REMR TECHNICAL NOTE CS-MG-1.1

ANCHOR EMBEDMENT IN HARDENED CONCRETE
(Supersedes previously issued CS-MG-1.1)

Pull-out test on anchor installed under wet conditions.

PURPOSE: To provide guidance on materials and techniques for anchor embedment in hardened concrete.

BACKGROUND: Rehabilitation of hydraulic structures usually requires removal of deteriorated concrete and replacement with new concrete. Steel dowels are normally used to anchor the replacement material to the existing concrete. Typically, anchors are installed by (a) drilling a small-diameter hole into the remaining sound concrete, (b) cleaning the hole, (c) inserting a capsule containing either polyester resin or vinylester resin, and (d) spinning the anchor into the hole. Early-age field pullout tests on anchors installed under wet conditions resulted in a number of failures (Ref. a and b). Consequently, in a research study, the effectiveness of selected grout systems for embedment of anchors in concrete was evaluated.

EVALUATION OF GROUTING SYSTEMS:

a. Pullout Strength Tests: The effectiveness of neat portland-cement grout, epoxy resin, and prepackaged polyester resin in embedding anchors in hardened concrete was evaluated under a variety of wet and dry installation and curing conditions (Ref. c). With the exception of the anchors embedded in polyester resin under submerged conditions, pullout strengths beyond 1-day age were essentially equal to the ultimate strength of the anchor when the anchors were installed under wet or submerged conditions. The overall average pullout strength of anchors embedded in polyester resin under submerged conditions was 35 percent less than the strength of similar anchors installed and cured under dry conditions. The largest reductions in pullout strength, approximately 50 percent, occurred at ages of 6 and 16 months. Also, the overall average pullout strength of anchors embedded in polyester resin under submerged conditions, was approximately one-third less than the strength of anchors embedded in epoxy resin and portland-cement grout under wet and submerged conditions, respectively, and cured under submerged conditions. Although the epoxy resin performed well in these tests when placed in wet holes, it should be noted that the manufacturer does not recommend placement under submerged conditions.

b. Creep Tests: Creep tests were conducted for anchors embedded in portland-cement grout and epoxy resin. Average slippage for anchors embedded in wet conditions was 0.0028 and 0.0033 in., respectively, or 2 to 4 times higher than results under dry conditions. Slippage for anchors embedded in polyester resin under dry conditions was about 30 times higher than for those embedded in portland-cement grout and epoxy resin. Anchors embedded in polyester resin, installed and cured under submerged conditions, exhibited significant slippage; in fact, in one case the anchor pulled completely out of the concrete after 14 days under load. After 6 months under load, the two remaining specimens exhibited an average anchor slippage of 0.0822 in., approximately 30 times higher than anchors embedded in portland-cement grout under the same conditions.

c. Compressive Strength Tests: Long-term durability of the embedment materials was evaluated by periodic compressive strength tests. After 32 months, the average compressive strength of polyester-resin and epoxy-resin specimens stored in water was 37 and 26 percent less, respectively, than that of companion specimens stored in air. The strength of portland-cement grout cubes stored in water averaged 5 percent higher than that of companion specimens stored in air during the same period.

d. Vinylester Resin Capsules: A 1987 review of available manufacturers' literature on anchor grouting systems for concrete revealed that a vinylester resin, prepackaged in glass capsules, was being promoted for use under submerged conditions. According to the manufacturers' representatives, the performance of anchors embedded in vinylester resin under submerged conditions was similar to that of comparable anchors installed in the dry. Since no test data were furnished, the New Orleans District initiated testing by the US Army Engineer Waterways Experiment Station (WES) to evaluate the performance of anchors embedded in vinylester resin under dry and submerged conditions (Ref. d).

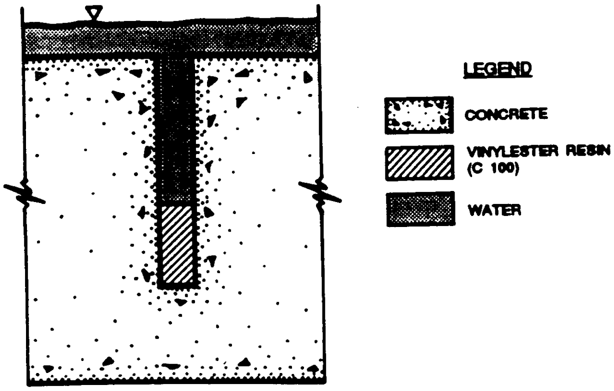
Pullout test results on anchors installed in dry holes (15-in. embedment length) were remarkably consistent with an overall average tensile capacity of 105 kips at 0.1-in. displacement and an average ultimate load of approximately 125 kips, which was near the yield load of the anchors. In comparison, results of pullout tests on anchors installed under submerged conditions were relatively erratic, with an overall tensile capacity of 36 kips at 0.1-in. displacement and an average ultimate load of 48 kips. Obviously, the tensile load capacity of anchors embedded in concrete with vinylester-resin capsules was significantly reduced when the anchors were installed under submerged conditions. At a displacement of 0.1 in., the tensile capacity of anchors embedded under submerged conditions was approximately one-third that of similar anchors embedded in dry holes.

The reduced tensile capacity of anchors embedded in concrete under submerged conditions with prepackaged polyester-resin and vinylester-resin cartridges was primarily attributed to the anchor installation procedure. Although insertion of the adhesive capsule or cartridge into the drill hole displaced the majority of the water in the hole, water did remain between the walls of the adhesive container and the drill hole. Insertion of the anchor trapped this water in the drill hole and caused it to become mixed with the adhesive, resulting in an anchor with reduced tensile capacity.

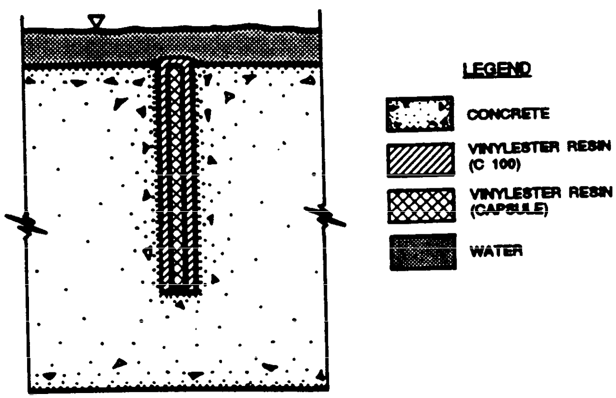
These findings generated concern in the geotechnical community regarding the ultimate performance of rock bolts previously installed under similar conditions. Because of this concern, the Geotechnical Laboratory at WES initiated testing with the U.S. Bureau of Mines Denver Research Center. As a result of these tests, it was concluded that water is detrimental to the successful curing of polyester resins only in situations involving very short anchors (less than 2 ft) (Ref. e). To solve this problem, it was recommended that the anchor hole be drilled 1 ft deeper than desired and an additional cartridge of resin be added.

In subsequent tests on anchors embedded in vinylester under submerged conditions, it was found that increasing the embedment length from 12 to 24 in. resulted in a 60 percent increase in tensile capacity at 0.1-in. displacement (Ref. f). However, this increased tensile capacity of anchors installed under submerged conditions was still only about one-half the load capacity of anchors with 12-in. embedment lengths installed in dry holes. While it may be possible to improve anchor performance under submerged conditions by increasing embedment lengths, the costs of additional material and labor are significant. Therefore, the development of improved anchor-installation procedures which do not require excessive embedment lengths was necessary.

e. Two-Step Installation Procedure: A revised anchor-installation procedure eliminated the problem of resin and water mixing in the drill hole (Ref. f) (Figure 1). First a small volume of adhesive in



a. Step 1



b. Step 2

Figure 1. Revised anchor installation procedure

bulk form was injected into the bottom of the drill hole. This injection was easily accomplished with recently developed paired plastic cartridges (Figure 2) containing the vinylester resin and a hardener

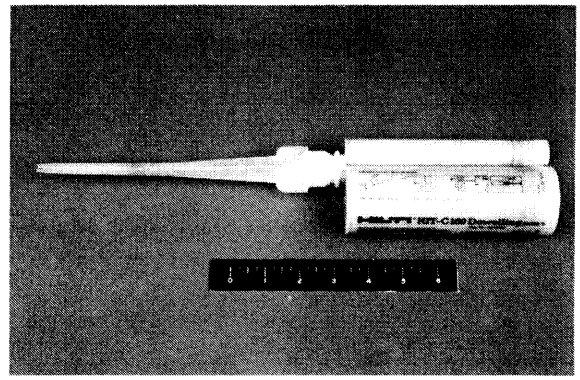


Figure 2. Paired plastic cartridges and static mixing tube

and a tool similar to a caulking gun, which automatically dispensed the proper material proportions through a mixture tube directly into the drill hole. Next, a prepackaged vinylester-resin capsule, which displaced the remainder of the water in the drill hole, was inserted, and then the anchor was spun into place.

Anchors with 15-in. embedment lengths installed with the revised procedure exhibited essentially the same tensile capacity under dry and submerged conditions. At 0.1-in. displacement, the tensile capacity of vertical anchors installed with the revised procedure under submerged conditions averaged more than three times greater than that of similar anchors installed with the original procedure. Also, the ultimate tensile capacity of anchors installed under submerged conditions with the revised procedure averaged more than 130 kips compared to an average ultimate capacity of less than 50 kips for similar anchors installed with the original procedure.

Horizontal anchors installed with the revised procedure under both dry and submerged conditions also exhibited excellent tensile load capacities. Overall, the difference in tensile capacity between horizontal anchors installed under dry and submerged conditions was less than 2 percent at 0.1-in. displacement. Similarly, the average difference in tensile capacity between horizontal and vertical anchors was only 3 and 5 percent for anchors installed under submerged and dry conditions, respectively.

RECOMMENDATIONS: The two-step anchor installation procedure should be followed when prepackaged polyester resin or vinylester resin is to be used as an embedment material for short (less than 15-in. embedment length) steel anchors in hardened concrete under submerged conditions. The two-step installation procedure may not be necessary for rock anchors which normally have longer embedment lengths. Tests, to date, on anchors installed with the revised procedure have been limited to short duration loadings at relatively early ages. Additional testing should be conducted to determine the long-term performance of vinylester resin under wet, alkaline conditions. Also, creep tests should be conducted to evaluate the effect of sustained loads on anchors installed with the revised procedure.

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