ROUTING AND TRANSMITTAL SLIP	DATE: March 14, 2000

TO:	INITIALS	DATE
1. Sher Bahadur		
2. → Herman Graves,		
3. Thanks.		
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REMARKS

The enclosed slides have been prepared for the upcoming seminar on the **"Performance of Anchors in Cracked and UnCracked Concrete,"** which is scheduled for Wednesday, March 29, at the ACI Spring Convention in San Diego, CA. The slides are based on work completed last year under NRC Job Code, W6454, "Technical Basis for Anchorage Criteria."

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A14

PERFORMANCE OF ANCHORS IN SEISMIC APPLICATIONS

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

ACI Convention
San Diego, California
March 2000

Ferguson Structural Engineering Laboratory - The University of Texas at Austin

PROJECT PARTICIPANTS

USNRC Contact

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OBJECTIVE OF PROJECT

"Verify, by testing, the adequacy of the assumption (used in US nuclear power plant designs) that behavior and strength of anchors and their supporting concrete under seismic loads do not differ significantly from those for static conditions."

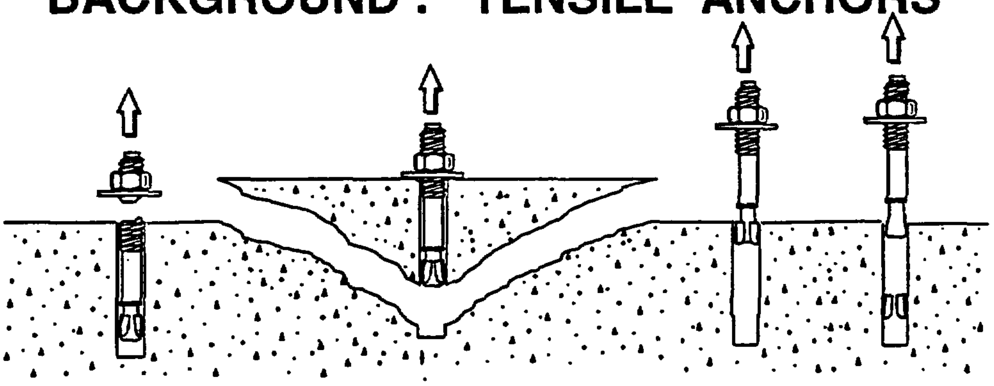
OBJECTIVES OF PRESENTATION

- *Review results of 4-year program of experiment and analysis, sponsored by US Nuclear Regulatory Commission*
- *Propose procedures for the evaluation and design of multiple-anchor connections to cracked concrete, subjected to seismic loads.*

SCOPE OF PRESENTATION

- *Experimental Testing*
  - *single tensile anchors*
  - *single anchors under tension and shear*
  - *multiple - anchor tensile connections*
  - *near - edge , double - anchor shear connections*
  - *multiple - anchor connections with eccentric seismic shear*
- *Numerical Analysis*
  - *FEM analysis*
  - *BDA5 program (macro - level program)*

BACKGROUND : TENSILE ANCHORS



Yield and fracture of anchor shank

Concrete breakout
CC Method:
(k : 40 for bearing
35 for expansion)

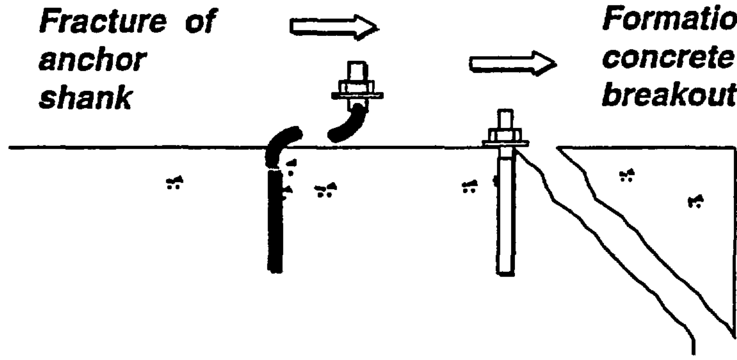
Pull - out

Pull - through

BACKGROUND : SHEAR ANCHORS

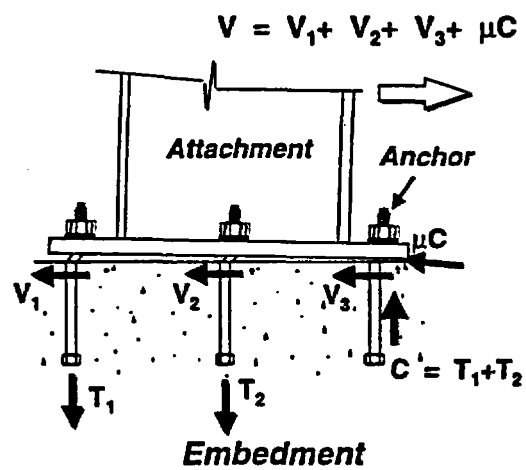
Fracture of anchor shank

Formation of concrete breakout cone



BACKGROUND : MULTIPLE ANCHORS

- ***Load Distribution:***
  Loads in anchors are distributed according to stiffness (elastic design) or strength (plastic design)
- ***Kinematics :***
  Deformations of each anchor must be consistent with the deformations of the attachment



TESTED ANCHOR TYPES AND LOAD - TRANSFER MECHANISMS

ANCHOR	DIAMETER	MECHANISM
■ *Undercut Anchor*		*Bearing*
– *UC1*	*3/8", 3/4"*	
– *UC2*	*3/4"*	
■ *Cast - in - Place Anchor*	*3/4"*	*Bearing*
■ *Expansion Anchor*		*Friction*
– *EAII*	*3/4"*	
■ *Grouted Anchor*	*3/4"*	*Friction*
■ *Sleeve Anchor*	*10 mm, 20 mm*	*Friction*

CRACKED CONCRETE TESTING

- *0.3 - mm cracks*
- *Cracks established and opened using splitting wedges*
- *Crack width monitored during testing, but restrained by internal reinforcement only*

EXPERIMENTAL TESTING

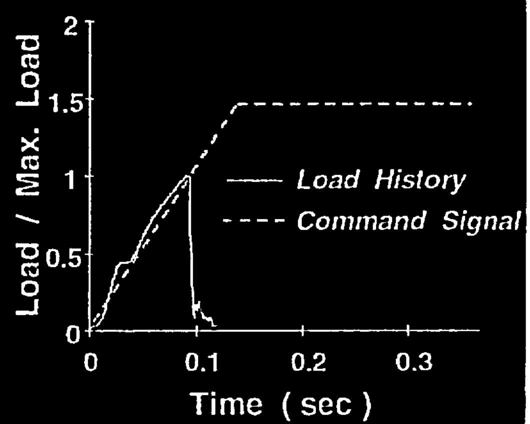
- ✓ *single tensile anchors*
- *double tensile anchors*
- *multiple - anchor connections with eccentric seismic shear*

OBJECTIVE FOR TESTS ON SINGLE TENSILE ANCHORS

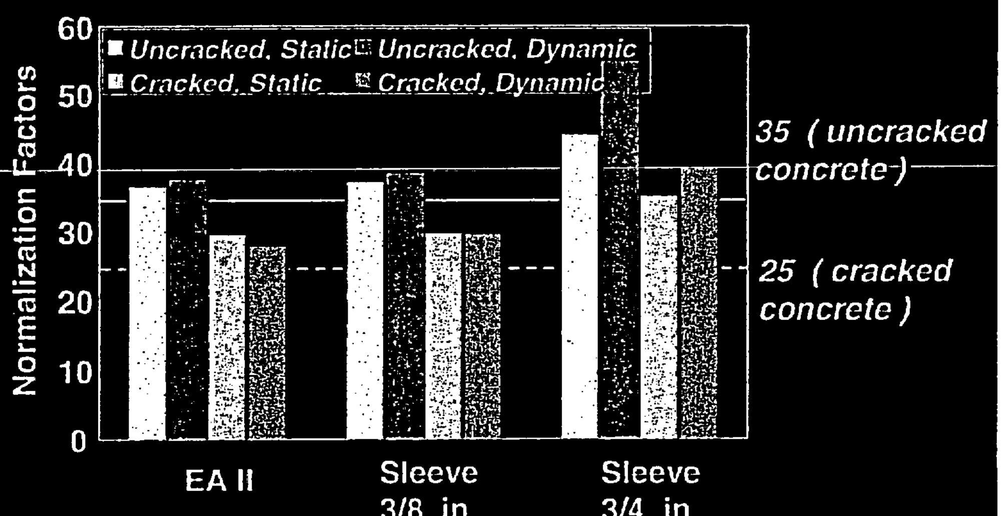
- *to investigate effect of concrete cracking on static and dynamic behavior of single anchors*
  - *anchors had shallow embedments to force concrete breakout failure*

DYNAMIC LOADING IN TENSILE TESTS

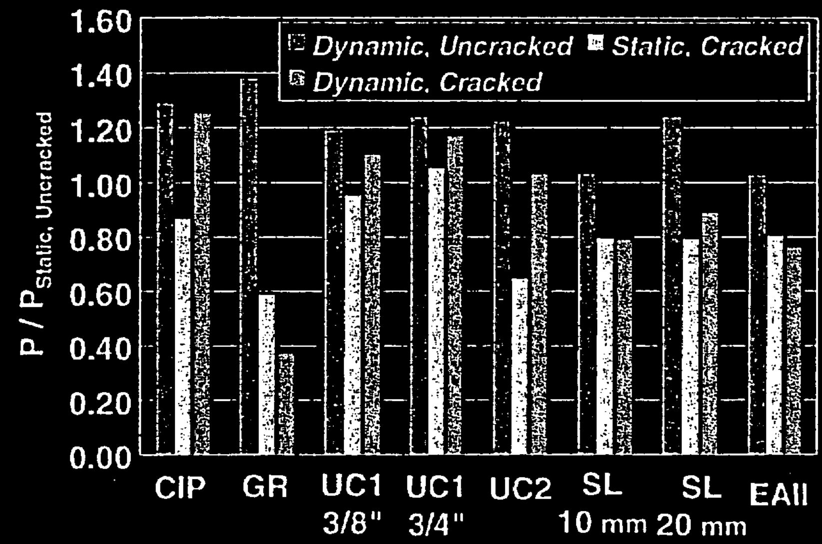
- *time to failure about 0.10 sec*
- *ramp command signal*
  - *1.5 times estimated load capacity*
  - *rise time 0.15 sec*



NORMALIZATION FACTORS FOR SINGLE TENSILE ANCHORS (EXPANSION TYPE)



TENSILE BREAKOUT CAPACITY / STATIC, UNCRACKED CAPACITY



CONCLUSIONS FROM SINGLE - ANCHOR TENSILE TESTS

- *CC Method generally describes static tensile breakout capacity in uncracked concrete*
- *Cracks reduce concrete breakout capacity by 10% (CIP , UC1) to 20% (EAII)*
- *Dynamic loading changes failure mode of EAII to pullout , pull - through (smaller frictional forces)*
- *Grouted anchors have low capacity in cracked concrete*

EXPERIMENTAL TESTING

- *single tensile anchors*
- ✓ *double tensile anchors*
- *multiple - anchor connections with eccentric seismic shear*

OBJECTIVE FOR DOUBLE - ANCHOR TENSION TESTS

- *to investigate whether the effects of anchor spacing on concrete breakout capacity are the same under dynamic as under static loading*
  - *critical spacing 3* h_{ef}
  - *critical edge distance 1.5* h_{ef}

CONCLUSIONS FROM DOUBLE - ANCHOR TENSION TESTS

- *effects of anchor spacing on concrete breakout capacity are the same under dynamic as under static loading*
  - *critical spacing 3 h_{ef}*
  - *critical edge distance 1.5 h_{ef}*

EXPERIMENTAL TESTING

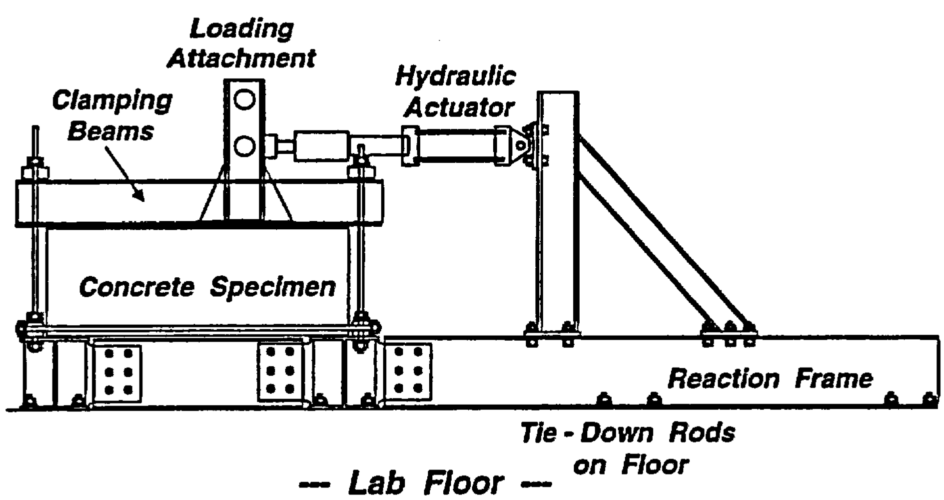
- *single tensile anchors*
- *double tensile anchors*

✓ *multiple - anchor connections with eccentric seismic shear*

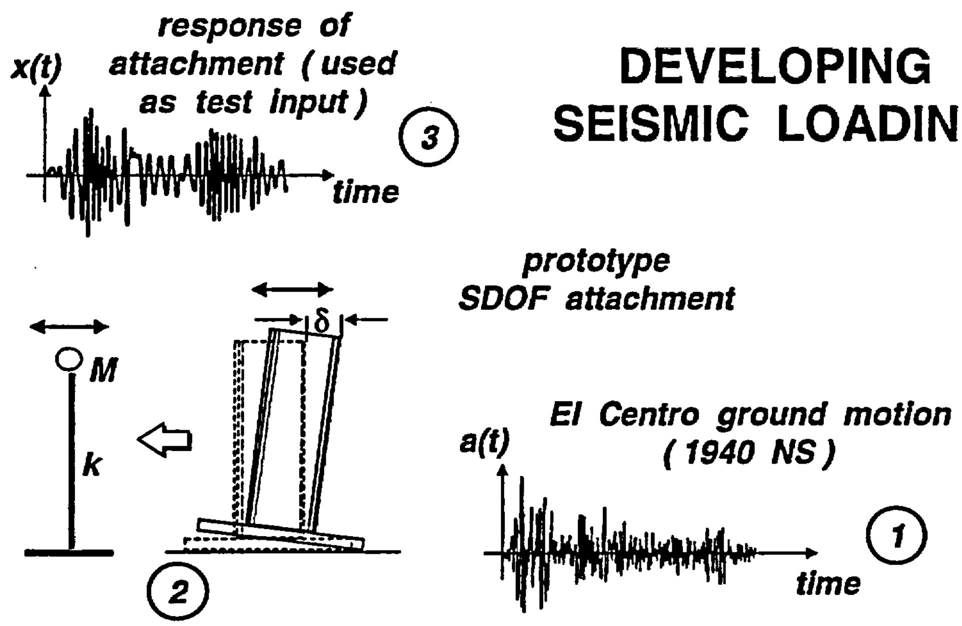
OBJECTIVE OF MULTIPLE - ANCHOR CONNECTION TESTS

- *To investigate behavior of multiple - anchor connections loaded in eccentric shear, affected by:*
  - *Loading type*
  - *Eccentricities*
  - *Types of anchor bolts*
  - *Concrete cracking*
  - *Proximity of concrete member edge*
  - *Hairpins*

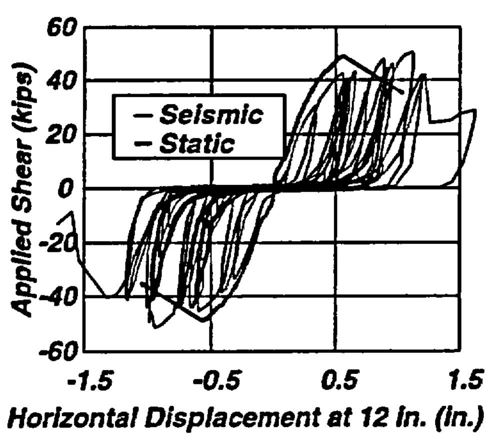
SETUP FOR MULTIPLE - ANCHOR SEISMIC TESTS



DEVELOPING SEISMIC LOADING



BEHAVIOR OF CONNECTIONS WITH UC1 ANCHORS IN UNCRACKED CONCRETE



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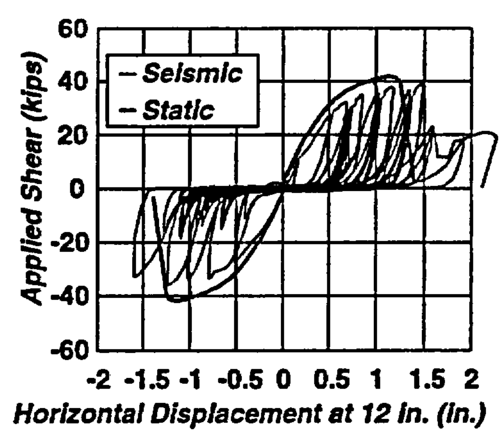

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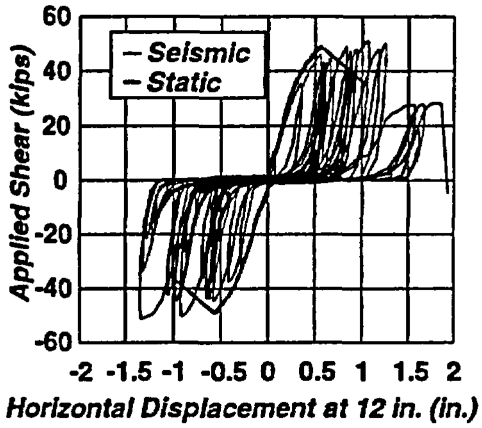
BEHAVIOR OF CONNECTIONS WITH UC1 ANCHORS IN CRACKED CONCRETE



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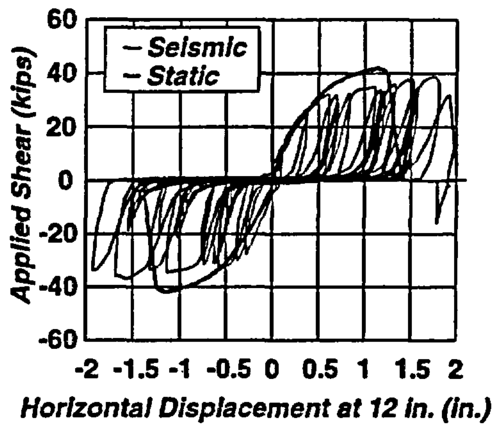

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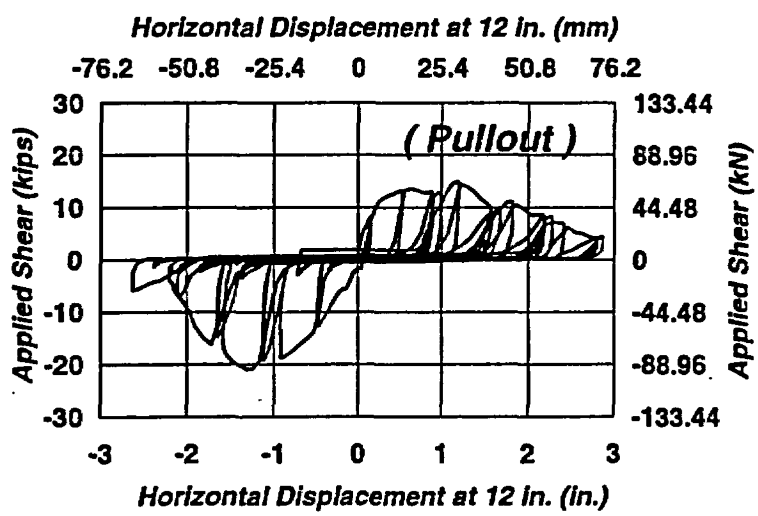
BEHAVIOR OF CONNECTION WITH EAII ANCHORS IN CRACKED CONCRETE



CONCLUSIONS FROM MULTIPLE - ANCHOR SEISMIC TESTS

- *Seismic behavior of multiple - anchor connections in cracked concrete is consistent with, and bounded by, static behavior in uncracked concrete.*
- *Anchors with good static performance in cracked concrete will probably behave well in under seismic loading in cracked concrete.*
- *Some expansion anchors with good static behavior, pull out under seismic loading.*