

605 STEEL REINFORCEMENT

605-1 Description

Reinforced concrete is a mixture of concrete and steel reinforcement. Concrete is weak in tension and cracks easily when it shrinks or creeps under sustained loading. It is a brittle material. When concrete fails, it breaks suddenly without warning. Steel, on the other hand, is 100 times stronger in tension than concrete; is 6 times stiffer; and will stretch 17 times more than concrete before failing. Steel reinforcement provides reinforced concrete the tensile strength, stiffness, and ductility needed to make it an efficient, durable, versatile, and safe building material.

For reinforced concrete to work as the Designer intended, the Inspector and Resident Engineer must ensure that reinforcing steel placed in a structure is:

- the correct grade and type of steel;
- the correct size, shape and length;
- placed in its specified location and spaced properly;
- tied and spliced together properly;
- clean and will get an adequate cover of concrete in all directions; and
- placed in the correct quantities.

Primary and Secondary Reinforcement

In any reinforced concrete structure, the reinforcing steel can be divided into two categories. *Primary reinforcement* is the steel in the concrete that helps carry the loads placed on a structure. Without this steel, the structure would certainly collapse. *Secondary reinforcement* is the steel placed in a structure that enhances the durability and holds the structure together. It provides the resistance to cracking, shrinkage, temperature changes, and impacts necessary for a long service life of the structure. Primary reinforcement can be thought of as the steel that holds up the structure while secondary reinforcement can be thought of as the steel that holds a structure together.

For example, the bottom mat of rebar and the truss bars in a bridge deck are intended to function as primary reinforcement. They resist the tensile stress that is induced by the bending of the deck as vehicles pass over it. If this steel was not there, the concrete could collapse and a vehicle could fall between the girders. On the other hand, the steel in the front face of a cantilever retaining wall functions more for crack and shrinkage control. Its main job is to hold the concrete together. It's the steel on the backfill face of the wall that helps the structure retain the soil.

It's important for the Resident Engineer and Inspector to become familiar with the primary and secondary steel reinforcement in structure. Not only does this help the Inspector visualize how the steel should look, but it helps in getting compliance from the Contractor by being able to discuss the reasons for good placement procedures and how each bar in the structure is intended to function. The Designer can help identify which steel is primary and which is secondary reinforcement.

Reinforcing Steel Changes in the Field

Contractors may request changes in how reinforcing steel is specified and designed to facilitate construction. These changes can include:

- moving bars;
- bending bar;
- substituting bars for different sizes, grades or types;
- cutting or torching bars;
- welding bars; and
- using different splice details or splice locations.

Any requests that would change the location, size, shape, type, grade, length, or splice location of any bar must have the approval of the Designer of the structure. In fact, any request (written or oral) that would change the design of the steel reinforcement in a structure must have the approval of the Designer. As mentioned earlier, steel reinforcement can be divided into primary and secondary reinforcement. Even minor changes in either category can have a profound impact on the behavior and longevity of the structure. This is why it is important to contact the Designer on rebar changes so the impacts can be accurately assessed and accounted for in the design.

The Resident Engineer can deal with changes in how steel is tied, cleaned, supported, stored, and handled with input from Bridge Group and Materials Group, as needed.

605-2 Materials

Steel bars, steel wire, welded wire fabric, and other structural steel shapes used as reinforcement must be certified as conforming to the specifications before being covered with the concrete. In addition to the certification requirements, random samples must be taken by the Inspector in accordance with the *Materials Testing Manual*, Sampling Guide Schedule and the *Materials Policy and Procedure Directives Manual* (PPD No. 92-2). PPD No. 92-2 is an excellent guide for identifying the type, sizes, and grades of reinforcing steel and discusses the sampling and certification requirements in much detail.

One important point about rebar sampling that should be stressed: precut bars furnished by the supplier as "sample bars" are not acceptable. Sample bars must be removed from a steel shipment at random when delivered to the project site. The Department now requires only one copy of the certificate of compliance for steel reinforcement.

Steel Type, Grade, and Bar Size Substitutions

Most reinforcing steel for ADOT structures is specified as Type A615M (billet steel), Grade 420. Occasionally the Contractor may want to substitute A706 steel for the A615 type. This kind of substitution is generally acceptable as long as the grade of steel stays the same or is better and there are no changes in bar sizes or lengths. A no-cost minor alteration should be executed with the concurrence of the Structural Designer and Materials Group. Other types of reinforcing steel such as ASTM A616 (rail steel) and A617 (axle steel) are not acceptable substitutes.

Contractors may always furnish Grade 420 steel when Grade 300 is specified. However if the Contractor proposes to use Grade 520 steel for Grade 420, the Structural Designer and Bridge Group should be contacted for their approval. Grade 520 steel has a much higher yield strength than Grade 420 and could adversely affect how a structure behaves during a failure.

The Designer must approve all changes in bar sizes. Even when the Contractor wants to substitute larger bar sizes over what is specified, check with the Designer. Larger bars can cause clearance problems and in some cases may lead to over-reinforcement of a concrete section (a violation of AASHTO bridge specifications).

Welded Wire Fabric (Wire Mesh)

Wire mesh is sometimes specified by a Designer to control shrinkage and cracking in a concrete slab or wall. Information on identifying and placing wire mesh can be found in the CRSI *Manual of Standard Practice* referenced at the end of this chapter (a copy is available at Bridge Group and the ADOT Library).

605-3 Construction Requirements

605-3.01 General

Every Inspector that regularly inspects reinforcing on an ADOT project should have the latest copy of *Placing Reinforcing Bars* published by the CRSI (see references).

Bar Bending Diagrams, Bar Lists, and Cut Sheets

Although bar bending diagrams are shown in the Project Plans, it is not a common practice for the Designer to show bar lists in the Project Plans. A sample bar list (or cut sheet as they are known locally) is shown at the end of Chapter 8 of *Placing Reinforcing Bars*. The Contractor needs to submit the bar lists for a structure to the Resident Engineer prior to fabricating the reinforcing steel. The intent is to get the Inspector and the Resident Engineer to review these lists before the steel is made and shipped to the project. This proactive approach will help prevent any delays to the project due to bars that have been cut the wrong length, bent the wrong way, or specified as the wrong size. Waiting until the steel arrives on the job to begin checking bar dimensions is a reactionary practice that the Department would like to avoid.

Bending, Heating, and Cutting Bars

Contractors may want to field bend bars to simplify reinforcing steel installation or to improve access around a structure. Grade 40 bars smaller than # 8 can be bent out of the way and then re-bent to their final shape.

The Contractor can only bend # 8 and larger bars once and any bars made from Grade 60 steel. This means that they cannot be bent then re-bent once they are no longer in the way. The bars cannot be bent temporarily to accommodate other construction activities. Furthermore if the bars have already been bent once in the shop, no further bending is allowed in the field. Bending these bars more than once weakens the steel at the bends due to metal fatigue. (This is similar to what happens every time you bend a coat hanger or a paper clip back and forth—the repeated bending action weakens the steel until it breaks.) Heating the steel to bend it is not acceptable. The heat, if not strictly controlled and closely monitored, produces a metallurgical change of the steel. This change is called a *notching effect* because too much heat will cause a permanent and local weakening of the steel's crystalline structure just like an actual notch in the steel.

If bars have to be bent, there is a minimum bending radius that the bars must meet or exceed. The minimum radius, which depends on the bar size, can be found in Design Aid 2.13.1 of the ADOT *Bridge Design and Detailing Manual*.

Cutting or torching bars because they are a hindrance to steel installation or concrete placement must not be allowed without the approval of both the Structure Designer and the Resident Engineer.

Cutting the bars and then splicing them after they are out of the way is another practice that should be discouraged. The problem with cutting the bars and then splicing them has to do more with the splicing than the cutting of the bar. If the bar has to be spliced, the type of splice and the location of the splice should be

discussed with and approved by the Designer before the bar is cut. Many times, Contractors want to cut rebar at locations where stresses in the steel are too high or insufficient bar length is available after the cut to fully develop the splice. These are the reasons why the Designer must be involved in any bar cutting decisions.

Rusty, Oily and Dirty Rebar

Actually rust is not detrimental to rebar unless the amount of rust is so excessive that it flakes off the bars or reduces their cross-sectional area significantly. Oil, dirt, and loose mortar are the most detrimental to rebar since all three reduce the adhesion between the steel and the surrounding concrete.

Oil, especially form oil, acts as a bond breaker. When this gets on the bars, the Inspector has no choice but to insist upon its removal. Removal may be done with petroleum-based solvent such as naphtha, gasoline, or diesel fuel. A hand-held torch can be used to lightly heat up the bar and burn off the oil.

Loose mortar, dirt, and mud can weaken the bond between the steel and concrete. The steel should be wiped or washed clean of these contaminants. In severe cases, wire brushing may be needed especially on any primary reinforcement. If a small amount of mortar in random locations is tightly bonded to the steel so that vigorous wire brushing cannot easily remove it, the mortar is probably acceptable. However check with the Resident Engineer before approving the steel.

Rebar Cover and Clearance

Reinforcing steel must have adequate concrete cover near any exposed surface. This cover is needed to prevent corrosion of the reinforcing steel due to moisture, atmospheric conditions (like high humidity), and reactive soils.

The Project Plans should clearly indicate the amount of cover required for reinforcing steel. If the Plans do not, the Designer should be contacted. AASHTO and ACI have minimum cover requirements on all reinforcing steel. As a guide, consult Chapter 10 of Placing Reinforcing Bars (see references), which has an excellent section on concrete cover requirements.

Adequate clearance is needed between reinforcing bars so all of the concrete mix can completely surround the bar. When bars are spaced too close together, two things can happen:

1. An air void can develop between the bars because there is not enough room for the concrete to flow between the bars. This void severely weakens reinforced concrete locally because there is no concrete bonded to the steel. The void also causes stress concentrations in the surrounding concrete because the concrete must transfer additional stresses that the void cannot.
2. The area between the bars is filled only with mortar, and is void of coarse aggregate. The problems with only having mortar between the bars include:
 - A. a reduced shearing strength in the mortar due to the absence of coarse aggregate;
 - B. increased stresses in the steel as the mortar tries to shrink around the bars in the absence of coarse aggregate; and
 - C. surrounding areas of weakened concrete that have too much coarse aggregate and not enough mortar.

ADOT's Standard Specifications do not specifically limit the clearance between individual bars. Instead Subsection 1006-3.01 limits the maximum size of coarse aggregate in the concrete mix based on the minimum rebar clearance. In other words, the Contractor must adjust the concrete mix design to fit the minimum rebar clearances in the structure. The Inspector's responsibility is to check areas of minimum rebar clearance and verify that the Contractor's concrete mix will meet Subsection 1006-3.01 (you'll need to examine the mix design to do this). If the mix does not, either the Contractor submits a new mix design or the Designer is contacted about moving bars so the Contractor's mix can adequately coat the bars. See "Steel-Reinforcement Placement" in subsection 601-3.03 of this manual for a detailed discussion and example of how to calculate the required rebar clearance for a given mix design.

Common locations where rebar congestion is a problem are:

1. lap splices of longitudinal bars and
2. column and cap beam connections where the cap beam reinforcing steel crosses the column steel protruding into the cap.

Tolerances for Cutting, Bending, and Placing

As soon as reinforcing steel is delivered to the project, it should be sampled in accordance with the Sampling Guide. The Inspector should determine if the bars are of the proper size and length and if the bends and bend dimensions are in accordance with the Project Plans and the tolerances shown herein. After placement of the steel in the structure, a complete final inspection must be made and documented.

In the cutting, bending, and placing of reinforcing steel, it is recognized that it is not reasonable to require all bars to be cut, bent, and placed precisely as shown on the Project Plans. On the other hand, the strength of each member of a structure is dependent upon the cutting, bending, and placing being within reasonable tolerances. Because of these facts, the Department has adopted allowable tolerances that are considered reasonable and practical to meet yet will not significantly reduce the strength of the structural member below the theoretical design strength.

Cutting and Bending Tolerances

The following tolerances are based on industry standards established by the Concrete Reinforcing Steel Institute (refer to Chapter 6 of Placing Reinforcing Bars).

1. Cutting to length on straight bars: ± 1 inch (25 mm).
2. Hooked bars, out-to-out: ± 1 inch (25 mm).
3. Truss bars, out-to-out: ± 1 inch (25 mm). The height (H) or drop (rise): $\pm 1/2$ inch (13 mm). Bend down points and bend up points shall be within 2 inches (50 mm) of position indicated on the Project Plans.
4. Spirals or circles ties, out-to-out dimension: $\pm 1/2$ inch (13 mm).
5. Column ties or stirrups, out-to-out dimension: $\pm 1/2$ inch (13 mm).

Subsection 105.05 applies to reinforcing steel just like it does to all other construction materials and workmanship. Bars that are consistently too short or consistently bent to the wrong dimensions are cause for rejection. Improper cutting and bending can also result in failure to meet placement tolerances in the forms.

Placement Tolerances (Refer to Subsection 606-3.01)

1. Height of bottom bars above forms shall be as indicated on the Project Plans, $\pm 1/4$ inch (6 mm).
2. Top bars shall have the clearance indicated on the Project Plans, $\pm 1/4$ inch (6 mm).
3. Clearance from forms on vertical walls, columns, wings, and similar members shall be as indicated on the Project Plans, $\pm 1/4$ inch (6 mm).
4. Spacing of bars in long runs of slabs or walls may vary up to 2 inches (50 mm), but it is important that the proper number of bars is placed.

The effectiveness of the reinforcement and the strength of the structure are dependent upon the reinforcing bars being placed in the concrete in nearly the exact position shown on the Project Plans. If they are not placed as shown, the structure will likely not have the strength that the Designer anticipated. For example; when the depth (H) of all truss bars in a structural concrete member is $1/2$ inch (13 mm) less than shown on the Project Plans, the strength of that member is reduced from 15 to 25 percent.

The correct position of the steel, in relation to the tension face of the concrete, is of great importance. If it is too far away from the face, the strength of the member will be adversely affected. If the position is too close, particularly in bridge decks, water and de-icing chemicals penetrate to the steel and cause it to rust. The rusting process causes an expansion in the volume occupied by the steel that will cause spalling of the concrete.

Sometimes cover problems with reinforcing steel are the results of errors in the formwork rather than errors in steel placement. If a cover problem does not seem to be the result of improper rebar installation then check the dimensions of the forms for the correct forming tolerances.

Bar Supports

Adequate support for reinforcing steel must take into account not only the weight of the steel, but the stresses and strains encountered while placing the concrete as well. The Concrete Reinforcing Steel Institute publication, *Placing Reinforcing Bars*, contains recommended spacing for metal chair supports. Regardless of the recommendations, there must be enough supports to keep the reinforcing steel within the placement tolerances and to keep it from deflecting under construction loading (concrete pours and foot traffic usually) until it is covered with concrete.

Chairs should be observed to detect whether they are bending or are indenting the form material. It may be necessary to use more chairs or chairs with broader feet to carry the load exerted by the reinforcing steel and the ironworkers. Heavy rebar cages containing large bar sizes are candidates for bar support inspection by the Inspector. Wall and column reinforcement should be checked for adequate lateral support to prevent the reinforcement from being pushed against the forms during concrete placement.

The Resident Engineer and Inspector should pre-approve all bar supports and bar support methods in advance of any steel placement (preferably when the bar bending diagrams are approved).

If precast mortar blocks are used as bar supports, the blocks must have a compressive strength that meets or

exceeds the strength of the concrete poured around them. The Inspector must take one sample of precast mortar blocks for every 50 placed and send it to the Regional or Central Lab for strength testing.

Reinforcing Steel Inspection

The Inspector shall not permit the start of concrete operations on any portion of the structure until he or she has thoroughly checked all of the steel for conformance with the Project Plans and the following:

- number of bars
- spacing
- clearance
- cleanliness
- size
- splices
- tying
- length
- bends
- support

This inspection cannot be made in a few minutes and it cannot be properly made until all of the steel is in place. Therefore the Contractor must allow sufficient time for the Inspector to make this check when planning the start of concrete placement. The Contractor should be made aware of the time necessary for this inspection. If this matter is discussed at the preconstruction conference, the Contractor should be informed again just before he or she begins concrete and steel work.

Inspectors doing rebar inspection should have the latest edition of *Placing Reinforcing Steel*, published by CRSI (see references) available to them.

605-3.02 Splicing and Lapping

Reinforcing steel is often specified in lengths that are too long for the steel to be delivered and placed as a single piece. As a result, two or more pieces are often spliced together at the site to form one long single bar. The following are three methods that ADOT allows to splice rebar.

Lap Splices

Lap splices are formed when two bars are overlapped for a certain length and tied together. The length of the overlap is called the lap length and is specified in the Project Plans. A sufficient lap length is needed to adequately transfer loads between the bars. Lap lengths can be longer than specified, but never shorter. Inadequate lap length can cause severe cracking in the concrete around the lap.

Reinforced concrete is typically its weakest around the lap splices in the primary reinforcement bars. For this reason, lap splices are placed in areas where the stresses in a reinforced concrete section are the lowest. The Inspector must ensure that the Contractor laps reinforcing steel only in the places specified in the Project Plans and with sufficient lap length. If the Contractor wishes to move a lap splice, the Designer must approve the location change. In areas of high bending and tensile stresses, the Department should insist on using continuous bars or either mechanical or welded splices.

Lap splices can present problems with concrete cover and clearance between bars. Lap splices must have adequate concrete cover for corrosion protection just like continuous bars. It is important to ensure that the spacing between the lap splices allows for the adequate flow of concrete around the splice (see Subsection 1006-3.01). Sometimes the lap splices in a group of bars are staggered to reduce congestion at the splice location.

Designers and Contractors have joint responsibility to ensure that lap splices are workable in terms of spacing

and adequate cover. The Designers need to ensure that lap splices will fit within the dimensions of a concrete member. Concrete cover must be adequate and rebar clearance must take into account a reasonable coarse aggregate size. If lap splices do not work, alternatives such as resizing the member, stagger splices, or a different splice detail should be specified. Contractors, on the other hand, have a responsibility to identify congested rebar sections on the Project Plans and adjust their concrete mix design accordingly. They also have a responsibility to place lapped bars well within the allowable placement tolerances when congestion at a lap splice is a problem.

Non-Contact Lap Splices

When a precast member is structurally connected to a cast-in-place concrete member or another precast member, the rebar from both members is lap spliced together to ensure adequate stress transfer across the two members. Sometimes due to the positioning of the precast member or because of placement tolerances in the reinforcing steel, the lapped bars do not end up touching each other at the splice. In other words, there is a gap between the two bars at the lap splice. The Designer must approve any *non-contact laps* that are not shown on the Project Plans.

When non-contact laps are permitted, the bars must not be spaced too far apart or a zigzag crack in the concrete may develop between the bars. Usually the gap is limited to the lesser of 1/5 the lap length or 6 inches (150 mm). Non-contact laps are generally permitted in secondary reinforcement and in some minor structures. However they should not be allowed as an alternative to chronically poor workmanship.

Mechanical Couplers

When mechanical couplers are used to splice rebar, the couplers should be submitted to the Department ahead of time for approval. Couplers shown on the ADOT [Approved Products List](#) do not need to be pre-tested. Couplers not on the list should be pre-tested by ADOT Materials Group before they are covered with concrete.

For each type of mechanical coupler used, the Inspector should have the manufacturer's recommendations on how to make field splices. It is part of the Inspector's job to verify that the Contractor is following the manufacturer's recommendation for making mechanical splices.

It is also the Inspectors responsibility to sample mechanical couplers in accordance with the Subsection 605-3.02 even if the mechanical couplers have been pre-approved. The samples must be taken at random and after the splices have been made. The samples should be sent to Materials Group for testing. The Contractor is entitled to no additional costs for providing samples of mechanical splices used for testing or for the cost of repairing the rebar where the samples have been taken (see Subsection 605-4.02 and 605-5).

Welding Rebar and Welded Splices

Most rebar is specified as ASTM A615 steel. There are no strict controls on the chemical composition of the steel as long as the desired mechanical properties are met. Because there are no strict chemical controls, heating this type of steel for welding or cutting purposes can adversely alter the chemical composition of the steel. The steel can become permanently weakened and brittle due to the applied heat. As a result, most construction specifications (including ADOT's) prohibit the welding and torching of A615 rebar. Like a chain, a piece of rebar is only as strong as its weakest link so even minor tack or spot welding is prohibited.

Tack welding is not permitted unless approved in writing by the Engineer. When welding is permitted, ASTM A706 steel must be used and the welding must be performed by an AWS certified welder. Butt-welded splices

are the only acceptable welded splices.

The welder should have the correct mill test report (chemical analysis) from the heat in which steel was made. Welding procedures do change to reflect the actual chemical composition of the steel. This test report should be included in the Certificate of Analysis.

No welding should be performed near prestressing strands without protecting the cable from welding splatter. Even the slightest nick or burn mark in the strands is enough to cause failure during tensioning.

Chapter 10 of *Placing Reinforcing Bars* contains additional information about rebar splices.

Changing the Type of Rebar Splice

For placement reasons, safety reasons, or for other constructability reasons, Contractors may want to use mechanical couplers or welded splices in place of lap splices. Subsection 605-3.02 gives the option to the Contractor of what type of splice to use as long as the Department approves the splices. The Designer may show only lap splices, but the Contractor may need to change the type of splice to make the steel easier or safer to place, lift, and handle.

Just because lap splices are shown, doesn't mean the Contractor is limited to this type of splice. The Contractor must choose the appropriate type of splice based on how he or she intends to construct the work. Changing lap splices to mechanical couplers or welded splices should be at no cost to the Department since the Standard Specifications clearly allow the Contractor other splicing options. The Contractor's selection of a different splicing option is not a changed condition unless the Project Plans or Special Provisions specifically preclude other splicing options.

605-3.03 Epoxy-Coated Reinforcement

When epoxy-coated steel reinforcement is specified, Inspectors need to be watchful in how the Contractor handles the bars. Scratches, nicks, and other marks are to be kept to a minimum. Don't allow the Contractor to mishandle the rebar with the intent of fixing any damage to epoxy coating later. The intent of Subsection 605-3.03 is to avoid mishandling the bars in the first place. Repair procedures should only be allowed for the occasional accident.

For the epoxy coating to prevent rebar corrosion, the entire bar supports (i.e. chairs, tie wires, and mechanical couplers) must be corrosion proof. It makes no sense to support an epoxy-coated bar on a bare-metal chair. The Resident Engineer and Materials Group must pre-approve all bar supports, couplers, and tie wires for epoxy-coated rebar. The Contractor should submit samples and product literature well in advance of any placement work.

It is the Department's policy not to allow any metal bar supports or metal tie wire (coated or uncoated) for epoxy coated rebar in concrete barrier wall. Non-metallic supports and tie wire must be used since the steel in a barrier wall is highly susceptible to corrosion.

The CRSI has an excellent inspection guide for epoxy-coated rebar, which is referenced at the end of this chapter.

605-4 & 5 Method of Measurement & Basis of Payment

Most reinforcing steel is paid for as part of a lump sum structure item or is included in the cost of another contract item. Rarely is an ADOT contract setup to measure reinforcing steel on weight basis. However when there is a quantity dispute or additional work under a lump sum payment provision (605-4.02), the weight basis (605-4.03) is used to measure reinforcing steel to equitably adjust the contract amount.

Even when reinforcing steel is measured on a lump sum basis, the Inspector should still collect the cut sheets that accompany each steel shipment and note any quantities used for placements, aids, or left out of the structure. The date and time the steel was placed in the structure should be noted. This process should not be much different than collecting concrete tickets, where the Inspector tracks the concrete quantities, placement location, and waste.

Tracking steel quantities as steel is placed is important for heading off quantity disputes. Often these disputes arise because the quantity shipped to the project is different than the quantity shown in the bidding schedule or Project Plans. However Inspectors need to keep in mind that there is a yield factor that applies to rebar similar to the yield factor that applies to ready mixed concrete. With rebar, there are end pieces that are not used, bars that are used as placement aids, and waste from rebar cutting. Sometimes even extra bars are sent at the Contractor's request to replace damaged bars previously shipped.

Inspectors don't need to document every single bar placed in a structure, but they do need to scrutinize cut sheets and other shipping documents and note any quantity discrepancies as steel is placed.