WIRE REINFORCEMENT INSTITUTE®

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Technical Blog

Small-Diameter Welded Wire Reinforcement and Slabs-on-Ground

Welded wire reinforcement (WWR) is a high-strength steel reinforcement for concrete that has a longstanding presence in reinforced concrete design codes and standards. Designing with WWR is intuitive, as the material fits the traditional sectional strength models predicated on equilibrium and strain compatibility. Put simply, WWR is a mild steel reinforcement that is interchangeable with reinforcing bars (rebar) in structural reinforced concrete design equations and is commonly specified in sizes up to and including 5/8” diameter deformed or plain structural wires (W31/D31).

Among numerous structural concrete applications, WWR also has a long history of use in slabs-on-ground. There are essentially two “categories” of ground-supported slabs.

The first category consists of those slabs that are relied upon to transmit vertical loads or lateral forces from other portions of the structure to the ground. Generally speaking, these slabs fall under the purview of ACI 318 design provisions and are designed as structural elements with due consideration for flexural, axial, shear, and shrinkage & temperature effects.

The second category consists of those slabs that transfer the effects of applied loading directly into the supporting ground below, without being a participant in the load path of a superstructure. The design of these slabs is best guided by ACI 360 and is heavily dependent on the quality of the subsurface upon which the slab resides.

It is the second category that is the focus of this particular WRI blog entry, as it is in these slab applications where “stock” small-diameter WWR usage continues to be prevalent. Small-diameter WWR consists of wire sizes smaller than W4.0 (D4.0). For the purpose of this discussion, we will refer to these slabs as *nominal slabs*.

As the reference suggests, these nominal slabs are typically only nominally reinforced, with designs that are driven largely by consideration of shrinkage & temperature effects. The design itself is a serviceability exercise that focuses on how best to control surface cracks, slab panel curling, and joint faulting that impact aesthetics and function. Resulting reinforcement requirements often manifest in the form of small-diameter WWR with modest cross-sectional steel areas. These smaller steel areas, then, end up being achieved through the designer’s specification of smaller “stock” style WWR mats. For example:

WWR STYLE	STEEL AREA PER UNIT FOOT (IN^2/FT)
6X6 W1.4/W1.4	0.028
6X6 W2.1/W2.1	0.042
6X6 W2.9/W2.9	0.058
4X4 W2.9/W2.9	0.087

Small-diameter WWR mat material is inherently flexible, and placement on the jobsite in conformance with the specifier’s design intent can pose a challenge in the absence of (a) a well-defined placement tolerance and (b) the proper type and arrangement of supports.

The first issue is that Specifiers often fail to recognize the need for the definition of project-specific tolerances for placement of WWR comprised of wire sizes less than W4.0 (D4.0). This need exists largely because <u>there is currently no prescriptive tolerance established by ACI for wires of this size</u>. For any design, the Specifier has a responsibility to define constructible configurations that inherently acknowledge a certain permissible amount of "play" on the jobsite, either by invoking prescriptive tolerances found in an appropriate published standard or by establishing project-specific tolerances themselves. If small-diameter mild reinforcement material is to be used in nominal slab construction, the Specifier must not only establish appropriate placement tolerances that would result in a constructed assembly that still conforms to the design intent, but they should also be prepared to validate and enforce that placement tolerance. This is in contrast to, say, conventional design of reinforced concrete structural elements which have permissible tolerances prescriptively defined in ACI 117.

The second issue is the practice of laying WWR mats directly on the subgrade (or vapor retarder) and then "hooking up" the mats during the concrete pour in a futile attempt to position the reinforcement somewhere close to where the specifier detailed it to be. Under no circumstances should a Contractor deploy this method of WWR placement, regardless of whether or not the Specifier has properly defined a placement tolerance. <u>At a minimum</u>, and as an empirical starting point, WWR comprised of wires smaller than W4.0 (D4.0) should be supported at intervals not exceeding 24" to 36" on center as suggested in WRI's TF 702 Tech Fact and WWR-500 Manual of Standard Practice.

Across all constructed designs, there is shared responsibility on the part of both the Specifier and Contractor to acknowledge and discuss candidly the construction challenges and solutions being considered to achieve general conformance with the design intent.

The obligation to collaborate is no less critical for nominal slabs reinforced with small-diameter WWR, yet somehow for these elements the interaction seems to be commonly trivialized or altogether bypassed. Perhaps this is because nominal slabs are rarely – if ever – considered to be building features that are critical to occupant life safety, or maybe the application in its most basic form is simplistically viewed as a means to an end; something that needs to get done as fast and cheap as possible in order for other scheduled trades and tasks to commence. Regardless of the reason or rationale, well-coordinated design and construction are paramount. In the end, it is the WWR material itself (and not just the small-diameter variety) that receives criticism for issues that are in large part the result of insufficient or incomplete decision-making and communication, and/or ill-advised installation methods.

Following is a list of related information on ground-supported nominal slab construction.

- **<u>Relevant ACI 301-20 Content:</u>** ACI 301-20 Section 3.3.2.5(a) notes that welded wire reinforcement in slabs-on-ground shall be placed into position before concrete placement and shall be placed as indicated in Contract Documents. ACI 301-20 Section 3.3.2.5(a) goes on to state that for specified reinforcement less than W4.0 or D4.0, the continuous support spacing shall not exceed 12 inches.

It is the WRI's position that reinforcement support spacing should be derived on a case-by-case basis with due consideration for attributes including, but not limited to:

- *Reinforcement type, size, and spacing*
- *Intended function/performance of the reinforced concrete element*
- *Project-specific placement tolerance defined by the Specifier*
- *Construction traffic and equipment weight, disposition, and duration*
- *Support type and substrate composition upon which the support rests*

It is the WRI's position that the ACI 301 12-inch support spacing 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.

- **Alternative WWR Configurations**: Modern WWR manufacturing versatility is such that many easy-to-produce alternatives to "common stock" small-diameter WWR mats are available. See below for potential WWR substitutions that are based on maintaining steel area equivalency, all of which would supersede the ACI 301 12-inch support spacing requirement while at the same time giving the contractor the labor and placement savings benefit they are accustomed to receiving with reinforcement in WWR form.

WWR "Original" Style	Steel Area per Unit Foot (in^2/ft)	WWR Alternative Styles
6X6 W1.4/W1.4	0.028	18x18 D4.2/D4.2
6X6 W2.1/W2.1	0.042	18x18 D6.3/D6.3
		16x16 D5.6/D5.6
		14x14 4.9/D4.9
		12x12 D4.2/D4.2
6X6 W2.9/W2.9	0.058	18x18 D8.7/D8.7
		16x16 D7.8/D7.8
		14x14 D6.8/D6.8
		12x12 D5.8/D5.8
		10x10 D4.9/D4.9
4X4 W2.9/W2.9	0.087	18x18 D13.1/D13.1
		16x16 D11.6/D11.6
		14x14 D10.2/D10.2
		12x12 D8.7/D8.7
		10x10 D7.3/D7.3
		8x8 D5.8/D5.8
		6x6 D4.4/D4.4

Deformed wires with the prefix "D" are tabulated here. Plain wire (prefix "W") is interchangeable for steel area and spacing shown. 18-inch spacing is a practical maximum spacing per ACI.

- **Rebar in Lieu of Small-Diameter WWR**: There may be times when rebar is considered for substitution in lieu of small-diameter WWR in nominal slab applications. The issue here, of course, is that the smallest bar size is a #3, which provides 0.11 in^2 of cross-sectional steel area. See below for a substitution table and the steel material overages. The net result is that all of the labor and placement benefits are lost due to the need to place individual hand-ties reinforcing bars, and the contractor actually ends up paying for and installing significantly more steel than is actually required by the nominal slab design.

WWR "Original" Style	Steel Area per Unit Foot (in^2/ft)	Alternative Rebar
6X6 W1.4/W1.4	0.028	#3@18" oc (**2.6X** specified)
6X6 W2.1/W2.1	0.042	#3@18" oc (**1.8X** specified)
6X6 W2.9/W2.9	0.058	#3@18" oc (**1.3X** specified)
4X4 W2.9/W2.9	0.087	#3@15" oc (1.0x specified)
		#3@12" oc (**1.3x** specified)
		#4@18" oc (**1.5x** specified)
		#4@16" oc (**1.7x** specified)
		#4@14" oc (**2.0x** specified)
		#4@12" oc (**2.3x** specified)

- **Fiber Reinforcement as a Replacement for WWR or Rebar in Nominal Slabs**: Steel or synthetic macrofiber reinforcement has been observed to be heavily marketed as a simpler and more cost-effective reinforcement solution than WWR and rebar for ground-supported nominal slab applications. There will always be a justifiable debate on this topic, as the integration of fiber reinforcement in and of itself is not labor-free nor is it a cost neutral solution. Two of the most commonly observed talking points presented by fiber reinforcement advocates are that proper installation of mild steel reinforcement is more laborious, and that the mild reinforcement is more dangerous due to tripping hazards on the jobsite. Yet fiber reinforcement has its own unique challenges to address in batching, design, and construction, some of which are presented below.

    - Fiber reinforcement doesn't prevent cracking. In fact, no different than WWR or rebar, the material is a passive-type reinforcement that is only activated once an actual crack develops. A fundamental difference between conventional steel reinforcement and fiber reinforcement is that the latter's capabilities are typically predicated on crack control and durability enhancement, while WWR and rebar each offer similar benefit but with the inherent advantage of providing reliable and redundant flexural continuity far beyond first concrete crack and physical yielding of the reinforcement material.

    - Proper performance of fiber reinforced concrete is contingent upon the presence of uniformly-distributed fibers throughout the concrete matrix. The potential for balling or clumping of fibers, however, is a very real consideration, and if not prevented can negatively impact the slab's in-service performance no different than what might be experienced with an improperly placed mat of rebar or WWR. Numerous batch attributes must be closely monitored and controlled to mitigate the possibility of fiber balling/clumping, with process and sequence varying to suit a selected fiber's dosage, geometry, and material stiffness. This can represent a significant increase in the level of planning, time, and labor at the plant level beyond what would be experienced with "conventional" non-fiber concrete mixes. Plant design or mixing sequence considerations that can impact fiber balling/clumping include, but are not limited to:

  - Addition of too many fibers to the mixture (high percentage by volume)
  - Incompatible concrete mix proportions, resulting in insufficient coating of the fibers
  - The fiber dispensing method and continuity of the dispensing process
  - The timing of the fiber dispensing relative to other concrete mix "ingredients" and the concrete mix's consistency/slump at the time of addition
  - The mix operation's speed and duration

- The introduction of fiber to a concrete mix can itself represent a safety hazard. Personal Protective Equipment (PPE) are required when handling and adding fibers to a batching system, most notably with steel fiber reinforcement solutions. Safety during a fiber batching process is no less critical than on-site operational safety.

- Special attention may be required during slab finishing to ensure that surface fibers are sufficiently buried, otherwise "hairy" slabs can result. The presence of these exposed fibers – and the available methods used to remediate their exposure – are not aesthetically pleasing yet can be a challenge to avoid.

- Special attention to and timing of the introduction of contraction joints can be required for slabs reinforced with macrofibers. In order to create the intended weakened plane, it is critical for saw-cut contraction joints to be introduced as soon as the concrete surface has hardened sufficiently, but this point in time often precedes the period during which fibers would remain sufficiently secured within the concrete without being at risk of pull-out, damage, and exposure (not to mention the resulting damage to the joint itself). In effect, the timing of saw-cutting contraction joints is often at odds with the presence of fiber reinforcement, as the required "early entry" of the saw-cut operation can actually be detrimental to fibers that have not been fully seated.

- Design of fiber reinforced concrete is generally carried out based on guidance in ACI 544.4R using a performance-based approach. Design relies upon the results of lab-based fiber reinforced concrete specimen tests that yield a series of post-crack / residual strength values. These values are in turn used in mathematical formulas to derive or validate calculated capacities. While the fiber reinforced concrete design procedure is to some degree modeled after conventional reinforced concrete design methodologies, the behavior is fundamentally different because the constituent embedded reinforcement's interaction with the surrounding concrete is different.

- Design of fiber reinforced concrete can be viewed by the EOR to be a specialty exercise and as such may end up being delegated to a specialty designer. As with any other delegated design, the lines of responsibility, communication, and professional liability must be clearly drawn and the relationship between EOR, Delegated Designer, and Contractor must be transparent and collaborative. Delegation of certain work tasks inherently increases the criticality of collaboration and clear communication, yet can be inadvertently glazed over or altogether bypassed on something that is perceived to be as basic or simple as a nominal slab.

- The basis of design and construction using fiber reinforcement is heavily dictated by and contingent upon testing and pre-project pours/trials. As noted, design (or design validation) cannot be reliably carried out in the absence of characteristic values derived from purpose-made specimen tests that are undertaken in a controlled lab environment. Similarly, confirmation that a fiber reinforced concrete solution is actually appropriate for a specific project application, using a specific fiber type, geometry, and dosage, is largely dependent upon pre-project mock trials/pours, the absence / bypassing of which could potentially increase the risk and liability exposure for both the Designer and Contractor on a given project pursuit.

Achieving the advertised elegance of a fiber reinforced concrete solution is always going to be a function of how well the plethora of additional mechanisms and special procedural demands are executed from testing, to design, to batch, and finally to on-site finishing. The formulation and eventual use of fiber reinforced concrete on a project requires quality control and quality assurance measures that must be overseen by knowledgeable and experienced project stakeholders at every turn in order to minimize the potential for variability that would be detrimental to slab performance.

The Takeaway:

Despite a history of conforming construction and in-service performance of nominal slabs reinforced with small-diameter WWR styles, the material is increasingly stigmatized, often in contrast to the usage by builders and specifiers who continue to rely on the product as a reinforcement solution and who put in the necessary collaborative effort to ensure its successful implementation.

As the construction landscape continues to evolve, and Specifiers and Contractors seek alternatives to small-diameter WWR in order to sidestep project-specific concerns related to restrictive support spacing, the WRI encourages both Specifier and Contractor to directly discuss with WRI producing members or WRI Technical Staff the multitude of larger-diameter WWR options that are available. There are numerous, readily-produced WWR styles that can be implemented to satisfy design intent while still accomplishing the on-site labor and installation savings that have long been synonymous with a welded wire reinforcement solution.

For more information on WWR, refer to www.wirereinforcementinstitute.org.