ISBN: 978-628-96613-3-0. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2026.1.1.2478

# Pull-Out Testing of Mechanical and Adhesive Anchors for High-Strength Concrete

Jorge Antonio Tito
University of Houston Downtown, USA, *tito-izquierdojor@uhd.edu*

Abstract– **Experimental pull-out tests are conducted to evaluate the pull-out behavior of mechanical and adhesive post-installed concrete anchors embedded in high-strength concrete. The study compares measured pull-out capacities with code-based strength predictions in accordance with ACI 318-19 anchorage provisions. Anchors are installed in concrete blocks by drilling holes following manufacturers' installation requirements. Mechanical anchors are installed using hammer-driven expansion, whereas adhesive anchors are installed by injecting epoxy into the drilled holes prior to anchor placement. Mechanical anchors are tested immediately after installation, while adhesive anchors are tested after a minimum epoxy curing period of 24 hours. Pull-out testing is performed using an M2008 heavy-duty tester. Concrete blocks measure 20 in × 20 in in plan and 8 in in thickness and are cast with a mix design achieving a compressive strength exceeding 8 ksi. Anchors are placed at corner, edge, and interior locations to investigate the influence of anchor location on pull-out capacity and failure mode. Experimental results are compared with pull-out strength predictions based on ACI 318-19 provisions using the 8 ksi concrete strength limitation. The results highlight the influence of concrete strength, anchor type, installation method, and edge distance on pull-out performance and provide insight into the applicability of current code-based design assumptions for post-installed anchors subjected to pull-out loading.**

**Keywords— Post-installed anchors, Pull-out testing, Mechanical anchors, Adhesive anchors**

## I. INTRODUCTION

Concrete anchors are widely used in construction to transfer tensile and shear forces from structural and nonstructural components to concrete foundations [1]. The pull-out performance of post-installed anchors depends on anchor type, installation method, concrete properties, embedment depth, and edge distance [1]. According to ACI 318-19 anchorage provisions, pull-out failure of post-installed anchors may occur through steel tensile failure, concrete breakout failure in tension including splitting, pull-out failure, side-face blowout failure, or, in the case of adhesive anchors, bond failure [1]. The governing failure mode is influenced by both anchor characteristics and installation quality [1].

Post-installed anchors are commonly used in retrofit, repair, and equipment installation applications where flexibility in anchor placement is required [1], [2], [3]. These anchors are generally classified as mechanical anchors, which develop resistance through expansion or bearing mechanisms, and adhesive anchors, which rely on bond between the anchor, adhesive material, and surrounding concrete [2], [3]. Proper installation is critical for both anchor types, as deviations from manufacturer requirements may significantly reduce pull-out capacity and alter the expected failure mode [5], [7].

This study presents an experimental investigation of the pull-out performance of post-installed mechanical and adhesive concrete anchors installed in concrete with compressive strength exceeding 8 ksi. Experimental results are compared with theoretical pull-out strength predictions obtained using PROFIS software (Hilti) [4] to evaluate the influence of anchor type, installation method, concrete properties, and anchor location. The software follows ACI 318-19 Chapter 17 provisions and applies the concrete strength limitation of 8 ksi [1].

## II. METHODOLOGY

### *A. Materials and Concrete Specimens*

Concrete specimens consist of slabs measuring 20 in. × 20 in. in plan and 8 in. in thickness, reinforced with #4 rebars at 6 in. spacing, as shown in Fig. 1. For the mechanical anchor tests, six concrete slabs incorporating three different mix designs are provided by Locke Solutions. The concrete mixtures include cement and fly-ash blends and are proportioned to achieve a compressive strength exceeding 8 ksi at 28 days. Six additional slabs used for adhesive anchor tests are also provided by Locke Solutions and consist of a single mix design with a target compressive strength of 8 ksi at 28 days. Concrete compressive strength is verified through standard cylinder testing prior to pull-out testing. Table I summarizes the mix design used for each concrete slab.

a. Reinforcement of concrete slabs: #4 @ 6”

b. Concrete blocks

Fig. 1 Concrete blocks 20”x20” in plan and 8” thick.

TABLE I
MIX DESIGN FOR CONCRETE BLOCKS

| Block | Material | | | | | |
|---|---|---|---|---|---|---|
| | Cement Type I/II lb | Flyash Type F lb | 3/8” River Rock lb | Sand lb | Water lb | Admixture oz |
| LS-1 | 800 | 0 | 1450 | 1443 | 265 | 68 |
| LS-2 | 560 | 240 | 1450 | 1389 | 265 | Ad1: 68 |
| LS-3 | 560 | 240 | 1450 | 1389 | 265 | Ad1: 68 |
| LS-4 | 800 | 0 | 1450 | 1443 | 265 | 68 |
| LS-5 | 800 | 0 | 1450 | 1443 | 265 | 68 |
| A, C, D, E | 544 | 233 | 1550 | 1424 | 264 | Ad1: 74<br>Ad2: 0<br>Ad3: 23<br>Ad4: 128<br>Ad5: 0 |

Note: Ad1: Water Reducer; Ad2: Air Entrainment; Ad3: Viscosity Modifier; Ad4: Accelerator; Ad5: Carbon Cure

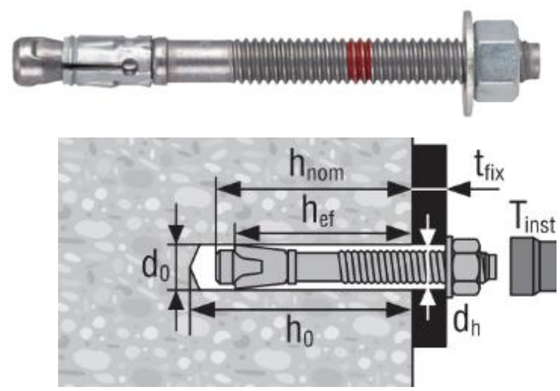
### *B. Anchors and Installation Procedure*

All anchors and installation accessories used in this study are supplied by Hilti and are installed in accordance with the manufacturer’s published installation requirements after receiving technical training from the manufacturer [5], [6], [7]. Drilled holes are created using a Hilti TE 2-22 cordless rotary hammer equipped with TE-CX imperial hammer drill bits. Prior to anchor installation, drilled holes are cleaned using a Hilti HIT-RB cleaning brush in accordance with adhesive anchor installation procedures.

Mechanical anchors are installed using a hammer-driven method and are tightened to the manufacturer-specified installation torque using a Hilti SIW 4AT-22 torque-control tool, as shown in Fig. 2.

a. Drill Hilti TE 2-22 & TE-CX 9/16” drill bit

b. Adaptive torque system Hilti SIW 4AT-22½”




c. Hilti KB-TZ2 ½”ϕ
do = ½”
hef = 3 ¼”
hnom = 3 ¾”
ho = 4 ¼”
dh = 9/16”
Tins = 50 ft-lb (Torque applied for installation)

Fig. 2 Tools used for installation of mechanical anchor KB-TZ2 ½”ϕ and 3 ¾” nominal concrete embedment

Adhesive anchors consist of Hilti HAS-E-55 anchor rods installed in clean drilled holes using Hilti HIT-HY 200-R V3 injectable adhesive, as shown in Fig. 3. The adhesive is dispensed into the drilled holes using a Hilti HDE 500-22 cordless adhesive dispenser equipped with static mixing nozzles to ensure proper mixing of the adhesive components. Adhesive anchors are tested only after the minimum curing time specified by the manufacturer has elapsed.


a. Drill Hilti TE 2-22, TE-CX 9/16” drill bit & HIT-RB 9/16” Brush

b. HDE 500-22 Adhesive dispenser & HIT-HY 200-R V3 Adhesive

c. HAS-E-55 Anchor rod ½”x8”

Fig. 3 Tools used for installation of adhesive anchor HAS-E55 ½”ϕ

### *C. Pull-Out Test Setting*

As illustrated in Fig. 4, anchor bolts are classified as central anchors when located less than 2 in. from the block center, edge anchors when positioned 3 in. from the edge and less than 2 in. from the block centerline, and corner anchors when located 3 in. from the block corner. The exact anchor coordinates (X, Y) are provided in Table II.

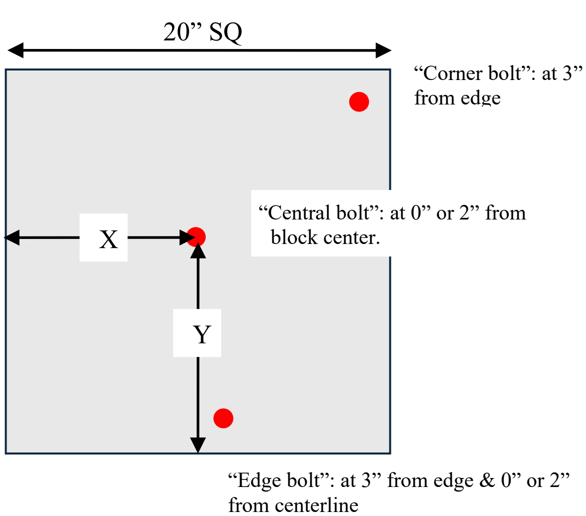



Fig. 4 Location of anchor bolts: Central, Corner or Edge

For all tests, including both mechanical and adhesive anchors, an M2008 heavy-duty pull-out tester [9] is used to apply tensile load and to measure anchor displacement using a laser deflectometer, as shown in Fig. 5.

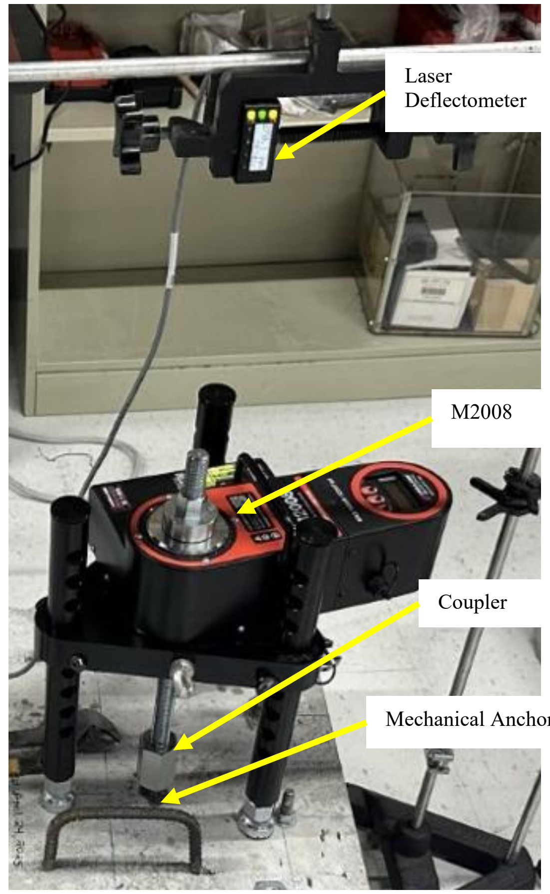



Fig. 5 Setting of heavy-duty Pull-Out tester M2008

## III. RESULTS

### *A. Failure Mode Identification and Theoretical Comparison*

Observed failure modes are classified in accordance with ACI 318-19 anchorage definitions [1] and include steel failure or yielding, concrete failure, and bond failure for adhesive anchors. Concrete splitting is also observed as a concrete-related failure mode. Splitting is not explicitly predicted by ACI breakout equations and occurs when radial tensile stresses exceed the tensile capacity of concrete under limited edge distance and confinement; this behavior is further influenced by the small edge distance and the limited confinement provided by the block thickness. Experimental pull-out capacities are compared with theoretical strength predictions obtained using Hilti PROFIS software and are evaluated within the framework of ACI 318-19 anchorage provisions and ACI 355 anchor qualification concepts [2], [3].

### *B. Test Results of Mechanical Anchors*

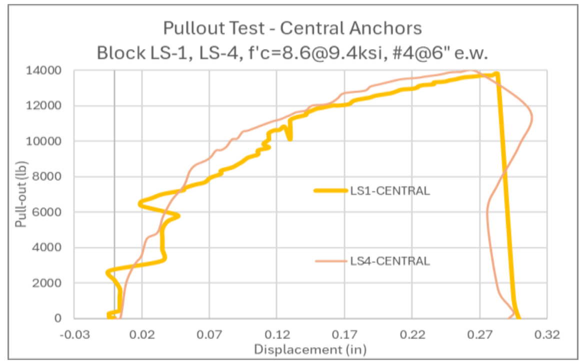
Table II summarizes the concrete block compressive strength, f'c, the anchor location (X, Y) measured from a corner, the pull-out force at failure, and the corresponding failure mode for tests with mechanical anchors.

TABLE II
PULL-OUT TEST OF MECHANICAL ANCHORS HILTI KB-TZ2
½"ϕ - 3 ¾" EMBEDDED

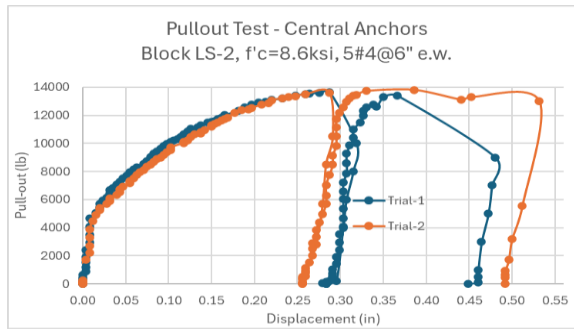
| Mechanical Anchor | Block | Location (See Fig. 5) | | | Pull-out force, lb | Failure mode |
|---|---|---|---|---|---|---|
| | | Type | X | Y | | |
| MA-1 | LS-1<br>f'c=8.6 ksi<br>ft = 1.75 ksi<br>5#4@6"E.W. | Central | 8" | 8" | 13800 | Steel Yielding |
| MA-2 | LS-1 | Edge | 7" | 3" | 11225 | Splitting |
| MA-3 | LS-1 | Corner | 3" | 3" | 9900 | Splitting |
| | | | | | | |
| MA-4 | LS-2<br>f'c=9.4 ksi<br>ft = 1.55 ksi<br>4#4@6"E.W. | Central | 10" | 10" | 13650 | Steel Yielding & Rupture |
| MA-5 | LS-2 | Edge | 10" | 3" | 8700 | Splitting |
| MA-6 | LS-2 | Corner | 3" | 3" | 12200 | Splitting |
| | | | | | | |
| MA-7 | LS-3<br>f'c=9.4 ksi<br>ft = 1.55 ksi<br>5#4@6"E.W | Corner | 3" | 3" | 11500 | Splitting |
| | | | | | | |
| MA-8 | LS-4<br>f'c=9.0 ksi<br>ft = 1.23 ksi<br>5#4@6"E.W | Central | 8" | 8" | 13925 | Steel Yielding |

Fig. 6a presents the relationship between pull-out force and vertical displacement for the central mechanical anchor Hilti KB-TZ2 with ½" diameter and 3 ¾" nominal embedment into concrete. Fig. 6b presents the loading and unloading of the central anchor in block LS-1, while Fig. 6c shows the corresponding responses for the edge and corner anchors.

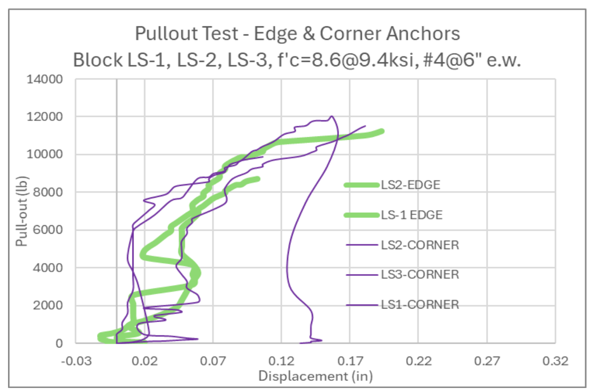
Fig. 7 illustrates the observed failure modes. Steel yielding or rupture is shown in Fig. 7a. In the case of rupture, necking occurs near the lower wedge of the anchor. Greater displacement is observed in central anchors compared with edge and corner anchors, where failure occurs by concrete splitting. Anchors failing by steel yielding or rupture exhibit ductile behavior, with ultimate displacement exceeding twice the yielding displacement.




a. Central anchors MA-1, MA-8




b. Central anchor MA-4 – loading & unloading

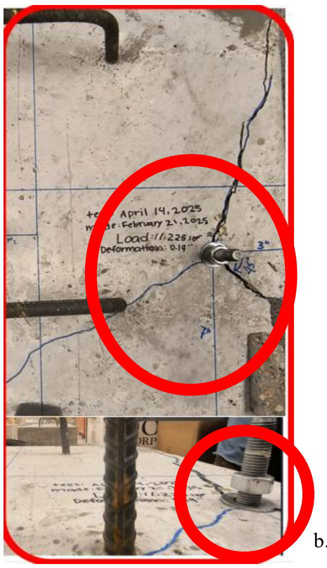



c. Edge and corner anchors MA-5, MA-2, MA-6, MA-7, MA-3

Fig. 6 Pull-out load vs. Vertical displacement of mechanical anchors Hilti KB-TZ2 ½"ϕ – 3 ¾" embedment

Figures 7b and 7c show typical concrete splitting when the anchor is located near the edge or corner, respectively. In these cases, failure occurs at smaller anchor displacement, corresponding to a brittle response.


a. Steel yielding or rupture



b. Concrete splitting at edge

b. Concrete splitting at corner

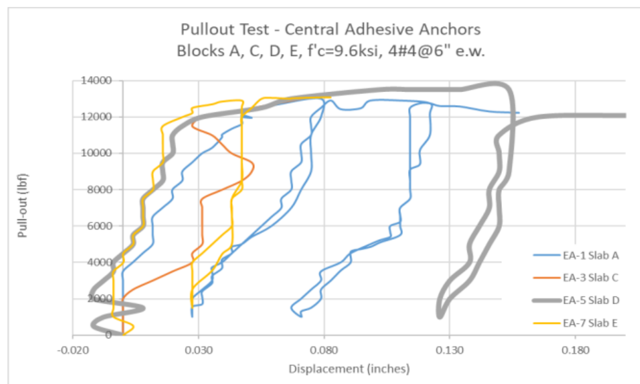
Fig. 7 Modes of failure of Mechanical Anchors Hilti KB-TZ2 ½"ϕ – 3 ¾" embedment

### C. *Test Results of Adhesive Anchors*

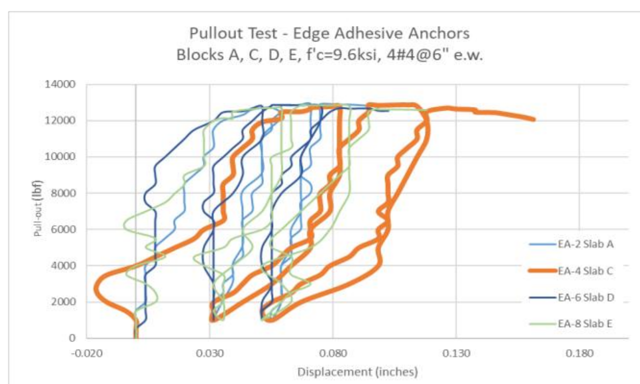
Table III summarizes the concrete block compressive strength, f'c, the anchor location (X, Y) measured from a corner, the pull-out force at failure, and the corresponding failure mode for adhesive anchors tests.

TABLE III
PULL-OUT TEST OF ADHESIVE ANCHORS HILTI HAS ½"ϕ 6" EMBEDDED

| Adhesive Anchor | Block f'c=9.6 ksi 4#4@6"E.W. | Location (See Fig. 5) | | | Pull-out force, lb | Failure mode |
|---|---|---|---|---|---|---|
| | | Type | X | Y | | |
| EA-1 | A | Central | 10" | 10" | 13000 | Steel Yielding |
| EA-2 | A | Edge | 10" | 3" | 12900 | Steel Yielding |
| EA-3 | C | Central | 10" | 10" | 13000 | Steel Yielding |
| EA-4 | C | Edge | 10" | 3" | 12850 | Steel Yielding |
| EA-5 | D | Central | 10" | 10" | 13350 | Steel Yielding |
| EA-6 | D | Edge | 10" | 3" | 12875 | Steel Yielding |
| EA-7 | E | Central | 10" | 10" | 13075 | Steel Yielding |
| EA-8 | E | Edge | 10" | 3" | 12850 | Steel Yielding |




a. Central anchor – loading & unloading




b. Edge anchor – loading & unloading

Fig. 8 Pull-out load vs. Vertical displacement of adhesive anchors Hilti HAS E55 ½"ϕ – 6" embedded

Fig. 8a shows the relationship between pull-out force and vertical displacement for the central adhesive anchor Hilti HAS-E55 with ½-in. diameter and 6-in. nominal embedment. Fig. 8b presents the loading and unloading response of an edge anchor. Fig. 9 illustrates typical steel yielding and rupture of the HAS-E55 anchor rod.

All adhesive anchor tests exhibit ductile behavior under pull-out loading, with ultimate displacement approximately three to six times the yielding displacement.

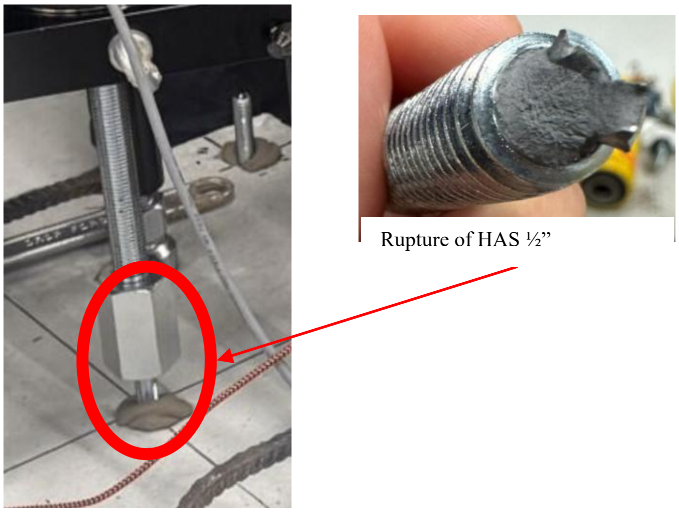



Fig. 9 Mode of failure of Adhesive Anchors Hilti HAS E55 ½”ϕ – 6” embedment

## IV. COMPARE TEST RESULTS WITH THEORETICAL CALCULATIONS

The Hilti PROFIS software is used to perform theoretical calculations [4]. The software applies ACI 318-19 equations to estimate anchor pull-out strength [1]. For comparison with experimental results, the strength reduction factor is removed ($\varphi$ = 1.0). Because ACI 318-19 limits concrete compressive strength to f'c=8 ksi for anchor design, calculations are performed using this value rather than the measured compressive strength.

### A. *Mechanical Anchors*

Table IV presents the comparison between experimental pull-out capacity and PROFIS predictions for concrete breakout and steel rupture. In all cases, the measured pull-out load exceeds the predicted value; however, the observed failure mode differs from the predicted mode.

For central anchors, the observed failure mode is steel yielding, whereas the theoretical prediction indicates concrete breakout. The average overstrength ratio is 1.56 relative to the predicted concrete breakout capacity and 1.22 relative to the predicted steel capacity.

TABLE IV
COMPARE TEST FAILURE WITH THEORY USING PROFIS (from HILTI) FOR MECHANICAL ANCHORS KB-TZ2 ½”ϕ – 3 ¾” EMBEDMENT

| Test | Failure Pull-out Tu, kip | Failure mode | PROFIS | | Tu/ Tn | Failure Type |
|---|---|---|---|---|---|---|
| | | | Tn kip | Failure mode | | |
| MA1 central | 13.8 | Steel yielding | 8.9<br>11.2 | Concrete<br>Steel | **1.55**<br>1.23 | Steel yielding, different than theory |
| MA2 Edge | 11.2 | Splitting | 6.4 | Concrete | **1.75** | Splitting |
| MA3 Corner | 9.9 | Splitting | 5.6 | Concrete | **1.77** | Splitting |
| MA4 Central | 13.65 | Steel yielding | 8.9<br>11.2 | Concrete<br>Steel | **1.53**<br>1.22 | Steel yielding, different than theory |
| MA5 Edge | 8.7 | Splitting | 6.4 | Concrete | **1.36** | Splitting |
| MA6 Corner | 12.2 | Splitting | 5.6 | Concrete | **2.18** | Splitting |
| MA7 Corner | 11.5 | Splitting | 5.6 | Concrete | **2.05** | Splitting |
| MA8 Central | 13.93 | Steel yielding | 8.9<br>11.2 | Concrete<br>Steel | **1.57**<br>1.24 | Steel yielding, different than theory |

Edge and corner anchors exhibit failure governed by concrete splitting, while PROFIS predicts concrete breakout characterized by a conical failure surface. Splitting occurs due to internal tensile stresses exceeding the tensile capacity of concrete. The average overstrength ratio relative to predicted concrete capacity ranges from 1.36 to 1.77 for edge anchors and from 1.77 to 2.18 for corner anchors.

### A. *Adhesive Anchors*

Table V presents the comparison between experimental pull-out capacity and PROFIS predictions for adhesive anchors. In all cases, the measured pull-out load exceeds the predicted value, and the observed failure mode differs from the predicted mode.

For both central and edge anchors, the observed failure mode is steel yielding, whereas the theoretical model predicts bond failure. The average overstrength ratio is 1.22 for central anchors relative to predicted steel capacity and 2.25 for edge anchors relative to predicted bond capacity. All adhesive anchor tests demonstrate ductile behavior, with no bond-controlled failure observed.

TABLE V
COMPARE TEST FAILURE WITH THEORY USING PROFIS (from HILTI) FOR ADHESIVE ANCHORS HAS 55E ½”ϕ – 6” EMBEDMENT

| Test | *Failure Pull-out Tu, kip* | Failure mode | PROFIS | | Tu/ Tn | Failure type |
|---|---|---|---|---|---|---|
| | | | Tn kip | Failure mode | | |
| EA-1 Central | 13.0 | Steel yielding | 17.9<br>13.3<br>10.6 | Concrete<br>Bond<br>Steel | 0.73<br>0.98<br>**1.23** | Steel yielding |
| EA-2 Edge | 12.90 | Steel yielding | 8.6<br>5.7<br>10.6 | Concrete<br>Bond<br>Steel | 1.50<br>**2.26**<br>1.22 | Steel yielding. PROFIS: Bond |
| EA-3 Central | 13.00 | Steel yielding | 17.9<br>13.3<br>10.6 | Concrete<br>Bond<br>Steel | 0.73<br>0.98<br>**1.23** | Steel yielding. |
| EA-4 Edge | 12.85 | Steel yielding | 8.6<br>5.7<br>10.6 | Concrete<br>Bond<br>Steel | 1.49<br>**2.25**<br>1.21 | Steel yielding. PROFIS: Bond |
| EA-5 Central | 13.35 | Steel yielding | 17.9<br>13.3<br>10.6 | Concrete<br>Bond<br>Steel | 0.75<br>1.00<br>**1.26** | Steel yielding. |
| EA-6 Edge | 12.88 | Steel yielding | 8.6<br>5.7<br>10.6 | Concrete<br>Bond<br>Steel | 1.50<br>**2.26**<br>1.22 | Steel yielding. PROFIS: Bond |
| EA-7 Central | 13.08 | Steel yielding | 17.9<br>13.3<br>10.6 | Concrete<br>Bond<br>Steel | 0.73<br>0.98<br>**1.23** | Steel yielding. |
| EA-8 Edge | 12.85 | Steel yielding | 8.6<br>5.7<br>10.6 | Concrete<br>Bond<br>Steel | 1.49<br>**2.25**<br>1.21 | Steel yielding. |

## V. CONCLUSIONS AND RECOMMENDATIONS

Pull-out tests were conducted on mechanical and adhesive anchors installed in concrete blocks with compressive strengths ranging from 8.6 to 9.4 ksi. The design provisions of ACI 318-19 are applicable to concretes with a maximum specified compressive strength of 8 ksi; therefore, the experimental results are compared with code-based predictions using this limiting value in the calculations. For consistency in comparison, the strength reduction factor is taken as 1.0 for all theoretical evaluations.

Mechanical anchors located away from edges (central anchors) exhibit failure governed by steel yielding without evidence of concrete failure and demonstrate ductile behavior, which is not predicted by the theoretical model. Anchors located near edges or corners exhibit concrete splitting, which represents a brittle failure mode and is generally consistent with theoretical expectations. In all cases, the maximum load obtained from testing exceeds the theoretical capacity predicted by ACI 318-19.

Adhesive anchors exhibit failure governed by steel yielding for both central anchors and anchors located near edges. For anchors near edges, the theoretical model predicts bond failure; however, this failure mode is not observed experimentally. In all cases, the measured pull-out load exceeds the theoretical predictions, and the anchors exhibit ductile behavior.

Edge and corner anchors exhibit failure governed by concrete splitting, while PROFIS predicts concrete breakout characterized by a conical failure surface. Splitting occurs due to internal tensile stresses exceeding the tensile capacity of the concrete and is influenced by reduced edge distance and limited confinement provided by the specimen thickness. The average overstrength ratio relative to the predicted concrete capacity ranges from 1.36 to 1.77 for edge anchors and from 1.77 to 2.18 for corner anchors.

Overall, the results indicate that ACI 318-19 design provisions provide conservative predictions for anchors installed in high-strength concrete exceeding the 8 ksi limit. Steel yielding governs when sufficient embedment and edge distance are provided, while concrete splitting becomes critical for anchors located near edges in relatively thin concrete members. Proper consideration of edge effects and confinement is therefore essential when applying code-based anchor design provisions.


## ACKNOWLEDGMENT

Special thanks are extended to former students Alan Gonzales, Gisele Martinez, Jayleen Montano, Haily Weber, Alondra Ramirez, Miranda Santiago, Jennifer Ocampo for their contribution to the testing program.

The author gratefully acknowledges Locke Solutions for donating the concrete blocks used in this experimental study and Hilti for providing technical training and guidance on anchor installation procedures.

Acknowledgment is also given to the ORCA program at UHD for providing the funding necessary to purchase the equipment and materials required for the testing program.


## REFERENCES


[1] American Concrete Institute, *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary*, Farmington Hills, MI, USA: ACI, 2019.

[2] American Concrete Institute, *Qualification of Post-Installed Mechanical Anchors in Concrete (ACI 355.2)*, Farmington Hills, MI, USA: ACI, 2019.

[3] American Concrete Institute, *Qualification of Post-Installed Adhesive Anchors in Concrete (ACI 355.4)*, ACI, Farmington Hills, MI, USA, 2018.

[4] Hilti, Inc., *Hilti PROFIS Engineering Software – Anchor Design and Verification*, Hilti Corp., Plano, TX, USA, 2024.

[5] Hilti, Inc., *HIT-HY 200-R V3 Injectable Adhesive – Product and Installation Documentation*, Hilti Corp., Plano, TX, USA, 2024.

[6] Hilti, Inc., *HAS-E Threaded Rods – Technical Data and Installation Instructions*, Hilti Corp., Plano, TX, USA, 2024.

[7] Hilti, Inc., *Post-Installed Mechanical Anchor Installation and Torque Verification Guidelines*, Hilti Corp., Plano, TX, USA, 2024.

[8] Enerpac, *RCH-Series Hydraulic Cylinders – Operating Instructions and Specifications*, Enerpac Tool Group, Menomonee Falls, WI, USA, 2023.

[9] Humboldt Mfg. Co., *M2008 Heavy-Duty Pull-Out Tester – Operating Manual*, Humboldt Mfg. Co., Elgin, IL, USA, 2023.

[10] Locke Solutions, *Precast Concrete Slabs – Mix Design and Material Properties*, Locke Solutions, Houston, TX, USA, 2025.