



UNITED STATES
NUCLEAR REGULATORY COMMISSION

WASHINGTON, D.C. 20555-0001

April 29, 1997

MEMORANDUM TO: Andrew J. Murphy, Chief
Structural & Geological Engineering Branch
Division of Engineering Technology, RES

FROM: Herman L. Graves
Structural & Geological Engineering Branch
Division of Engineering Technology, RES

SUBJECT: TRIP REPORT, AMERICAN CONCRETE INSTITUTE
ANNUAL CONVENTION, APRIL 9-11, 1997, SEATTLE,
WASHINGTON

During April 9-11, 1997, I attended the American Concrete Institute (ACI), 349 Subcommittee 3, ACI 349 Main Committee, and ACI 355 committee meetings. I also attended a special Technical Session on Anchorage Design. The meeting highlights are discussed below.

ACI 349 - Subcommittee 3. "Embedded Steel"

The Subcommittee met Wednesday morning April 9 and Thursday morning April 10, 1997 during the ACI convention held at the Westin hotel.

Topics discussed included the proposed revision to ACI 349.2R94, "Embedment Design Examples." This publication is not due for a revision until 1999 but subcommittee 3 members want to issue an interim revision to demonstrate how to design for the new embedment shear provisions in Appendix B. The Data Task Force chairman gave a presentation on their latest efforts to analyze anchorage test data from various sources. The database consists of over 1,500 anchor tests and is divided into six anchor categories. The Subcommittee is using the Data Task Force to examine the relative merits of the "CC-Method" and 45° Cone approach. It appears that the committee members are in favor of adopting the proposed ACI 318 chapter 23 and making needed changes for Nuclear industry application.

A draft chapter 23 has been made available for 318 subcommittee ballot. The 318 group recognizes the differences between their mission and 349's mission and will work to establish anchor guidance that will be useful in general building situations without the rigor of nuclear designs. It is assumed that the ballot will not go to the main 318 committee until 2001 since the 318 task group on anchors made the new chapter 23 contingent upon the publication of two new ASTM standards on anchors. That is the ASTM XXX "Standard Test Methods for Anchorages in Cracked Concrete," and ASTM XZXX "Standard Test Methods in Uncracked and Cracked Concrete." Since the development of chapter 23 by ACI 318 more anchor manufacturers are participating in the development of the ASTM standards. The anchor manufacturers participation will lead to an acceptable standard but has also served to lengthen the process.

A17

I gave a report on the recent test results from the NRC sponsored research at the University of Texas at Austin and indicated that reports on the work should be available by November 1997.

ACI 355. Anchorage to Concrete

This subcommittee met April 9, Wednesday afternoon at the Westin Hotel. Topics of discussion were the State of the Art Report, members decided to delay publishing this report until a later date. It was concluded that a comprehensive design guide based on the proposed ACI 318 chapter 23 would be helpful to the industry, plans were made to develop this document. Other discussion centered ongoing or new test programs. I highlighted the USNRC test work, R. Eligehausen mentioned that a lot of work at the University of Stuttgart was being done on the use of channel anchors under various load conditions. Don Mienheit of Wiss Janey Elsner mentioned that his firm was presently doing work for issuing a revision of the PCI Handbook on Anchor design. It was also learned that ASCE has published a report entitled "State of the Art for Petrochemical Cast In Place Anchorages."

Technical Session. "Design of Fastening to Concrete"

This session was held on Thursday afternoon April 10. Participants included committee members from ACI 318, 349, and 355. An audience of about 100 persons listened to presentations that outlined present and plan code provisions for anchorages; highlighted the importance of establishing an anchor database; and presented typical design examples. Attached is a list of topics presented and copies of available handouts.

ACI 349 Main Committee. Concrete Nuclear Structures

The main committee met on Friday April 11. Discussion included committee roster changes, the most significant change was the committee chairman. Mr. Charles A. Zalesiak, Reynold Metals Company four term as chairman expired at the conclusion of the Seattle meeting. Mr. Albert Y. C. Wong, Stone & Webster Corporation will serve as the new chairman. Subcommittees 2 and 3 reports were given and discussed by the main committee.

The remainder of the meeting focused on the status of committee documents. The latest proposed revisions were published in the December 1996 Concrete International magazine. The next committee action is due to ACI Technical Activities Committee in 2001.

C. P. Tan of NRR was in attendance and covered the Subcommittee 2, Design, meeting. Two other subcommittees 1, Materials, and 4, Repository Structures, did not hold meetings.

Attachment: As stated

cc: See Attached Page

cc: N. Chokshi
J. Costello
G. Bagchi
J. Ma
H. Ashar
C.P. Tan
R. Shewmaker
J. Phillip
P.Y. Chen

TECHNICAL SESSION

THURSDAY, APRIL 10
2:00 PM - 5:00 PM

ROOM: GRAND 3

DESIGN OF FASTENING TO CONCRETE

Sponsored by Committee 355

Session Moderator: Richard E. Wollmershauser
 Director, Technical Services
 Hilti, Inc.
 Tulsa, OK

Session Co-Moderator: Richard E. Klingner
 Professor
 Department of Civil Engineering
 The University of Texas at Austin
 Austin, TX

Introduction **2:00**
 Richard E. Wollmershauser, Director, Technical
 Services, Hilti, Inc., Tulsa, OK

Introduction to the Concrete Capacity Design Method **2:05**
 Ronald A. Cook, Associate Professor, Department of Civil
 Engineering, University of Florida, Gainesville, FL

Data Base Analysis and Estimation of ϕ -Factors **2:45**
 Richard E. Klingner, Professor, Department of Civil
 Engineering, The University of Texas at Austin, Austin, TX

Fastening to Concrete: Practical Implications **3:15**
from the Designers Perspective
 Roger J. Becker, Vice President, and LeRoy A. Lutz, Vice
 President, Computerized Structural Design, Inc.,
 Milwaukee, WI

Areas of Current Technical Discussion **3:35**
 Richard E. Wollmershauser, Director, Technical
 Services, Hilti, Inc., Tulsa, OK

Design Examples **3:55**
 Peter J. Carrato, Senior Technical Specialist, Bechtel
 Corp., Gaithersburg, MD, and Harry Wiewel, President,
 Techmar, Inc., Long Beach, CA

Questions and General Discussion **4:35**

Areas of Current Technical Discussion

Presented by:
Richard E. Wollmershauser, PE
Director, Technical Services
Hilti Inc., Tulsa, OK

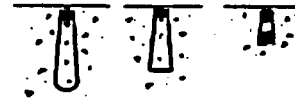
OVERVIEW OF OPEN SUBJECTS

- Subjects not covered by present draft
- General topics under discussion
- ACI 349 (Subcommittee 3) special issues

SUBJECTS NOT COVERED BY CURRENT DRAFT

- Anchor types not included:
 - C-I-P specialty anchors
 - Adhesive-bonded anchors
 - Very large anchors with dia. > 2 in.
 - » very deep embedments
 - » close edge distances
 - » heavy reinforcement

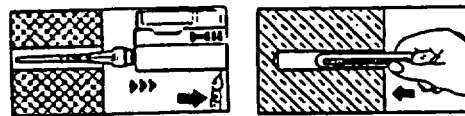
Specialty Anchors



Specialty Anchors

- Very limited data base - not included in current data base
- Mostly proprietary anchors and data

Adhesive-bonded anchors



- Injection and capsule anchors

Adhesive-bonded anchors

- Limited technical data base available
 - Single anchors only
- Multiple anchor and edge and spacing testing underway
- Developing performance prediction equations
 - For publication in *ACI Structural Journal* in 1997/98

GENERAL TOPICS UNDER DISCUSSION

- ASTM anchor performance standards in preparation
- Performance at deep embedments
- Basis for predictor equations
- Effects of cracked concrete
- Elastic and plastic design methods

ASTM anchor prequalification standards

- Two anchor prequalification standards in preparation - draft 6
 - Cracked and uncracked concrete
 - Uncracked concrete
- Covers only tests to qualify and provide data for Chapter 23 (CB30)
- Expect ASTM adoption in 1998

ASTM Anchor Prequalification Standards

- Prescribes suitability and service condition tests for anchor prequalification
- Based on tests, defines classes or grades of anchors and assigns ϕ factors

Performance at deep embedments

- Proposal to fit one equation to all data
 - exponent on embedment h_{ef} 1.5, 1.6, or 1.7
- Current draft gives:
 - 1.5 for $h_{ef} < 10$ in. (250 mm)
 - 5/3 for $h_{ef} > 10$ in. (250 mm)

Basis for design equations

- 5 % fractile (lower bound)
or
- Mean value
- Current draft uses lower bound



Effects of cracked concrete

- Current draft assumes performance in cracked concrete = $0.7 \times$ uncracked concrete, from data base
- Recent testing at Univ. of Texas for USNRC indicates that for some anchors 0.7 is conservative
 - headed bolts, heavy duty sleeve anchors, some undercuts,

ACI 349 SPECIAL ISSUES

- ACI 349 Sub 3 proposes to accept draft Chapter 23 as basis, and
- Add and modify requirements for Nuclear Concrete Code

not a requirement

ACI 349 differences

- Uses only class/grade 1 or 2 anchors from ASTM prequalification tests
- Proposes ductile yielding of attachment
- Discourages brittle concrete failure

ACI 349 differences

- Different "k" and " ϕ " factors

		k	ϕ
– based on mean test data	ACI 318	21	0.9
– gives similar results	ACI 349	28	0.65

ACI 349 differences

- Transition from shallow to deep embedment equations
 - ACI 318/355 draft uses 10 in.
 - ACI 349 Sub 3 draft uses 8 in.

ACI 349 differences

- Changed terminology:
 - uses "Embedments" rather than "Fasteners"

no longer used

ACI 349 differences

- Retains from current Appendix B:
 - Structural shapes
 - Embedded plates and shear lugs
 - Grouted Embedments

Summary - Areas of Current Technical Discussion

- ACI 355, ACI 318 and ACI 349 working together to harmonize new CCD method fastener provisions
- ACI 355 is developing a *Design Guide: Fastening to Concrete* Publish in 1998?
- Current proposals will be improved upon and expanded in the future
 - Adhesive anchors, etc.

Introduction to the Concrete Capacity Design (CCD) Method for Fastening to Concrete

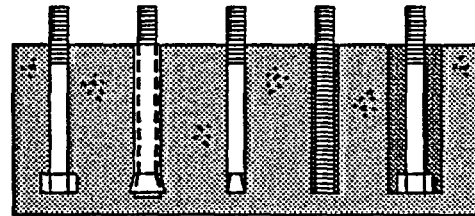
Presented by: Ronald A. Cook, Ph.D., P.E.

Based on the draft Chapter 23 of ACI-318 (CCD) with
comparisons to ACI-349 and PCI methods (45° cone)

University of Florida
Department of Civil Engineering



Types of Anchors



Cast-In Place Undercut Expansion Adhesive Grouted

Objectives

- ◆ History of development of CCD method
- ◆ Steel strength - comparison of methods
- ◆ Evaluation of embedment strength using the CCD method
 - Tension
 - Shear
- ◆ Comparison of test data to CCD and ACI 349
- ◆ Summary

History

- ◆ the 45° cone (349/PCI) method was developed in the early and mid 70's from tests on cast-in-place anchors with embedment lengths around 100 to 150 mm
- ◆ in the 80's, comprehensive tests of different types of anchors with various embedment lengths and edge distances were performed at the University of Stuttgart

History

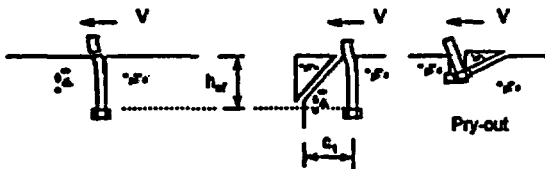
- ◆ the results of the Stuttgart testing led to the development of the K' method which was introduced to ACI 349 and 355 in the late 80's
- ◆ In 1990 the K' method was improved to be more user-friendly at the University of Texas at Austin, this resulted in the CCD method
- ◆ an International data base was assembled during the same period

History

- ◆ since 1991, the majority of the work of ACI committees 349 and 355 has been to evaluate both the CCD and the 45° cone (349/PCI) method using the International data base of test results
- ◆ as a result of this evaluation, both ACI 349 and ACI 355 have voted to proceed with implementation of the CCD method

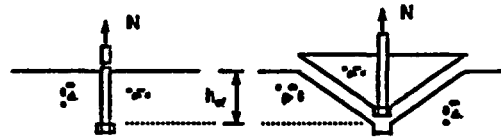
Shear failure modes

- ◆ Steel failure
- ◆ Embedment failure



Tensile failure modes

- ◆ Steel failure
- ◆ Embedment failure



Basic design requirement

Tension:

$$N_u \leq \min(\phi_s N_s, \phi_e N_e)$$

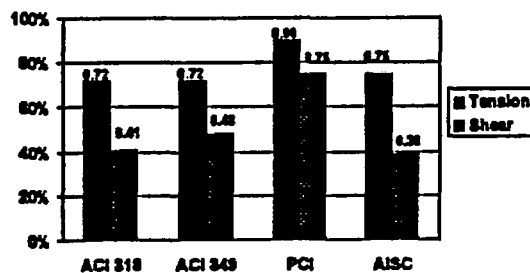
Shear:

$$V_u \leq \min(\phi_s V_s, \phi_e V_e)$$

Implementation of basic design requirement - ACI 318 Chapter 23

- ◆ design strength "shall be based on design models which result in predictions of strength in substantial agreement with results of comprehensive tests"
- ◆ same wording as Chapter 10 of ACI 318 which permits the use of the "stress block" for concrete beams
- ◆ the CCD method satisfies this requirement

Design steel strength as % of $A_s f_{ut}$



Summary - steel strength

- ◆ some inconsistencies between design methods (bolts vs. welded studs)
- ◆ embedment strength is getting the most attention
- ◆ each type of strength needs to be addressed

Basic differences between the CCD method and the 349/PCI method

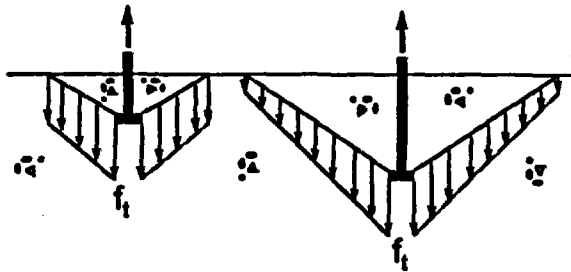
- ◆ fracture mechanics "size effect"
- ◆ 35° failure angle rather than 45°
- ◆ non-uniform stress distribution around an anchor when close to an edge
- ◆ uneven distribution of load on anchors in a group (eccentricity)
- ◆ uncracked and cracked concrete

Embedment failure - tension General form for single anchor

$$N_b = k \sqrt{f'_c} h_{ef}^2 \quad \text{349 \& PCI}$$

$$N_b = k \sqrt{f'_c} h_{ef}^{1.5} \quad \text{CCD}$$

Variation in tensile stress distribution with embedment length, h_{ef}



Embedment failure accounting for size effect (fracture mechanics)

$$N_b = \frac{k \sqrt{f'_c} h_{ef}^2}{h_{ef}^{0.5}} \quad \begin{array}{l} \leftarrow \text{Basic 349/PCI equation} \\ \leftarrow \text{Modification for "size factor"} \end{array}$$

Result:

$$N_b = k \sqrt{f'_c} h_{ef}^{1.5} \quad \text{CCD}$$

The "size effect" factor

- ◆ based on fracture mechanics
- ◆ accounts for increasingly non-uniform distribution of stresses and strains over the failure surface with increasing embedment length (i.e., size)
- ◆ also observed in flexural and shear strength of unreinforced beams

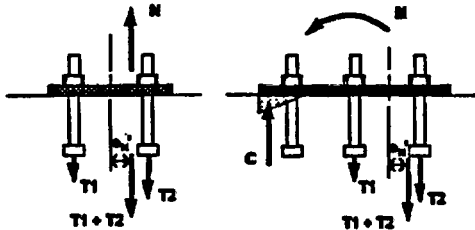
Embedment failure - tension General form for edges and groups

$$N_n = \frac{A_N}{A_{No}} \psi_1 \psi_2 \psi_3 N_b$$

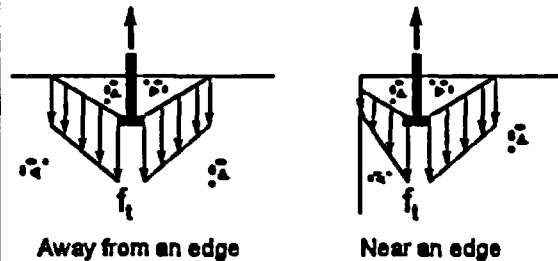
\swarrow accounts for projected area of failure surface (single and group)
 \swarrow accounts for eccentricity in the fastening
 \swarrow accounts for edge effects
 \swarrow accounts for cracked concrete
 \swarrow basic single anchor strength

The "eccentricity" factor, ψ_1

- ♦ accounts for the tensile resultant not acting through the centroid of the anchor group



Variation in tensile stress distribution near an edge, "edge effect" factor ψ_2



The "edge effect" factor, ψ_2

- ♦ "edge effect" accounts for the unsymmetrical distribution of stresses and strains when an anchor is located near an edge

$$\psi_2 = 1.0 \quad \text{if } c_1 \geq 1.5h_{ef}$$

$$\psi_2 = 0.7 + 0.3 \frac{c_1}{1.5h_{ef}} \quad \text{if } c_1 < 1.5h_{ef}$$

Cracked and uncracked concrete, ψ_3

- ♦ to be consistent with other parts of ACI 318, Chapter 23 is based on the assumption that concrete cracks
- ♦ the relationship between cracked and uncracked strength is based primarily on tests conducted in Europe (minimal U.S. testing)

$$\psi_3 = 1.0 \quad \text{for cracked concrete}$$

$$\psi_3 = 1.4 \quad \text{for uncracked concrete}$$

Embedment failure - tension General form for CCD method

$$N_n = \frac{A_N}{A_{No}} \psi_1 \psi_2 \psi_3 N_b$$

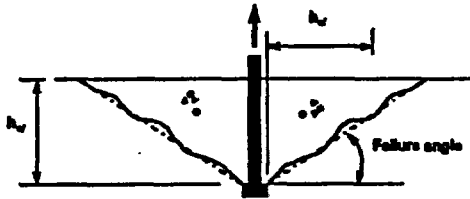
$$N_b = k \sqrt{f'_c} h_{ef}^{1.5}$$

Comparisons of CCD and ACI 349 (45° cone) methods to test results

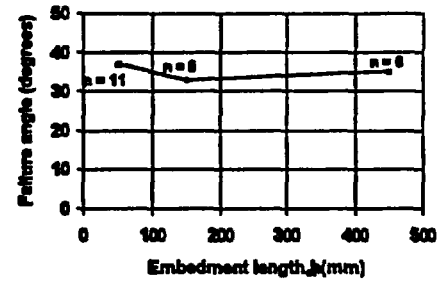
- ♦ uncracked concrete, $\psi_3 = 1.4$
- ♦ no eccentricity in the fastening, $\psi_1 = 1.0$
- ♦ $\phi = 1.0$
- ♦ comparisons of methods to test results from international data base (U.S. and Europe)

Note: uncracked concrete and no eccentricity used since 349/PCI does not cover these effects

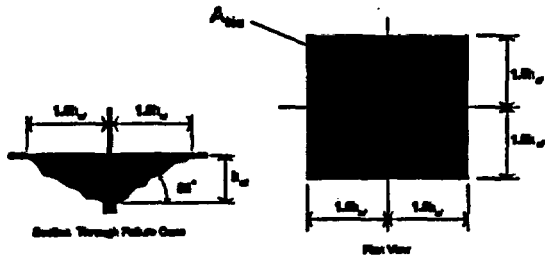
Failure angle: 35° vs. 45°



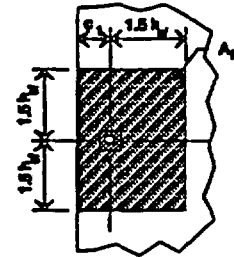
Measured failure angles



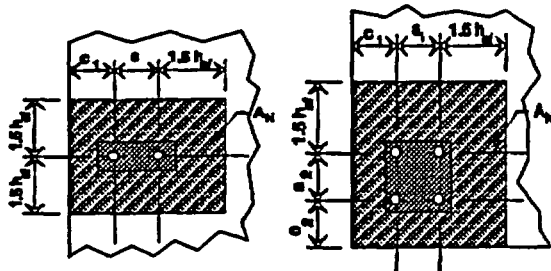
Idealized failure surface for an individual anchor - CCD method



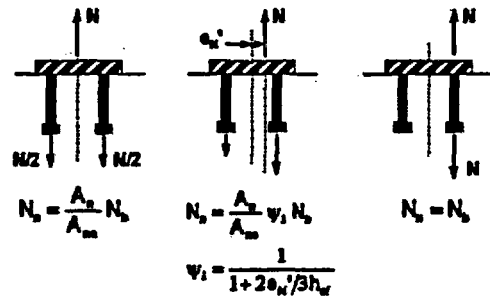
Calculation of A_N for an individual anchor near an edge - CCD method



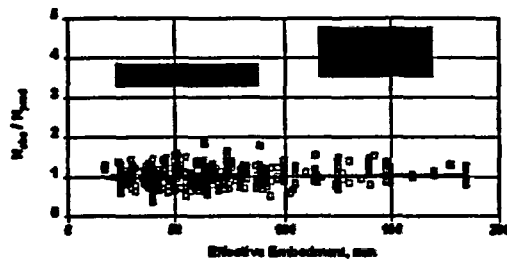
Calculation of A_N for groups of anchors in tension near an edge - CCD method



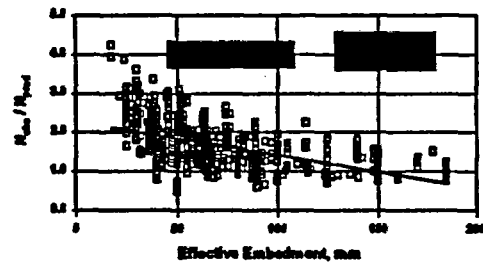
The "eccentricity" factor, ψ_1



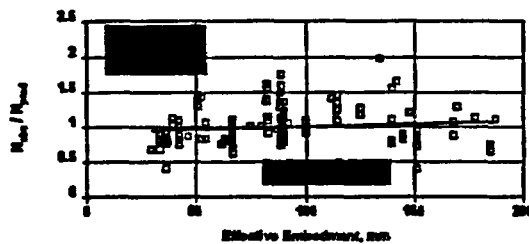
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
CCD METHOD
SINGLE ANCHORS, NO EDGES, EMBEDMENTS < 8"**



**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
45° CONE METHOD
SINGLE ANCHORS, NO EDGES, EMBEDMENTS < 8"**



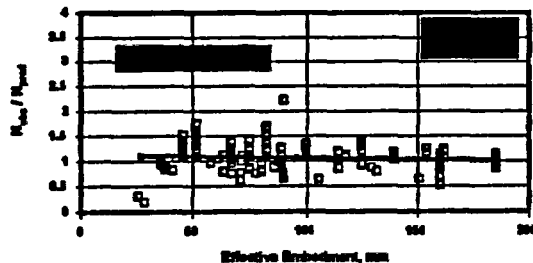
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
CCD METHOD
SINGLE ANCHORS, EDGE EFFECTS, EMBEDMENTS < 8"**



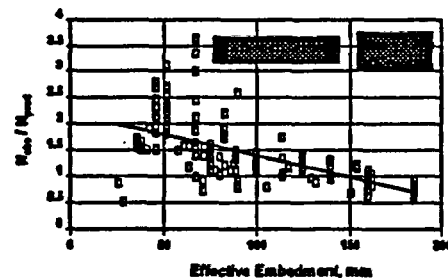
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
45° CONE METHOD
SINGLE ANCHORS, EDGE EFFECTS, EMBEDMENTS < 8"**



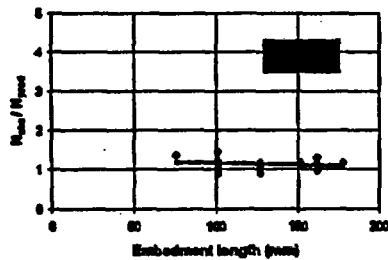
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
CCD METHOD
ANCHOR GROUPS, NO EDGES, EMBEDMENTS < 8"**



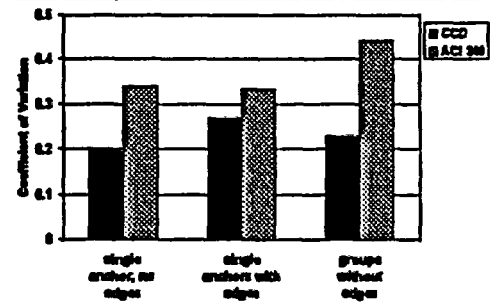
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
45° CONE METHOD
ANCHOR GROUPS, NO EDGES, EMBEDMENTS < 8"**



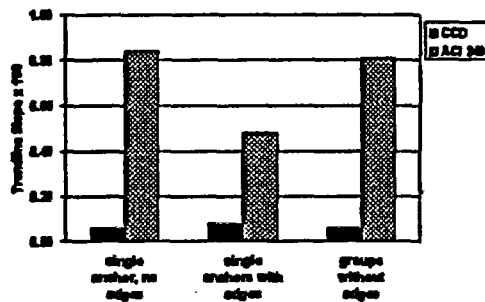
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
ORIGINAL DATA USED FOR ACI 349 - 45° METHOD
SINGLE ANCHORS (NO EDGES & EDGES), & GROUPS**



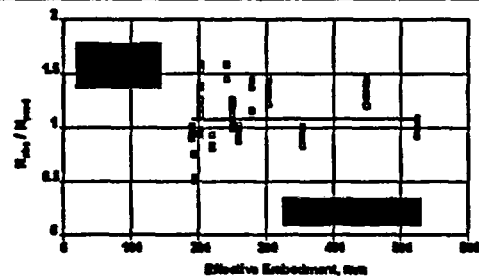
Comparison of COV's - $h_{ef} < 8"$



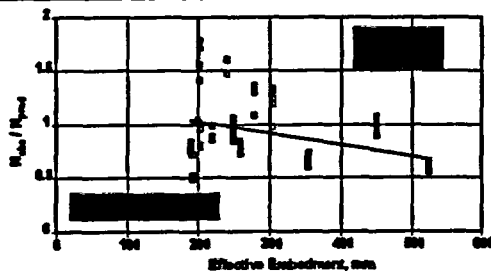
Comparison of trendline slopes - $h_{ef} < 8"$



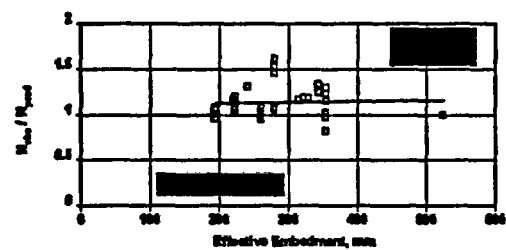
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
CCD METHOD
SINGLE ANCHORS, NO EDGES, EMBEDMENTS $\geq 8"$**



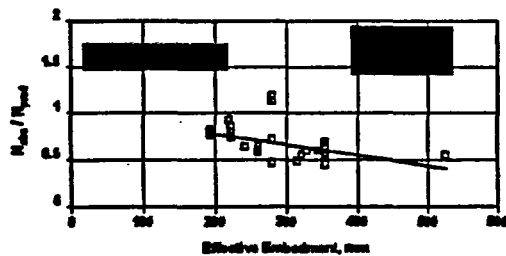
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
45° CONE METHOD
SINGLE ANCHORS, NO EDGES, EMBEDMENTS $\geq 8"$**



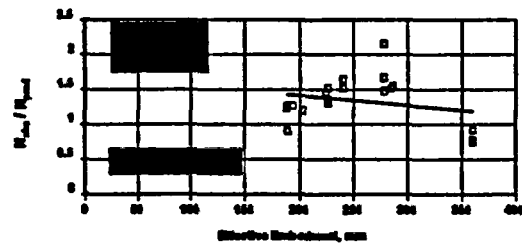
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
CCD METHOD
SINGLE ANCHORS NEAR EDGES, EMBEDMENTS $\geq 8"$**



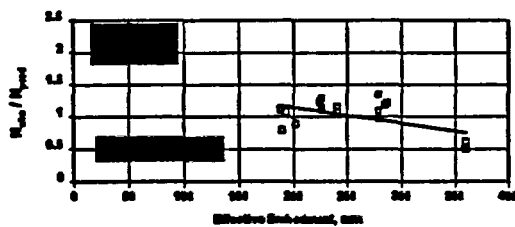
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
45° CONE METHOD
SINGLE ANCHORS NEAR EDGES, EMBEDMENTS $\geq 8"$**



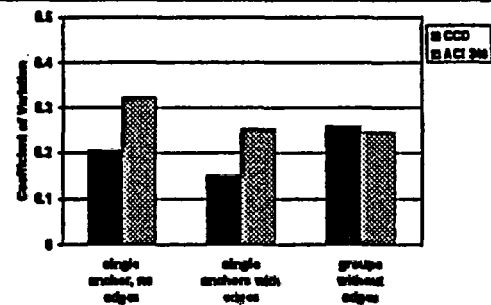
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
CCD METHOD
ANCHOR GROUPS, NO EDGES, EMBEDMENTS $\geq 8"$**



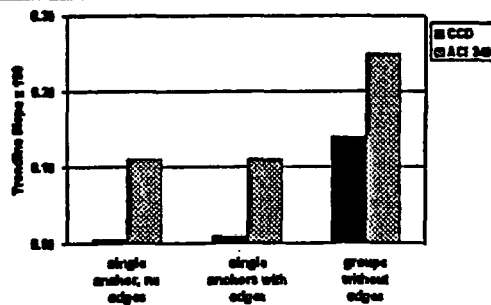
**RATIOS OF OBSERVED TO PREDICTED CAPACITIES
45° CONE METHOD
ANCHOR GROUPS, NO EDGES, EMBEDMENTS $\geq 8"$**



Comparison of COV's - $h_{ef} \geq 8"$



Comparison of trendline slopes - $h_{ef} \geq 8"$



Mean, nominal, & design strengths

$$\text{Mean strength} = N_{avg}$$

$$\text{Nominal strength} = N_n$$

$$N_n = N_{avg} (1 - 1.67 COV)$$

$$\text{Design strength} = \phi N_n$$

Embedment failure - shear
General form for single anchor

$$V_b = k \sqrt{f'_c} c_1^2 \quad 349 \text{ \& PCI}$$

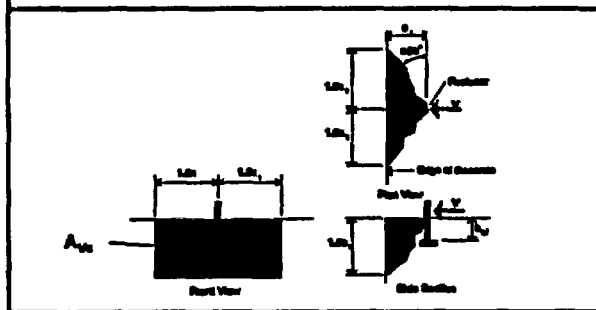
$$V_b = k \left(\frac{\ell}{d_0} \right)^{0.2} \sqrt{d_0} \sqrt{f'_c} c_1^{1.5} \quad \text{CCD}$$

Embedment failure - shear
General form for edges and groups

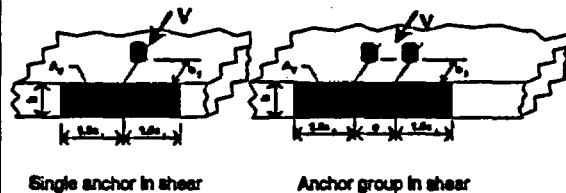
$$V_n = \frac{A_v}{A_{v0}} \psi_4 \psi_5 \psi_6 V_b$$

\swarrow basic single anchor strength
 \swarrow accounts for cracked concrete
 \swarrow accounts for edge effects
 \swarrow accounts for eccentricity in the fastening
 \swarrow accounts for projected area of failure surface (single and group)

Idealized failure surface for an individual anchor in shear - CCD method



Calculation of A_v for anchors in shear limited by slab thickness - CCD method



Summary

- ◆ the 45° cone method is acceptable if used for the embedment lengths from which the method was developed, $h_{ef} \approx 100 - 150 \text{ mm}$
- ◆ the 45° cone method is not consistent over the full range of embedment lengths
- ◆ the CCD method is consistent for the full range of embedment lengths

Summary

- ◆ based on a review of the test data over the past 5 years, ACI committees 349 and 355 have voted to proceed with implementation of the CCD method
- ◆ there are still discussions over whether the exponent on h_{ef} should be 1.5 or 1.6 but a 2.0 factor and a 45° failure surface are no longer being considered

Conclusion

- ◆ the CCD method is based on rational engineering principles and provides a consistent fit over the full range of behavior
- ◆ based on personal experience working design examples for ACI 355, the CCD method is much easier to use than the ACI 349 method

Acknowledgments

- ◆ Dr. John Breen - University of Texas
- ◆ Dr. Richard Klingner - University of Texas
- ◆ Dr. Werner Fuchs - University of Stuttgart
- ◆ Dr. Rolf Elgehausen - University of Stuttgart
- ◆ Mr. Jack Daly - Sargent & Lundy Engineers
- ◆ Mr. John Russ - KPFF Consulting Engineers

Parting Thought

Please think of the CCD method as
evolution over the last 20 years and
not revolution

University of Florida
Department of Civil Engineering



STATISTICAL REVIEW OF DATA ON TENSILE ANCHORS TO CONCRETE

Richard E. Klingner

April 1997

STATISTICAL REVIEW OF DATA ON TENSILE ANCHORS TO CONCRETE

*Prof. Richard E. Klingner
The University of Texas at Austin*

*ACI Committee 355 Seminar
ACI Convention
Seattle, Washington
April 1997*

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OBJECTIVE OF PRESENTATION

- Discuss ongoing work in ACI Committees 318, 349 and 355 regarding competing code provisions for anchorage to concrete

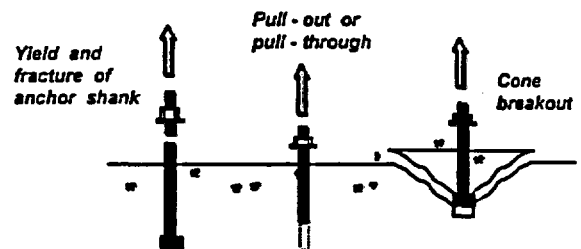
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OBJECTIVES OF WORK

- Propose and develop a rational approach for deciding between different methods of predicting concrete breakout capacity of tensile anchors to concrete
- Using that approach, decide on the best method, and propose corresponding understrength factors

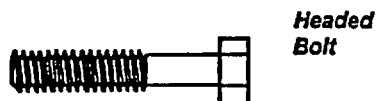
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ANCHOR TENSILE BEHAVIOR



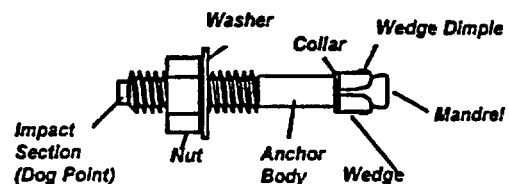
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TYPICAL CIP ANCHOR



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TYPICAL WEDGE ANCHOR



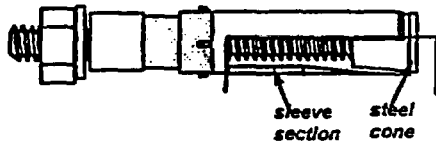
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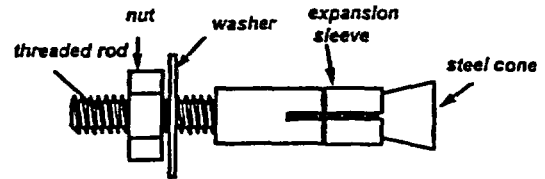
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TYPICAL SLEEVE ANCHOR



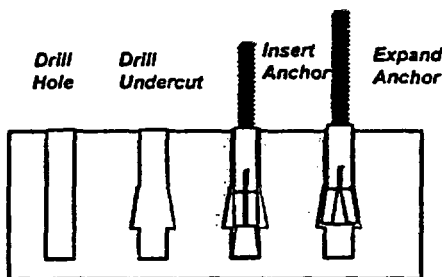
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TYPICAL UNDERCUT ANCHOR



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ACTION OF UNDERCUT ANCHOR



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COMMONLY USED METHODS FOR PREDICTING BREAKOUT CAPACITY

- 45 - Degree Cone Method
 - currently used in ACI 349 Appendix B
- Concrete Capacity Method ("CC Method")
 - in current draft of ACI 318, Chapter 23
 - currently under study in ACI Committees 349 and 355

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RATIONAL APPROACH FOR DECIDING BETWEEN TWO METHODS

- Prepare consensus data base (Werner Fuchs, Jack Daly, Chris Heinz, John Hughes, John Russ)
- Study that data base for different anchor categories

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OVERALL VIEW OF DATA BASE

- About 1200 test results at different embedment depths
- Various anchor types (CIP, retrofit)
- Some tests with close edge distances, anchor groups
- All failures in concrete breakout
- Common units, concrete strengths

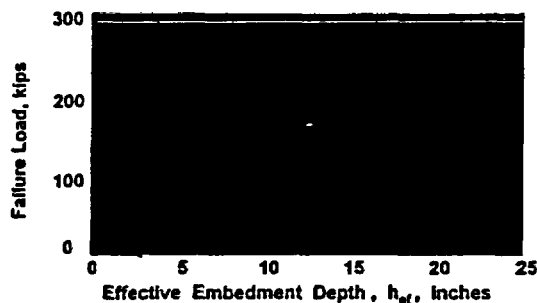
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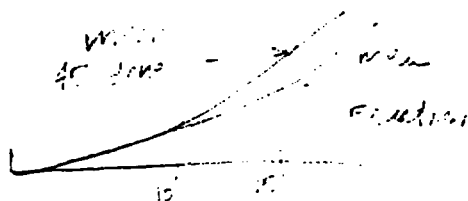
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TYPICAL BEHAVIOR OF METHODS



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IMMEDIATE IMPRESSIONS FROM OVERVIEW OF DATA BASE

- Two methods differ more as embedment depth increases
- Necessary to distinguish among different categories of embedment depth and anchor configurations

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GROUP DATA BASE IN 6 CATEGORIES

- Shallow, no edge effects
- Deep, no edge effects
- Shallow, edge effects
- Deep, edge effects
- Shallow groups, no edge effects
- Deep groups, no edge effects

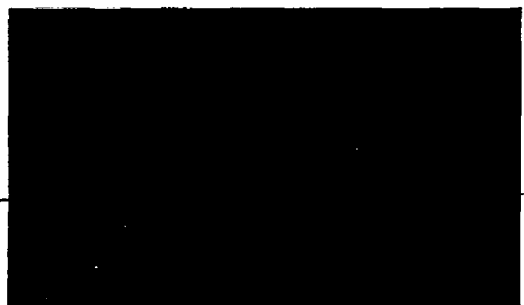
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POSSIBLE APPROACHES FOR EVALUATING TWO METHODS

- Compare ratios of Observed / Predicted Capacities for two methods
- Examine probabilities of failure of each method in context of particular design framework

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OBSERVED / PREDICTED CAPACITIES



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OBSERVATIONS FROM OBSERVED / PREDICTED CAPACITIES FOR CC METHOD

- Mean value close to 1.0
- Small coefficient of variation
- Small systematic error

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OBSERVED / PREDICTED CAPACITIES



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OBSERVATIONS FROM OBSERVED / PREDICTED CAPACITIES FOR 45-DEGREE CONE METHOD

- Mean value larger than 1.0
- Larger coefficient of variation than CC Method
- Larger systematic error than CC Method

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LIMITATIONS OF COMPARING RATIOS OF OBSERVED / PREDICTED CAPACITIES FOR TWO METHODS

- Difficult to quantify results
- Difficult to assess relative significance of Mean and Coefficient of Variation
- No guidance on selection of understrength factors

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EXAMINE PROBABILITIES OF FAILURE OF EACH METHOD USING PARTICULAR DESIGN FRAMEWORK

- Design framework of ACI 349, Appendix B
- Probability of failure under known loads
- Probability of brittle failure under unlimited loads

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DESIGN OF TENSILE ANCHORS BY ACI 349 APPENDIX B

- Given factored design tension, select tensile stress area of anchor to prevent anchor yield (conventional)
- Using tensile stress area, provide sufficient embedment so that failure will be ductile -- that is, steel will yield and fracture before concrete breakout (ductile design requirement)

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DESIGN OF TENSILE ANCHORS BY ACI 349 APPENDIX B

$$\begin{aligned} \bullet \quad N_u &\leq \phi_s A_s f_y \\ \bullet \quad A_s f_{ut} &\leq \phi_c N_{n \text{ concrete}} \end{aligned}$$

$N_{n \text{ concrete}}$ can be computed by CC Method or 45-Degree Cone Method

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STATISTICAL REVIEW OF DATA ON TENSILE ANCHORS TO CONCRETE

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BASIC EQUATION OF CC METHOD

$$N_n = k \sqrt{f'_c} h_g^{1.5}$$

$k = 35$ for expansion anchors

$k = 39$ for CIP and undercut anchors
uncracked concrete

units of lbs and inches

edges and adjacent anchors accounted for
by intersecting rectangles

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BASIC EQUATION OF 45-DEGREE CONE METHOD

$$N_n = 4 \sqrt{f'_c} h_g (h_g + d_o)$$

d_o = head diameter

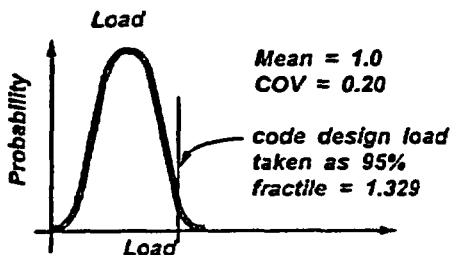
uncracked concrete

units of lbs and inches

edges and adjacent anchors accounted for
by intersecting cones

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ASSUMED DISTRIBUTION OF LOADS



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CALCULATED DISTRIBUTION OF STEEL CAPACITIES

- Given factored design load, compute required steel area
- Given required steel area, compute theoretical ultimate tensile capacity
- Given theoretical ultimate tensile capacity, calculate statistical distribution of steel capacities, based on previous test results

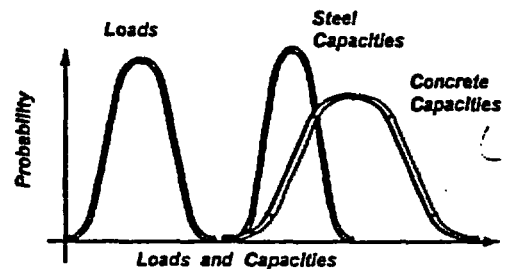
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CALCULATED DISTRIBUTION OF CONCRETE CAPACITIES

- Given required steel area, compute required embedment depth for ductile failure
- Given that embedment depth, compute theoretical concrete breakout capacity
- Using the statistical distribution of observed to predicted capacities for each method, calculate statistical distribution of concrete capacities

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LOADS AND CAPACITIES



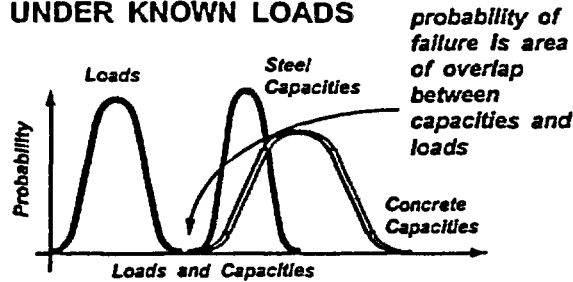
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Richard E. Klingner

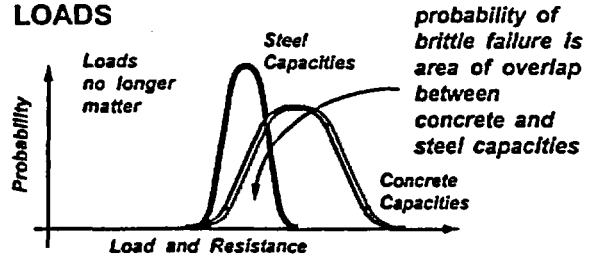
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PROBABILITY OF FAILURE UNDER KNOWN LOADS



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PROBABILITY OF BRITTLE FAILURE UNDER UNLIMITED LOADS



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MONTE CARLO ANALYSIS

- Generate values of Load, Steel Capacity and Concrete Capacity consistent with observed distributions
- Compare randomly selected combinations of those values
- See how many times failure occurs

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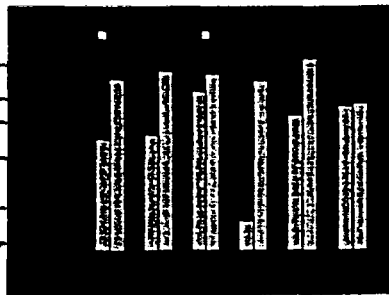
RESULTS OF MONTE CARLO ANALYSES



- only two graphs
- lots of information

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MONTE CARLO RESULTS FOR FAILURE UNDER KNOWN LOADS

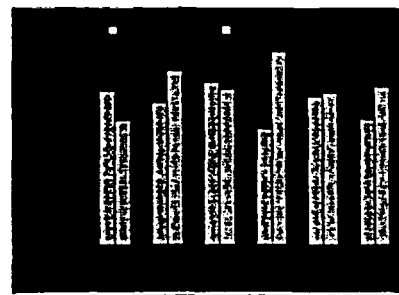


- CC Method has smaller probabilities of failure in all anchor categories

Prob. of brittle failure

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MONTE CARLO RESULTS FOR BRITTLE FAILURE UNDER UNLIMITED LOADS



- CC Method has smaller probabilities of brittle failure in most anchor categories

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Anchor categories 1 2 3 4 5

Anchor categories 1 2 3 4 5

STATISTICAL REVIEW OF DATA ON TENSILE ANCHORS TO CONCRETE

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April 1997

SUMMARY AND CONCLUSIONS . . .

- *For known loads, CC Method has lower probabilities of failure than 45-Degree Cone Method.*
- *For known loads, probabilities of failure are acceptably small using mean values and concrete understrength factors of 0.65.*

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. . . SUMMARY AND CONCLUSIONS

- *For unlimited loads, CC Method has lower probabilities of brittle failure than 45-Degree Cone Method.*
- *For unlimited loads, probabilities of brittle failure are acceptably small using mean values and concrete understrength factors of 0.65.*

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REFERENCES ON ANCHORAGE TO CONCRETE

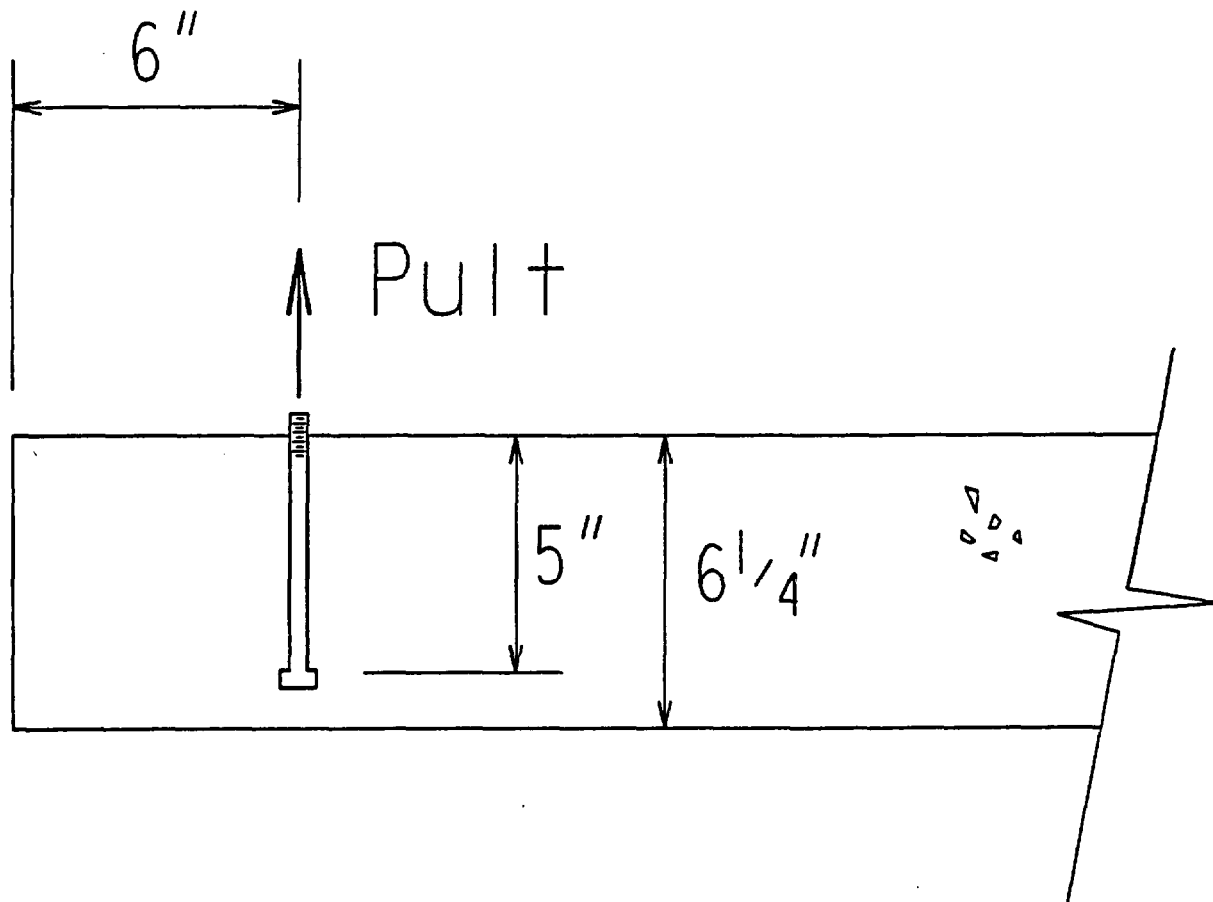
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ANCHORAGE TO CONCRETE CALCULATION SHEET

PROBLEM NO. 1.1	TITLE Single Anchor Tension, Insufficient Member Thickness	REV. NO. 0	SHEET NO. 1/3
ORIGINATOR Pete Carrato	DATE April 1997	CHECKED	DATE



Example 1.1



ANCHORAGE TO CONCRETE CALCULATION SHEET

PROBLEM NO 1.1	TITLE Single Anchor Tension, Insufficient Member Thickness	REV. NO. 0	SHEET NO. 2/3
ORIGINATOR Pete Carrato	DATE April 1997	CHECKED	DATE

UNITS: kip := 1000-lb kN := .225-kip

GIVEN INFORMATION:

f_c := 3000 psi Concrete Cylinder Strength
 f_{ut} := 120000 psi Ultimate Steel Strength
 h_{ef} := 5 inches Effective Embedment Length
 c_1 := 6 inches Edge Distance
 D := .625 inches Anchor Diameter
 $thick$:= 6.25 inches Slab Thickness
 n_t := 11 threads per inch of bolt

ASSUMPTIONS:

- 1) The anchor is a cast-in-place headed bolt.
- 2) No supplementary reinforcement is provided (Condition B of 318)
- 3) No concrete cracking
- 4) Normal weight concrete
- 5) Anchor will be torqued
- 6) No eccentric load on anchor

318 COEFFICIENTS:

Per Section 23.0 take: λ := 1.0
Per Section 23.5.2 take: k := 21
Per Section 9.3.2.5 take: ϕ := 0.75
Per Section 23.5.4 take: Ψ_1 := 1.0
Per Section 23.5.6 take: Ψ_3 := 1.4



ANCHORAGE TO CONCRETE CALCULATION SHEET

PROBLEM NO 1.1	TITLE Single Anchor Tension, Insufficient Member Thickness	REV. NO. 0	SHEET NO. 3/3
ORIGINATOR Pete Carrato	DATE April 1997	CHECKED	DATE

DESIGN EMBEDMENT LENGTH:

$$h_e := h_{ef}$$

EDGE DISTANCE: Section 23.5.5

$$\Psi_2 := .7 + .3 \cdot \left(\frac{c_1}{1.5 \cdot h_{ef}} \right) \quad \Psi_2 = 0.94$$

CONCRETE STRENGTH: Section 23.5

$$N_b := \frac{k}{\lambda} \cdot \sqrt{f_c} \cdot h_{ef}^{1.5} \cdot l_b \quad (23-5) \quad N_b = 12.9 \cdot \text{kip} \quad \text{Basic concrete breakout tensile strength}$$

$$A_{No} := 9 \cdot h_e^2 \quad (23-4) \quad A_{No} = 225 \text{ in-sq} \quad \text{Single anchor projected area}$$

Because insufficient edge distance is provided reduce projected area.

$$A_N := 2 \cdot (1.5 \cdot h_e) \cdot (1.5 \cdot h_e + c_1) \quad A_N = 202.5 \text{ in-sq}$$

$$N_n := \left(\frac{A_N}{A_{No}} \right) \cdot \Psi_1 \cdot \Psi_2 \cdot \Psi_3 \cdot N_b \quad (23-3) \quad N_n = 15.2 \cdot \text{kip} \quad \text{Nominal concrete breakout tensile strength}$$

$$N_u := \phi \cdot N_n \quad (23-1) \quad N_u = 11.4 \cdot \text{kip} \quad \text{Ultimate concrete breakout capacity}$$

349 EVALUATION:

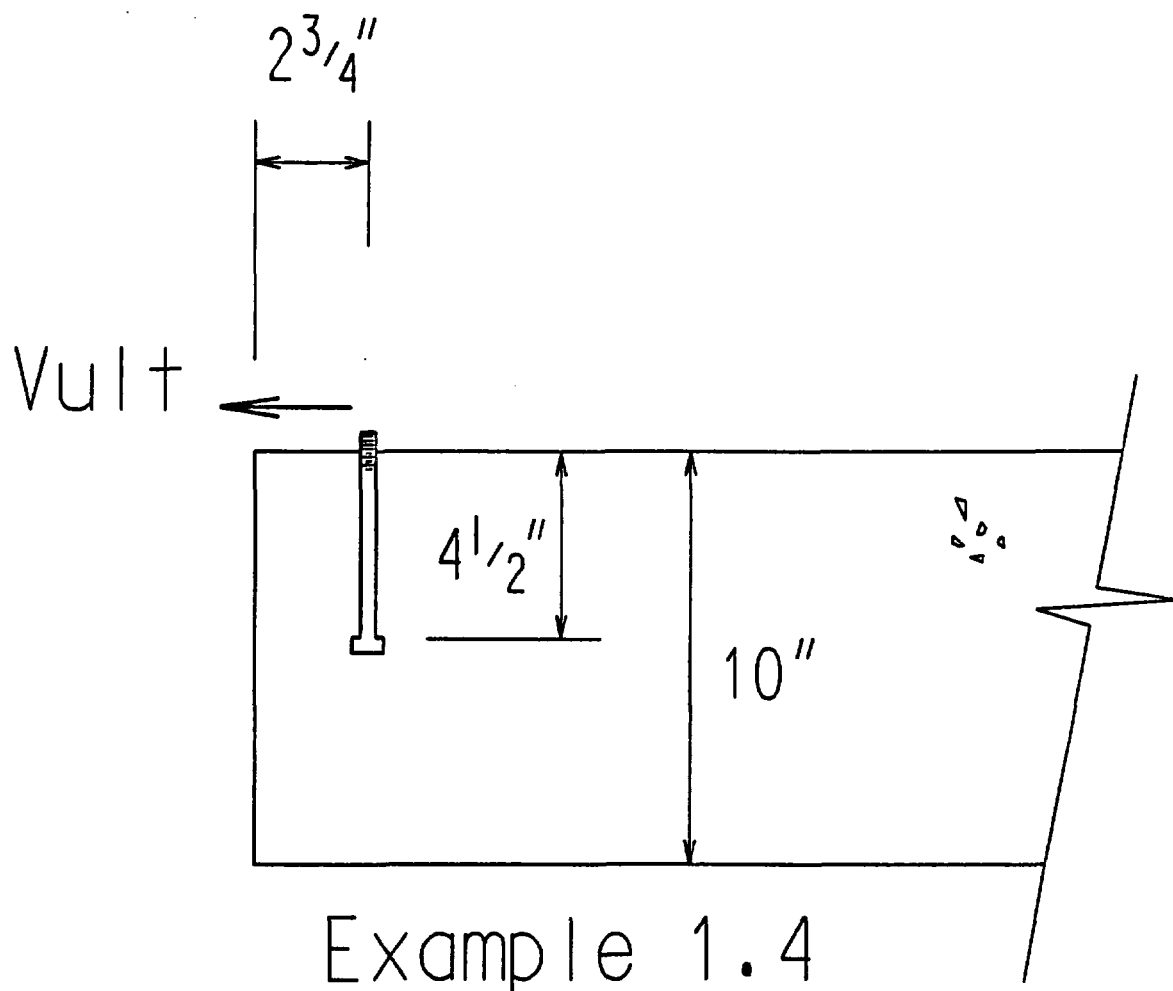
$$\phi := .85 \quad \text{No cracking}$$

$$N_{349} := 4 \cdot \phi \cdot \sqrt{f_c} \cdot \pi \cdot h_{ef}^2 \cdot l_b \quad N_{349} = 14.6 \cdot \text{kip} \quad \text{Section B.4.2}$$



ANCHORAGE TO CONCRETE CALCULATION SHEET

PROBLEM NO 1.4	TITLE Single Anchor Shear, Toward Free Edge	REV. NO. 0	SHEET NO. 1/3
ORIGINATOR Pete Carrato	DATE April 1997	CHECKED	DATE





ANCHORAGE TO CONCRETE CALCULATION SHEET

PROBLEM NO 1.4	TITLE Single Anchor Shear, Toward Free Edge	REV. NO. 0	SHEET NO. 2/3
ORIGINATOR Pete Carrato	DATE April 1997	CHECKED	DATE

UNITS: kip := 1000-lb kN := .225-kip

GIVEN INFORMATION:

$f_c := 3000$ psi Concrete Cylinder Strength
 $f_{ut} := 120000$ psi Ultimate Steel Strength
 $h_{ef} := 4.5$ inches Effective Embedment Length
 $c_1 := 2.75$ inches Edge Distance
 $c_2 := 48$ inches Edge Distance
 $D := .625$ inches Anchor Diameter
thick := 10 inches Slab Thickness

ASSUMPTIONS:

- 1) The anchor is a cast-in-place headed bolt.
- 2) No supplementary reinforcement is provided (Condition B of 318)
- 3) No concrete cracking
- 4) Normal weight concrete
- 5) No eccentric load on anchor

318 COEFFICIENTS:

Per Section 23.0 take: $\lambda := 1.0$

Per Section 9.3.2.5 take: $\phi := 0.75$

Per Section 23.6.4 take: $\Psi_4 := 1.0$

Per Section 23.6.5 take: $\Psi_5 := 1.0$ ie $c_1 \cdot 1.5 = 4.125 > c_2$

Per Section 23.6.6 take: $\Psi_6 := 1.4$



ANCHORAGE TO CONCRETE CALCULATION SHEET

PROBLEM NO 1.4	TITLE Single Anchor Shear, Toward Free Edge	REV. NO. 0	SHEET NO. 3/3
ORIGINATOR Pete Carrato	DATE April 1997	CHECKED	DATE

SHEAR PARAMETERS:

$$c_{1 \text{ prime}} := \text{if} \left(\frac{c_2}{1.5} > \frac{h_{ef}}{1.5}, \frac{c_2}{1.5}, \frac{h_{ef}}{1.5} \right) \quad c_{1 \text{ prime}} = 32 \text{ inches}$$

$$c_e := \text{if} (c_{1 \text{ prime}} > c_1, c_1, c_{1 \text{ prime}}) \quad c_e = 2.75 \text{ inches}$$

$$L := \text{if} (8 \cdot D > h_{ef}, h_{ef}, 8 \cdot D) \quad L = 4.5 \text{ inches}$$

AREAS:

$$A_{V_0} := 4.5 \cdot c_e^2 \quad A_{V_0} = 34.031 \text{ sq.in.}$$

$$A_V := 2 \cdot (1.5 \cdot c_1) \cdot (1.5 \cdot c_1) \quad A_V = 34.031 \text{ sq.in.}$$

SHEAR CAPACITY:

$$V_b := 7 \cdot \left(\frac{L}{D} \right)^{0.2} \cdot \sqrt{D} \cdot \left(\frac{\sqrt{f_c}}{\lambda} \right) \cdot c_e^{1.5} \cdot \text{lb} \quad V_b = 2.1 \cdot \text{kip} \quad (23-10)$$

$$V_n := \left(\frac{A_V}{A_{V_0}} \right) \cdot \Psi_4 \cdot \Psi_5 \cdot \Psi_6 \cdot V_b \quad V_n = 2.87 \cdot \text{kip} \quad (23-8)$$

$$V_u := V_n \cdot \phi \quad V_u = 2.15 \cdot \text{kip}$$

349 EVALUATION:

Reference B.5.1 Commentary

$$\phi := .85 \quad \text{No cracking}$$

$$m := .625 \cdot \sqrt{\frac{f_{ut}}{73 \cdot f_c}} \cdot \text{in} \quad m = 3.424 \cdot \text{in} \quad \text{Greater than } c_1 \text{ -- needs special reinforcing}$$

$$V_{349} := 2 \cdot \phi \cdot f_c^{.5} \cdot c_1^2 \cdot \pi \cdot \text{lb} \quad V_{349} = 2.2 \cdot \text{kip}$$