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UNIFIED FACILITIES SUPPLEMENT (UFS)

PORTAL CRANE TRACKAGE DESIGN

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CHAPTER 1 INTRODUCTION

1-1 INCORPORATES AND CANCELS.

This UFS incorporates and cancels UFC 4-860-02N, Chapter 2, Wide Gage Portal Crane Trackage, dated 16 January 2004. UFC 4-860-02N, Chapter 1, Railroad Trackage, was incorporated and canceled by UFC 4-860-01.

1-2 PURPOSE AND SCOPE.

This UFS presents design criteria and standards for trackage for different types of wide gage portal cranes. Particular reference is made to rails, rail supports, turnouts, crossings, alignment, components, curves of all types, and design procedures. The criteria herein covers design of both new trackage and rehabilitation of existing trackage.

1-3 APPLICABILITY.

This UFS follows the same applicability as UFC 1-200-01, paragraph 1-3, with no exceptions.

1-4 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01, *DoD Building Code*. UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and sustainability requirements, and safety. Use this UFS in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-5 CYBERSECURITY.

All facility-related control systems (including systems separate from a utility monitoring and control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-6 PIERS AND WHARVES.

For criteria on portal crane rail supports (deck fittings), wheel loads, and trackage location and arrangement on waterfront structures (deck structure design) see UFC 4-152-01.

1-7 WEIGHT HANDLING EQUIPMENT.

For Navy only: Use NAVCRANECENINST 11450.2A for design of Navy shore weight handling equipment.

For Army only: Use ASME 30.2 and the following USACE engineering manuals with design guidance on weight handling equipment: EM 1110-2-2610, EM 1110-2-3006 (See Chapter 20 Load Handling Equipment), and EM 1110-2-3200.

For Air Force only: Use ASME 30.2.

1-8 GLOSSARY.

APPENDIX C contains acronyms, abbreviations, and terms.

1-9 REFERENCES.

APPENDIX D contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 PORTAL CRANE TRACKAGE SYSTEMS

2-1 TYPES OF PORTAL CRANE TRACKAGE.

The following paragraphs describe the different types of portal crane trackage systems in use at DoD facilities.

2-1.1 Two-Rail System.

This system consists of two crane rails that support the cranes. Each rail is supported on either:

- A concrete foundation that supports one rail, or
- A ballast track section with special half ties that support one rail.

The gage between the rails varies. Rail gage should be as wide as allowed by local interferences to enhance crane stability but should be consistent with other track gages in the connected rail system. Gages currently used in shipyards range from 18 feet to 40 feet (5.5 to 12.2 m). The gage is measured to the center of the rails. The cranes for this system are equipped with double-flanged wheels. Figure 2-1 is a typical section of the two-rail system. This is the preferred track system.

2-1.2 Four-Rail System.

This system consists of two parallel, standard railroad tracks that also carry railroad train traffic. The cranes for this system are equipped with 4-wheel bogies that are similar to the bogies used on railroad cars. Single-flanged railroad-type wheels are used on the bogies. The gage is measured between the centerlines of the railroad tracks, which is also the centerline of the bogies. Figure 2-2 is a typical section of the four-rail system. This system is the most expensive and interferes with railroad service. This system requires larger radius horizontal curves than the two-rail system, resulting in increased real estate. Do not use four-rail systems for new portal crane track installations.

2-1.3 Three-Rail System.

This is a hybrid system where one side of the crane is supported by a single crane rail and the other side of the crane is supported by the outside rail of a standard two-rail railroad track. Figure 2-3 depicts a typical section of the three-rail system. Three-rail systems are typically located in paved areas with the railroad track and crane rail supported by concrete strip foundations. The cranes have double-flanged wheels on both sides. The crane rail is parallel to the railroad track, and the railroad track also carries regular railroad train traffic. The advantage of the three-rail system is that it allows for both crane and railroad operations in congested areas. The disadvantage is the conflict between crane and railroad operations. Do not use three-rail systems for new portal crane track installations where adequate space is available for a two-rail system.

Figure 2-1 Portal Crane Two-Rail System

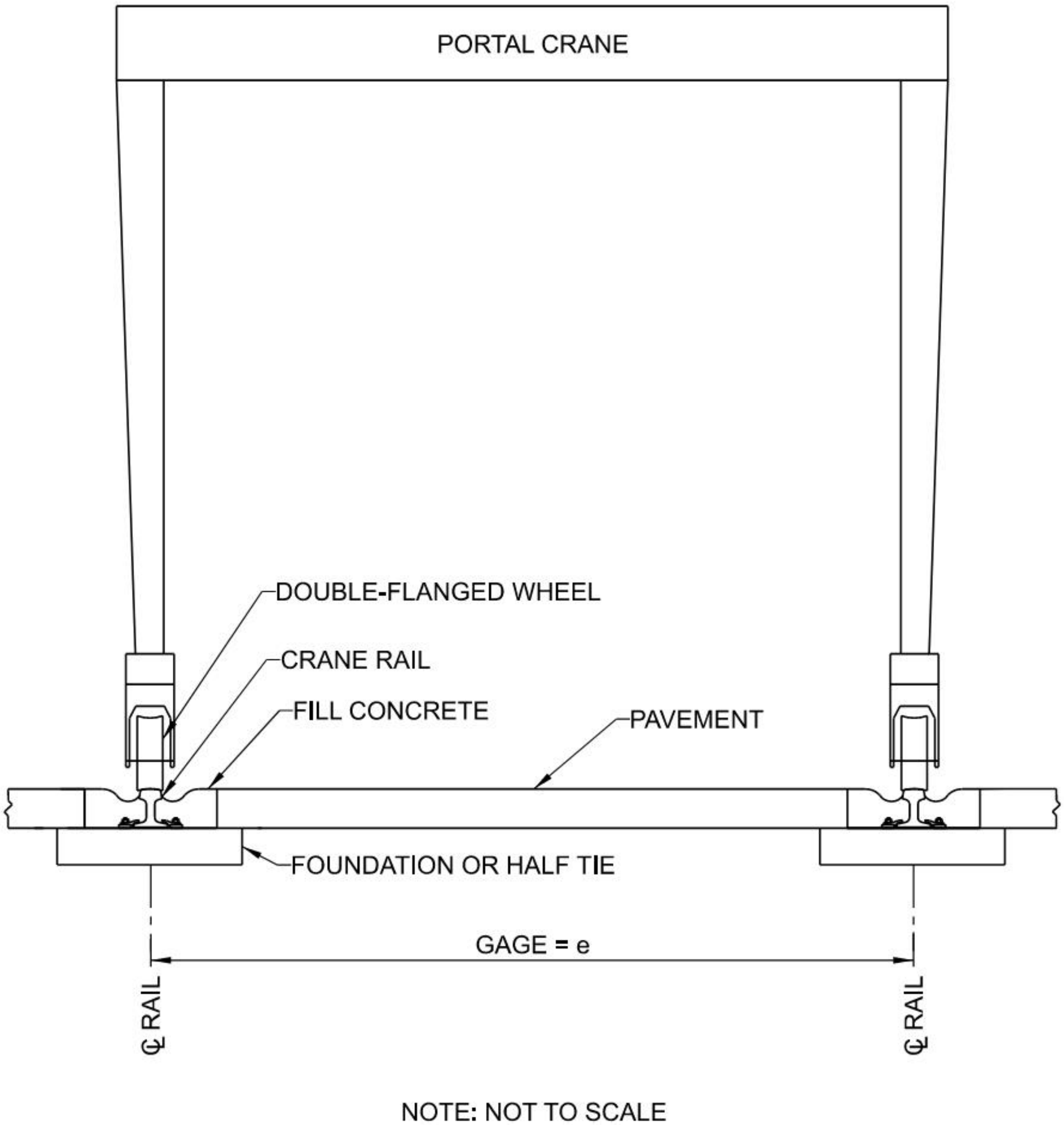


Figure 2-2 Portal Crane Four-Rail System

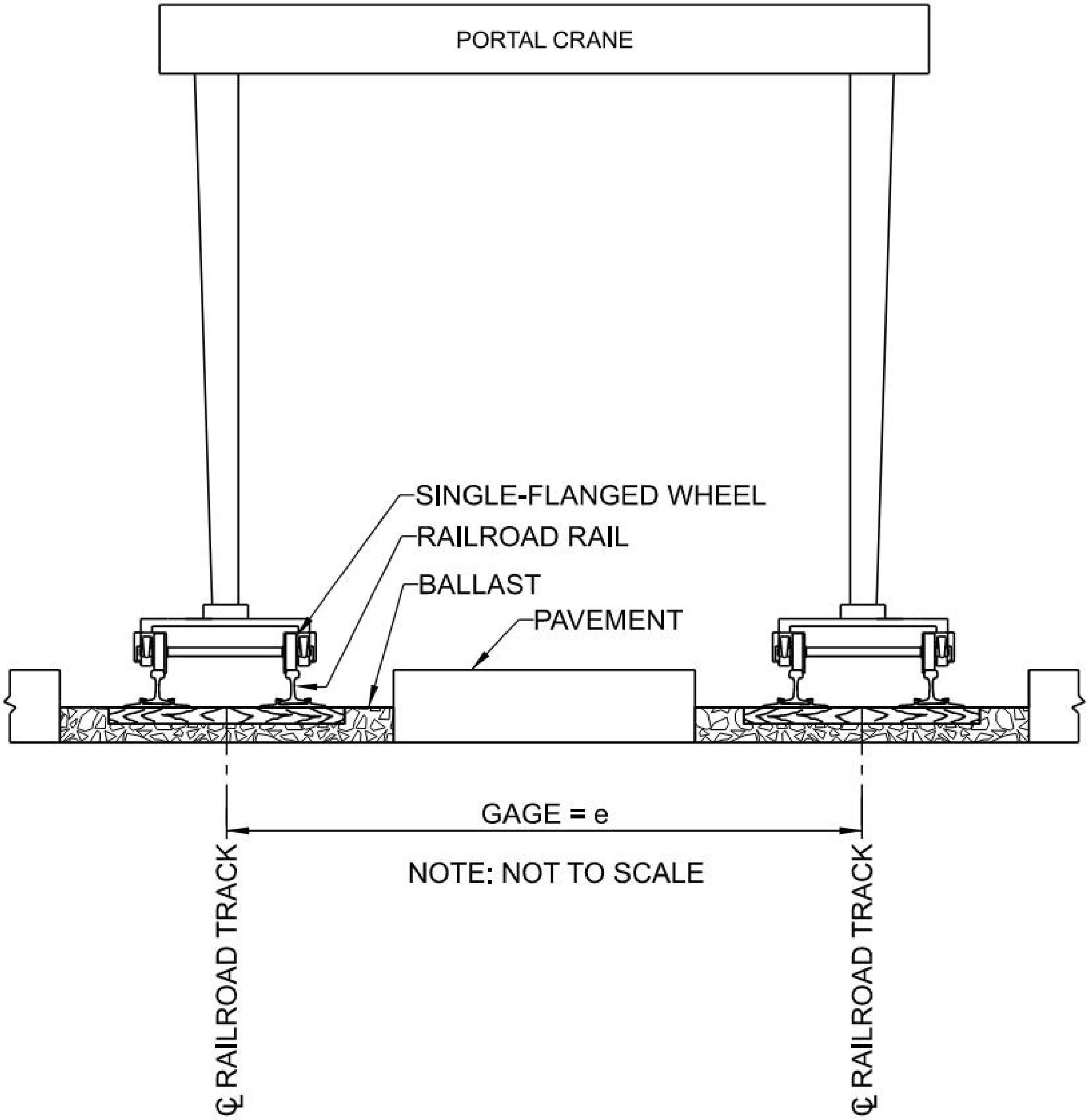
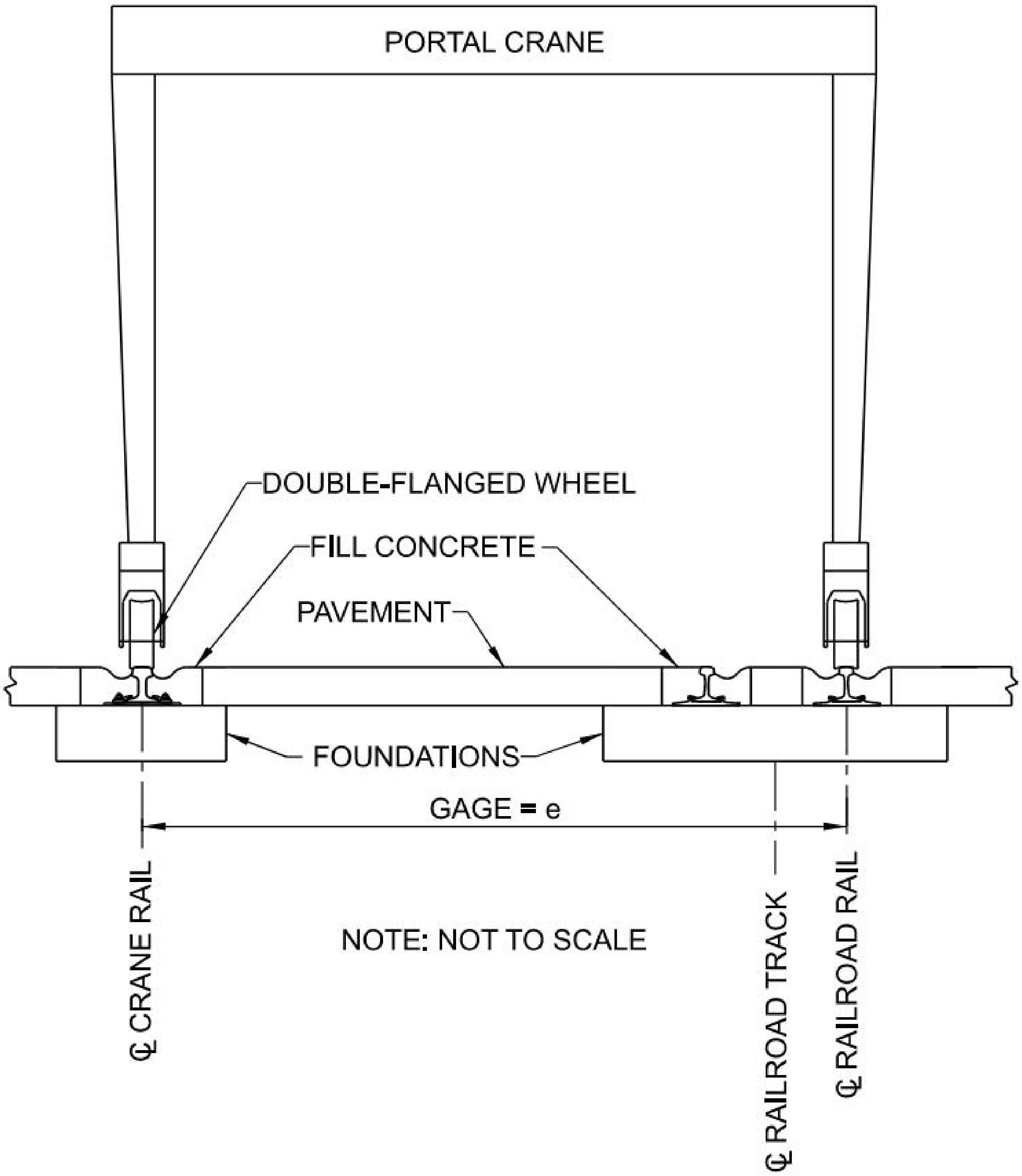


Figure 2-3 Portal Crane Three-Rail System



CHAPTER 3 TRACKAGE COMPONENTS FOR TWO RAIL SYSTEMS

3-1 RAILS.

Crane rails have thicker webs than the rails used for railroad tracks. The 135-pound crane rail section, 135 CR as specified by ASTM A759, is the most widely used. The minimum crane rail section is dependent on the existing crane rail in use at the facility, the capacity of the portal crane, and the number of wheels used to support the portal crane. Crane rail is purchased in 39 or 80-ft lengths (12 or 24 m). Use longer rails when possible to reduce the number of joints or welds. The lengths must be welded together whenever possible to create continuous welded rail (CWR) and eliminate joints. Use bolted joints only in existing track with bolted joints or when connecting to a frog. Crane rail must be control-cooled with a minimum Brinell hardness of 250. Control-cooled rail may be sufficient for straight track and other areas not subject to high wear. Use head-hardened, heat-treated rail with a Brinell hardness of 321 – 388 for sharp curves and other areas subject to high wear. Some installations with a high volume of crane traffic use head-hardened rail throughout their rail circuit.

Weld rail onsite using special thermite welding kits designed for the purpose and by people with the necessary training and experience in welding crane rail. When many welds are required, utilize specialized contractors that have truck-mounted, electric flash butt welding units designed for this purpose. Electric flash butt welding units result in higher quality welds but are not economical for a small number of welds.

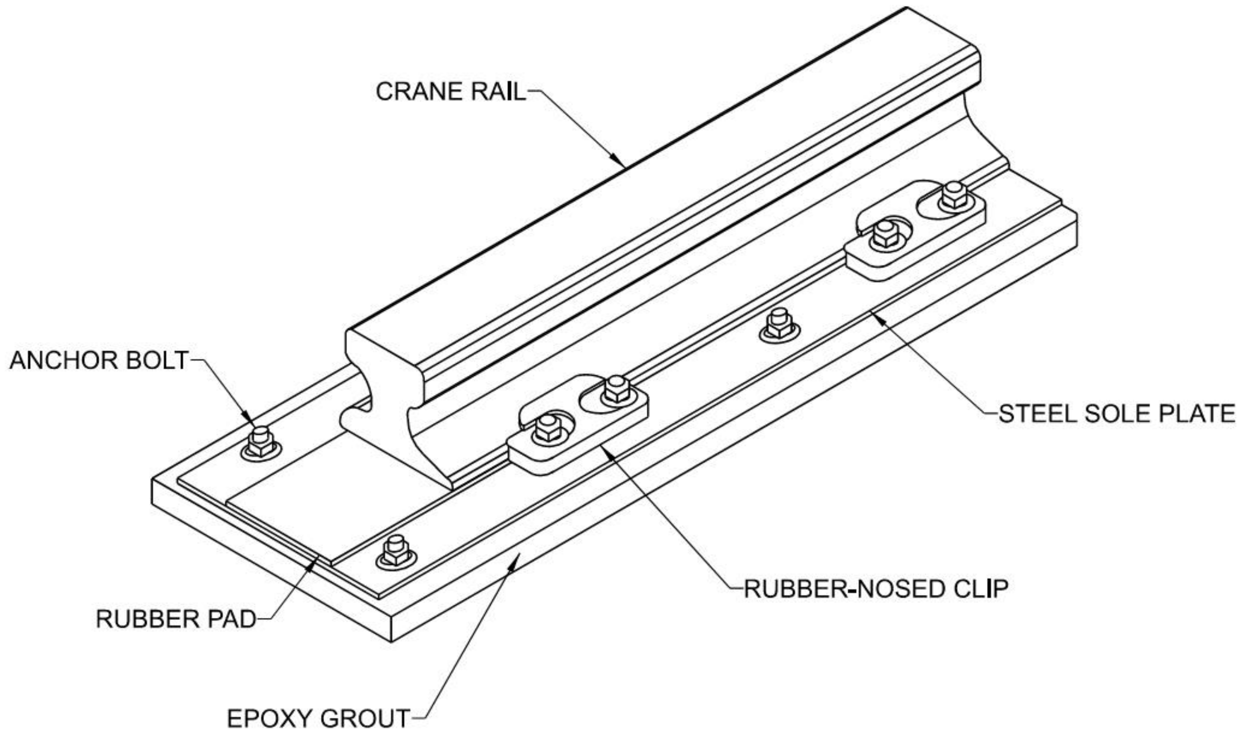
3-1.1 Grounding of Crane Rails.

Rail for portal crane trackage needs to be grounded in situations noted and in accordance with UFC 4-860-01.

3-2 CONTINUOUS CRANE RAIL SUPPORT SYSTEMS.

Continuous support systems must be used for new crane track and are the predominant system used in existing crane track. The system consists of the components shown in Figure 3-1 and described in the following paragraphs.

Figure 3-1 Continuous Crane Rail Support System Components



3-2.1 Rubber Pad.

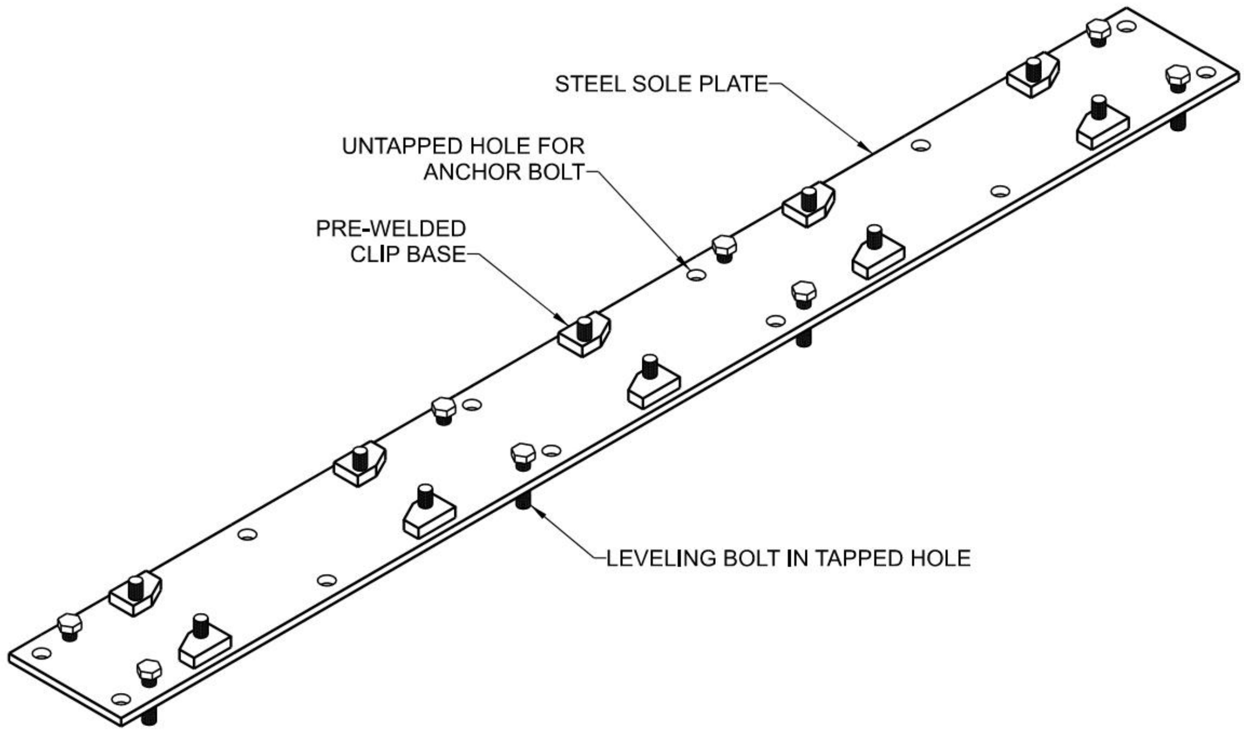
In the preferred, modern installation, the crane rail rests on a continuous, steel-reinforced rubber pad. The pad compensates for imperfections in the base of the rail and the underlying sole plate, increasing actual bearing area. It also allows the rail to rotate side-to-side slightly to match the side-to-side hunting motion of wheels as the crane travels down the track. However, the rubber pad may be omitted in rehabilitation projects on existing systems that do not include a rubber pad.

3-2.2 Sole Plate.

A sole plate, sometimes referred to as a base plate, supports the rubber pad. It is typically made up of approximately 10-foot (3 m) long by 12 to 13-inch (300 to 330 mm) wide by 1-inch (25 mm) thick plates placed end-to-end. ¾-inch (19 mm) thick steel plates may be used for rehabilitation projects at sites with an existing rail system that utilizes ¾-inch thick plates. For new installations, use two-piece rail clips with the base of the rail clips pre-welded to the sole plate as shown in Figure 3-2. Use leveling bolts in tapped holes to temporarily support and level sole plates prior to grouting underneath, and include holes for anchor bolts that will secure the sole plate to the concrete foundation. Anchor bolts utilize the same spacing as the rail clips, typically 24 inches (610 mm), so they fit between the clips. Space leveling bolts to fit between the other components while providing adequate support to prevent sagging of the plate. The plates are hot-dip galvanized after fabrication.

On rehabilitation projects at installations where the rail clips are attached using the anchor bolts, the rail clips may continue to be attached using the anchor bolts. In this case, reduce the width of the sole plates to match the existing sole plates.

Figure 3-2 Typical Sole Plate



3-2.3 Rail Clips.

Rail clips used in crane rail continuous support systems are different than the rail spring clips used in railroad track. The rail clips secure the crane rail to the sole plate. For new construction, use two-piece, rubber nose clips. The bottom piece is pre-welded to the sole plate. The top piece attaches to the bottom piece with one or two bolts. The two-piece clips provide lateral adjustability to properly seat the top piece against the base of the rail. This allows for minor adjustment to the horizontal position of the rail. One-bolt clips are the most common. Use two-bolt clips when additional lateral capacity is needed. The minimum spacing for rail clips is 24 inches (610 mm) and is determined based on the lateral, horizontal load (side thrust) of the crane wheels. See crane rail and hardware suppliers for the applicable clip spacing design charts. Use rubber nose clips in conjunction with rubber pads under the rail. This combination reduces stress by allowing some rotation of the rail to match the profile of the crane wheel and provides better distribution of the bearing stress under the base of the rail to the sole plate. It also reduces longitudinal stress in the rail by allowing longitudinal movement due to thermal expansion.

One-piece clips that do not include rubber noses may be used for rehabilitation of older, existing systems that incorporate similar clips. Clips without rubber noses have a disadvantage in that they do not allow for lateral adjustment. The most common clip without a rubber nose is the Number 62 clip, which is bolted to stud that is welded to the sole plate. Another type of one-piece clip attaches using the anchors bolts that secure the sole plate to the foundation. These clips also do not allow for lateral adjustment, but they may be used to match existing conditions on rehabilitation projects. The clips that attach to the anchor bolts may or may not include rubber noses.

3-2.4 Epoxy Grout.

A layer of non-shrink, epoxy grout supports the sole plate on the concrete foundation. The epoxy grout is a three-component, self-leveling grout designed for grouting under crane track sole plates. The minimum 28 day compressive strength for the epoxy grout is 13,000 psi (90,000 kPa) when tested per ASTM C579B. Allowable non-shrink epoxy grouts expand a small amount during curing, usually 0.1% or less. The epoxy grout layer is typically 1 ½-inch (38 mm) thick and is poured under the sole plate after the sole plate and rail assembly are installed and leveled to the design profile using the leveling bolts incorporated into the sole plate. The threads of the leveling bolts are oiled or greased to prevent bonding with the epoxy grout.

Place the epoxy grout using a head box from one side of the sole plate and ensure the epoxy grout completely fills the area under the sole plate and flows through to the form on the opposite side of the sole plate. Once the epoxy grout cures, unscrew the leveling bolts a few turns so that the sole plate is only supported by the epoxy grout.

3-2.5 Anchor Bolts.

Anchor bolts secure the sole plate to the foundation. Locate anchor bolts between the rail clips. Determine the length of the anchor bolts based on the required embedment for drilled-in installation per structural concrete design methods for the applied loads. Anchor bolts vary in size, but 1-inch (25 mm) in diameter is common. In existing track, smaller anchor bolts may be used to match the existing conditions. Anchor bolts must be ASTM F3125/F3125M minimum and galvanized.

Design anchor bolt embedment to be installed by drilling holes and securing them into cured concrete using an epoxy adhesive rather than casting them into the concrete. Drilling the anchor bolts in-place provides the accuracy needed to match the pre-punched holes in the sole plates. Specify that the sole plates are temporarily set in place to accurately locate and drill the holes for the anchor bolts.

3-2.6 Reinforced Concrete Foundation.

A concrete strip foundation supports each crane rail. The type and design of the concrete foundation depends on the location of the portal crane track and soil conditions. Use crane live loads provided by the crane manufacturers. For preliminary design when the crane wheel loads are not known, see UFC 4-152-01, Paragraph 3-3.4.1 for preliminary wheel loads.

3-2.6.1 Portal Cranes on Piers, Wharves, or Docks.

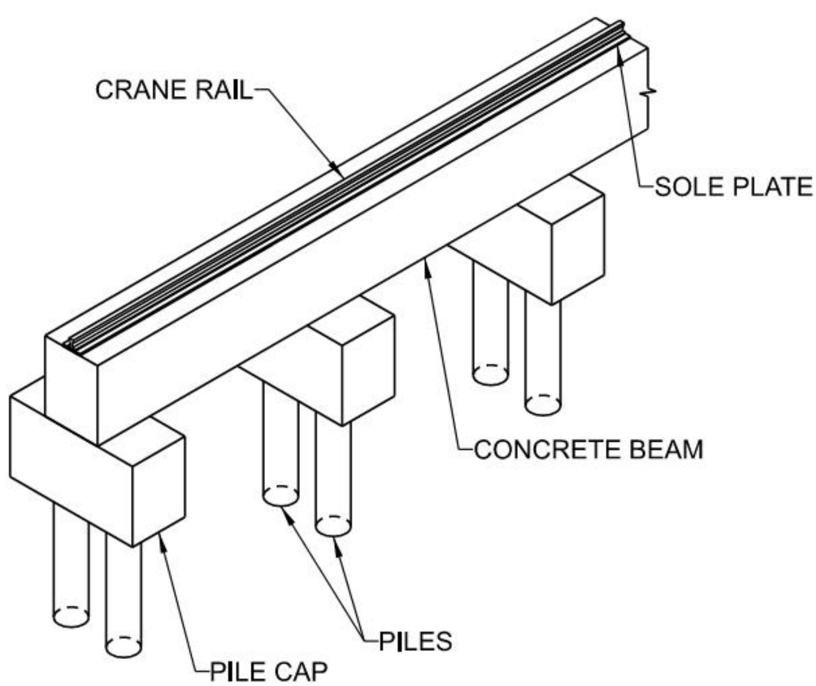
Many portal crane tracks are part of a pier, wharf, or dock. When this is the case, see UFC 4-152-01 Chapters 3 and 4 for structural design guidance.

3-2.6.2 Portal Cranes not Located on Piers, Wharves, or Docks.

A pile-supported concrete beam foundation is typically used when the portal crane track is not located on a pier, wharf, or dock. The concrete beam bears on a series of pile caps with each pile cap connecting between and bearing on two or more piles as shown in Figure 3-3. See UFC 4-152-01 Chapters 3 and 4 for structural design guidance of pile-supported concrete beam foundations that are not on a pier, wharf, or dock as the guidance is also applicable for this situation.

In special circumstances, the concrete foundation may bear directly on the subgrade rather than piles. This is only allowable when the subgrade is coarse-grained, free-draining, and the ground water level is consistently 6 feet (1.8 m) below the bottom of the footing. In this case, design the foundation as a beam-on-elastic foundation using the modulus of subgrade reaction per UFC 3-220-20, Paragraph 5-4 in conjunction with a finite element computer program. Due to the large stress reversals induced by a passing crane, fatigue often controls the design of the reinforcement in these foundations. If the subgrade does not meet the subgrade requirements, the foundation may be susceptible to loss of support due to pumping of the subgrade.

Figure 3-3 Pile-Supported Crane Rail Foundation



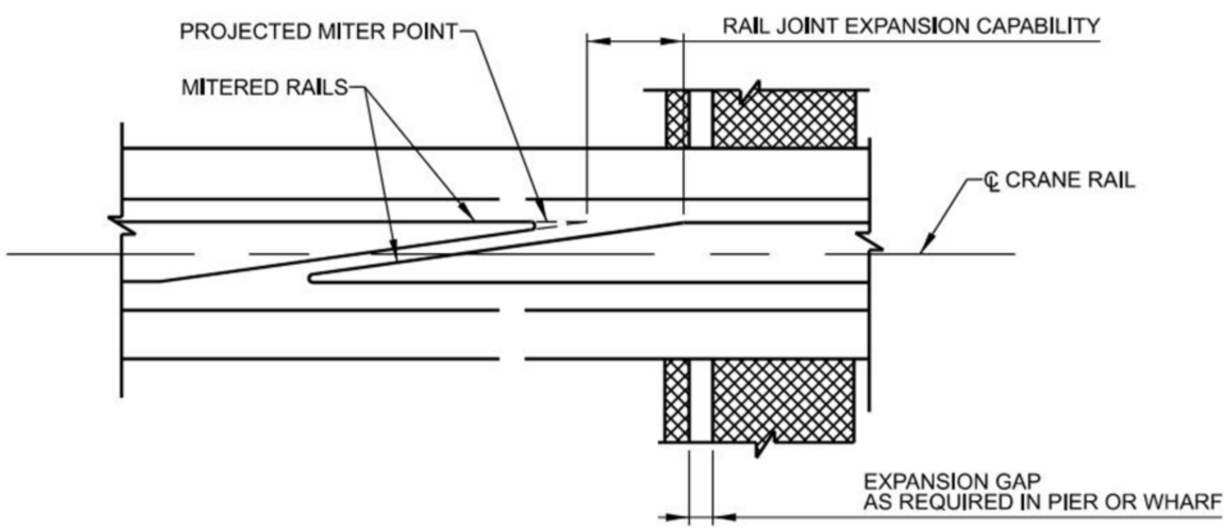
3-2.7 Seismic Design.

In areas of seismic activity, design the rail clips, anchor bolts, and reinforced concrete foundation for lateral seismic loads provided by the crane manufacturers. Also account for seismic loads from the cranes in the design of piers and wharves per UFC 4-152-01.

3-2.8 Rail Expansion Joints.

Rail expansion joints are composed of a vertical, diagonal miter in the rail as shown in Figure 3-4. The length of the miter overlap typically varies from 5.5 to 7.5 feet (1.7 to 2.3 m). The joints typically allow for 4 inches (100 mm) of movement. When at full expansion, there is no gap between the mitered rails. The gap opens for cooler temperatures. Incorporate rail expansion joints where expansion joints occur in the supporting structure, such as piers, wharves, and docks. In addition, place rail expansion joints at a maximum spacing of 400 feet (120 m).

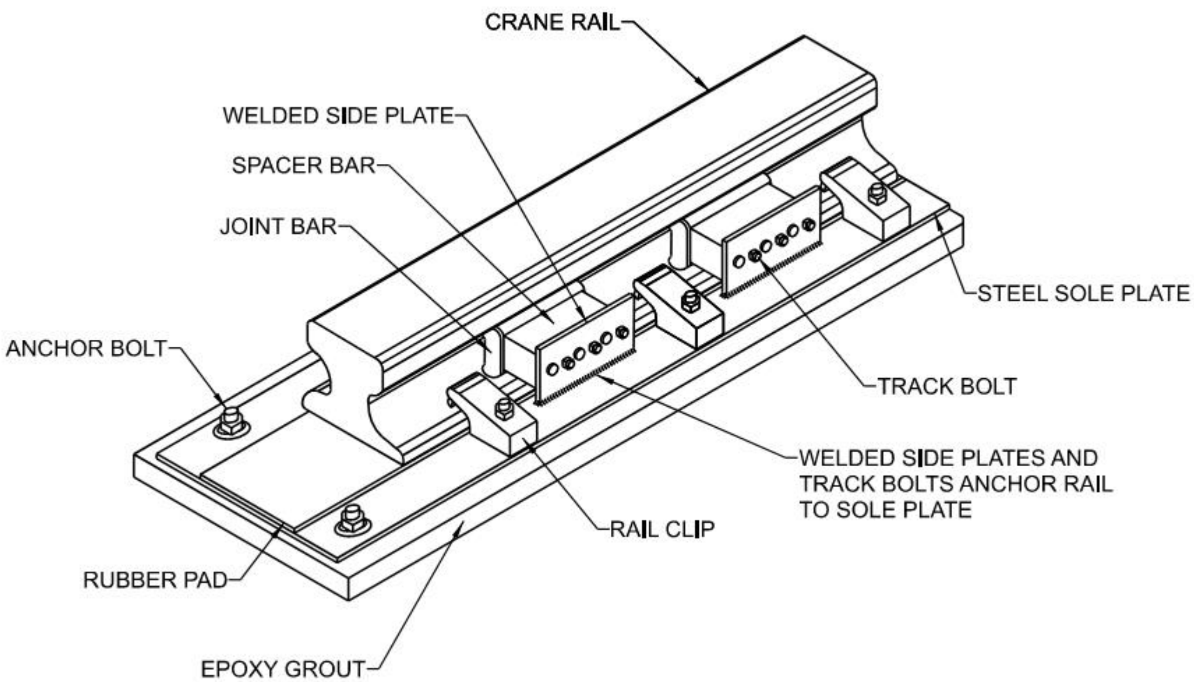
Figure 3-4 Rail Expansion Joint Plan View



3-2.9 Rail Anchors.

Rail anchors rigidly anchor the rail to the foundation to prevent longitudinal movement of the rail. Rail anchors must be placed at the midpoints between rail expansion joints. An example of a rail anchor for a continuous support system is shown in Figure 3-5.

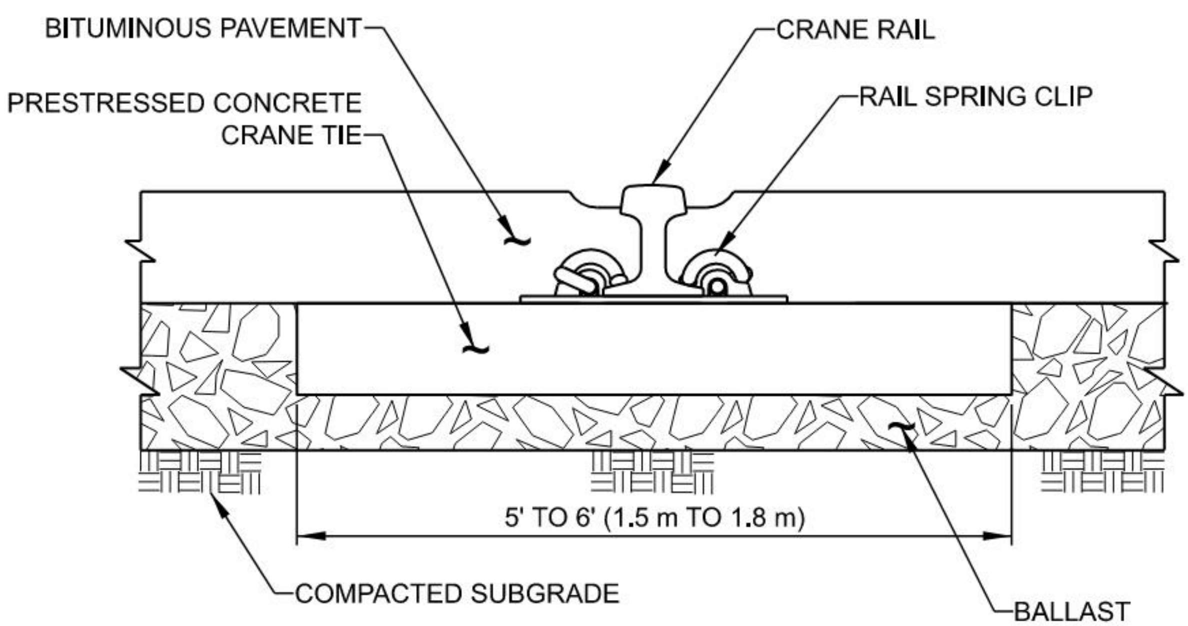
Figure 3-5 Rail Anchor Assembly



3-3 TIE-SUPPORTED CRANE RAIL SYSTEMS.

Tie-supported systems are not recommended for new crane track. However, rehabilitation of existing tie-supported systems may be required. Tie-supported systems include the components shown in Figure 3-6 and described in the following paragraphs.

Figure 3-6 Tie System Components



3-3.1 Ties for Crane Systems.

Use prestressed concrete ties for new installations. Also use prestressed concrete ties for rehabilitation of tie-supported crane track unless conditions require the use of wood ties or the majority of the track will remain wood ties.

3-3.2 Rail Spring Clips.

Rail spring clips are elastic, forged steel fasteners that attach the rail to the concrete ties. The clips provide a large clamping force and prevent horizontal and vertical movement of the rail relative to the tie. These are the same rail spring clips that are used with concrete ties in railroad track. See UFC 4-860-01 for additional guidance.

3-3.3 Ballast.

Ballast performs three primary functions:

- Distributes tie loads to the subgrade or other foundation materials.
- Restrains the track laterally and longitudinally.
- Allows the track structure to drain.

Refer to UFC 4-860-01 for additional information on ballast. The tie support system must incorporate a drainage system to outlet water from the ballast.

3-3.4 Tie Spacing and Depth of Ballast.

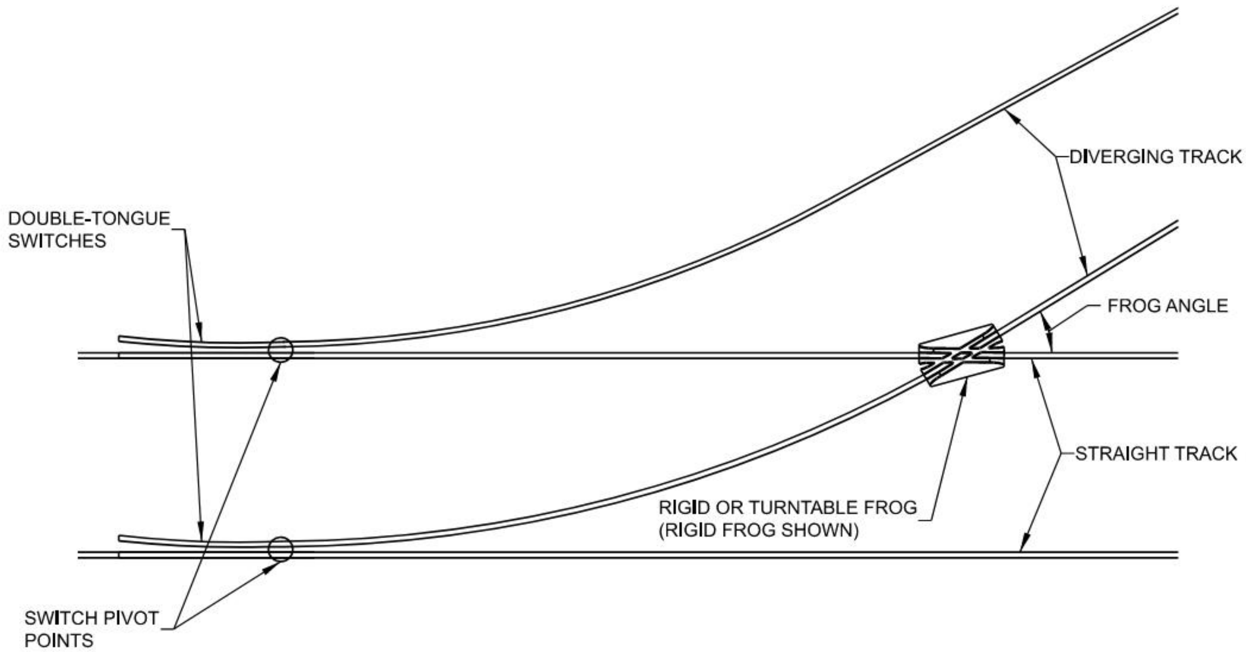
Determine the tie spacing and depth of ballast using the method in Chapter 16 of the AREMA *Manual for Railway Engineering* with wheel loads supplied by the crane manufacturers. The minimum tie spacing is 18 inches (460 mm) to allow for surfacing of the track.

3-4 TURNOUTS AND TRACK CROSSINGS FOR TWO-RAIL SYSTEMS.

A turnout is an arrangement of two switch points and a frog, which divert the crane from one track to another. See Figure 3-7 for a typical turnout arrangement. The switch points and frogs required for the wide-gage crane systems are different than those used for railroads due to the double-flanged wheels used on cranes. These fittings must provide double flangeways for crane wheels as they diverge at switches and cross at frogs. Standard drawings of these components are provided as “related material” on the WBDG website. In addition, special switches and frogs are needed where crane tracks and standard railroad tracks intersect or in a three-rail system where cranes and railroad traffic share one rail of a standard railroad track. These fittings allow for the intermingling of double-flanged crane wheels with the single-flanged railroad wheels.

Locate crane turnouts and track crossings only on level grade. In addition, use standard switches and frogs on all new and replacement construction.

Figure 3-7 Typical Turnout Arrangement



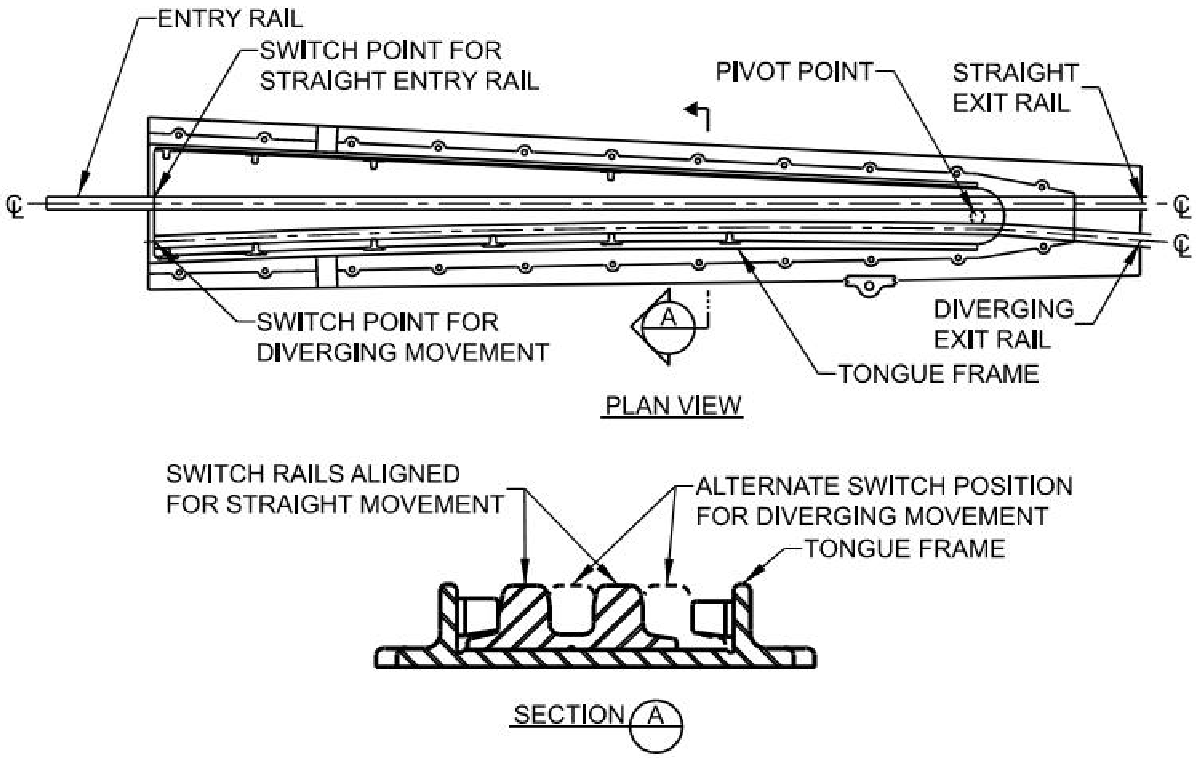
3-4.1 Switches.

The double-tongue switch is required in turnouts on two-rail systems to accommodate the double-flanged crane wheels. The double-tongue switch consists of two rail heads on a base (the tongue) that pivots at the exit end of the switch. The switch pivots to align each rail head with the single incoming rail at the entry end of the switch. Each rail head connects to a different rail at the exit end. One rail continues on the straight movement in line with the incoming rail, and the other rail continues on the diverging movement to the new alignment. The main parts of a double-tongue switch are illustrated in Figure 3-80. There are flangeways between the two rail heads and along the outside of the rail heads.

3-4.1.1 Material.

The standard drawings provided as “related material” on the WBDG website include drawings for double-tongue switches made of cast manganese and ones made of fabricated steel plate material. However, only cast manganese switches are typically accepted in modern applications because they provide a longer service life. Fabricated switches are only accepted for temporary tracks if they provide a significant cost saving compared to cast manganese switches.

Figure 3-8 Double-Tongue Switch



3-4.1.2 Lubrication

For new construction and switch replacements, use a dry graphite lubricant rather than the traditional grease. Dry graphite improves performance, reduces maintenance requirements, and does not impact the environment like grease or other petroleum lubricants. Also omit lubricant fittings that may be shown in older switch fabrication drawings.

3-4.1.3 Flangeway Spacing Computation.

The standard drawings for double-tongue switches provide dimensions for the flangeway between the rails on the tongue. However, if a custom switch is needed rather than the standard switch, calculate the flangeway spacing using the following procedure.

For each distance X where the flangeway spacing must be determined, sum the corresponding circular and linear offsets as shown below. Then subtract the railhead width to obtain the flangeway spacing per Equation 3-3. See Figure 3-9 for an illustration of the computation. Switch length, L_T, and the distance between the rail centerlines, b, at the end of the switch can be varied as required for the situation.

Equation 3-1. Circular Offset

$$V = R - R\cos\left(\sin^{-1}\frac{X}{R}\right)$$

Where:
V = circular offset from tangent
R = radius of curve
X = distance from entry end of switch along tangent, $0 < X < L_T$
L_T = length of entry end of switch to pivot point of tongue

Equation 3-2. Linear Offset

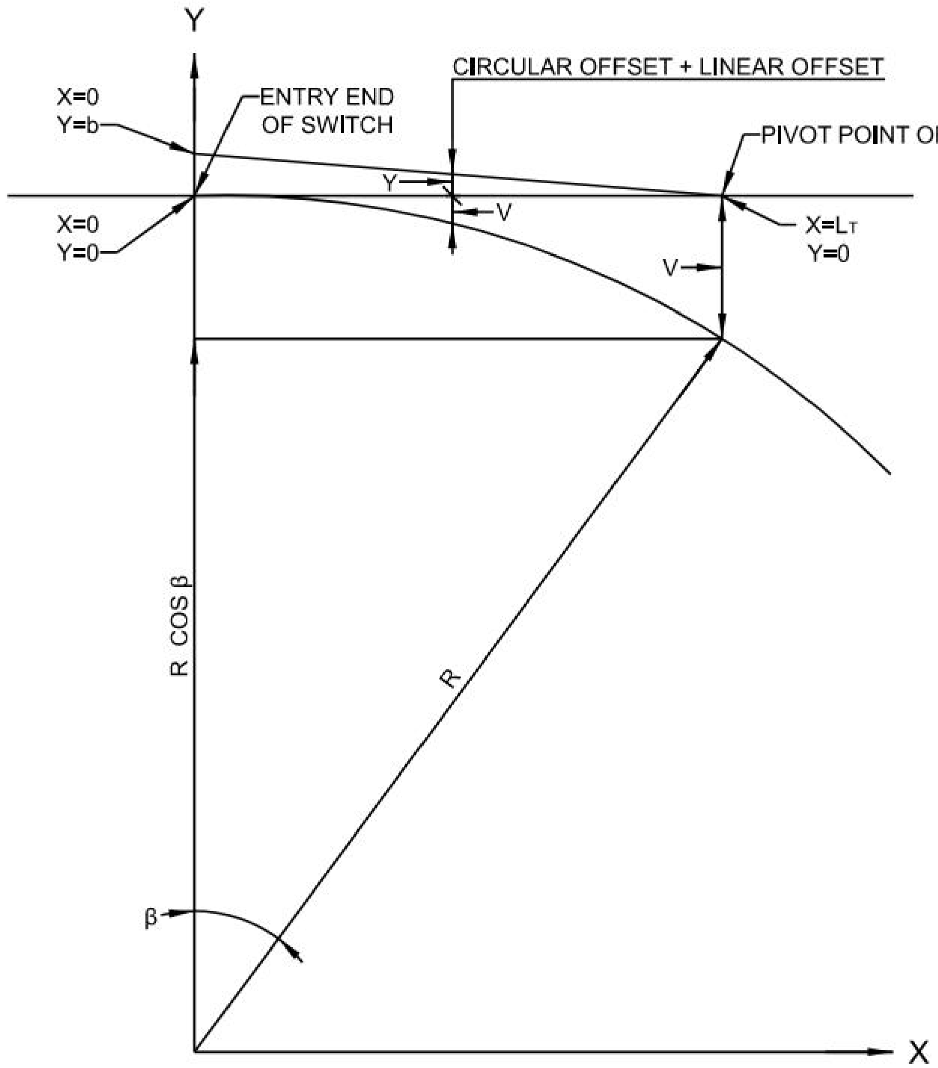
$$Y = aX + b$$

Where:
Y = linear offset from tangent
a = $-b/L_T$
b = desired distance between rail centerlines at entry end of switch

Equation 3-3. Flangeway Spacing

Flangeway Spacing = *V* + *Y* – *Rail Head Width*

Figure 3-9 Flangeway Width Calculation



FLANGEWAY WIDTH = CIRCULAR OFFSET + LINEAR OFFSET - RAIL HEAD WIDTH

WHERE:

1. CIRCULAR OFFSET COMPUTATION:

   V=CIRCULAR OFFSET FROM TANGENT

   X=COORDINATE OF POSITION FROM ENTRY END OF SWITCH

   R=RADIUS OF CURVE

   β=CENTRAL ANGLE OF ARC

   $$\beta = \sin^{-1} \frac{X}{R}$$

   $$V = R - R \cos \beta$$

2. LINEAR OFFSET COMPUTATION

   b=DESIRED DISTANCE BETWEEN RAIL CENTERLINES AT ENTRY END OF SWITCH

   Y=LINEAR OFFSET

   $0 < X < L_T$ $Y = aX + b$ WHERE $a = \frac{-b}{L_T}$

   @ $X=0$, $Y=b$

   @ $X=L_T$, $Y=0$

3-4.1.4 Switch Throw Mechanisms.

Throw mechanisms for crane switches may be manually-operated or power-operated. Manually-operated mechanisms utilize a bell crank or lever so that the switch can be operated by one person. Power-operated mechanisms utilize a pneumatic or hydraulic driven actuator to throw the switch. Power-operated mechanisms must include a manually-operated backup system to operate the switch in the event the power system fails. Both manual and power-operated mechanisms must include an indicator that is visible to the crane operator to indicate the position of the switch.

Simpler, older systems do not include a link between the switches on each rail. This requires the ground crew to throw the switch on each rail in two separate operations to line a track for a movement. The more advanced, modern systems include a link between the switches on each rail so that both switches are thrown in a single operation. On new installations, use systems with mechanisms that throw the switches on both rails simultaneously.

3-4.2 Frogs.

3-4.2.1 Rigid Frogs.

Rigid frogs for crane track have no moving parts and allow wheels running on a rail to cross the rail of a diverging rail, similar to the frogs used in standard railroad track. However, the crane rail frogs must allow for double-flanged wheels to cross rather than single-flanged wheels. This requires two flangeways to cross the other rail, resulting in a diamond-shaped island when two crane rails cross as shown in Figure 3-10. Special versions of rigid frogs are used when crane rails cross standard railroad track.

When transversing a frog, the crane wheels need to pass over the gap of the crossing flangeway. To prevent a bump and the resulting impact forces on the frog and the wheels, the flangeways ramp up before and after the gap so that the wheel rides on its flanges over the gap rather than on its center tread. To keep the gap of the frog from being too long, rigid frogs may not be used if the crossing angle is too acute (too small). The use of rigid frogs is permissible only in cases where the actual frog angle is greater than that shown in Figure 3-11 for the actual crane rail radius. The minimum frog angle for the use of rigid frogs is 20 degrees for the common case of a horizontal inside curve radius of 150-feet (45.7 m) or greater and a flangeway width of 2 ¼ inches (57 mm).

Figure 3-10 Portal Crane Rigid Frog

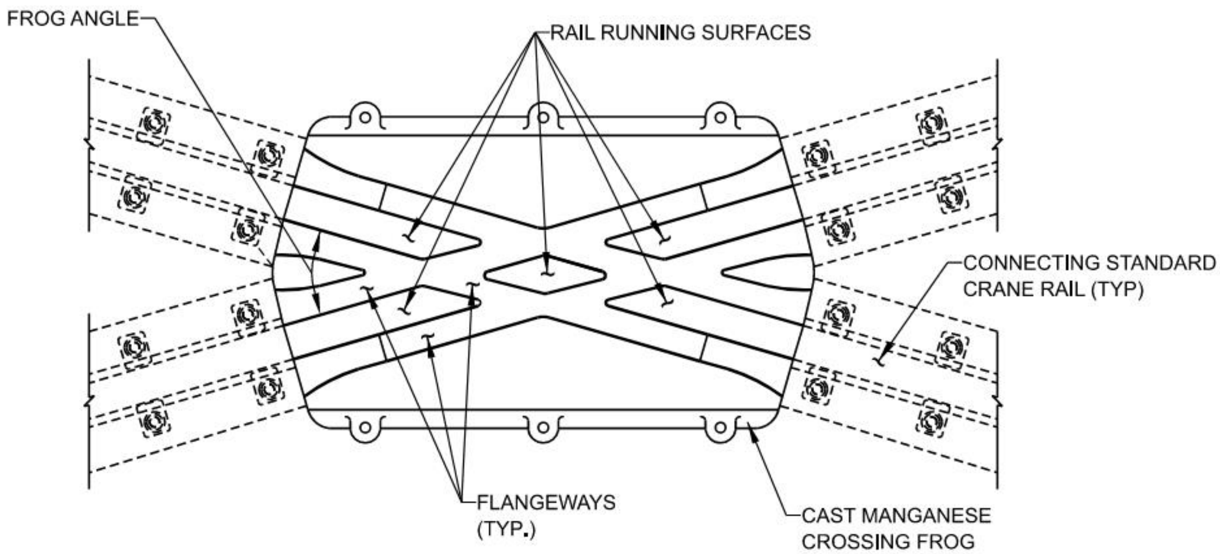
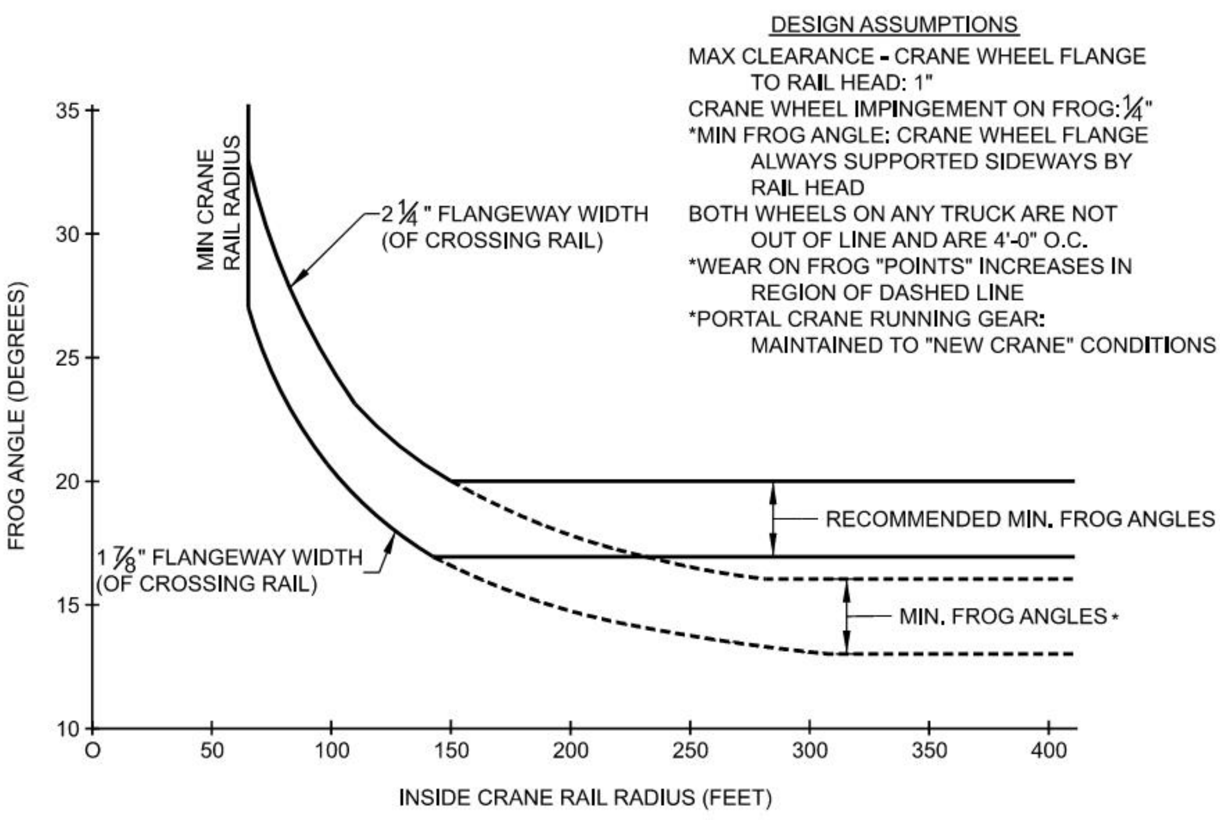


Figure 3-11 Minimum Rigid Frog Angle-Portal Crane Rails



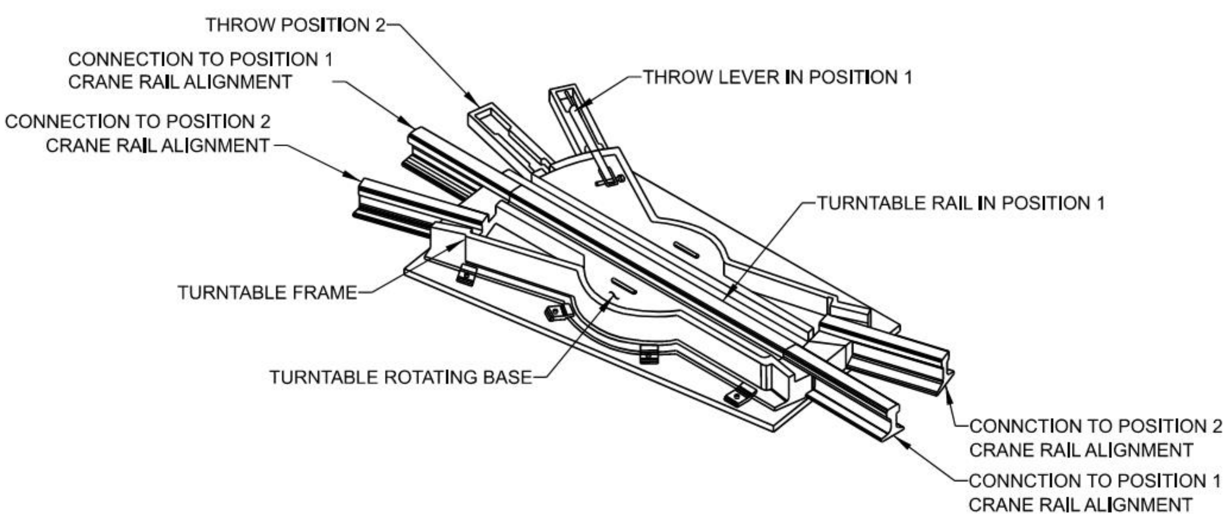
3-4.2.2 Turntable Frogs.

Turntable frogs rotate around their center point (the turntable) to align the rail of the frog with the rail of the track the crane will transverse as shown in Figure 3-12. This eliminates the flangeway gap to provide for a smoother ride. Turntable frogs must be used in locations where rigid frogs are not allowed, as indicated by Figure 3-11. However, turntable frogs must be thrown manually to allow for travel on the crossing rail, and there is the danger of derailment if the frog is not properly aligned for a crane movement. Due to these disadvantages, the additional expense, and the result that most crane rail crossings have a frog angle of 20 degrees or more, turntable frogs are rarely used for new crane trackage. Turntable frogs utilize throw mechanisms similar to crane switches.

3-4.2.3 Materials.

The standard drawings provided as “related material” on the WBDG website include drawings for rigid and turntable frogs made of either cast manganese or fabricated steel plate material. However, only cast manganese frogs are typically accepted in modern applications because they provide a longer service life and worn areas can be repaired by welding. Fabricated rigid and turntable frogs are only accepted for temporary tracks if they provide a significant cost saving compared to cast manganese frogs.

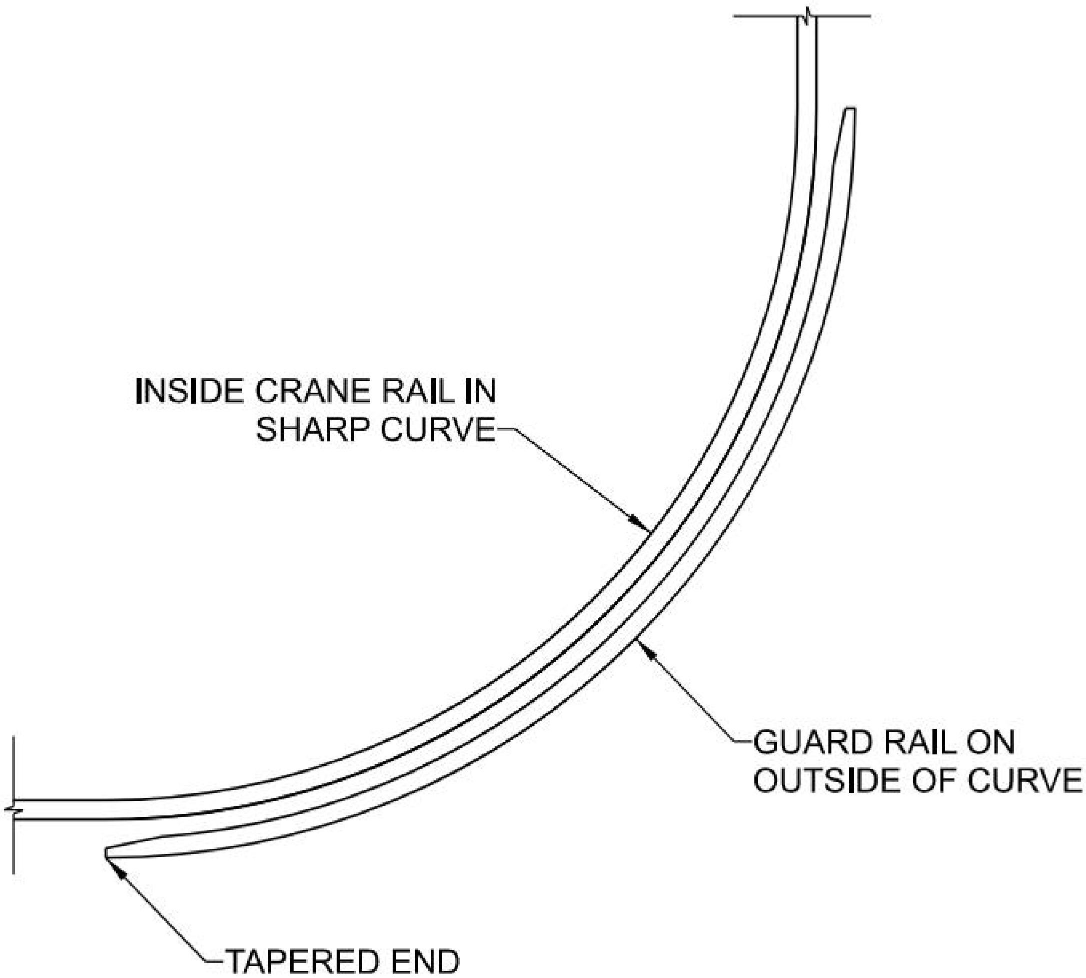
Figure 3-12 Turntable Frog



3-5 GUARD RAILS.

Guard rails help reduce rail wear in sharp curves. Consider using guard rails when the radius of the inside rail is less than 150 feet (45 m). As shown in Figure 3-13, place the guard rail on the outside of the inside crane rail. The guard rail pushes on the outside flange of the crane wheels to help the crane negotiate the curve. Guard rails are typically not needed adjacent to the outside crane rail since the outside crane rail has a larger radius.

Figure 3-13 Guard Rail



3-6 END STOPS.

End stops serve as the last means to stop a crane before it goes off the end of a track. Place end stops at the end of each crane rail where a track ends. Design the end stops to match the height of the hydraulic bumper on the cranes. Consult with the crane manufacturer regarding design loads for the end stop.

3-6.1 Static End Stops.

Static end stops are typically a steel structure that is anchor bolted to a concrete foundation. Static end stops may also be reinforced concrete. Static end stops have no means to reduce the impact of a crane. They are just a block designed to withstand the impact force imparted by the hydraulic bumper on the cranes. Figure 3-14 is a photo of a typical steel end stop.

Figure 3-14 Static End Stop

3-6.2 Hydraulic End Stops.

Hydraulic end stops incorporate a hydraulic piston to reduce the impact force from a crane. However, they are more expensive and require maintenance to ensure adequate buffering of crane forces. Also, the pistons required for buffering of portal cranes are long, which can be an issue in shipyards with limited space. Due to these reasons, hydraulic end stops are rarely used at military facilities. Figure 3-15 is a photo of a hydraulic end stop.

Figure 3-15 Hydraulic End Stop

CHAPTER 4 TRACKAGE COMPONENTS FOR FOUR & THREE-RAIL SYSTEMS

4-1 FOUR-RAIL SYSTEMS.

4-1.1 Support System.

As shown in Figure 2-2, two parallel railroad tracks are the support for four-rail systems. The tracks consist of the same components as typical railroad tracks and include:

- Rail with a section typical for railroads,
- Tie plates,
- Ties, and
- Ballast.

Use UFC 4-860-01 for criteria on these components. However, use a minimum rail size of 132 RE in four and three-rail systems.

4-1.2 Turnouts and Crossings.

Since they use single-flanged wheels, turnouts and crossings for four-rail systems use the same switches and frogs as are used for typical railroad tracks. Refer to UFC 4-860-01 for information on these components and the geometry of turnouts.

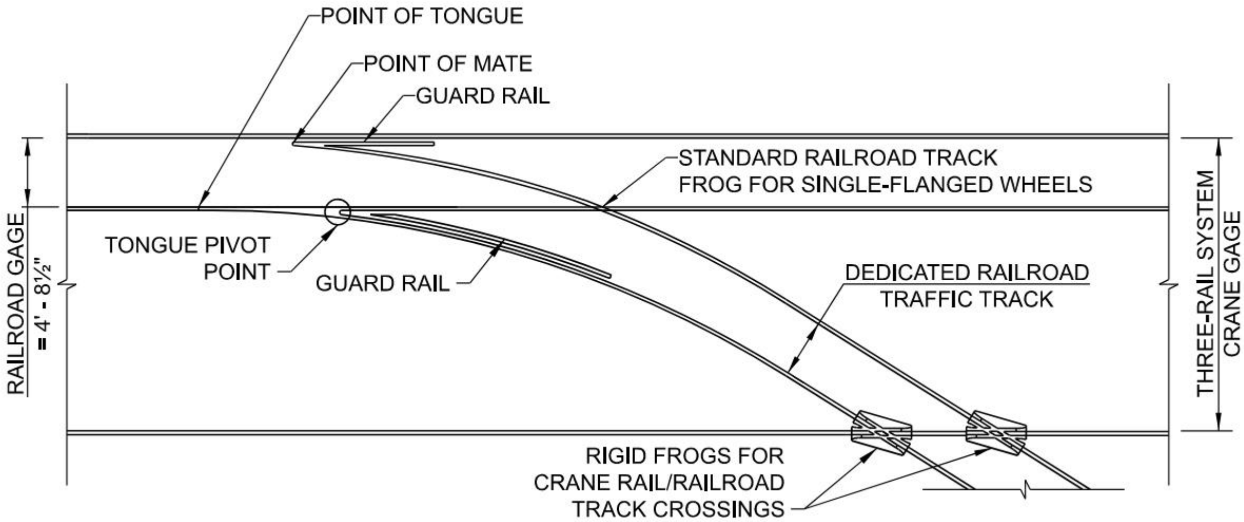
4-2 THREE-RAIL SYSTEMS.

The side of the three-rail system with the single crane rail utilizes the same support systems and components as two-rail systems. The side with the standard railroad track requires special components to handle the mix of double-flanged wheels on one rail while accommodating single-flanged railroad traffic on both rails. This section describes those special components.

4-2.1 Tongue-and-Mate Switches.

A less common, specialty switch for standard railroad track, the tongue-and-mate switch, also has application for the railroad track in three-rail crane systems. These specialty switches are typically used for railroad turnouts in paved areas. The AREMA *Portfolio of Trackwork Plans* includes drawings PT 980 and PT 982, which are standard drawings for tongue-and-mate switches. In three-rail systems, use a tongue-and-mate switch to divert a new railroad track from the railroad track that is shared by the crane and railroad traffic. The new diverging railroad track must only carry railroad traffic. Place the mate side of the switch against the rail that supports the crane. The mate allows the single-flanged railroad wheels to divert from the shared rail without interfering with the crane's double-flanged wheels. Figure 4-1 depicts the situation where a tongue-and-mate switch is applicable.

Figure 4-1 Tongue-and-Mate Switch Track Arrangement



4-2.2 Frogs.

4-2.2.1 Railroad-Type Frogs.

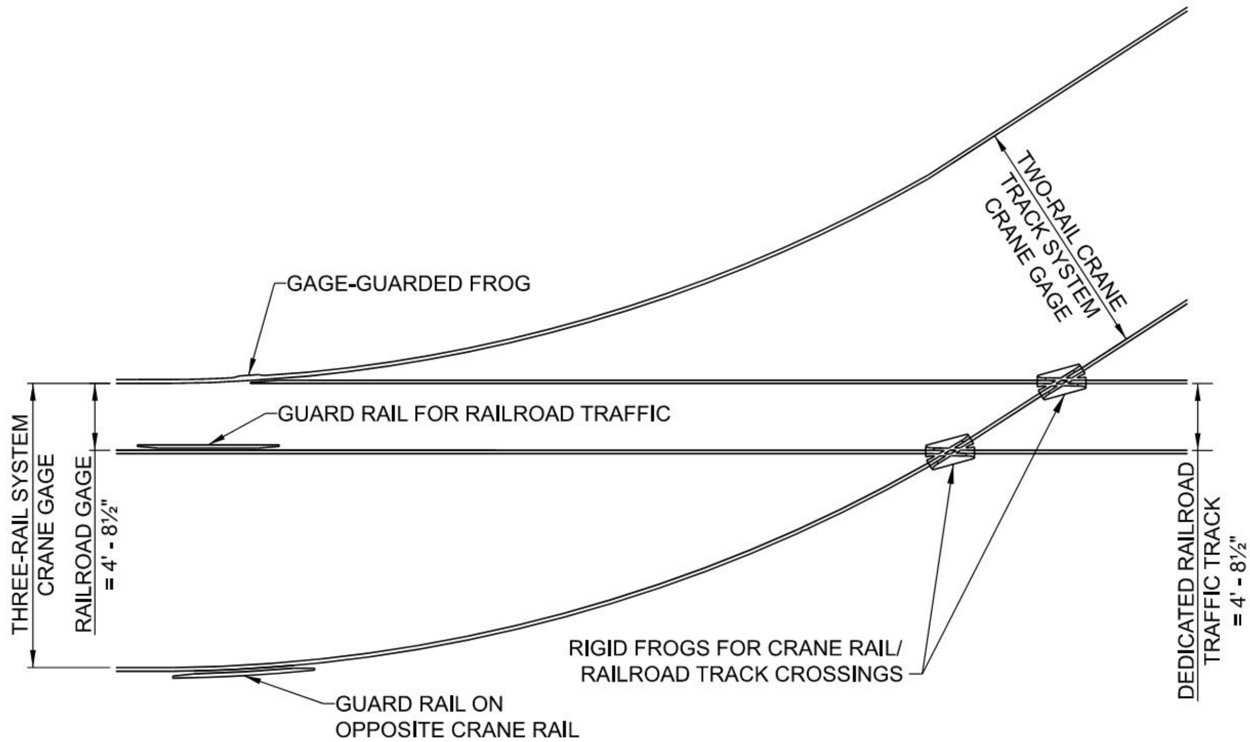
Do not use standard railroad-type frogs on any rail where a crane wheel will travel. However, use them in three-rail systems at locations where both intersecting rails are only used by single-flanged railroad wheels. For example, use a standard railroad-type frog on the diverging side of a tongue-and-mate switch where the curved closure rail crosses the straight closure rail.

Note that self-guarded frogs are not desirable in the paved areas typical of crane trackage due to the tripping hazard imposed by the raised guard face. Instead, use standard frogs with separate guard rails.

4-2.2.2 Gage-Guarded Frogs.

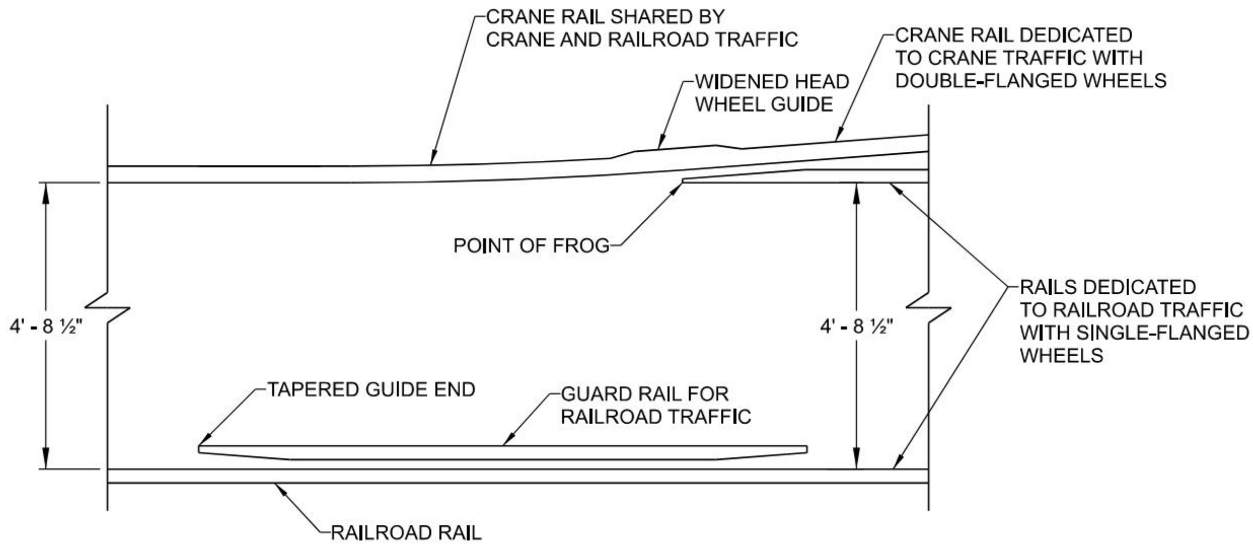
In three-rail systems, use a gage-guarded frog when a crane rail dedicated to crane traffic diverges from a railroad track that is shared by both crane and railroad traffic. The railroad track must only carry railroad traffic after the diversion. Figure 4-2 illustrates the situation where a gage-guarded frog is appropriate.

Figure 4-2 Gage-Guarded Frog Track Arrangement



As shown in Figure 4-3, the crane rail at a gage-guarded frog has a widened head at the diversion point. The widened head pushes the double-flanged wheels of the crane away from the point of the frog and towards the crane rail dedicated to crane traffic. A guard rail adjacent to the other crane rail assists in pushing the crane away from the point of the frog and toward the diverging route. Another guard rail located adjacent to the other railroad rail pulls the single-flanged railroad wheels to the other side of the point of frog so they continue along the rails dedicated to railroad traffic. The gage-guarded frog accomplishes the diversion without any moving parts.

Figure 4-3 Gage-Guarded Frog



CHAPTER 5 PORTAL CRANE TRACK HORIZONTAL CURVE REQUIREMENTS

5-1 PROBLEM DESCRIPTION.

Track for portal cranes is at a much wider gage than standard railroad track, and the distance between the legs of a crane on a rail is much longer than the distance between the wheels on a railroad car bogie. In addition, the curves used in portal crane tracks are much sharper than those used in railroad tracks. The combination of these factors results in unique requirements for the design of horizontal curves in portal crane track. The unique requirements include:

- Reduced Gage: Track gage must be reduced on curves with a radius less than 300 feet (91 m) on the inside rail because the crane frame is rectangular and therefore non-radial when negotiating a curve. Gage reduction on curves with a radius greater than 300 feet (91 m) on the inside rail is normally not required, as the float capability of most cranes allows the gage of the cranes to adjust enough to negotiate these curves. Actual gage reduction for a given radius may be computed precisely, but since the crane frame straddles across a number of curve segments with different radii while traversing the transition curve, the gradual reduction between the tangent gage and the gage at the end of the transition curve is an approximation. The shorter the radius, the greater the gage reduction required.
- Transition Curves: The reduction in gage must occur gradually. This requires a transition curve on either side of the main circular curve to accomplish the transition. The transition curve also transitions the radius of curvature from the curvature included in the switch, typically 300 feet (91 m), to the shorter radius of the main circular curve.
- Corrections for the Outside Rail in a Curve: Curves in crane track often begin with a switch to a new, diverging track. To standardize the switch and enhance economy, the same switch with the same radius of curvature, typically 300 feet (91 m), is used on both rails. This results in the inside and outside rails not being radial, requiring a correction for the additional length needed in the outside rail. This correction is included at the end of the switch curve in the outside rail. In addition, the beginning of the outside transition curve is shifted toward the switch to accomplish the reduction in gage. This shift creates another shortfall in length that requires a second correction using a short tangent between the sharp end of the outer transition curve and the beginning of the outer main circular curve.

5-2 APPLICABILITY.

Apply the design procedure outlined in this chapter to:

a. All new curved portal crane track projects.

b. Curved extensions to existing crane trackage.

c. Rehabilitation projects where new track foundations are required throughout a curve.

Rehabilitation design for curved trackage on existing foundations has different methods of calculation than those outlined in this chapter. Some of the criteria specified for new track cannot be applied to rehabilitation projects because of the need to fit the track on the existing foundation while meeting gage reduction requirements; however, wherever possible, the definitions and objectives of this chapter should be utilized for replacement design. Criteria for rehabilitation design of curved track on existing foundations are specified in CHAPTER 7.

5-3 FACTORS AFFECTING GAGE REDUCTION.

5-3.1 Crane Equivalent Length.

Equivalent length is the length of a theoretical crane that has its corners riding directly over the centerline of the rails when all the wheels of the actual crane are on the rails within the limit of the curve. The equivalent length is 2E in Figure 5-1 through 5-3 for 32-wheel and 24-wheel cranes respectively. The equivalent length is used to calculate the gage reduction.

Figure 5-1 Gage Reduction Diagram (32-Wheel Crane)

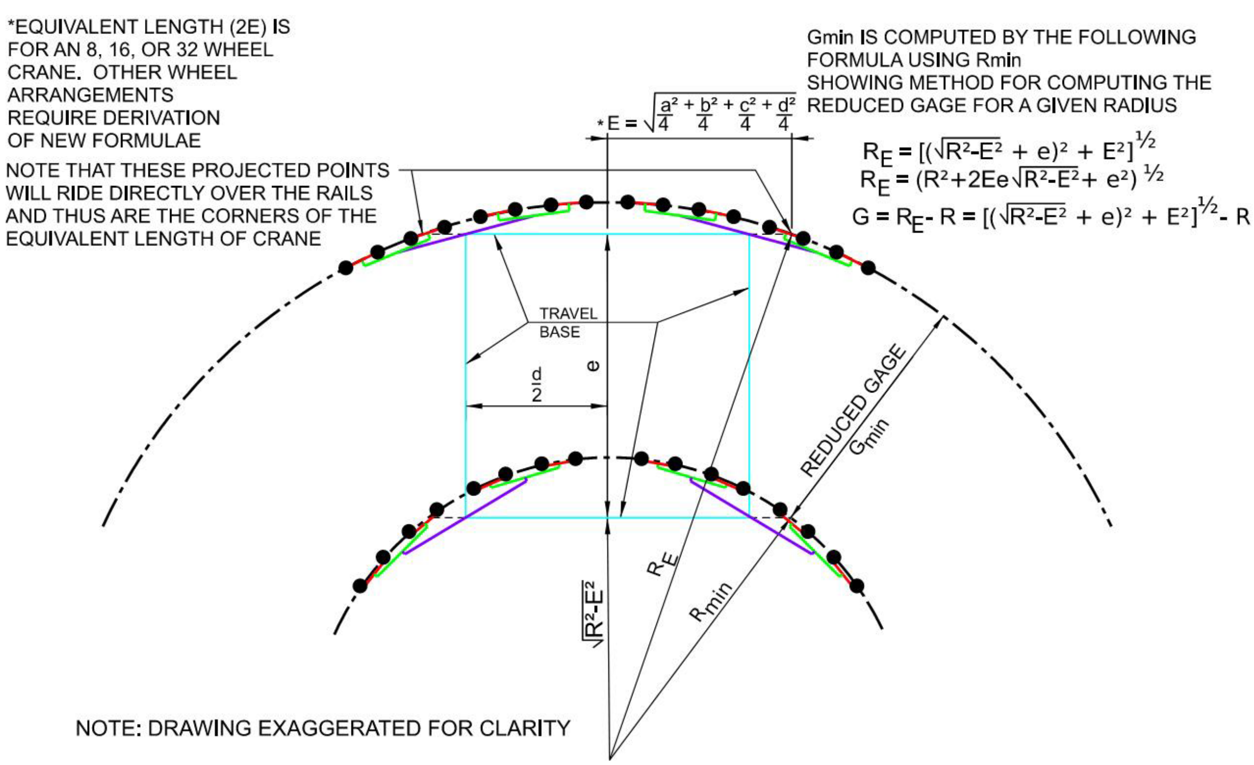


Figure 5-2 Equivalent Length of Crane (32-Wheel Crane Inner Rail)

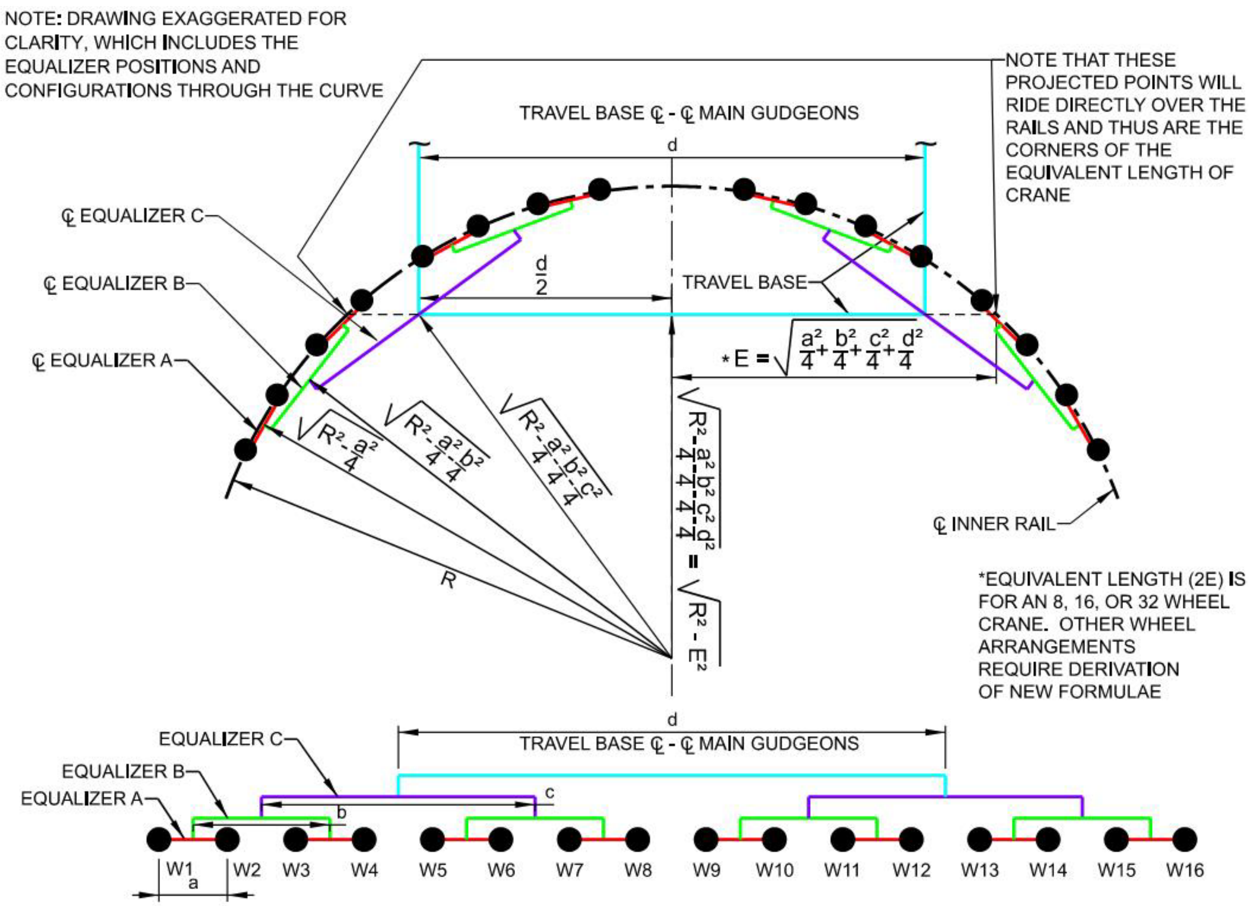
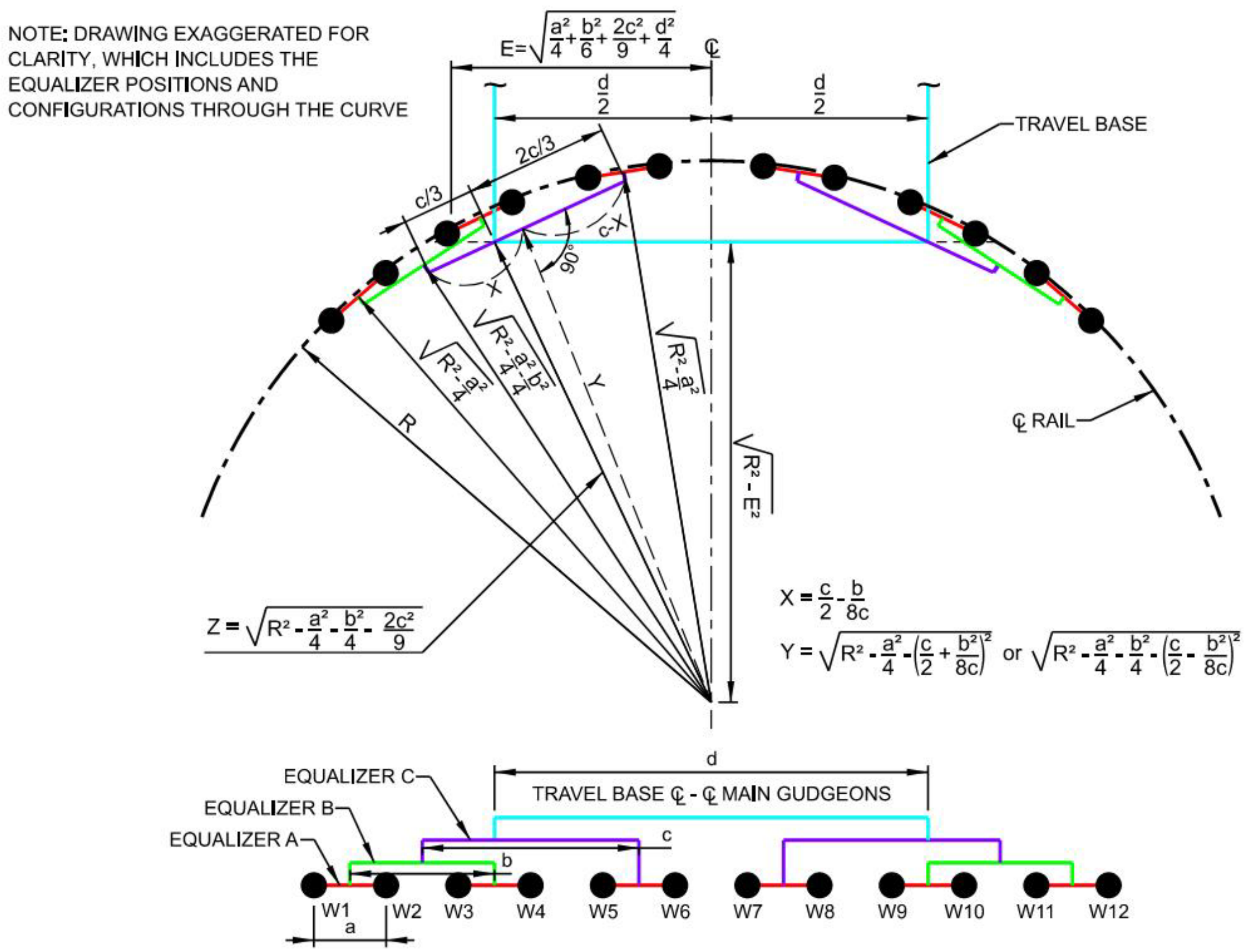


Figure 5-3 Equivalent Length of Crane (24-Wheel Crane)

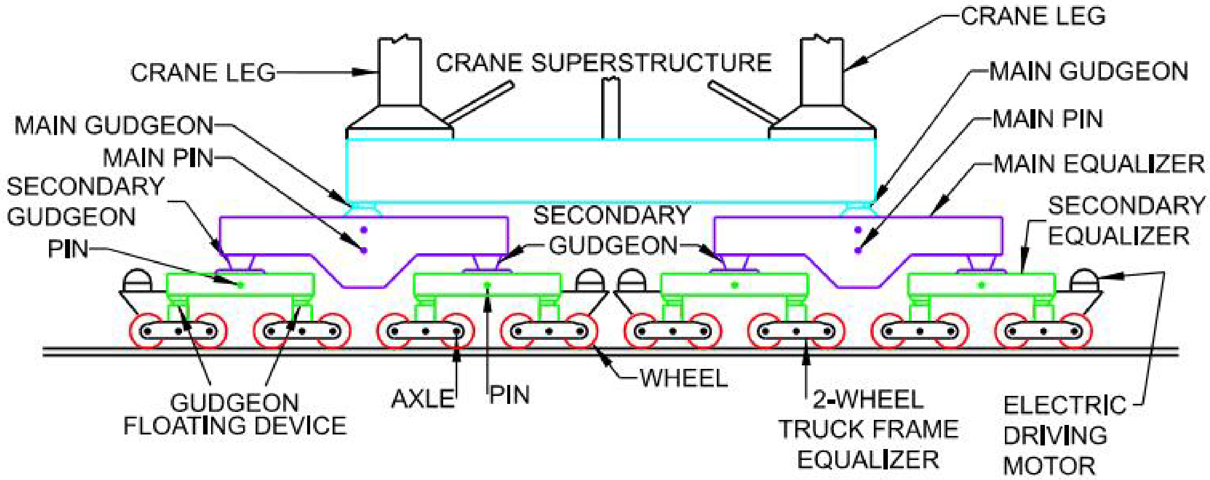


5-3.2 Lateral Float.

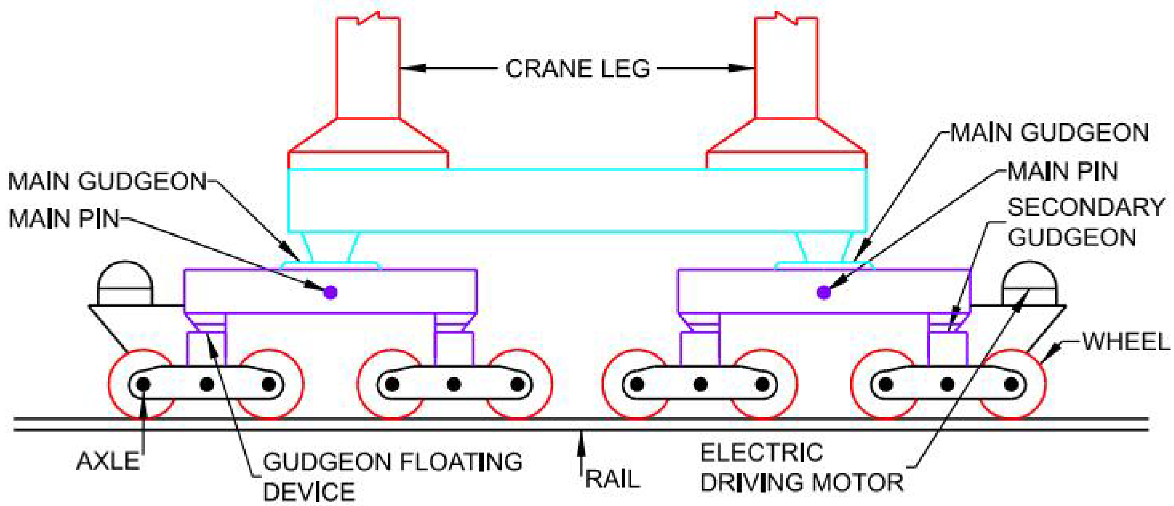
Lateral float is the amount of transverse movement provided on the gudgeon pins of the crane (See Figure 5-4 and Figure 5-5). Normally, the float capacity of a crane allows it to transverse a curve of 300-foot (91 m) radius on the inside rail with a safety factor greater than two without gage reduction. Lateral float is required to provide flexibility even when gage reduction is incorporated in crane track.

Prior to purchase of new cranes, investigate the existing track system to determine the gage to which the crane must be built and the amount of lateral float required in the crane. When cranes are transferred from one track system to another, determine float requirements and reconstruct the running gear as required to fit the new track system.

Figure 5-4 Travel Bases for Cranes

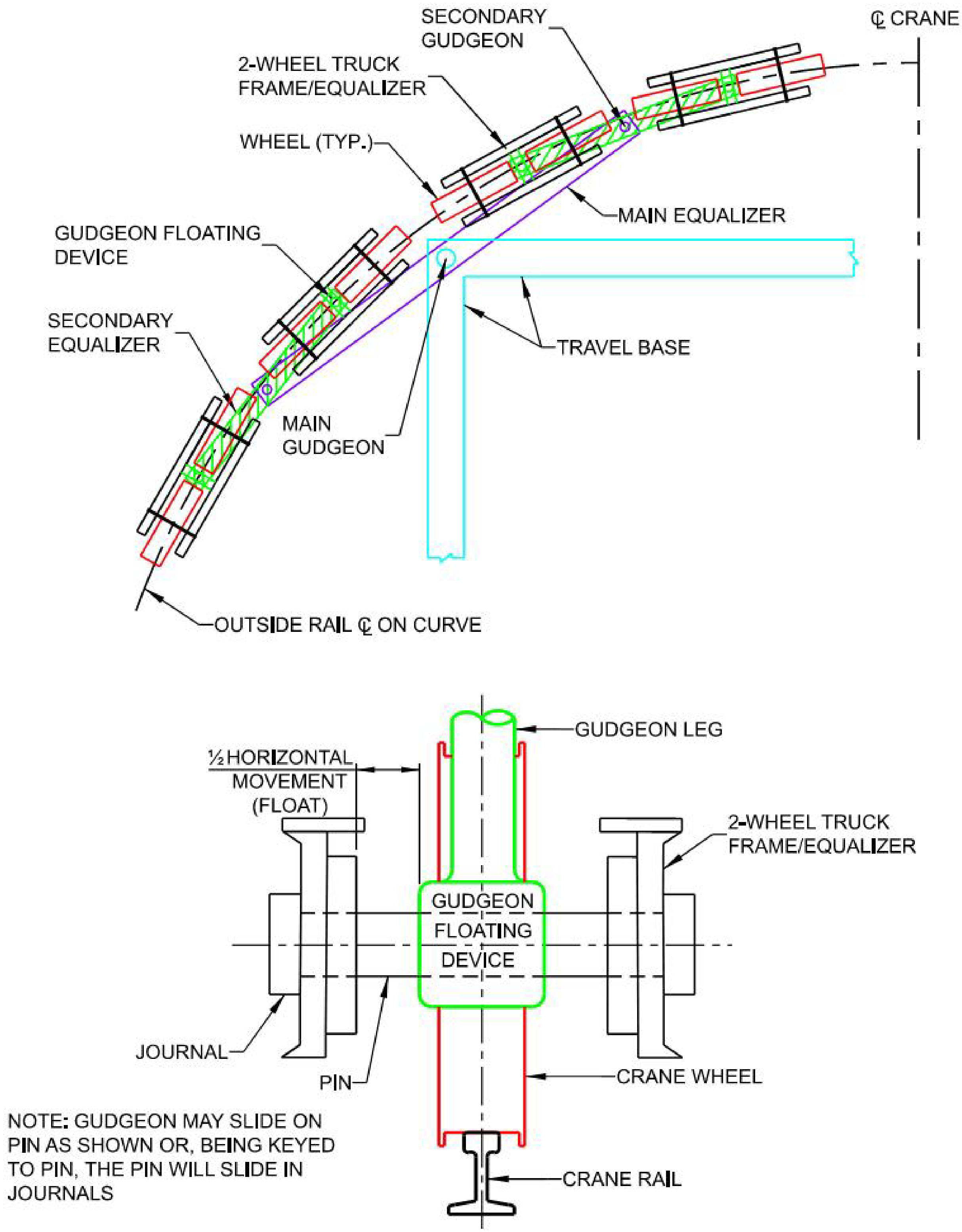


A. TWO RAIL 32-WHEEL CRANE



B. TWO RAIL 16-WHEEL CRANE

Figure 5-5 Partial Plan of Wheel Base (One Crane Leg) for 32 Wheel Crane



5-4 GENERAL CURVE REQUIREMENTS.

5-4.1 Definition of Curvature.

The curve design procedure requires curvature to be measured in degrees using the arc definition indicated in Equation 5-1.

Equation 5-1. Curvature (Arc Definition)

$$D = \frac{18{,}000}{\pi R} \approx \frac{5{,}729.58}{R}$$

Where:
D = Degree of curve (decimal degrees)
R = Radius of curve (feet)

Note that the definition of curvature for crane track is different than the definition for railroad track, which is the chord definition.

5-4.2 Minimum Tangent Length between Reverse Curves.

When curves of different directions immediately follow in sequence (reverse curves), install a tangent with a minimum length equal to the equivalent length of the crane, 2E, between the two curves.

5-5 ELEMENTS OF THE INSIDE RAIL CURVE (OR CONTROL CURVE).

5-5.1 Switch Curve (Inner).

The switch curve is the first part of the curve coming off the tangent. It is a 20-foot-long (6.1 m) arc with a constant radius of 300 feet (91 m). All switch curves, being identical, permit the standard crane rail, double-tongue switch to be inserted at the point of tangency of any curve, which is why it is called the switch curve. See Figure 5-6 for the relationship of the switch curve to the tangent and the transition curve. Begin curves with a switch curve even if the curve does not begin with a turnout switch.

5-5.1.1 Switch Alignment.

Although the body of the switch may project a few inches beyond the pivot point of the switch curve (See 0), the switch alignment will match any designed transition curve. Do not install a switch in curved track unless the radius of the curve is greater than 300 feet (91 m) and the diverging side of the turnout is to the inside of the curve. This is illustrated in Figure 5-7.

5-5.2 Transition Curve (Inner).

The transition curve transitions from the radius of the switch curve to the radius of the main circular curve. It is a series of compounding circular arcs, in which change of degree of curve is uniform and directly proportional to the transition curve length.

Figure 5-6 Relationship of Curves

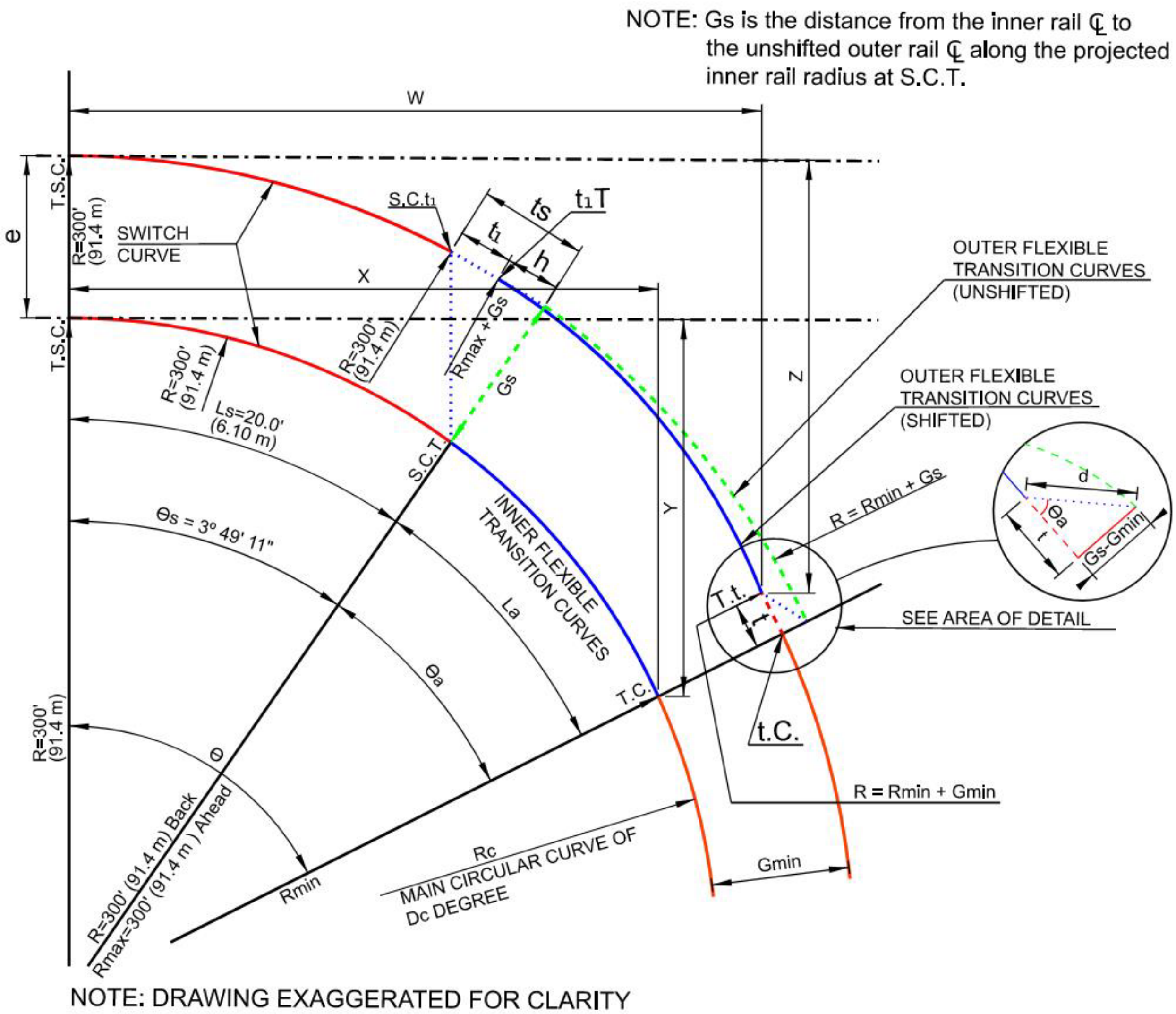
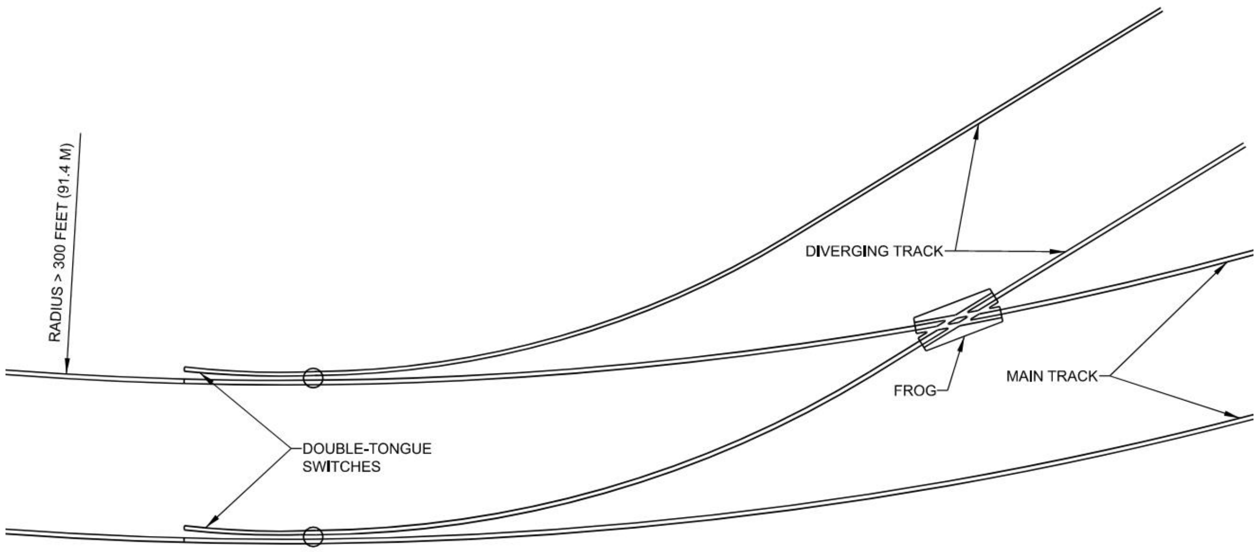


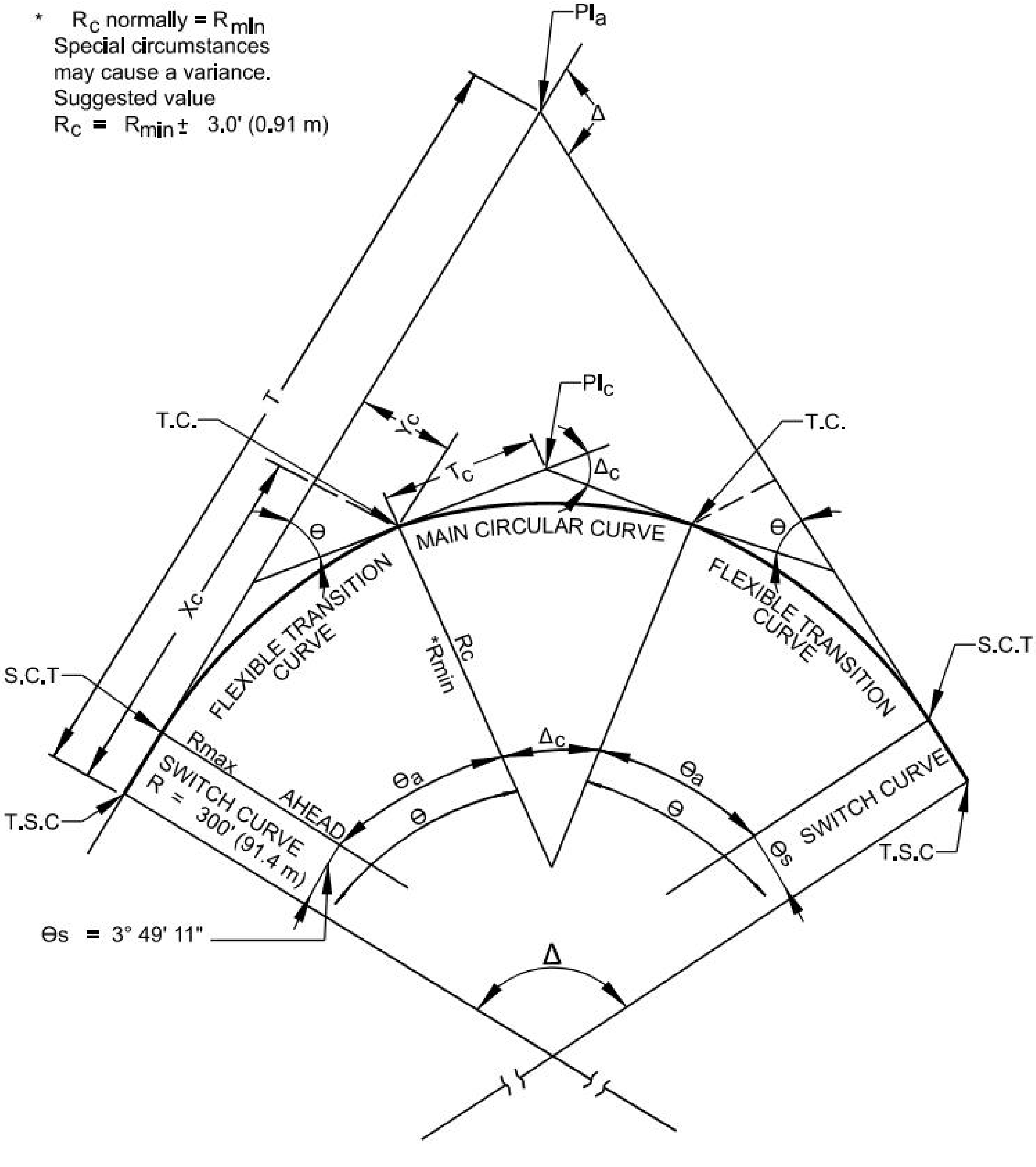
Figure 5-7 Switch Installation in a Curve



5-5.3 Main Circular Curve (Inner).

This curve is an arc of constant radius located between the beginning and ending transition curves (See Figure 5-6 and Figure 5-8).

Figure 5-8 Elements of Inner or Control Curve



5-5.3.1 General Design Procedure.

The radius of the main circular curve is denoted as R_c. Typically, the radius of the last, sharpest segment of the transition curve, which is denoted as R_{min}, is the same as the radius of the main circular curve. However, special circumstances arise that may cause R_c and R_{min} to be slightly different. Examples of situations when R_c and R_{min} may be different is when designing a curve to provide clearance around an object or to fit available space. In either example, the available float of any crane using the track must not be exceeded. The solution is an iterative procedure because the shift in location of the main circular curve caused by the transition curve is not known initially.

A guess of R_{min} is made and the coordinates of the transition curve are calculated using the process in this chapter. This results in the coordinates of the end of the transition curve (T.C.). The main circular curve is then placed at the end of the transition curve using $R_c = R_{min}$. The layout is then checked to make sure it provides adequate clearance to the object or fits the available space. If the layout with $R_c = R_{min}$ does not provide adequate clearance, R_c may be adjusted up to ± 3.00 feet (0.91 m) (using the same coordinates for the T.C. If this results in adequate clearance, the solution may be accepted with the difference in R_c and R_{min}.

5-5.3.2 Computer-Aided Drafting.

Use computer-aided drafting to aid in the process to determine R_{min} and R_c. Draft the inner curve using an estimate of R_c and use spirals in place of the transition curve. Use spiral lengths equal to the calculated length of the transition curve. If necessary, iterate R_c with the associated length of the spirals until adequate clearance is achieved. Finally, using the process in this chapter, calculate the transition curve using R_{min} equal to the iterated value for R_c. Using this process, a negligible difference between R_{min} and R_c should be achieved.

5-5.3.3 Minimum Radius.

Unless extreme space limitations dictate otherwise, it is desirable that neither R_{min} nor R_c be less than 80 feet (24 m).

5-5.3.4 Selection of Radius.

The following are suggested methods for selecting R_{min} and R_c for use in the design procedure presented in Table 5-1.

a. For a symmetrical curve with Δ = 180° (i.e. parallel tangents forming a “horse-shoe” curve), a first approximation of R_{min} should be:

$$R_{min} = 0.93M$$

The radius of the main circular curve is:

$$R_c = \frac{M - Y_c}{\cos\theta}$$

Where:
Δ = intersection angle of main control tangents
M = one half the distance between the parallel tracks
Yc = Y coordinate to the T.C.
θ = central angle from point of T.S.C. to the T.C.

This situation occurs in the head-end of drydock and is illustrated in Figure 5-9. See paragraph 5-10 for additional information.

b. For 90° ≤ Δ < 180°, a recommended first approximation of R_{min} would be a value equal to one half the distance from the beginning Point of Tangent to Switch Curve (T.S.C.) to the ending T.S.C.. Refer to Figure 5-8.

Note: The choice of R_{min} in this case is strictly an approximation. Iterate using the general design procedure to determine the final choice of R_{min}.

c. For Δ < 90°, it is recommended that the first trial should be based upon historical data of a similar curve if available. Otherwise, estimate and refine by trial and error using the general design procedure.

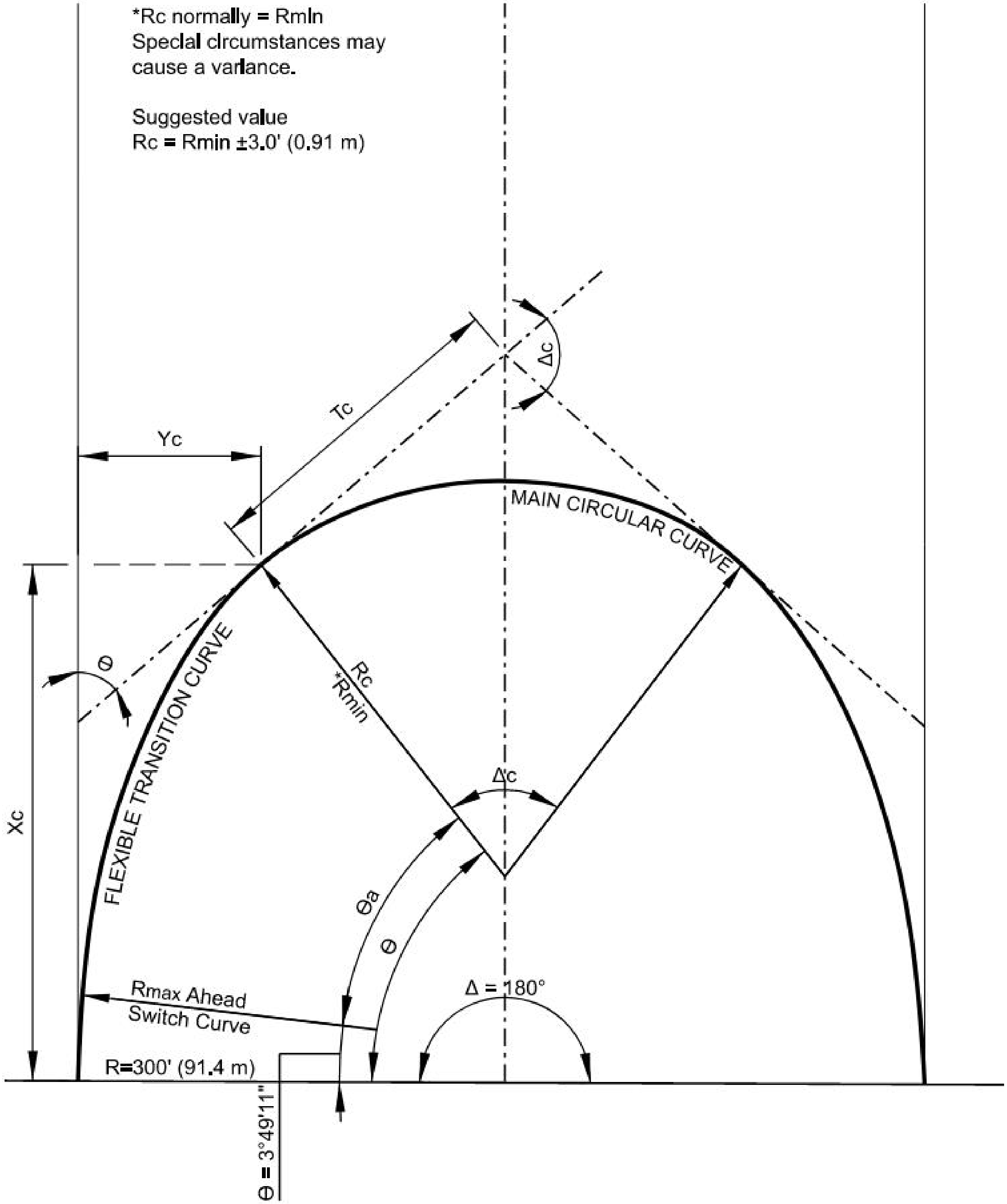
5-5.4 Complete Inner Curve Combination.

A complete curve combination consists of a minimum of two switch curves and two abutting transition curves, or a maximum of two switch curves and two transition curves, separated by one main circular curve (See Figure 5-6 and Figure 5-8).

5-5.4.1 Complete Curve without Main Circular Curve.

When the main intersection angle (Δ) is 90 degrees or less, the curve may be made transitional throughout. When the curves are transitional throughout, the inner transition curves abut, but the outer transition curves are separated by a tangent of 2t length.

Figure 5-9 Complete Inner Curve for Δ=180° at Drydock Head End



5-6 ELEMENTS OF THE OUTSIDE RAIL CURVE.

5-6.1 Switch Curve (Outside).

Similar to the inner rail, the outer switch curve is the first part of the curve coming off the tangent. It is a 20-foot-long (6.1 m) arc with a constant radius of 300 feet (91 m) and identical to the switch curve on the inner rail. This permits the standard switch to be inserted to begin a turnout. This also results in the outer switch curve not being concentric with the inner switch curve since they have the same radius. Therefore, the outer switch curve converges on the inner switch curve. Fortunately, this convergence closely approximates the required gage reduction so that a negligible amount of misalignment is introduced.

5-6.1.1 Switch Lead.

Since the inner and outer switch curves are not concentric, the point radially opposite the rear, pivot point end of the inner switch curve is ahead of the rear, pivot point end of the outer switch curve. This distance is called the lead and denoted as t_s in Figure 5-6.

5-6.2 Transition Curve (Outside).

Similar to the inner transition curve, the outer transition curve transitions from the radius of the switch curve to the radius of the main circular curve using a series of compounding circular arcs. However, the compounding circular arcs are not concentric with the corresponding arcs of the inside transition curve. The outside transition curve is further complicated since it is used to obtain the desired gage reduction. The components of the outside transition curve are as follows:

5-6.2.1 Central Angle.

The series of compound arcs comprising the outer flexible transition curve have the same central angle, θ_a, as the corresponding arc of the inside transition curve. See θ_a in Figure 5-6 and Figure 5-8).

5-6.2.2 Radii.

The radii of the arcs of this transition are obtained by adding G_s, the reduced gage at the end of the switch curve on the inner rail (the S.C.T. in Figure 5-6), to the radii of the corresponding arc of the inner transition curve.

5-6.2.3 Gage Reduction.

The required gage reduction through the transition curve is obtained by shifting the beginning of the outer curve along tangent t_s (the lead) a distance h closer to the switch and before the S.C.T. See Figure 5-6.

5-6.2.4 Alignment Closure.

A short tangent distance t_1 is then introduced between the end of the switch curve and the beginning of the outer flexible transition curve to make up the gap between the two. See Figure 5-6. There is also a shortfall between the end of the flexible transition curve and the main circular curve which is made up by add a short tangent distance, denoted as t, between the two. This correction is also shown in Figure 5-6.

5-6.3 Main Circular Curve (Outside).

The main outside circular curve is an arc of constant radius which is concentric with the corresponding inside main circular curve. Therefore, the outside main circular curve has the same central angle as the inside main circular curve. The gage between the outer and inner main circular curves is constant and equal to G_{min}. As a result, calculate the radius of the outside main circular curve by adding the G_{min} to the radius of the inside main circular curve (R_c). Refer to Figure 5-6.

5-7 DESIGN PROCEDURE.

See Table 5-1 for the procedures to design the inside and outside curves.

Table 5-1 Design Procedure

Description	Procedure	Reference
Equivalent length	Equivalent length of crane equals 2E where: $$E = \sqrt{\left(\frac{a^2}{4} + \frac{b^2}{4} + \frac{c^2}{4} + \frac{d^2}{4}\right)} \quad (8, 16, 32\ wheel)$$ $$E = \sqrt{\left(\frac{a^2}{4} + \frac{b^2}{6} + \frac{2c^2}{9} + \frac{d^2}{4}\right)} \quad (24\ wheel)$$	Figures 5-1, 5-2 and 5-3
Reduced gage (G_R)	For any circular curve, of a given radius R, where R is the radius of the inner rail: $$G_R = (R^2 + 2e\sqrt{(R^2 - E^2)} + e^2)^{1/2} - R$$ Notes: (1) Check to be certain that a gage reduction is not required for a 300-ft. (91.44-m) radius, i.e., *$G - G_R \leq$ ½ float of crane* (2) For two or more cranes, use the average equivalent length of the cranes to obtain the reduced gage, and check to ascertain that this gage reduction is within the float capability of each crane. If the gage reduction is too great for any crane, adjust the track design using the equivalent length of the critical crane until a satisfactory reduced gage is obtained.	Figure 5-1
Lateral Float	Lateral float considerations: (a) ($e - G_R$) ≤ ½ (available lateral float), for a large radius curve, i.e., R > 300 ft. (91.44 m) (b) ($G_{n1} - G_{n2}$) ≤ ½ (available lateral float), for any two points, not more than equivalent length of crane apart	Par. 5-3.2 Figures 5-5 and 5-6
<u>Inside or Control Curve</u> Switch (fixed) curve	(1) Length of switch and number of compounding arcs L_s = 20.00 ft. (6.10 m) N_s = 1	Par. 5-5.1 Figures 5-8, 5-9 and B-1

Description	Procedure	Reference
Switch (fixed) curve (continued)	(2) Degree of curve and radius at both the T.S.C. and S.C.T. R_s = 300.00 ft. (91.44 m) D_s = 19° 5' 55" (3) Central angle θ_s = 3° 49' 11" (4) The coordinates at the S.C.T. are: $X_s = R_s \sin \theta_s$ $Y_s = R_s - R_s \cos \theta_s$	
Transition (flexible) curve	(1) R_{min}, as established in "Main Circular Curve". Notes: (1) For two-rail portal crane, the radius is to the centerline of the inside rail. (2) For four-rail portal crane, the radius is to the centerline of the inside track. (2) Number of intermediate arcs of equal length: N = 10 (may be changed if necessary) (3) Degree of curve and corresponding radius for an arc: $$D_n = D_{n-1} + \frac{(D_{max} - 19.0986°)}{N}$$ $$R_n = \frac{5729.578}{D_n}$$ Note: When n = 1, $D_o = D_s$ = 19.0986° (4) Method of establishing length L_a Known e, E, F, and R_{min} Where: F = ½ the maximum lateral float capability, in feet. Note: Where the length of flexible transition (L_a) computed is greater than the space available, the length may be reduced by shortening the value of R_{min} in accordance Paragraph 5-5.3.	Par 5-5.3 Figures 5-8, 5-9 and B-1 Figures 5-8, 5-9 and B-1 Figure 5-6

Description	Procedure	Reference
Transition (flexible) curve (continued)	Determine: R_{2E} the radius at a point on the transition curve, 2E distance back from the TC *Step (a)* $$G_{min} = \left(R^2_{min} + 2e\sqrt{(R^2_{min} - E^2)} + e^2\right)^{½} - R_{min}$$ *Step (b)* $$R_{2E} = \frac{-b \pm \sqrt{(b^2 - 4ac)}}{2a}$$ Where: $a = 2e – F – 2G_{min}$ $b = e\ (2e – F – 2G_{min})$ $c = -\ eE^2$ Determine: L_a *Step (a)* $$D_{max} = \frac{5729.578}{R_{min}}$$ $$D_1 = D_s + \frac{D_{max} - 19.0986°}{N}, where\ D_s = 19.0986°$$ $$R_{max} = \frac{5729.578}{D_1}$$ *Step (b)* $$D_{2E} = \frac{5729.578}{R_{2E}}$$ *Step (c)* $$L_a = \frac{2E\ (D_{max} - D_1)}{D_{max} - D_{2E}}$$ Notes:	

Description	Procedure	Reference
Transition (flexible) curve (continued)	(1) L_a should be adjusted to the nearest foot to facilitate computations. (2) Computation of L_a by this method leads to the probable satisfaction of the float considerations set forth in the first part of this table.) (5) Arc length and central angle, corresponding with the degree of curve D_n for an arc (n): $$A_n = \frac{L_a}{N}$$ $$\Delta_n = \frac{AnDn}{100}$$ (6) The central angle from the T.S.C. to any P.C.C. is: $$\theta_n = \theta_{n\text{-}1} + \Delta_n \text{ or}$$ $$\theta_n = 3.8197° + \frac{L_n - 20}{200}(D_1 + D_n)$$ (7) The central angle of the flexible transition is: $$\theta_a = \theta - \theta_s \text{ or,}$$ $$\theta a = \frac{L_a}{200}(D_1 + D_{max})$$ (8) The coordinates for any P.C.C. are: $$X_n = X_{n-1} + R_n(\sin\theta_n - \sin\theta_{n-1})$$ $$Y_n = Y_{n-1} + R_n(\cos\theta_{n-1} - \cos\theta_n)$$ Note: θ_n, X_n, and Y_n are used herein to designate angles and offset distances from the T.S.C. to the points of compound curvature only. They are not used to designate angles or offsets to any arbitrary point on the transition curve.	
Complete curve combination	The tangent distance for the complete curve is: $$T = X_c - (R_c \sin\theta) + (R_c \cos\theta + Y_C)\tan\frac{\Delta}{2}$$	Figure 5-8

Description	Procedure	Reference
<u>Outside Curve</u> Switch (fixed)	(1) This curve is identical with the switch curve (inside or control) (2) The lead is: t_s = G sin 3° 49’ 11”	Figure 5-8, 5-9 Figure 5-6 Par. 5-6.1
Reduced gage (G_s)	G_s at the S.C.T., by convergence of outer and inner rails of switch curve is: G_s = G cos 3° 49’ 11”	Figure 5-6
Transition curve	(1) Radius and length of any arc R_n = G_s + radius of corresponding arc of inner curve $A_n = R_n\Delta_n$ (A_n in feet (meters), Δ_n in radians) (2) Distance shifted back of the S.C.T. along tangent t_s is: $h = \frac{G_s - G_{min}}{sin\ \theta_a}$ (3) Tangent length between end of switch curve and beginning of flexible curve, and its offset distances in the W and Z directions are: $t_1 = t_s - h$ W direction = t_1 cos 3° 49’ 11” Z direction = t_1 sin 3° 49’ 11” (4) Tangent length between end of flexible curve and main circular curve, and its offset distances in the W and Z directions are: $t = \frac{G_s - G_{min}}{tan\ \theta_a}$ W direction = $t \cos \theta$ Z direction = $t \sin \theta$	Figure 5-6 Figure 5-6 Par. 5-6.2 Figure 5-6 Par. 5-6.2

Description	Procedure	Reference
Transition (flexible) curve (continued)	(5) The coordinates for any P.C.C. are: $W_n = W_{n-1} + R_n (\sin \theta_n - \sin \theta_{n-1})$ $Z_n = Z_{n-1} + R_n (\cos \theta_{n-1} - \cos \theta_n)$ (6) The gage at any P.C.C. of the transition curve, back of R_{min} is: $G_n = G_s - h \sin (\theta_n - \theta_s)$	
Main Circular Curve	The central angle is equal to: $\Delta_c = \Delta - 2\theta$ Radius of inner main circular curve = R_c Radius of outer main circular curve = $R_c + G_{min}$ Gage on main circular curve is G_{min}	Figures 5-6, 5-8 and 5-9

5-8 SAMPLE CURVE COMPUTATIONS.

See APPENDIX B, Table B-1 for example.

5-9 TABULATION OF SAMPLE CURVE COMPUTATION.

See APPENDIX B, Table B-2 for tabulation of sample calculation.

5-10 DRYDOCK HEAD-END.

The head-end curve in drydocks is a special case of a complete curve combination in which a curve having a 180-degree central angle is required to connect two parallel tangent tracks that are on either side of the drydock. The geometry of the head-end curve is illustrated in Figure 5-9. See paragraph 5-5.3.4 for guidance on selecting the radius for the head-end curve.

The following considerations are essential to design:

a. Do not make access connections, such as turnouts to other crane tracks, to the continuous circular curve connecting both sides of a drydock. Instead, make connections to other tracks to the tangents on either side of the drydock.

b. Where feasible, make the curve combination symmetrical about a line equidistant between the parallel tangent tracks on either side of the drydock.

CHAPTER 6 VERTICAL ALIGNMENT (DESIGN OF GRADE).

Portal cranes are more sensitive to changes in grades than railroad vehicles. While there is often little change in grade on piers and wharves where portal cranes are typically located, changes in grade must be accommodated when necessary to connect parts of a track system constructed at different elevations. Grades are measured by the amount of rise or fall over a horizontal distance and are expressed in percent. For example, a rise of one unit over a horizontal distance of 100 units would be a 1-percent grade.

6-1 MAXIMUM GRADES.

The maximum grade is typically 1 percent on horizontally straight track but consult the crane manufacturer for the maximum grade each crane can negotiate.

6-2 GRADE DESIGN CRITERIA.

Design grades using the following criteria:

- To enhance crane operations, limit grades as much as possible.
- Use a level grade (0-percent) within the limits of turnouts or crossing with other crane tracks or railroad tracks.
- Begin non-level grades a minimum distance of the crane length (centerline to centerline of end wheels) from any horizontal curve, turnout, or crossing with another crane track or a railroad track.
- Design horizontal curves for level grade to minimize the possibility of derailment. See paragraph 6-3.
- Obtain approval from the authority having jurisdiction for the applicable military branch if there is an absolute necessity to use other than a level grade within the limits of a horizontal curve.
- When nonlevel grade is permitted by the authority having jurisdiction, use the formulas and procedure of the example in Paragraph 6-4.1.

6-3 TRANSITIONS BETWEEN GRADES.

Transitions between grades are made with parabolic vertical curves. See the AREMA *Manual for Railway Engineering*, Chapter 5, Section 3.6 for the equation to determine the elevations of the parabolic vertical curve. Vertical curves must not occur within the limits of horizontal curves or turnouts.

6-3.1 Minimum Vertical Curve Length.

The minimum length of vertical curve is the greater of the following:

- 100 feet (30.5 m).

- Crane length = centerline to centerline of end wheels.

6-4 RISK OF NON-LEVEL GRADES IN HORIZONTAL CURVES.

If a horizontally curved track is placed on non-level grade, there is a risk of derailment, with the added risk of overturning due to the following conditions:

a. Points on the rails directly under the corners of the crane traversing the curved track are at different elevations and not in the same plane. Because the frame and legs are a rigid structure, the sills and girders cannot appreciably conform to a non-plane surface.

b. The crane is a rigid rectangular frame. The higher inside corner and the lower outside corner of this frame, which are always diagonally opposite, will remain on the rails at all times. Of the other two corners, the one nearer the center of gravity will be forced to the rail, thus suspending the fourth corner (diagonally opposite) above the rail by twice the difference in elevation at points on the rails under laterally opposite corners.

c. An identical suspension occurs at the corresponding point on the sill of the actual crane traversing such track. The suspension of one truck above the rail will be the amount of suspension at the sill multiplied by N' where:

Equation 6-1. Truck Suspension Factor 1

$$N' = \frac{\text{total number of pivot points (at one corner)} + 1}{2}$$

Equation 6-2. Truck Suspension Factor 2

$$N' = \frac{\text{total number of wheels of crane}}{8}$$

The application of these factors is illustrated in Paragraph 6-4.1.3 Vertical Positions.

6-4.1 Example Case: Non-Level Grades in Horizontal Curves.

The following calculation illustrates the application of this procedure for a case of a -1.00 percent grade on a horizontal curve with a radius of 100 feet (30.48 m) at the inner rail and a crane with an equivalent length of 37.74 feet (11.50 m).

6-4.1.1 Plan View Geometry.

From the plan view of Figure 6-1:

$$\psi = \arc\sin \frac{18.8716\, ft\ (5.75206\, m)}{100.00\, ft\ (30.48\, m)}$$

ψ = 10 deg 52 min 40 sec

$$\Phi = \text{arc}\sin\frac{18.8716\ ft\ (5.75206\ m)}{120.00\ ft\ (36.576\ m)}$$

Φ = 9 deg 02 min 53 sec

$\Delta_2 = \psi - \Phi$ = 1 deg 49 min 47 sec

Arc cb and Arc ha = (100.00 ft (30.48 m)) (radian 1 deg 49 min 47 sec)
= 3.193 ft (0.973 m). (6)

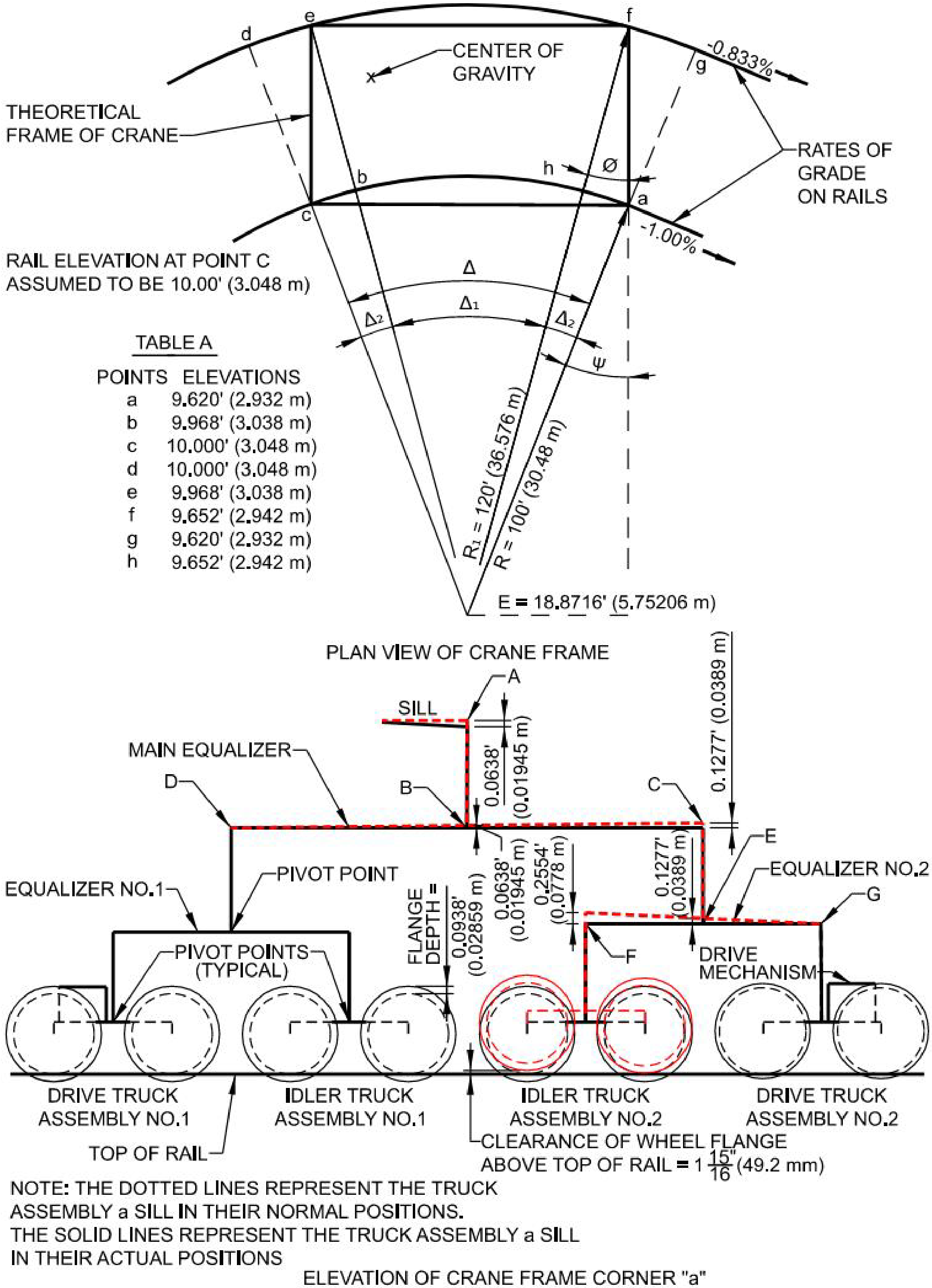
$\Delta_1 = 2\ \Phi$ = 18 deg 05 min 46 sec

Arc bh = (100.00 ft (30.48 m)) (radian 18 deg 05 min 46 sec)
= 31.584 ft (9.627 m).

6-4.1.2 Vertical Suspension of Truck at Crane Corner.

The crane track is laid level, laterally between the rails. Therefore, the difference of elevation between points c and b, or h and a, is 3.193 feet (0.973 m) multiplied by 1.00 percent, which is equal to the difference between points c and e or a and f. See Table A of Figure 6-1 for the elevations of these points. Frame corner "a" is suspended 0.0319 feet (0.0097 m) multiplied by 2, and the sill at point A of the elevation view in Figure 6-1 is suspended an identical amount, or 0.0638 feet (0.0194 m). The suspension at point B, a pivot point, equals the suspension at point A. The truck intermediate equalizers, in all probability, are not exactly balanced; therefore, assume point D does not move and point C rises.

Figure 6-1 Crane Reaction to Grades on Horizontal Curves



6-4.1.3 Vertical Position.

The vertical position of point C is now 0.1277 feet (0.0389 m) above normal; it follows that point E is the same amount above normal. The drive truck assembly No. 2, being heavier than the idler truck assembly No. 2, will cause point F to rise 0.1277 feet (0.0389 m) above point E. Point F will now be 0.2554 feet = 3 1/16 inches (0.0778 m = 77.8 mm) above point G, the normal position. The flange is 1 1/8 inches (28.6 mm) in depth, which leaves a clearance (3-1/16 - 1-1/8) = 1 15/16 inches = 0.1615 feet (77.8 mm - 28.6 mm = 49.2 mm = 0.0492 m) between the top of the rail and the flange on each wheel of idler truck assembly No. 2, assuming that the idler truck assembly remains balanced because of friction. This clearance will permit the truck assembly to swivel and cause derailment. Distance (S) of the wheels of one truck assembly above the rail is determined by:

Equation 6-3. Distance of Truck above the Rail

$$S(truck) = R\left[radian\left(arc\ sin\frac{E}{R} - arc\ sin\frac{E}{R_1}\right)\right]\ (g)\ \left[\frac{w}{4}\right]$$

in which g is the rate of grade on the inside rail, and w is the total number of wheels.

Given: R = 100 ft (30.48 m)

R_1 = 120 ft (36.576 m)

E = 18.87 ft (5.752 m)

g = 1.00%

w = Total number of wheels of crane = 32

S(truck) = 100 (Radian 1 deg 49 min 47 sec) (0.01) $\left[\frac{32}{4}\right]$

= 0.2554 feet (0.0778 m) or 3 1/16 inches (77.8 mm)

This can also be calculated based on the suspension of the crane sill using Equation 6-1 and Equation 6-2 as follows:

$$N' = \frac{7+1}{2} = 4 \quad per\ Equation\ 6-1$$

or

$$N' = \frac{32}{8} = 4 \quad per\ Equation\ 6-2$$

S(truck) = N' (suspension of sill) = 4 (0.0638 feet (0.01945 m)) = 0.2554 feet = 3 1/16 inches (0.0778 m = 77.8 mm)

6-4.1.4 Balance between Wheels on Idler Truck.

If the wheels of idler truck assembly No. 2 do not remain balanced, which is the most likely condition, the distance (S) which one wheel, or pair of wheels, will be above the rail is twice the amount shown by Equation 6-3. Therefore, the formula for the worst, most likely condition is:

Equation 6-4. Distance of Wheel above the Rail

$$S(wheel) = 2R\left[radian\left(arc\ sin\frac{E}{R} - arc\ sin\frac{E}{R_1}\right)\right]\ (g)\ \left[\frac{w}{4}\right]$$

In this example, the resulting height of the wheel above the rail is 0.5108 feet (0.1557 m) or 6 1/8 inches (156 mm).

CHAPTER 7 PORTAL CRANE TRACK REPLACEMENT CURVE ALIGNMENT

7-1 SURVEY REQUIREMENTS.

For all replacement track design, where the existing foundation is to be reused, the following survey tolerances are required.

7-1.1 Track Survey Measurement Tolerance.

Conduct survey to locate the centerline of the existing track to the closest 0.005 foot (0.0015 m) for distances and 20 seconds for angles. The centerline of rail for two-rail systems shall be the centerline of each rail, while the centerline of rail for a four-rail system shall be the centerline of standard gage. For four-rail systems, the top of each rail should be surveyed and the centerline of track computed as the midpoint between the two rails. The survey data should include coordinates for points at approximately 5-foot (1.5 m) intervals along the existing inner and outer rails. Control points should be made permanent to last at least 2 years and located in areas that will not be disturbed by construction.

7-1.2 Dig-Up Foundation Survey Measurement Tolerance.

Dig-up survey, to locate the centerline of the existing foundations to compare to the centerline of the existing rails, should be made at locations spaced at 15-to 25-foot (4.6 to 7.6 m) intervals along the curves. The actual number of dig-up locations is determined by the type of curve and the difference between the rail and foundation centerlines.

7-2 FOUNDATION STRUCTURAL ANALYSIS REQUIREMENTS.

Perform structural analysis to determine the maximum allowable eccentricity that the rail centerline may be offset from the foundation centerline.

7-3 REPLACEMENT TRACK DESIGN REQUIREMENTS.

Design a replacement alignment for the inner and outer rails in accordance with the criteria of this UFS. Ensure that the following criteria are satisfied:

a. Deviations. Deviations of design alignment from centerline of existing foundations shall not exceed the allowable structural eccentricities. Deviations of 1 inch (25 mm) or less can generally be achieved.

b. Offset Closures. The perpendicular distance from the surveyed curve tangent to the design curve tangent at each end of the curve (at the T.S.C. points) must be 0.2 inch (5 mm) or less. Figure 7-1 illustrates this requirement.

c. Tangent Closures. For 180-degree horseshoe curves, the tangent closures where each half of the main circular curve come together after beginning the replacement design from each T.S.C. must not overlap.

Overlapping tangent closures indicate that the two halves of the main circular curve have no common point of tangency. This results in a kink. Figure 7-2 illustrates this requirement. However, it is acceptable if each half of the main circular curve stops short and a tangent connects the two halves.

d. Required Float. Required crane float used in the design of the replacement alignment must not exceed the allowable float for any crane that will traverse the track.

Figure 7-1 Offset Closure Requirement

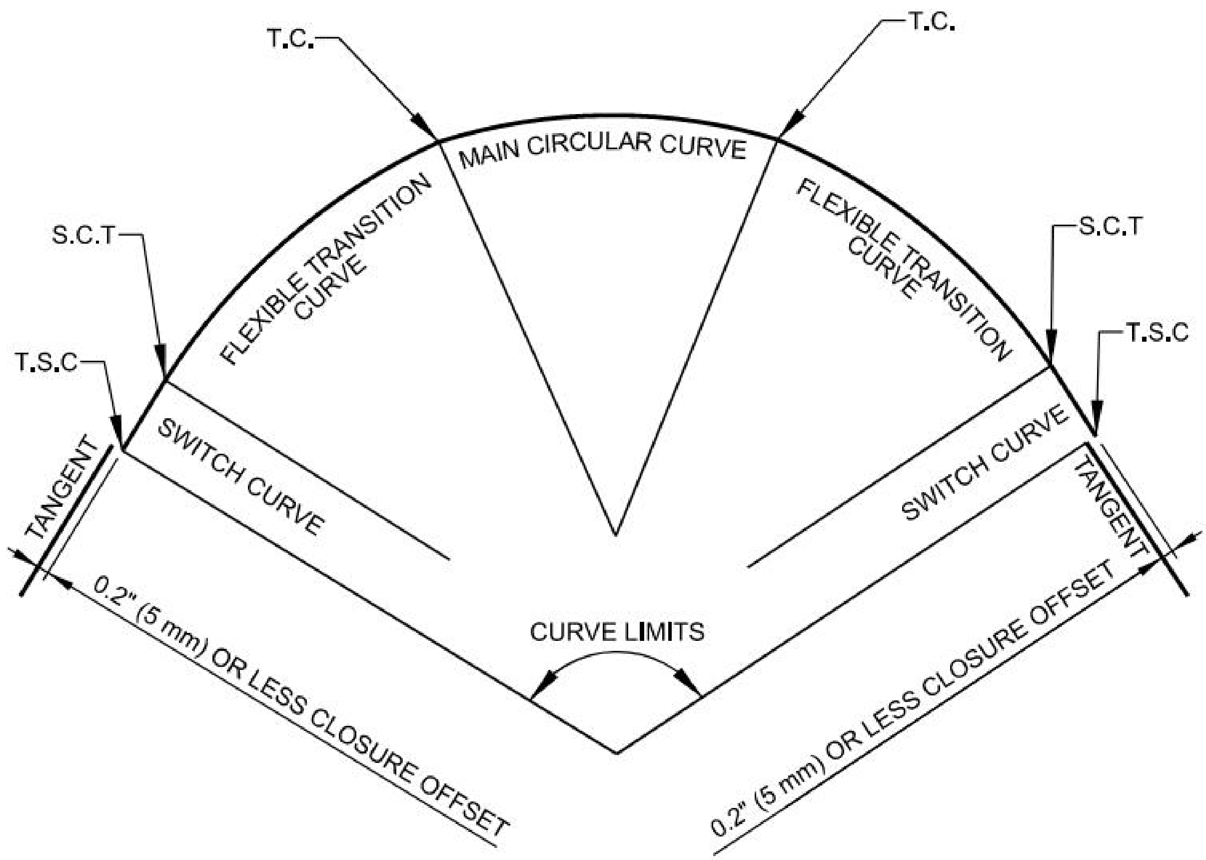
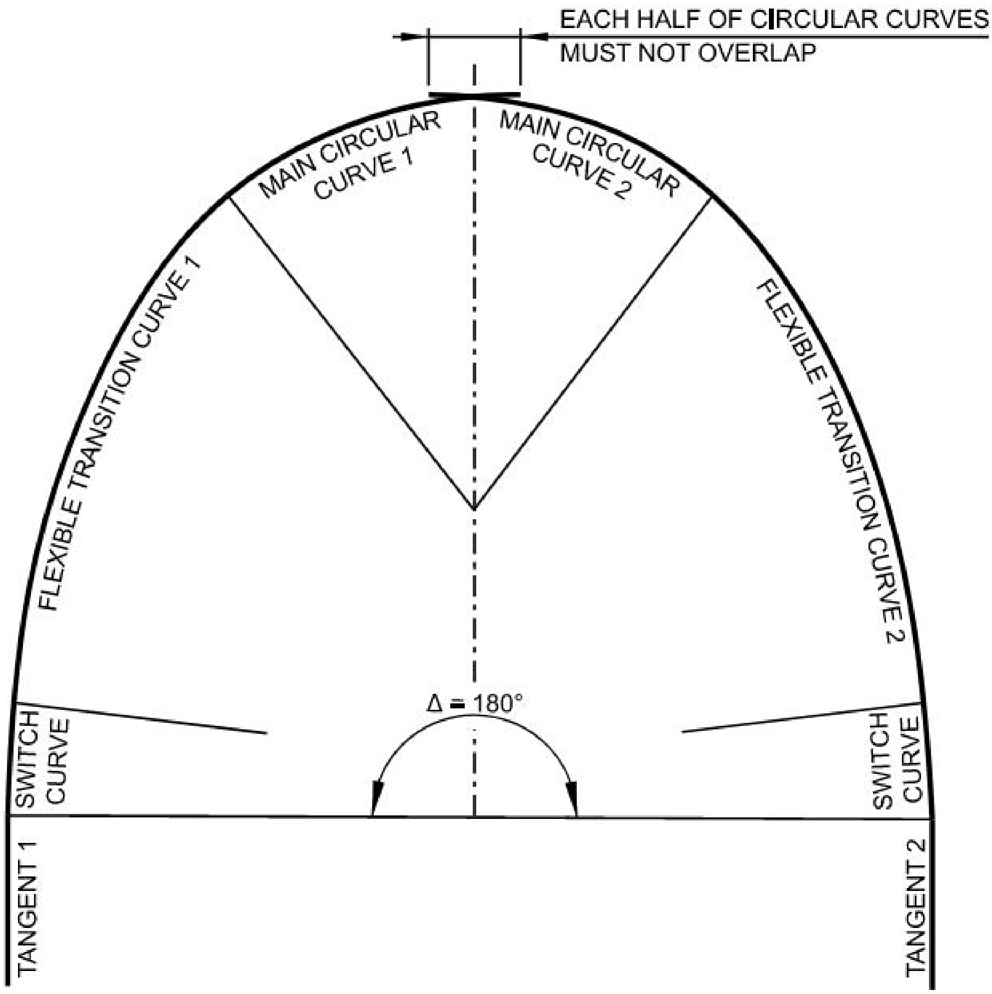


Figure 7-2 Tangent Closure Requirement for 180-Degree Horseshoe Curves



7-4 RAIL CONSTRUCTION DRAWING REQUIREMENTS.

Prior to any portal crane track curve construction, all float requirements of portal cranes traversing the design curve must be satisfied. Prepare working drawings showing adequate information for track alignment construction. These drawings are formal, scaled layouts of the track alignment and should contain the following design information as a minimum:

a. Tangent lengths

b. T.S.C., S.C.T., T.C., PI_a, and PI_c locations for curves

c. For each segment

1. Tangent offsets to segment = Y for the inner rail or = Z for the outer rail

2. Delta angles
3. Radii
4. Arc Lengths
5. Stations of P.C.C.'s
6. Gages

This information is also necessary for construction drawings for new curved trackage described in CHAPTER 5.

7-4.1 Obstruction Checks.

Check physical obstructions before allowing a new crane on the track.

7-5 MAINTENANCE

For Navy only: See NAVFACINST 11230.1 for maintenance of crane trackage.

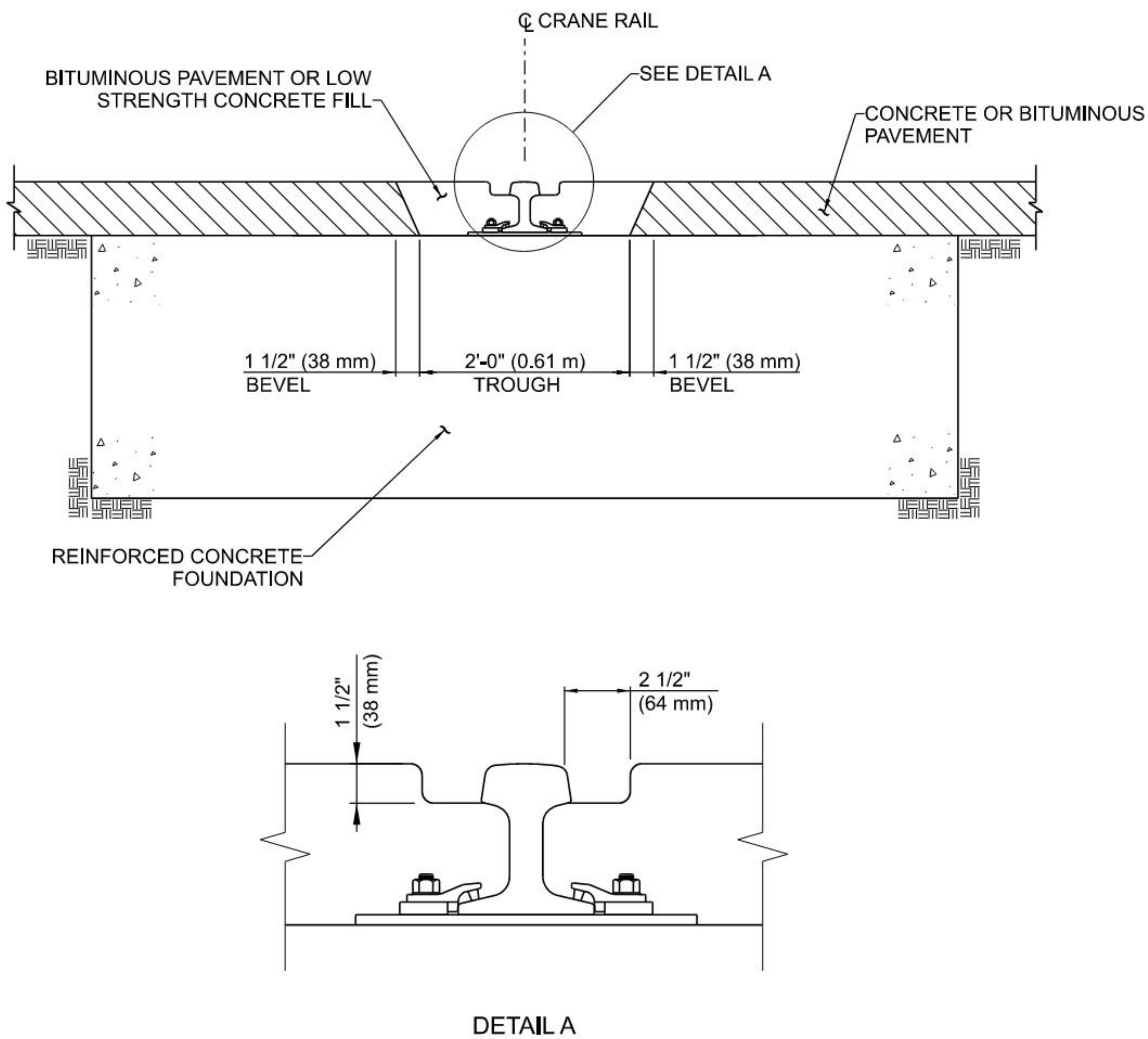
For Army and Air Force only: See CMAA Specification Number 70 and AIST Technical Report Number 6 for rail alignment and maintenance criteria.

APPENDIX A BEST PRACTICES

A-1 INTERFACE OF PAVEMENT AND CRANE RAIL

Provide dimensions on design drawings to detail the forming of the pavement around the crane rail and its support system. Use a 2-foot-wide (0.6 m) trough for the crane rail with sloped sides as shown in Figure A-1. After the crane rail is installed and aligned, place fill concrete as shown in Figure A-1 to mitigate the tripping hazard associated with the rail. Include a drainage system for the crane rail troughs per UFC 4-152-01.

Figure A-1 Interface of Pavement and Crane Rail



APPENDIX B SAMPLE CURVE COMPOSITION EXAMPLE

Table B-1 Sample Curve Composition

Item	Computation (partial)	Reference
Crane Information	Given: 32-Wheel Crane a = 4.0826 ft. (1.2444 m) b = 8.1653 ft. (2.4888 m) c = 16.3305 ft. (4.9776 m) d = 32.6611 ft. (9.9551 m) Average float capability of crane 0.50 ft. (0.152 m) in either direction. Crane Gage = e = 30 ft. (9.14 m)	Figures 5-1, 5-2, and 5-5
One half equivalent length of crane	$E = \sqrt{\frac{(4.0826)^2}{4} + \frac{(8.1653)^2}{4} + \frac{(16.3305)^2}{4} + \frac{(32{,}6611)^2}{4}}$ E = 18.820 ft. (5.736 m)	Figure 5-2
Switch Curve	Given: D_s = 19.0986° R_s = 300 ft. (91.44 m) L_s = 20 ft. (6.10 m)	
Transition curve (inside or control):	Given: D_{max} = 70.000°	
Transition Curve, R_{min}	$R_{min} = \frac{5729.578}{70^0}$ = 81.851 ft. (24.948 m)	
G_{min}	$G_{min} = (81.851^2 + 2(30)\sqrt{(81.851^2 - 18.820^2)} + 30^2)^{0.5} - 81.851$ G_{min} = 29.410 ft. (8.964 m)	
Number of arcs ______	N = 10	
R_{2E}	R_{2E} inputs: a = (2 x 30) - 0.5 – (2 x 29.410) = 0.680 ft. (0.207 m) b = 30 x [(2 x 30) – 0.5 – (2 x 29.410)] = 20.39 ft^2. (1.89 m^2) c = 30 x (18.82)^2 = 10,625.79 ft^3. (300.90 m^3) $R_{2E} = \frac{-20.4 \pm \sqrt{20.4^2 - 4(0.68)(-10{,}625.79)}}{2(0.68)}$ = 110.946 ft.(33.816 m)	
D_{2E}	$D_{2E} = \frac{5729.578}{110.946}$ = 51.643° ft. (51.643 ° m)	

Item	Computation (partial)	Reference
Degree of arc No. 1	$D_1 = 19.0986 + \frac{70.000 - 19.0986}{10} = 24.1887°$	
Length of Flexible Transition Curve	$L_A = \frac{2 \ x \ 18.82 \ x \ (70 - 24.1887)}{70 - 51.64}$ = 93.93 ft. (28.63 m) Round L_A to nearest ft., gives L_A = 94.0 ft. (28.65 m)	
Control Point Sta. of P.C.C No. 1	(Sta. 0+20) + $\frac{94.0}{10}$ = Sta. 0+29.40 (0+008.96 m)	
Degree of arc No. 2	$D_2 = 24.1887 + \frac{70.000 - 19.0986}{10} = 29.2789°$	
Degree of arc No. 3	$D_3 = 29.2789 + \frac{70.000 - 19.0986}{10} = 34.3690°$	
Central angle arc No. 1	$\Delta_1 = \frac{9.4 \ x \ 24.1887}{100} = 2.2737° = 2°16'25"$	
Central angle arc No. 2	$\Delta_2 = \frac{9.4 \ x \ 29.2789}{100} = 2.7522° = 2°45'08"$	
Central angle to S.C.T.	θ_s = 3° 49' 11"	Figures 5-6 and 5-8
θ_n for arcs to P.C.C. 1	θ_1 = 3° 49' 11" + 2° 16' 25" = 6° 05' 36"	
θ_n for arcs to P.C.C. 2	θ_2 = 6° 05' 36" + 2° 45' 08" = 8° 50' 44"	
Coordinates for P.C.C. 7	X_7 = 74.671 + 104.689 (sin 29° 47' 02" – sin 24° 38' 21") = 83.028 ft. (25.307 m) Y_7 = 13.122 + 104.689 (cos 24° 38' 21" – cos 29° 47' 02") = 17.419 ft. (5.309 m)	
Tangent distance for θ = 120° 00' 00"	T = 104.986 – (81.851 sin 48° 05' 18") + [(81.851 cos 48° 05' 18" + 34.943) tan 60° 00' 00"] = 199.280 ft. (60.741 m)	Figure 5-8
Transition curve (outside): Lead t_s	t_s = 30.000 sin 3° 49' 11" = 1.999 ft. (0.609 m)	
Reduced gage	G_s = 30.000 cos 3° 49' 11" = 29.933 ft. (9.124 m) $G_{min} = \left(81.851^2 - 60\sqrt{81.851^2 - 18.820^2} + 30.000\right)^{1/2}$ - 81.851 = 29.410 ft. (8.964 m)	Figure 5-6 Figure 5-6

Item	Computation (partial)	Reference
θ_a, Central angle of Flexible Transition Curve	$\theta_a = \frac{94.000}{200100} = (24.1887 + 70) = 44.2687 = 44° 16' 07"$	Figure 5-6
Distance shifted back of S.C.T.	$h = \frac{29.9333 - 29.410}{sin\ 44° 16' 07"} = 0.749\ ft.$ (0.229 m)	Figure 5-6
Distance between end of transition and main curves	$t = \frac{29.933 - 29.410}{tan\ 44° 16' 07"} = 0.537\ ft.$ (0.164 m)	Figure 5-6

Notes: For complete design procedure, see Table 5-1.

For all values for P.C.C. No. 1 through 9, see Table B-2 and Figure B-1.

Table B-2 Tabulation of Sample Curve Composition

Inner Curve - U.S. Customary Units

	1	2	3	4	5	6	7	8	9	10	11	12	13
												Coordinates	
	Control Point	Control Point Station	D_n Degrees	R_n Feet	Δ_n Degrees (Decimals)	Δ_n Degrees, Min., Sec.	θ_n	Sine θ_n	Sine θ_n minus Sine θ_{n-1}	Cosine θ_n	Cosine θ_{n-1} minus Cosine θ_n	X Feet	Y Feet
Switch Curve	T.S.C	0+00.00										0.000	0.000
			19.0986	300.00									
			19.0986	300.00				0.0666170		0.9977786			
	S.C.T	0+20.00										19.985	0.666
Flexible Transition Curve	S.C.T	0+20.00					3° 49′ 11″	0.0666170		0.9977786		19.985	0.666
			24.1887	236.870	2.2737	2° 16′ 25″			0.0395326		0.0034284		
	P.C.C.	0+29.40					6° 5′ 36″	0.1061495		0.9943502		29.349	1.479
			29.2788	195.690	2.7522	2° 45′ 8″			0.0476229		0.0062439		
	P.C.C.	0+38.80					8° 50′ 44″	0.1537725		0.9881063		38.669	2.700
			34.3690	166.708	3.2307	3° 13′ 50″			0.0554415		0.0102364		
	P.C.C.	0+48.20					12° 4′ 35″	0.2092140		0.9778699		47.911	4.407
			39.4591	145.203	3.7092	3° 42′ 33″			0.0628219		0.0155828		
	P.C.C.	0+57.60					15° 47′ 8″	0.2720359		0.9622871		57.033	6.670
			44.5493	128.612	4.1876	4° 11′ 15″			0.0695427		0.0224339		
	P.C.C.	0+67.00					19° 58′ 23″	0.3415786		0.9398532		65.977	9.555
			49.6394	115.424	4.6661	4° 39′ 58″			0.0753239		0.0309020		
	P.C.C.	0+76.40					24° 38′ 21″	0.4169026		0.9089512		74.671	13.122
			54.7295	104.689	5.1446	5° 8′ 40″			0.0798255		0.0410449		
	P.C.C.	0+85.80					29° 47′ 2″	0.4967280		0.8679063		83.028	17.419
			59.8197	95.781	5.6230	5° 37′ 23″			0.0826501		0.0528473		
	P.C.C.	0+95.20					35° 24′ 25″	0.5793781		0.8150589		90.944	22.480
			64.9098	88.270	6.1015	6° 6′ 5″			0.0833509		0.0661996		
	P.C.C.	1+04.60					41° 30′ 30″	0.6627290		0.7488593		98.302	28.324
			70.0000	81.851	6.5800	6° 34′ 48″			0.0814465		0.0808752		
	T.C.	1+14.00					48° 5′ 18″	0.7441755		0.6679841		104.968	34.944

Outer Curve - U.S. Customary Units

	14	15	16	17	18	19	20	21
				Coordinates				
	R_n Feet	Δ_n Radians	A Feet	W Feet	Z Feet	Control Point Station	Control Point	G_n Feet
Switch Curve				0.000	0.000	0+00.00	T.S.C	
				19.985	0.666	0+20.00	S.C.t_1	
Flexible Transition Curve		t_1 =	1.25					
				21.231	0.750	0+21.25	t_1T	
	266.803	0.0396836	10.588					
				31.779	1.664	0+31.84	P.C.C.	29.9036
	225.623	0.0480351	10.838					
				42.524	3.073	0+42.67	P.C.C.	29.8677
	196.641	0.0563861	11.088					
				53.426	5.086	0+53.76	P.C.C.	29.8257
	175.136	0.0647370	11.338					
				64.428	7.815	0+65.10	P.C.C.	29.7780
	158.545	0.0730879	11.588					
				75.454	11.372	0+76.69	P.C.C.	29.7249
	145.357	0.0814389	11.838					
				86.403	15.864	0+88.53	P.C.C.	29.6670
	134.622	0.0897898	12.088					
				97.149	21.389	1+00.61	P.C.C.	29.6053
	125.714	0.0981407	12.338					
				107.539	28.033	1+12.95	P.C.C.	29.5408
	118.203	0.1064917	12.588					
				117.392	35.858	1+25.54	P.C.C.	29.4752
	111.784	0.1148426	12.838					
				126.496	44.899	1+38.38	T.t	29.4102
		t =	0.537					
				126.855	45.298	1+38.91	t.C.	

Inner Curve - Metric Units

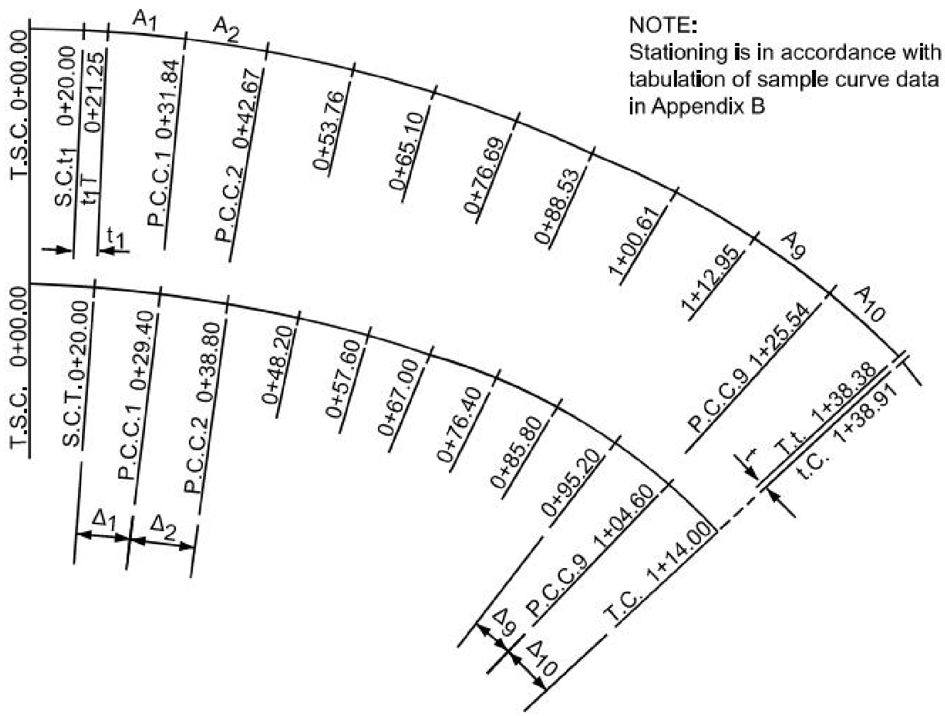
	1	2	3	4	5	6	7	8	9	10	11	12	13
												Coordinates	
	Control Point	Control Point Station	D_n Degrees	R_n (m)	Δ_n Degrees (Decimals)	Δ_n Degrees, Min., Sec.	θ_n	Sine θ_n	Sine θ_n minus Sine θ_{n-1}	Cosine θ_n	Cosine θ_{n-1} minus Cosine θ_n	X (m)	Y (m)
Switch Curve	T.S.C	0+000.00										0.000	0.000
			19.0986	91.44									
			19.0986	91.44				0.0666170		0.9977786			
	S.C.T	0+006.10										6.091	0.203
Flexible Transition Curve	S.C.T	0+006.10					3° 49′ 11″	0.0666170		0.9977786		6.091	0.203
			24.1887	72.198	2.2737	2° 16′ 25″			0.0395326		0.0034284		
	P.C.C.	0+008.96					6° 5′ 36″	0.1061495		0.9943502		8.946	0.451
			29.2788	59.646	2.7522	2° 45′ 8″			0.0476229		0.0062439		
	P.C.C.	0+011.83					8° 50′ 44″	0.1537725		0.9881063		11.786	0.823
			34.3690	50.813	3.2307	3° 13′ 50″			0.0554415		0.0102364		
	P.C.C.	0+014.69					12° 4′ 35″	0.2092140		0.9778699		14.603	1.343
			39.4591	44.258	3.7092	3° 42′ 33″			0.0628219		0.0155828		
	P.C.C.	0+017.56					15° 47′ 8″	0.2720359		0.9622871		17.384	2.033
			44.5493	39.201	4.1876	4° 11′ 15″			0.0695427		0.0224339		
	P.C.C.	0+020.42					19° 58′ 23″	0.3415786		0.9398532		20.110	2.912
			49.6394	35.181	4.6661	4° 39′ 58″			0.0753239		0.0309020		
	P.C.C.	0+023.29					24° 38′ 21″	0.4169026		0.9089512		22.760	3.999
			54.7295	31.909	5.1446	5° 8′ 40″			0.0798255		0.0410449		
	P.C.C.	0+026.15					29° 47′ 2″	0.4967280		0.8679063		25.307	5.309
			59.8197	29.194	5.6230	5° 37′ 23″			0.0826501		0.0528473		
	P.C.C.	0+029.02					35° 24′ 25″	0.5793781		0.8150589		27.720	6.852
			64.9098	26.905	6.1015	6° 6′ 5″			0.0833509		0.0661996		
	P.C.C.	0+031.88					41° 30′ 30″	0.6627290		0.7488593		29.962	8.633
			70.0000	24.948	6.5800	6° 34′ 48″			0.0814465		0.0808752		
	T.C.	0+034.75					48° 5′ 18″	0.7441755		0.6679841		31.994	10.651

Outer Curve - Metric Units

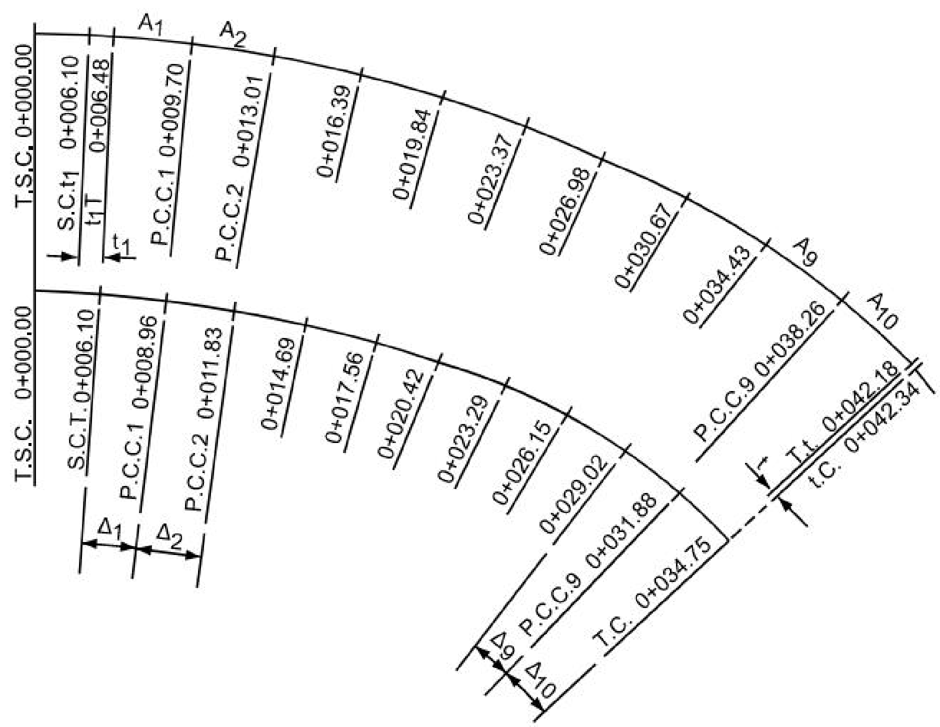
	14	15	16	17	18	19	20	21
				Coordinates				
	R_n (m)	Δ_n Radians	A (m)	W (m)	Z (m)	Control Point Station	Control Point	G_n (m)
Switch Curve				0.000	0.000	0+000.00	T.S.C	
				6.091	0.203	0+006.10	S.C.t_1	
Flexible Transition Curve		t_1 =	0.38					
				6.471	0.228	0+006.48	t_1T	
	81.322	0.0396836	3.227					
				9.686	0.507	0+009.70	P.C.C.	9.1146
	68.770	0.0480351	3.303					
				12.961	0.937	0+013.01	P.C.C.	9.1037
	59.937	0.0563861	3.380					
				16.284	1.550	0+016.39	P.C.C.	9.0909
	53.382	0.0647370	3.456					
				19.638	2.382	0+019.84	P.C.C.	9.0763
	48.325	0.0730879	3.532					
				22.998	3.466	0+023.37	P.C.C.	9.0602
	44.305	0.0814389	3.608					
				26.336	4.835	0+026.98	P.C.C.	9.0425
	41.033	0.0897898	3.684					
				29.611	6.519	0+030.67	P.C.C.	9.0237
	38.318	0.0981407	3.761					
				32.778	8.544	0+034.43	P.C.C.	9.0041
	36.029	0.1064917	3.837					
				35.781	10.930	0+038.26	P.C.C.	8.9841
	34.072	0.1148426	3.913					
				38.556	13.685	0+042.18	T.t	8.9643
		t =	0.164					
				38.665	13.807	0+042.34	t.C.	

Figure B-1 Stationing for Sample Curve Composition

U.S. Customary Units



Metric Units



APPENDIX C GLOSSARY

C-1 ACRONYMS.

AFCEC	Air Force Civil Engineer Center
AIST	Association for Iron and Steel Technology
AREMA	American Railway Engineering and Maintenance-of-Way Association
ASME	American Society of Mechanical Engineers
BIA	Bilateral Infrastructure Agreement
CCR	Criteria Change Request
CMAA	Crane Manufacturers Association of America, Inc.
CWR	Continuous Welded Rail
DoD	Department of Defense
EM	Engineering Manual
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Construction Agreements
INST	Instruction
NAVCRANECEN	Navy Crane Center
NAVFAC	Naval Facilities Engineering Systems Command
SOFA	Status of Forces Agreements
UFC	Unified Facilities Criteria
UFS	Unified Facilities Supplement
U.S.	United States

C-2 DEFINITION OF TERMS.

A_n	Length of arcs of Flexible Transition Curve.
A_s	Length of arc of Fixed Transition Curve (Switch Curve).
D	Degree of curve (central angle subtended by arc of 100 ft (30.48 m)).

D_c	Degree of curve of main circular curve.
D_{max}	Degree of curve at T.C.
D_{min}	Degree of curve at the end of the Switch Curve.
D_n	Degree of curve at any arc of the Transition Curve.
D_s	Degree of curve of switch curve = 19^0 5’ 55”.
E	One half equivalent length of crane.
e	Crane gage (also normally tangent track gage).
F	One-half maximum lateral float capability, where maximum float equals sum of float in either direction.
Float	Amount of change in gage a crane can accommodate.
G	Nominal track gage on tangent track, centerline to centerline of rail of a two-rail-system or centerline to centerline of track of a four rail-system.
g	Rate of grade of inside rail.
G_{min}	Reduced gage at P.C.T. or T.C.
G_n	Gage at any P.C.C. of Transition Curve.
G_R	Reduced gage for a given radius.
G_s	Reduced gage at S.C.T.
h	Distance of shift of beginning of outer transition curve along tangent t_s (the lead) closer to the switch to achieve the reduced gage, G_{min}, at the t.C.
L	Length of Transition Curve (total length of Switch Curve and Flexible Transition Curve).
L_a	Length of Flexible Transition Curve.
L_n	Length along Transition Curve from T.S.C. to any P.C.C.
L_s	Length of switch curve (20.00 ft (6.10 m)).
L_T	Length entry end of switch to pivot point of tongue.
M	One half the distance between the parallel tangent tracks.
N	Number of arcs of Transition Curve

n	Any point of Compound Curvature.
P.C.C.	Point of Compound Curvature (common point of any two successive circular arcs of transition).
P.C.T.	Point of Compound Transition (on inner alignment where no main circular curve is employed).
PI_a	Point of intersection of main control tangents.
PI_c	Point of intersection of main circular curve tangents.
R_c	Radius of main circular curve.
R_E	Radius of main circular curve outer rail for the equivalent crane length.
R_{max}	Radius of flattest arc of Flexible Transition Curve.
R_{min}	Radius of sharpest arc of Flexible Transition Curve.
R_s	Radius of switch curve (300' (91.4 m) constant).
S.C.T.	End of Switch Curve and beginning of Flexible Transition Curve (on inner alignment).
$S.C.t_1$	End of outer switch curve and beginning of tangent t_1.
$S_{(truck)}$	Crane truck suspension.
$S_{(wheel)}$	Crane wheel suspension.
T	Tangent distance from PI_a to T.S.C.
t	Short tangent length between sharp end of outer Transition Curve and beginning of outer main circular curve.
T.C.	End of Transition Curve (point of Transition Curve to main circular curve).
T_c	Tangent distance from PI_c to T.C.
t.C.	End of tangent t and beginning of main circular curve (on outer alignment).
T.S.C.	Point of Tangent to Switch (fixed) Curve.
t_s	Length of lead of inner Switch Curve over outer Switch Curve.
T.t	End of outer Flexible Transition Curve and beginning of tangent t.

t.t. Point of tangent to tangent (outer alignment where no main circular curve is employed).

t_1 Short tangent length between outer Switch Curve and outer Flexible Transition Curve.

t_1.T End of tangent t_1 and beginning of outer Flexible Transition Curve.

V Circular offset component of flangeway width

W X-coordinate to point n on outer curve.

w Total number of wheels of crane.

X X-coordinate to point n on inner curve.

X_c X-coordinate to T.C.

Y Y-coordinate to point n on inner curve.

Y_c Y-coordinate to T.C.

Z Y-coordinate to point n on outer curve.

β Central angle of arc for flangeway width computation

Δ Intersection angle of main control tangents.

Δ_c Central angle of main circular curve.

Δ_n Central angle of circular arcs of Flexible Transition Curve.

θ Central angle from T.S.C. to T.C.

θ_a Central angle of Flexible Transition Curve (S.C.T. to T.C.).

θ_n Central angle from T.S.C. to any P.C.C.

θ_s Central angle of switch curve (3° 49' 11").

φ Angle between radial line from center of main circular curve to crane leg on outer rail and the transverse line between crane legs on opposite rails.

ψ Angle between radial line from center of main circular curve to crane leg on inner rail and the transverse line between crane legs on opposite rails.

APPENDIX D REFERENCES

AMERICAN INSTITUTE FOR IRON AND STEEL TECHNOLOGY (AIST)

https://www.aist.org/

AIST Technical Report Number 6, *Specifications for Electric Overhead Cranes for Steel Mill Service*, Warrendale, PA

AMERICAN RAILWAY ENGINEERING AND MAINTENANCE OF WAY ASSOCIATION (AREMA)

https://www.arema.org/

AREMA Manual for Railway Engineering, Volumes 1 – 4, Lanham, MD

AREMA Portfolio of Trackwork Plans, Lanham, MD

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

ASME 30.2: *Overhead and Gantry Cranes*, New York, NY

ASTM INTERNATIONAL

ASTM A759, *Standard Specification for Carbon Steel Crane Rails*

ASTM C579, *Standard Test Methods for Compressive Strength of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes*

ASTM F3125/F3125M, *Standard Specification for High Strength Structural Bolts and Assemblies, Steel and Alloy Steel, Heat Treated, Inch Dimensions 120 ksi and 150 ksi Minimum Tensile Strength, and Metric Dimensions 830 MPa and 1040 MPa Minimum Tensile Strength*

CRANE MANUFACTURERS ASSOCIATION OF AMERICA (CMAA)

CMAA Specification 70, Specification for Top Running Bridge and Gantry Type Multiple Girder Electric Overhead Traveling Cranes

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (NAVFAC)

NAVFACINST 11230.1, *Inspection, Certification, and Audit of Crane and Railroad Trackage*

NAVY CRANE CENTER

NAVCRANECENINST 11450.2A, *Weight Handling Equipment Design*

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

UFC 1-200-01, *DoD Building Code*

UFC 3-220-20, *Foundations and Earth Structures*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

UFC 4-152-01, *Design: Piers and Wharves*

UFC 4-860-01, *Railroad Design and Rehabilitation*

U.S. ARMY CORPS OF ENGINEERS ENGINEERING MANUALS

EM 1110-2-2610, *Mechanical and Electrical Design for Lock and Dam Operating Equipment*

EM 1110-2-3006, *Mechanical and Electrical Design of Hydroelectric Power Plants*

EM 1110-2-3200, *Wire Rope for Civil Works Structures*