Testing Anchors in Cracked Concrete

Guidance for testing laboratories: how to generate cracks

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ACI Committee 355, Anchorage to Concrete, introduced qualification requirements for post-installed mechanical anchors in cracked concrete as part of ACI 355.2-01.[1] This document is, in turn, referenced in both ACI 318-02[2] and ACI 349-01[3] as an acceptable method for the prequalification of mechanical anchors for use in concrete structures designed with the methods of these model codes. The qualification requirements in ACI 355.2 are applicable for anchors located in zones of reinforced concrete members where cracking might occur due to load or the restraint of imposed deformations (such as shrinkage, creep, temperature variations, or support settlement).

While ACI 355.2 contains the test requirements and acceptance criteria to qualify an anchor for cracked concrete, it does not describe in detail the methods for both forming and opening the cracks in concrete test members. This article provides guidance for initiating, opening, and controlling cracks during testing of an anchor for use in cracked concrete.

TYPES OF TESTS IN CRACKED CONCRETE

To qualify anchors for use in cracked concrete, ACI 355.2 specifies three types of tests to be performed in cracks.

The first type of test is static tension loading of an anchor in both 0.012-in. (0.3 mm) and 0.020-in.-wide (0.5 mm) static cracks. A hairline crack (width < 0.002 in. [0.05 mm]) is formed first in the concrete member by one of the methods described in the section "Forming cracks." A hole is then drilled perpendicular to the surface of the test member through the crack so that the axis of the anchor is in the plane of the crack. The anchor is installed and set according to the manufacturer's specified instructions. The crack is then opened by the specified width and the anchor is monotonically loaded according to the test procedure contained in ACI 355.2.

The second type of test is the application of a static tension load to an anchor that is installed in a crack whose width is cycled. As described previously, a hairline crack is formed in the concrete, the anchor is installed, the crack is opened by a width of 0.012 in. (0.3 mm), and the tension load prescribed in ACI 355.2 is applied to the anchor. Then the crack width is cycled 1000 times between 0.012 in. (0.3 mm) and 0.004 in. (0.1 mm) while the tension load is kept constant. At the end of the crack cycling test, the crack is opened to 0.012 in. (0.3 mm) and the anchor is loaded monotonically to failure to determine the system's residual capacity.

The third type of test is an optional seismic qualification test. After anchor installation as described previously, the crack is opened by 0.020 in. (0.5 mm). A simulated seismic load cycle is applied to the anchor. At the end of the test, the anchor is tested monotonically to failure to determine the system's residual capacity while the crack is open. Separate tests may be performed with all three methods to qualify the anchor for tension or shear loading.

To ensure reproducibility of the test results and to simulate possible unfavorable field conditions, the crack width must be roughly constant over the depth of the concrete member. Furthermore, the crack must run approximately perpendicular to the surface of the test member to ensure that the axis of the anchor, and in particular the expansion mechanism (expansion anchors) or undercut (undercut anchors), is in the plane of the crack. To achieve such cracks, the tests are performed on concrete specimens that have a sufficiently high reinforcement percentage and are loaded by a centric tensile force.

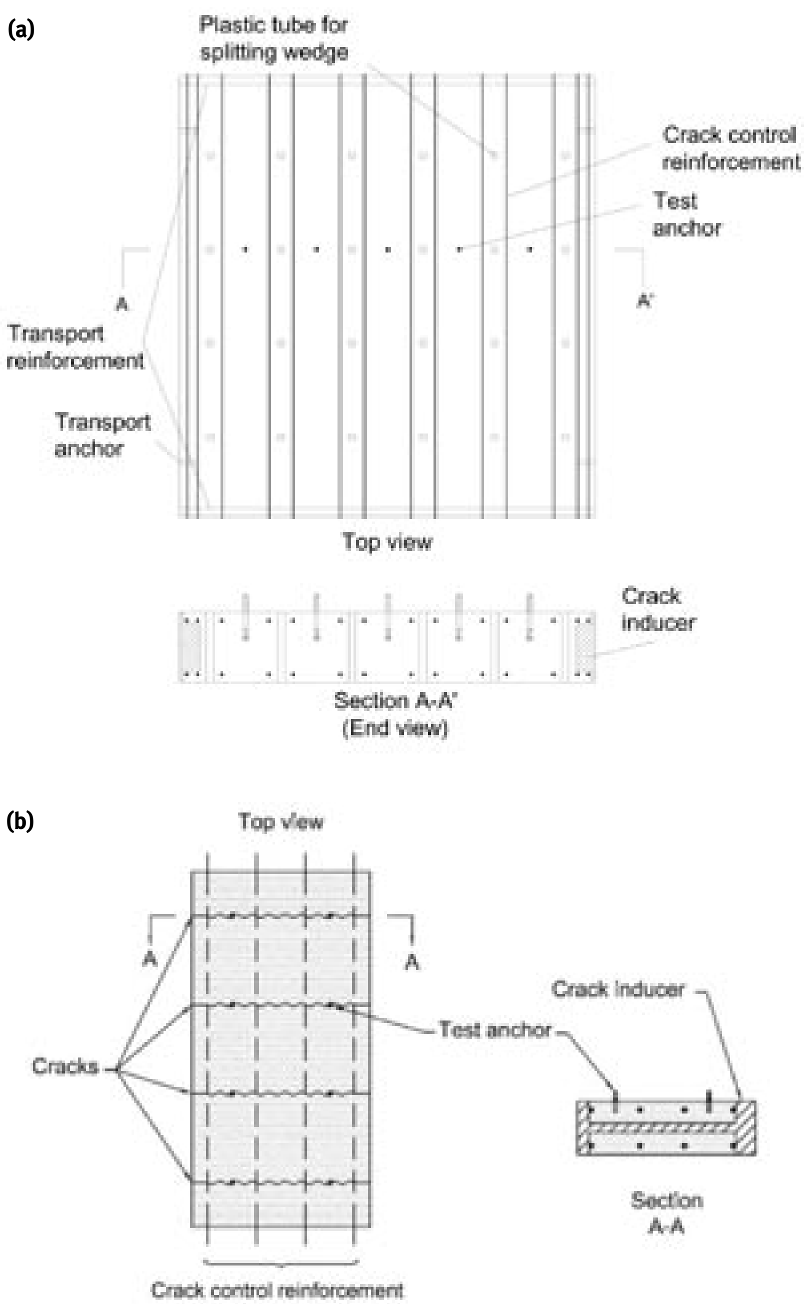

Fig. 1: Typical test members for testing anchors in cracked concrete: (a) cracks generated by splitting wedges; and (b) cracks generated by pulling on the reinforcement

DESCRIPTION OF CRACKED CONCRETE TEST MEMBERS

ACI 355.2 does not provide a detailed concrete test member configuration, but it does give recommendations on the important considerations for designing test members. Figure 1 shows a schematic of concrete members and reinforcement layouts for testing anchors in cracked concrete. The total area of the reinforcement in the test member should be about 1% of the cross-sectional area of the concrete parallel to the plane of the crack. This reinforcement should be placed symmetrically near the top and bottom surfaces of the test member to provide an almost uniform crack width through the thickness of the concrete test member when the centric tensile force is applied.

The ratio of reinforcement to the concrete test member's cross-sectional area has a significant effect on the crack width during the loading of the anchor (see discussion in the section on Controlling crack widths), as well as on the extent of crack closure in tests in which the crack width is cycled. Consequently, the reinforcement ratio of the test member strongly influences the test results. Therefore, it is important that the reinforcement percentage of the test member is at least 1%.

To help create the cracks within a narrow band, the use of crack inducers is recommended. Crack inducers are usually thin strips of sheet metal that are cast into the concrete member, thus locally weakening the cross section of the concrete at the desired location. To reduce the bond between the metal strips and the concrete, the strips should be oiled or greased.

Crack inducers should be located at a distance equal to the expected mean crack spacing in the concrete test member, calculated according to standard methods, to reduce their influence on the test results.

It is assumed that the crack inducers do not influence the test results if they do not intersect the expected failure cone. Crack inducers facilitate a more precise location of the crack across the width and through the depth of the test member. However, the crack location may still vary as the crack propagates from the point of crack initiation to the concrete surface. The use of a boroscope can confirm that the crack intersects the drilled hole over the entire depth of anchor embedment.

FORMING CRACKS

The forming of cracks in a concrete test member can be accomplished by three different methods. All methods apply load to the concrete member's reinforcing bars, which elongate elastically, acting as springs to open and close the cracks and controlling the crack widths.

The simplest method to form a crack in concrete is to use splitting wedges, similar to those used for rock splitting. Figure 2(a) shows a splitting wedge consisting of two halves of an expansion sleeve and a wedge. Three or more splitting wedges may be used across the width of the test member. The steel expansion sleeve should extend through the depth of the concrete test member. Holes are drilled through the concrete along a line that is at the desired location of the crack or plastic tubes may be cast into the concrete (Fig. 1(a)), which are removed after hardening of the concrete. After the expansion sleeves have been placed into the holes, the wedges are sequentially hammered into the expansion sleeves (Fig. 2(b)) until the concrete cracks along the line of the wedges. To reduce friction, the mating parts of the wedges should be well lubricated. Crack inducers may be used with this method; however, they can only be placed at the sides of the concrete member (Fig. 1(a)) due to the presence of the splitting wedges along the crack. This method permits the reasonably precise control of the crack width at relatively low cost.

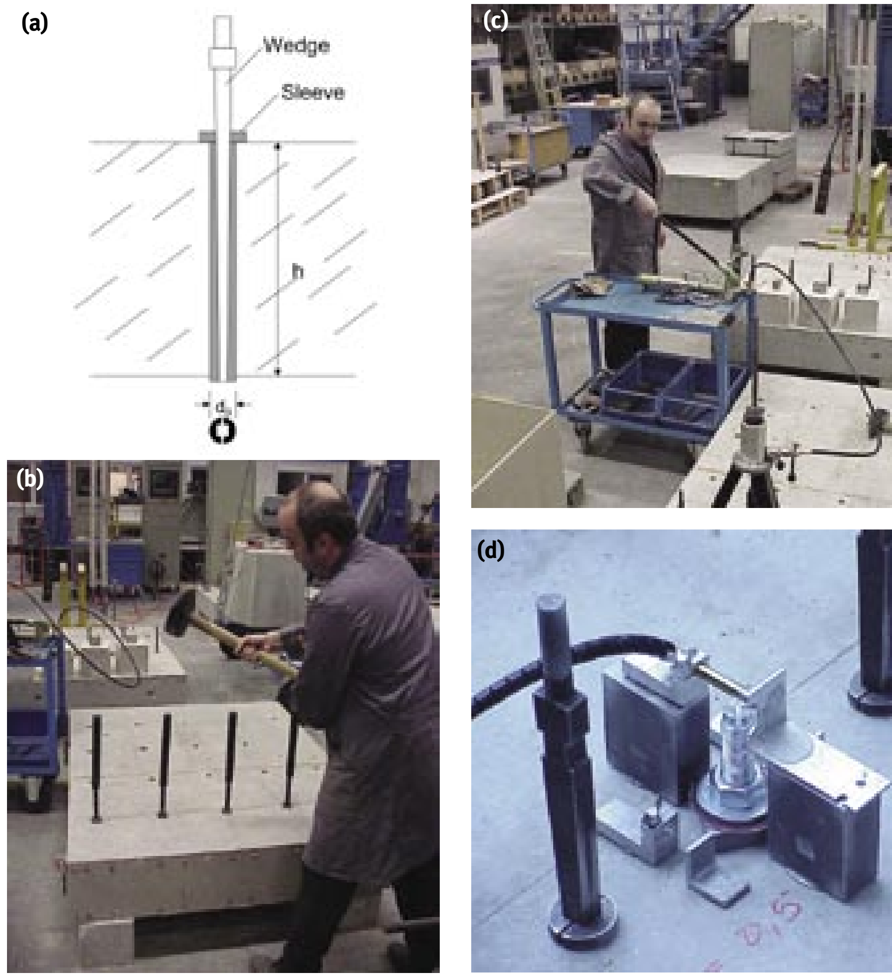

Fig. 2: Opening of cracks by steel wedges: (a) sketch of steel wedge consisting of expansion sleeve and wedge; (b) hammering in of wedges; (c) withdrawal of wedges using hydraulic ram; and (d) measurement of crack width across anchor (measurement devices shown beside the anchor)

A second method, which is a variation of the first technique, uses a hydraulic expander set into a drilled hole, or an expander hose cast into the concrete. Oil under high pressure is pumped into the expander, which in turn forces the concrete apart, much like the splitting wedges. This method can also use crack inducers at the sides of the concrete member.

The third method is to exert a centric external tensile loading on the reinforcing bars. Figure 3 shows two suitable test setups. Crack inducers that extend over the width of the member (Fig. 1(b)) may be used with these setups. Figure 3(a) shows a configuration where only two hydraulic rams are required regardless of the number of crack control reinforcement bars. The reinforcement of the test member is rigidly connected to steel cross beams. This is facilitated by using reinforcing bars with ribs in the form of a thread and corresponding nuts. Hydraulic rams are placed within the steel testing frame,

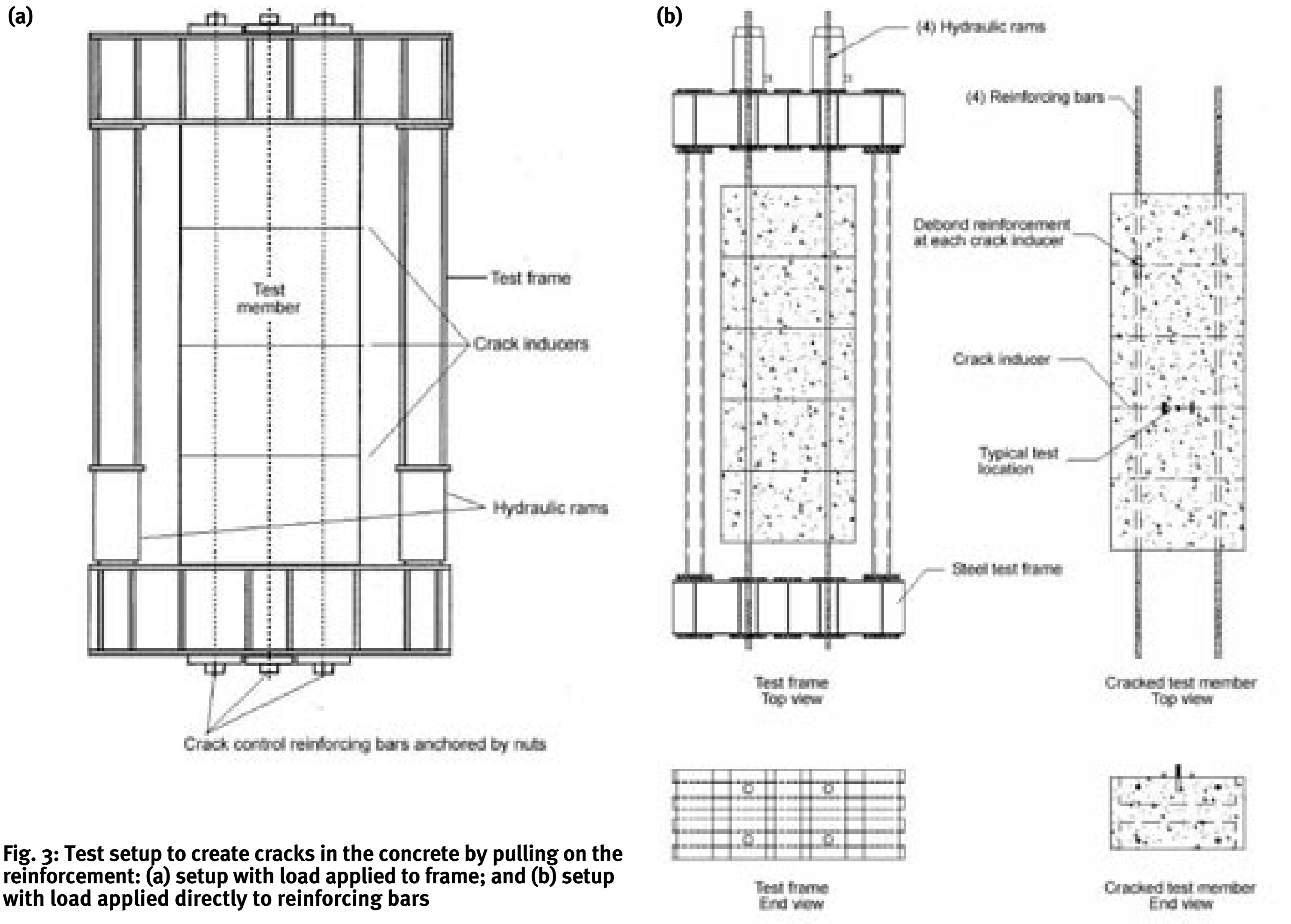

Fig. 3: Test setup to create cracks in the concrete by pulling on the reinforcement: (a) setup with load applied to frame; and (b) setup with load applied directly to reinforcing bars

as shown in Fig. 3(a). A tension force is applied to the reinforcement by oil pressure activating the rams. This action pulls the concrete test member apart as the reinforcing bars undergo elastic elongation, with the cracking occurring at the crack-inducer locations.

Figure 3(b) shows a configuration that requires a number of hydraulic rams equal to the number of reinforcing bars. With this setup, a tension force is applied directly to the reinforcement. Depending on the length of the specimen, one or more cracks can be formed in each concrete test member. This method has the advantage of precise crack width control, especially for the test requiring the cycling of the crack width. This method, however, typically requires a more complicated and expensive computer-controlled servo-valve system to vary the hydraulic pressure to control the crack width within the required parameters.

Reducing the bond over a short length of the crack control reinforcement bars at the locations where the bars intersect the crack inducers (Fig. 3(b)) will help to achieve the required crack width at a steel stress well below the reinforcement's yield strength. The bond can be reduced by covering the reinforcement bars in these regions with a thin plastic tube. This measure, however, is not necessary to obtain the crack widths required in ACI 355.2.

Regardless of which method is used, once the cracks are formed, they should be opened slightly and their traces marked on the concrete surface before closing the crack for installation of the anchor. The closing method depends on the method used to open the cracks. If steel splitting wedges are used, they should be withdrawn using a test setup with a hydraulic ram (Fig. 2(c)). If hydraulic expanders or the test setup according to Fig. 3 are used, the oil pressure is simply reduced to zero. After completely unloading the concrete test member, a small crack width will remain (width < 0.002 in. [0.05 mm]).

CONTROLLING CRACK WIDTHS

After the anchor has been installed, the crack is re-opened to the desired width. In Fig. 2(d), a precise measurement of the crack opening at the anchor location is shown in which displacements are measured across the anchor using an electronic displacement transducer. ACI 355.2 allows, however, for the crack opening to be measured as the average of "two dial gages or electronic transducers, one on either side of the anchor, oriented perpendicular to the crack."[1] The dial gages or transducers should be placed as close as possible to the anchor.

The control of the crack width during crack opening depends on the method used for opening the cracks. If steel splitting wedges are employed, they should be hammered in sequentially across the crack length. This method of crack width control works well for anchors in a crack with a defined width. The anchors can be tested in either tension or shear, as required.

When using hydraulic expanders or expander hoses, the crack is opened by pumping oil into the expanders. This method is suitable to test anchors loaded in tension or shear in a crack having a defined width. It may also be used to perform tests when the crack width is cycled; however, electronic control of the applied load is necessary.

The most versatile method is to use hydraulic rams to apply an external loading to the reinforcing bars as the method for crack width control. This method requires more electronic control of the loading system. It is well-suited for tests with a defined crack width or for cycling of the crack width.

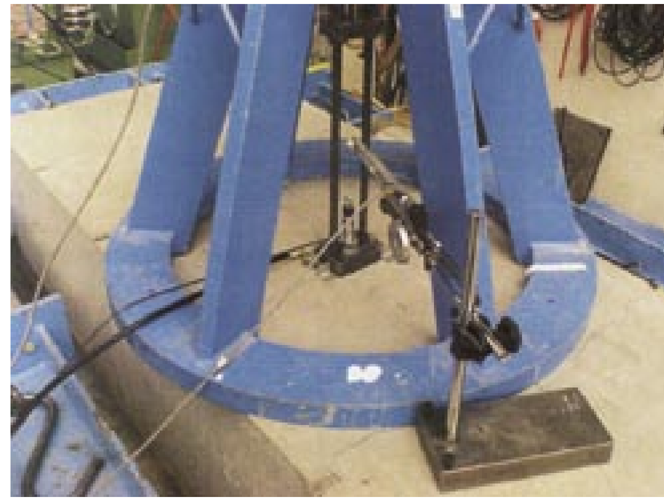

Fig. 4: Test setup for tension test of an anchor

With all methods, the crack widths before loading the anchor must comply with the requirements of ACI 355.2. The average crack opening width for a test series shall be equal to or greater than the specified crack width. Individual crack opening widths shall be within ± 15% of the specified crack width for that test series.

During loading of the anchor, measurement of the crack width directly over the anchor is often not possible. Thus, during loading, the crack width is typically obtained as the average crack width measured using two measuring devices located to either side of each anchor (Fig. 2(d)). When loading the anchor, the crack width is not controlled but rather monitored. By applying a tension force to the anchor, the concrete test specimen is subjected to a bending moment.

If the supports of the hydraulic ram used to apply the tension force to the anchor are placed parallel to the crack direction, the bending moment will induce an additional tension force in the top reinforcement and reduce the tension force in the bottom reinforcement. Therefore, the width of the crack will increase at the top of the specimen and decrease at the bottom during anchor loading, resulting in a non-uniform crack width over the depth of the concrete member.

If the supports of the hydraulic ram are placed perpendicular to the crack direction, tensile stresses are induced in the concrete that may cause a crack perpendicular to the intended one in the region of the anchor. This will negatively influence the anchor behavior. Therefore, to reduce the opening of the crack at the top surface of the concrete member and to avoid the forming of another crack during anchor loading, a circular or square support of the hydraulic ram used to apply the tension force to the anchor, and a test member with a suitable depth (> $2h_{ef}$, where h_{ef} is the effective embedment depth, measured from the concrete surface to the deepest point at which the anchor tension load is transferred to the concrete) should be used.

Even when an appropriate circular or square support is used, some additional cracks will occur during the loading of the anchor. The extent of this crack opening is governed by the test member's reinforcement ratio. Figure 4 shows a suitable test setup with two transducers for measuring crack width and a device to measure the anchor displacements at the anchor head. If an anchor displacement measurement setup such as that shown in Fig. 4 is used, the bending stiffness of the setup should be large enough to reduce measurement error.

SOME FINAL GUIDANCE

In principle, testing of anchors in cracked concrete is not significantly different from testing anchors in uncracked concrete; however, additional equipment is needed to form and control cracks in the concrete. The method used to form and open cracks is decided by the testing agency or institute, taking into account economic aspects. The dimensions of the test specimen depend on many parameters (for example, anchor size, method to open and control the crack, and specimen weight that can be handled). Therefore, the specimen dimensions are not standardized in ACI 355.2. They must be chosen by the testing agency such that the above requirements for the percentage and detailing of the reinforcement, the crack width distribution over the member depth and width, and the location of the anchor with respect to the crack and reinforcement are fulfilled.

The proper formation and control of cracks is critical for obtaining valid test results. The procedures described in this article for forming and controlling cracks have been successfully used for more than 20 years. For further background on anchors and cracked concrete, the reader is referred to a Code background paper by Eligehausen and Balogh.[4]

References

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Selected for reader interest by the editors.

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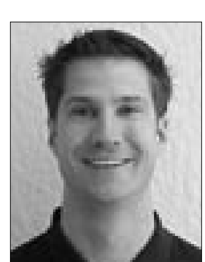

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