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9.1 General

The *Wisconsin Standard Specifications for Highway and Structure Construction* (hereafter referred to as *Standard Specifications*) contains references to *ASTM Specifications* or *AASHTO Material Specifications* which provide required properties and testing standards for materials used in highway structures. The service life of a structure is dependent upon the quality of the materials used in its construction as well as the method of construction. This chapter highlights applications of materials for highway structures and their properties.

In cases where proprietary products are experimentally specified, special provisions are written which provide material properties and installation procedures. Manufacturer's recommendations for materials, preparation and their assistance during installation may also be specified.

Materials that are proposed for incorporation into highway structure projects performed under the jurisdiction of the Wisconsin Department of Transportation (WisDOT) may be approved or accepted by a variety of procedures:

- Laboratory testing of materials that are submitted or samples randomly selected.
- Inspection and/or testing at the source of fabrication or manufacture.
- Inspection and/or testing in the field by WisDOT regional personnel.
- Manufacturer's certificate of compliance and/or manufacturer's certified report of test or analysis, either as sole documentation for acceptance or as supplemental documentation.
- Inspection, evaluation and testing in the normal course of project administration of material specifications.
- Some products are on approved lists or from fabricators, manufacturers, and certified sources approved by WisDOT. Lists of approved suppliers, products, and certified sources are located at:

https://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/tools/appr-prod/default.aspx

The *Wisconsin Construction and Materials Manual* (CMM) contains a description of procedures for material testing and acceptance requirements in Chapter 8, Section 45. Materials, unless otherwise permitted by the specifications, cannot be incorporated in the project until tested and approved by the proper authority.

9.2 Concrete

Concrete is used in many highway structures throughout Wisconsin. Some structure types are composed entirely of concrete, while others have concrete members. Different concrete compressive strengths (f'_c) are used in design and depend on the structure type or the location of the member. Compressive strengths are verified by cylinder tests done on concrete samples taken in the field. The *Standard Specifications* describe the requirements for concrete in Section 501.

Some of the concrete structure types/members and their design strengths for new projects are:

- Decks, Diaphragms, Overlays, Curbs, Parapets, Medians, Sidewalks and Concrete Slab Bridges (f'_c = 4 ksi)
- Other cast-in-place structures such as Culverts, Cantilever Retaining Walls and Substructure units (f'_c = 3.5 ksi)
- Other types of Retaining Walls (f'_c - values as specified in Chapter 14)
- Prestressed "I" Girders (f'_c = 6 to 8 ksi)
- Prestressed Box Girders (f'_c = 5 ksi)
- Prestressed Deck Panels (f'_c = 6 ksi)

Grade "E" concrete (Low Slump Concrete) is used in overlays for decks and slabs as stated in Section 509.2.

The modulus of elasticity of concrete, E_c, is a function of the unit weight of concrete and its compressive strength **LRFD [C5.4.2.4]**. For a unit weight of 0.150 kcf, the modulus of elasticity is:

f'_c = 3.5 ksi ; E_c = 3600 ksi

f'_c = 4 ksi ; E_c = 3800 ksi

For prestressed concrete members, the value for E_c is based on studies in the field and is calculated as shown in 19.3.3.8.

The modulus of rupture for concrete, f_r, is a function of concrete strength and concrete density, and is described in **LRFD [5.4.2.6]**. The coefficient of thermal expansion for normal weight concrete is 6×10^{-6} in/in/°F per **LRFD [5.4.2.2]**.

Air entraining admixture is added to concrete to provide durability for exposure to freeze and thaw conditions. Other concrete admixtures used are set retarding and water reducing admixtures. These are covered in Section 501 of the *Standard Specifications.*

9.3 Reinforcement Bars

Notice: Section 9.3 contents and the **LRFD [**article numbers**]** referenced in this Section are based on AASHTO LRFD Bridge Design Specifications (7th Edition – 2014).

Reinforced concrete structures and concrete members are designed using Grade 60 deformed bar steel with a minimum yield strength of 60 ksi. The modulus of elasticity, E_s , for steel reinforcing is 29,000 ksi. Reinforcement may be epoxy coated and this is determined by its location in the structure as described below. Adequate concrete cover and epoxy coating of reinforcement contribute to the durability of the reinforced concrete structure. The *Standard Specifications* describe the requirements for steel reinforcement and epoxy coating in Section 505.

Epoxy coated bars shall be used for both top and bottom reinforcement on all new decks, deck replacements, concrete slab superstructures, structural approach slabs and top slab of culverts (with no fill on top). They shall be used in other superstructure elements such as curbs, parapets, medians, sidewalks, diaphragms and pilasters. Some of the bars in prestressed girders are epoxy coated and are specified in the Chapter 19 - Standards. Also use coated bars for sign bridge footings.

Use epoxy coated bar steel on all piers detailed with expansion joints and on all piers at grade separations. Use epoxy coated bars down to the top of the footing elevation.

At all abutments, use epoxy coated bars in the parapets and in the wing walls. For A3 abutments, use epoxy coated bars in the paving block and in the abutment backwall. For A1(fixed) abutments, use epoxy coated dowel bars.

Welding of bar steel is not permitted unless approved by the Bureau of Structures or used in an approved butt splice as stated in Section 505.3.3.3 of the *Standard Specifications*. Test results indicate that the fatigue life of steel reinforcement is reduced by welding to them. Supporting a deck joint by welding attachments to the bar steel is not permitted. The bar steel mat does not provide adequate stiffness to support deck joints or similar details during the deck pour and maintain the proper joint elevations.

The minimum and maximum spacing of reinforcement, and spacing between bar layers is provided in **LRFD [5.10.3.1, 5.10.3.2]**. Use minimum and maximum values shown on Standards where provided.

Bridge plans show the quantity of bar steel required for the structure. Details are not provided for bar chairs or other devices necessary to support the reinforcement during the placement of the concrete. This information is covered by the *Standard Specifications* in Section 505.3.4 and these devices are part of the bid quantity.

Reinforcement for shrinkage and temperature stresses shall be provided near surfaces of concrete as stated in **LRFD [5.10.8]**.

When determining the anchorage requirements for bars, consider the bar size, the development length for straight bars and the development length for standard hooks. Note in Table 9.9-1 and Table 9.9-2 that smaller bars require considerably less development length than larger bars and the development length is also less if the bar spacing is 6 inches or more. By detailing smaller bars to get the required area and providing a spacing of 6 inches or more, less steel is used. Bar hooks can reduce the required bar development lengths, however the hooks may cost more to fabricate. In cases such as footings for columns or retaining walls, hooks may be the only practical solution because of the concrete depth available for developing the capacity of the bars.

Fabricators stock all bar sizes in 60 foot lengths. For ease of handling, the detailed length for #3 and #4 bars is limited to 45 feet. Longer bars may be used for these bar sizes at the discretion of the designer, when larger quantities are required for the structure. All other bar sizes are detailed to a length not to exceed 60 feet, except for vertical bars. Bars placed in a vertical position are detailed to match optional construction joint spacing plus lap. The location of optional horizontal construction joints in pier shafts or columns will generally determine the length of vertical bars in piers. All bars are detailed to the nearest inch.

The number of bars in a bundle shall not exceed four, except in flexural members the bars larger than #11 shall not exceed two in any one bundle. Individual bars in a bundle, cut off within the span of a member, shall be terminated at different points with at least a 40-bar diameter stagger. Where spacing limitations are based on bar size, bundled bars shall be treated as a single bar of a diameter derived from the equivalent total area **LRFD [5.10.3.1.5]**.

Stainless steel deformed reinforcement meeting the requirements of ASTM A955 has been used on a limited basis with the approval of the Bureau of Structures. It has been used in bridge decks, parapets and in the structural approach slabs at the ends of the bridge. Fabricators typically stock #6 bars and smaller in 60 foot lengths and #7 bars and larger in 40 foot lengths. Follow the guidance above for selecting bar lengths based on ease of handling.

9.3.1 Development Length and Lap Splices for Deformed Bars

Table 9.9-1 and Table 9.9-2 provide the development length, ℓ_d , for straight bars and the required lap length of spliced tension bars according to **LRFD [5.11.2.1, 5.11.5.3]**. The basic development length, ℓ_{db} , is a function of bar area, A_b , bar diameter, d_b , concrete strength, f'_c and yield strength of reinforcement, f_y. The basic development length is multiplied by applicable modification factors to produce the required development length, ℓ_d. The lap lengths for spliced tension bars are equal to a factor multiplied times the development length, ℓ_d . The factor applied depends on the classification of the splice; Class A, B or C. The class selected is a function of the numbers of bars spliced at a given location and the ratio of the area of reinforcement provided to the area required. The values for development length (required embedment) are equal to Class "A" splice lengths shown in these tables. Table 9.9-1 gives the development lengths and required lap lengths for a concrete compressive strength of f'_c = 3.5 ksi and a reinforcement yield strength of f_y = 60 ksi. Table 9.9-2 gives these same lengths for a concrete compressive strength of f'_c = 4 ksi and a reinforcement yield strength of f_y = 60 ksi. In tensile stress zones the maximum allowable change in bar size at a lap is three bar sizes. The spacing of lap splice reinforcement is provided in **LRFD [5.10.3.1.4]**, but values on Standards should be used where provided.

The development length of individual bars within a bundle, shall be that for the individual bar, increased by 20% for a three-bar bundle and by 33% for a four-bar bundle **LRFD [5.11.2.3]**. For determining the modification factors specified in **LRFD [5.11.2.1.2, 5.11.2.1.3]**, a unit of bundled bars shall be treated as a single bar of a diameter determined from the equivalent total area.

Lap splices within bundles shall be as specified in **LRFD [5.11.2.3]**. Individual bar splices within a bundle shall not overlap. Entire bundles shall not be lap spliced **LRFD [5.11.5.2.1]**.

Hook and embedment requirements for transverse (shear) reinforcement are stated in **LRFD [5.11.2.6.2]**. The lap length for pairs of U-stirrups or ties that are placed to form a closed unit shall be considered properly anchored and spliced where lengths of laps are not less than 1.7 ℓ_d **LRFD [5.11.2.6.4]**. In members not less than 18 inches deep, the length of the stirrup leg for anchoring closed stirrup splices is described in **LRFD [5.11.2.6.4]**.

The Bureau of Structures interprets the lap length to be used for temperature and distribution reinforcement to be a Class “A” splice (using “top” or “others”, as appropriate). See Table 9.9-1 and Table 9.9-2 for definition of “top” bars.

The required development length, ℓ_{dh}, for bars in tension terminating in a standard hook is detailed in **LRFD [5.11.2.4]**. This length increases with the bar size. The basic development length, ℓ_{hb}, for a hooked bar is a function of bar diameter, d_b, and concrete strength, f'_c. The basic development length is multiplied by applicable modification factors to produce the required development length, ℓ_{dh}. Figure 9.9-2 shows typical development lengths for standard hooks in tension.

Embedment depth is increased for dowel bars (with hooked ends) that run from column or retaining wall into the footing, if the hook does not rest on top of the bar steel mat in the bottom of the footing. This is a construction detail which is the preferred method for anchoring these bars before the concrete is placed.

Dowel bars are used as tensile reinforcement to tie columns or retaining walls to their footings. The amount of bar steel can be reduced by varying the dowel bar lengths projecting above the footing, so that only half the bars are spliced in the same plane. This is a consideration for long retaining walls and for some columns. This allows a Class “B” splice to be used, as opposed to a Class “C” splice where equal length dowel bars are used and all bars are spliced in the same plane.

The length of lap, ℓ_c , for splices in compression is provided in **LRFD [5.11.5.5.1]**.

9.3.2 Bends and Hooks for Deformed Bars

Figure 9.9-1 shows standard hook and bend details for development of longitudinal tension reinforcement. Figure 9.9-3 shows standard hook and bend details for transverse reinforcement (open stirrups and ties). Figure 9.9-4 shows details for transverse reinforcement (closed stirrups). Dimensions for the bending details are shown as out to out of bar, as stated in the *Standard Specifications* Section 505.3.2. The diameter of a bend, measured on the inside of the bar for a standard bend is specified in **LRFD [5.10.2.3]**. Where a larger bend radius is required (non-standard bend) show the inside bend radius on the bar detail. When computing total bar lengths account for the accumulation in length in the bends. Use the figures mentioned above to account for accumulation in length for standard hooks and bends. One leg of bent bars is not dimensioned so that the tolerance for an error in the length due to bending is placed there. Fabrication tolerances for bent bars are specified in the *Concrete Reinforcing Steel Institute (CRSI) Manual of Standard Practices* or the *American Concrete Institute (ACI) Detailing Manual* as stated in Section 505.2.1 of the *Standard Specifications*.

Figure 9.3-1 shows typical detailing procedures for bars with bends.

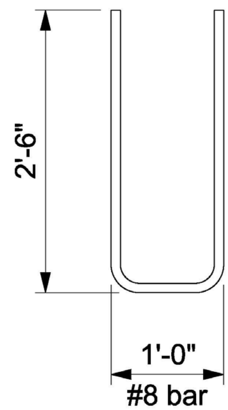


Figure 9.3-1
Bar Bend Detail (#8 bar)

Bar length = 1.0 ft + (2)(2.5 ft) – (2)(0.21 ft) = 5.58 ft or 5'-7" (to the nearest inch)

Where (0.21 ft) is (2.5"/12) and is the standard bar bend deduction found in Figure 9.9-1 for a #8 bar bent 90°.

9.3.3 Bill of Bars

Figure 9.9-5 shows a sample Bill of Bars table for a concrete slab. Different bar letter designations are used for abutments, slabs, and culverts, etc. If bundled bars are used, place a symbol adjacent to the bar mark of the bundled bars and a note below the Bill of Bars table stating the symbol represents bars to be bundled. A column for Bar Series is included if bars are cut.

9.3.4 Bar Series

A Bar Series table enables the detailer to detail bar steel in the simplest manner if it is used properly. Also, it helps the fabricator to prepare the Bill of Bars table.

The following general rules apply to the Bar Series table:

- Equal spacing of bars is required.
- There may be more than 1 Series with same number of bars.

- The total length of a bar is 60 feet (maximum).
- The minimum number of bars per Series is 4.
- Bent bars are bent after cutting.
- Set numbers are assigned to each Series used.

Figure 9.9-6 provides a sample layout for a Bar Series table. The Bill of Bars table will show the number of bars and the average bar length in the Series.

9.4 Steel

Structural steel is used in highway structures throughout Wisconsin. It is used for steel plate I-girders, rolled I-girders and box girders. Steel used for these three superstructure types are typically ASTM A709 Grades 36, 50 and 50W, but may also include high performance steel (HPS). Information on materials used for these superstructure types is provided in 24.2. Other types of steel superstructures are trusses, tied arches and cable-stayed bridges.

Steel is also used in other parts of the structure, such as:

- Bearings (Type A, B, A-T and top/interior plates for Laminated Elastomeric Bearings)
- Piling (H-Piles and CIP-Pile shells)
- Expansion Devices (single strip seal or modular joint)
- Drains (frame, grate and bracket)
- Railings (Type W, H, NY, M, PF, Tubular Screening, Fencing and Combination Railing)
- Steel diaphragms (attached to prestressed girders)

Structural carbon steel (ASTM A709 Grade 36) is used in components that are part of railings, and for steel diaphragms attached to prestressed girders. Structural carbon steel (ASTM A1011 Grade 36) is used in laminated elastomeric bearings. Structural carbon steel (ASTM A36) is used in components that are part of drains. The minimum yield strength is 36 ksi.

High strength structural steel (ASTM A709 Grade 50) is used in components that are part of railings and laminated elastomeric bearings, and (ASTM A572 Grade 50) is used in H-piles. High strength structural weathering steel (ASTM A709 Grade 50W) is used in bearings. The minimum yield strength is 50 ksi.

Structural steel tubing (ASTM A500 Grades B,C) is used in components that are part of railings, such as posts or rail members. The minimum yield strengths will have values around 46 to 50 ksi.

Steel pipe pile material (ASTM A252 Grade 2) is used as the shell to form cast-in-place (CIP) concrete piles. The minimum yield strength is 35 ksi.

Corrugated sheet steel (AASHTO M180, Class A, Type 2) is used as rail members for steel railing Type “W”. The minimum yield strength is 50 ksi.

Stainless steel (ASTM A240 Type 304) can be found as sheets on the surface of top plates for Type A and A-T bearings. It is also used for anchor plates cast into the ends of prestressed girders.

The grade of steel, ASTM Specification (or AASHTO Material Specification) associated with the bulleted items listed above (and their components) can be found in the *Bridge Manual*

Chapters or Standards corresponding to these items. This information may also be found in the *Standard Specifications* or “*Special Provisions*”.

The modulus of elasticity of steel, E_s , is 29,000 ksi and the coefficient of thermal expansion is 6.5 x 10^{-6} in/in/°F per **LRFD [6.4.1]**.

9.5 Miscellaneous Metals

The *Standard Specifications* provide the requirements for other materials made of metal that are used in highway structures. Some metals used or new products containing metal may be covered in the "*Special Provisions*".

Some of these metals, their applications and the Section of the *Standard Specifications* where they are covered are described below.

- Lubricated bronze plates are used on Type A expansion bearings. The requirements for these plates are found in Section 506.2.3.4.

- Bridge name plates are made from a casting of copper, lead, zinc and tin. The requirements for name plates are found in Section 506.2.4.

- Prestressed strands (low relaxation) are made from high tensile strength, 7-wire strands (0.5 or 0.6 inch diameter). The requirements for these strands are found in Section 503.2.3.

- Gray iron castings conforming to ASTM A48, Class 30 are used on Type GC floor drains and downspouts.

- Galvanized standard pipe conforming to ASTM A53 is used for downspouts on Type H floor drains.

- Sheet copper may be used as a waterstop for railroad bridges or as a flashing on movable bridge operator buildings. The requirements for these sheets are found in Section 506.2.3.9.

- Zinc plates may be used at deflection joints in sidewalks and parapets. The requirements for these plates are found in Section 506.2.3.10.

- Shear connectors are welded to the top flanges of steel girders to make the deck composite with the girder. Requirements for these connectors are in Section 506.2.7.

- Aluminum is used for sign bridges and some railings (Tubular Railing Type H). See Section 641.2.7 for sign bridges and Section 513.2.2 for railings that are made from aluminum. For sign bridges and sign supports made from steel, see Section 641.2.8 and 635.2 respectively.

- Steel grid floors are prefabricated grids set on girders and/or stringers. The top of the grid becomes the roadway surface. See Section 515 for the requirements for this steel.

- Welded deformed steel wire fabric has been used as an alternate to stirrup reinforcement for prestressed girders. It shall conform to the requirements of ASTM A1064 as shown on the Chapter 19 – Standards.

9.6 Timber

Timber has been used for timber structures on local roads in Wisconsin. Timber has also been used for piling, railings, falsework, formwork and as backing planks between or behind piling to retain soil.

The *Bridge Manual* and the *Standard Specifications* provide requirements for timber used in highway structures. These locations are highlighted below.

- Timber structures have material requirements that are covered in Chapter 23 of the *Bridge Manual*. Requirements for the condition of the timber members and applicable preservative treatments are covered in Section 507 of the *Standard Specifications*.

- Timber railings for timber structures have material requirements that are covered in Chapter 23 of the *Bridge Manual*. Requirements for the condition of the timber members are covered in Section 507 of the *Standard Specifications*.

- Timber backing plank requirements are covered in 12.10.

9.7 Miscellaneous Materials

Several types of materials are being used as part of a bridge deck protective system. Epoxy coated reinforcing steel, mentioned earlier, is part of this system. Some of these materials or products, are experimental and are placed on specific structures and then monitored and evaluated. A list of materials or products that are part of a bridge deck protective system and are currently used or under evaluation are:

- Galvanized or stainless steel reinforcing bars
- Waterproofing membrane with bituminous concrete overlay
- Microsilica modified concrete or polymer impregnated concrete
- Low slump concrete overlays
- Low-viscosity crack sealer
- Cathodic protection systems with surface overlays

Other materials or products used on highway structures are:

- Downspouts for Type GC and H drains may be fabricated from fiberglass conforming to ASTM D2996, Grade 1, Class A.
- Elastomeric bearing pads (non-laminated) are primarily used with prestressed “I” girders at fixed abutments and piers and at semi-expansion abutments. They are also used with prestressed “slab and box” sections at all supports. The requirements for these pads are described in Section 506.2.6 of the *Standard Specifications*.
- Elastomeric bearing pads (laminated) are primarily used with prestressed “I” girders at expansion supports. The requirements for these pads are described in Section 506.2.6 of the *Standard Specifications*.
- Preformed fillers are placed vertically in the joint between wing and diaphragm in A1 and A5 abutments, in the joint between wing and barrel in box culverts and at expansion joints in concrete cast-in-place retaining walls. Preformed fillers are placed along the front top surface of A1 and A5 abutments, along the outside top surfaces of fixed piers and under flanges between elastomeric bearing pad (non-laminated) and top edge of support. Cork filler is placed vertically on semi-expansion abutments. The requirements for fillers are described in Section 502.2.7 of the *Standard Specifications*.
- Polyethelene sheets are placed on the top surface of semi-expansion abutments to allow movement of the superstructure across the bearing surface. They are also placed between the structural approach slab and the subgrade, and the approach slab and its footing.

- Rubberized waterproofing membranes are used to seal horizontal and vertical joints at the backface of abutments, culverts and concrete cast-in-place retaining walls. See Section 516.2.3 of the *Standard Specifications*.

- Non-staining gray non-bituminous joint sealer is used to seal exposed surfaces of preformed fillers placed in joints as described above. It is also used to place a seal around exposed surfaces of plates used at deflection joints and around railing base plates. The requirement for this joint sealer is referenced in Section 502.2.9 of the *Standard Specifications*.

- Plastic plates may be used at deflection joints in sidewalks and parapets.

- Preformed Fabric, Class A, has been used as a bearing pad under steel bearings. The requirement for this material is given in Section 506.2.8.4 of the *Standard Specifications*.

- Neoprene strip seals are used in single cell and multi-cell (modular) expansion devices.

- Teflon sheets are bonded to steel plates in Type A-T expansion bearings. The requirements for these sheets are found in Section 506.2.8.3 of the *Standard Specifications*.

- Asphalt panels are used on railroad structures to protect the rubber membrane on top of the steel ballast plate from being damaged by the ballast. The requirements for these panels are in the "*Special Provisions*".

- Geotextile fabric is used for drainage filtration, and under riprap and box culverts. This fabric consists of sheets of woven or non-woven synthetic polymers or nylon. Type DF is used for drainage filtration in the pipe underdrain detail placed behind abutments and walls. The fabric allows moisture to drain to the pipe while keeping the backfill from migrating into the coarse material and then into the pipe. Type DF is also used behind abutments or walls that retain soil with backing planks between or behind piling and also for some of the walls detailed in Chapter 14 – Retaining Walls. This fabric will allow moisture to pass through the fabric and the joints in the walls without migration of the soil behind the wall. Type R or HR is placed below riprap and will keep the soil beneath it from being washed away. Type C is placed under breaker run when it is used under box culverts. The requirements for these fabrics are found in Section 645.2 of the *Standard Specifications*.

9.8 Painting

All highway grade separation structures require steel girders to be painted because unpainted steel is subject to additional corrosion from vehicle salt spray. Additional discussion on painting is presented in Chapter 24 – Steel Girder Structures and Chapter 40 – Bridge Rehabilitation. The current paint system used for I-girders is the three-coat epoxy system specified in Section 517 of the *Standard Specifications*. Tub girders utilize a two-coat polysiloxane system, which includes painting of the inside of the tubs.

Recommended paint colors and *AMS Standard Color Numbers* for steel girders in Wisconsin shall be in accordance with AMS Standard 595A and are:

White (For Inside of Box Girders)	#27925
Blue (Medium Sky Blue Tone)	#25240
[1] Brown (Similar to Weathering Steel)	#20059
Gray (Light Gray)	#26293
Green (Medium Tone)	#24260
Reddish-Brown (Red Brick Tone)	#20152
Gray (Dark Gray-DNR Request)	#26132
Black	#27038

Table 9.8-1
Standard Colors for Steel Girders

[1] Shop applied color for weathering steel.

AMS Standard 595A can be found at www.ams-std-595-color.com/

All steel bearing components which are not welded to the girder or do not have a Teflon or bronze surface, and anchor bolts shall be galvanized. In addition to galvanizing, some bearing components may also be field or shop painted as noted in the Standards for Chapter 27 – Bearings.

All new structural steel is blast cleaned including weathering steel. It has been shown that paint systems perform well over a longer period of time with proper surface preparation. The blast cleaned surface is a very finely pitted surface with pit depths of 1 ½ mils.

Corrosion of structural steel occurs if the agents necessary to form a corrosion cell are present. A corrosion cell is similar to a battery in that current flows from the anode to the cathode. As the current flows, corrosion occurs at the anode and materials expand. Water carries the electrical current between the anode and cathode. If there is salt in the water, the current travels much faster and the rate of corrosion is accelerated. Oxygen combines with the materials to help form the anodic corrosion cell.

The primary reason for painting steel structures is for the protection of the steel surface. Appearance is a secondary function that is maintained by using compatible top coatings over epoxy systems. Regarding appearance with respect to color retention, black is good, blues and greens are decent, and reddish browns are acceptable, but not the best. Reds are highly discouraged and should not be used.

Paint applied to the steel acts as a moisture barrier. It prevents the water from contacting the steel and then a corrosion cell cannot be formed. When applying a moisture barrier, it is important to get an adhering, uniform thickness as well as an adequate thickness. The film thickness of paint wears with age until it is finally depleted. At this point the steel begins to corrode as moisture is now present in the corrosion cell. If paint is applied too thick, it may crack and/or check due to temperature changes and allow moisture to contact the steel long before the film thickness wears down.

The paint inspector uses a paint gauge to randomly measure the film thickness of the paint according to specifications. Wet film thickness is measured and it is always thicker than the dry film thickness. A vehicle is added to the paint solids so that the solids can be applied to a surface and then it evaporates leaving only the solids on the surface. The percent of solids in a gallon of paint gives an estimate of the wet to dry film thickness ratio.

Recommended paint maintenance is determined with assistance from the Wisconsin Structures Asset Management System (WiSAMS), which utilizes information provided by the routine bridge inspections.

Recommended paint colors and *AMS Standard Color Numbers* for concrete in Wisconsin shall be in accordance with AMS Standard 595A and are:

Pearl Gray	#26622
Medium Tan	#33446
Gray Green	#30372
Dark Brown	#30140
Dawn Mist (Grayish Brown)	#36424
Lt. Coffee (Creamy Brown)	#33722

Table 9.8-2
Standard Colors for Concrete

Most paints require concrete to be a minimum of 30 days old before application. This should be considered when specifying completion times for contracts.

9.9 Bar Tables and Figures

(f'_c = 3500 psi; f_y = 60 ksi)											
BAR SPACING	BAR SIZE		4	5	6	7	8	9	10	11	TYPE
6” OR MORE	CLASS A	TOP [1]	1-2 1-5	1-5 1-9	1-9 2-1	2-3 2-9	3-0 3-8	3-9 4-7	4-10 5-10	5-11 7-2	UNCOATED EPOXY
	1.0 ℓ_d	OTHERS	1-0 1-0	1-0 1-6	1-3 1-10	1-8 2-5	2-2 3-3	2-9 4-1	3-5 5-2	4-3 6-4	UNCOATED EPOXY
	CLASS B	TOP [1]	1-6 1-9	1-10 2-3	2-3 2-8	3-0 3-7	3-11 4-8	4-11 5-11	6-3 7-7	7-8 9-3	UNCOATED EPOXY
	1.3 ℓ_d	OTHERS	1-1 1-3	1-4 2-0	1-7 2-5	2-2 3-2	2-9 4-2	3-6 5-3	4-5 6-8	5-6 8-2	UNCOATED EPOXY
	CLASS C	TOP [1]	1-11 2-4	2-5 2-11	2-11 3-6	3-10 4-8	5-1 6-2	6-5 7-9	8-1 9-10	10-0 12-1	UNCOATED EPOXY
	1.7 ℓ_d	OTHERS	1-5 1-8	1-9 2-7	2-1 3-1	2-9 4-2	3-8 5-5	4-7 6-10	5-10 8-8	7-2 10-8	UNCOATED EPOXY
LESS THAN 6”	CLASS A	TOP [1]	1-5 1-9	1-9 2-2	2-2 2-7	2-10 3-5	3-9 4-6	4-9 5-9	6-0 7-3	7-4 8-11	UNCOATED EPOXY
	1.0 ℓ_d	OTHERS	1-0 1-3	1-3 1-11	1-6 2-3	2-1 3-1	2-8 4-0	3-5 5-1	4-3 6-5	5-3 7-10	UNCOATED EPOXY
	CLASS B	TOP [1]	1-10 2-3	2-4 2-10	2-9 3-4	3-8 4-6	4-10 5-10	6-1 7-5	7-9 9-5	9-6 11-7	UNCOATED EPOXY
	1.3 ℓ_d	OTHERS	1-4 1-7	1-8 2-6	2-0 3-0	2-8 3-11	3-6 5-2	4-5 6-7	5-7 8-4	6-10 10-2	UNCOATED EPOXY
	CLASS C	TOP [1]	2-5 2-11	3-0 3-8	3-7 4-5	4-10 5-10	6-4 7-8	8-0 9-8	10-2 12-4	12-5 15-1	UNCOATED EPOXY
	1.7 ℓ_d	OTHERS	1-9 2-1	2-2 3-3	2-7 3-10	3-5 5-2	4-6 6-9	5-9 8-7	7-3 10-10	8-11 13-4	UNCOATED EPOXY

Table 9.9-1
Tension Lap Splice Length or Development Length - Deformed Bars
LRFD [5.11.2.1, 5.11.5.3.1] – 7th Edition (2014)

[1] Top Bar – is a horizontal or nearly horizontal bar with 12 inches of fresh concrete cast below it.

CLASS A - [A_s provided/A_s required] ≥ 2; Bars spliced are 75% or less.

CLASS B - [A_s provided/A_s required] < 2; Bars spliced are 50% or less (or) [A_s provided/A_s required] ≥ 2; Bars spliced are greater than 75%.

CLASS C - [A_s provided/A_s required] < 2; Bars spliced are greater than 50%.

(f'c = 4000 psi; fy = 60 ksi)											
BAR SPACING	BAR SIZE		4	5	6	7	8	9	10	11	TYPE
6" OR MORE	CLASS A 1.0 ℓ_d	TOP [1]	1-2	1-5	1-9	2-2	2-10	3-6	4-6	5-6	UNCOATED
			1-5	1-9	2-1	2-7	3-5	4-3	5-5	6-8	EPOXY
		OTHERS	1-0	1-0	1-3	1-6	2-0	2-6	3-3	3-11	UNCOATED
			1-0	1-6	1-10	2-3	3-0	3-9	4-10	5-11	EPOXY
	CLASS B 1.3 ℓ_d	TOP [1]	1-6	1-10	2-3	2-9	3-8	4-7	5-10	7-2	UNCOATED
			1-9	2-3	2-8	3-4	4-5	5-7	7-1	8-8	EPOXY
		OTHERS	1-1	1-4	1-7	2-0	2-7	3-3	4-2	5-1	UNCOATED
			1-3	2-0	2-5	3-0	3-11	4-11	6-3	7-8	EPOXY
	CLASS C 1.7 ℓ_d	TOP [1]	1-11	2-5	2-11	3-7	4-9	6-0	7-7	9-4	UNCOATED
			2-4	2-11	3-6	4-5	5-9	7-3	9-3	11-4	EPOXY
		OTHERS	1-5	1-9	2-1	2-7	3-5	4-3	5-5	6-8	UNCOATED
			1-8	2-7	3-1	3-10	5-1	6-5	8-2	10-0	EPOXY
LESS THAN 6"	CLASS A 1.0 ℓ_d	TOP [1]	1-5	1-9	2-2	2-8	3-6	4-5	5-7	6-10	UNCOATED
			1-9	2-2	2-7	3-3	4-3	5-4	6-9	8-4	EPOXY
		OTHERS	1-0	1-3	1-6	1-11	2-6	3-2	4-0	4-11	UNCOATED
			1-3	1-11	2-3	2-10	3-9	4-9	6-0	7-4	EPOXY
	CLASS B 1.3 ℓ_d	TOP [1]	1-10	2-4	2-9	3-5	4-6	5-9	7-3	8-11	UNCOATED
			2-3	2-10	3-4	4-2	5-6	6-11	8-10	10-10	EPOXY
		OTHERS	1-4	1-8	2-0	2-6	3-3	4-1	5-2	6-5	UNCOATED
			1-7	2-6	3-0	3-8	4-10	6-2	7-9	9-7	EPOXY
	CLASS C 1.7 ℓ_d	TOP [1]	2-5	3-0	3-7	4-6	5-11	7-6	9-6	11-8	UNCOATED
			2-11	3-8	4-5	5-6	7-2	9-1	11-6	14-2	EPOXY
		OTHERS	1-9	2-2	2-7	3-3	4-3	5-4	6-9	8-4	UNCOATED
			2-1	3-3	3-10	4-10	6-4	8-0	10-2	12-6	EPOXY

Table 9.9-2

Tension Lap Splice Length or Development Length – Deformed Bars

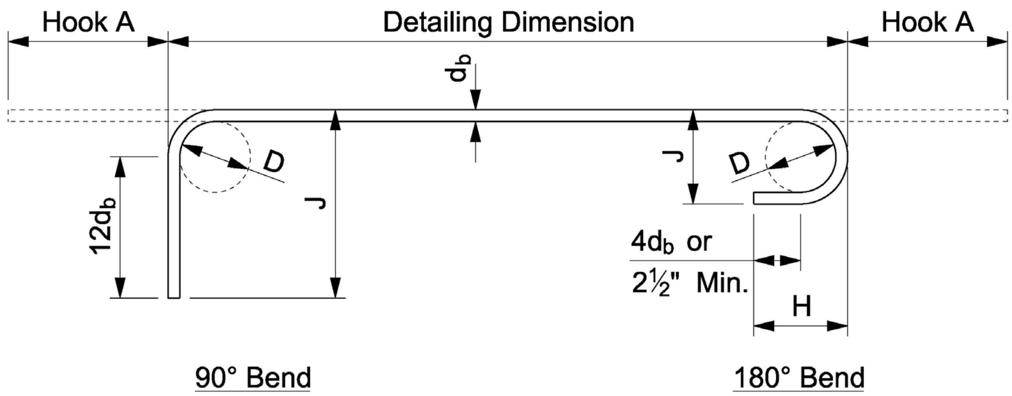
LRFD [5.11.2.1, 5.11.5.3.1] – 7th Edition (2014)

[1] Top Bar – is a horizontal or nearly horizontal bar with 12 inches of fresh concrete cast below it.

CLASS A – [A_s provided/A_s required] ≥ 2; Bars spliced are 75% or less.

CLASS B – [A_s provided/A_s required] < 2; Bars spliced are 50% or less (or) [A_s provided/A_s required] ≥ 2; Bars spliced are greater than 75%.

CLASS C - [A_s provided/A_s required] < 2; Bars spliced are greater than 50%.



d_b = nominal diameter of reinforcing bar (in)

Definition of standard hooks **LRFD [5.10.2.1, C5.11.2.4.1] – 7th Edition (2014)**

MINIMUM BEND DIAMETER (D) – **LRFD [5.10.2.3] – 7th Edition (2014)**

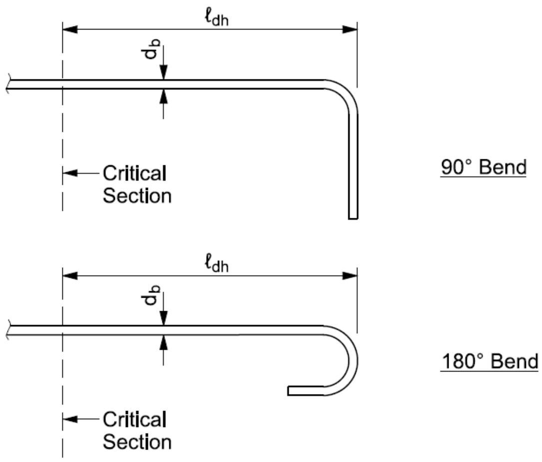
D = $6d_b$ FOR #3 THRU #8

D = $8d_b$ FOR #9, #10, and #11

BAR SIZE	MINIMUM HOOK, ALL GRADES					
	90° HOOKS			180° HOOKS		
	HOOK A	J	J MINUS HOOK A [1]	HOOK A	J	APPROX. H
4	7	8	1	6	4	4 ½
5	8 ½	10	1 ½	7	5	5
6	10	1-0	2	8	6	6
7	1-0	1-2	2	10	7	7
8	1-1 ½	1-4	2 ½	11	8	8
9	1-4	1-7	3	1-3	11 ¼	10 ¼
10	1-6	1-9 ½	3 ½	1-5	1-0 ¾	11 ½
11	1-8	2-0	4	1-7	1-2 ¼	1-0 ¾

Figure 9.9-1
Standard Hooks and Bends for Deformed Longitudinal Reinforcement

[1] "J" MINUS "HOOK A" = DEDUCTION FOR ONE BEND



f'c=3.5 ksi; fy=60 ksi		
Bar Size	ℓ_{dh}	
	Uncoated $\ell_{hb}(0.7)$	Epoxy $\ell_{hb}(0.7)(1.2)$
3	0' - 6"	0' - 7"
4	0' - 8"	0' - 9"
5	0' - 9"	0' - 11"
6	0' - 11"	1' - 1"
7	1' - 1"	1' - 3"
8	1' - 3"	1' - 6"
9	1' - 5"	1' - 8"
10	1' - 7"	1' - 10"
11	1' - 9"	2' - 1"

Figure 9.9-2
Development Length for Standard Hooks in Tension
(See Figure 9.9-1 for bend details)

The development length for standard hooks in tension, ℓ_{dh}, shall not be less than the product of the basic tension development length, ℓ_{hb}, and the appropriate modification factor(s), λ_i, $8d_b$, or 6-inches. The following equation is for the required development length for standard hooks in tension (in):

$\ell_{dh} = \max(\ell_{hb}\,\lambda_i,\ 8d_b,\ 6.0)$ **LRFD [5.11.2.4.1] – 7th Edition (2014)**

Where:

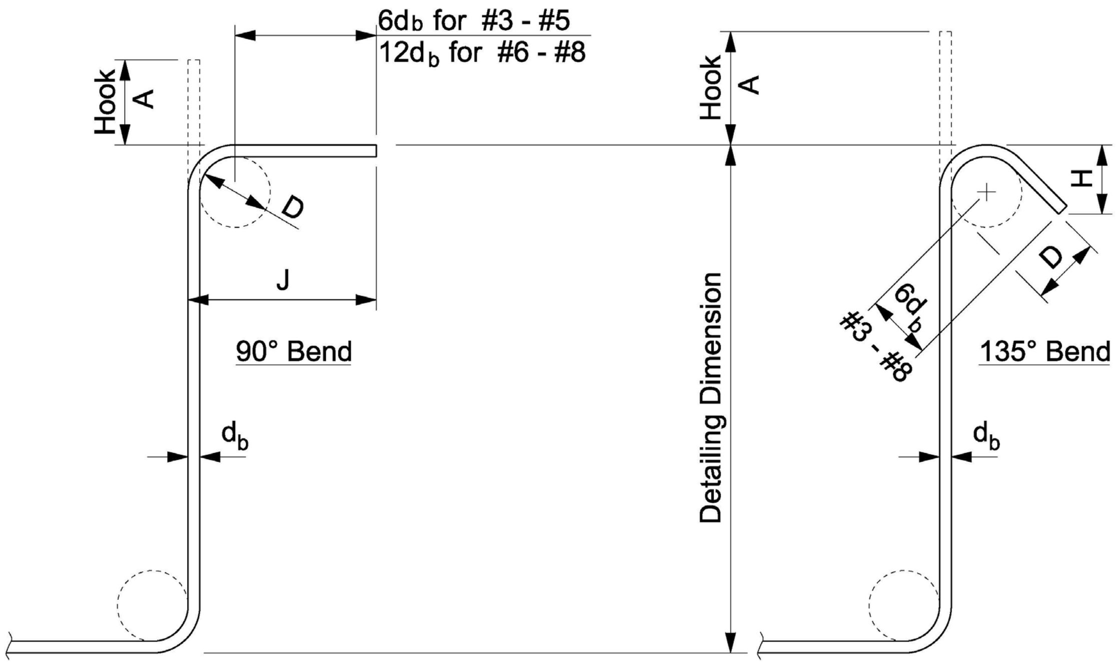
$\ell_{hb} = 38d_b / (f'_c)^{1/2}$ = basic hook development length (in.) **LRFD [Eq'n 5.11.2.4.1-1]**

λ_i = modification factor(s) **LRFD [5.11.2.4.2] – 7th Edition (2014)**

- (0.70) Side cover for #11 bar and smaller, normal to plane of hook, is not less than 2.5 inches, and 90 hook, cover on bar extension beyond hook not less than 2.0 inches
- (0.80) Hooks for #11 bar and smaller enclosed vertically or horizontally within ties or stirrups ties which are placed along the full development length, ℓ_{dh}, at a spacing not exceeding $3d_b$
- (1.20) Epoxy coated reinforcement

d_b = diameter of bar (in.)

f'_c = specified compressive strength of concrete (ksi)



d_b = nominal diameter of reinforcing bar (in)

Definition of Standard Hooks **LRFD [5.10.2.1] – 7th Edition (2014)**

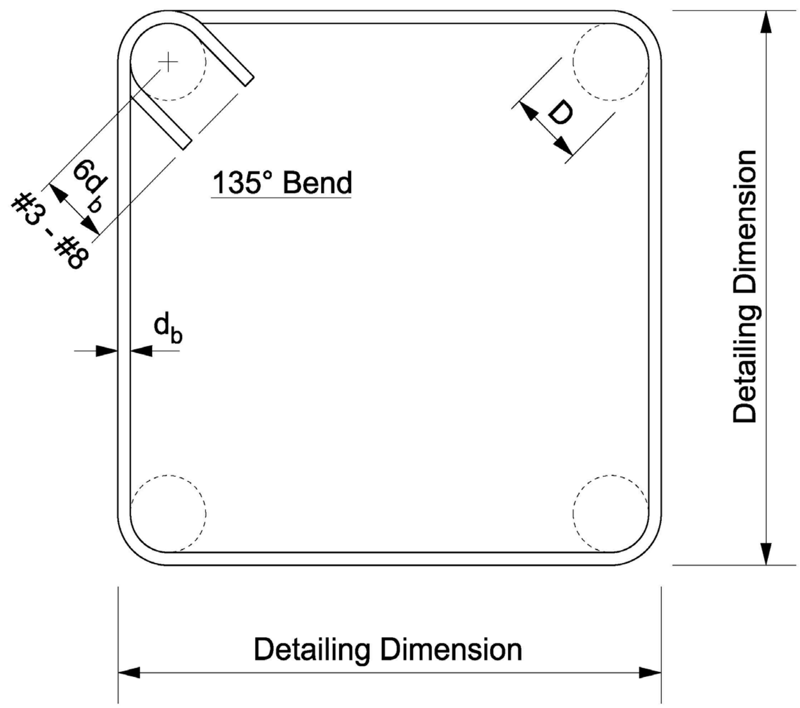
MINIMUM BEND DIAMETER (D) – **LRFD [5.10.2.3] – 7th Edition (2014)**

D = $4d_b$ FOR #3 THRU #5

D = $6d_b$ FOR #6 THRU #8

MINIMUM HOOK, ALL GRADES					
		90° HOOKS		135° HOOKS	
BAR SIZE	D	HOOK A	APPROX J	HOOK A	H
3	1 ½	3	4	4	2 ½
4	2	3 ½	4 ½	4 ½	3
5	2 ½	4 ½	6	5 ½	3 ¾
6	4 ½	10	1-0	8	4 ½

Figure 9.9-3
Standard Hooks and Bends for Deformed Transverse Reinforcement
(Stirrups and Ties)



Stirrup Bar Length equals sum of all Detailing Dimensions plus "Stirrup Add-On" from table

d_b = nominal diameter of reinforcing bar (in)

Definition of Standard Hooks **LRFD [5.10.2.1] – 7th Edition (2014)**

MINIMUM BEND DIAMETER (D) – **LRFD [5.10.2.3] – 7th Edition (2014)**

D = 4d_b FOR #3 THRU #5

D = 6d_b FOR #6 THRU #8

BAR SIZE	D	STIRRUP ADD-ON
3	1 ½	5
4	2	6
5	2 ½	8
6	4 ½	10
7	5 ¼	12
8	6	13

Figure 9.9-4
Standard Details and Bends for Deformed Transverse Reinforcement
(Closed Stirrups)

BILL OF BARS

NOTE: THE FIRST OR FIRST TWO DIGITS OF THE BAR MARK SIGNIFIES THE BAR SIZE.

BAR MARK	COAT	NO. REQ'D	LENGTH	BENT	BAR SERIES	LOCATION
S501		10	4-2		Δ	SLAB - TRANS.
S502		20	6-3		Δ	SLAB - TRANS.
S503	X	19	42-8			SLAB - LONG.

Δ LENGTH SHOWN FOR BAR IS AN AVERAGE LENGTH AND SHOULD ONLY BE USED FOR BAR WEIGHT CALCULATIONS. SEE BAR SERIES TABLE FOR ACTUAL LENGTHS.

Figure 9.9-5
Bill of Bars

BAR SERIES TABLE

MARK	NO. REQ'D.	LENGTH
S501	1 SERIES OF 10	2-1 TO 6-3
S502	2 SERIES OF 10	3-2 TO 9-5

BUNDLE AND TAG EACH SERIES SEPARATELY

Figure 9.9-6
Bar Series Table

BAR SIZE	BAR WEIGHT (lbs/ft)	NOM. DIA (in)	NOM. AREA (in^2)	NUMBER OF BARS								
				2	3	4	5	6	7	8	9	10
4	0.668	0.500	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00
5	1.043	0.625	0.31	0.62	0.93	1.24	1.55	1.86	2.17	2.48	2.79	3.10
6	1.502	0.750	0.44	0.88	1.32	1.76	2.20	2.64	3.08	3.52	3.96	4.40
7	2.044	0.875	0.60	1.20	1.80	2.40	3.00	3.60	4.20	4.80	5.40	6.00
8	2.670	1.000	0.79	1.58	2.37	3.16	3.95	4.74	5.53	6.32	7.11	7.90
9	3.400	1.128	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
10	4.303	1.270	1.27	2.54	3.81	5.08	6.35	7.62	8.89	10.16	11.43	12.70
11	5.313	1.410	1.56	3.12	4.68	6.24	7.80	9.36	10.92	12.48	14.04	15.60

Table 9.9-3
Bar Areas Per Number of Bars (in^2)

BAR SIZE	4 ½"	5"	5 ½"	6"	6 ½"	7"	7 ½"	8"	8 ½"	9"	10"	11"	12"
4	0.52	0.47	0.43	0.39	0.36	0.34	0.31	0.29	0.28	0.26	0.24	0.21	0.20
5	0.82	0.74	0.67	0.61	0.57	0.53	0.49	0.46	0.43	0.41	0.37	0.33	0.31
6	1.18	1.06	0.96	0.88	0.82	0.76	0.71	0.66	0.62	0.59	0.53	0.48	0.44
7	1.60	1.44	1.31	1.20	1.11	1.03	0.96	0.90	0.85	0.80	0.72	0.66	0.60
8	2.09	1.88	1.71	1.57	1.45	1.35	1.26	1.18	1.11	1.05	0.94	0.86	0.79
9	---	2.40	2.18	2.00	1.85	1.71	1.60	1.50	1.41	1.33	1.20	1.09	1.00
10	---	3.04	2.76	2.53	2.34	2.17	2.02	1.90	1.79	1.69	1.52	1.38	1.27
11	---	3.75	3.41	3.12	2.88	2.68	2.50	2.34	2.21	2.08	1.87	1.70	1.56

Table 9.9-4
Area of Bar Reinf. (in^2 / ft) vs. Spacing of Bars (in)

9.10 Granular Materials

Several types of granular materials are used for backfilling excavations, providing foundation improvements, and reinforcing soils. Table 9.10-5 provides recommended uses and notes for commonly used granular materials for structures. Refer to the specifications for material gradations, testing, compaction, and other requirements specific for the application. Refer to 6.4.2 for plan preparations.

Granular pay limits should be shown on all structure plans. See Standards for typical backfill limits and plan notes.

<table>
<tr><th>Granular Material Type</th><th>Uses</th><th>Notes</th></tr>
<tr><td>Backfill Structure – Type A</td><td><u>Backfill</u>
• Abutments
• Retaining walls</td><td rowspan="2">Type A facilitates better drainage than Type B.

Type A may be substituted for Type B material per specifications.</td></tr>
<tr><td>Backfill Structure – Type B</td><td><u>Backfill</u>
• Box culverts
• Structural plate pipes
• Pipe arches
<u>Retained Backfill (if needed)</u>
▪ Various structures
<u>Foundation</u>
• Abutments
• Retaining walls</td></tr>
<tr><td>Backfill Granular – Grade 1</td><td rowspan="2">Refer to Facilities Development Manual (FDM) for usages</td><td rowspan="2">Grade 1 may be substituted for Grade 2 material per specifications.</td></tr>
<tr><td>Backfill Granular – Grade 2</td></tr>
<tr><td>Base Aggregate Dense 1 1/4-inch</td><td>• Structural approach (base)
• GRS Walls (reinforced soil foundation and approach)</td><td></td></tr>
<tr><td>Reinforced Soils</td><td>• MSE Walls</td><td>Backfill included in MSE Wall bid items.</td></tr>
<tr><td>Base Aggregate Open Graded</td><td>• GRS Walls (reinforced soil)
• MSE Walls (for elevations below HW100)</td><td></td></tr>
<tr><td>Breaker Run</td><td>• Box culverts (foundation)</td><td>See Standard Detail 9.01 for alternatives and notes</td></tr>
<tr><td>Flowable Backfill</td><td>• Soldier pile walls</td><td></td></tr>
</table>

Table 9.10-5
Recommendations for Granular Material Usage

9.11 References

1. Ghorbanpoor, A., Kriha, B., Reshadi, R. *Aesthetic Coating for Steel Bridge Components – Amended Study*. S.1.: Wisconsin Department of Transportation, Final Report No. 0092-11-07, 2015.

9.12 Appendix - Draft Bar Tables

The following Draft Bar Tables are provided for information only. We expect the tables to be moved into the main text of Chapter 9 in January of 2020, and at that time to begin their use. We are delaying their use to allow time for modification of details and software that are affected.

The 2015 Interim Revisions to the AASHTO LRFD Bridge Design Specifications (7th Edition), modified the tension development lengths and tension lap lengths for straight deformed bars as follows - (**LRFD [**article number**]** references below match the AASHTO LRFD Bridge Design Specifications – 8th Edition):

The tension development length, ℓ_d ,shall not be less than the product of the basic tension development length, ℓ_{db} , and the appropriate modification factors, λ_i . **LRFD [5.10.8.2.1a]**

$$\ell_d = \ell_{db} \cdot (\lambda_{rl} \cdot \lambda_{cf} \cdot \lambda_{rc} \cdot \lambda_{er}) / \lambda$$

in which: $\ell_{db} = 2.4 \cdot d_b \cdot [f_y / (f'_c)^{1/2}]$

where:

ℓ_{db} = basic development length (in.)

λ_{rl} = reinforcement location factor

λ_{cf} = coating factor

λ = conc. density modification factor ; for normal weight conc. = 1.0 , **LRFD [5.4.2.8]**

λ_{rc} = reinforcement confinement factor

λ_{er} = excess reinforcement factor

f_y = specified minimum yield strength of reinforcement (ksi)

d_b = nominal diameter of reinforcing bar (in.)

f'_c = compressive strength of concrete for use in design (ksi)

Top bars will continue to refer to horizontal bars placed with more than 12” of fresh concrete cast below it. Bars not meeting this criteria will be referred to as Others.

Per **LRFD [5.10.8.4.3a]**, there are two lap splice classes, Class A and Class B.

- Class A lap splice ……………………1.0 ℓ_d
- Class B lap splice …………………... 1.3 ℓ_d

The criteria for where to apply each Class is covered in the above reference.

Draft Table

Epoxy Coated (f'_c = 4,000 psi; f_y = 60,000 psi)

Basic Lap - Others					
Bar Size	Min. Cover	Class A (1.0 ℓ_d) s < 6" cts.	Class A (1.0 ℓ_d) s ≥ 6" cts.	Class B (1.3 ℓ_d) s < 6" cts.	Class B (1.3 ℓ_d) s ≥ 6" cts.
4	1.5"	1'-6"	1'-6"	1'-11"	1'-11"
	2.0"	1'-6"	1'-6"	1'-11"	1'-11"
	≥ 2.5"	1'-6"	1'-6"	1'-11"	1'-11"
5	1.5"	2'-3"	2'-3"	3'-0"	3'-0"
	2.0"	2'-3"	1'-10"	3'-0"	2'-4"
	≥ 2.5"	2'-3"	1'-10"	3'-0"	2'-4"
6	1.5"	2'-11"	2'-9"	3'-10"	3'-7"
	2.0"	2'-11"	2'-9"	3'-10"	3'-7"
	≥ 2.5"	2'-11"	2'-2"	3'-10"	2'-10"
7	1.5"	3'-7"	3'-7"	4'-8"	4'-8"
	2.0"	3'-6"	3'-2"	4'-6"	4'-2"
	≥ 2.5"	3'-6"	3'-2"	4'-6"	4'-2"
8	1.5"	4'-6"	4'-6"	5'-11"	5'-11"
	2.0"	4'-6"	3'-8"	5'-11"	4'-9"
	≥ 2.5"	4'-6"	3'-8"	5'-11"	4'-9"
9	1.5"	5'-9"	5'-7"	7'-5"	7'-4"
	2.0"	5'-9"	4'-6"	7'-5"	5'-10"
	≥ 2.5"	5'-9"	4'-1"	7'-5"	5'-4"
10	1.5"	7'-4"	6'-9"	9'-7"	8'-10"
	2.0"	7'-4"	5'-6"	9'-7"	7'-2"
	≥ 2.5"	7'-4"	4'-10"	9'-7"	6'-3"
11	1.5"	9'-1"	8'-2"	11'-9"	10'-7"
	2.0"	9'-1"	6'-8"	11'-9"	8'-7"
	≥ 2.5"	9'-1"	6'-0"	11'-9"	7'-9"

Epoxy Coated (f'_c = 4,000 psi; f_y = 60,000 psi)

Horizontal Lap w/ >12" Concrete Cast Below - Top					
Bar Size	Min. Cover	Class A (1.0 ℓ_d) s < 6" cts.	Class A (1.0 ℓ_d) s ≥ 6" cts.	Class B (1.3 ℓ_d) s < 6" cts.	Class B (1.3 ℓ_d) s ≥ 6" cts.
4	1.5"	1'-11"	1'-11"	2'-6"	2'-6"
	2.0"	1'-11"	1'-11"	2'-6"	2'-6"
	≥ 2.5"	1'-11"	1'-11"	2'-6"	2'-6"
5	1.5"	2'-7"	2'-7"	3'-4"	3'-4"
	2.0"	2'-7"	2'-4"	3'-4"	3'-1"
	≥ 2.5"	2'-7"	2'-4"	3'-4"	3'-1"
6	1.5"	3'-4"	3'-1"	4'-4"	4'-0"
	2.0"	3'-4"	3'-1"	4'-4"	4'-0"
	≥ 2.5"	3'-4"	2'-10"	4'-4"	3'-8"
7	1.5"	4'-1"	4'-1"	5'-3"	5'-3"
	2.0"	4'-0"	3'-7"	5'-2"	4'-8"
	≥ 2.5"	4'-0"	3'-7"	5'-2"	4'-8
8	1.5"	5'-2"	5'-2"	6'-8"	6'-8"
	2.0"	5'-2"	4'-1"	6'-8"	5'-4"
	≥ 2.5"	5'-2"	4'-1"	6'-8"	5'-4"
9	1.5"	6'-6"	6'-4"	8'-5"	8'-3"
	2.0"	6'-6"	5'-1"	8'-5"	6'-7"
	≥ 2.5"	6'-6"	4'-8"	8'-5"	6'-0"
10	1.5"	8'-4"	7'-8"	10'-10"	10'-0"
	2.0"	8'-4"	6'-3"	10'-10"	8'-1"
	≥ 2.5"	8'-4"	5'-6"	10'-10"	7'-1"
11	1.5"	10'-3"	9'-3"	13'-4"	12'-0"
	2.0"	10'-3"	7'-6"	13'-4"	9'-9"
	≥ 2.5"	10'-3"	6'-10"	13'-4"	8'-10"

Draft Table

Uncoated (f'_c = 4,000 psi; f_y = 60,000 psi)

Basic Lap - Others					
Bar Size	Min. Cover	Class A (1.0 ℓ_d) s < 6" cts.	Class A (1.0 ℓ_d) s ≥ 6" cts.	Class B (1.3 ℓ_d) s < 6" cts.	Class B (1.3 ℓ_d) s ≥ 6" cts.
4	1.5"	1'-3"	1'-3"	1'-7"	1'-7"
	2.0"	1'-3"	1'-3"	1'-7"	1'-7"
	≥ 2.5"	1'-3"	1'-3"	1'-7"	1'-7"
5	1.5"	1'-6"	1'-6"	2'-0"	2'-0"
	2.0"	1'-6"	1'-6"	2'-0"	2'-0"
	≥ 2.5"	1'-6"	1'-6"	2'-0"	2'-0"
6	1.5"	2'-0"	1'-10"	2'-7"	2'-4"
	2.0"	2'-0"	1'-10"	2'-7"	2'-4"
	≥ 2.5"	2'-0"	1'-10"	2'-7"	2'-4"
7	1.5"	2'-5"	2'-5"	3'-1"	3'-1"
	2.0"	2'-4"	2'-2"	3'-0"	2'-9"
	≥ 2.5"	2'-4"	2'-2"	3'-0"	2'-9"
8	1.5"	3'-0"	3'-0	3'-11"	3'-11"
	2.0"	3'-0"	2'-5"	3'-11"	3'-2"
	≥ 2.5"	3'-0"	2'-5"	3'-11"	3'-2"
9	1.5"	3'-10"	3'-9"	5'-0"	4'-10"
	2.0"	3'-10"	3'-0"	5'-0"	3'-11"
	≥ 2.5"	3'-10"	2'-9"	5'-0"	3'-7"
10	1.5"	4'-11"	4'-6"	6'-4"	5'-11"
	2.0"	4'-11"	3'-8"	6'-4"	4'-9"
	≥ 2.5"	4'-11"	3'-3"	6'-4"	4'-2"
11	1.5"	6'-0"	5'-5"	7'-10"	7'-1"
	2.0"	6'-0"	4'-5"	7'-10"	5'-9"
	≥ 2.5"	6'-0"	4'-0"	7'-10"	5'-2"

Uncoated (f'_c = 4,000 psi; f_y = 60,000 psi)

Horizontal Lap w/ >12" Concrete Cast Below - Top					
Bar Size	Min. Cover	Class A (1.0 ℓ_d) s < 6" cts.	Class A (1.0 ℓ_d) s ≥ 6" cts.	Class B (1.3 ℓ_d) s < 6" cts.	Class B (1.3 ℓ_d) s ≥ 6" cts.
4	1.5"	1'-7"	1'-7"	2'-1"	2'-1"
	2.0"	1'-7"	1'-7"	2'-1"	2'-1"
	≥ 2.5"	1'-7"	1'-7"	2'-1"	2'-1"
5	1.5"	2'-0"	2'-0"	2'-7"	2'-7"
	2.0"	2'-0"	2'-0"	2'-7"	2'-7"
	≥ 2.5"	2'-0"	2'-0"	2'-7"	2'-7"
6	1.5"	2'-7"	2'-4"	3'-4"	3'-1"
	2.0"	2'-7"	2'-4"	3'-4"	3'-1"
	≥ 2.5"	2'-7"	2'-4"	3'-4"	3'-1"
7	1.5"	3'-1"	3'-1"	4'-0"	4'-0"
	2.0"	3'-0"	2'-9"	3'-11"	3'-7"
	≥ 2.5"	3'-0"	2'-9"	3'-11"	3'-7"
8	1.5"	3'-11"	3'-11"	5'-1"	5'-1"
	2.0"	3'-11"	3'-2"	5'-1"	4'-1"
	≥ 2.5"	3'-11"	3'-2"	5'-1"	4'-1"
9	1.5"	5'-0"	4'-10"	6'-5"	6'-4"
	2.0"	5'-0"	3'-11"	6'-5"	5'-1"
	≥ 2.5"	5'-0"	3'-7"	6'-5"	4'-7"
10	1.5"	6'-4"	5'-11"	8'-3"	7'-8"
	2.0"	6'-4"	4'-9"	8'-3"	6'-3"
	≥ 2.5"	6'-4"	4'-2"	8'-3"	5'-5"
11	1.5"	7'-10"	7'-1"	10'-2"	9'-2"
	2.0"	7'-10"	5'-9"	10'-2"	7'-6"
	≥ 2.5"	7'-10"	5'-2"	10'-2"	6'-9"

Draft Table

Epoxy Coated (f'_c = 3,500 psi; f_y = 60,000 psi)

Basic Lap - Others					
Bar Size	Min. Cover	Class A (1.0 ℓ_d)		Class B (1.3 ℓ_d)	
		s < 6" cts.	s ≥ 6" cts.	s < 6" cts.	s ≥ 6" cts.
4	1.5"	1'-7"	1'-7"	2'-0"	2'-0"
	2.0"	1'-7"	1'-7"	2'-0"	2'-0"
	≥ 2.5"	1'-7"	1'-7"	2'-0"	2'-0"
5	1.5"	2'-5"	2'-5"	3'-2"	3'-2"
	2.0"	2'-5"	1'-11"	3'-2"	2'-6"
	≥ 2.5"	2'-5"	1'-11"	3'-2"	2'-6"
6	1.5"	3'-2"	2'-11"	4'-1"	3'-9"
	2.0"	3'-2"	2'-11"	4'-1"	3'-9"
	≥ 2.5"	3'-2"	2'-4"	4'-1"	3'-0"
7	1.5"	3'-10"	3'-10"	5'-0"	5'-0"
	2.0"	3'-9"	3'-5"	4'-10"	4'-5"
	≥ 2.5"	3'-9"	3'-5"	4'-10"	4'-5"
8	1.5"	4'-10"	4'-10"	6'-3"	6'-3"
	2.0"	4'-10"	3'-11"	6'-3"	5'-0"
	≥ 2.5"	4'-10"	3'-11"	6'-3"	5'-0"
9	1.5"	6'-1"	6'-0"	7'-11"	7'-10"
	2.0"	6'-1"	4'-10"	7'-11"	6'-3"
	≥ 2.5"	6'-1"	4'-4"	7'-11"	5'-8"
10	1.5"	7'-10"	7'-3"	10'-2"	9'-5"
	2.0"	7'-10"	5'-11"	10'-2"	7'-8"
	≥ 2.5"	7'-10"	5'-2"	10'-2"	6'-8"
11	1.5"	9'-8"	8'-9"	12'-7"	11'-4"
	2.0"	9'-8"	7'-1"	12'-7"	9'-2"
	≥ 2.5"	9'-8"	6'-5"	12'-7"	8'-4"

Epoxy Coated (f'_c = 3,500 psi; f_y = 60,000 psi)

Horizontal Lap w/ >12" Concrete Cast Below - Top					
Bar Size	Min. Cover	Class A (1.0 ℓ_d)		Class B (1.3 ℓ_d)	
		s < 6" cts.	s ≥ 6" cts.	s < 6" cts.	s ≥ 6" cts.
4	1.5"	2'-0"	2'-0"	2'-8"	2'-8"
	2.0"	2'-0"	2'-0"	2'-8"	2'-8"
	≥ 2.5"	2'-0"	2'-0"	2'-8"	2'-8"
5	1.5"	2'-9"	2'-9"	3'-7"	3'-7"
	2.0"	2'-9"	2'-6"	3'-7"	3'-3"
	≥ 2.5"	2'-9"	2'-6"	3'-7"	3'-3"
6	1.5"	3'-7"	3'-4"	4'-7"	4'-3"
	2.0"	3'-7"	3'-4"	4'-7"	4'-3"
	≥ 2.5"	3'-7"	3'-0"	4'-7"	3'-11"
7	1.5"	4'-4"	4'-4"	5'-7"	5'-7"
	2.0"	4'-3"	3'-10"	5'-6"	5'-0"
	≥ 2.5"	4'-3"	3'-10"	5'-6"	5'-0"
8	1.5"	5'-6"	5'-6"	7'-1"	7'-1"
	2.0"	5'-6"	4'-5"	7'-1"	5'-8"
	≥ 2.5"	5'-6"	4'-5"	7'-1"	5'-8"
9	1.5"	6'-11"	6'-10"	9'-0"	8'-10"
	2.0"	6'-11"	5'-5"	9'-0"	7'-1"
	≥ 2.5"	6'-11"	4'-11"	9'-0"	6'-5"
10	1.5"	8'-11"	8'-2"	11'-7"	10'-8"
	2.0"	8'-11"	6'-8"	11'-7"	8'-8"
	≥ 2.5"	8'-11"	5'-10"	11'-7"	7'-7"
11	1.5"	10'-11"	9'-10"	14'-3"	12'-10"
	2.0"	10'-11"	8'-0"	14'-3"	10'-5"
	≥ 2.5"	10'-11"	7'-3"	14'-3"	9'-5"

Draft Table

Uncoated (f'_c = 3,500 psi; f_y = 60,000 psi)

Basic Lap - Others					
Bar Size	Min. Cover	Class A (1.0 ℓ_d)		Class B (1.3 ℓ_d)	
		s < 6" cts.	s ≥ 6" cts.	s < 6" cts.	s ≥ 6" cts.
4	1.5"	1'-4"	1'-4"	1'-8"	1'-8"
	2.0"	1'-4"	1'-4"	1'-8"	1'-8"
	≥ 2.5"	1'-4"	1'-4"	1'-8"	1'-8"
5	1.5"	1'-8"	1'-8"	2'-1"	2'-1"
	2.0"	1'-8"	1'-8"	2'-1"	2'-1"
	≥ 2.5"	1'-8"	1'-8"	2'-1"	2'-1"
6	1.5"	2'-1"	1'-11"	2'-9"	2'-6"
	2.0"	2'-1"	1'-11"	2'-9"	2'-6"
	≥ 2.5"	2'-1"	1'-11"	2'-9"	2'-6"
7	1.5"	2'-7"	2'-7"	3'-4"	3'-4"
	2.0"	2'-6"	2'-3"	3'-3"	2'-11"
	≥ 2.5"	2'-6"	2'-3"	3'-3"	2'-11"
8	1.5"	3'-3"	3'-3	4'-2"	4'-2"
	2.0"	3'-3"	2'-7"	4'-2"	3'-4"
	≥ 2.5"	3'-3"	2'-7"	4'-2"	3'-4"
9	1.5"	4'-1"	4'-0"	5'-4"	5'-2"
	2.0"	4'-1"	3'-3"	5'-4"	4'-2"
	≥ 2.5"	4'-1"	2'-11"	5'-4"	3'-10"
10	1.5"	5'-3"	4'-10"	6'-10"	6'-3"
	2.0"	5'-3"	3'-11"	6'-10"	5'-1"
	≥ 2.5"	5'-3"	3'-5"	6'-10"	4'-6"
11	1.5"	6'-5"	5'-10"	8'-5"	7'-7"
	2.0"	6'-5"	4'-9"	8'-5"	6'-2"
	≥ 2.5"	6'-5"	4'-3"	8'-5"	5'-7"

Uncoated (f'_c = 3,500 psi; f_y = 60,000 psi)

Horizontal Lap w/ >12" Concrete Cast Below - Top					
Bar Size	Min. Cover	Class A (1.0 ℓ_d)		Class B (1.3 ℓ_d)	
		s < 6" cts.	s ≥ 6" cts.	s < 6" cts.	s ≥ 6" cts.
4	1.5"	1'-8"	1'-8"	2'-2"	2'-2"
	2.0"	1'-8"	1'-8"	2'-2"	2'-2"
	≥ 2.5"	1'-8"	1'-8"	2'-2"	2'-2"
5	1.5"	2'-1"	2'-1"	2'-9"	2'-9"
	2.0"	2'-1"	2'-1"	2'-9"	2'-9"
	≥ 2.5"	2'-1"	2'-1"	2'-9"	2'-9"
6	1.5"	2'-9"	2'-6"	3'-6"	3'-3"
	2.0"	2'-9"	2'-6"	3'-6"	3'-3"
	≥ 2.5"	2'-9"	2'-6"	3'-6"	3'-3"
7	1.5"	3'-4"	3'-4"	4'-4"	4'-4"
	2.0"	3'-3"	2'-11"	4'-2"	3'-10"
	≥ 2.5"	3'-3"	2'-11"	4'-2"	3'-10"
8	1.5"	4'-2"	4'-2"	5'-5"	5'-5"
	2.0"	4'-2"	3'-4"	5'-5"	4'-4"
	≥ 2.5"	4'-2"	3'-4"	5'-5"	4'-4"
9	1.5"	5'-4"	5'-2"	6'-11"	6'-9"
	2.0"	5'-4"	4'-2"	6'-11"	5'-5"
	≥ 2.5"	5'-4"	3'-10"	6'-11"	4'-11"
10	1.5"	6'-10"	6'-3"	8'-10"	8'-2"
	2.0"	6'-10"	5'-1"	8'-10"	6'-8"
	≥ 2.5"	6'-10"	4'-6"	8'-10"	5'-10"
11	1.5"	8'-5"	7'-7"	10'-11"	9'-10"
	2.0"	8'-5"	6'-2"	10'-11"	8'-0"
	≥ 2.5"	8'-5"	5'-7"	10'-11"	7'-3"

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