Steel Reinforcement for Shotcreted Pools

INTRODUCTION

Shotcrete, as defined by ACI Concrete Terminology, is "concrete placed by a high-velocity pneumatic projection from a nozzle."

Concrete is strong in compression but weak in tension. Reinforcement, typically as deformed steel bars, is embedded in concrete to create a composite section that is strong in both compression and tension and behaves in a ductile manner. A concrete swimming pool must resist a variety of loads that create both compressive and tensile stresses in the structure. The majority of concrete swimming pools contain reinforcement to help carry these loads. This paper surveys the various areas of reinforcement concerns in pool design and highlights their relevant, currently available code principles.

CODES & GUIDES

The American Concrete Institute (ACI) develops codes and standards for a wide variety of reinforced concrete design. Two codes in particular, ACI 318-25 *Building Code Requirements for Structural Concrete* and ACI 350-20 *Code Requirements for Environmental Engineering Concrete Structures*, are often used for the design of concrete swimming pools. While ACI 318 provides shotcrete placement provisions, section 1.4.9 of ACI 318 states, "This Code does not apply to the design and construction of tanks and reservoirs." ACI 350, in comparison, is intended for the design of liquid-containing concrete structures, so it is currently the more appropriate code for concrete pool design. In the absence of a pool-specific concrete design code, a licensed design professional (LDP) should use good engineering judgment in properly using portions of existing codes for the design of swimming pools.

Of special note, the LDP should look to ACI 506.2-13 (18) *Specification for Shotcrete*, for guidance on shotcrete specifications when producing their project documents. ACI PRC 506.8-24 *Shotcrete Use in Pool Construction – Guide* is also a valuable resource for the LDP.

Complete design of concrete pools is beyond the scope of this paper, but we do provide guidance on design considerations for appropriate reinforcing in pool shells.

SPACING OF REINFORCEMENT

ACI 350 includes spacing requirements for reinforcement in concrete. ACI 350 allows a maximum spacing of 12 in. (300 mm). Section 12.6.1 of ACI 350 allows a minimum spacing of the bar diameter but not less than 1 in. (25 mm). The reduced spacing of ACI 350 provides improved crack control. For a given area of reinforcement, using more smaller-diameter reinforcing bars at a closer spacing is more effective in controlling cracking than a smaller number of larger bars at a greater spacing.

Alternative spacings are permitted by the ACI codes where shotcrete mockup panels are provided to demonstrate proper reinforcement encasement.

LAP SPLICES

Lap splices are required between staggered reinforcing bars to provide a continuous load path through the structure. ACI 350 contains equations for lap splice length and requires the LDP to specify lap splice lengths and locations on the structural drawings. Lap splices may be contact or non-contact splices. Contact splices occur where overlapping bars are in direct contact with one another and wired together. Non-contact splices occur where overlapping bars have a small gap between them. For non-contact splices, ACI 350 requires the center-to-center spacing of spliced bars not to exceed the lesser of one-fifth the required lap splice length and 6 in. (150 mm).

Non-contact lap slices are preferred in some shotcrete applications since contact lap splices are more difficult to encase in shotcrete. It is important to note that ACI 506.2 section 3.1.4.2 does not allow contact lap splices in shotcrete unless the plane of the spliced bars is oriented perpendicular to the surface of the shotcrete and the splice configuration is approved by the LDP. The shotcrete-specific reinforcement spacing requirements for non-contact lap splices in ACI 506.2 require clearance between laps of at least 3 times the diameter of the bar, 3 times the largest aggregate size, or 2 in. (50 mm), whichever is least unless otherwise specified: Non-contact lap splice lengths may need to be increased above code minimums to comply with requirements for both the

maximum center-to-center spacing and the minimum clear spacing between lapped bars.

REINFORCING BAR CONGESTION

In shotcrete structures, careful attention to reinforcement detailing is needed to prevent reinforcing bar congestion. Reinforcement congestion can prevent full shotcrete encasement of the reinforcement and increase rebound. Complex reinforcement layouts are sometimes needed at intersections between floors and walls for strength requirements. To complicate matters further, bars are often spliced at these locations. This can lead to congested reinforcement installations that violate the minimum clear spacing requirements described above. Licensed design professionals and installers should coordinate complex reinforcing layouts to ensure that requirements for both strength and constructability are met. The LDP should strive to maintain a 6 in. centering of reinforcing bars so that intersecting planes are not less than 3 in. (75 mm). Bundling of bars should be avoided as it makes it nearly impossible to encase all the individual reinforcing bars.

CONCRETE COVER

Steel reinforcement requires concrete cover to protect it from corrosion. The amount of concrete cover over reinforcing depends on the environmental conditions and the type of the concrete used. ACI 350 requires 3 in. of concrete cover for concrete installed against and permanently in contact with the ground. For concrete floors and walls exposed to earth, liquid, or weather, for primary reinforcing bars, ACI 350 section 12.7 requires a minimum of 2 in. of cover for this exposure condition regardless of bar size. Licensed design professionals may increase cover for future renovations, however when increasing the concrete cover, one should keep in mind that as the concrete cover increases, crack widths at the surface also increase. A maximum of 3 in. should be considered for cover.

SHRINKAGE AND TEMPERATURE REINFORCEMENT

Concrete experiences drying shrinkage as it cures and also undergoes volume changes as temperatures fluctuate. Restraint of these movements creates tension in the concrete that leads to cracks. These drying shrinkage cracks generally extend through the full depth of the concrete cross section. Drying shrinkage and temperature reinforcement is provided to limit the width of the cracks that form. Since concrete pools are intended to be watertight, it is critical that full depth crack widths are minimized. ACI PRC 224-01 *Control of Cracking in Concrete Structures*, indicates crack widths of up to 0.004 in. (0.1 mm) are reasonable for watertightness of water-retaining structures.

Section 24.4.3.2 of ACI 318 requires a minimum ratio of shrinkage and temperature reinforcement area to gross concrete area in a cross section of 0.0018. The commentary to this section indicates this ratio is not intended for leakage prevention. Structures designed to ACI 318 will allow cracks much greater than the 0.004 in. required for watertightness.

Table 12.13.2.1 of ACI 350 includes minimum shrinkage and temperature reinforcement ratios ranging from 0.0025 to 0.01, depending on the amount of restraint imposed on the concrete section. While the shrinkage and temperature reinforcement ratio of ACI 318 is too low for watertight concrete pools, the reinforcement ratio at the high end of the ACI 350 range is intended for highly restrained walls and may lead to reinforcing congestion and bar spacings that do not allow for shotcrete installation. In some cases, a lower shrinkage and temperature reinforcement ratio may be considered by removing or reducing restraint to shrinkage and temperature changes. Unless design calculations require more, a ratio of 0.005 is a good rule of thumb for liquid-containing structures without movement joints. A ratio of 0.005 creates minimal congestion for shotcrete structures while providing adequate reinforcement for control of volume change cracking and providing watertightness.

Additional consideration should be given for the inclusion of plumbing pipes found in swimming pool construction. Pipes and embedded fixtures are necessary components in swimming pool construction and often require additional design considerations. ACI 350 section 6.3.9 requires that pipes shall be placed between the top and bottom reinforcement. Section 6.3.10 requires that pipe, conduit, and fittings shall meet the minimum coverage requirements for reinforcement except where designed to intersect the surface.

ALTERNATIVES TO STEEL REINFORCEMENT

ACI 350 Commentary R10.6.4 states, “Testing has shown that inclusion of epoxy-coated reinforcement will cause an increase in the crack width of flexural members by approximately 30 percent.” Additionally, the abrasive nature of the shotcrete process tends to disrupt the epoxy coatings from reinforcing bars. Epoxy-coated bars also complicate the equipotential bonding requirements for swimming pools put forth by the *National Electrical Code* (NEC). For these reasons, epoxy-coated reinforcement is not recommended for concrete swimming pools.

GFRP (Glass Fiber Reinforced Polymer) bars are not widely used in swimming pool construction at this point in time. This is perhaps due to the interpretation of the NEC,

as well as the product not being able to be bent in the field. Further design considerations for the LDP are the much lower stiffness of GFRP bar compared to that of steel bar.

REINFORCEMENT SUPPORTS

In concrete pool construction, bars are frequently supported by bricks, concrete masonry, and broken pieces of old concrete. Many times, the spacing of reinforcement supports is inadequate, and bars sag between supports. These practices should be avoided as they incorporate weak material into the pool shell and do not comply with code requirements for concrete cover and reinforcement installation tolerances. In shotcrete applications, it is critical that the reinforcement be rigidly tied together and supported.

Vibration of loose reinforcing bar mats when impacted by shotcrete creates voids and sagging of plastic shotcrete. ACI 301 *Specifications for Structural Concrete* requires that reinforcement supports be furnished and installed in accordance with Concrete Reinforcing Steel Institute (CRSI) RB4.1 *Supports for Reinforcement Used in Concrete*. CRSI RB4.1 includes specifications for reinforcing bar support types and spacings.

Since concrete pools hold water and are often installed against earth forms, reinforcing bar supports should be corrosion resistant. The practice of supporting reinforcing bars by driving the bar into soil should be prohibited. The LDP should specify the proper type of supports to be used in their project.

MULTIPLE REINFORCEMENT LAYERS

Many concrete pool shells are installed with a single layer of reinforcing. This may be appropriate for concrete sections less than or equal to 8 in. (200 mm) in thickness. For these sections, it can be difficult to install multiple layers of reinforcement and still comply with requirements for concrete cover and clear spacing. As concrete sections increase in thickness beyond 8 in., additional layers of reinforcement are needed.

The LDP may also choose to require two layers of reinforcement to evenly distribute shrinkage and temperature bars to each face. For shotcrete applications, a reinforcing layer in the face of the wall nearest the nozzle can help the shotcreter 'hang' the shotcreted concrete and prevent sloughing. In this case, an additional layer may be added to the section; while it is not required by strength calculations, it improves constructability. However, care must be taken not to exceed the maximum allowable area of steel per ACI 350.

A pool is not always full of water and needs to be drained occasionally. The LDP should consider the forces that are applied when the pool is empty with hydrostatic pressure from saturated soils, as well as uplift from groundwater. Using two layers of reinforcing steel may help with serviceability when the pool is full and empty.

While not in the scope of this paper, it should be noted that pressure relief provisions or dewatering both during and after construction should be provided for when ground water is present.

FIELD BENDING

Field bending of reinforcing bars is common practice in concrete pool construction to accommodate curves and creative design elements. The problem with field bending is the lack of quality control. ACI 350 only allows field bending of reinforcing bars when it is permitted by the LDP or shown in the construction documents. The Code includes requirements for reinforcing bars' bend diameters. These requirements are derived from tests on reinforcing bars and concrete. Code equations for reinforcement hooks, ties, and stirrups assume standard bend diameters are used. Tight reinforcing bends can fracture bars and increase the likelihood of concrete crushing and splitting at the bend. Repeated cold bending of reinforcing, work hardens the material and decreases its ductility. Installers field bending reinforcement should obtain the approval of the LDP and implement a quality control program to ensure that field-bent bars conform to the requirements of ACI 350.

GRADE 40 VS GRADE 60

Reinforcing steel is graded based on its yield strength. Grades 40 and 60 reinforcement are most often used in concrete pool construction. Grade 40 reinforcement is typically requested by swimming pool installers planning to field bend the reinforcing bar. Grade 40 steel is easier to bend than Grade 60 steel due to its lower yield strength (40 ksi vs 60 ksi).

Where reinforcing steel strength requirements do not govern the concrete design, Grade 40 reinforcing may be a viable alternative for Grade 60 bar. ACI 350 requires Grade 60 steel for shrinkage and temperature reinforcement. If Grade 40 is used for shrinkage and temperature reinforcement, the LDP should consider increasing the percentages of reinforcing.

Designers need to adjust the design depending on whether Grade 40 or 60 reinforcing is to be used. Installers should not substitute Grade 40 bar for Grade 60 bar without approval from the LDP. Licensed design professionals are unlikely to allow substitution of Grade 40 reinforcement where Grade 60 reinforcement has been specified and used for concrete design calculations.

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NEW CODE DEVELOPMENT & SUMMARY

ACI has tasked ACI Technical Committee 322 with developing a Concrete Pool and Watershape Code. ACI 322 will address the concerns put forth here along with a broader range of considerations for the design of swimming pools using reinforced concrete. Until that code is released, licensed design professionals may conservatively lean on ACI 350 for guidance while considering the shotcrete provisions of ACI 506.2. This paper highlights relevant sections of each code and establishes principles that should be followed for the design and installation of reinforcement in concrete swimming pools.

REFERENCES

1. ACI CODE-318: Building Code for Structural Concrete – Code Requirements and Commentary
2. ACI CODE-350: Code Requirements for Environmental Engineering Concrete Structures and Commentary
3. ACI SPEC 506.2-13(18): Specification for Shotcrete
4. ACI PRC 224-01: Control of Cracking in Concrete Structures
5. NFPA 70 National Electrical Code – 2023
6. ACI SPEC-301: Specifications for Concrete Construction
7. CRSI RB4.1-2022 Supports Used for Reinforcement in Concrete

Position Statements

ASA has produced position statements on the best practices for proper shotcrete placement. To date, seven position statements from our Pool & Recreational Shotcrete Committee, four from our Underground Committee, and one from our Board of Direction have been issued. These statements have also been published in *Shotcrete* magazine.

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