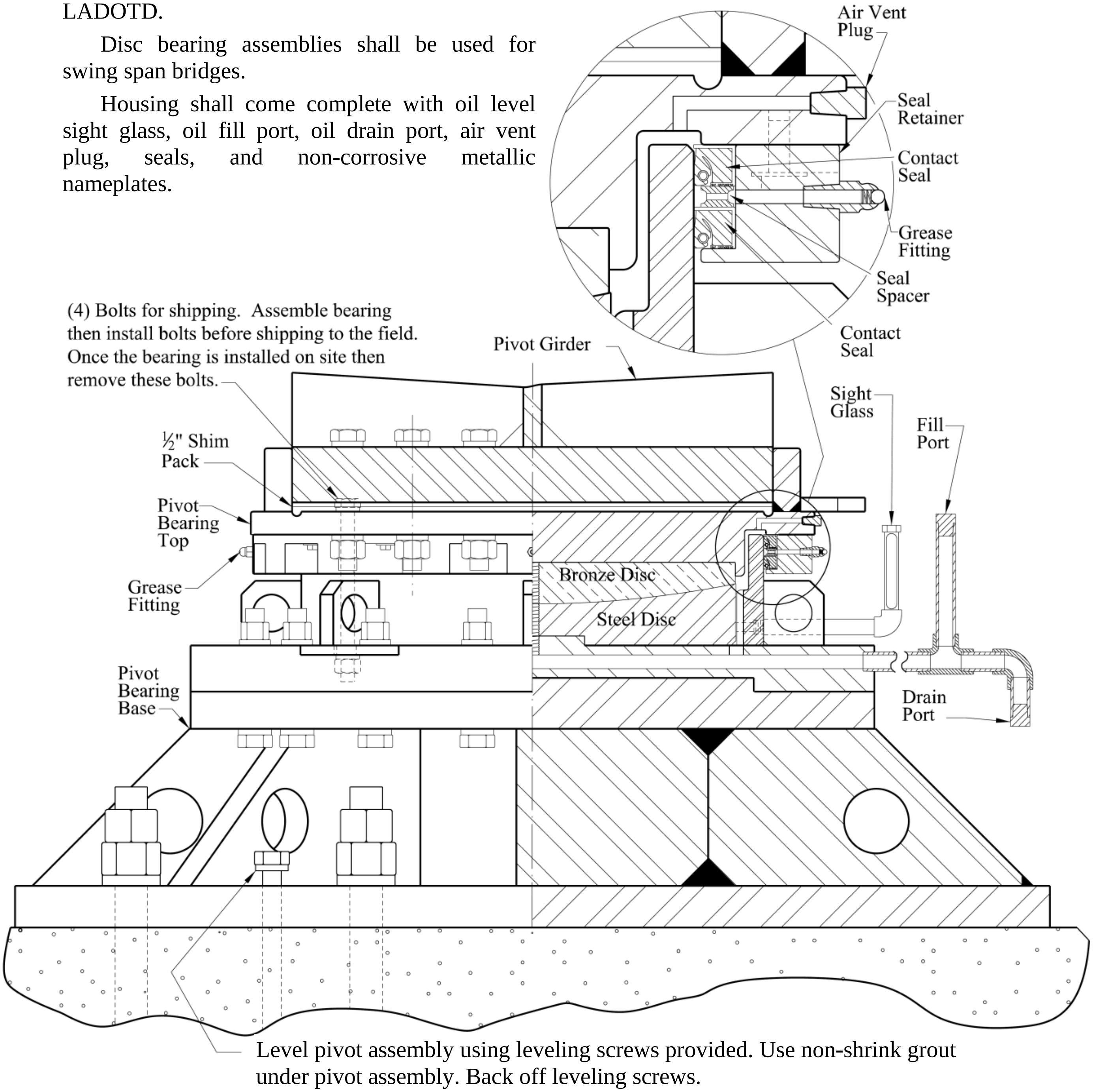


Figure 6.8.2.3-1—Disc Bearing Assembly

The above figure shows the disc bearing assembly with some of the preferred features.

6.8.2.4—End Lifts

The following shall supplement *A6.8.2.4.*

Span end lift wedges shall be designed to remain in their final set position upon loss of drive power.

Wedge drive linkages for mechanically powered assemblies are to be adjustable to allow being set at full-rotation drive position (i.e. straight axial linkage). This allows the use of the gear reduction drive line to maintain wedge positioning.

Hydraulic driven wedges shall utilize roller wedges with “over-the-hump” shoes to maintain static no-power positioning.

Due to the new *AASHTO LRFD Bridge Design Specifications* and permit vehicle loads, the end lifts may not be strong enough for future bridges. The engineer may consider material other than ASTM A668 or alternate designs.

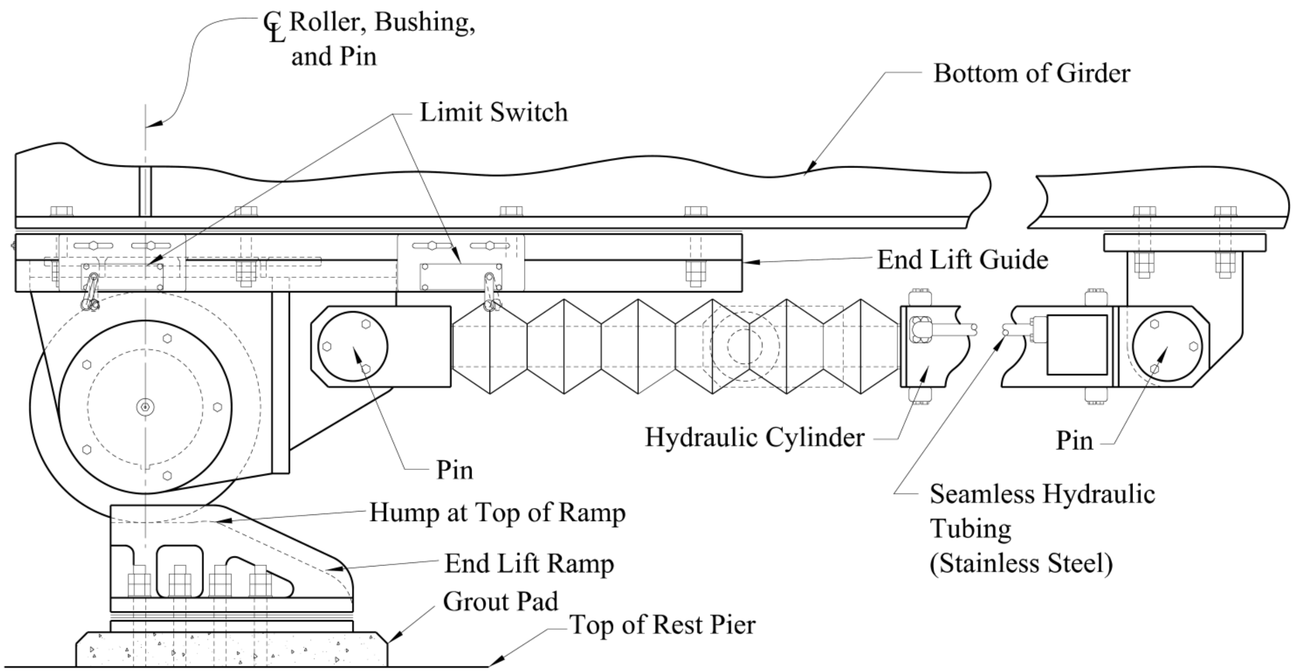


Figure 6.8.2.4-1—Typical Hydraulic End Lift Assembly

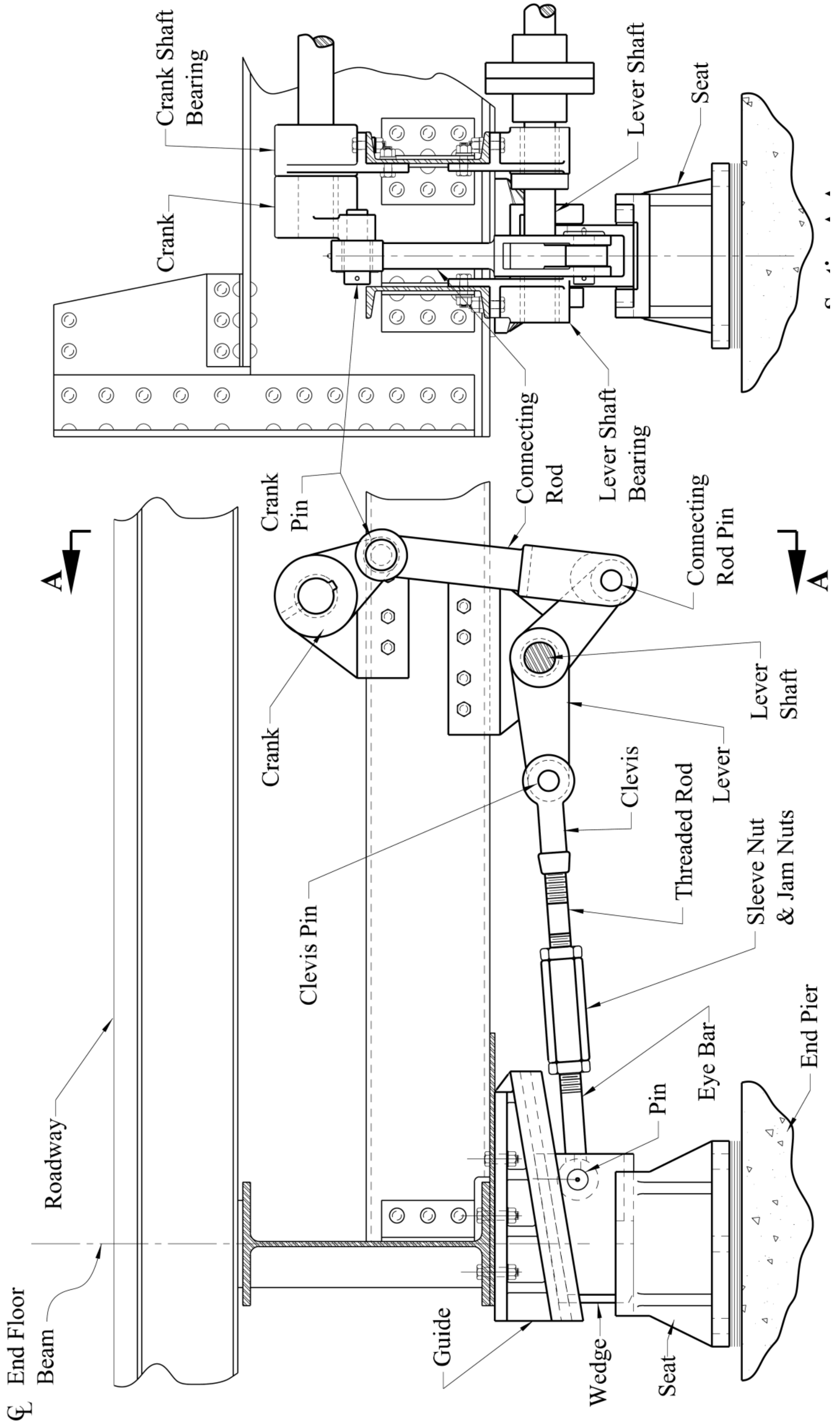


Figure 6.8.2.4-2—Typical Mechanical End Lift Assembly

6.8.2.5—Center Wedges

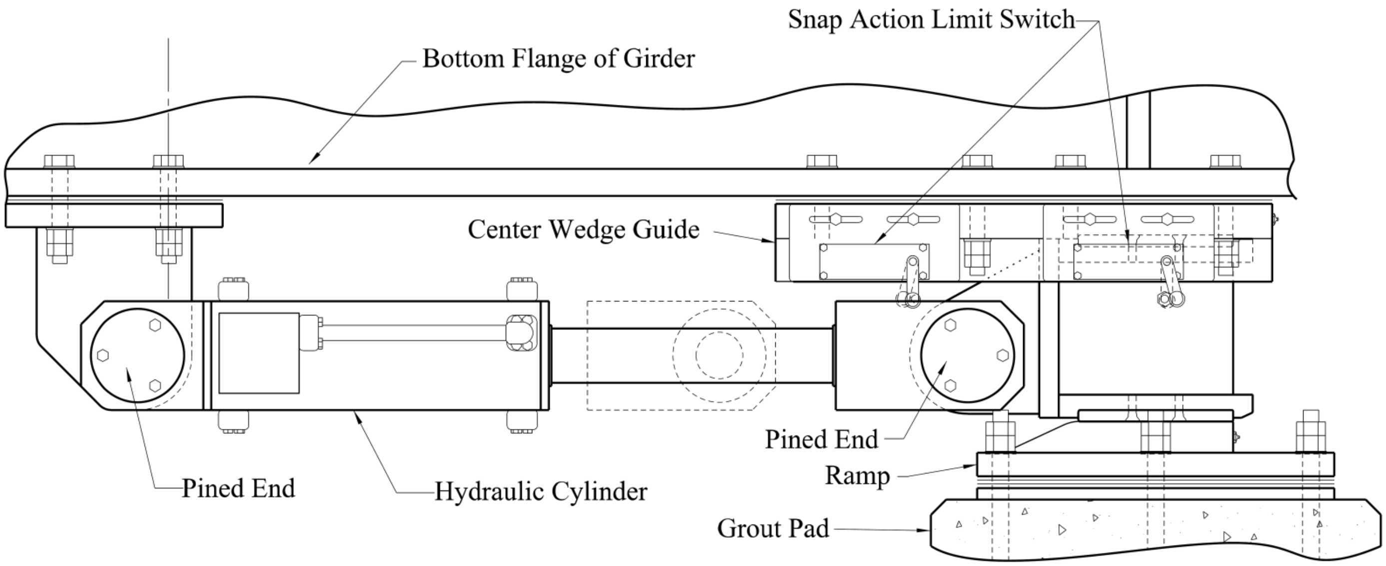


Figure 6.8.2.5-1—Typical Center Wedge Assembly

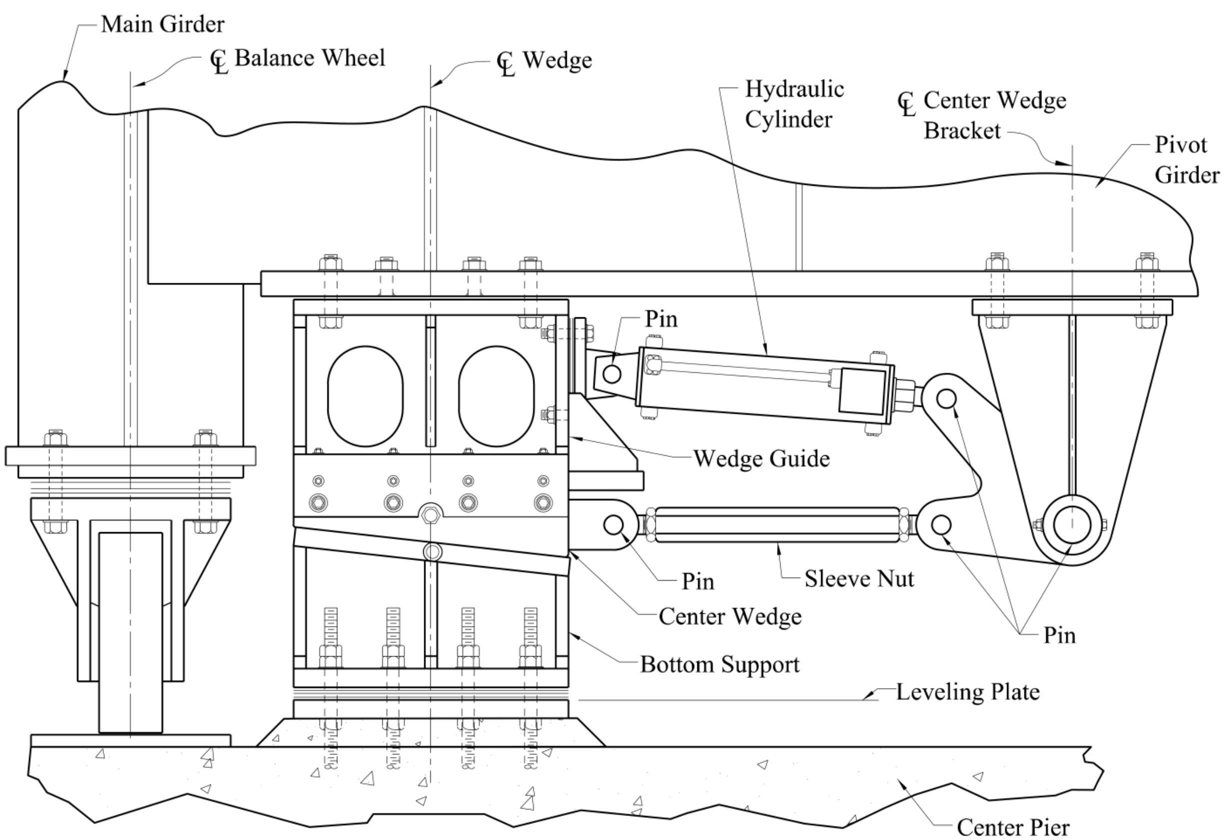


Figure 6.8.2.5-2—Typical Center Wedge Assembly

6.8.2.6—Balance Wheels

The following shall replace the 2nd sentence in the 1st paragraph of *A6.8.2.6***.**

The maximum overturning moment shall be determined using wind loading as defined in *A5.4.3* and *D5.4.3*.

C6.8.2.6

Ice loading may be neglected for bridges in Louisiana.

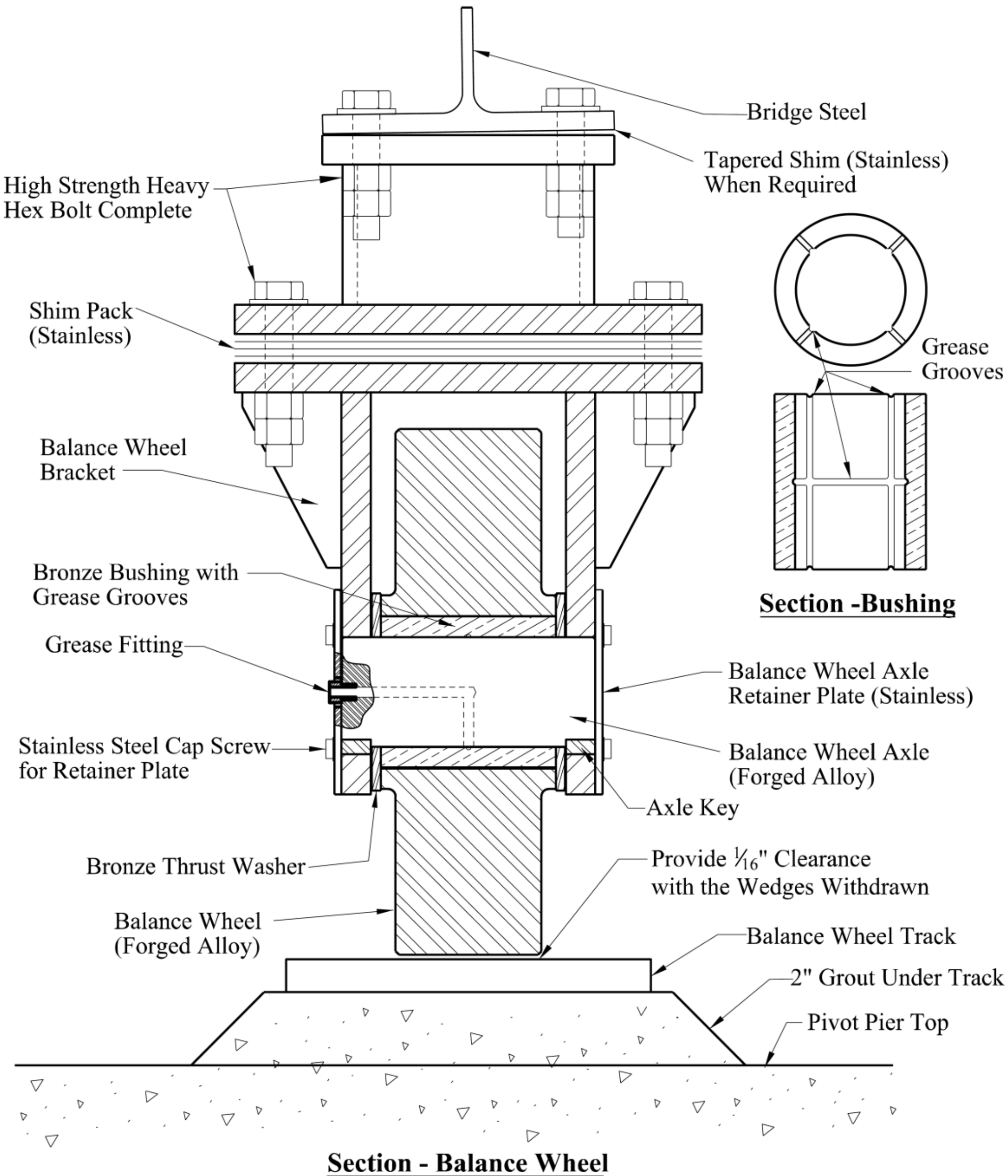


Figure 6.8.2.6-1—Typical Balance Wheel Assembly

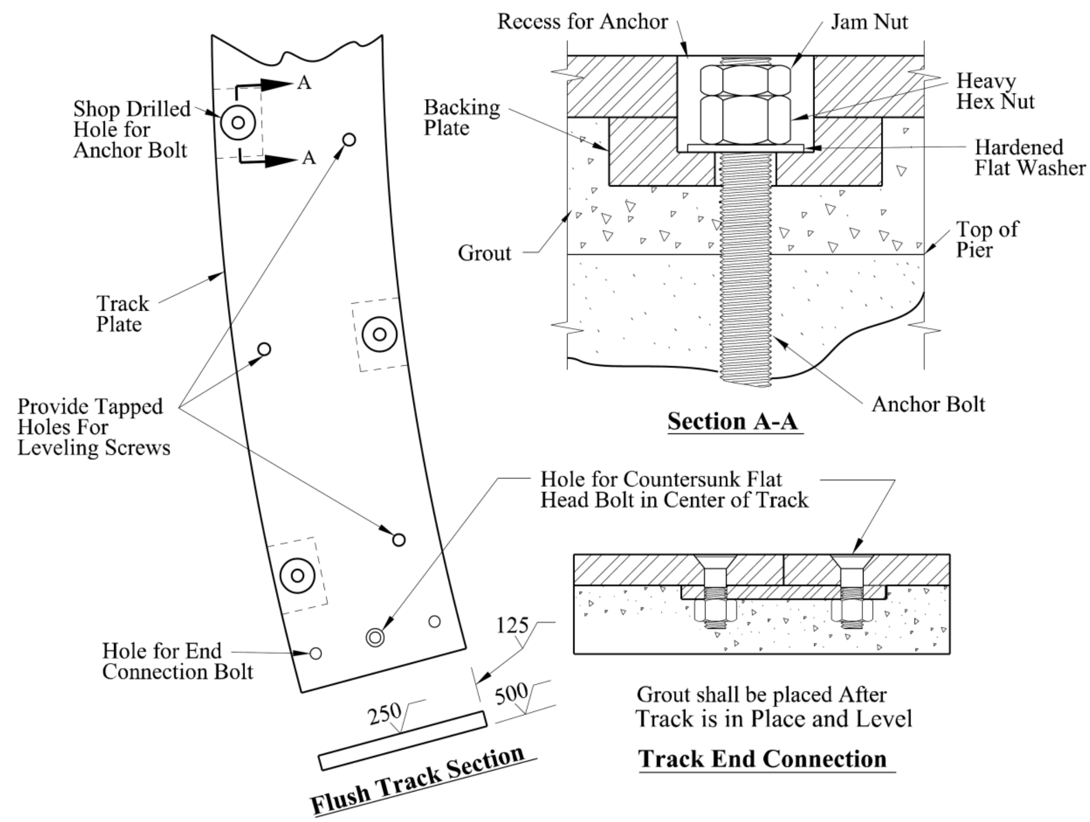


Figure 6.8.2.6-2—Flush Balance Wheel Track Example

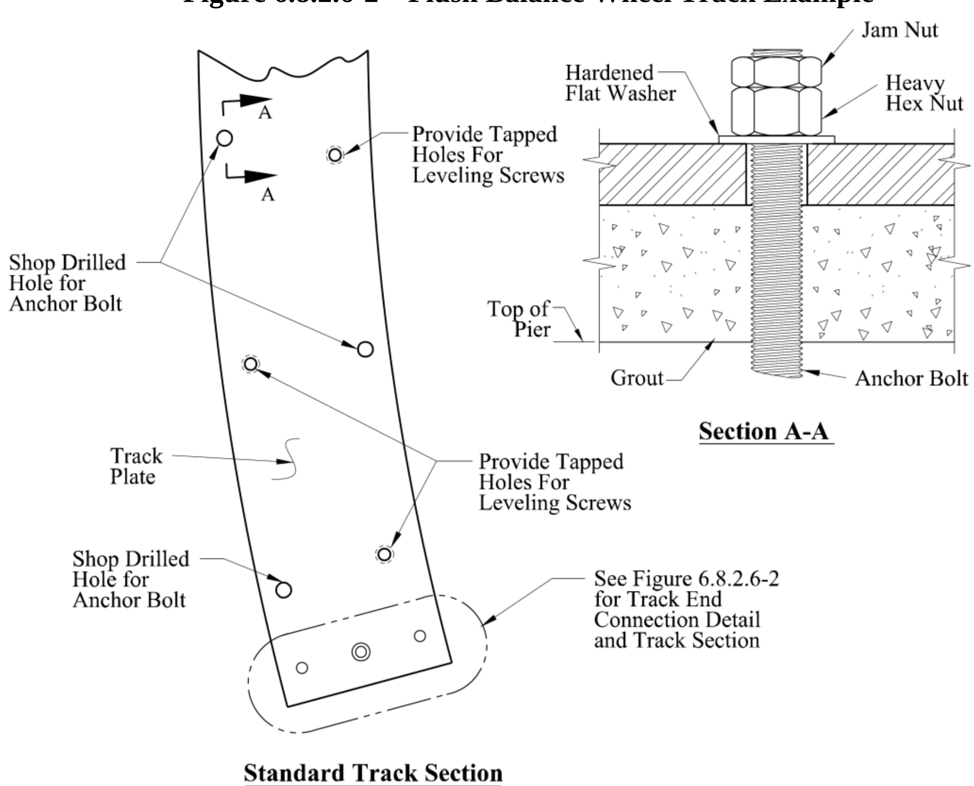


Figure 6.8.2.6-3—Standard Balance Wheel Track Example

6.8.2.7—Rim Bearing Wheels

The following shall supplement *A6.8.2.7*.

Rim bearing or combined rim and center bearing designs shall not be used unless approved by the Bridge Design Engineer Administrator.

6.8.2.8—Tracks

The following shall supplement *A6.8.2.8*.

The tracks defined here are for rim bearing wheels and are not for balance wheels.

6.8.2.9—Centering Devices

The following shall supplement *A6.8.2.9*.

Swing spans that use flared ramps for the end lifts do not need centering devices, provided the bridge control system stops the bridge in the closed position reliably enough to successfully drive the end lifts.

The following shall replace the 2nd sentence on *A6.8.2.9.*

The centering device(s) shall preferably be located on the centerline of the bridge, as near the roadway level as practicable, with a total clearance not to exceed ± ¼ in.

C6.8.2.9

The end lift ramps shall have flares capable of centering the bridge when the end lifts are driven. The flares shall allow as much as ± 1 in. from the center.

6.8.2.10—Span Locks

The following shall supplement *A6.8.2.10*.

Span locks are not needed for swing spans provided that the end lifts sufficiently pin the bridge in the closed position.

For swing spans normally kept in the open position, span locks shall be used and designed to hold the bridge open against the wind loads defined in *A5.4.3* and *D5.4.3*.

C6.8.2.10

A span lock located at the center pier should be used if the swing span is normally kept in the open position.

6.8.3—Vertical Lift Spans

6.8.3.1—Span Drive Vertical Lifts

The following shall supplement *A6.8.3.1*.

The primary design of a vertical lift bridge

C6.8.3.1

Span drive vertical lift bridges have the shall be that of the tower drive design.

A span drive vertical lift bridge shall only be allowed with the approval of the Bridge Design Engineer Administrator.

operating span machinery located on the moving span and require operating cables and drums to accomplish span movement. This configuration makes the bridge more difficult to maintain and exposes the span machinery to storm surge.

6.8.3.2—Tower Drive Vertical Lifts

6.8.3.2.1—Drive Machinery

The following shall supplement *A6.8.3.2.1*.

The primary gear reducer shall have two non-differential input shafts parallel with two output shafts. The input shafts shall be designed for twice the rated horsepower of the speed reducer.

The output shafts shall be capable of differential output and shall also be capable of being locked together to act as one shaft by means of a manual clutch mechanism.

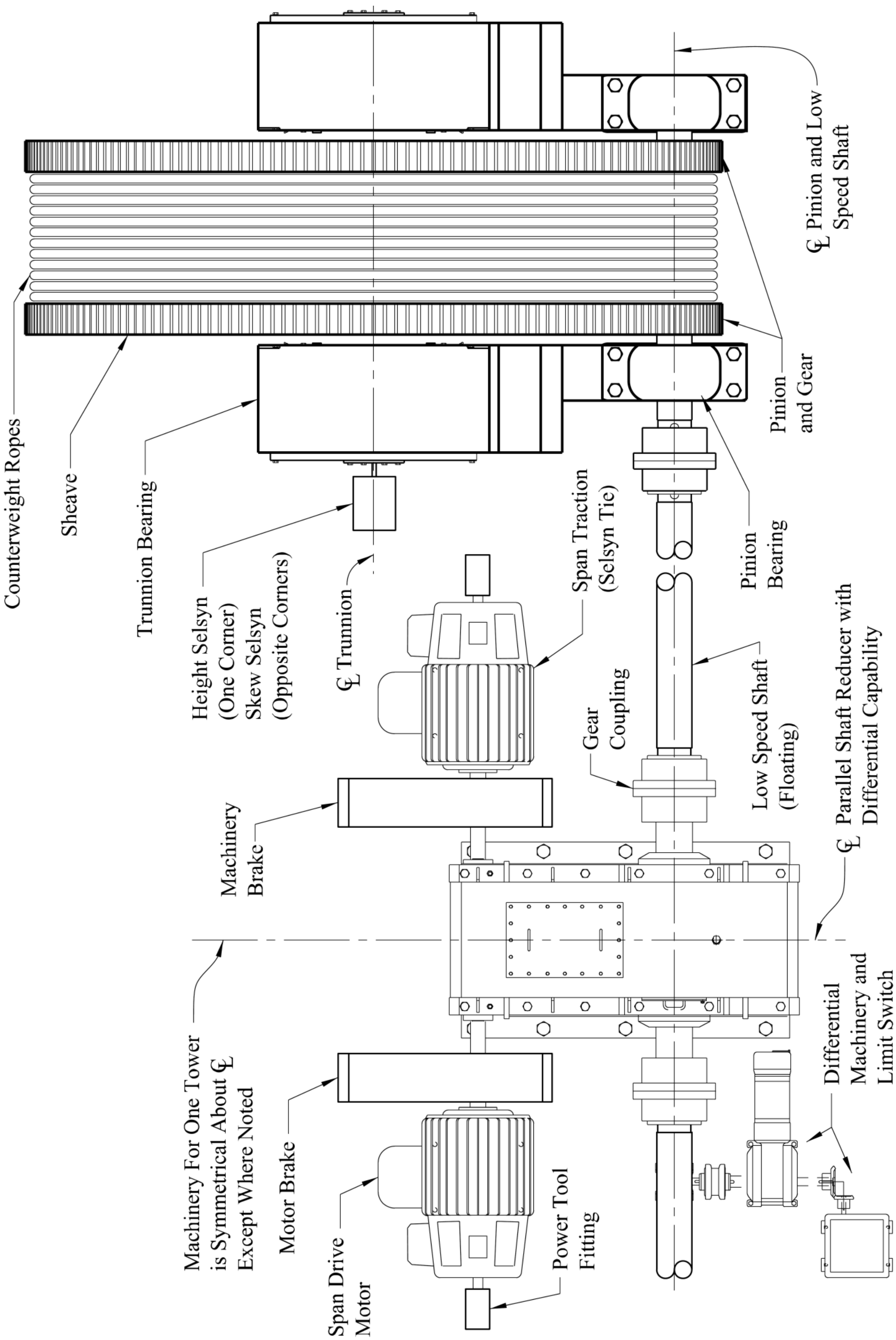


Figure 6.8.3.2.1—Tower Drive Machinery for a Vertical Lift Bridge

6.8.3.2.2—Ring Gears and Pinions

The following shall supplement *A6.8.3.2.2.*

The Designer shall give the fabricator the option of making the ring gear as one monolithic piece.

The pinion shall be 1 in. greater (½ in. on each side) in face width than the mating rack gear.

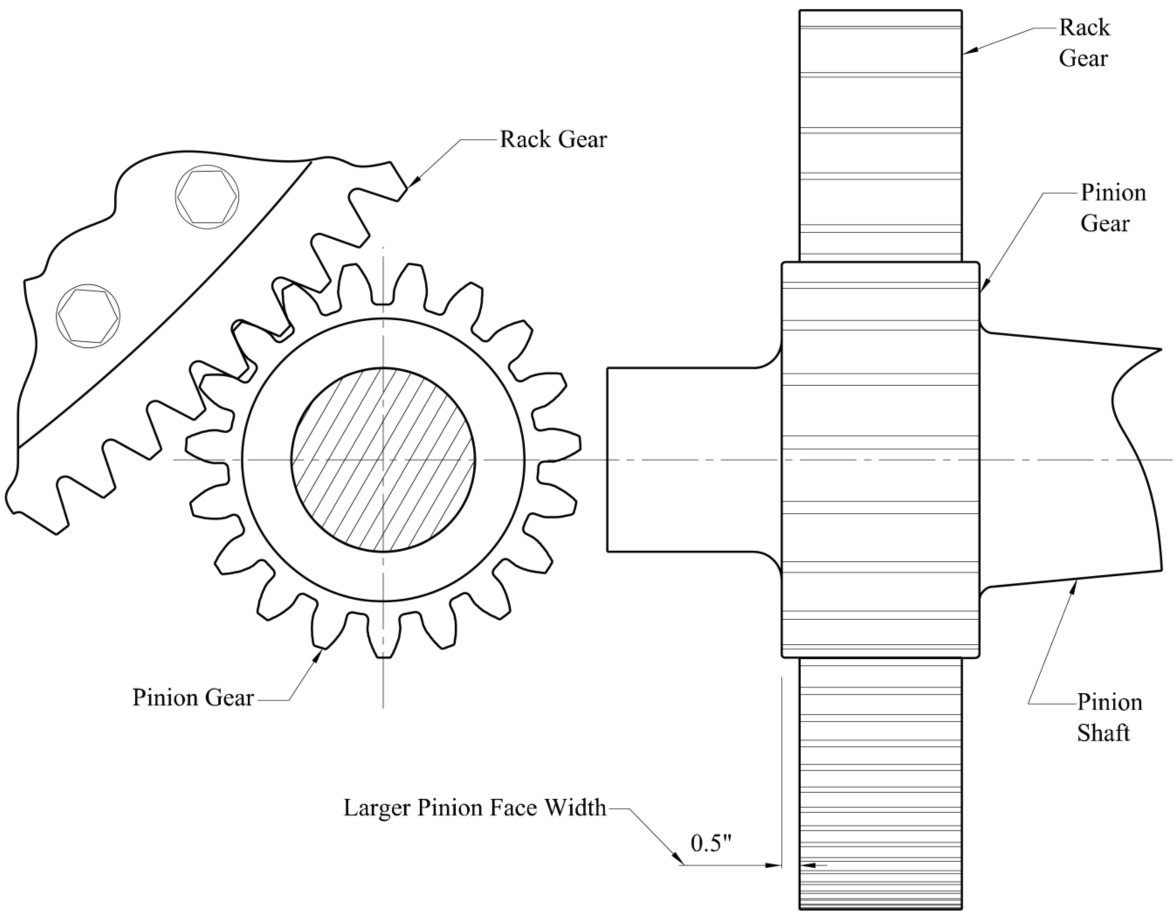


Figure 6.8.3.2.2-1—Pinion and Ring Gear Assembly - Tower Drive Vertical Lift Bridge

6.8.3.3—Wire Ropes and Sockets

The following shall supplement *A6.8.3.3*.

Wire ropes shall comply with the latest edition of the *Louisiana Standard Specifications for Roads and Bridges.*

6.8.3.3.1—Diameter of Wire Ropes

C6.8.3.3.1

After installation and tensioning of the counterweight ropes, it is recommended that the Contractor shall measure the "as-installed" diameter of each rope and furnish these diameters to the Bridge Design Engineer Administrator. This will provide a baseline diameter to compare to when inspecting/measuring the ropes in the future.

6.8.3.3.2—Construction

The following shall supplement *A6.8.3.3.2.*

Wire rope cores shall either be Hard Fiber Core (HFC) or an Independent Wire Rope Core (IWRC). Hard Fiber Cores for wire rope shall be of polypropylene fiber. Polypropylene fibers shall meet the requirements of MIL-P-24216, shall be of commercial quality, and shall be thoroughly cleaned, free of waste, evenly twisted, of uniform plies, and of good workmanship.

Zinc coating:

Zinc shall be in accordance with ASTM B6, High Grade (HG).

The weight of the zinc coating on the individual wires prior to the fabrication of the wire rope shall be not less than that specified in ASTM A1023.

Zinc coating shall be free from uncoated spots, lumps, pits, blisters, gritty areas, dross, and flux.

Lubrication during wire rope fabrication

All portions of wire ropes shall be lubricated during fabrication with a lubricant containing a rust inhibitor. The rope lubricant shall be approved by the Bridge Design Engineer Administrator and must be compatible with the approved field lubrication. Wire ropes shall be tested according to the latest edition of the *Louisiana Standard Specifications for Roads and Bridges*.

C6.8.3.3.2

This specification has been taken from the 1988 *AASHTO Specifications for Movable Highway Bridges.*

6.8.3.3.6—Wire Rope Tensile Strengths

The following shall supplement *A6.8.3.3.6.*

The Appendix of this chapter contains rope selection tables based on the weight of the lift span and the number of cables required for EIPS, and EIPS galvanized wire rope. Also contained in the Appendix is a table to be used when determining the sheave diameter and sheave groove diameter based on rope diameter.

IPS is no longer allowed by the LADOTD.

The following shall replace *Table 6.8.3.3.6-1*.

Table 6.8.3.3.6-1a—Physical Properties of Wire Rope with IWRC

Diameter (in.)	Weight per Length (lb./ft.)	Minimum Ultimate Strength (kips)			
		EIPS with IWRC		EEIPS with IWRC	
		Bright	Galvanized	Bright	Galvanized
1/2	0.46	26.6	23.9	29.2	26.3
9/16	0.58	33.6	30.2	37.0	33.3
5/8	0.72	41.2	37.1	45.4	40.9
3/4	1.04	58.8	52.9	64.8	58.3
7/8	1.41	79.6	71.6	87.6	78.8
1	1.85	103.4	93.1	113.8	102.4
1-1/8	2.34	130.0	117.0	143.0	128.7
1-1/4	2.89	159.8	143.8	175.8	158.2
1-3/8	3.49	192.0	172.8	212.0	190.8
1-1/2	4.16	228.0	205.2	250.0	225.0
1-5/8	4.88	264.0	237.6	292.0	262.8
1-3/4	5.66	306.0	275.4	338.0	304.2
1-7/8	6.49	348.0	313.2	384.0	345.6
2	7.39	396.0	356.4	434.0	390.6
2-1/8	8.34	442.0	397.8	486.0	437.4
2-1/4	9.35	494.0	444.6	544.0	489.6
2-3/8	10.42	548.0	493.2	602.0	541.8
2-1/2	11.60	604.0	543.6	664.0	597.6

Table 6.8.3.3.6-1b—Physical Properties of Wire Rope with HFC

Diameter (in.)	Weight per Length (lb./ft.)	Minimum Ultimate Strength (kips)			
		EIPS with HFC		EEIPS with HFC	
		Bright	Galvanized	Bright	Galvanized
1/2	0.42	23.6	21.2	25.8	23.2
9/16	0.53	29.8	26.8	32.6	29.3
5/8	0.66	36.8	33.1	40.4	36.4
3/4	0.95	52.4	47.2	57.6	51.8
7/8	1.29	70.8	63.7	78.0	70.2
1	1.68	92.0	82.8	101.2	91.1
1-1/8	2.13	115.8	104.2	127.2	114.5
1-1/4	2.63	142.2	128.0	156.4	140.8
1-3/8	3.18	171.0	153.9	188.0	169.2
1-1/2	3.78	202.0	181.8	222.0	199.8
1-5/8	4.44	236.0	212.4	258.0	232.2
1-3/4	5.15	272.0	244.8	300.0	270.0
1-7/8	5.91	310.0	279.0	342.0	307.8
2	6.73	352.0	316.8	388.0	349.2
2-1/8	7.60	394.0	354.6	434.0	390.6
2-1/4	8.52	440.0	396.0	484.0	435.6
2-3/8	9.49	488.0	439.2	538.0	484.2
2-1/2	10.50	538.0	484.2	590.0	531.0

6.8.3.3.7—Wire Rope Sockets

The following shall supplement *A6.8.3.3.7*.

All sockets used with wire ropes shall be made from forged solid blanks ASTM A668, Class D minimum, without the use of welding. For 1 ½” diameter wire rope sockets, ASTM A148 grade 80-50 cast steel may be used. All sockets shall conform to the requirements of the latest revision of Federal Specification RR-S-550, and shall be stronger than the wire rope. The sockets shall be neatly finished to the exact dimensions shown on the contract drawings.

All socket pins shall be class C normalized-steel forgings or shall be machined from hot-rolled ASTM A29 alloy steels, such as grades E4130 or 8620, and subsequently normalized or quenched and tempered to attain a 50 ksi minimum yield strength and 80 ksi minimum tensile strength. In every case, the dimensions of the sockets shall be such that no part under tension

C6.8.3.3.7

Example Counterweight Rope Design

A rope and socket design that has been used on the Prospect Street vertical lift bridge is described below.

A socket containing a threaded rod for rope tension adjustment is utilized on the span side connection.

The design and specification of counterweight ropes for movable bridges shall adhere to *Section 821.07.31* of the latest edition *Louisiana Standard Specifications for Roads and Bridges*.

All span side rope sockets shall be installed with a space between the shim top and the bottom of the lift head, see Figure 6.8.3.3.7-1 – Counterweight Rope Assembly, below. The shims are only for reference and are not intended to bear on any surface.

shall be stressed higher than 90 percent of yield strength when the rope is stressed to its specified ultimate strength.

The zinc used in attaching the sockets must not be too hot or it will anneal the wires. The correct temperature range for zinc for this purpose is from 850° Fahrenheit to 1050° Fahrenheit. Filling of the socket with zinc must be performed in one continuous operation.

The ropes shall be installed with the set screw on the span side block facing out in order to set the threaded rod during their installation on the bridge. After the wire ropes have been installed to the dimensions shown on the plans, the tension in each rope shall be determined and then the rope lengths shall be adjusted using the hex nut on the threaded rod. When the tension is equalized throughout all of the ropes, the lock nut shall be tightened.

The Contractor must use an approved method to verify rope tension equality.

After all tension adjustments are completed and the bridge operated at least four times, rope tensions shall be rechecked. The tensions in the counterweight rope shall not differ by more than 8 percent of each other. Upon completion of the project, rope tension or frequency shall be submitted to the Bridge Design Engineer Administrator in report form.

See Figures 6.8.3.3.7-1 – Counterweight Rope Assembly and 6.8.3.3.7-2– Wire Rope and Socket Assembly, below.

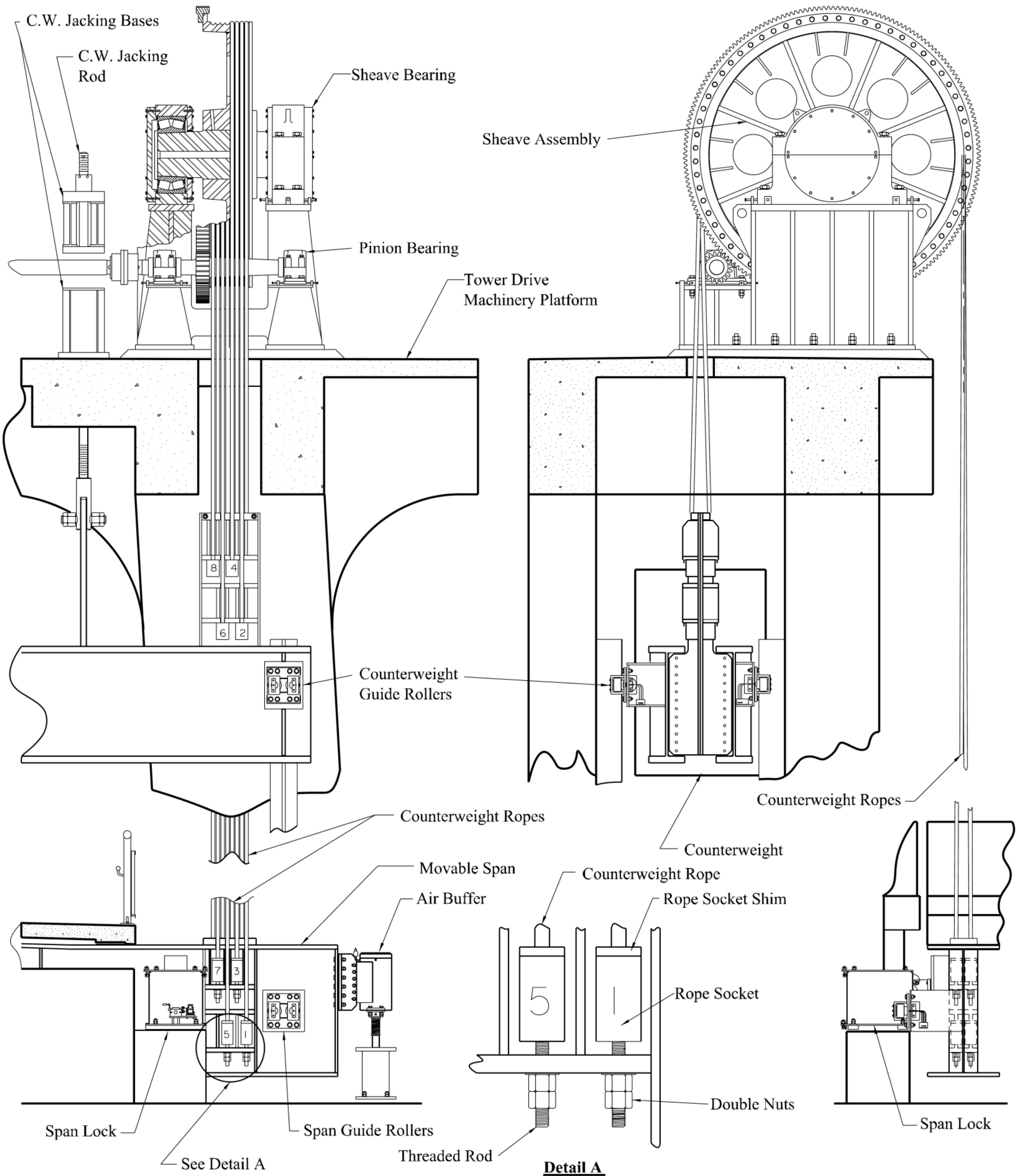


Figure 6.8.3.3.7-1—Counterweight Rope Assembly

The above figure shows the design for equal rope lengths. The figure was taken from the Prospect Bridge contract drawings, LADOTD 2009,State Project 065-91-0016.

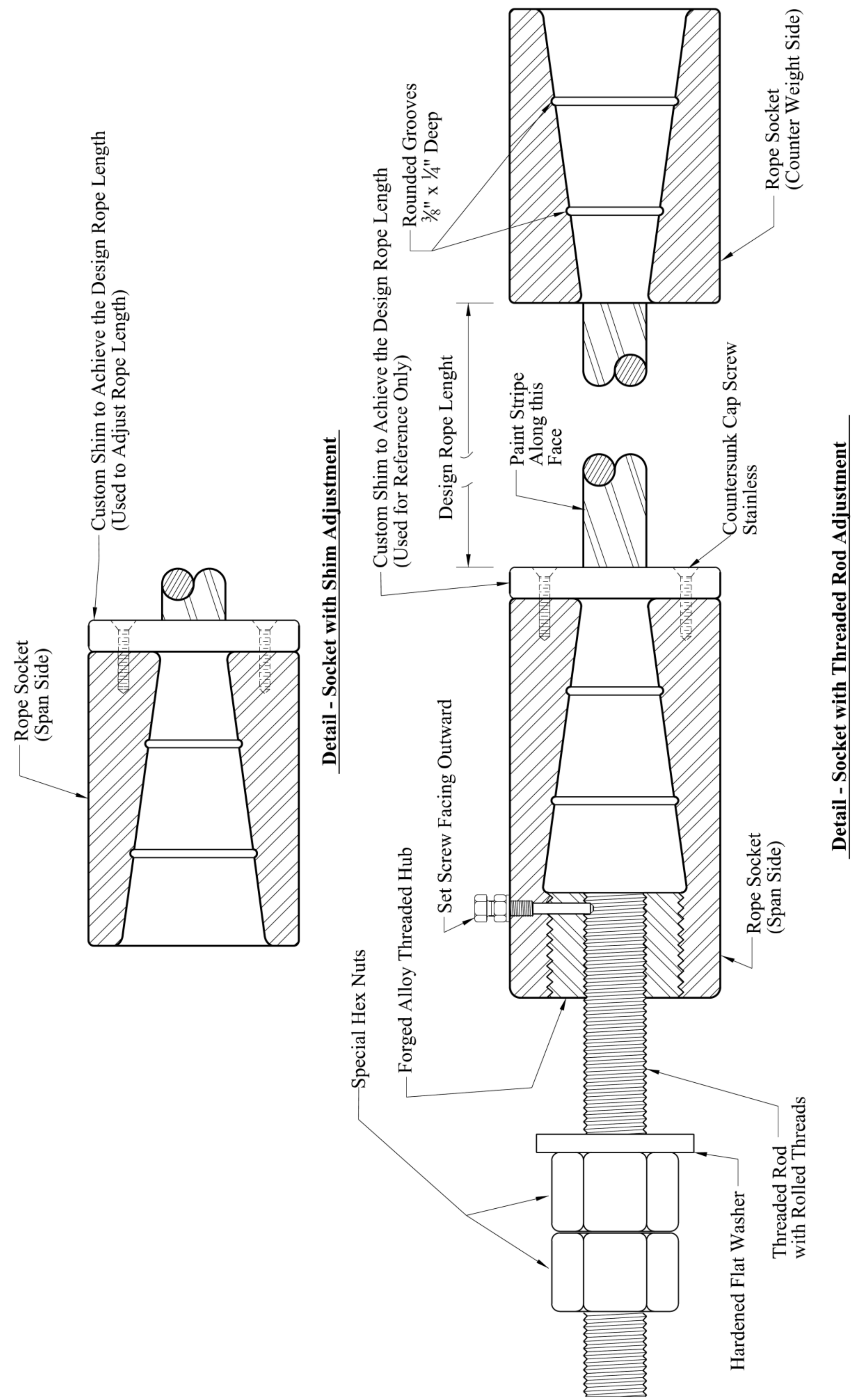


Figure 6.8.3.3.7-2—Wire Rope and Socket Assembly

6.8.3.4—Sheaves

6.8.3.4.1—General

The following shall supplement *A6.8.3.4.1*.

Sheave rims and hubs shall be one-piece forged whenever practical.

Sheave rims, hubs, web, and stiffener plates shall be designed to utilize similar low-strength steels that are weldable and have similar stress relieving temperatures.

Common steel types include:

ASTM A709, grade 36;- ASTM A668 class D

ASTM A709 grade 50 – ASTM A668 class G

6.8.3.4.2—Counterweight Sheaves

The following shall supplement *A6.8.3.4.2*. Sheaves having 10 cables or fewer shall be of the single web design.

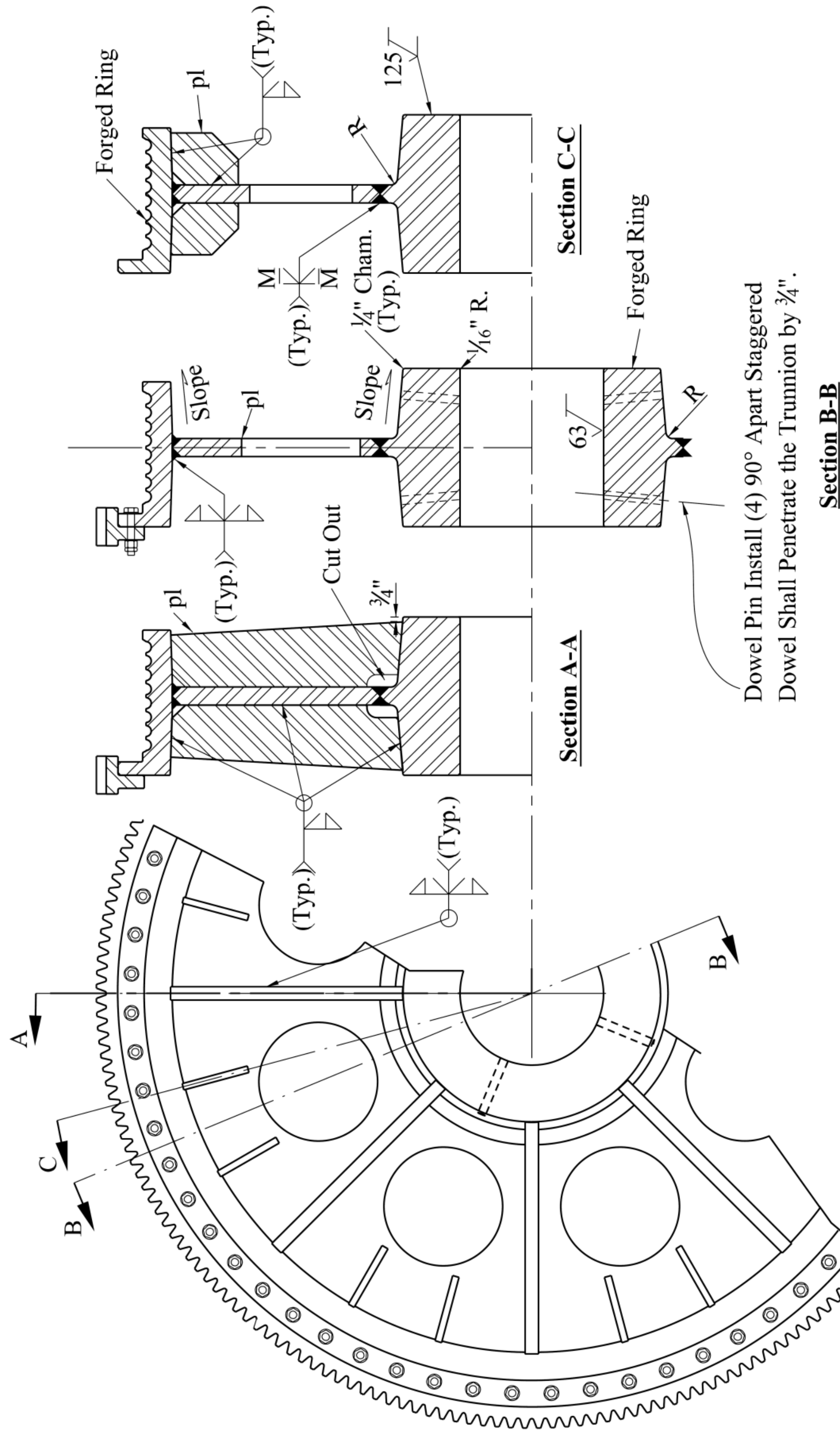


Figure 6.8.3.4.2-1—Single Web Counterweight Sheave

The above figure shows a single web sheave's typical welds, slopes, radii, and chamfers.

6.8.3.4.3—Sheave Trunnions and Bearings

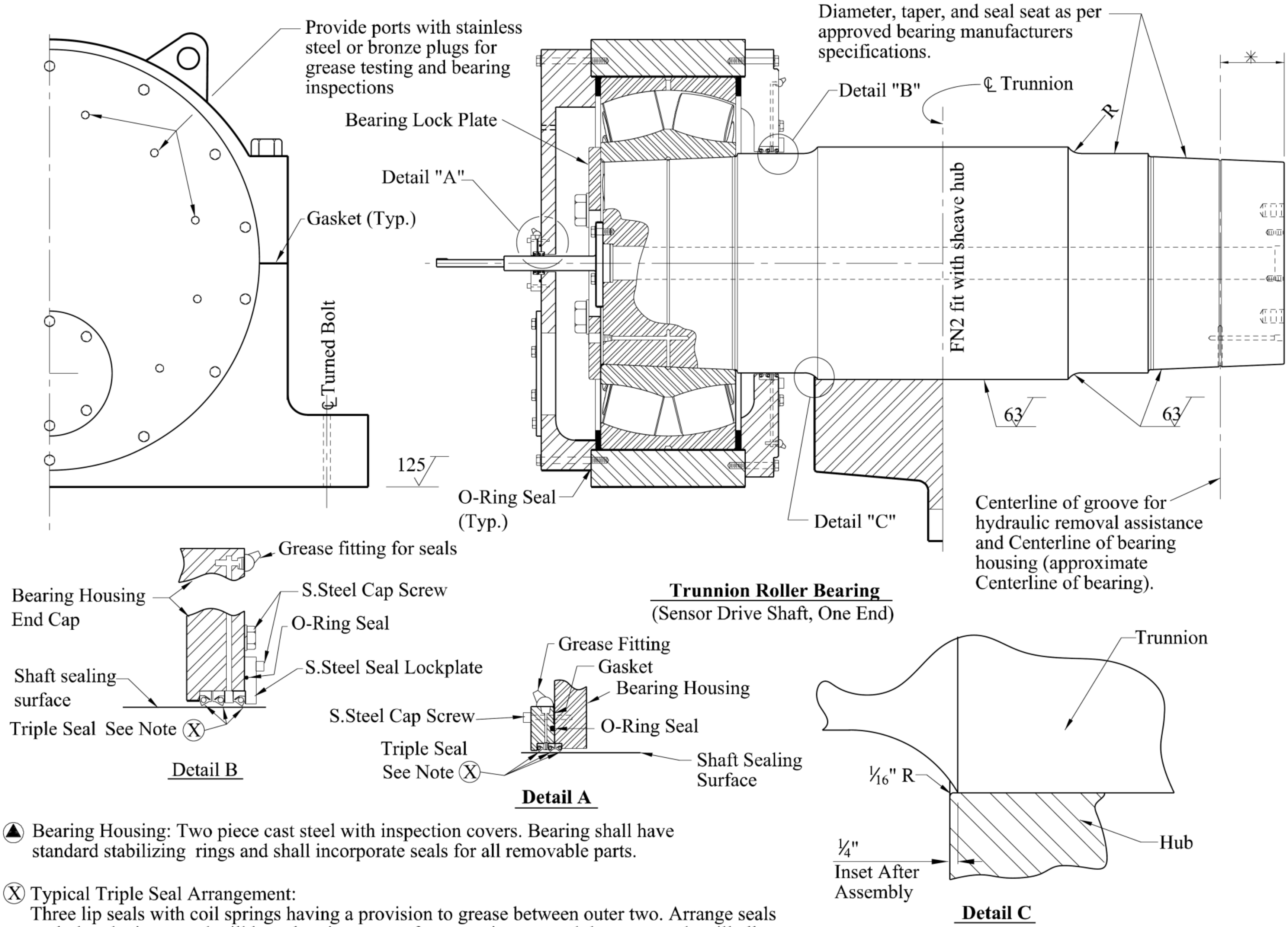
The following shall supplement *A6.8.3.4.3*.

Trunnions:

1. FN3 and greater fits are not recommended between trunnions and their hubs. See *A6.7.9.1* and *D6.7.9.1*.
2. Provide shoulders with fillets of appropriate radii.
3. Provide clearances for thermal expansion between shoulders and bearings.
4. Do not use keys between the trunnion and the hub.
5. For trunnions over 8 in. diameter, provide a hole 1/5 the trunnion diameter lengthwise through the center of the trunnion.
6. In addition to the shrink fit, drill and fit dowels of appropriate size through the hub into the trunnion after the trunnion is in place. The dowels shall have a means to vent air when they are being installed.
7. Three of the trunnions shall have a small shaft attached to the outboard end extending thru the bearing housing to accommodate the height selsyn and skew control equipment.

Bearings:

1. Spherical roller bearings shall preferably be used for this application. Selection of these bearings shall be done under the guidance of the bearing manufacturer.
2. The bearing housing end caps shall have ports with stainless-steel or bronze plugs for grease testing and bearing inspections.
3. For more on bearing design and selection see *A6.7.7.2* and *D6.7.7.2*.



▲ Bearing Housing: Two piece cast steel with inspection covers. Bearing shall have standard stabilizing rings and shall incorporate seals for all removable parts.

Ⓧ Typical Triple Seal Arrangement:
Three lip seals with coil springs having a provision to grease between outer two. Arrange seals such that the inner seal will keep bearing grease from seeping out and the outer seals will allow contaminents to purge out from housing when grease is pumped between the two. See details A and B.

Figure 6.8.3.4.3-1—Trunnion Spherical Roller Bearing Assembly

6.8.3.5—Counterweights and Rope Anchorages

6.8.3.5.2—Counterweights and Rope Anchorages

The following shall supplement *A6.8.3.5.2*.

All Vertical Lift Bridges shall be designed to accommodate the securing, raising and holding of the counterweight while in the span down position (under traffic) to allow for wire rope replacement. All ancillary structural devices/facilities will be part of the Project and are to be provided/ stored at the bridge site.

See Figure 6.8.3.3.7-1 – Counterweight Rope Assembly, above. This drawing shows the counterweight jacking rods and bases.

6.8.3.5.3—Clearance Below Counterweights

This clearance is when the span is in the "*past open"* position.

C6.8.3.5.3

LADOTD requires the span to open 5 ft. above permit height. For "past open," use 2 ft. above roadway. For "normal open," use 7 ft. above roadway. The "past open" condition must also account for barriers, access ladders, guard rails, or hand rails.

6.8.3.6—Buffers

The following shall supplement *A6.8.3.6*.

The following figure represents a typical air buffer used on vertical lift bridges in Louisiana.

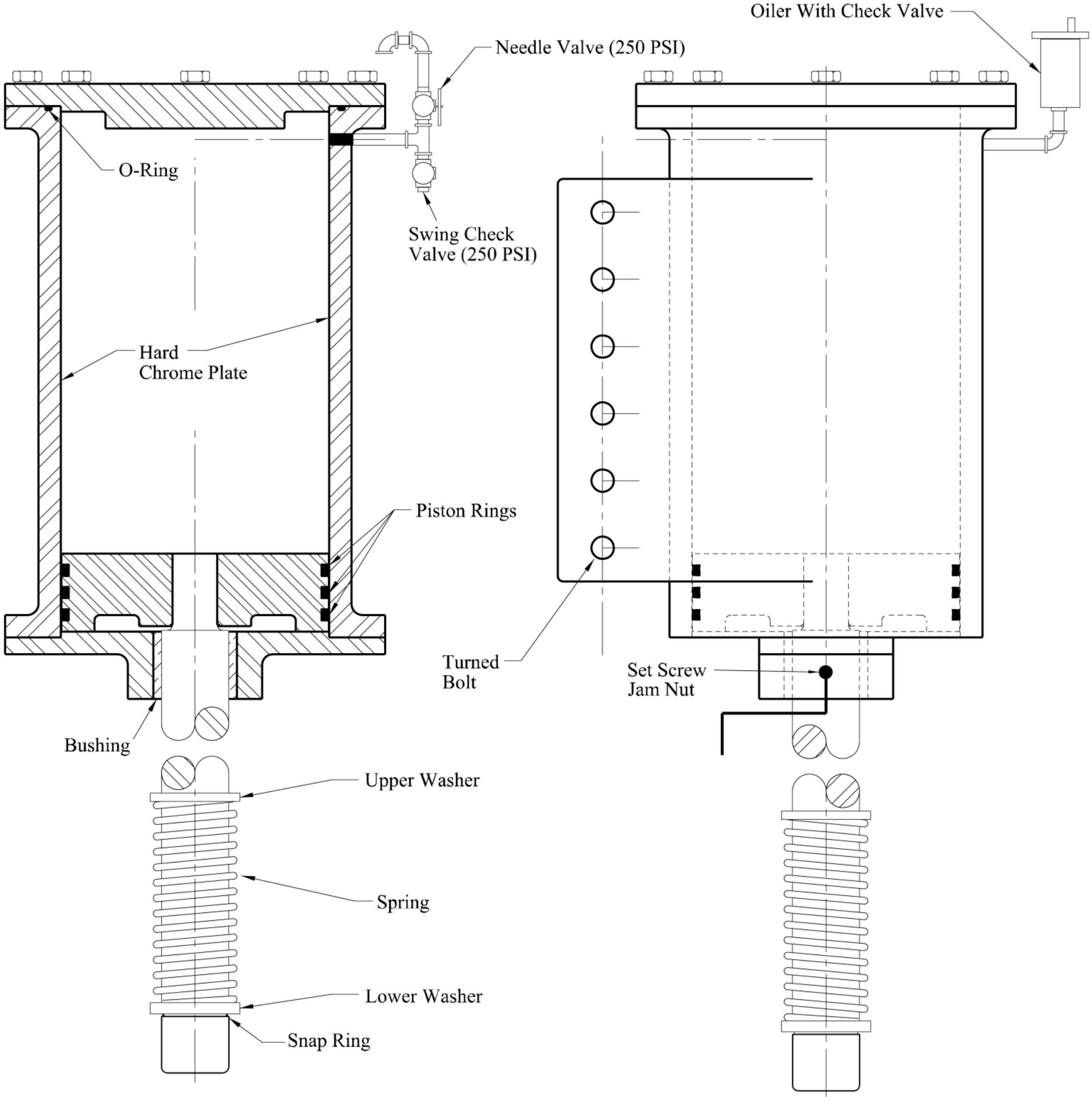


Figure 6.8.3.6-1—Typical Air Buffer Used on a Vertical Lift Span

6.8.3.7—Span Locks and Centering Devices

6.8.3.7.1—Locking Devices

The following figure is an example of the type of span lock used on vertical lift bridges in Louisiana. Other types of span locks are also used and include the lock bar type. See Figure 6.8.1.5.1-1 – Typical Lock Bar Assembly for a Bascule Bridge.

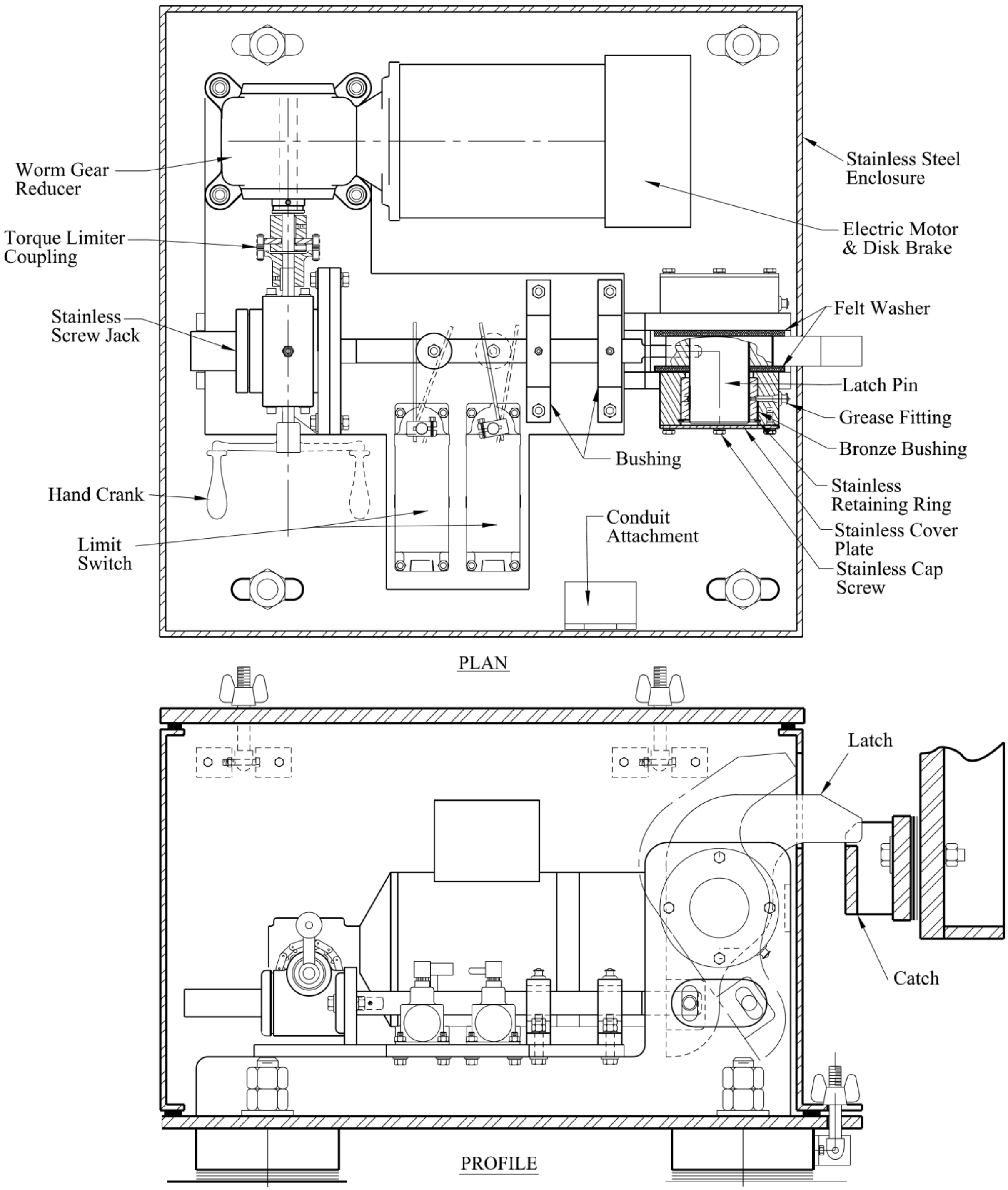


Figure 6.8.3.7.1-1—Example of the Latching Type of Span Lock

6.8.3.8—Span and Counterweight Guides

The following shall replace the 3rd sentence in *A6.8.3.8:*

Guides shall be of the rolling type (guide rollers) attached to the movable span engaging the guide flanges attached to the towers. The fixed and free span guide rollers shall coincide with the fixed and free span shoes.

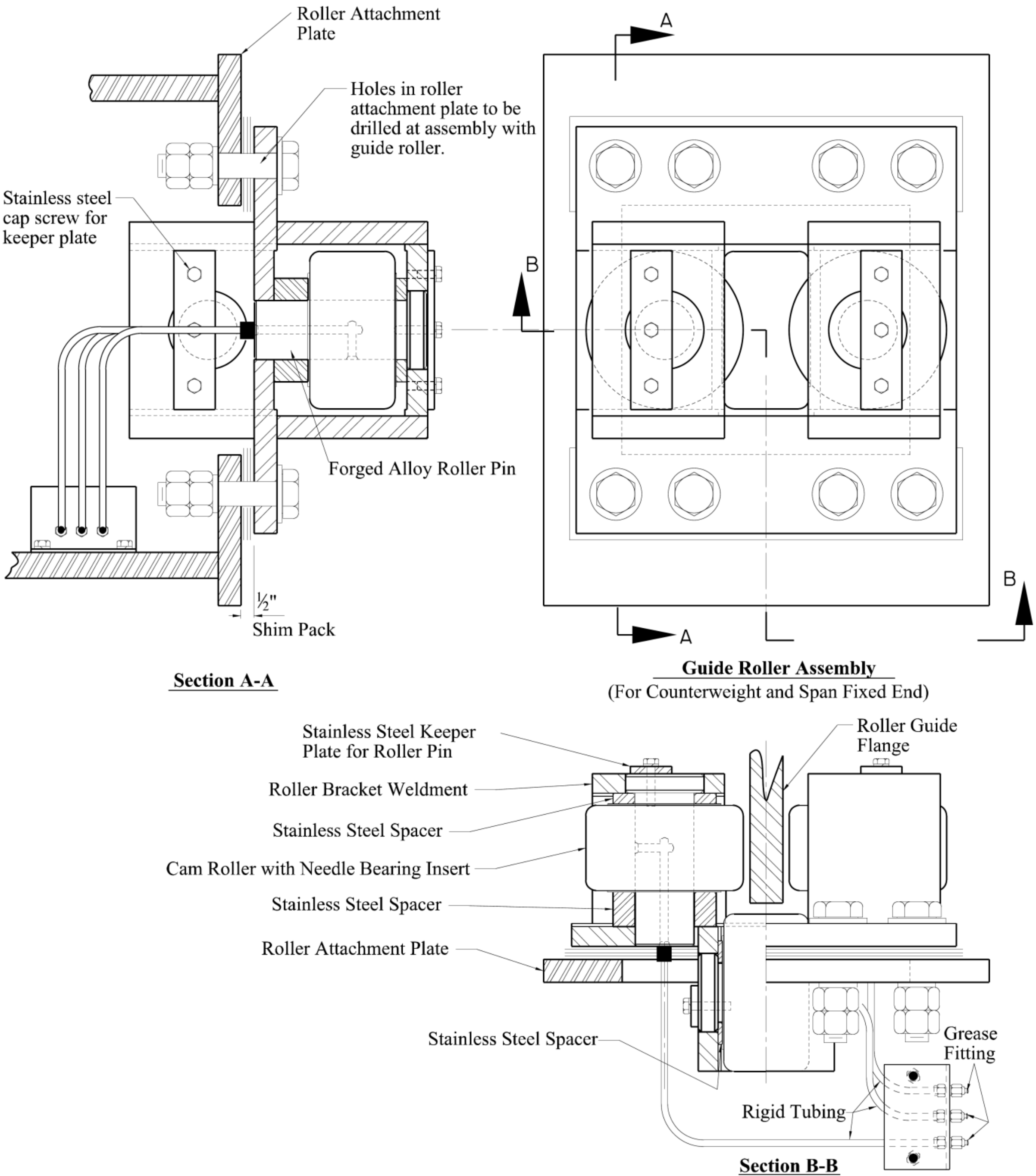


Figure 6.8.3.8-1—Example of a Vertical Lift Bridge Guide Roller Assembly for the Fixed End

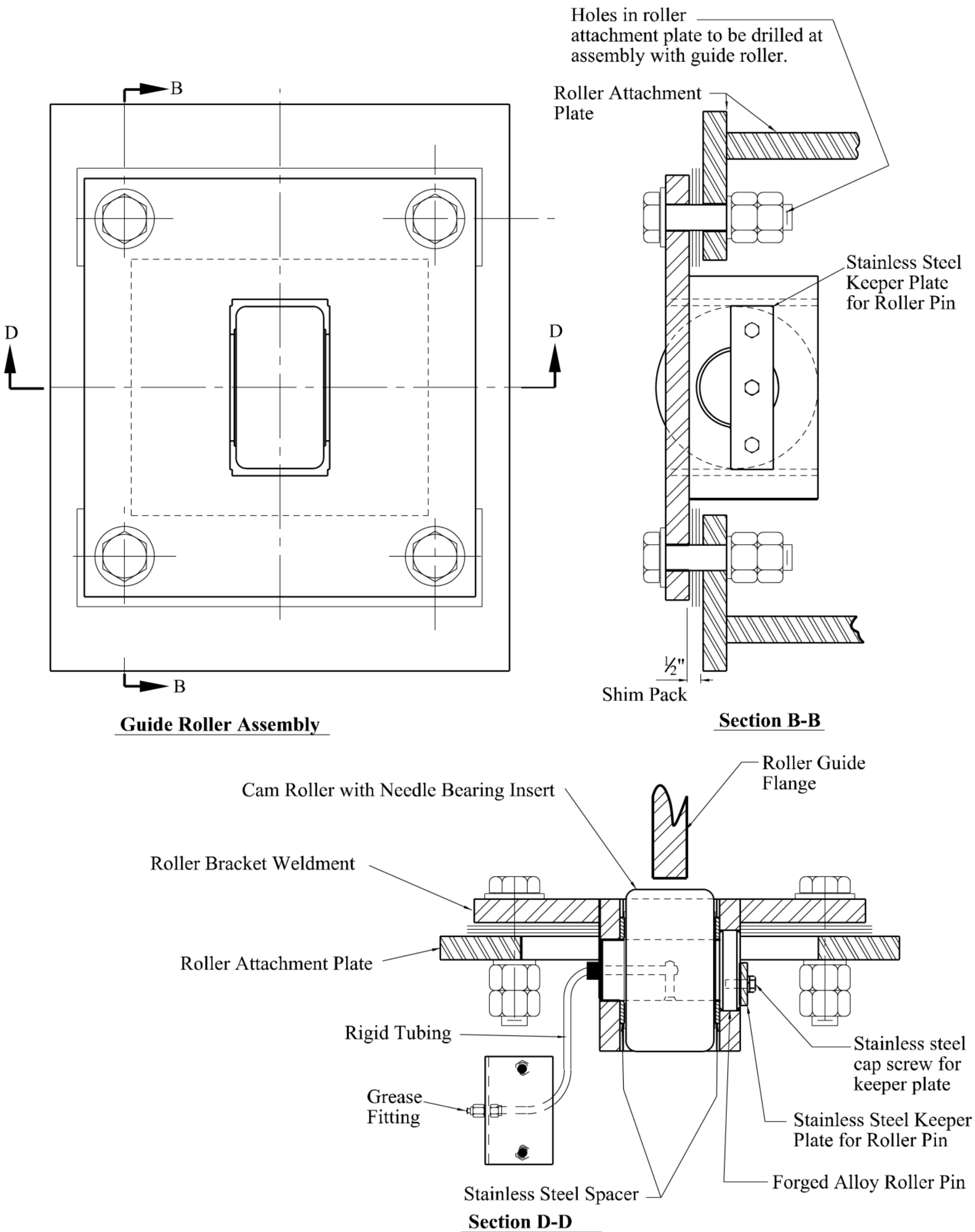


Figure 6.8.3.8-2—Example of a Vertical Lift Bridge Guide Roller Assembly For the Free End

6.9—EMERGENCY DRIVES

6.9.1—Engines for Driving Generators, Hydraulic Power Units, and Span Drive

The following shall supplement *A6.9.1*.

Gas or diesel engines shall not be used to back up span drive systems unless otherwise specified by the Bridge Design Engineer Administrator.

REFERENCES

AASHTO LRFD Bridge Construction Specifications, Latest Edition, American Association of State Highway and Transportation Officials, Washington D.C.

AASHTO LRFD Bridge Design Specifications, Latest Edition, American Association of State Highway and Transportation Officials, Washington D.C.

AASHTO LRFD Movable Highway Bridge Design Specifications, Latest Edition, American Association of State Highway and Transportation Officials, Washington D.C.

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Gimpert, Dennis. *A new Standard in Gear Inspection*. Gear Solutions. Media Solutions Inc. www.gearsolutions.com. 2013.

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Oberg, E. and F. D. Jones, et al. *Machinery's Handbook.* 28th Edition. Industrial Press Inc., New York, 2008.

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Young, Warren C. and Budynas, Richard G. *Roark's Formulas for Stress and Strain*. 7th Edition. McGraw-Hill Inc., New York, 2002.

Applicable Codes and Standards:

AGMA—American Gear Manufacturers Association
AISE—Association of Iron and Steel Engineers
ANSI—American National Standards Institute
ASTM—American Society for Testing and Materials
NEMA—National Electrical Manufacturers Association

APPENDIX—Vertical Lift Sheave Dimensions

AASHTO LRFD					
Vertical Lift Bridge Sheave Dimensions					
c = Wire Rope Diameter (in)	D = Sheave		D_{rg} = Rope Groove Diameter (in)		
	72c	80c			
	Use if span operated infrequently	Use if span operated frequently	Wire Rope Tolerance = x	D_{rg} = c + x (Fraction)	D_{rg} = c + x (Decimal)
3/4	4'-6"	5'-0"	1/32	25/32	0.78125
7/8	5'-3"	5'-10"	3/64	59/64	0.921875
1	6'-0"	6'-8"	3/64	1 3/64	1.046875
1 1/8	6'-9"	7'-6"	3/64	1 11/64	1.171875
1 1/4	7'-6"	8'-4"	1/16	1 5/16	1.3125
1 3/8	8'-3"	9'-2"	1/16	1 7/16	1.4375
1 1/2	9'-0"	10'-0"	1/16	1 9/16	1.5625
1 5/8	9'-9"	10'-10"	3/32	1 23/32	1.71875
1 3/4	10'-6"	11'-8"	3/32	1 27/32	1.84375
1 7/8	11'-3"	12'-6"	3/32	1 31/32	1.96875
2	12'-0"	13'-4"	3/32	2 3/32	2.09375
2 1/8	12'-9"	14'-2"	3/32	2 7/32	2.21875
2 1/4	13'-6"	15'-0"	3/32	2 11/32	2.34375
2 3/8	14'-3"	15'-10"	1/8	2 1/2	2.5
2 1/2	15'-0"	16'-8"	1/8	2 5/8	2.625

Minimum spacing between ropes = **c** + 1/4"

APPENDIX—Rope Selection (EIPS) (4 ropes per sheave)

2008 AASHTO LRFD (EIPS)												
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = $0.4c^2$ (in^2)	**d** = Wire Strand Dia. (in)	P_{ut} = Min. Ult. Tensile Str. of 1 Rope (lbs)	**Vertical Lift Span Weight**								
		For 6x19 rope, d is approx. = c/16	Extra Improved Plow Steel (EIPS)	**4 Ropes/Sheave * 4 Sheaves = 16 Ropes**								
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	52,400	3.60	104,800	**103,726**	63,438	57,094	186,311	**121,615**	**127,893**
7/8	0.3063	0.0547	70,800	4.90	141,600	**140,149**	86,345	77,711	251,733	**163,693**	**172,239**
1	0.4000	0.0625	92,000	6.40	184,000	**182,115**	112,778	101,500	327,111	**212,137**	**223,300**
1 1/8	0.5063	0.0703	115,600	8.10	231,200	**228,831**	142,734	128,461	411,022	**265,539**	**279,666**
1 1/4	0.6250	0.0781	142,200	10.00	284,400	**281,486**	176,215	158,594	505,600	**326,010**	**343,451**
1 3/8	0.7563	0.0859	171,000	12.10	342,000	**338,496**	213,220	191,898	608,000	**390,735**	**411,838**
1 1/2	0.9000	0.0938	202,000	14.40	404,000	**399,861**	253,750	228,375	718,222	**459,713**	**484,828**
1 5/8	1.0563	0.1016	236,000	16.90	472,000	**467,164**	297,804	268,023	839,111	**535,761**	**565,236**
1 3/4	1.2250	0.1094	274,000	19.60	548,000	**542,385**	345,382	310,844	974,222	**622,397**	**656,582**
1 7/8	1.4063	0.1172	312,000	22.50	624,000	**617,607**	396,484	356,836	1,109,333	**705,545**	**744,787**
2	1.6000	0.1250	352,000	25.60	704,000	**696,787**	451,111	406,000	1,251,556	**792,243**	**836,892**
2 1/8	1.8063	0.1328	394,000	28.90	788,000	**779,926**	509,262	458,336	1,400,889	**882,491**	**932,896**
2 1/4	2.0250	0.1406	440,000	32.40	880,000	**870,984**	570,938	513,844	1,564,444	**983,328**	**1,039,836**
2 3/8	2.2563	0.1484	488,000	36.10	976,000	**966,000**	636,137	572,523	1,735,111	**1,087,714**	**1,150,676**
2 1/2	2.5000	0.1563	538,000	40.00	1,076,000	**1,064,975**	704,861	634,375	1,912,889	**1,195,650**	**1,265,414**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$P_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$W_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $P_{DTL\ Tot}$ - $P_{B\ DTL}$ = lbs
$P_{B\ DTL}$ = Direct Tension Load in ropes due to braking = $((W_{S\ DTL}/32.2)*v)/t$ = lbs
$P_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = $(0.7*E*d*a_{Total})/(72*c)$= lbs
$P_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = $(0.7*E*d*a_{Total})/(80*c)$= lbs
$P_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$W_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 72}$ + $P_{brake\ Bend}$) = lbs
$W_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 80}$ + $P_{brake\ Bend}$) = lbs
$P_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = $((W_{S\ Bend\ 72}/32.2)*v)/t$ = lbs
$P_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 80}$ = $((W_{S\ Bend\ 80}/32.2)*v)/t$ = lbs

APPENDIX—Rope Selection (EIPS) (6 ropes per sheave)

2008 AASHTO LRFD (EIPS)												
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in)	P_{ut} = Min. Ult. Tensile Str. of 1 Rope (lbs)	Vertical Lift Span Weight								
		For 6x19 rope, d is approx. = c/16	Extra Improved Plow Steel (EIPS)	6 Ropes/Sheave * 4 Sheaves = 24 Ropes								
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	52,400	5.40	157,200	**155,589**	95,156	85,641	279,467	**182,422**	**191,840**
7/8	0.3063	0.0547	70,800	7.35	212,400	**210,224**	129,518	116,566	377,600	**245,540**	**258,359**
1	0.4000	0.0625	92,000	9.60	276,000	**273,172**	169,167	152,250	490,667	**318,206**	**334,949**
1 1/8	0.5063	0.0703	115,600	12.15	346,800	**343,247**	214,102	192,691	616,533	**398,308**	**419,499**
1 1/4	0.6250	0.0781	142,200	15.00	426,600	**422,229**	264,323	237,891	758,400	**489,015**	**515,176**
1 3/8	0.7563	0.0859	171,000	18.15	513,000	**507,744**	319,831	287,848	912,000	**586,102**	**617,757**
1 1/2	0.9000	0.0938	202,000	21.60	606,000	**599,791**	380,625	342,563	1,077,333	**689,570**	**727,242**
1 5/8	1.0563	0.1016	236,000	25.35	708,000	**700,746**	446,706	402,035	1,258,667	**803,642**	**847,855**
1 3/4	1.2250	0.1094	274,000	29.40	822,000	**813,578**	518,073	466,266	1,461,333	**933,596**	**984,872**
1 7/8	1.4063	0.1172	312,000	33.75	936,000	**926,410**	594,727	535,254	1,664,000	**1,058,318**	**1,117,181**
2	1.6000	0.1250	352,000	38.40	1,056,000	**1,045,180**	676,667	609,000	1,877,333	**1,188,365**	**1,255,338**
2 1/8	1.8063	0.1328	394,000	43.35	1,182,000	**1,169,889**	763,893	687,504	2,101,333	**1,323,737**	**1,399,343**
2 1/4	2.0250	0.1406	440,000	48.60	1,320,000	**1,306,475**	856,406	770,766	2,346,667	**1,474,991**	**1,559,755**
2 3/8	2.2563	0.1484	488,000	54.15	1,464,000	**1,449,000**	954,206	858,785	2,602,667	**1,631,571**	**1,726,014**
2 1/2	2.5000	0.1563	538,000	60.00	1,614,000	**1,597,463**	1,057,292	951,563	2,869,333	**1,793,476**	**1,898,122**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$P_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$W_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $P_{DTL\ Tot}$ - $P_{B\ DTL}$ = lbs
$P_{B\ DTL}$ = Direct Tension Load in ropes due to braking = (($W_{S\ DTL}$/32.2)***v**)/**t** = lbs
$P_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***a_{Total})/(72***c**)= lbs
$P_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***a_{Total})/(80***c**)= lbs
$P_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$W_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 72}$ + $P_{brake\ Bend}$) = lbs
$W_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 80}$ + $P_{brake\ Bend}$) = lbs
$P_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = (($W_{S\ Bend\ 72}$/32.2)***v**)/**t** = lbs
$P_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 80}$ = (($W_{S\ Bend\ 80}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EIPS) (8 ropes per sheave)

2008 AASHTO LRFD (EIPS)											
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in)	P_{ut} = Min. Ult. Tensile Str. of 1 Rope (lbs)	Vertical Lift Span Weight							
		For 6x19 rope, d is approx. = c/16	Extra Improved Plow Steel (EIPS)	8 Ropes/Sheave * 4 Sheaves = 32 Ropes							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	52,400	7.20	209,600	**207,452**	126,875	114,188	372,622	**243,229**	**255,787**
7/8	0.3063	0.0547	70,800	9.80	283,200	**280,298**	172,691	155,422	503,467	**327,387**	**344,479**
1	0.4000	0.0625	92,000	12.80	368,000	**364,230**	225,556	203,000	654,222	**424,275**	**446,599**
1 1/8	0.5063	0.0703	115,600	16.20	462,400	**457,662**	285,469	256,922	822,044	**531,078**	**559,332**
1 1/4	0.6250	0.0781	142,200	20.00	568,800	**562,972**	352,431	317,188	1,011,200	**652,020**	**686,902**
1 3/8	0.7563	0.0859	171,000	24.20	684,000	**676,992**	426,441	383,797	1,216,000	**781,469**	**823,676**
1 1/2	0.9000	0.0938	202,000	28.80	808,000	**799,721**	507,500	456,750	1,436,444	**919,427**	**969,657**
1 5/8	1.0563	0.1016	236,000	33.80	944,000	**934,328**	595,608	536,047	1,678,222	**1,071,522**	**1,130,473**
1 3/4	1.2250	0.1094	274,000	39.20	1,096,000	**1,084,770**	690,764	621,688	1,948,444	**1,244,794**	**1,313,163**
1 7/8	1.4063	0.1172	312,000	45.00	1,248,000	**1,235,213**	792,969	713,672	2,218,667	**1,411,090**	**1,489,575**
2	1.6000	0.1250	352,000	51.20	1,408,000	**1,393,574**	902,222	812,000	2,503,111	**1,584,486**	**1,673,784**
2 1/8	1.8063	0.1328	394,000	57.80	1,576,000	**1,559,852**	1,018,524	916,672	2,801,778	**1,764,982**	**1,865,791**
2 1/4	2.0250	0.0000	440,000	64.80	1,760,000	**1,741,967**	1,141,875	1,027,688	3,128,889	**1,966,655**	**2,079,673**
2 3/8	2.2563	0.1484	488,000	72.20	1,952,000	**1,932,000**	1,272,274	1,145,047	3,470,222	**2,175,428**	**2,301,352**
2 1/2	2.5000	0.1563	538,000	80.00	2,152,000	**2,129,951**	1,409,722	1,268,750	3,825,778	**2,391,301**	**2,530,829**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$\mathbf{P_{DTL\ Tot}}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ DTL}}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $\mathbf{P_{DTL\ Tot}}$ - $\mathbf{P_{B\ DTL}}$ = lbs
$\mathbf{P_{B\ DTL}}$ = Direct Tension Load in ropes due to braking = (($\mathbf{W_{S\ DTL}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{Bend\ 72}}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(72***c**)= lbs
$\mathbf{P_{Bend\ 80}}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(80***c**)= lbs
$\mathbf{P_{Bend\ Tot}}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ Bend\ 72}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 72}}$ + $\mathbf{P_{brake\ Bend}}$) = lbs
$\mathbf{W_{S\ Bend\ 80}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80c dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 80}$ + $P_{brake\ Bend}$) = lbs
$\mathbf{P_{B\ Bend\ 72}}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = (($W_{S\ Bend\ 72}$/32.2)*v)/t = lbs
$\mathbf{P_{B\ Bend\ 80}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 80}}$ = (($\mathbf{W_{S\ Bend\ 80}}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EIPS) (10 ropes per sheave)

2008 AASHTO LRFD (EIPS)											
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4c^2 (in^2)	**d** = Wire Strand Dia. (in)	P_{ut} = Min. Ult. Tensile Str. of 1 Rope (lbs)	**Vertical Lift Span Weight**							
		For 6x19 rope, d is approx. = c/16	Extra Improved Plow Steel (EIPS)	**10 Ropes/Sheave * 4 Sheaves = 40 Ropes**							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	52,400	9.00	262,000	**259,316**	158,594	142,734	465,778	**304,037**	**319,734**
7/8	0.3063	0.0547	70,800	12.25	354,000	**350,373**	215,864	194,277	629,333	**409,233**	**430,598**
1	0.4000	0.0625	92,000	16.00	460,000	**455,287**	281,944	253,750	817,778	**530,343**	**558,249**
1 1/8	0.5063	0.0703	115,600	20.25	578,000	**572,078**	356,836	321,152	1,027,556	**663,847**	**699,165**
1 1/4	0.6250	0.0781	142,200	25.00	711,000	**703,715**	440,538	396,484	1,264,000	**815,025**	**858,627**
1 3/8	0.7563	0.0859	171,000	30.25	855,000	**846,240**	533,051	479,746	1,520,000	**976,837**	**1,029,596**
1 1/2	0.9000	0.0938	202,000	36.00	1,010,000	**999,652**	634,375	570,938	1,795,556	**1,149,283**	**1,212,071**
1 5/8	1.0563	0.1016	236,000	42.25	1,180,000	**1,167,910**	744,510	670,059	2,097,778	**1,339,403**	**1,413,091**
1 3/4	1.2250	0.1094	274,000	49.00	1,370,000	**1,355,963**	863,455	777,109	2,435,556	**1,555,993**	**1,641,454**
1 7/8	1.4063	0.1172	312,000	56.25	1,560,000	**1,544,016**	991,211	892,090	2,773,333	**1,763,863**	**1,861,968**
2	1.6000	0.1250	352,000	64.00	1,760,000	**1,741,967**	1,127,778	1,015,000	3,128,889	**1,980,608**	**2,092,230**
2 1/8	1.8063	0.1328	394,000	72.25	1,970,000	**1,949,816**	1,273,155	1,145,840	3,502,222	**2,206,228**	**2,332,239**
2 1/4	2.0250	0.1406	440,000	81.00	2,200,000	**2,177,459**	1,427,344	1,284,609	3,911,111	**2,458,319**	**2,599,591**
2 3/8	2.2563	0.1484	488,000	90.25	2,440,000	**2,415,000**	1,590,343	1,431,309	4,337,778	**2,719,285**	**2,876,690**
2 1/2	2.5000	0.1563	538,000	100.00	2,690,000	**2,662,439**	1,762,153	1,585,938	4,782,222	**2,989,126**	**3,163,536**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$P_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$W_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $P_{DTL\ Tot}$ - $P_{B\ DTL}$ = lbs
$P_{B\ DTL}$ = Direct Tension Load in ropes due to braking = $((W_{S\ DTL}/32.2)*v)/t$ = lbs
$P_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = $(0.7*E*d*a_{Total})/(72*c)$= lbs
$P_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = $(0.7*E*d*a_{Total})/(80*c)$= lbs
$P_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$W_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 72}$ + $P_{brake\ Bend}$) = lbs
$W_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 80}$ + $P_{brake\ Bend}$) = lbs
$P_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = $((W_{S\ Bend\ 72}/32.2)*v)/t$ = lbs
$P_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 80}$ = $((W_{S\ Bend\ 80}/32.2)*v)/t$ = lbs

APPENDIX—Rope Selection (EIPS) (12 ropes per sheave)

2008 AASHTO LRFD (EIPS)											
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in)	$\mathbf{P_{ut}}$ = Min. Ult. Tensile Str. of 1 Rope (lbs)	**Vertical Lift Span Weight**							
		For 6x19 rope, d is approx. = c/16	Extra Improved Plow Steel (EIPS)	**12 Ropes/Sheave * 4 Sheaves = 48 Ropes**							
				$\mathbf{a_{Total}}$	$\mathbf{P_{DTL\ Tot}}$	$\mathbf{W_{S\ DTL}}$	$\mathbf{P_{Bend\ 72}}$	$\mathbf{P_{Bend\ 80}}$	$\mathbf{P_{Bend\ Tot}}$	$\mathbf{W_{S\ Bend\ 72}}$	$\mathbf{W_{S\ Bend\ 80}}$
3/4	0.2250	0.0469	52,400	10.80	314,400	**311,179**	190,313	171,281	558,933	**364,844**	**383,680**
7/8	0.3063	0.0547	70,800	14.70	424,800	**420,448**	259,036	233,133	755,200	**491,080**	**516,718**
1	0.4000	0.0625	92,000	19.20	552,000	**546,344**	338,333	304,500	981,333	**636,412**	**669,899**
1 1/8	0.5063	0.0703	115,600	24.30	693,600	**686,493**	428,203	385,383	1,233,067	**796,617**	**838,999**
1 1/4	0.6250	0.0781	142,200	30.00	853,200	**844,458**	528,646	475,781	1,516,800	**978,030**	**1,030,353**
1 3/8	0.7563	0.0859	171,000	36.30	1,026,000	**1,015,488**	639,661	575,695	1,824,000	**1,172,204**	**1,235,515**
1 1/2	0.9000	0.0938	202,000	43.20	1,212,000	**1,199,582**	761,250	685,125	2,154,667	**1,379,140**	**1,454,485**
1 5/8	1.0563	0.1016	236,000	50.70	1,416,000	**1,401,492**	893,411	804,070	2,517,333	**1,607,283**	**1,695,709**
1 3/4	1.2250	0.1094	274,000	58.80	1,644,000	**1,627,156**	1,036,146	932,531	2,922,667	**1,867,192**	**1,969,745**
1 7/8	1.4063	0.1172	312,000	67.50	1,872,000	**1,852,820**	1,189,453	1,070,508	3,328,000	**2,116,636**	**2,234,362**
2	1.6000	0.1250	352,000	76.80	2,112,000	**2,090,361**	1,353,333	1,218,000	3,754,667	**2,376,730**	**2,510,676**
2 1/8	1.8063	0.1328	394,000	86.70	2,364,000	**2,339,779**	1,527,786	1,375,008	4,202,667	**2,647,474**	**2,798,687**
2 1/4	2.0250	0.1406	440,000	97.20	2,640,000	**2,612,951**	1,712,813	1,541,531	4,693,333	**2,949,983**	**3,119,509**
2 3/8	2.2563	0.1484	488,000	108.30	2,928,000	**2,898,000**	1,908,411	1,717,570	5,205,333	**3,263,142**	**3,452,028**
2 1/2	2.5000	0.1563	538,000	120.00	3,228,000	**3,194,926**	2,114,583	1,903,125	5,738,667	**3,586,951**	**3,796,243**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$\mathbf{P_{DTL\ Tot}}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ DTL}}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $\mathbf{P_{DTL\ Tot}}$ - $\mathbf{P_{B\ DTL}}$ = lbs
$\mathbf{P_{B\ DTL}}$ = Direct Tension Load in ropes due to braking = (($\mathbf{W_{S\ DTL}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{Bend\ 72}}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(72***c**)= lbs
$\mathbf{P_{Bend\ 80}}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(80***c**)= lbs
$\mathbf{P_{Bend\ Tot}}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ Bend\ 72}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 72}}$ + $\mathbf{P_{brake\ Bend}}$) = lbs
$\mathbf{W_{S\ Bend\ 80}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 80}}$ + $\mathbf{P_{brake\ Bend}}$) = lbs
$\mathbf{P_{B\ Bend\ 72}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 72}}$ = (($\mathbf{W_{S\ Bend\ 72}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{B\ Bend\ 80}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 80}}$ = (($\mathbf{W_{S\ Bend\ 80}}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EIPS Galvanized) (4 ropes per sheave)

2008 AASHTO LRFD (EIPS- Galvanized)											
c = Wire Rope Dia.(in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in)	P_{ut} = Min. Ult. Tensile Str. of 1 Rope (lbs)	**Vertical Lift Span Weight**							
		For 6x19 rope, d is approx. = c/16	(EIPS) Galvanized	**4 Ropes/Sheave * 4 Sheaves = 16 Ropes**							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	47,200	3.60	94,400	**93,433**	63,438	57,094	167,822	**103,315**	**109,594**
7/8	0.3063	0.0547	63,700	4.90	127,400	**126,095**	86,345	77,711	226,489	**138,708**	**147,254**
1	0.4000	0.0625	82,800	6.40	165,600	**163,903**	112,778	101,500	294,400	**179,761**	**190,924**
1 1/8	0.5063	0.0703	104,200	8.10	208,400	**206,265**	142,734	128,461	370,489	**225,421**	**239,548**
1 1/4	0.6250	0.0781	128,000	10.00	256,000	**253,377**	176,215	158,594	455,111	**276,038**	**293,479**
1 3/8	0.7563	0.0859	153,900	12.10	307,800	**304,646**	213,220	191,898	547,200	**330,558**	**351,661**
1 1/2	0.9000	0.0938	181,800	14.40	363,600	**359,875**	253,750	228,375	646,400	**388,627**	**413,742**
1 5/8	1.0563	0.1016	212,400	16.90	424,800	**420,448**	297,804	268,023	755,200	**452,710**	**482,185**
1 3/4	1.2250	0.1094	244,800	19.60	489,600	**484,584**	345,382	310,844	870,400	**519,639**	**553,823**
1 7/8	1.4063	0.1172	279,000	22.50	558,000	**552,283**	396,484	356,836	992,000	**589,414**	**628,656**
2	1.6000	0.1250	316,800	25.60	633,600	**627,108**	451,111	406,000	1,126,400	**668,370**	**713,019**
2 1/8	1.8063	0.1328	354,600	28.90	709,200	**701,934**	509,262	458,336	1,260,800	**743,838**	**794,242**
2 1/4	2.0250	0.1406	396,000	32.40	792,000	**783,885**	570,938	513,844	1,408,000	**828,486**	**884,995**
2 3/8	2.2563	0.1484	439,000	36.10	878,000	**869,004**	636,137	572,523	1,560,889	**915,277**	**978,239**
2 1/2	2.5000	0.1563	484,200	40.00	968,400	**958,478**	704,861	634,375	1,721,600	**1,006,321**	**1,076,085**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$P_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$W_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $P_{DTL\ Tot}$ - $P_{B\ DTL}$ = lbs
$P_{B\ DTL}$ = Direct Tension Load in ropes due to braking = (($W_{S\ DTL}$/32.2)***v**)/**t** = lbs
$P_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***a_{Total})/(72***c**)= lbs
$P_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***a_{Total})/(80***c**)= lbs
$P_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$W_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 72}$ + $P_{brake\ Bend}$) = lbs
$W_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 80}$ + $P_{brake\ Bend}$) = lbs
$P_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = (($W_{S\ Bend\ 72}$/32.2)***v**)/**t** = lbs
$P_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 80}$ = (($W_{S\ Bend\ 80}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EIPS Galvanized) (6 ropes per sheave)

2008 AASHTO LRFD (EIPS- Galvanized)											
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in)	P_{ut} = Min. Ult. Tensile Str. of 1 Rope (lbs)	**Vertical Lift Span Weight**							
		For 6x19 rope, d is approx. = c/16	(EIPS) Galvanized	**6 Ropes/Sheave * 4 Sheaves = 24 Ropes**							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	47,200	5.40	141,600	**140,149**	95,156	85,641	251,733	**154,973**	**164,391**
7/8	0.3063	0.0547	63,700	7.35	191,100	**189,142**	129,518	116,566	339,733	**208,061**	**220,880**
1	0.4000	0.0625	82,800	9.60	248,400	**245,855**	169,167	152,250	441,600	**269,642**	**286,385**
1 1/8	0.5063	0.0703	104,200	12.15	312,600	**309,397**	214,102	192,691	555,733	**338,131**	**359,322**
1 1/4	0.6250	0.0781	128,000	15.00	384,000	**380,066**	264,323	237,891	682,667	**414,057**	**440,219**
1 3/8	0.7563	0.0859	153,900	18.15	461,700	**456,969**	319,831	287,848	820,800	**495,836**	**527,492**
1 1/2	0.9000	0.0938	181,800	21.60	545,400	**539,812**	380,625	342,563	969,600	**582,940**	**620,613**
1 5/8	1.0563	0.1016	212,400	25.35	637,200	**630,671**	446,706	402,035	1,132,800	**679,065**	**723,277**
1 3/4	1.2250	0.1094	244,800	29.40	734,400	**726,875**	518,073	466,266	1,305,600	**779,458**	**830,735**
1 7/8	1.4063	0.1172	279,000	33.75	837,000	**828,424**	594,727	535,254	1,488,000	**884,121**	**942,984**
2	1.6000	0.1250	316,800	38.40	950,400	**940,662**	676,667	609,000	1,689,600	**1,002,555**	**1,069,528**
2 1/8	1.8063	0.1328	354,600	43.35	1,063,800	**1,052,900**	763,893	687,504	1,891,200	**1,115,756**	**1,191,363**
2 1/4	2.0250	0.1406	396,000	48.60	1,188,000	**1,175,828**	856,406	770,766	2,112,000	**1,242,729**	**1,327,492**
2 3/8	2.2563	0.1484	439,000	54.15	1,317,000	**1,303,506**	954,206	858,785	2,341,333	**1,372,915**	**1,467,358**
2 1/2	2.5000	0.1563	484,200	60.00	1,452,600	**1,437,717**	1,057,292	951,563	2,582,400	**1,509,482**	**1,614,128**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$P_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$W_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $P_{DTL\ Tot}$ - $P_{B\ DTL}$ = lbs
$P_{B\ DTL}$ = Direct Tension Load in ropes due to braking = (($W_{S\ DTL}$/32.2)***v**)/**t** = lbs
$P_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***a_{Total})/(72***c**)= lbs
$P_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***a_{Total})/(80***c**)= lbs
$P_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$W_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 72}$ + $P_{brake\ Bend}$) = lbs
$W_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 80}$ + $P_{brake\ Bend}$) = lbs
$P_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = (($W_{S\ Bend\ 72}$/32.2)***v**)/**t** = lbs
$P_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 80}$ = (($W_{S\ Bend\ 80}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EIPS Galvanized) (8 ropes per sheave)

2008 AASHTO LRFD (EIPS- Galvanized)											
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = $0.4\mathbf{c}^2$ (in²)	**d** = Wire Strand Dia. (in)	$\mathbf{P}_{ut}$ = Min. Ult. Tensile Str. of 1 Rope (lbs)	Vertical Lift Span Weight							
		For 6x19 rope, d is approx. = c/16	(EIPS) Galvanized	8 Ropes/Sheave * 4 Sheaves = 32 Ropes							
				$\mathbf{a}_{Total}$	$\mathbf{P}_{DTL\ Tot}$	$\mathbf{W}_{S\ DTL}$	$\mathbf{P}_{Bend\ 72}$	$\mathbf{P}_{Bend\ 80}$	$\mathbf{P}_{Bend\ Tot}$	$\mathbf{W}_{S\ Bend\ 72}$	$\mathbf{W}_{S\ Bend\ 80}$
3/4	0.2250	0.0469	47,200	7.20	188,800	**186,866**	126,875	114,188	335,644	**206,630**	**219,188**
7/8	0.3063	0.0547	63,700	9.80	254,800	**252,189**	172,691	155,422	452,978	**277,415**	**294,507**
1	0.4000	0.0625	82,800	12.80	331,200	**327,807**	225,556	203,000	588,800	**359,523**	**381,847**
1 1/8	0.5063	0.0703	104,200	16.20	416,800	**412,530**	285,469	256,922	740,978	**450,842**	**479,096**
1 1/4	0.6250	0.0781	128,000	20.00	512,000	**506,754**	352,431	317,188	910,222	**552,077**	**586,959**
1 3/8	0.7563	0.0859	153,900	24.20	615,600	**609,293**	426,441	383,797	1,094,400	**661,115**	**703,322**
1 1/2	0.9000	0.0938	181,800	28.80	727,200	**719,749**	507,500	456,750	1,292,800	**777,254**	**827,484**
1 5/8	1.0563	0.1016	212,400	33.80	849,600	**840,895**	595,608	536,047	1,510,400	**905,419**	**964,370**
1 3/4	1.2250	0.1094	244,800	39.20	979,200	**969,167**	690,764	621,688	1,740,800	**1,039,278**	**1,107,646**
1 7/8	1.4063	0.1172	279,000	45.00	1,116,000	**1,104,566**	792,969	713,672	1,984,000	**1,178,828**	**1,257,312**
2	1.6000	0.1250	316,800	51.20	1,267,200	**1,254,216**	902,222	812,000	2,252,800	**1,336,740**	**1,426,038**
2 1/8	1.8063	0.1328	354,600	57.80	1,418,400	**1,403,867**	1,018,524	916,672	2,521,600	**1,487,675**	**1,588,484**
2 1/4	2.0250	0.1406	396,000	64.80	1,584,000	**1,567,770**	1,141,875	1,027,688	2,816,000	**1,656,972**	**1,769,990**
2 3/8	2.2563	0.1484	439,000	72.20	1,756,000	**1,738,008**	1,272,274	1,145,047	3,121,778	**1,830,554**	**1,956,478**
2 1/2	2.5000	0.1563	484,200	80.00	1,936,800	**1,916,956**	1,409,722	1,268,750	3,443,200	**2,012,643**	**2,152,171**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$\mathbf{P}_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$\mathbf{W}_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $\mathbf{P}_{DTL\ Tot}$ - $\mathbf{P}_{B\ DTL}$ = lbs
$\mathbf{P}_{B\ DTL}$ = Direct Tension Load in ropes due to braking = (($\mathbf{W}_{S\ DTL}$/32.2)***v**)/**t** = lbs
$\mathbf{P}_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***$\mathbf{a}_{Total}$)/(72***c**)= lbs
$\mathbf{P}_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***$\mathbf{a}_{Total}$)/(80***c**)= lbs
$\mathbf{P}_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$\mathbf{W}_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $\mathbf{P}_{bend\ Tot}$ - ($\mathbf{P}_{bend\ 72}$ + $\mathbf{P}_{brake\ Bend}$) = lbs
$\mathbf{W}_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $\mathbf{P}_{bend\ Tot}$ - ($\mathbf{P}_{bend\ 80}$ + $\mathbf{P}_{brake\ Bend}$) = lbs
$\mathbf{P}_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $\mathbf{W}_{S\ Bend\ 72}$ = (($\mathbf{W}_{S\ Bend\ 72}$/32.2)***v**)/**t** = lbs
$\mathbf{P}_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $\mathbf{W}_{S\ Bend\ 80}$ = (($\mathbf{W}_{S\ Bend\ 80}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EIPS Galvanized) (10 ropes per sheave)

2008 AASHTO LRFD (EIPS- Galvanized)											
c = Wire Rope Dia.(in)	**a** = Wire Rope Cross Section Area = 0.4c^2 (in^2)	**d** = Wire Strand Dia. (in)	P_{ut} = Min. Ult. Tensile Str. of 1 Rope (lbs)	**Vertical Lift Span Weight**							
		For 6x19 rope, d is approx. = c/16	(EIPS) Galvanized	**10 Ropes/Sheave * 4 Sheaves = 40 Ropes**							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	47,200	9.00	236,000	**233,582**	158,594	142,734	419,556	**258,288**	**273,985**
7/8	0.3063	0.0547	63,700	12.25	318,500	**315,237**	215,864	194,277	566,222	**346,769**	**368,134**
1	0.4000	0.0625	82,800	16.00	414,000	**409,758**	281,944	253,750	736,000	**449,403**	**477,309**
1 1/8	0.5063	0.0703	104,200	20.25	521,000	**515,662**	356,836	321,152	926,222	**563,552**	**598,870**
1 1/4	0.6250	0.0781	128,000	25.00	640,000	**633,443**	440,538	396,484	1,137,778	**690,096**	**733,698**
1 3/8	0.7563	0.0859	153,900	30.25	769,500	**761,616**	533,051	479,746	1,368,000	**826,394**	**879,153**
1 1/2	0.9000	0.0938	181,800	36.00	909,000	**899,686**	634,375	570,938	1,616,000	**971,567**	**1,034,355**
1 5/8	1.0563	0.1016	212,400	42.25	1,062,000	**1,051,119**	744,510	670,059	1,888,000	**1,131,774**	**1,205,462**
1 3/4	1.2250	0.1094	244,800	49.00	1,224,000	**1,211,459**	863,455	777,109	2,176,000	**1,299,097**	**1,384,558**
1 7/8	1.4063	0.1172	279,000	56.25	1,395,000	**1,380,707**	991,211	892,090	2,480,000	**1,473,535**	**1,571,641**
2	1.6000	0.1250	316,800	64.00	1,584,000	**1,567,770**	1,127,778	1,015,000	2,816,000	**1,670,925**	**1,782,547**
2 1/8	1.8063	0.1328	354,600	72.25	1,773,000	**1,754,834**	1,273,155	1,145,840	3,152,000	**1,859,594**	**1,985,605**
2 1/4	2.0250	0.1406	396,000	81.00	1,980,000	**1,959,713**	1,427,344	1,284,609	3,520,000	**2,071,215**	**2,212,487**
2 3/8	2.2563	0.1484	439,000	90.25	2,195,000	**2,172,510**	1,590,343	1,431,309	3,902,222	**2,288,192**	**2,445,597**
2 1/2	2.5000	0.1563	484,200	100.00	2,421,000	**2,396,195**	1,762,153	1,585,938	4,304,000	**2,515,804**	**2,690,213**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$P_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$W_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $P_{DTL\ Tot}$ - $P_{B\ DTL}$ = lbs
$P_{B\ DTL}$ = Direct Tension Load in ropes due to braking = (($W_{S\ DTL}$/32.2)***v**)/**t** = lbs
$P_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***a_{Total})/(72***c**)= lbs
$P_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***a_{Total})/(80***c**)= lbs
$P_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$W_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 72}$ + $P_{brake\ Bend}$) = lbs
$W_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 80}$ + $P_{brake\ Bend}$) = lbs
$P_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = (($W_{S\ Bend\ 72}$/32.2)***v**)/**t** = lbs
$P_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 80}$ = (($W_{S\ Bend\ 80}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EIPS Galvanized) (12 ropes per sheave)

2008 AASHTO LRFD (EIPS- Galvanized)

c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in) For 6x19 rope, d is approx. = c/16	P_{ut} = Min. Ult. Tensile Str. of 1 Rope (lbs) (EIPS) Galvanized	**Vertical Lift Span Weight** **12 Ropes/Sheave * 4 Sheaves = 48 Ropes**							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	47,200	10.80	283,200	**280,298**	190,313	171,281	503,467	**309,946**	**328,782**
7/8	0.3063	0.0547	63,700	14.70	382,200	**378,284**	259,036	233,133	679,467	**416,123**	**441,761**
1	0.4000	0.0625	82,800	19.20	496,800	**491,710**	338,333	304,500	883,200	**539,284**	**572,771**
1 1/8	0.5063	0.0703	104,200	24.30	625,200	**618,794**	428,203	385,383	1,111,467	**676,263**	**718,644**
1 1/4	0.6250	0.0781	128,000	30.00	768,000	**760,131**	528,646	475,781	1,365,333	**828,115**	**880,438**
1 3/8	0.7563	0.0859	153,900	36.30	923,400	**913,939**	639,661	575,695	1,641,600	**991,673**	**1,054,984**
1 1/2	0.9000	0.0938	181,800	43.20	1,090,800	**1,079,624**	761,250	685,125	1,939,200	**1,165,881**	**1,241,226**
1 5/8	1.0563	0.1016	212,400	50.70	1,274,400	**1,261,343**	893,411	804,070	2,265,600	**1,358,129**	**1,446,555**
1 3/4	1.2250	0.1094	244,800	58.80	1,468,800	**1,453,751**	1,036,146	932,531	2,611,200	**1,558,916**	**1,661,469**
1 7/8	1.4063	0.1172	279,000	67.50	1,674,000	**1,656,848**	1,189,453	1,070,508	2,976,000	**1,768,242**	**1,885,969**
2	1.6000	0.1250	316,800	76.80	1,900,800	**1,881,325**	1,353,333	1,218,000	3,379,200	**2,005,110**	**2,139,057**
2 1/8	1.8063	0.1328	354,600	86.70	2,127,600	**2,105,801**	1,527,786	1,375,008	3,782,400	**2,231,513**	**2,382,726**
2 1/4	2.0250	0.1406	396,000	97.20	2,376,000	**2,351,656**	1,712,813	1,541,531	4,224,000	**2,485,458**	**2,654,984**
2 3/8	2.2563	0.1484	439,000	108.30	2,634,000	**2,607,012**	1,908,411	1,717,570	4,682,667	**2,745,830**	**2,934,716**
2 1/2	2.5000	0.1563	484,200	120.00	2,905,200	**2,875,434**	2,114,583	1,903,125	5,164,800	**3,018,964**	**3,228,256**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$P_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$W_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $P_{DTL\ Tot}$ - $P_{B\ DTL}$ = lbs
$P_{B\ DTL}$ = Direct Tension Load in ropes due to braking = (($W_{S\ DTL}$/32.2)***v**)/**t** = lbs
$P_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***a_{Total})/(72***c**)= lbs
$P_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***a_{Total})/(80***c**)= lbs
$P_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$W_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 72}$ + $P_{brake\ Bend}$) = lbs
$W_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 80}$ + $P_{brake\ Bend}$) = lbs
$P_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = (($W_{S\ Bend\ 72}$/32.2)***v**)/**t** = lbs
$P_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 80}$ = (($W_{S\ Bend\ 80}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EEIPS) (4 ropes per sheave)

AASHTO LRFD (EEIPS)											
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in)	$\mathbf{P_{ut}}$ = Min. Ult. Tensile Str. of 1 Rope (lbs)	**Vertical Lift Span Weight**							
		For 6x19 rope, d is approx. = c/16	Double Extra Improved Plow Steel (EEIPS)	**4 Ropes/Sheave * 4 Sheaves = 16 Ropes**							
				$\mathbf{a_{Total}}$	$\mathbf{P_{DTL\ Tot}}$	$\mathbf{W_{S\ DTL}}$	$\mathbf{P_{Bend\ 72}}$	$\mathbf{P_{Bend\ 80}}$	$\mathbf{P_{Bend\ Tot}}$	$\mathbf{W_{S\ Bend\ 72}}$	$\mathbf{W_{S\ Bend\ 80}}$
3/4	0.2250	0.0469	57,600	3.60	115,200	**114,020**	63,438	57,094	204,800	**139,914**	**146,193**
7/8	0.3063	0.0547	78,000	4.90	156,000	**154,402**	86,345	77,711	277,333	**189,031**	**197,577**
1	0.4000	0.0625	101,200	6.40	202,400	**200,326**	112,778	101,500	359,822	**244,513**	**255,675**
1 1/8	0.5063	0.0703	127,200	8.10	254,400	**251,793**	142,734	128,461	452,267	**306,361**	**320,488**
1 1/4	0.6250	0.0781	156,400	10.00	312,800	**309,595**	176,215	158,594	556,089	**375,981**	**393,422**
1 3/8	0.7563	0.0859	188,000	12.10	376,000	**372,148**	213,220	191,898	668,444	**450,560**	**471,663**
1 1/2	0.9000	0.0938	222,000	14.40	444,000	**439,451**	253,750	228,375	789,333	**530,096**	**555,211**
1 5/8	1.0563	0.1016	258,000	16.90	516,000	**510,713**	297,804	268,023	917,333	**613,182**	**642,657**
1 3/4	1.2250	0.1094	300,000	19.60	600,000	**593,852**	345,382	310,844	1,066,667	**713,895**	**748,079**
1 7/8	1.4063	0.1172	342,000	22.50	684,000	**676,992**	396,484	356,836	1,216,000	**811,119**	**850,361**
2	1.6000	0.1250	388,000	25.60	776,000	**768,049**	451,111	406,000	1,379,556	**918,932**	**963,581**
2 1/8	1.8063	0.1328	434,000	28.90	868,000	**859,107**	509,262	458,336	1,543,111	**1,023,256**	**1,073,661**
2 1/4	2.0250	0.1406	484,000	32.40	968,000	**958,082**	570,938	513,844	1,720,889	**1,138,169**	**1,194,678**
2 3/8	2.2563	0.1484	538,000	36.10	1,076,000	**1,064,975**	636,137	572,523	1,912,889	**1,263,670**	**1,326,632**
2 1/2	2.5000	0.1563	590,000	40.00	1,180,000	**1,167,910**	704,861	634,375	2,097,778	**1,378,645**	**1,448,409**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$\mathbf{P_{DTL\ Tot}}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ DTL}}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $\mathbf{P_{DTL\ Tot}}$ - $\mathbf{P_{B\ DTL}}$ = lbs
$\mathbf{P_{B\ DTL}}$ = Direct Tension Load in ropes due to braking = (($\mathbf{W_{S\ DTL}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{Bend\ 72}}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(72***c**)= lbs
$\mathbf{P_{Bend\ 80}}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(80***c**)= lbs
$\mathbf{P_{Bend\ Tot}}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ Bend\ 72}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 72}}$ + $\mathbf{P_{brale\ Bend}}$) = lbs
$\mathbf{W_{S\ Bend\ 80}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 80}}$ + $\mathbf{P_{brale\ Bend}}$) = lbs
$\mathbf{P_{B\ Bend\ 72}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 72}}$ = (($\mathbf{W_{S\ Bend\ 72}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{B\ Bend\ 80}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 80}}$ = (($\mathbf{W_{S\ Bend\ 80}}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EEIPS) (6 ropes per sheave)

AASHTO LRFD (EEIPS)												
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in)	$\mathbf{P_{ut}}$ = Min. Ult. Tensile Str. of 1 Rope (lbs)	**Vertical Lift Span Weight**								
		For 6x19 rope, d is approx. = c/16	Double Extra Improved Plow Steel (EEIPS)	**6 Ropes/Sheave * 4 Sheaves = 24 Ropes**								
				$\mathbf{a_{Total}}$	$\mathbf{P_{DTL\ Tot}}$	$\mathbf{W_{S\ DTL}}$	$\mathbf{P_{Bend\ 72}}$	$\mathbf{P_{Bend\ 80}}$	$\mathbf{P_{Bend\ Tot}}$	$\mathbf{W_{S\ Bend\ 72}}$	$\mathbf{W_{S\ Bend\ 80}}$
3/4	0.2250	0.0469	57,600	5.40	172,800	**171,030**	95,156	85,641	307,200	**209,871**	**219,289**
7/8	0.3063	0.0547	78,000	7.35	234,000	**231,602**	129,518	116,566	416,000	**283,547**	**296,366**
1	0.4000	0.0625	101,200	9.60	303,600	**300,489**	169,167	152,250	539,733	**366,770**	**383,513**
1 1/8	0.5063	0.0703	127,200	12.15	381,600	**377,690**	214,102	192,691	678,400	**459,541**	**480,732**
1 1/4	0.6250	0.0781	156,400	15.00	469,200	**464,393**	264,323	237,891	834,133	**563,972**	**590,134**
1 3/8	0.7563	0.0859	188,000	18.15	564,000	**558,221**	319,831	287,848	1,002,667	**675,840**	**707,495**
1 1/2	0.9000	0.0938	222,000	21.60	666,000	**659,176**	380,625	342,563	1,184,000	**795,144**	**832,816**
1 5/8	1.0563	0.1016	258,000	25.35	774,000	**766,070**	446,706	402,035	1,376,000	**919,773**	**963,986**
1 3/4	1.2250	0.1094	300,000	29.40	900,000	**890,779**	518,073	466,266	1,600,000	**1,070,842**	**1,122,118**
1 7/8	1.4063	0.1172	342,000	33.75	1,026,000	**1,015,488**	594,727	535,254	1,824,000	**1,216,678**	**1,275,542**
2	1.6000	0.1250	388,000	38.40	1,164,000	**1,152,074**	676,667	609,000	2,069,333	**1,378,398**	**1,445,371**
2 1/8	1.8063	0.1328	434,000	43.35	1,302,000	**1,288,660**	763,893	687,504	2,314,667	**1,534,884**	**1,610,491**
2 1/4	2.0250	0.1406	484,000	48.60	1,452,000	**1,437,123**	856,406	770,766	2,581,333	**1,707,254**	**1,792,017**
2 3/8	2.2563	0.1484	538,000	54.15	1,614,000	**1,597,463**	954,206	858,785	2,869,333	**1,895,505**	**1,989,948**
2 1/2	2.5000	0.1563	590,000	60.00	1,770,000	**1,751,865**	1,057,292	951,563	3,146,667	**2,067,967**	**2,172,613**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$\mathbf{P_{DTL\ Tot}}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ DTL}}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $\mathbf{P_{DTL\ Tot}}$ - $\mathbf{P_{B\ DTL}}$ = lbs
$\mathbf{P_{B\ DTL}}$ = Direct Tension Load in ropes due to braking = (($\mathbf{W_{S\ DTL}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{Bend\ 72}}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(72***c**)= lbs
$\mathbf{P_{Bend\ 80}}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(80***c**)= lbs
$\mathbf{P_{Bend\ Tot}}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ Bend\ 72}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 72}}$ + $\mathbf{P_{brale\ Bend}}$) = lbs
$\mathbf{W_{S\ Bend\ 80}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 80}}$ + $\mathbf{P_{brale\ Bend}}$) = lbs
$\mathbf{P_{B\ Bend\ 72}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 72}}$ = (($\mathbf{W_{S\ Bend\ 72}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{B\ Bend\ 80}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 80}}$ = (($\mathbf{W_{S\ Bend\ 80}}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EEIPS) (8 ropes per sheave)

AASHTO LRFD (EEIPS)												
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in)	$\mathbf{P_{ut}}$ = Min. Ult. Tensile Str. of 1 Rope (lbs)	Vertical Lift Span Weight								
		For 6x19 rope, d is approx. = c/16	Double Extra Improved Plow Steel (EEIPS)	8 Ropes/Sheave * 4 Sheaves = 32 Ropes								
				$\mathbf{a_{Total}}$	$\mathbf{P_{DTL\ Tot}}$	$\mathbf{W_{S\ DTL}}$	$\mathbf{P_{Bend\ 72}}$	$\mathbf{P_{Bend\ 80}}$	$\mathbf{P_{Bend\ Tot}}$	$\mathbf{W_{S\ Bend\ 72}}$	$\mathbf{W_{S\ Bend\ 80}}$
3/4	0.2250	0.0469	57,600	7.20	230,400	**228,039**	126,875	114,188	409,600	**279,828**	**292,386**
7/8	0.3063	0.0547	78,000	9.80	312,000	**308,803**	172,691	155,422	554,667	**378,062**	**395,154**
1	0.4000	0.0625	101,200	12.80	404,800	**400,652**	225,556	203,000	719,644	**489,027**	**511,351**
1 1/8	0.5063	0.0703	127,200	16.20	508,800	**503,587**	285,469	256,922	904,533	**612,722**	**640,976**
1 1/4	0.6250	0.0781	156,400	20.00	625,600	**619,190**	352,431	317,188	1,112,178	**751,963**	**786,845**
1 3/8	0.7563	0.0859	188,000	24.20	752,000	**744,295**	426,441	383,797	1,336,889	**901,120**	**943,327**
1 1/2	0.9000	0.0938	222,000	28.80	888,000	**878,902**	507,500	456,750	1,578,667	**1,060,192**	**1,110,422**
1 5/8	1.0563	0.1016	258,000	33.80	1,032,000	**1,021,426**	595,608	536,047	1,834,667	**1,226,364**	**1,285,314**
1 3/4	1.2250	0.1094	300,000	39.20	1,200,000	**1,187,705**	690,764	621,688	2,133,333	**1,427,789**	**1,496,158**
1 7/8	1.4063	0.1172	342,000	45.00	1,368,000	**1,353,984**	792,969	713,672	2,432,000	**1,622,238**	**1,700,722**
2	1.6000	0.1250	388,000	51.20	1,552,000	**1,536,098**	902,222	812,000	2,759,111	**1,837,863**	**1,927,161**
2 1/8	1.8063	0.1328	434,000	57.80	1,736,000	**1,718,213**	1,018,524	916,672	3,086,222	**2,046,512**	**2,147,321**
2 1/4	2.0250	0.1406	484,000	64.80	1,936,000	**1,916,164**	1,141,875	1,027,688	3,441,778	**2,276,338**	**2,389,356**
2 3/8	2.2563	0.1484	538,000	72.20	2,152,000	**2,129,951**	1,272,274	1,145,047	3,825,778	**2,527,341**	**2,653,264**
2 1/2	2.5000	0.1563	590,000	80.00	2,360,000	**2,335,820**	1,409,722	1,268,750	4,195,556	**2,757,290**	**2,896,818**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$\mathbf{P_{DTL\ Tot}}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ DTL}}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $\mathbf{P_{DTL\ Tot}}$ - $\mathbf{P_{B\ DTL}}$ = lbs
$\mathbf{P_{B\ DTL}}$ = Direct Tension Load in ropes due to braking = (($\mathbf{W_{S\ DTL}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{Bend\ 72}}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(72***c**)= lbs
$\mathbf{P_{Bend\ 80}}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(80***c**)= lbs
$\mathbf{P_{Bend\ Tot}}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ Bend\ 72}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 72}}$ + $\mathbf{P_{brale\ Bend}}$) = lbs
$\mathbf{W_{S\ Bend\ 80}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 80}}$ + $\mathbf{P_{brale\ Bend}}$) = lbs
$\mathbf{P_{B\ Bend\ 72}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 72}}$ = (($\mathbf{W_{S\ Bend\ 72}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{B\ Bend\ 80}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 80}}$ = (($\mathbf{W_{S\ Bend\ 80}}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EEIPS) (10 ropes per sheave)

AASHTO LRFD (EEIPS)											
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4c^2 (in^2)	**d** = Wire Strand Dia. (in)	P_{ut} = Min. Ult. Tensile Str. of 1 Rope (lbs)	Vertical Lift Span Weight							
		For 6x19 rope, d is approx. = c/16	Double Extra Improved Plow Steel (EEIPS)	10 Ropes/Sheave * 4 Sheaves = 40 Ropes							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	57,600	9.00	288,000	**285,049**	158,594	142,734	512,000	**349,785**	**365,482**
7/8	0.3063	0.0547	78,000	12.25	390,000	**386,004**	215,864	194,277	693,333	**472,578**	**493,943**
1	0.4000	0.0625	101,200	16.00	506,000	**500,816**	281,944	253,750	899,556	**611,283**	**639,189**
1 1/8	0.5063	0.0703	127,200	20.25	636,000	**629,484**	356,836	321,152	1,130,667	**765,902**	**801,220**
1 1/4	0.6250	0.0781	156,400	25.00	782,000	**773,988**	440,538	396,484	1,390,222	**939,954**	**983,556**
1 3/8	0.7563	0.0859	188,000	30.25	940,000	**930,369**	533,051	479,746	1,671,111	**1,126,399**	**1,179,158**
1 1/2	0.9000	0.0938	222,000	36.00	1,110,000	**1,098,627**	634,375	570,938	1,973,333	**1,325,239**	**1,388,027**
1 5/8	1.0563	0.1016	258,000	42.25	1,290,000	**1,276,783**	744,510	670,059	2,293,333	**1,532,955**	**1,606,643**
1 3/4	1.2250	0.1094	300,000	49.00	1,500,000	**1,484,631**	863,455	777,109	2,666,667	**1,784,736**	**1,870,197**
1 7/8	1.4063	0.1172	342,000	56.25	1,710,000	**1,692,480**	991,211	892,090	3,040,000	**2,027,797**	**2,125,903**
2	1.6000	0.1250	388,000	64.00	1,940,000	**1,920,123**	1,127,778	1,015,000	3,448,889	**2,297,329**	**2,408,952**
2 1/8	1.8063	0.1328	434,000	72.25	2,170,000	**2,147,766**	1,273,155	1,145,840	3,857,778	**2,558,141**	**2,684,152**
2 1/4	2.0250	0.1406	484,000	81.00	2,420,000	**2,395,205**	1,427,344	1,284,609	4,302,222	**2,845,423**	**2,986,695**
2 3/8	2.2563	0.1484	538,000	90.25	2,690,000	**2,662,439**	1,590,343	1,431,309	4,782,222	**3,159,176**	**3,316,580**
2 1/2	2.5000	0.1563	590,000	100.00	2,950,000	**2,919,775**	1,762,153	1,585,938	5,244,444	**3,446,612**	**3,621,022**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$P_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$W_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $P_{DTL\ Tot}$ - $P_{B\ DTL}$ = lbs
$P_{B\ DTL}$ = Direct Tension Load in ropes due to braking = $((W_{S\ DTL}/32.2)*v)/t$ = lbs
$P_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = $(0.7*E*d*a_{Total})/(72*c)$= lbs
$P_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = $(0.7*E*d*a_{Total})/(80*c)$= lbs
$P_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$W_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 72}$ + $P_{brale\ Bend}$) = lbs
$W_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 80}$ + $P_{brale\ Bend}$) = lbs
$P_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = $((W_{S\ Bend\ 72}/32.2)*v)/t$ = lbs
$P_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 80}$ = $((W_{S\ Bend\ 80}/32.2)*v)/t$ = lbs

APPENDIX—Rope Selection (EEIPS) (12 ropes per sheave)

AASHTO LRFD (EEIPS)

c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4c^2 (in^2)	**d** = Wire Strand Dia. (in) — For 6x19 rope, d is approx. = c/16	P_{ut} = Min. Ult. Tensile Str. of 1 Rope (lbs) — Double Extra Improved Plow Steel (EEIPS)	**Vertical Lift Span Weight** — 12 Ropes/Sheave * 4 Sheaves = 48 Ropes							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	57,600	10.80	345,600	**342,059**	190,313	171,281	614,400	**419,742**	**438,579**
7/8	0.3063	0.0547	78,000	14.70	468,000	**463,205**	259,036	233,133	832,000	**567,093**	**592,731**
1	0.4000	0.0625	101,200	19.20	607,200	**600,979**	338,333	304,500	1,079,467	**733,540**	**767,026**
1 1/8	0.5063	0.0703	127,200	24.30	763,200	**755,380**	428,203	385,383	1,356,800	**919,083**	**961,464**
1 1/4	0.6250	0.0781	156,400	30.00	938,400	**928,785**	528,646	475,781	1,668,267	**1,127,944**	**1,180,267**
1 3/8	0.7563	0.0859	188,000	36.30	1,128,000	**1,116,443**	639,661	575,695	2,005,333	**1,351,679**	**1,414,990**
1 1/2	0.9000	0.0938	222,000	43.20	1,332,000	**1,318,352**	761,250	685,125	2,368,000	**1,590,287**	**1,665,632**
1 5/8	1.0563	0.1016	258,000	50.70	1,548,000	**1,532,139**	893,411	804,070	2,752,000	**1,839,546**	**1,927,971**
1 3/4	1.2250	0.1094	300,000	58.80	1,800,000	**1,781,557**	1,036,146	932,531	3,200,000	**2,141,684**	**2,244,236**
1 7/8	1.4063	0.1172	342,000	67.50	2,052,000	**2,030,975**	1,189,453	1,070,508	3,648,000	**2,433,357**	**2,551,083**
2	1.6000	0.1250	388,000	76.80	2,328,000	**2,304,148**	1,353,333	1,218,000	4,138,667	**2,756,795**	**2,890,742**
2 1/8	1.8063	0.1328	434,000	86.70	2,604,000	**2,577,320**	1,527,786	1,375,008	4,629,333	**3,069,769**	**3,220,982**
2 1/4	2.0250	0.1406	484,000	97.20	2,904,000	**2,874,246**	1,712,813	1,541,531	5,162,667	**3,414,507**	**3,584,034**
2 3/8	2.2563	0.1484	538,000	108.30	3,228,000	**3,194,926**	1,908,411	1,717,570	5,738,667	**3,791,011**	**3,979,897**
2 1/2	2.5000	0.1563	590,000	120.00	3,540,000	**3,503,730**	2,114,583	1,903,125	6,293,333	**4,135,935**	**4,345,227**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$P_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$W_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $P_{DTL\ Tot}$ - $P_{B\ DTL}$ = lbs
$P_{B\ DTL}$ = Direct Tension Load in ropes due to braking = (($W_{S\ DTL}$/32.2)***v**)/**t** = lbs
$P_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***a_{Total})/(72***c**)= lbs
$P_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***a_{Total})/(80***c**)= lbs
$P_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$W_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 72}$ + $P_{brake\ Bend}$) = lbs
$W_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 80}$ + $P_{brake\ Bend}$) = lbs
$P_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = (($W_{S\ Bend\ 72}$/32.2)***v**)/**t** = lbs
$P_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 80}$ = (($W_{S\ Bend\ 80}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EEIPS Galvanized) (4 ropes per sheave)

AASHTO LRFD (EEIPS- Galvanized)											
c = Wire Rope Dia.(in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in)	$\mathbf{P_{ut}}$ = Min. Ult. Tensile Str. of 1 Rope (lbs)	Vertical Lift Span Weight							
		For 6x19 rope, d is approx. = c/16	(EEIPS) Galvanized	4 Ropes/Sheave * 4 Sheaves = 16 Ropes							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	51,800	3.60	103,600	**102,539**	63,438	57,094	184,178	**119,503**	**125,782**
7/8	0.3063	0.0547	70,200	4.90	140,400	**138,961**	86,345	77,711	249,600	**161,582**	**170,128**
1	0.4000	0.0625	91,100	6.40	182,200	**180,333**	112,778	101,500	323,911	**208,970**	**220,132**
1 1/8	0.5063	0.0703	114,500	8.10	229,000	**226,654**	142,734	128,461	407,111	**261,668**	**275,795**
1 1/4	0.6250	0.0781	140,800	10.00	281,600	**278,715**	176,215	158,594	500,622	**321,083**	**338,524**
1 3/8	0.7563	0.0859	169,200	12.10	338,400	**334,933**	213,220	191,898	601,600	**384,400**	**405,504**
1 1/2	0.9000	0.0938	199,800	14.40	399,600	**395,506**	253,750	228,375	710,400	**451,971**	**477,086**
1 5/8	1.0563	0.1016	232,200	16.90	464,400	**459,642**	297,804	268,023	825,600	**522,388**	**551,864**
1 3/4	1.2250	0.1094	270,000	19.60	540,000	**534,467**	345,382	310,844	960,000	**608,321**	**642,505**
1 7/8	1.4063	0.1172	307,800	22.50	615,600	**609,293**	396,484	356,836	1,094,400	**690,765**	**730,007**
2	1.6000	0.1250	349,200	25.60	698,400	**691,244**	451,111	406,000	1,241,600	**782,390**	**827,039**
2 1/8	1.8063	0.1328	390,600	28.90	781,200	**773,196**	509,262	458,336	1,388,800	**870,526**	**920,931**
2 1/4	2.0250	0.1406	435,600	32.40	871,200	**862,274**	570,938	513,844	1,548,800	**967,843**	**1,024,352**
2 3/8	2.2563	0.1484	484,200	36.10	968,400	**958,478**	636,137	572,523	1,721,600	**1,074,341**	**1,137,303**
2 1/2	2.5000	0.1563	531,000	40.00	1,062,000	**1,051,119**	704,861	634,375	1,888,000	**1,171,017**	**1,240,780**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$\mathbf{P_{DTL\ Tot}}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ DTL}}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $\mathbf{P_{DTL\ Tot}}$ - $\mathbf{P_{B\ DTL}}$ = lbs
$\mathbf{P_{B\ DTL}}$ = Direct Tension Load in ropes due to braking = (($\mathbf{W_{S\ DTL}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{Bend\ 72}}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(72***c**)= lbs
$\mathbf{P_{Bend\ 80}}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(80***c**)= lbs
$\mathbf{P_{Bend\ Tot}}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ Bend\ 72}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 72}}$ + $\mathbf{P_{brake\ Bend}}$) = lbs
$\mathbf{W_{S\ Bend\ 80}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 80}}$ + $\mathbf{P_{brake\ Bend}}$) = lbs
$\mathbf{P_{B\ Bend\ 72}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 72}}$ = (($\mathbf{W_{S\ Bend\ 72}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{B\ Bend\ 80}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 80}}$ = (($\mathbf{W_{S\ Bend\ 80}}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EEIPS Galvanized) (6 ropes per sheave)

AASHTO LRFD (EEIPS- Galvanized)											
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in)	**P**$_{ut}$ = Min. Ult. Tensile Str. of 1 Rope (lbs)	**Vertical Lift Span Weight**							
		For 6x19 rope, d is approx. = c/16	(EEIPS) Galvanized	**6 Ropes/Sheave * 4 Sheaves = 24 Ropes**							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	51,800	5.40	155,400	**153,808**	95,156	85,641	276,267	**179,255**	**188,673**
7/8	0.3063	0.0547	70,200	7.35	210,600	**208,442**	129,518	116,566	374,400	**242,373**	**255,192**
1	0.4000	0.0625	91,100	9.60	273,300	**270,500**	169,167	152,250	485,867	**313,455**	**330,198**
1 1/8	0.5063	0.0703	114,500	12.15	343,500	**339,981**	214,102	192,691	610,667	**392,502**	**413,693**
1 1/4	0.6250	0.0781	140,800	15.00	422,400	**418,072**	264,323	237,891	750,933	**481,625**	**507,786**
1 3/8	0.7563	0.0859	169,200	18.15	507,600	**502,399**	319,831	287,848	902,400	**576,600**	**608,256**
1 1/2	0.9000	0.0938	199,800	21.60	599,400	**593,259**	380,625	342,563	1,065,600	**677,957**	**715,629**
1 5/8	1.0563	0.1016	232,200	25.35	696,600	**689,463**	446,706	402,035	1,238,400	**783,583**	**827,796**
1 3/4	1.2250	0.1094	270,000	29.40	810,000	**801,701**	518,073	466,266	1,440,000	**912,481**	**963,758**
1 7/8	1.4063	0.1172	307,800	33.75	923,400	**913,939**	594,727	535,254	1,641,600	**1,036,147**	**1,095,011**
2	1.6000	0.1250	349,200	38.40	1,047,600	**1,036,866**	676,667	609,000	1,862,400	**1,173,584**	**1,240,558**
2 1/8	1.8063	0.1328	390,600	43.35	1,171,800	**1,159,794**	763,893	687,504	2,083,200	**1,305,789**	**1,381,396**
2 1/4	2.0250	0.1406	435,600	48.60	1,306,800	**1,293,411**	856,406	770,766	2,323,200	**1,451,765**	**1,536,528**
2 3/8	2.2563	0.1484	484,200	54.15	1,452,600	**1,437,717**	954,206	858,785	2,582,400	**1,611,512**	**1,705,955**
2 1/2	2.5000	0.1563	531,000	60.00	1,593,000	**1,576,678**	1,057,292	951,563	2,832,000	**1,756,525**	**1,861,171**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$P_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$W_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $P_{DTL\ Tot} - P_{B\ DTL}$ = lbs
$P_{B\ DTL}$ = Direct Tension Load in ropes due to braking = $((W_{S\ DTL}/32.2)*v)/t$ = lbs
$P_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = $(0.7*E*d*a_{Total})/(72*c)$= lbs
$P_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = $(0.7*E*d*a_{Total})/(80*c)$= lbs
$P_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$W_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $P_{bend\ Tot} - (P_{bend\ 72} + P_{brake\ Bend})$ = lbs
$W_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $P_{bend\ Tot} - (P_{bend\ 80} + P_{brake\ Bend})$ = lbs
$P_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = $((W_{S\ Bend\ 72}/32.2)*v)/t$ = lbs
$P_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 80}$ = $((W_{S\ Bend\ 80}/32.2)*v)/t$ = lbs

APPENDIX—Rope Selection (EEIPS Galvanized) (8 ropes per sheave)

AASHTO LRFD (EEIPS- Galvanized)											
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4c^2 (in^2)	**d** = Wire Strand Dia. (in)	P_{ut} = Min. Ult. Tensile Str. of 1 Rope (lbs)	Vertical Lift Span Weight							
		For 6x19 rope, d is approx. = c/16	(EEIPS) Galvanized	8 Ropes/Sheave * 4 Sheaves = 32 Ropes							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	51,800	7.20	207,200	**205,077**	126,875	114,188	368,356	**239,006**	**251,564**
7/8	0.3063	0.0547	70,200	9.80	280,800	**277,923**	172,691	155,422	499,200	**323,164**	**340,256**
1	0.4000	0.0625	91,100	12.80	364,400	**360,666**	225,556	203,000	647,822	**417,940**	**440,265**
1 1/8	0.5063	0.0703	114,500	16.20	458,000	**453,307**	285,469	256,922	814,222	**523,336**	**551,590**
1 1/4	0.6250	0.0781	140,800	20.00	563,200	**557,430**	352,431	317,188	1,001,244	**642,166**	**677,048**
1 3/8	0.7563	0.0859	169,200	24.20	676,800	**669,866**	426,441	383,797	1,203,200	**768,800**	**811,008**
1 1/2	0.9000	0.0938	199,800	28.80	799,200	**791,011**	507,500	456,750	1,420,800	**903,942**	**954,172**
1 5/8	1.0563	0.1016	232,200	33.80	928,800	**919,284**	595,608	536,047	1,651,200	**1,044,777**	**1,103,727**
1 3/4	1.2250	0.1094	270,000	39.20	1,080,000	**1,068,934**	690,764	621,688	1,920,000	**1,216,641**	**1,285,010**
1 7/8	1.4063	0.1172	307,800	45.00	1,231,200	**1,218,585**	792,969	713,672	2,188,800	**1,381,530**	**1,460,014**
2	1.6000	0.1250	349,200	51.20	1,396,800	**1,382,489**	902,222	812,000	2,483,200	**1,564,779**	**1,654,077**
2 1/8	1.8063	0.1328	390,600	57.80	1,562,400	**1,546,392**	1,018,524	916,672	2,777,600	**1,741,052**	**1,841,861**
2 1/4	2.0250	0.1406	435,600	64.80	1,742,400	**1,724,548**	1,141,875	1,027,688	3,097,600	**1,935,687**	**2,048,704**
2 3/8	2.2563	0.1484	484,200	72.20	1,936,800	**1,916,956**	1,272,274	1,145,047	3,443,200	**2,148,683**	**2,274,606**
2 1/2	2.5000	0.1563	531,000	80.00	2,124,000	**2,102,238**	1,409,722	1,268,750	3,776,000	**2,342,033**	**2,481,561**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$P_{DTL\ Tot}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$W_{S\ DTL}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $P_{DTL\ Tot}$ - $P_{B\ DTL}$ = lbs
$P_{B\ DTL}$ = Direct Tension Load in ropes due to braking = (($W_{S\ DTL}$/32.2)*v)/t = lbs
$P_{Bend\ 72}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7*E*d*a_{Total})/(72*c)= lbs
$P_{Bend\ 80}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7*E*d*a_{Total})/(80*c)= lbs
$P_{Bend\ Tot}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$W_{S\ Bend\ 72}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 72}$ + $P_{brake\ Bend}$) = lbs
$W_{S\ Bend\ 80}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $P_{bend\ Tot}$ - ($P_{bend\ 80}$ + $P_{brake\ Bend}$) = lbs
$P_{B\ Bend\ 72}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 72}$ = (($W_{S\ Bend\ 72}$/32.2)*v)/t = lbs
$P_{B\ Bend\ 80}$ = Direct Tension Load in ropes due to braking using $W_{S\ Bend\ 80}$ = (($W_{S\ Bend\ 80}$/32.2)*v)/t = lbs

APPENDIX—Rope Selection (EEIPS Galvanized) (10 ropes per sheave)

AASHTO LRFD (EEIPS- Galvanized)											
c = Wire Rope Dia.(in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in)	**P**$_{ut}$ = Min. Ult. Tensile Str. of 1 Rope (lbs)	Vertical Lift Span Weight							
		For 6x19 rope, d is approx. = c/16	(EEIPS) Galvanized	10 Ropes/Sheave * 4 Sheaves = 40 Ropes							
				a_{Total}	$P_{DTL\ Tot}$	$W_{S\ DTL}$	$P_{Bend\ 72}$	$P_{Bend\ 80}$	$P_{Bend\ Tot}$	$W_{S\ Bend\ 72}$	$W_{S\ Bend\ 80}$
3/4	0.2250	0.0469	51,800	9.00	259,000	**256,346**	158,594	142,734	460,444	**298,758**	**314,455**
7/8	0.3063	0.0547	70,200	12.25	351,000	**347,404**	215,864	194,277	624,000	**403,955**	**425,320**
1	0.4000	0.0625	91,100	16.00	455,500	**450,833**	281,944	253,750	809,778	**522,425**	**550,331**
1 1/8	0.5063	0.0703	114,500	20.25	572,500	**566,634**	356,836	321,152	1,017,778	**654,170**	**689,488**
1 1/4	0.6250	0.0781	140,800	25.00	704,000	**696,787**	440,538	396,484	1,251,556	**802,708**	**846,310**
1 3/8	0.7563	0.0859	169,200	30.25	846,000	**837,332**	533,051	479,746	1,504,000	**961,001**	**1,013,760**
1 1/2	0.9000	0.0938	199,800	36.00	999,000	**988,764**	634,375	570,938	1,776,000	**1,129,928**	**1,192,716**
1 5/8	1.0563	0.1016	232,200	42.25	1,161,000	**1,149,105**	744,510	670,059	2,064,000	**1,305,971**	**1,379,659**
1 3/4	1.2250	0.1094	270,000	49.00	1,350,000	**1,336,168**	863,455	777,109	2,400,000	**1,520,802**	**1,606,263**
1 7/8	1.4063	0.1172	307,800	56.25	1,539,000	**1,523,232**	991,211	892,090	2,736,000	**1,726,912**	**1,825,018**
2	1.6000	0.1250	349,200	64.00	1,746,000	**1,728,111**	1,127,778	1,015,000	3,104,000	**1,955,974**	**2,067,596**
2 1/8	1.8063	0.1328	390,600	72.25	1,953,000	**1,932,990**	1,273,155	1,145,840	3,472,000	**2,176,315**	**2,302,327**
2 1/4	2.0250	0.1406	435,600	81.00	2,178,000	**2,155,684**	1,427,344	1,284,609	3,872,000	**2,419,609**	**2,560,880**
2 3/8	2.2563	0.1484	484,200	90.25	2,421,000	**2,396,195**	1,590,343	1,431,309	4,304,000	**2,685,853**	**2,843,258**
2 1/2	2.5000	0.1563	531,000	100.00	2,655,000	**2,627,797**	1,762,153	1,585,938	4,720,000	**2,927,541**	**3,101,951**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$\mathbf{P_{DTL\ Tot}}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ DTL}}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $\mathbf{P_{DTL\ Tot}}$ - $\mathbf{P_{B\ DTL}}$ = lbs
$\mathbf{P_{B\ DTL}}$ = Direct Tension Load in ropes due to braking = (($\mathbf{W_{S\ DTL}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{Bend\ 72}}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(72***c**)= lbs
$\mathbf{P_{Bend\ 80}}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(80***c**)= lbs
$\mathbf{P_{Bend\ Tot}}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ Bend\ 72}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 72}}$ + $\mathbf{P_{brake\ Bend}}$) = lbs
$\mathbf{W_{S\ Bend\ 80}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 80}}$ + $\mathbf{P_{brake\ Bend}}$) = lbs
$\mathbf{P_{B\ Bend\ 72}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 72}}$ = (($\mathbf{W_{S\ Bend\ 72}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{B\ Bend\ 80}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 80}}$ = (($\mathbf{W_{S\ Bend\ 80}}$/32.2)***v**)/**t** = lbs

APPENDIX—Rope Selection (EEIPS Galvanized) (12 ropes per sheave)

AASHTO LRFD (EEIPS- Galvanized)												
c = Wire Rope Dia. (in)	**a** = Wire Rope Cross Section Area = 0.4**c**^{2} (in^2)	**d** = Wire Strand Dia. (in) For 6x19 rope, d is approx. = c/16	$\mathbf{P_{ut}}$ = Min. Ult. Tensile Str. of 1 Rope (lbs) (EEIPS) Galvanized	**Vertical Lift Span Weight** 12 Ropes/Sheave * 4 Sheaves = 48 Ropes								
				$\mathbf{a_{Total}}$	$\mathbf{P_{DTL\ Tot}}$	$\mathbf{W_{S\ DTL}}$	$\mathbf{P_{Bend\ 72}}$	$\mathbf{P_{Bend\ 80}}$	$\mathbf{P_{Bend\ Tot}}$	$\mathbf{W_{S\ Bend\ 72}}$	$\mathbf{W_{S\ Bend\ 80}}$
3/4	0.2250	0.0469	51,800	10.80	310,800	**307,616**	190,313	171,281	552,533	**358,510**	**377,346**
7/8	0.3063	0.0547	70,200	14.70	421,200	**416,884**	259,036	233,133	748,800	**484,745**	**510,384**
1	0.4000	0.0625	91,100	19.20	546,600	**541,000**	338,333	304,500	971,733	**626,910**	**660,397**
1 1/8	0.5063	0.0703	114,500	24.30	687,000	**679,961**	428,203	385,383	1,221,333	**785,004**	**827,385**
1 1/4	0.6250	0.0781	140,800	30.00	844,800	**836,144**	528,646	475,781	1,501,867	**963,249**	**1,015,572**
1 3/8	0.7563	0.0859	169,200	36.30	1,015,200	**1,004,798**	639,661	575,695	1,804,800	**1,153,201**	**1,216,511**
1 1/2	0.9000	0.0938	199,800	43.20	1,198,800	**1,186,517**	761,250	685,125	2,131,200	**1,355,914**	**1,431,259**
1 5/8	1.0563	0.1016	232,200	50.70	1,393,200	**1,378,925**	893,411	804,070	2,476,800	**1,567,165**	**1,655,591**
1 3/4	1.2250	0.1094	270,000	58.80	1,620,000	**1,603,402**	1,036,146	932,531	2,880,000	**1,824,962**	**1,927,515**
1 7/8	1.4063	0.1172	307,800	67.50	1,846,800	**1,827,878**	1,189,453	1,070,508	3,283,200	**2,072,295**	**2,190,021**
2	1.6000	0.1250	349,200	76.80	2,095,200	**2,073,733**	1,353,333	1,218,000	3,724,800	**2,347,169**	**2,481,116**
2 1/8	1.8063	0.1328	390,600	86.70	2,343,600	**2,319,588**	1,527,786	1,375,008	4,166,400	**2,611,579**	**2,762,792**
2 1/4	2.0250	0.1406	435,600	97.20	2,613,600	**2,586,821**	1,712,813	1,541,531	4,646,400	**2,903,530**	**3,073,057**
2 3/8	2.2563	0.1484	484,200	108.30	2,905,200	**2,875,434**	1,908,411	1,717,570	5,164,800	**3,223,024**	**3,411,910**
2 1/2	2.5000	0.1563	531,000	120.00	3,186,000	**3,153,357**	2,114,583	1,903,125	5,664,000	**3,513,050**	**3,722,341**

E = Modulus of Elasticity = psi	**29,000,000**
v = Velocity of span = ft/sec	**1**
t = Braking Time = seconds	**3**

$\mathbf{P_{DTL\ Tot}}$ = Max. allowable Direct Tension Load (DTL) of the given rope system (all ropes on all sheaves) = 1/8 (12.5%) of the minimum ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ DTL}}$ = Max. weight of span for given rope system based on Direct Tension Load (DTL) = $\mathbf{P_{DTL\ Tot}}$ - $\mathbf{P_{B\ DTL}}$ = lbs
$\mathbf{P_{B\ DTL}}$ = Direct Tension Load in ropes due to braking = (($\mathbf{W_{S\ DTL}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{Bend\ 72}}$ = Load due to bending on the rope system based on sheave diameter of 72**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(72***c**)= lbs
$\mathbf{P_{Bend\ 80}}$ = Load due to bending on the rope system based on sheave diameter of 80**c** = (0.7***E*****d***$\mathbf{a_{Total}}$)/(80***c**)= lbs
$\mathbf{P_{Bend\ Tot}}$ = Max. allowable Total Load (DTL + bending) on the given rope system (all ropes on all sheaves) = 2/9 (22.2%) of the ultimate tensile strength of the rope system. = lbs
$\mathbf{W_{S\ Bend\ 72}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 72**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 72}}$ + $\mathbf{P_{brake\ Bend}}$) = lbs
$\mathbf{W_{S\ Bend\ 80}}$ = Max. weight of span for given rope system based on Total Load (DTL + bending) and 80**c** dia. Sheave = $\mathbf{P_{bend\ Tot}}$ - ($\mathbf{P_{bend\ 80}}$ + $\mathbf{P_{brake\ Bend}}$) = lbs
$\mathbf{P_{B\ Bend\ 72}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 72}}$ = (($\mathbf{W_{S\ Bend\ 72}}$/32.2)***v**)/**t** = lbs
$\mathbf{P_{B\ Bend\ 80}}$ = Direct Tension Load in ropes due to braking using $\mathbf{W_{S\ Bend\ 80}}$ = (($\mathbf{W_{S\ Bend\ 80}}$/32.2)***v**)/**t** = lbs