Substitution Welded Wire Reinforcement Sizes

For building structure applications such as slabs and walls, the Wire Reinforcement Institute encourages design professionals to consider a progressive approach to preparation of contract documents by doing one of the following:

1. Include permissive language that "pre-approves" the contractor's use of WWR as a substitution for originally-specified arrangements of reinforcing bar sizes and spacing.
2. Define the design cross-sectional areas of reinforcement instead of explicitly specified reinforcement sizes and spacings.

These options, along with the WWR detailer's responsibility in ensuring the process is executed smoothly and correctly, are discussed in more detail in the WRI's Design and Detailing Guide (2021 WWR-600-DDG).

A key aspect of any reinforcement substitution or area-based reinforcement definition is that, ultimately, it is possible for a variety of wire sizes to comprise the final design solution, and the selected solution may not be fully known until the reinforcement submittal is issued for review. As such, this size variety needs to be addressed by the designer on the contract documents from the start.

Suggestion #1 – Set an appropriate range of wire sizes for the project

The roster of available wire sizes that can be manufactured today is fairly expansive, so it is important as the designer to acknowledge this and, if so desired, limit it to suit the needs of the project design.

If we focus on welded deformed wire reinforcement comprised of deformed wires, ACI 318 establishes the acceptable design range for structural wire sizes to be from D4.0 to D31.0. if we include all available *one-hundredth of one-square inch* incremental wire sizes, that is 271 potential sizes, with a D4.0 wire having a 0.226" diameter and a D31.0 wire having a 0.628" diameter.

As the designer you have control of just how many of these sizes you are willing to work with on a given project. Some engineers prefer a restrictive range of acceptable wires sizes for use in flexural applications. For example, a minimum wire size of D11.0 (0.374" diameter) or D15.0 (0.437" diameter) might be expected to establish the low end of the range, while the high end would be defined by the D31.0. With that said, for the purposes of this discussion, let's assume the entire D4.0 through D31.0 range is still permitted for use.

Suggestion #2 – Base your strength design calculations on the largest possible wire size

If the engineer bases all strength design calculations on the largest wire diameter in their pre-defined size range, there is a corresponding dimension ("d") measured from the extreme compression fiber to the centroid of the longitudinal tension reinforcement that is at its geometrically smallest value. As such, the calculation will yield a “worst case” conservative calculated capacity that would theoretically only get larger if a smaller wire diameter ends up being used.

For example, let’s look at an 8” thick 4000 psi concrete slab with A_s = 0.248 in^2/foot bottom reinforcement (80 ksi) placed at 1 1/2" clear from the bottom surface:

<u>If D31.0 @ 15” o.c. are used:</u>

Wire diameter = 0.628 inches
A_s provided = 0.248 in^2/foot
d = 8” – 1.5” – 0.628”/2 = 6.186”
Tensile strain in steel reinforcement = 0.029 in/in, φ = 0.9
φM_n = 8.85 kip-ft

<u>If D8.3 @ 4” o.c. are used:</u>

Wire diameter = 0.325 inches
A_s provided = 0.249 in^2/foot
d = 8” – 1.5” – 0.325”/2 = 6.34”
tensile strain in steel reinforcement = 0.030 in/in, φ = 0.9
φM_n = 9.11 kip-ft

From the above we can see that available strengths only get larger as the wire diameter that is used to comprise the required “unit” cross-sectional area of steel reinforcement gets smaller.

Also note that the calculation of tensile strain in the steel reinforcement is as follows:

$$\varepsilon_s = \frac{0.003\beta_1 d}{a} - 0.003$$

So as the “d” dimension increases due to a smaller wire size being used, the corresponding tensile strain value increases, moving it further into the tension-controlled range and away from the minimum threshold at which strength reduction factors would start to fall below the maximum value of 0.90.

Suggestion #3 – Create a tension lap splice length schedule for wire / WWR and include it as “typical” on all contract drawings.

It probably isn’t realistic for the designer to re-calculate lap splice lengths for each and every wire size scenario potentially encountered from one project to the next (remember, there are 271 sizes between a D4.0 and a D31.0). Instead, no different than with reinforcing bars, the designer should consider establishing a fixed frame of reference for lap splice lengths that satisfy the design intent. This would typically be done in the form of a lap splice schedule that is broad enough to capture the most prevalent scenarios but refined enough to avoid excessive conservatism. The WRI’s website offers an example of such a lap splice schedule, available for free download.

https://wirereinforcementinstitute.org/application/files/9616/4296/2461/WWR.6_WDWR_LAP_SPLICE_SCHEDULE.pdf

Comparatively, a "simplified" method of lap splice length definition by the designer would be to maintain a rebar lap splice schedule while providing footnotes that capture WWR requirements to suit. For example, as a footnote accompaniment to the rebar lap splice schedule:

- Wire sizes with diameter ≤ 0.375", use #3 rebar lap splice length
- Wire sizes with diameter ≤ 0.500", use #4 rebar lap splice length
- Wire sizes with diameter ≤ 0.625", use #5 rebar lap splice length

This above simplified approach is made possible by the fact that the lap splice calculations for reinforcing bars and WWR – when contribution of welded intersections is ignored – are identical as outlined in ACI 318. It should be noted, however, that size correlation between bar and wire is not exact, and in using the simplified approach could result in excessive conservatism that yields more steel WWR tonnage on a project than is actually required. For example:

- A #4 bar's diameter is 0.500", while a D20 wire's diameter is 0.505". Using the ranges noted above, a D20 wire would default to a lap splice length requirement equal to that of a #5 bar, which is grossly conservative.
- A #5 bar's diameter is 0.625", while a D31 wire's diameter is 0.628". Extrapolating from the ranges noted above, a D31 wire would default to a lap splice length requirement equal to that of a #6 bar, which is grossly conservative.

If the designer wants to stick with using a reinforcing bar lap splice schedule only and does not want to introduce a separate schedule for wire / WWR, a hybrid approach would be preferred. This method would be characterized by a lap splice schedule for reinforcing bars with calibrated tabulated values for a #4 bar and a #5 bar to capture the permitted use of WWR substitutions. For example:

REINFORCING BAR SIZE (60 KSI) (2" clear cover)	**MINIMUM TENSION LAP SPLICE LENGTH (f'c = 4000 psi NWC)**
#3 bar / D11 wire and smaller	**12"**
#4 / D20 wire and smaller	**15"**
#5 / D31 wire and smaller	**18.5"**
#6	**22.2"**
#7	**32.4"**
#8	**37"**

The value in the schedule shown for #4 / D20 wire and smaller is calibrated to capture a diameter of 0.505", and correlates to a 15-inch lap splice length versus a 14.8-inch length if based on a 0.500" #4 bar. Similarly, the value shown for #5 / D31 wire and smaller is calibrated to capture a diameter of 0.628", and correlates to an 18.6-inch lap splice length versus an 18.5-inch length if based on a 0.625" #5 bar. Note that this method still results in unnecessary conservatism if an "incremental" wire size were to be selected (for example, if a D20.5 wire size is used, it would default to an 18.5-inch lap splice based on the scheduled requirement versus the 15.12-inch lap splice calculated specifically for its diameter).

Last but not least, perhaps the most efficient approach is for the designer to dictate that, as an accompaniment to the reinforcing submittal, the WWR detailer provides precise lap splice length calculations corresponding to the selected wire sizes. This allows for a code-compliant “sharpening of the pencil” on the designer’s scheduled lap splice values.

Suggestion #4 – Provide sufficient direction to the contractor / WWR detailer for selection of supports for reinforcement.

For a slab (or a tilt-wall panel), there will be bottom supports that rest on the bottom form (or ground/substrate) that provide direct support for the bottom steel. For the top steel, there will either be high chairs resting on the bottom form (or ground/substrate) or bolsters that rest on the bottom mat of steel. It is imperative that the designer is consistent in their definition of required clear cover dimensions that in turn correlate to chair/bolster height selection. Clear cover dimensions are typically established in schedule form, similar to below.

ACI 318 TABLE 20.5.1.3.1 SPECIFIED CLEAR COVER SCHEDULE: CAST-IN-PLACE NONPRESTRESSED CONCRETE

CONCRETE EXPOSURE	MEMBER	REINFORCEMENT	SPECIFIED COVER, INCHES
CAST AGAINST AND PERMANENTLY IN CONTACT WITH GROUND	ALL (EXCLUDING SLAB-ON-GROUND)	ALL	3
CAST AGAINST AND PERMANENTLY IN CONTACT WITH GROUND	SLAB-ON-GROUND	ALL	PROJECT-SPECIFIC: SEE NOTES AND DETAILS THIS SET
EXPOSED TO WEATHER OR IN CONTACT WITH GROUND	ALL	#6 THROUGH #18	2
		#5 AND SMALLER D31 AND SMALLER	1 1/2
NOT EXPOSED TO WEATHER OR IN CONTACT WITH GROUND	SLABS, JOISTS, AND WALLS	#14 AND #18	1 1/2
		#11 AND SMALLER D31 AND SMALLER	3/4
	BEAMS, COLUMNS, PIERS, AND TENSION TIES	PRIMARY REINFORCEMENT, STIRRUPS, TIES, SPIRALS, HOOPS	1 1/2

NOTE: COVER DIMENSIONS ANNOTATED IN PROJECT DETAILS OR NOTES SUPERSEDE COVER DIMENSIONS PRESENTED IN THIS SCHEDULE.

Ultimately, the selection of bolster/chair heights is the responsibility of the WWR detailer and/or contractor, and it is always preferable for the variation in bolster and chair heights utilized on a project to be kept to an absolute minimum.

The wildcard with WWR substitutions is that the variability in size could create potential uncertainty in selecting bolsters/chairs for the top reinforcement, as a change in wire size results in a change in clear cover dimension measured between the top tangent point of the wire and the intended top surface of concrete. For this reason, it is important for bolster/chair selection to be based on the largest wire size permitted by the designer. If this is done, and a smaller wire size ends up being utilized in the design as selected by the WWR detailer, the resulting clear cover dimension effectively increases and there is no concern over the designer’s minimum clear cover ever being encroached upon.

Instead of tasking the WWR detailer / contractor with selection of multiple bolsters/chairs to match varying wire sizes, the designer needs to be sure that the resulting “range” of clear covers is compatible with the structural design intent. As long as the design depth “d” has been properly accounted for as mentioned in Suggestion #2 (which is implicitly achieved if Suggestion #4 is followed), an increase in clear cover is rarely a concern from a strength standpoint. The focus would shift, then, to crack control given that the top reinforcement would be positioned slightly further from the top surface of the concrete as the wire size decreases.

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