Chapter Two

Welded Wire Reinforcement in ACI 318-19

Structural Design Using Welded Wire Reinforcement

The best starting point for gaining familiarity with the permitted use of welded deformed wire reinforcement as mild reinforcement in cast-in-place concrete building structures is Table 20.2.2.4a in ACI 318-19. An abbreviated version is presented below with acceptable usages noted in green.

Usage	Application		Maximum value of f_y or f_{yt} permitted for design calculations, psi	Welded Deformed Wire Reinforcement
Flexure; axial force; and shrinkage and temperature	Special seismic systems	Special moment frames	80,000	(3)
		Special structural walls	100,000	
	Other		100,000	
Lateral support of longitudinal bars; or concrete confinement	Special seismic systems		100,000	(1)
	Spirals		100,000	(2)
	Other		80,000	
Shear	Special seismic systems	Special moment frames	80,000	(1)
		Special structural walls	100,000	
	Spirals		60,000	(2)
	Shear friction		60,000	
	Stirrups, ties, hoops		60,000	
			80,000	
Torsion	Longitudinal and transverse		60,000	
Anchor Reinforcement	Other (non-special seismic system)		80,000	
Regions designed using strut-and-tie method	Longitudinal ties		80,000	
	Other		60,000	

(1) ASTM A1064 welded wire reinforcement is permitted in special seismic systems if the welds themselves are not relied upon to resist stresses in response to confinement, lateral support of longitudinal bars, shear, or other actions. Here the design and manufacturing solution is to have WWR mats fabricated with hooked terminations.

(2) Equipment used to produce ASTM A1064 welded wire reinforcement mats cannot physically form spiral/helical geometry, so WWR use in spiral applications is a non-starter.

(3) WWR is not permitted for flexural, axial, or shrinkage/temperature use in earthquake-resistant applications in which large inelastic rotation capacity must be exhibited by the primary structural members in special moment frames and special structural walls. To ensure that the level of inelastic behavior necessary for energy absorption is exhibited by these members during a design seismic event, ACI 318-19 establishes minimum ductility requirements for the "primary" reinforcement used therein. These ductility requirements are such that acceptable reinforcement is limited to ASTM A706 deformed reinforcing bars and ASTM A615 deformed reinforcing bars exhibiting a minimum tensile-yield ratio, minimum fracture and uniform elongations, and a maximum spread between actual yield strength and specified yield strength. In the case of WWR, the aforementioned ductility identity is not currently established in the ASTM A1064 material specification, and as such WWR is excluded.

2.1 Pertinent Code Sections

The reader is referred to the ACI 318-19 *Quick Reference for Welded Deformed Wire Reinforcement* (available as a free download on the WRI website) for a comprehensive summary of ACI provisions that are applicable to WDWR. These provisions will look very familiar to the practicing structural engineer, as they are also the basis for design using of reinforcing bars.

Obviously, there is strong emphasis on the code-supported direct interchangeability of reinforcement (reinforcing bars ↔ WWR) in *The Guide*. But in addition to this, just as "prohibited" applications were candidly discussed in Section 2.1, *The Guide* would be remiss in not highlighting a unique WWR attribute that in certain instances can offer potential design and detailing advantages over loose rebar. That attribute is the ability to rely upon the presence of welded wire intersections to reduce development length and lap splice dimensions for non-seismic applications, as well as to eliminate altogether the hooked curtailment often seen in flexural and shear reinforcement applications of gravity system applications..

ACI 318-19 Sections 25.4.6 (development length), 25.5.3 (lap splice), and 25.7.1.4 (hook replacement in shear application) illustrate how this unique attribute can be implemented in design if so chosen by the EOR, and Chapters 5 through 10 will contain selected beneficial examples of its use.

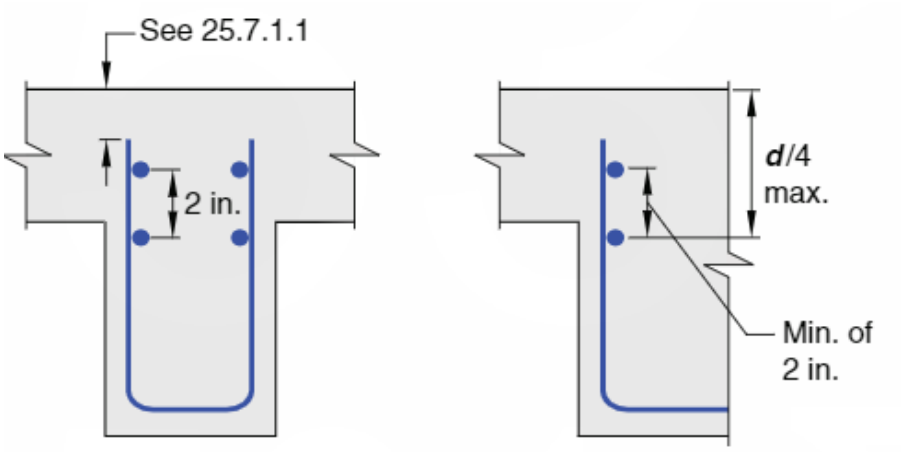

Figure 2-1: Stirrup in shear application using welded wire intersection in lieu of hooks (ACI 318-19 Section 25.7.1.4)

Image by the American Concrete Institute

2.2 Common Designer Questions

Suffice it to say that, despite extensive WWR inclusion throughout the design provisions of the ACI 318-19 Standard, there is still a certain amount of consternation on the part of design professionals as it pertains to usage of WWR. The list below is intended to provide rudimentary design-related clarity that otherwise might not be readily apparent in the black and white of the ACI standard.

Question	Response
1. What methods of corrosion protection are available for welded wire reinforcement?	Welded wire reinforcement can by epoxy-coated, hot-dipped galvanized, or comprised of stainless steel wires. The applicable material specifications are ASTM A1060, ASTM A884, and ASTM A1022.
2. Can welded wire reinforcement be manually welded (stick welded)?	Manual welding of welded wire reinforcement is permitted as noted in several ASTM Standard Specifications, including C1577 (precast monolithic concrete box sections), C478 (precast concrete manhole sections), C76 (reinforced concrete culvert for storm drain and sewer pipe), and C507 (reinforced concrete elliptical culvert). Other instances of manual welding may be permitted by the licensed design professional, as noted in ACI 318-19 Section 26.6.4.
3. With wires welded in an orthogonal pattern, is there any design advantage derived from potential “two-way” interactive flexural behavior?	ACI 318-19 does not recognize any two-way interaction that might exist as a result of orthogonally-arranged WWR. In structural engineering practice, reinforcement for each primary direction is essentially analyzed separately, independent of the presence of welds, with the only exception being those instances in which perpendicular perimeter/edge welded wires are depended upon for development or curtailment.
4. Is WWR permitted for use as flexural reinforcement in beams, walls, and structural slabs?	ACI 318-19 Table 20.2.2.4(a) allows the use of ASTM A1064 WWR as flexural, axial, and/or shrinkage and temperature reinforcement in all conventional beam, wall, and structural slab applications. WWR is not used as flexural, axial, and/or shrinkage and temperature reinforcement in special seismic systems (special moment frames and special structural walls).

Question	Response
5. Is WWR permitted for use as transverse reinforcement in special seismic systems?	ASTM A1064 welded wire reinforcement is permitted as transverse reinforcement in special moment frames and special structural walls per ACI 318-19 Table 20.2.2.4(a), but the welds themselves are not permitted to be relied upon for resistance to any stresses. As such, for WWR used in seismic applications, bond and anchorage of the reinforcement must be derived from wire surface deformations and hooked wire curtailments only, with any potential contribution by welded intersections ignored/disregarded.
6. How is the welding done, and how is weld integrity confirmed?	Welding is carried out by automated welding machines using a controlled cross-wire resistance welding process. Unlike fusion welding characterized by the depositing of a consumable electrode, electrical resistance welding is predicated on welded parts (two wires) being pressed together to allow the flow of electricity across the contact interface, resulting in the material being fused together. This process is acknowledged in ACI 318-19 Section R26.6.4. Confirmation of weld integrity and strength is carried out as part of the material's certification process during manufacture, with ASTM A1064 as the governing material specification, which is also referenced in ACI 318-19.
7. If a design is to rely on a welded intersection for development or curtailment purposes, how strong does the weld need to be to be considered "structural"?	By way of the ACI 318-19 reference to ASTM A1064, the required weld strength shall not be less than 35 ksi x nominal area of the larger wire at the intersection. This is also referenced in ACI 318-19 R20.2.2.4 and confirmed during manufacture.
8. For the purposes of simplifying design, can the engineer ignore potential contribution from the welded intersections despite the intersections being present?	Yes. In fact, save for instances where perimeter/edge welded wires might be depended upon for development or curtailment as a designer's option, the ACI 318 standard treats welded deformed wire reinforcement the same as reinforcing bars or loose, individual deformed wires: familiar rules for straight-line development length, lap splice, and hook development are applicable.

Question	Response
9. Is there a size relationship requirement for deformed wires being welded together?	If the structural design is relying upon welded intersections for the purposes of development or curtailment, then, yes, there exists a wire size relationship: the smaller wire must have a cross-sectional area at least 40% that of the larger wire per ASTM A1064. This is a requisite wire size relationship for the “structural” weld strength provision (Item #7, above) to be relied upon. In this case, the deformed wire must not be less than a D4.0. If the structural design does not rely upon welded intersections, then there is no wire size relationship requirement. Per ASTM A1064, the WWR producer is still required to verify that welded intersections exhibit a weld shear strength of 800 pounds. This is typically for basic transport, handling, and placing purposes.
10. ACI 301 currently requires a 12" support spacing for wire sizes smaller than D4.0 / W4.0. What are WRI's recommendations for support spacing of WWR?	The ACI 301 mandated support spacing 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, 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. Refer also to TF 702 in the WRI technical document library. In all instances, the Wire Reinforcement Institute encourages close collaboration between a project’s contractor and design professional of record to ensure appropriate placement criteria and procedures are established and maintained.

Question	Response
11. In Section 20.2.1.7.3 of ACI 318-19, the standard states that, for non-stirrup applications, a maximum spacing of 16” for welded intersections in the direction of calculated stress is applicable. What if I want to specify reinforcement in welded deformed wire reinforcement mat form, but only need structural wires in one direction and not the other? Do I still need to satisfy the spacing requirement for what are essentially non-structural wires?	The need for “single-direction” welded deformed wire reinforcement mats is very common. It is noteworthy that ACI 318-19 acknowledges treatment of welded deformed wire reinforcement in a manner identical to individual loose deformed bars and deformed wires when welded intersections are either absent or are not intentionally-positioned for tensile development or curtailment. With this treatment established, and in light of modern welded wire manufacturing capabilities, it is difficult to find a technical justification for a broadly-applied prescriptive maximum spacing of welded intersections as is done in Section 20.2.1.7.3 ACI 318-19 Sections 25.4.6.4 and 25.5.3.1.1 outline the common scenario in which the absence of intentionally-positioned welded intersections in turn requires calculation of welded deformed wire reinforcement development length and lap splice length, respectively, to be based on the same equations that are used for individual (loose, non-welded) deformed bars and deformed wires. In essence, these ACI 318 provisions direct the designer to disregard any contribution a welded intersection might make to bond and development, and have the designer instead base these attributes on the deformed wire surface's contribution alone. We encourage designers and contractors to continue to take advantage of the highly-customizable welded deformed wire reinforcement mat arrangements capable of being produced by modern automated welding equipment. This includes “single-direction” welded wire reinforcement mats characterized by structural deformed wires in one direction and perpendicular non-structural wire positioned as required in the other direction.

Question	Response
12. Is welded wire reinforcement a proprietary product?	No. welded wire reinforcement is a mild steel reinforcement required to conform to the ASTM A1064 Standard Specification. All welded wire reinforcement manufacturers are held to this common standard. While it is feasible for one welded wire reinforcement producer to pursue different markets or applications than its competitors, or for one producer to have slightly different internal processes and/or automated welding equipment than its competitors, the reinforcement itself must always be compliant with the ASTM Specification's requirements, and this is confirmed through ASTM A1064 certification and testing measures. Welded wire reinforcement is a manufactured product in the same sense as reinforcing bars or structural steel sections, and as such should not be subject to unique proprietary-like scrutiny on the basis of its inherent pre-assembly.