



Manual of Standard Practice

Manual of Standard Practice 2021

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Welded Wire Reinforcement



1.1 Introduction to Welded Wire Reinforcement

Welded wire reinforcement (WWR) is a prefabricated reinforcement consisting of high strength, cold-drawn or cold-rolled wire welded together in square or rectangular grids. Each wire intersection is electrically resistance-welded by a continuous automatic welding machine. The welding machines use a combination of pressure and heat to fuse the intersecting wires into a homogeneous section (Figure 1) while fixing all wires in their intended position. Plain wires with smooth surface, deformed wires with ribbed or indented surface, or a combination of both wire types may be used in the production of WWR mats (sheets). The manufacture of welded wire reinforcement is governed by the *ASTM A1064 Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete*.



Figure 1: A close-up view of WWR welded intersections

Welded plain wire reinforcement is characterized by smooth circumferential wire surfaces. Its bond to hardened concrete achieved solely through the positive mechanical anchorage that is derived from a combination of concrete bearing and weld shear strength at each welded wire intersection. In contrast, welded deformed wire reinforcement is unique in that it can either utilize both wire surface deformations and welded intersections to contribute concurrently to bond and anchorage, or the welded intersections themselves can be ignored. In the latter case the bond and anchorage behavior would be based solely on the deformed wire surfaces.

Concrete structures continue to be successfully and economically reinforced with high-strength, distributed wires in WWR mat form.

From the designer's perspective, the wide range of wire sizes and spacings available makes it possible to furnish precise cross-sectional steel area required in sectional strength calculations, without any modification to the design routines themselves. From the contractor's and inspector's point-of-view, the welded wire intersections hold the structural reinforcement in the proper shape and position, expediting the placement operation and providing an extremely high level of tolerance control for structural reinforcement. The resulting ease and speed with which WWR can be handled and installed considerably reduces placing time (Figure 2), in turn translating to significant comparative cost reductions relative to placement of individual, loose reinforcing bars. Reduced construction time is of particular benefit to the owner by affording earlier occupancy and reducing total project cost. Additional cost savings in the form of reduced overall reinforcement tonnage can also be realized in certain applications by specifying equivalent welded wire reinforcement of higher yield strength with lower cross-sectional steel areas.

This *Manual of Standard Practice (MSP)* provides information on WWR product attributes and properties, material specification references, and commentary on manufacture, transport, and usage. The MSP is intended to be used as one of three complementary publications, with its two counterparts described below containing targeted content not extensively presented in this MSP:

WWR-400 Bending Welded Wire Reinforcement

Content specific to the post-welding, highly versatile bending fabrication operations, including example bend drawings and representative bent WWR applications.

WWR-600 The WRI Welded Wire Reinforcement Design and Detailing Guide

The Design and Detailing Guide provides comprehensive designer commentary and step-by-step structural design examples, complete with ACI 318 references, engineering calculations, and welded deformed wire reinforcement mat and placement illustrations.

In addition to the aforementioned WRI Standards, designer-related references are available from the WRI website as noted below:

ACI 318-19 Quick Fact: A Welded Deformed Wire Reinforcement Primer

A resource for practicing structural engineers intended to spotlight the most common welded deformed wire reinforcement attributes encountered and leveraged in modern structural design.

ACI 318-19 Quick Reference for Welded Deformed Wire Reinforcement

A comprehensive summary of ACI 318 sections applicable to the design and usage of welded wire reinforcement. The reference presents correlated content under headings that include Manufacture, Design, Minimum Steel, Detailing, and Seismic. The Quick Reference is a cheat-sheet for the practicing design professional to help with navigation of ACI 318 relevant to the implementation of WWR in daily design.

WWR Sample Specification: Section 03 22 00 – Welded Wire Reinforcement for Concrete

A sample specification section presented using the modern Construction Specifications Institute (CSI) MasterFormat content structure, intended for download and direct incorporation into Division 03 of a given project's specifications manual.

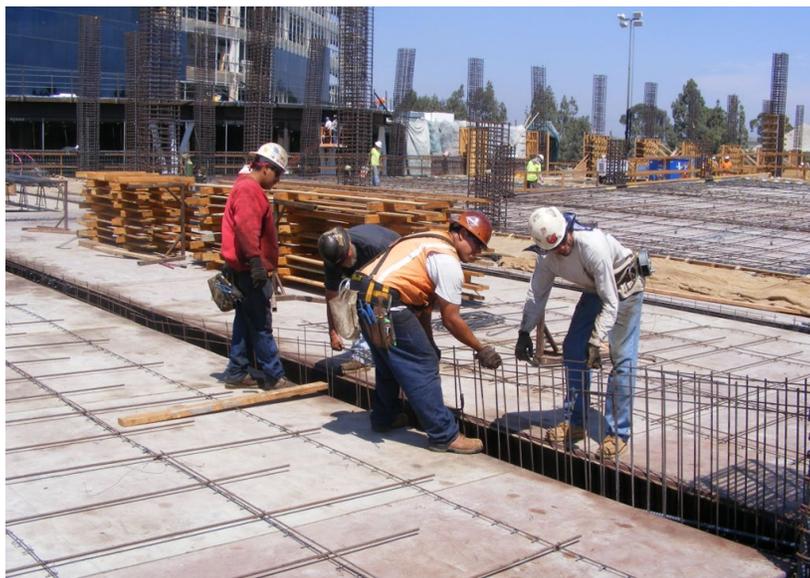


Figure 2: A placement crew installing a bent WWR mat for use as shear reinforcement in a post-tensioned concrete parking garage beam. Also note the flat WWR mats already placed for use as minimum mild steel reinforcement in the structural slab that will span perpendicular to the beams.

Chapter Two

Nomenclature

2.1 Item Description

In the welded wire industry, an “item” is the term used to designate a complete unit of WWR as it appears on an order form and within a manufacturer’s internal bookkeeping structure. As it translates to the downstream designer and contractor, an item simply correlates to a unique, individual mat of welded wire reinforcement. Figure 3 shows a representative product tag including item reference, while Figure 4 shows tagged WWR bundles.

| | |
|---|--|
| Date: 08-JUN-2020 1 of 1 | XYZ WWR Town, USA 01234 |
| Lot: 275284-20200604_516186_3 #Pieces: 1 Unit Weight: 148.2177 Wind: ASTM A1064 | BUY AMERICA The use of this product conforms with Buy America requirements set forth in 23 CFR Subpart D, Section 635.410, Buy America Requirements and Title 49 - Transportation, Chapter VI, Federal Transit Administration, Department of Transportation Part 661 - Buy America Requirements - Surface Transportation Assistance Act of 1982, As Amended |
| C1577 AS2-4-5 8x6x6 1-2' FILL SGL ABC Inc. | |
| ITEM: 540-344427 | |



Figure 3: A sample item tag with item reference clearly identified along with WWR supporting information. Tag information varies from one manufacturer to another, with ASTM A1064 dictating the inclusion of certain attributes and the individual manufacturer then providing supplemental identifying references.

Figure 4: WWR bundles staged at the manufacturer’s yard, with tags attached.

2.2 Wire Size Designation

Individual wire (plain and deformed) size designations are based on the cross-sectional area of a given wire. Historically, gage numbers were used exclusively for many years. The industry changed over to a letter-number combination in the 1970s, which utilizes the prefixes “W” and “D” in combination with a trailing number. The letter “W” designates a plain wire and the letter “D” denotes a deformed wire. The number following the letter gives the cross-sectional area in hundredths of a square inch. For example, wire designation W4.6 would indicate a plain wire with a cross-sectional area of 0.046 in² and a D22.8 designation would indicate a deformed wire with a cross-sectional area of 0.228 in².

Welded wire reinforcement mat descriptions (also known as “styles”; see Section 2.3) maintain the letter-number designation for wires comprising the mat, and supplement this identifying attribute by inclusion of numerical spacing information.



Figure 5: WWR mats in a bundle, showing deformed wires welded to plain wires. Notice the contrast in surface profile.

When describing metric wire, the prefix “M” is added. MW describes metric plain wire, and MD metric deformed wire. The wire spacings in metric WWR are given in millimeters (mm) and the cross-sectional areas of the wires in square millimeters (mm²).

Nominal cross-sectional area of a deformed wire is determined from the weight (mass) per foot of wire rather than the diameter due to the practical challenge of measuring the physical diameter of a deformed surface. Per ASTM A1064, the nominal diameter of a deformed wire is equivalent to the nominal diameter of a plain wire having the same weight per foot as the deformed wire.

2.3 Style

Spacings and sizes of wires in WWR are identified by “style.” On page 5 See Figure 6 for illustrative examples of several style designations. The basic structure of a WWR style consists of identification of the wire spacing in both directions followed by identification of the corresponding wire sizes.

In manufacturing, the longitudinal wires on a mat are traditionally those that run through the welder in a direction perpendicular to the row of welding electrodes on the welding machine. These longitudinal wires are commonly referred to as “linewires”, with a helpful visual being that these are the wires that run in the “assembly line” output direction of the welded wire reinforcement production line. The transverse wires on a mat, then, run parallel to the row of welding electrodes and are welded at a right angle to the longitudinal wires. These transverse wires are referred to as “crosswires”, as they run in a direction across the production line.

It is important to understand that the longitudinal linewire and transverse crosswire manufacturing terminology referred to herein does not necessarily correlate to the longitudinal and transverse axes of the structural element itself. The availability of highly-illustrative reinforcement submittals eliminates the potential for uncertainty as to the orientation of the WWR when installed.

Figure 6: Examples of WWR mat style nomenclature

Example 1



Style shown represents a pattern consisting of D12 wires (0.120 in²) spaced at 6 inches on center in the “linewire” (LW) direction of the mat welded to W5.0 wires (0.050 in²) spaced at 12 inches on center in the “crosswire” (CW) direction of the mat, perpendicular to the linewires.

Example 2



Style shown represents a pattern consisting of D30.7 wires (0.307 in²) spaced at 16 inches on center in the “linewire” (LW) direction of the mat welded to D14.5 wires (0.145 in²) spaced at 3.5 inches on center in the “crosswire” (CW) direction of the mat, perpendicular to the linewires.

Notice that in contrast to Example 1, the nomenclature used in Example 2 drops the hyphen between spacing pattern and wire information and uses a slash separator for the wire information in lieu of an “X”. Both approaches, as well as subtle variations thereof, are acceptable provided there is discernible delineation between spacing information and wire size information.

Example 3



Style shown represents a pattern consisting of D20.0 wires (0.200 in²) at a variable spacing (V1) in the “linewire” (LW) direction of the mat welded to D12.6 wires (0.126 in²) at a variable spacing (V2) in the “crosswire” (CW) direction of the mat, perpendicular to the linewires. Variable spacing patterns must then be explicitly annotated as part of the overall mat description, which can be seen in **Section 2.4**.

Example 4



Style shown represents a pattern consisting of two wire sizes – D18.0 (0.180 in²) and D14.5 (0.145 in²) in the “linewire” (LW) direction of the mat and arranged at variable spacing (V1). The linewires are welded to D9.5 wires (0.095 in²) spaced at 24 inches on center in the “crosswire” (CW) direction of the mat, perpendicular to the linewires. The variable spacing pattern, in this case made further complex by the presence of multiple linewire sizes, must then be explicitly annotated as part of the overall mat description, which can be seen in **Section 2.4**.

Figure 6: Examples of WWR mat style nomenclature

In metric terms, styles in **Figure 6** would be expressed as follows:

Example 1: 152 X 305 – MW77 X MW32

Example 2: 406 X 89 MW198 / MW94

Example 3: V1 X V2 MW129 / MW81

Example 4: V1 X 610 – MW116 X MW94 / MW61

Note that welded wire reinforcement style gives spacings and sizes of wires only and does not provide any other dimensional information such as width and length of sheet. Detailed dimensional information is ultimately provided in a mat's description that accompanies the style itself (mat description information is presented in Section 2.4).

As can be seen in Figure 6 on the previous page and in significant illustrative detail subsequently presented in Section 2.4, WWR with variable (non-uniform) wire spacings and sizes is available and quite common. State-of-the-art automated welding machines are capable of producing welded wire reinforcement arrangements that are far more complex than those that could be manufactured as recently as fifteen years ago. As a result, and for anything beyond the most simplistic mat arrangements that were characteristic of decades past, the manner in which the WWR industry communicates its product attributes has evolved considerably to ensure there is sufficient descriptive and dimensionally-illustrative accompaniment. Figures 7 through 21 show a sampling of non-traditional welded wire reinforcement mat configurations.



Figure 7: WWR mat with variable linewire spacing



Figure 8: WWR mat with variable linewire and crosswire spacing, size, and length

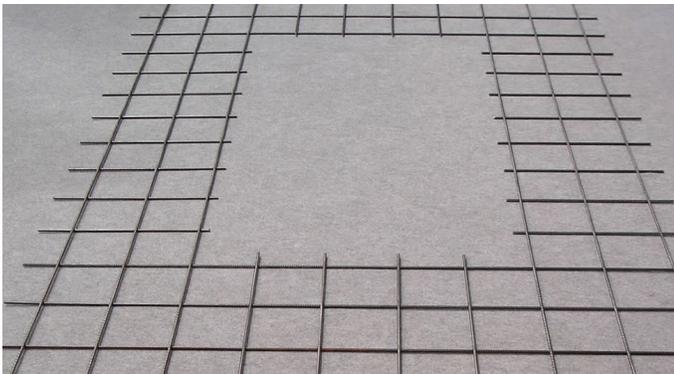


Figure 9: WWR mat produced with variable length linewires and crosswires, automatically assembled and welded so as to allow for an opening in the precast concrete panel into which the mat will be cast.



Figure 10: WWR mat bundle showing project-specific wire arrangement and overhangs



Figure 11: WWR mat bundle showing variable spacing of linewires and crosswires



Figure 12: WWR mat bundle showing configuration to be used in a precast concrete application. Note the manufacturer-bent wire terminations.



Figure 13: WWR mat bundle showing a configuration intended for a circular slab application

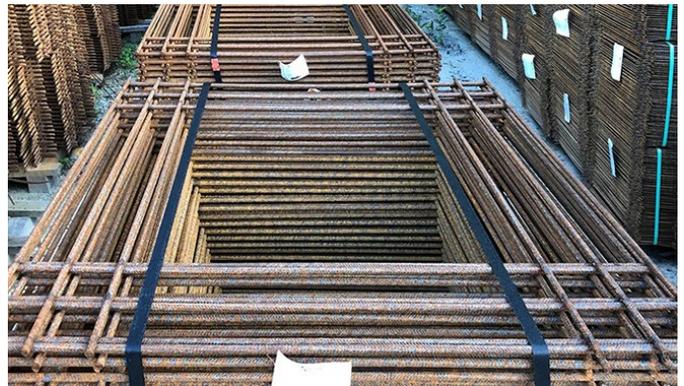


Figure 14: WWR mat bundle showing a configuration intended for the top slab of a square concrete riser structure



Figure 15: WWR mat bundle showing a configuration for use in a precast concrete element.



Figure 16: WWR mat bundle showing a configuration for use in a precast concrete element.



Figure 17: WWR mat bundle showing a configuration to be used in a structural slab. Notice the extended overhangs to facilitate the lap splice continuity of adjacent mats once placed in the field.



Figure 18: WWR mat bundle showing a configuration characterized by wide wire spacing.

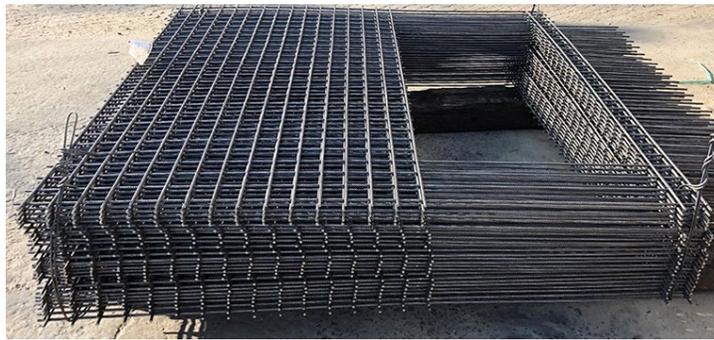


Figure 19: WWR mat bundle showing a configuration intended for a precast panel application with a finished opening

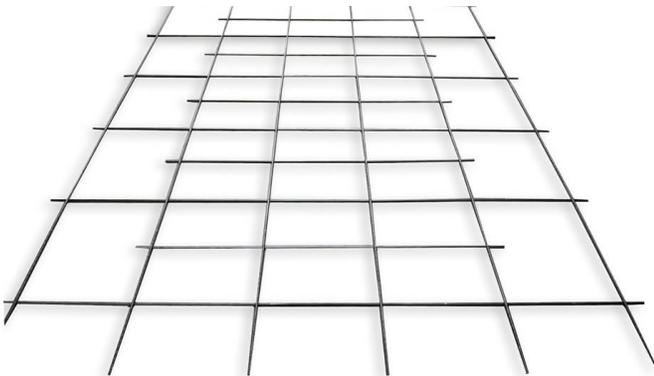


Figure 20: WWR mat with specifically-distributed wires to suit cross-sectional area requirements.

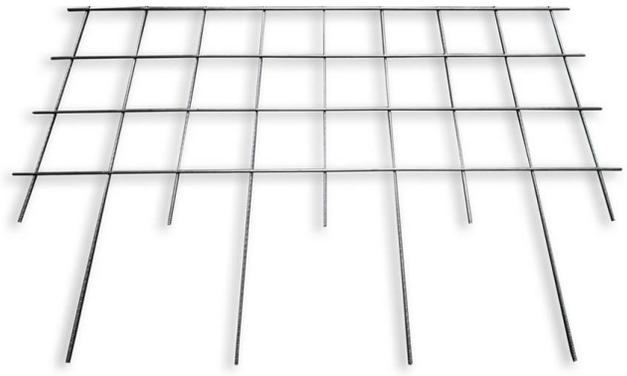
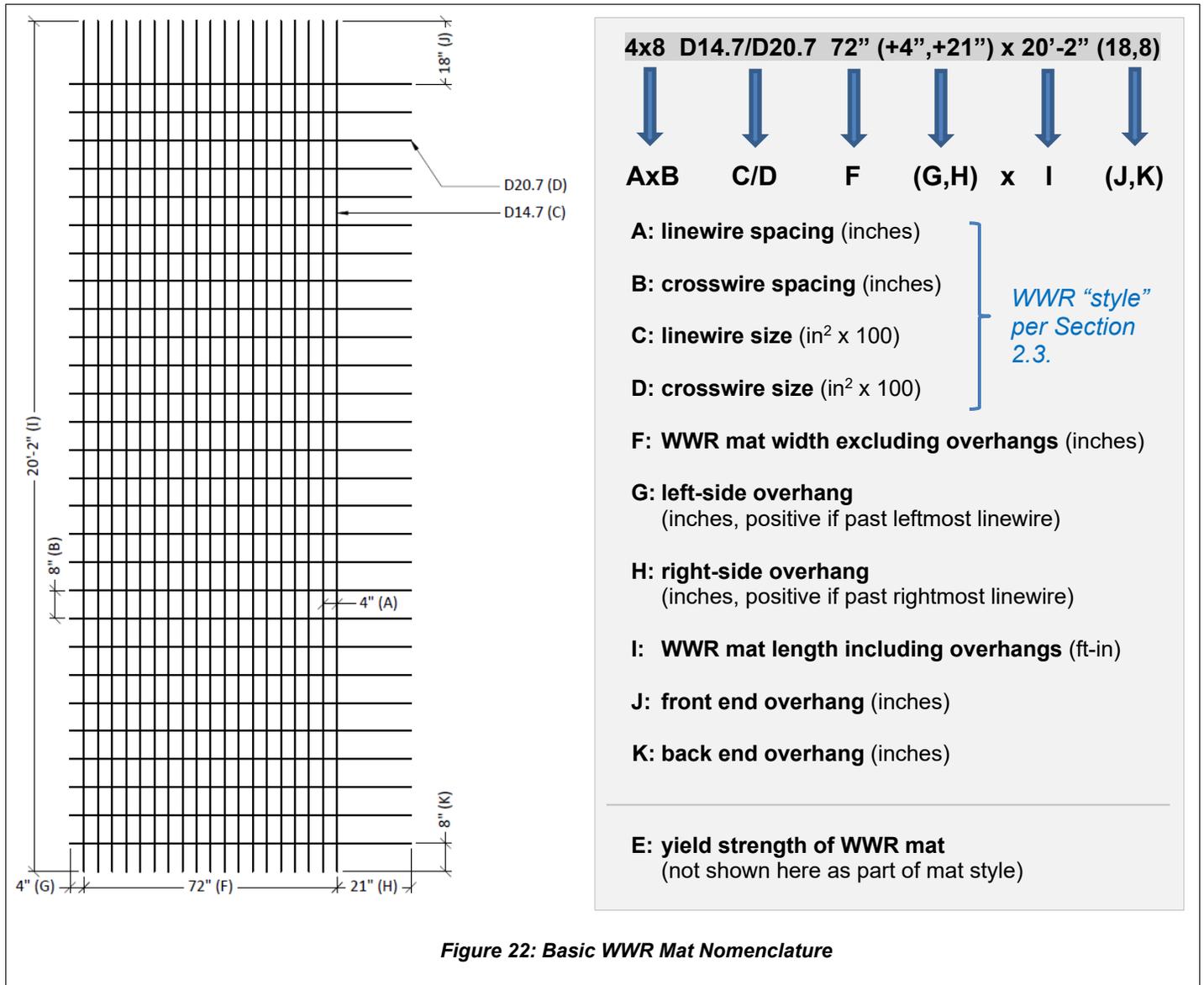


Figure 21: WWR mat showing the manufacturing ability to provide variable length overhangs to facilitate staggered tension lap splices.

2.4 Dimensions

Description of WWR width, length, overhang dimensions, and variable spacing information (when applicable) is illustrated below.



The WWR sheet description shown in Figure 22 reflects a simplistic wire arrangement that theoretically would not need an accompanying illustrative detail due to the relative straightforwardness of the configuration. Basic definitions are as follows:

Mat Length (I)

Tip-to-tip dimension of longitudinal wires (linewires), including linewire overhang beyond the endmost transverse wires (crosswires). This measurement is notable as it corresponds to the full length of linewire being "pulled" through the production welding line.

Mat Width (F)

Center-to-center distance between outermost longitudinal wires (linewires), excluding transverse wire (crosswire) overhangs. This measurement is notable as it represents the maximum transverse extent of the welding head group that is necessary to actually produce the sheet.

Mat Overall Width (G+F+H)

Mat dimension including the transverse wire (crosswire) overhangs.

Chapter Three

Manufacturing & Availability

3.1 Manufacturing Process

The wire used in welded wire reinforcement is produced from controlled-quality, hot-rolled steel rods. These rods are cold-worked through a series of dies or cassettes to reduce the rod diameter to the specified diameter, as well as to introduce indentations or protrusions in the case of deformed wire. Inherent to the cold-working process is an increase in yield strength of the wire. Chemical composition of the steel is carefully selected to give proper welding characteristics in addition to desired mechanical properties.

Automatic welding machines are designed and operated for consistent manufacturing of a wide variety of welded wire reinforcement mat configurations. After wires are drawn to size, longitudinal wires are straightened and fed through the machine while the straightened and cut transverse wires, entering from the side of the welder, are individually welded at right angles to the longitudinal wires as the longitudinal wires are advanced through the welding head group. Depending on the size of wires being welded together, the welding electrode settings are electronically adjusted to provide the appropriate combination of pressure and heat necessary to achieve the prescribed electric resistance weld characteristics. As high electrical current is passed through two wires in contact, molten metal is instantaneously formed at the wire interface to fuse the wires together. This process is in stark contrast to traditional arc welding processes, as there is no consumable electrode (filler material) being deposited to fuse the workpieces together.

Figures 24 through 31 show various stations associated with the WWR manufacturing process line.



Figure 24: A down-the-line view of a welding production line



Figure 25: A view showing staging area populated with straightened and cut-to-length individual wires that will be automatically positioned and pulled through the machine. These wires will ultimately serve as the linewires on the automatically-welded WWR structural mat.



Figure 26: An overhead view of a dual feed assembly station on the welding line. Straightened and cut-to-length wires are pre-loaded and fed down from hoppers to the line of welding electrodes, at which point these cross wires are electric resistance welded to the longitudinally oriented linewires.

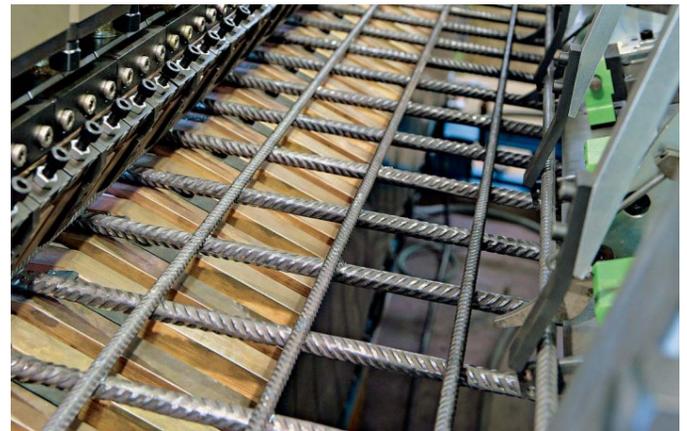


Figure 27: Transverse view of the welding electrode line with heavy structural welded deformed wire reinforcement



Figure 28: View of the welding electrode line in action.



Figure 29: A close-up transverse view of wire intersections being fused by the electric resistance welding process on a modern automatic welding machine.



Figure 30: Output side of the WWR production line, showing a WWR mat intended for structural slab usage.



Figure 31: A view of the output side of the production line, showing completed WWR mats downstream of the welding station. Modern equipment is utilized to stack (as well as "flip" for better nesting of material within a bundle) the finished WWR mats. The WWR mats are then either transferred to a bending fabrication station or, for material to remain flat, directly to a staging area for subsequent loading onto trucks for delivery.

WWR is manufactured with the following variables:

- Longitudinal wire spacing
- Longitudinal wire size
- Width
- Side and end overhangs
- Transverse wire size
- Transverse wire spacing
- Length

These variables may be changed in the manufacturing process with different amounts of time required depending on the type and extent of the change (or combination of changes). With significant advances in modern welding equipment and manufacturing plant layout, changeover times necessary to transition from one WWR mat configuration to the next in a continuous production run can be reduced significantly. The state-of-the-art manufacturing operation has evolved to allow for a greater emphasis to be placed on process automation, in turn facilitating more efficient allocation of man-hours on the plant floor.

As with any other manufactured structural product, the use of welded wire reinforcement becomes more efficient and economical as the amount of repetition in reinforcement increases. Economy is a function of the efficiency of the manufacturing process itself in conjunction with the repeatability and volume of a particular WWR configuration to be produced. In response to this, industry standard practice is to carry certain common welded wire reinforcement items as inventory to align with market trends and customer demand. Beyond the standard inventory, welded wire reinforcement manufacturers are well-versed in collaborating with individual customers and leveraging their in-house engineering and detailing resources to satisfy orders characterized by project-specific, highly variable WWR mat configurations.

It is commonplace for manufacturers to consult with both specifiers and purchasers regarding topics including but not limited to production capabilities, mat customization options, availability of in-house engineering and detailing, and fabrication resources.

3.2 Fabrication Capabilities

For projects on which shaped reinforcement arrangements are required to “fit” a structural element’s cross-section, flat welded wire reinforcement mats go through a post-welding fabrication process.

Fabrication of WWR typically consists of bending and/or cutting of mats to achieve project- and application-specific reinforcement geometries. Once the automatic welding process is completed and welded wire reinforcement mats are accumulated and stacked at the end of the process line, the flat mats are transferred to a fabrication station and the designed spatial arrangement of the reinforcement is completed.

The fabrication of welded wire reinforcement into various structural shapes is readily accomplished with two basic pieces of portable equipment: a bending machine and a cutting device, each of which operates on electric power.

The automatic bending machine provides the flexibility of adjusting to various wire spacings, angles of bend, and bending radii. This equipment is manufactured in sizes ranging in length from 8 to 40 feet. Capacities range from small wire sizes to heavy structural wires up to 3/4” diameter. The mats of welded wire are bent on the machine by an arm which rotates through an angle of 0° to 180°, shaping the wires around the circular mandrels. This arm can be preset to stop at any angle; additionally, both the mandrel size and their positioning are adjustable, allowing for variation in diameter and spacing along the length of the mat as required to meet the design requirement for bend radius and wire layout.

Cutting equipment can be a simple hand tool capable of cutting one wire at a time or larger powered equipment, which cuts the full width of a sheet in one operation. This powered equipment allows the use of more economically manufactured sheets of wire reinforcement. Similar to bending equipment, cutting equipment is also portable and made available to contractors for on-site use.

WRI’s *WWR-400 Bending Welded Wire Reinforcement* provides a more comprehensive discussion on typical manufacturer fabrication capabilities, standards, and examples of bent welded wire reinforcement produced to suit specific structural applications.

Figures 32 through 40 show various stages and attributes related to the WWR bending fabrication process.



Figure 32: A long WWR mat on a bender. Note the alignment of wires with the individual bending mandrels, and the mat itself being pushed through an angle by the continuous rail arm behind.

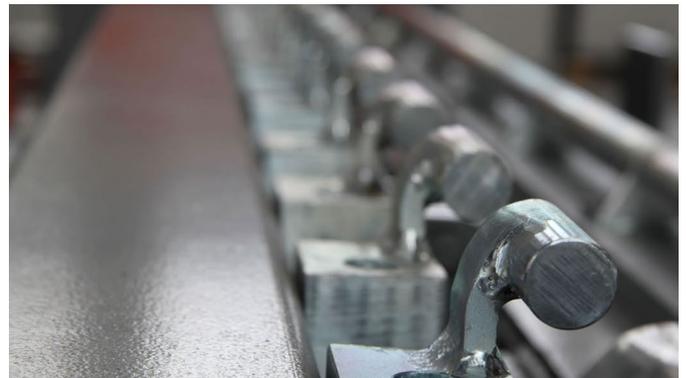


Figure 33: A close-up view of an interchangeable bending mandrel. Mandrels are produced in varying diameters to suit the required bend diameter. Positioning of the mandrels along the length of a bender can be adjusted to suit the specific spacing of the wires on the mat.



Figure 34: Bending of a WWR mat with large diameter wires



Figure 35: A WWR mat on a bender. Notice the staging of the remaining WWR mats to be bent as part of the scheduled bending operation.



Figure 36: A down-the-line view of a bent WWR mat, shaped to suit a U-cage for use in a barrier rail.



Figure 37: A precast beam stressing line populated with bent stem and flange WWR mats.



Figure 38: Bent WWR installed in forms for the production of precast concrete stadium risers.



Figure 39: WWR mat used in the stem of a precast prestressed girder, showing bent terminations of stem reinforcement positioned to extend into a subsequently cast-in-place bridge deck.



Figure 40: A bent WWR mat with 135-degree hooked terminations for use in the beams of special moment frames (high seismic application).

3.3 Specifying and Ordering

The specification of welded wire reinforcement is the responsibility of the design professional of record, with reinforcement selected to suit the strength and serviceability requirements of the concrete structure or element being designed.

A common misconception is that it is the specifier's responsibility to present the full style and description of a WWR mat (covered in MSP Chapter 2) in their design documentation in order for the manufacturer to be able to properly process the information. In reality, and in large part due to how the manufacturing industry's collective technical capabilities have rapidly evolved in recent years, the extent to which WWR is actually defined on a set of structural drawings and/or in a set of project specifications is fairly minimal.

In its most basic form, using the **Direct Specification Method** to effectively specify WWR, the following attributes must be clearly identified for the manufacturer to in turn produce the representative reinforcement:

1. Wire size
2. Wire spacing
3. Wire grade
4. Wire shape "in structure"
5. Wire lap splicing requirements (when applicable)

Wire size, spacing, and grade are defined through simple annotations. Wire shape is communicated via drawings – typically a combination of plan, section, and elevation views that are standard illustrative representations for even the most basic of structural designs. And lap splice requirements are derived directly from the appropriate reference standard or code, such as ACI, AASHTO, or AREMA, and are often presented on drawings in the form of a lap splice schedule.

With the above designer’s directly-specified information in hand, the manufacturer will in turn derive and detail the appropriate WWR mat geometries, quantities, and descriptions.

As an alternative to the Direct Specification Method, an increasingly popular method of specifying WWR is to utilize **Specification by Pre-Approval**. Specification by Pre-Approval allows for the design professional to maintain their longstanding design and detailing routines that are predicated on the use of reinforcing bars, while allowing for welded wire reinforcement inclusion as a substitution to rebar by way of permissive language “built in” to the drawings/specifications themselves. This method is made possible by the fact that – from a reinforced concrete design perspective as outlined in prevailing design standards (ACI, AASHTO, and AREMA) - reinforcing bars and welded wire reinforcement are largely interchangeable as mild reinforcement used in the determination of sectional strength of structural concrete. To deploy the **WWR Specification by Pre-Approval** method, the following attributes must be clearly identified for the manufacturer to produce the representative equivalent reinforcement:

1. Rebar size
2. Rebar spacing
3. Rebar grade
4. Rebar shape “in structure”
5. Rebar lap splice requirements (when applicable)
6. WWR pre-approval language, typically presented in the “General Notes” section of project drawings

An excerpt showing an example of WWR pre-approval language is presented in Figure 41.

MILD REINFORCING STEEL

1. TYPICAL DEFORMED REINFORCING BARS (REBAR) SHALL CONFORM TO ASTM A615, GRADE 80. BARS SHALL BE LAPPED IN ACCORDANCE WITH THE REBAR LAP SCHEDULE UNLESS OTHERWISE EXPLICITLY DETAILED.
2. LONGITUDINAL REINFORCEMENT IN SPECIAL MOMENT FRAME BEAMS AND COLUMNS, AND VERTICAL AND HORIZONTAL REINFORCEMENT IN SPECIAL STRUCTURAL (SHEAR) WALLS SHALL BE ASTM A706 GRADE 60 OR GRADE 80 AS NOTED. TENSILE AND ELONGATION PROPERTIES SHALL BE CONFIRMED THROUGH MILL REPORT DOCUMENTATION PROVIDED AS PART OF THE PROJECT REINFORCEMENT SUBMITTAL.
3. WELDED DEFORMED WIRE REINFORCEMENT SHALL CONFORM TO ASTM A1064 GRADE 80 AND SHALL BE PROVIDED IN SHEET FORM. REINFORCEMENT SHEETS SHALL BE MANUFACTURED WITH OVERHANG LENGTHS SUFFICIENT TO ACHIEVE A LAP SPLICE LENGTH EQUAL TO THE GREATER OF 12 INCHES OR THE LAP SPLICE DIMENSION SHOWN IN THE REBAR LAP SCHEDULE FOR BAR OF EQUAL (OR GREATER) DIAMETER AND GRADE, UNLESS OTHERWISE NOTED. SHEETS AND ASSOCIATED LAP REGIONS SHALL BE INSTALLED COPLANAR SO AS TO NOT “STACK”.
4. WELDED DEFORMED WIRE REINFORCEMENT OF EQUAL AREA, EQUAL OR LESSER SPACING, AND IDENTICAL CURTAILMENT (HOOKS AND LAP SPLICES) IS PERMITTED AS A SUBSTITUTION FOR DEFORMED REINFORCING BARS, EXCEPT IN THE FOLLOWING STRUCTURAL APPLICATIONS:
 - A. LONGITUDINAL STEEL IN SPECIAL MOMENT FRAMES
 - B. VERTICAL AND HORIZONTAL STEEL IN SPECIAL STRUCTURAL WALLS

Figure 41: General Notes excerpt showing WWR permissive language and specific exclusions. Note that this engineer is calling for identical curtailment of WWR and has listed two specific exclusions where applications must remain rebar.

With the designer’s pre-approval information clearly stated on the contract structural drawings, combined with the “standard” familiar rebar detailing and curtailment, the manufacturer will in turn derive and detail the appropriate WWR mat geometries, quantities, and descriptions, and will furnish accompanying submittal information clearly defining the applications for which WWR substitutions are to be used by the contractor, as well as appropriate strength / steel area equivalencies. An example of submittal equivalency information that is provided to the designer by the manufacturer is shown in Figure 42.

| Spread Footing Reinforcement | | | | | | | WWR Substitution | | | | | | |
|---|-------------------------|---|--|--|--|---|---------------------|--|--|--|---|--|--|
| Project: ABC Office Building | | | | To: Project General Contractor | | | Date: June 10, 2021 | | | | Structural EOR: Project Structural Engineering Firm | | |
| By: WWR Designer | | | | | | | | | | | | | |
| Specified Rebar – $f_y = 80$ ksi | | | | | | | | | | | | | |
| Footing | Specified Reinforcement | Total Reinforcement Area (in ²) | Hooked Termination? | Approximate Bar Spacing Based on Edge Cover (in) | Nominal Rebar Tensile Strength (kips) $N_a = A_s \times f_y$ | WWR ID Utilized | | | | | | | |
| F80 | (7) #6 EW B | 3.08 | N | 15 | 246.4 | WWR-F80 | | | | | | | |
| | (0) EW T | 0 | N/A | N/A | N/A | N/A | | | | | | | |
| Substituted WWR – $f_y = 80$ ksi | | | | | | | | | | | | | |
| WWR ID | Mat Type | Mats Per Footing | Wires in X/Y Directions (For uni-directional mats, Y-Dir non-structural wires) | Average Wire Spacing (in) | Reinforcement Area Provided, X/Y (in ²) | Nominal Tensile Strength Provided $N_a = A_s \times f_y$ (kips) | | | | | | | |
| WWR-F80 | B | 1 | (11) D28.0/ (11) D28.0 | 9 | 3.08/3.08 | 246.4 | | | | | | | |
| Mat Type: | | | | | | | | | | | | | |
| A. <i>Uni-directional</i> - structural wires in the primary direction; minimal non-structural holding wires at wide intervals in secondary direction, positioned to maintain mat shape. | | | | | | | | | | | | | |
| B. <i>Bi-directional</i> - structural reinforcement in both orthogonal directions fabricated on a common WWR mat | | | | | | | | | | | | | |
| Bending: None | | | | | | | | | | | | | |
| Material: ASTM A1064, 80 ksi yield strength | | | | | | | | | | | | | |
| NOTES: | | | | | | | | | | | | | |
| 1. See placement drawings for detailed WWR mat description, geometry, and arrangement in the structure. | | | | | | | | | | | | | |
| 2. Field trimming of mats is not permitted. | | | | | | | | | | | | | |

Figure 42: Example of manufacturer’s submittal showing WWR substitution for rebar in spread footing

While the **Direct Specification Method** and **Specification by Pre-Approval** are the most common and preferable approaches to communicating WWR usage on a project as part of its design documentation, there are of course notable exceptions. For example:

1. Because welded wire reinforcement has long been established as a natural fit for precast elements such as box culverts, reinforced concrete pipe, riser segments, and double tees, precasters themselves are often familiar with and comfortable enough to define WWR styles in much greater detail during design than would be required by the aforementioned Direct Specification or Pre-Approval methods.
2. In many instances, specifically for underground water conveyance structures like box culverts and pipes, the respective ASTM specifications actually identify for an expansive tabulation of predefined structural geometries the reinforcement requirements in terms of steel area per linear foot. These tabulated steel areas are then correlated by the manufacturer, and representative WWR mats are derived to suit and confirmed by the design professional of record as acceptable prior to fabrication.
3. During the bid phase it is not uncommon for contractors to contact manufacturers directly to seek “value engineered” substitutions for reinforcing bar arrangements on projects for which the design phase has been completed. Once a VE scope is clearly defined and coordinated between the contractor and manufacturer, and the scope and proposed substitutions deemed acceptable by the design professional of record, applicable cost and time savings are then built into the bid.

Once a project's reinforcement requirements are defined and the manufacturer has correlated the information into a representative welded wire reinforcement package, an order can be placed. Ordering welded wire reinforcement is an intuitive process. Because of the evolution of manufacturers' in-house technical and engineering staffs in response to more expansive and complex utilizations of WWR on structural projects, order summaries are commonly accompanied by illustrative representations of the material comprising the order (See Figure 43).

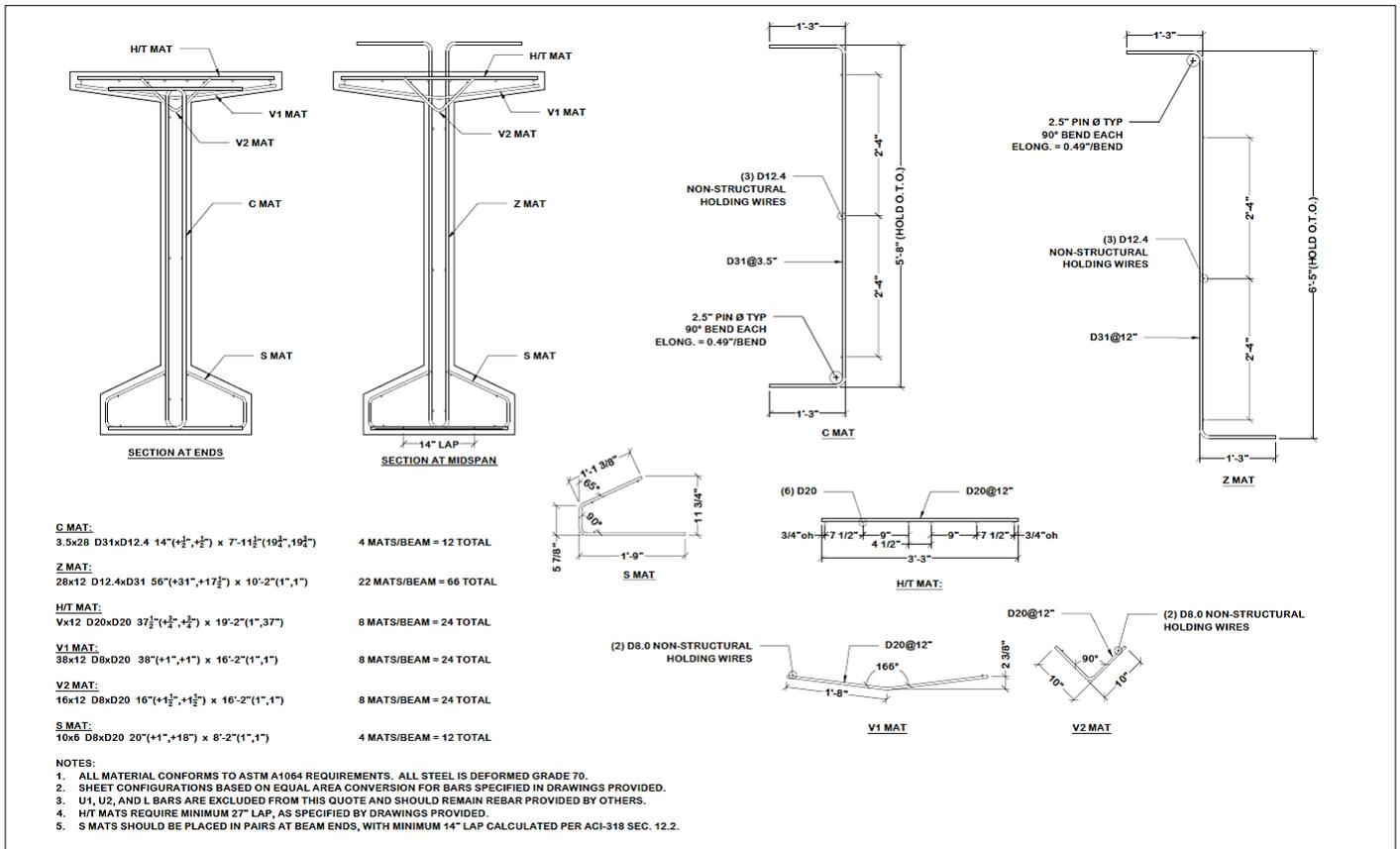


Figure 43: Illustrative accompaniment to a WWR order; in this case, reinforcement for a precast bridge girder

Welded wire reinforcement orders consist of the following components and are defined in ASTM A1064 Section 4:

1. Quantities and/or square area for welded wire reinforcement
2. Name of the WWR mats
3. Wire size number, wire spacing, and mat width, length, and other relevant geometric attributes
4. Minimum yield strength of material
5. Packaging and marking for traceability
6. ASTM designation and year of issue
7. Purchaser-defined special requirements, including but not limited to exclusion of over-steeling, additional testing, or packaging requirements, and/or additional mechanical property requirements

Chapter Four

Material Properties and Specifications

4.1 ASTM Standard Specification

ASTM International has established specifications for plain and deformed wires as well as welded plain and deformed wire reinforcements. These specifications are noted in Table 4.1.

| ASTM Number | Standard Specification for |
|-------------|--|
| A1064 | Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete |
| A884 | Epoxy-Coated Steel Wire and Welded Wire Reinforcement |
| A1022 | Deformed and Plain Stainless-Steel Wire and Welded Wire for Concrete Reinforcement |
| A1060 | Zinc-Coated (Galvanized) Steel Welded Wire Reinforcement, Plain and Deformed, for Concrete |

Governmental agencies may invoke supplemental provisions that append to those requirements set forth in the ASTM standards. It should be understood by the specifier that manufacturers, by default, produce material in conformance with ASTM standards, and that additional specifier preferences or requirements must be identified as a “special requirement” as permitted by ASTM A1064 Section 4.

It is also worth noting that the now withdrawn ASTM standards (A82, A185, A496, and A497) that preceded ASTM A1064 are no longer considered appropriate specification references for new construction or newly-renovated construction, and as such are superseded by ASTM A1064.

4.2 Yield Strength and Tensile Strength

Welded wire reinforcement yield strength and tensile strength requirements are defined in ASTM A1064 as shown in Tables 4.2, 4.3, and 4.4.

| Grade | Yield Strength, minimum measured (psi) | Tensile Strength, minimum measured (psi) |
|-------|--|--|
| 65 | 65,000 | 75,000 |
| 70 | 70,000 | 80,000 |
| 72.5 | 72,500 | 82,500 |
| 75 | 75,000 | 85,000 |
| 77.5 | 77,500 | 87,500 |
| 80 | 80,000 | 90,000 |

1. Minimum reduction of area in sample during tensile test = 30%

Table 4.3 – Plain Wire for Welded Wire Reinforcement¹; Wire Size < W1.2

| Grade | Yield Strength, minimum measured (psi) | Tensile Strength, minimum measured (psi) |
|-----------|--|--|
| 56 | 56,000 | 70,000 |

1. Minimum reduction of area in sample during tensile test = 30%

Table 4.4 – Deformed Wire for Welded Wire Reinforcement¹

| Grade | Yield Strength, minimum measured (psi) | Tensile Strength, minimum measured (psi) |
|-------------|--|--|
| 70 | 70,000 | 80,000 |
| 72.5 | 72,500 | 82,500 |
| 75 | 75,000 | 85,000 |
| 77.5 | 77,500 | 87,500 |
| 80 | 80,000 | 90,000 |

1. Minimum average height of deformations in percent of nominal wire diameter: D3 and smaller (4%); larger than D3 through D10 (4.5%); larger than D10 (5%)

Yield strength is determined and reported according to ASTM A370 using a Class B1 extensometer at either an extension under load of 0.5% of gage length or by the 0.2% offset method. The 0.5% EUL measurement is consistent with the methodology cited in the AASHTO LRFD Bridge Specification, while the 0.2% offset measurement aligns with the standard procedure referenced in the ACI 318 Building Code Requirements for Structural Concrete. In determining the yield strength, it is permissible to remove the extensometer after the yield strength has been determined.

As outlined in ASTM A1064, and unless otherwise specified by the purchaser as a special requirement, test results for yield strength and tensile strength are reported for welded plain wire reinforcement above Grade 65 and for welded deformed wire reinforcement above Grade 70. When the tensile tests are carried out, the wire samples used are cut from the welded wire reinforcement and tested either across or between welded intersections, with not less than 50% of these tests being carried out across welds.

4.3 Weld Shear Strength

A unique attribute of welded wire reinforcement is the contribution made by welded intersections to the anchorage and bond of the reinforcement within hardened concrete.

For welded plain wire reinforcement, because of the smooth wire surfaces, weld shear strength is the only means by which a pullout-type failure mode can be resisted. As visualized in Figure 44, when tension is applied to the reinforcement mat, the hardened concrete bears against the surfaces of wires positioned perpendicular to the tensile force. As a result, a shear force develops at the interface between welded wires, and the resistance to this shear force is resolved entirely by the weld that exists at those locations.

Reference standards including ACI 318 and AASHTO LRFD Bridge Specification provide equations to determine required tension development length and tension lap splice length for welded plain wire reinforcement. The development length requirements are predicated on intentional positioning of welded intersections relative to the critical section of the member, while the tension lap splice requirements are contingent upon intentional positioning of welded intersections relative to the lap splice region and the adjoining WWR mat.

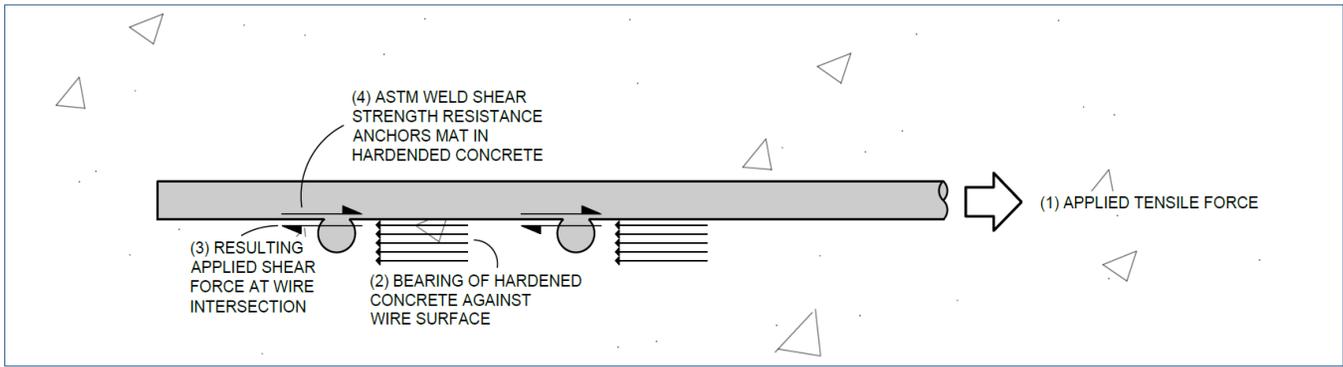


Figure 44: Conceptual detail of weld shear strength

For welded deformed wire reinforcement, the designer ultimately has a choice. Anchorage and bond behavior can be achieved through one of the following:

- A. A combination of weld shear strength (as noted previously for welded plain wire reinforcement) and bond that develops along the deformed wire surface as a result of hardened concrete bearing against the protruding or indented deformations.
- B. Bond that develops along the deformed wire surface as a result of hardened concrete bearing against the protruding or indented deformations, without contribution from welded intersections

Reference standards including ACI 318 and AASHTO LRFD Bridge Specification provide equations for the determination of tension development length and tension lap splice based on (A), which is predicated on intentional positioning of welded intersections relative to the member critical section and lap splice region, respectively. These reference standards also provide for (B), with the routine essentially disregarding any contribution to anchorage or bond made by the welded intersections themselves, in turn requiring the designer to calculate development length and lap splice length based on the deformed wire surface alone. In many - if not most - instances for welded deformed wire reinforcement, utilizing the approach in (B) can actually result in more economical and spatially-compatible reinforcement configurations, with the added benefit being that the approach is inherently familiar considering the design equations used are the exact same as those used to calculate development length and lap splice length for loose deformed bars or loose deformed wires.

Weld shear strength requirements per ASTM A1064 are presented in Figure 45 below.

| Figure 45 - ASTM A1064 Minimum Average Weld Shear Strength (pounds) ¹ | | |
|---|---|--|
| Relationship at Welded Intersection | Welded Deformed Wire Reinforcement ² | Welded Plain Wire Reinforcement |
| $A_{s,smaller\ wire} \geq 0.40 \times A_{s,larger\ wire}$ (also known as the "40% Rule") | $35,000 \times A_{s,larger\ wire}^3$ | $35,000 \times A_{s,larger\ wire}$ |
| $A_{s,smaller\ wire} < 0.40 \times A_{s,larger\ wire}$ | 800 lbs | Not Permitted for structural applications ⁴ |

1. Wire cross-sectional area noted as and presented in terms of square inches (in^2)
2. Smallest deformed wire size is D4.
3. The design professional is permitted to waive the weld shear requirement for welded deformed wire reinforcement in those design applications where welded intersections satisfying the 40% Rule are not relied upon for tension development length, tension lap splice, or shear stirrup anchorage. Waiver would need to be communicated as a "special requirement" per ASTM A1064 Section 4.2. When this waiver is applied, minimum average weld strength at intersections would default to 800 pounds and the welded intersections would be considered non-structural.
4. Because welded plain wire reinforcement relies entirely on the presence of structural welds to be considered a viable structural reinforcement, a wire size relationship not satisfying the 40% Rule renders the wire intersection inappropriate for structural use.

4.4 Corrosion Mitigation

There are several options available for welded wire reinforcement mats used in structures subjected to deleterious or corrosive environments.

Epoxy Coating of Welded Wire Reinforcement in accordance with ASTM A884 is applied by a CRSI (ANSI) certified coating applicator and provides a complete epoxy corrosion protection barrier of the steel surface to prevent corrosion against the elements and concrete chemicals. The certified epoxy coating process starts with the cleaning/preparation of the steel surface through a steel grit shot blasting process. Upon completion of the steel shot blasting process, the metal surface is tested for backside contamination, chlorides and profile (etched depth of the steel). After passing these pre-coating CRSI Epoxy Coating requirements, and within 180 minutes of blasting, the welded wire reinforcement is preheated in an oven to the prescribed metal temperature prior to applying the certified epoxy coating. Once at temperature, the certified Epoxy coating is applied and then cured per the certified epoxy coating manufacturer's curing schedule. Post inspecting, handling, storage, and delivery to the jobsite is then completed per the CRSI Certified Epoxy Coating Standards to ensure the durability and protection of the epoxy coated welded wire reinforcement. Figure 46 shows epoxy-coated bent WWR mats that have been bundled for shipment after completion of the coating process.



Figure 46: Bundled epoxy-coated WWR

Hot-dip galvanizing of welded wire reinforcement in accordance with ASTM A1060 can be applied to flat or bent WWR mats after the automatic welding process and bending fabrication. As part of the galvanizing process, the WWR mats are prepped, chemically and/or mechanically cleaned, run through a series of rinsing, fluxing, and zinc bath immersions, and then placed in a drying oven to ensure a continuous and reliable zinc-rich coating.

The use of stainless-steel wires in the manufacture of welded stainless-steel wire reinforcement is carried out in accordance with ASTM A1060. Stainless steel wires, typically produced to “design diameter” and furnished in stock straight lengths, are subsequently delivered to the WWR manufacturing plant at which point the material itself is run through the automatic welders, resulting in a welded stainless steel wire reinforcement mat. For the resulting stainless steel WWR mats, necessary precautions must be taken to ensure that stainless product and carbon steel product – two dissimilar metals - are stored/staged as required to eliminate the potential for galvanic corrosion.

Chapter Five

Structural Applications

5.1 Design Reference Standards

The following documents and publications are relevant to the specification and design of structures utilizing welded wire reinforcement.

Publications of the Wire Reinforcement Institute (WRI)

WWR-400 Bending Welded Wire Reinforcement

WWR-600 Welded Wire Reinforcement Design and Detailing Guide

Publications of the American Concrete Institute (ACI):

ACI 117 Specification for Tolerances for Concrete Construction and Materials

ACI 301 Specification for Structural Concrete

ACI 302.1 Guide to Concrete Floor and Slab Construction

ACI 315 Guide to Presenting Reinforcing Steel Details

ACI 318 Building Code Requirements for Structural Concrete

ACI 360 Guide to Design of Slabs-on-Ground

Publications of the Association of State Highway and Transportation Officials (AASHTO):

LRFD Bridge Design Specifications

Publications of the American Railway Engineering and Maintenance-of-Way Association (AREMA):

Manual of Railway Engineering

Publications of the Precast/Prestressed Concrete Institute (PCI)

PCI Design Handbook

The above publications coupled with additional WRI resources noted in Chapter 1 serve as the basis for structural design using welded wire reinforcement. Generally speaking, with a few exceptions related to high-seismic applications (such as those specifically identified in ACI to be part of the primary reinforcement of special structural walls and special moment frames), welded deformed wire reinforcement is interchangeable with loose deformed reinforcing bars as it relates to calculation of sectional strengths and bond and development behavior. Design routines and procedures carried out by the licensed design professional are essentially unchanged.

5.2 Precast Concrete

The prefabricated, modular-like construction of precast structures and building elements has long been a natural fit for the implementation of welded wire reinforcement. Examples of precast concrete utilizing welded wire reinforcement are noted in **Table 5.1** below. The precast industry continues to lead the way in its progressive use of welded wire reinforcement and its wide

Table 5.1 Common Precast Concrete Applications

| Structure / Structural Element | Reinforcement Utilization |
|--|---|
| Box culvert | Walls and slabs: A, M, ST, V |
| Concrete pipe | Walls: A, M, ST, V |
| Wingwalls and safety end treatments | M, ST |
| Manhole riser | Walls and slabs: A, M, ST |
| Prestressed bridge girders | Stems: V, T Flanges: M, T |
| Median barrier rail | ST, IP |
| Segmental arch bridge | Walls and slab: A, M, ST |
| Parking garage and building double tees | Stems: V Flanges: M (transverse to stem) |
| Parking garage and building inverted-tee girders | ST, T, V |
| Parking garage and building columns | T, V |
| Stadium seating risers | M, ST |
| Underground Tunnel segments | M, T, V |
| Roadside sound wall panels | M, ST |

Symbols:

| | |
|--|----|
| Axial | A |
| Flexure | M |
| Shrinkage/temperature | ST |
| Confinement / support of longitudinals | T |
| Shear | V |
| Impact | IP |

Refer to applicable standard (ACI, AASHTO, AREMA, PCI) for limitations related to high seismic usage.

5.3 Cast-in-Place Concrete

The cast-in-place concrete industry derives significant time and labor savings from the implementation of welded wire reinforcement into structural assemblies traditionally associated with individual reinforcing bars. Refer to Table 5.2 for cast-in-place building elements that utilize welded wire reinforcement.

Table 5.2 Representative Cast-in-Place Concrete Applications

| Structure / Structural Element | Reinforcement Utilization |
|--|---------------------------|
| Gravity beams and girders | A, M, ST, T, V |
| Beams and girders in special moment frames | T, V |
| Gravity columns | A, M, ST, T, V |
| Columns in special moment frames | T, V |
| Walls (ordinary load-bearing, foundation, and retaining) | A, M, ST, T, V |
| Shear walls (ordinary reinforced structural walls) | A, M, ST, T, V |
| Shear walls (special structural walls) | T, V |
| One-way slabs | A, M, ST, T, V |
| Two-way slabs | A, M, ST, T, V |
| Elevated slabs contributing to special seismic system frame action | T, V |
| Structural mat slabs | A, M, ST, T, V |
| Structural mat slabs contributing to special seismic system inelastic behavior | T, V |
| Slabs-on-ground | A, M, ST |
| Footings and pile caps | A, M, ST |
| Footings and pile caps part of the special seismic system | T, V |

Symbols:

| | |
|--|----|
| Axial | A |
| Flexure | M |
| Shrinkage/temperature | ST |
| Confinement / support of longitudinals | T |
| Shear | V |

5.4 Non-Traditional Applications

There are numerous applications in which welded wire reinforcement can be deployed as a solution other than those presented in Section 5.2 and 5.3. The utilization of welded wire reinforcement in applications other than those specific to use as a structural reinforcement for concrete — or in non-typical reinforced concrete applications — is a function of purchaser and manufacturer collaboration and creativity. Some common applications are referenced below.

- Gabion wall cages
- Soundwall panels and columns
- Pile repair encasement reinforcement
- Shotcrete wall repair
- Shotcrete swimming pool walls and slabs
- Mechanically-stabilized earth (MSE) coursing and anchorage mats
- Standee mats for voided slab reinforcement
- Cast stone reinforcement
- Concrete countertops and related architectural elements and appurtenances

Chapter Six

Material Handling, Shipping and Unloading

Welded wire reinforcement sheets are bundled in quantities depending on size of sheets and corresponding weights in accordance with customer requirements and capacities, and then then shipped. Bundles can weigh between 2,000 and 5,000 pounds. The bundles are bound together using steel strapping or wire rod ties. It is particularly important to note that the strapping or wire ties are selected and installed for the sole purpose of holding the sheets together during shipping and unloading and should NEVER be used to lift the bundles. Bundles are commonly assembled by flipping alternate sheets allowing the sheets to “nest”. This allows for a greater number of sheets to be stacked and provides additional stability.

Once sheets are bundled, they are transported to storage or loading areas by forklift trucks or by overhead cranes. Bundles of relatively short sheets can be handled by either forklift trucks with sheet dollies, roller conveyors, or overhead cranes to the storage and loading areas. In some instances, a combination of material handling equipment is used to move material through the plant and to the storage and loading areas. Generally, shorter sheets are loaded onto flatbed trailers using forklifts. Longer sheets are usually loaded with an overhead crane or forklift truck using a spreader bar or frame with a 6-point pick-up so that longer sheets will not deflect or bend excessively when lifted (See Figure 47). Cables or chains are passed through the bundles and fastened to the bottom wires.

After the sheet bundles are loaded onto the flatbed trailers they are secured to the flatbed using chains and binders, nylon straps, steel strapping, or a combination of these devices, in accordance with applicable federal, state and local safety regulations (See Figures 48 through 51). At the shipping destination (either job site or storage facility), the bundles are removed in much the same manner in which they were loaded. Where forklifts are not available, front end loaders equipped with lifting chains may be used. Similar to the overhead cranes used for lifting bundles at the manufacturer’s plant, truck cranes, tower cranes, or hydraulic cranes may be used for off-loading at the job site or storage facility. At all times during off-loading of materials requiring lifting equipment, extreme caution should be exercised, and all safety regulations and practices must be observed.

Geometric limitations during transport are at times a consideration made by the welded Wire reinforcement detailer to ensure that additional charges related to oversize loads are not incurred. For this reason, it is not uncommon to limit welded wire reinforcement sheet widths to 102 inches. On projects where wider sheets are required or preferred to best suit the design, appropriate permits are obtained to allow for load widths in excess of 102 inches.



Figure 47: Forklift loading of WWR bundles onto truck



Figure 48: A truck loaded with a variety of WWR mats ready for transport to the site



Figure 49: A truck loaded with a variety of WWR mats ready for transport to the site



Figure 50: Bundles of bent WWR mats loaded on a truck, ready for transport



Figure 51: A combination of flat and bent WWR loaded on a truck, ready for transport. Placement of the various WWR mat bundles is carefully planned to maximize the amount of material that can fit on the truck without incurring violations related to dimensional and/or weight restriction.

Chapter Seven

Placing

The design professional specifies the amount of reinforcement required and the correct position of the reinforcement within the structural component. To ensure proper performance of the reinforcement, it is essential that the welded wire reinforcement mats be placed on supports to maintain their required position during concrete placement. The supports (either concrete blocks, steel or plastic “chair” devices, bolsters, spacers, or a combination of these) must be appropriately spaced in order to work effectively.

ACI 301 defines a prescriptive support spacing for lighter gage (less than W4.0 / D4.0) welded wire reinforcement configurations, but it should be understood by both the designer and contractor that the prescription itself does not guarantee conformance with a project's specified acceptable tolerance, nor does it allow for alternative support patterns or methods that would achieve conforming results.

Support spacing should be derived on a case-by-case basis with due consideration for attributes such as the reinforcement itself (type, size, and spacing), the intended function/performance of the reinforced concrete element, the selected chair/bolster type, and the substrate upon which the support rests, just to name a few.

Pre-established tolerances - whether through a combination of ACI 318 and ACI 117 requirements or through a design professional's project-specific requirement - should govern placement of welded wire reinforcement.

As a tool for the designer and contractor, WRI TF702 provides guidelines for support spacing based on many years of past successful experience. An excerpt from TF 702 is presented in Figure 52.

| Figure 52 - Suggested Spacings of Supports | | |
|--|---------------------|---------------------------|
| Welded Wire Reinforcement Range | Welded Wire Spacing | Suggested Support Spacing |
| W or D 9 or larger* | 12" and greater | 4-6 ft. |
| W or D5 to W or D8 | 12" and greater | 3-4 ft. |
| W or D9 and larger | Less than 12" | 3-4 ft |
| W or D4 to W or D8 | Less than 12" | 2-3 ft |
| Less than W or D4** | Less than 12" | 2-3 ft. or Less |

Figure 52:

* Spacing of supports for WWR with wires larger than W or D9 could possibly be increased over the spacings shown depending on the construction loads applied.

** Consider using additional rows of supports when large deflections or deformations occur – also spacing of supports may be increased provided supports are placed and properly positioned as concrete is screeded.

Figures 53 through 58 are included herein, showing various placement activities involving WWR as a reinforcement for structural concrete.



Figure 53: Placement of concrete in a post-tensioned parking deck structure where WWR was used as the mild reinforcement in beams and one-way slabs.



Figure 54: This project contained two distinct WWR usages: first, as a reinforcement for the topping slab over a structure constructed of precast double-tees (the mats can be seen staged on top of the double tees), and second as a reinforcement for a two-way mild steel reinforced elevated slab system (a unidirectional mat is being carried by the workers in the foreground, showing structural wires in one direction and non-structural holding wires in the transverse direction).



Figure 55: A worker checks the positioning of bent WWR mats in a casting bed for a precast prestressed girder.



Figure 56: Workers utilize a telehandler to assist in the placement of WWR wall mats.



Figure 57: A placing crew installs WWR stem reinforcement in a casting bed for a precast prestressed highway bridge girder.

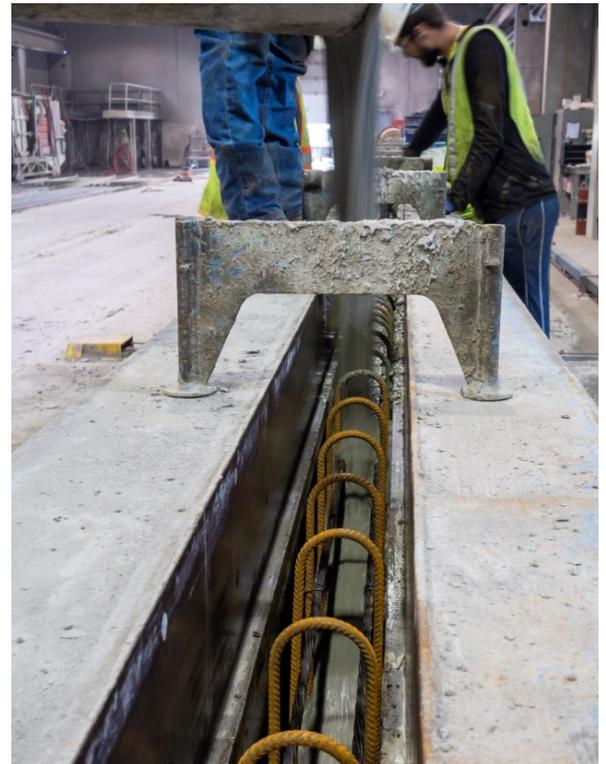


Figure 58: Concrete is poured around a WWR mat assembly positioned in a casting bed for a precast prestressed girder.