ISSN 2229-5518

AnchorsBonded in Concrete Under Sustained Loading

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ABSTRACT: Anchors can be installed to pre or post to the structure, The Post installed anchors come in either mechanical anchors that develop their strength through mechanical interlock with the base concrete. The bonded anchors that develop their strength by bonding anchor rod to the base concrete.

Bonded anchors are either grouted, typically, cementitious material, or adhesive, a chemical material. This thesis presents a current literature review of post-installed bonded anchors, preliminary testing of adhesive bonded anchors, and details of short term and long term test setups for future testing. The purpose of this thesis was to develop the test setups that will be used for future testing onanchors.

KEYWORDS: -Bonded Anchors in concrete under retained loading, bonded anchors to retain load. Anchors used for serviceability limits of concrete

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INTRODUCTION

Concrete is a material used extensively in structural applications across the world, creating a need to anchor other materials. Anchorage to concrete can be accomplished through a piece of steel, such as a threaded rod, bolt, or proprietary anchor, partially embedded in the base concrete and used to connect additional members. Anchorage of this type can be categorized as either cast in place or post installed. Cast in place anchors are embedded in the concrete before it hardens. Advantages of cast in place anchors are their predictable and more reliable behavior and failure modes, but require a high level of accuracy in their placement toensure proper alignment as they cannot be moved after the concrete hardens. Post installed anchors typically use proprietary methods to attach to hardened concrete. This allows for freedom in placement to ensure proper alignment, but can be subject to much more variability in performance and capacity of the anchor. Post installed anchors can be categorized as either mechanical or bonded anchors. Mechanical post installed anchors use friction and mechanical interlock to transfer their load from the anchor rod to the concrete. ACI 318-02 Appendix D was the first edition of anchor design standards in the ACI Building Code Requirements for structural Concrete. It covered cast in place anchors and post installed mechanical anchors and gave design standards for both. Bonded anchorage systems generally comprise of a steel anchor rod, either threaded or dowel (rebar), and a bonding material. Bonding materials are loosely defined as either adhesive or grouted depending on hole diameter (Zamora et al. 2003 p. 222). Grouted anchors have a hole diameter greater than 1.5 times theanchor diameter where adhesive anchors are less,

Related Work

Post installed anchors in a variety of projects, such as connecting new construction to existing structures,fitting two hardened pieces of concrete after forms are removed and hanging structural orarchitectural features from concrete. And preventing creep in the structure under the guidelines of AASHTO (2010) and ACI 355.4 (2011)

Bonded anchors, both adhesive and grouted, are generally installed the same way. A hole is drilled in base concrete using a rotary impact hammer or a diamond bit core drill. The hole is then cleaned with a brush, compressed air, and/or water jet. The bonding material then fills the hole and the anchor rod is inserted to the bottom of the hole. This process varies greatly by manufacturer. Adhesive anchors are generally installed with a caulking type gun or by a glass capsule that mixes the components in the hole, while cementitious anchors are mixed like concrete in the field or come ready to use from the manufacturer. The bonding material is then allowed to cure based a manufactures' recommendations, generally between 24 hours nd28days, and load can then be applied.

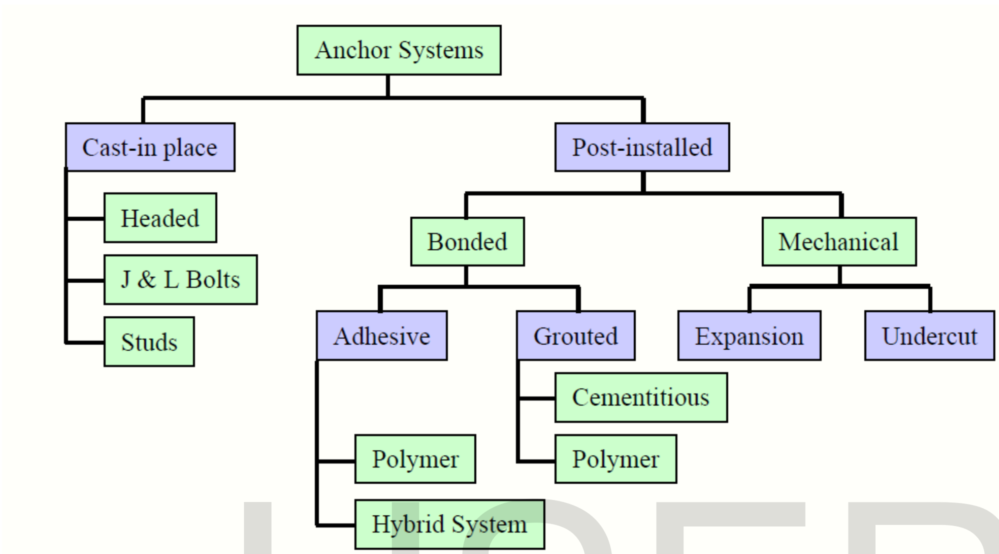

Figure 1.1 Anchor Systems

Post installed anchors allow contractors the freedom to put anchors in the proper position after the concrete base member is cast, but their behavior is less predictable and more susceptible to changes in environmental conditions. Both adhesive and grouted anchors can creep, deform or displace over time due to sustained stress. Creep over a period of sustained load can cause failure in adhesive anchors at loads lower than their short term static capacity. Adhesive anchor research has recently beensummarized in two National Cooperative Highway Research Program (NCHRP) reports, Cook et al. (2009) and Cook et al. (2013). These reports differed from Cook and Burtz (2003) and Zamora et al. (2003) by focusing only on adhesive anchors and specifically creep characteristics of adhesive anchors. Adhesive anchors are known to creep
AASHTO TP-84 (AASHTO TP-84 2010) which provides a stress versus time-to-failure test for adhesive anchors.

MODEL SYSTEM AND FAILURE MODES OF ANCHORS

The types of Anchors,

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i. Adhesive Anchors System.
ii.Grouted Anchor systems.

Adhesive Anchor system: -An adhesive anchor system has a hole less than 50% of the anchor rod diameter,the material used in these anchors is defined by ACI355.4 (2011) as “Organic polymers used in adhesives can include, but are not limited to, epoxies,polyurethanes, polyesters, methyl methacrylate’s and vinyl esters; or inorganic polymers.” Mostof the organic polymer adhesives are contain two parts that require mixing just prior toapplication. This is typically done with a caulking type gun that mixes the two components asthey are installed into the hole. Inorganic adhesive anchors allow for the use of cementitiousproducts, typically reserved for grouted anchor applications with a hole diameter of greaterthan 1.5 times the anchor diameter. Adhesive anchor manufacturers provide a table listingallowable load and ultimate load for their anchor system based on anchor rod diameter,embedment depth, and concrete compressive capacity. Separately they provide a list of holediameters to use with each acceptable anchor rod diameter.

Grouted Anchor system: -A grouted anchor system has a holelarger than 50% of the anchor rod diameter,these anchors can be classified as either cementitious or polymer based. Cementitious anchorsare a mixture of sand, cement, water, and other additives. Most structural applications ofcementitious anchors use non-shrink grout products that conform to ASTM C1107 which tests for compressive strength and shrinkage over time. Polymer grouts consist of small aggregates (i.e. sand), a resin, and a curing agent. The inclusion of small aggregates allows polymer grouts to fill larger holes, differentiate polymer grouted anchors from polymer adhesive anchors.

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Modes of Failure of Anchors

The four failure modes investigated in this project and mostliterature are concrete breakout failure, adhesive (or grout)/concrete interface bond failure,steel/adhesive (or grout) interface bond failure, and partial adhesive (or grout)/concrete andpartial steel/adhesive (or grout) interface bond failure. The latter three failure modes areaccompanied by a secondary shallow concrete cone failure plane for both adhesive and groutedanchors. Use of a headed anchor rod in grouted anchors precludes the grout/steel interfacebond failure allowing for only threepossible failure modes of headed grouted anchor systems

Concrete breakout failure is predicted using the Concrete Capacity Design (CCD). The three bond failure modes are predicted using a uniform bond stress model. The CCD model was developed for cast in place and mechanical anchors, but is applicable to grouted anchors that fail with a full concrete breakout cone. The three bond failure modes are exclusive to bonded anchors

Concrete Capacity Design (CCD): -It assumes that the base concrete fails in tension and a 35° fullcone is formed from the end of the embedded head to the concrete surface,thisdesign method was validated for headed cast in-place anchors and post-installed mechanicalanchors and has been the model used by ACI for headed anchors that fail in tension or shear(cast in place or mechanical)

ISSN 2229-5518

$$Nb = \mathrm{k}\sqrt{\mathrm{f}'}c^{h}\ ef^{1.5}$$

PARAMETERS THAT AFFECT ANCHOR CAPACITY

parameters that can affect adhesive anchor system capacities.Two ratios were used to compare the effect of a parameter on bond strength. The first is an alpha reduction ratio. This value is a ratio between a baseline test and a test at a specific parameter.For example, an adhesive with a baseline static capacity of 20 kips (89 kN) that has an elevated temperature static capacity of 18 kips (80 kN) would have an alpha reduction ratio of 0.9 for the elevated temperature parameter. A similar alpha reduction ratio can be found for long term performance by comparing a baseline creep test and a creep test subjected to a specific parameter. The other ratio is the influence ratio. This is the comparison of alpha reduction ratios for long term and short term tests of a specific parameter. For example, if the short term alpha reduction ratio is 0.9 and the long term alpha reduction ratio is 0.75, the influence ratio is1.2. Influence ratios greater than 1 show a parameter has more of an effect on creep capacitythan it does on short term capacity and short term tests will not accurately predict long term performance under the conditions of a specific parameter. Additionally, polymer grouted anchors may have different performance from cementitious grouted anchors for certain parameters. Those cases will beaddressed in this chapter as well.

PARAMETER: Elevated In-Service Temperature - sustained elevated temperatures during a structure's life.

Adhesive: Elevated temperatures are shown to greatly reduce the creep capacity of adhesive anchors as tested by Cook et al. (2013). Of all the parameters tested, elevated temperature had the greatest effect on creep capacity of adhesive anchors, specifically, at temperatures over 120°F. For example, baseline MSL of adhesive B in Cook et al. (2013) was 22.9 kips (101.7 kN) when tested at 110°F. The MSL when tested at 70°F was 27.2 kips. A similar comparison canbe made with the creep tests conducted at 110°F and 70°F. Three creep tests greater than 75% MSL at 110°F were run at 20.9 kips (93 kN) (81% MSL), 20.7 kips (92 kN) (81% MSL), and 19.2

kips (85.4 kN) (75% MSL). The respective failure times were 0.11 hours, 0.02 hours (failed before reaching 20.7 kips (92 kN)), and 0.04 (failed before reaching 19.2 kips (85.4 kN)). Compare that to three creep tests run at 70 °F at 20.4 kips (90.7 kN) (75% of 70°F MSL and 89% of 110°F MSL) that failed at 0.8 hours, 1.2 hours, and 2118 hours. (Cook et al. 2013)

Grouted: Cementitious grouts are believed to be less sensitive to temperature than polymer grouts and adhesive anchors (Cook et al. 2013). Polymer grouts would most likely be affected similarly, to polymer adhesive anchor systems, but there is no research to validate this.

PARAMETER: Reduced In-Service Temperature – sustained reduced temperatures during a structure's life

Adhesive: Reduced Temperatures make adhesives more brittle, but no standard exists for testing adhesives at reduced in-service temperature, though ACI 355.4 (2011) provides a standard test for reduced installation temperature

RESULTS

Three preliminary test series were run as part of this thesis. The purpose of these test series was to validate equipment and procedures for future testing. Test Series 0a resulted in a final design for the non-rigid coupler and the height of the short term and long term tests to account for the non-rigid coupler. Test series 0b resulted in improved installation techniques and higher capacity threaded rod. Test series 0c resulted in experience with cementitious anchor.

These tests will be conducted on three adhesives. Allthree adhesives have been tested to ICC-ES 308 standards.

Adhesive A is the same adhesive used in test series 0b. This adhesive is a combination of Bisphenol A and Bisphenol F epoxy resins with fillers and m-xylene diamine and aliphatic polyamine hardeners. The manufacturer lists an uncracked bond stress of 2,140 psi (14.75 MPa) for 5/8 in (15.9 mm) diameter threaded rod. This would equate to a static capacity of 13.1 kips (58.2kN).

Adhesive B is a BisphenolA/Epichlorohydrin (Epoxy Resin) with a Dimethaneamine hardener. It lists an uncracked bond stress of 2,075 psi (14.3 MPa) which should cause bond failure at 12.7 kips (56.5 kN) for these tests.

Adhesive C is Bisphenol A and Bisphenol F epoxy resins with amine hardeners. The listed uncracked bond stress is 2,148 psi (14.7MPa) and should have a static capacity of 13 kips (58 kN) for this research

Conclusions

Many lessons were learned from Test Series 0a. The data from this test series is notvalid for comparing performance of adhesive anchor systems, but it is valid to show thefunctionality of the designed test apparatus. It also led to changes in testing procedures for TestSeries 0b and 0c. Test 0a-1 shows that the short term test set up is capable of applying a failureload to an anchor. Tests 0a-2 and 0a-3 led to a new design for the non-rigid coupler. Test 0a-4shows that a sustained load can be applied to an anchor and that the load and displacement canbe measured. Test 0a-4 also shows the need to take care when aligning a long-term test set upto avoid non-vertical displacements of the spring. Overall, Test series 0a shows that sustainedloadexperiments produce expected results. Lessons from this test series were applied to Test Series 0b and 0c.Test Series 0b lead to a re-design of the non-rigid coupler with a hole 1/16 in (1.59 mm)larger than nominal anchor diameter used in testing. The failure of the B7 threaded rod lead tofuture research using the higher capacity ASTM A354 GR BD threaded rod. This test series alsoshowed a potential need to measure displacement of the anchor from a different point than thenon-rigid coupler. Future researches will investigate methods of measuringdisplacement fromthe top of the anchor rod instead of at the non-rigid coupler.Test set ups discussed in Chapter 7 are a result of a thorough literature review andpreliminary experiments and represent the main conclusion of this MS research project.

RECOMMENDED FUTURE WORK

Future work would be to continue exploring the creep characteristicsof cementitious anchors. Other future testing should look at the combined effects ofparameters. Currently, tests of just one parameter are used to find a reduction factor andindividual reduction factors are applied. Testing an anchor under multiple parameters todetermine if effects are additive would be worthwhile. For example, an anchor could beinstalled in moistened concrete, cured in a moist environment for the minimum manufacturer'srecommendation, and then tested under sustained load at high heat. This final sustained loadtest could be compared to individual tests of moisture during installation, moisture duringcuring, minimum cure time of adhesive, and sustained

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loading to determine if testing oneparameter at a time is a valid way to predict performance under combined conditions

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BIOGRAPHY

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