SOLUTIONS FOR THE BUILT WORLD

Development of Database for Structural Load Tests

Mohamed ElBatanouny[1], PhD, SE, PE
Aaron Larosche[2], PhD, SE, PE
Paul Ziehl[3], PhD, PE

[1]*Wiss, Janney, Elstner Associates*
[2]*Pivot Engineers*
[3]*University of South Carolina*

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Session - Novel Techniques and Advances in Load Testing Concrete Structures

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Introduction

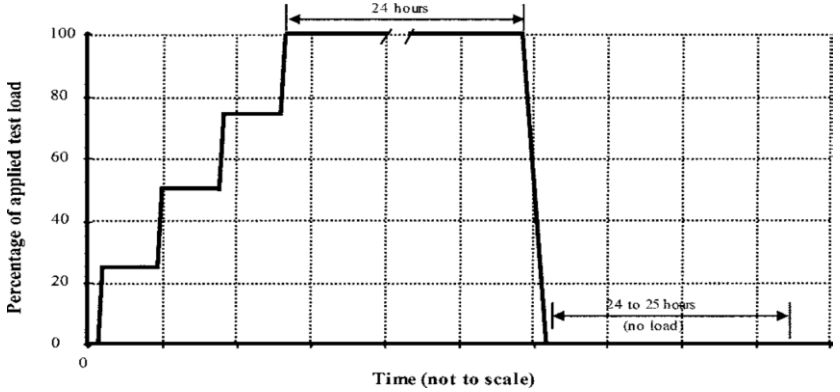
- ACI 437 Committee formed a new subcommittee with the task of collecting a data base for structural load tests
- The new subcommittee – ACI 437-A is currently developing a template to share with researchers/practitioners to collect load test data for field and laboratory studies
- This presentation discusses the:
  - Objectives of the new committee
  - Purpose of building a test data base for load tests
  - Expected outcomes of the effort

Introduction

- Load testing of existing structures is part of the following ACI codes:
  - ACI 318-19 – Chapter 27 Strength Evaluation of Existing Structures
  - ACI 437.2 - Code Requirements for Load Testing of Existing Concrete Structures and Commentary
- Both documents allow the use of two load testing methods
  - Monotonic (24 hour) load test
  - Cyclic load test
- The use of maximum deflection limit as part of acceptance criteria have been discussed in recent years with some significant changes, which prompted this effort

Difference Between Tests

Monotonic Load Test

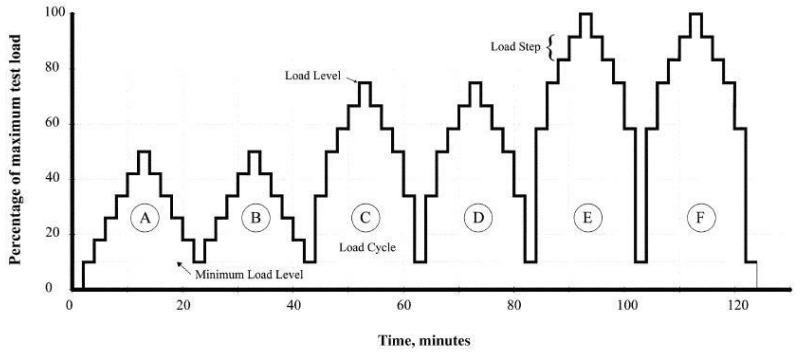


- *Essentially a proof test*
- *Slower to perform (at least 48-hr)*
- *Generally easy to perform*
- *Criteria is based on deflections*

Acceptance Criteria:

1) Residual deflection
2) ~~Maximum deflection~~

Cyclic Load Test



- *Performance standard*
- *Faster to perform*
- *Hydraulics need to react against something*
- *Criteria is based on stiffness*

Acceptance Criteria:

1) Deviation from linearity
2) Permanency ratio
3) Residual deflection

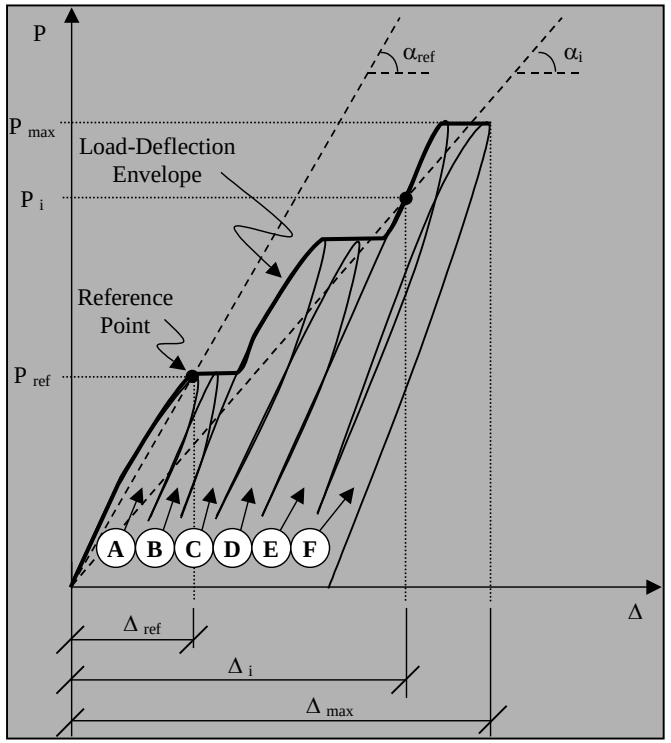
Monotonic Loading Acceptance Criteria

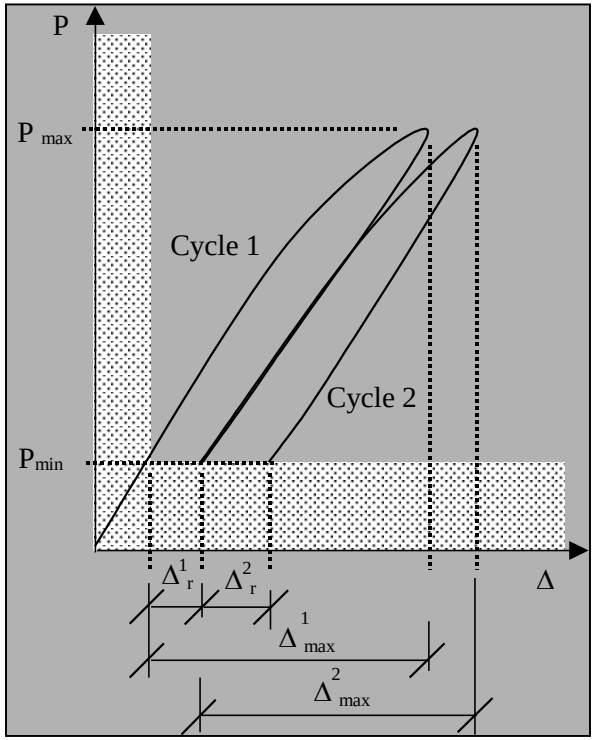
- Deflection limit
  - Δ_r – residual deflection
  - Δ_l – maximum deflection
  - L_t – span length
  - h – member height

ACI 318-19	ACI 437.2-13
Passing: *The structure passes the test if the measured deflections satisfy one of the following equations:* $\Delta_r \leq \Delta_1 / 4$ ~~$\Delta_1 \leq l_t^2 / 20{,}000h$~~ *The residual deflection requirement is waived if the maximum deflection is less than 0.05 in. or lt/2000*	**Passing:** *The structure passes the test if the measured deflections satisfy both the following equations:* $\Delta_r \leq \Delta_1 / 4$ $\Delta_l \leq l_t / 180$ *The residual deflection requirement is waived if the maximum deflection is less than 0.05 in. or l_t/2000*
Retesting: $\Delta_r \leq \Delta_2 / 5$	**Retesting:** $\Delta_{rrt} \leq \Delta_{l2} / 10$

Cyclic Loading Acceptance Criteria

- Deviation from Linearity Index (I_{DL})
  - $I_{DL} = 1 - \tan(\alpha_i) \ / \tan(\alpha_{ref}) \ < \ 0.25$
- Permanency Ratio (I_{PR})
  - $I_{PR} = I_{p(i+l)} \ / \ I_{pi} \ < \ 0.50$
  - $I_{pi} = \Delta^i_r \ / \ \Delta^i_{max}$
  - $I_{p(i+l)} = \Delta^{i+1}_r \ / \ \Delta^{i+1}_{max}$
- Residual Deflection
  - $\Delta_r \leq \Delta_l \ /4$
- Re-testing
  - 437.2 – Allowed if $\Delta_l \leq l_t \ /180$
  - 318 - $\Delta_l \leq l_t \ /180$ requirement is waived





Cyclic Loading Acceptance Criteria

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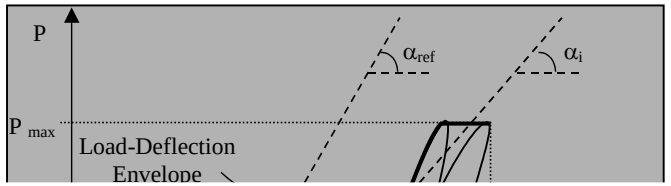
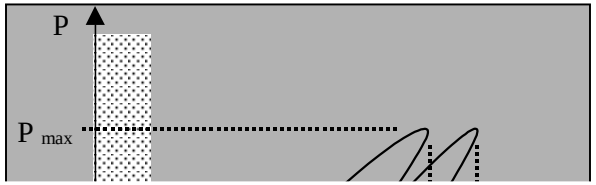
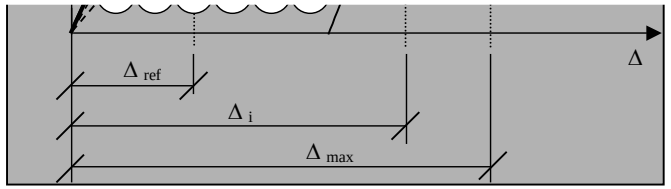
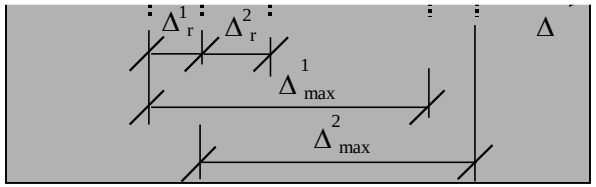




- There is a need to research a maximum deflection limit for structural load tests
- There is a need to evaluate how CLT compares to monotonic

- $\Delta_r \leq \Delta_l / 4$
- Re-testing
  - 437.2 – Allowed if $\Delta_l \leq l_t / 180$
  - 318 - $\Delta_l \leq l_t / 180$ requirement is waived

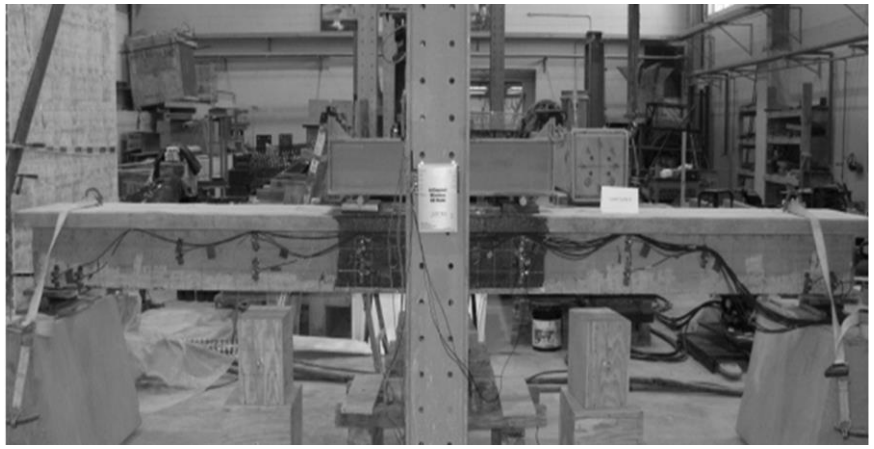




Load Test Database

Load Test Database

- ACI 437A load test database:
  - The committee will identify papers to collect load test data
  - The committee will also contact practitioners to collect unpublished load test data
  - Only general information regarding the structure will be collected
  - Both laboratory and field test data will be collected



Load Test Database

- Information to be collected include:
  - Structure Type: RC, PC, PT
  - Element Description: age, type, span, depth, cross section, reinforcement, compressive strength, expected/calculated capacity
  - Reason for testing: flexural, shear, punching shear, other background information
  - Test Protocol: monotonic or CLT, field or laboratory
  - Loading and geometry: distributed load, point loads, multiple spans, etc.
  - TLM: method to calculate, DL/LL ratio, applied TLM
  - Code: ACI 318 or 562, publication year, load magnitude
  - Repaired or new structure

Load Test Database

- Information to be collected include:
  - Test results: maximum deflection, residual deflection, cycles deflection if using CLT
  - Cracking observed: cracking before test, description of cracks during test
  - Pass/Fail, was the test stopped for any reason other than the acceptance criteria
  - Re-test information, if applicable
  - Response measurements: deflections, strain, rotation, other (AE, DIC)

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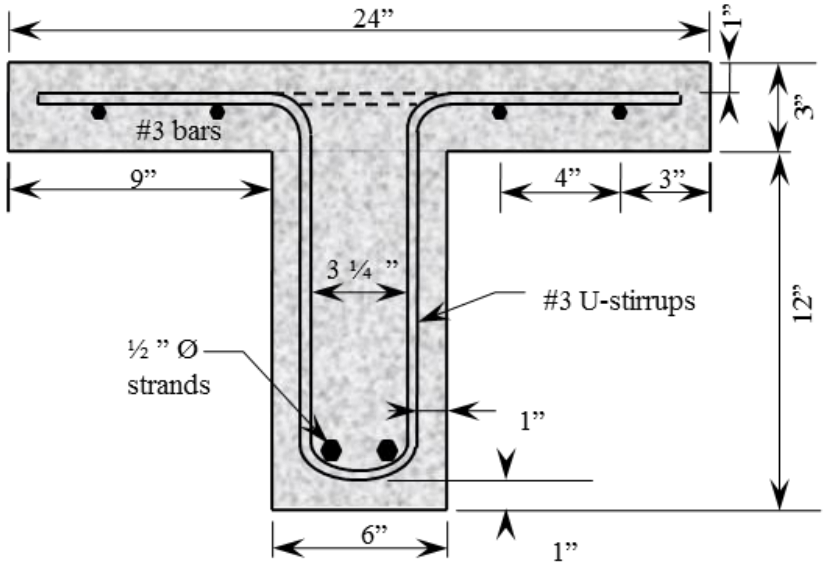
Example – Prestressed T-Beams

- University of South Carolina Structures Laboratory

ElBatanouny, M., *Nanni, A., Ziehl, P., and Matta, F. (2015). "Condition Assessment of Prestressed Concrete Girders Using Cyclic and Monotonic Load Tests", ACI Structural Journal, V. 112, No. 1, pp.81-90.*

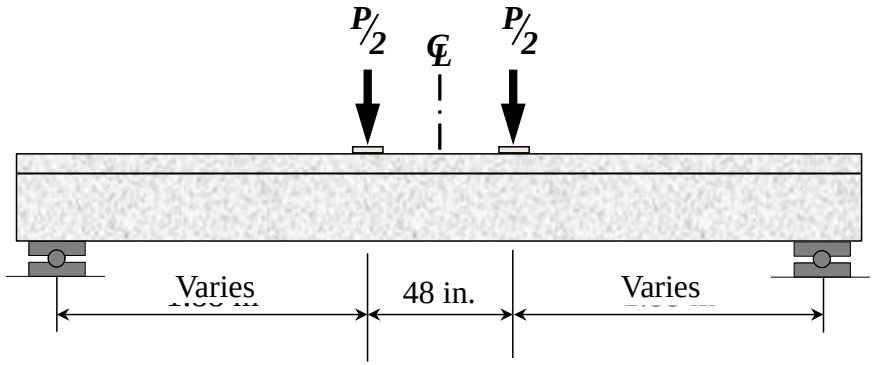
Laboratory Prestressed T-beams

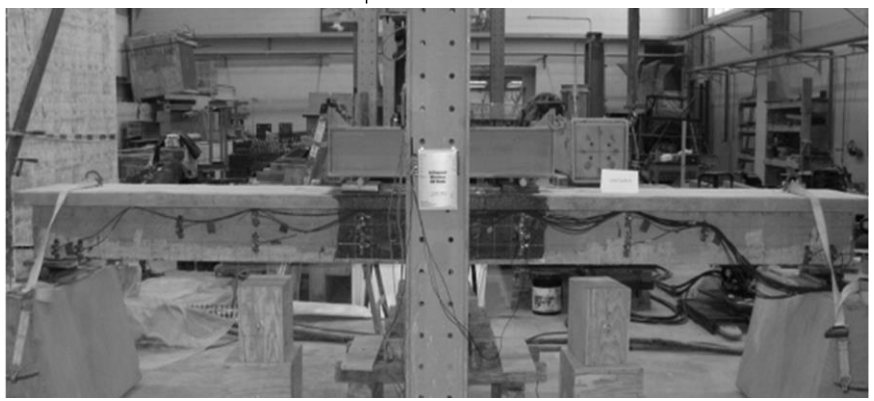
- Eight flexural-type prestressed T-shaped beams measuring 16 feet 4 inches
- Twelve shear-type prestressed concrete measuring 9 feet 8 inches

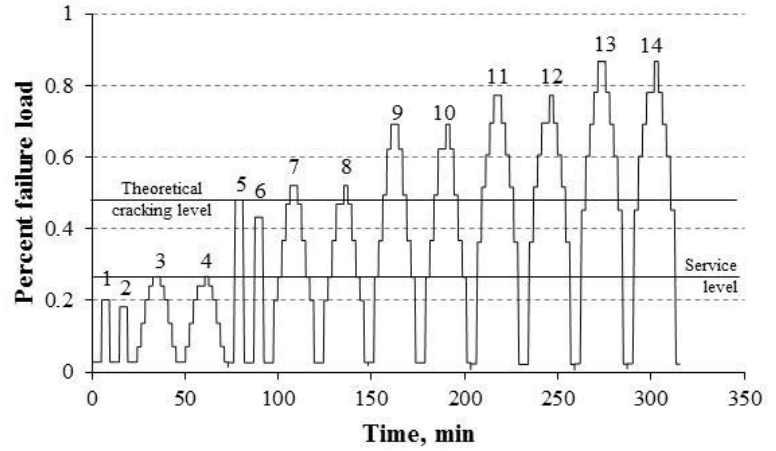


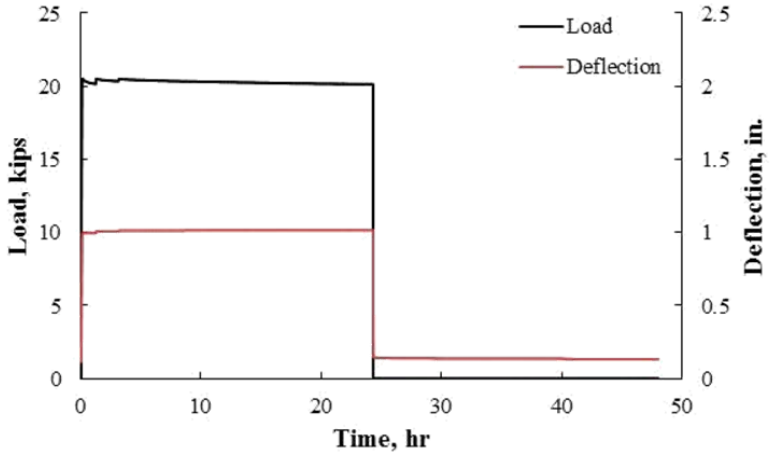
Test Setup

- Cyclic load test is applied for a total of 14 cycles followed by the monotonic load test









Flexural Beams - Monotonic Load Test Results

ACI 318-14

Passing:

The structure passes the test if the measured deflections satisfy one of the following equations:

Eq. 318-1: $\Delta_r \leq \Delta_l / 4$

Eq. 318-2: $\Delta_l \leq l_t^2 / 20{,}000h$

ACI 437.2-13

Passing:

The structure passes the test if the measured deflections satisfy both the following equations:

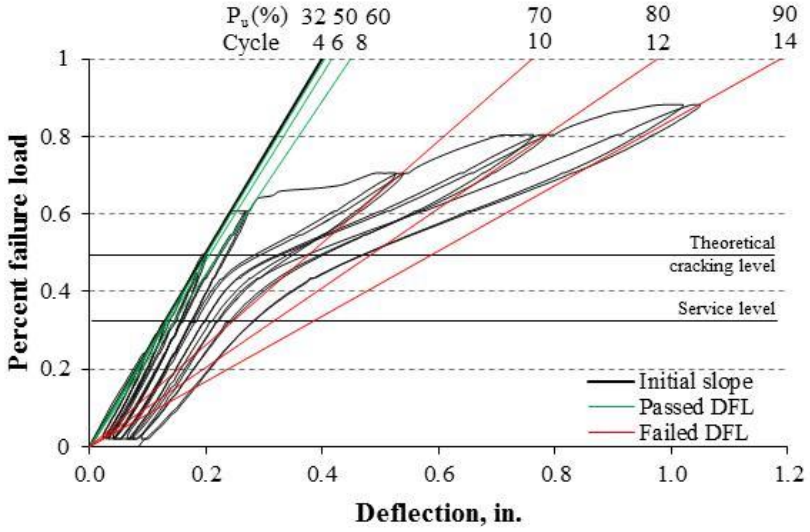
Eq. 437-1: $\Delta_r \leq \Delta_l / 4$

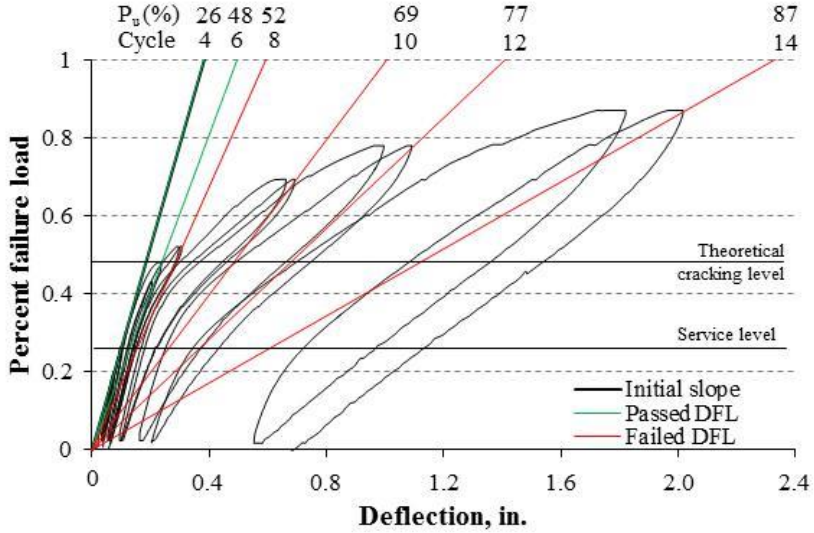
Eq. 437-2: $\Delta_l \leq l_t / 180$

Specimen	TLM	Δ_r, in. (Eq. 318-1/437-1)	Δ_l, in. (Eq. 318-2)	Performance ACI 318	Δ_l, in. (Eq. 437-2)	Performance ACI 437
U1	0.90Pu	0.153 < 0.254	1.015 > 0.113	Pass	1.015 < 1.022	Pass
U2	0.80Pu	0.295 < 0.448	1.789 > 0.113	Pass	1.789 > 1.022	Fail
U3	0.80Pu	0.575 < 0.658	2.633 > 0.113	Pass	2.633 > 1.022	Fail
C1-0.4	0.68Pu	0.057 < 0.184	0.734 > 0.113	Pass	0.734 < 1.022	Pass
C2-0.4	0.78Pu	0.221 < 0.419	1.674 > 0.113	Pass	1.674 > 1.022	Fail
C4-0.4	0.72Pu	0.078 < 0.199	0.795 > 0.113	Pass	0.795 < 1.022	Pass
C5-0.8	0.70Pu	0.062 < 0.266	1.064 > 0.113	Pass	1.064 > 1.022	Fail

Flexural Beams - Cyclic Load Test Results

Control specimen U1





Cracked specimen C2-0.4

Specimen	Deviation from Linearity	Load
U1	Failed at cycle 9	$0.70P_u$
U2	Failed at cycle 9	$0.70P_u$
U3	Failed at cycle 9	$0.70P_u$
C1-0.4	Failed at cycle 7	$0.52P_u$
C2-0.4	Failed at cycle 7	$0.52P_u$
C3-0.4	Failed at cycle 5	$0.60P_u$
C4-0.4	Failed at cycle 5	$0.45P_u$
C5-0.8	Failed at cycle 7	0.50Pu

Shear Beams - Monotonic Load Test Results

ACI 318-14

Passing:

The structure passes the test if the measured deflections satisfy one of the following equations:

Eq. 318-1: $\Delta_r \leq \Delta_l / 4$

Eq. 318-2: $\Delta_l \leq l_t^2 / 20{,}000h$

ACI 437.2-13

Passing:

The structure passes the test if the measured deflections satisfy both the following equations:

Eq. 437-1: $\Delta_r \leq \Delta_l / 4$

Eq. 437-2: $\Delta_l \leq l_t / 180$

Specimen	TLM	Δ_r, in. (Eq. 318-1/437-1)	Δ_l, in. (Eq. 318-2)	Performance ACI 318	Δ_l, in. (Eq. 437-2)	Performance ACI 437
SP1	$0.86P_u$	0.06 < 0.18	0.70 > 0.04	Pass	0.70 > 0.58	Fail
SP2	P_u	0.62 > 0.32	1.28 > 0.04	Fail	1.28 > 0.58	Fail
SP3	$0.88P_u$	0.46 > 0.20	0.80 > 0.04	Fail	0.80 > 0.58	Fail
SS1	$0.85P_u$	0.15 < 0.16	0.64 > 0.04	Pass	0.64 > 0.58	Fail
SS2	$0.85P_u$	0.14 < 0.15	0.55 > 0.04	Pass	0.55 < 0.58	Pass
SF1	$0.80P_u$	0.17 < 0.18	0.70 > 0.04	Pass	0.70 > 0.58	Fail
SF2	$0.78P_u$	0.37 > 0.21	0.85 > 0.04	Fail	0.85 > 0.58	Fail
SB1	$0.68P_u$	0.23 > 0.13	0.50 > 0.04	Fail	0.50 < 0.58	Fail
SB3	$0.82P_u$	0.15 < 0.19	0.74 > 0.04	Pass	0.74 > 0.58	Fail
SB4	$0.74P_u$	0.17 < 0.19	0.77 > 0.04	Pass	0.77 > 0.58	Fail
SB5	$0.84P_u$	0.12 < 0.22	0.86 > 0.04	Pass	0.86 > 0.58	Fail

Shear Beams - Cyclic Load Test Results

ACI 437.2-13

Deviation from Linearity Index (I_{DL})

$I_{DL} = 1 - \tan(\alpha_i) / \tan(\alpha_{ref}) < 0.25$

Permanency Ratio (I_{PR})

$I_{PR} = I_{p(i+l)} / I_{pi} < 0.50$

Specimen	Permanency ratio	Deviation from linearity	Test Load
SP1 (pre-corroded strand)	Failed at loadset 5	Failed at loadset 4	0.60Pu
SP2	Failed at loadset 3	Failed at loadset 3	0.80Pu
SP3	Failed at loadset 6	Failed at loadset 3	0.80Pu
SS1	Failed at loadset 6	Failed at loadset 6	0.78Pu
SS2	Failed at loadset 6	Failed at loadset 5	0.78Pu
SF1	Failed at loadset 4	Failed at loadset 6	0.70Pu
SF2	Failed at loadset 4	Failed at loadset 3	0.67Pu
SB1	Failed at loadset 4	Failed at loadset 4	0.63Pu
SB2	Failed at loadset 4	Failed at loadset 4	0.63Pu
SB3	Failed at loadset 4	Failed at loadset 5	0.52Pu
SB4	Failed at loadset 3	Failed at loadset 6	0.47Pu
SB5 (pre-corroded strand)	Failed at loadset 7	Failed at loadset 5	0.47Pu

Shear Beams - Monotonic versus Cyclic Load Test

Specimen	ACI 318		ACI 437.2		Comments
	Safe load	Performance ACI 318	Safe load	Performance ACI 437	
SP1 (pre-corroded strand)	$0.86P_u$	Pass	0.60Pu	DFL	CLT is more restrictive
SP2	P_u	Fail	0.80Pu	DFL/ Permanency	Inconclusive
SP3	$0.88P_u$	Fail	0.80Pu	DFL	Inconclusive
SS1	$0.85P_u$	Pass	0.78Pu	DFL/ Permanency	CLT is more restrictive
SS2	$0.85P_u$	Pass	0.78Pu	DFL	CLT is more restrictive
SF1	$0.80P_u$	Pass	0.70Pu	Permanency ratio	CLT is more restrictive
SF2	$0.78P_u$	Fail	0.67Pu	DFL/ Permanency	Inconclusive
SB1	$0.68P_u$	Fail	0.63Pu	DFL/ Permanency	Inconclusive
SB2	Failed during load hold		0.63Pu	DFL/ Permanency	Inconclusive
SB3	$0.82P_u$	Pass	0.52Pu	Permanency ratio	CLT is more restrictive
SB4	$0.74P_u$	Pass	0.47Pu	Permanency ratio	CLT is more restrictive
SB5 (pre-corroded strand)	$0.84P_u$	Pass	0.47Pu	DFL	CLT is more restrictive

Summary and Conclusions

- Laboratory tests show that ACI 318 previous maximum deflection limit always failed for the tested prestressed T-beams. The difference between the maximum deflection limit of ACI 318 and ACI 437.2 gave inconsistent pass/fail results for the same members

- CLT and monotonic load test give inconsistent results when used to evaluate the same members

- The newly formed subcommittee will collect and evaluate load test data with the aim of developing *hopefully* a new maximum deflection limit and evaluating the acceptance criteria of both methods

Questions?

Thanks for attending!

Email: melbatanouny@wje.com