Seismic Connections for Positive Moments in Precast Prestressed Girders

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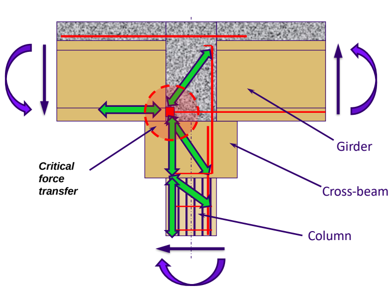
UNIVERSITY of WASHINGTON WSDOT

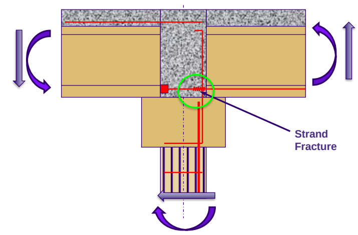
Goal

- **Jointless connection at an interior column.**
- **Resist longitudinal seismic loading.**
- **Prestressed concrete girders**

Concept:
Precast, pre-tensioned girder bridge.
Longitudinal seismic loading.
Need frame action between columns and girders.

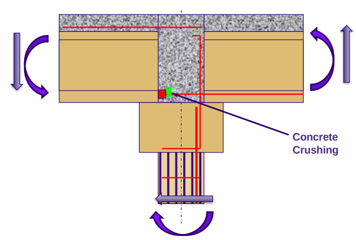


Possible Failure Modes: Strand yield

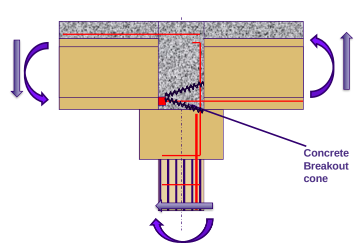


Strand yield and fracture is the preferred mode.
Need to prevent others.

Possible Failure Modes: Concrete crushing



Possible Failure Modes: Concrete breakout cone



Outline

- Tests: Bearing capacity at anchorage.
- Tests: Group anchor breakout capacity.
- Analysis: Distribution of moments among girders.

Strand Anchorage

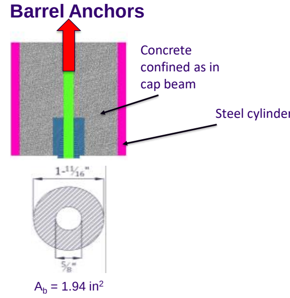
Barrel Anchors – Try with no bearing plate

Outline

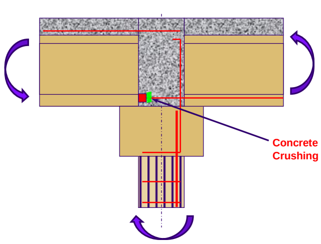
- Tests: Bearing capacity at anchorage.
- Tests: Group anchor breakout capacity.
- Analysis: Distribution of moments among girders.

Anchorage Test Specimens

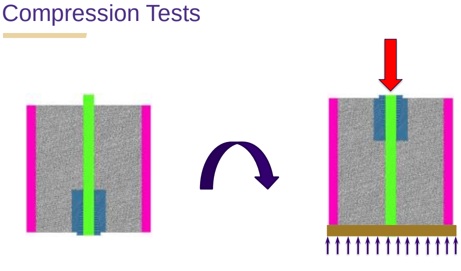
Barrel Anchors



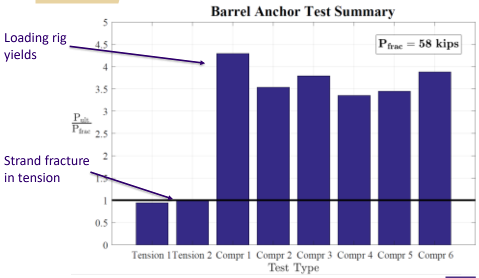
Strand Anchorage Tests



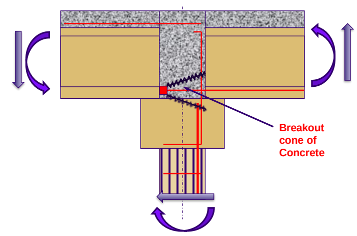
Compression Tests



Strand Anchorage Test Results



Possible Failure modes: Group breakout.



Individual Anchor Tests: Conclusions

> **No bearing plate necessary behind the barrel anchor.**

> **Little local crushing and slip of strand chuck.**

> **Failure occurs due to strand fracture - no bearing failure of concrete.**

Breakout Tests

Goal:
Find the embedded length of strand.
Want to fracture the strand, avoid group breakout.

Outline

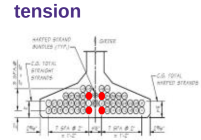
> **Tests: Bearing capacity at anchorage.**

> **Tests: Group anchor breakout capacity.**

> **Analysis: Distribution of moments among girders.**

Breakout Tests Overview

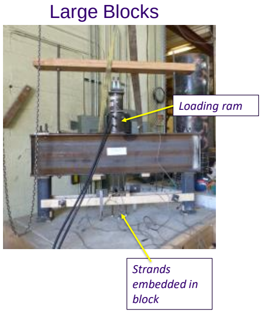
> **Strands, anchored with strand vices and embedded in concrete blocks, tested in tension**



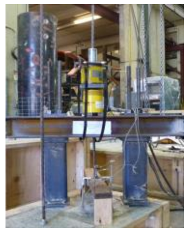
Pattern	Specimen
	U_1_O_1.75
	U_1_O_3.63
	U_1_O_5.19
	U_1_O_6.06
	B_1_O_1.75
	B_1_O_3.50
	B_1_O_5.00
	B_1_O_6.50
	U_2_L_2.75
	U_4_L_5.50
	U_4_L_9.25
	U_4_S_9.750
	U_4_S_14.50
	U_4_S_16.50

Breakout Test Setup

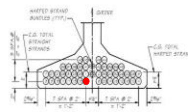
Large Blocks

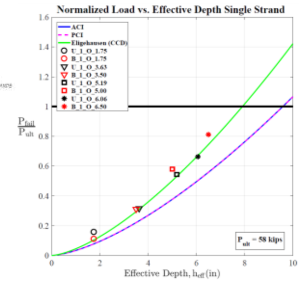


Small Blocks



Breakout Test Results

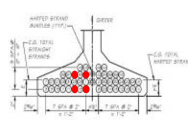


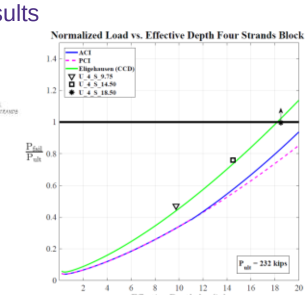


Breakout Test Specimens

> **Smaller specimens – one and two strands – breakout failure**

Breakout Test Results

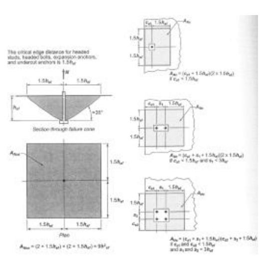




Concrete Capacity Design (CCD) Method

$$N = k_{nc}\frac{A_{Nc}}{A_{Nco}}\sqrt{f'c}\,h_{ef}^{1.5}$$

$$k_{nc} = \begin{cases} 40\ (CCD) \\ 24\ (ACI\ and\ PCI) \end{cases}$$

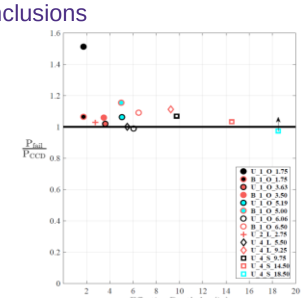


(ACI 318-11, Appendix D)

Breakout Test Conclusions

> **CCD model fits data very well.**

> **Can be used to determine the required embedment depth for different strand patterns extending into the cap beam**



Outline

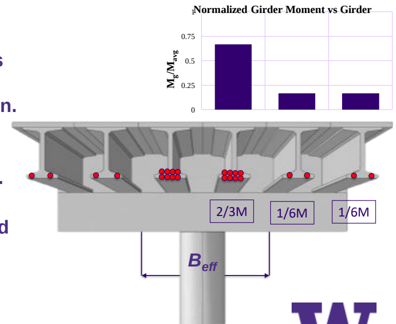
> **Tests: Bearing capacity at anchorage.**

> **Tests: Group anchor breakout capacity.**

> **Analysis: Distribution of moments among girders.**

Current Design Practice: Extended strands

> **High moments in girders nearest column.**
> **All girders designed for worst case no. of strands.**
> **Many extended strands**
> **Interference**



Analysis of Bridge Superstructure

Girder moment distribution:

Present approach
- Assigns large moments to girders closest to the column.
- Uses many extended strands.
- Is hard to construct.

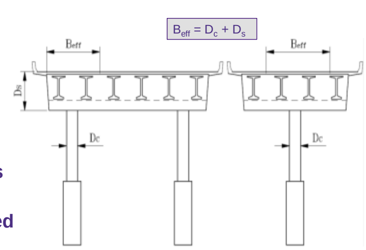
Goal
- Investigate validity of present distribution.
- Develop something better if needed.

Approach

> **UCSD tests used CA-style "flush cap beam."**
> **Low torsional stiffness.**
> **Non-uniform distribution of moments**

Current WSDOT Design Practice

> **Current practice: Priestley/Holombo tests at UCSD.**
> **Defines B_{eff} of cap beam.**
> **2/3 of moment resisted by girders within B_{eff}.**
> **Based on measured strains in deck reinforcement.**

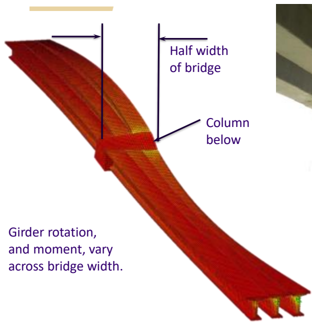


WSDOT BDM, 2015

WA Bent System: "Drop cap beams". Much larger, torsionally stiffer than CA.

Investigate distribution of girder moments.

California Bent Cap System



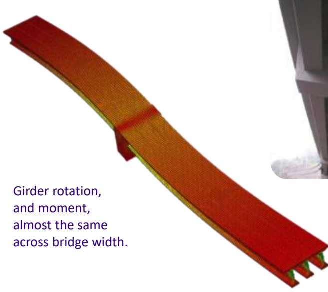
Girder rotation, and moment, vary across bridge width.

Continuous Model Overview

Model: Torsional beam-on-elastic-foundation.

- Cap beam: torsional line element.
- Girders: replaced by a continuous rotational spring.
- Closed form solution identifies controlling parameters.

Washington Bent Cap System



Girder rotation, and moment, almost the same across bridge width.

Continuous Model Conclusions

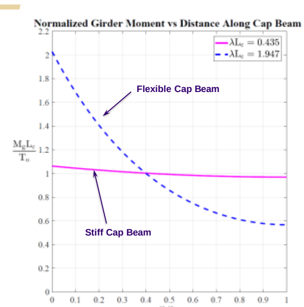
- **Controlling parameters:**
  - **Stiffness ratio, λL_c,**
  - **Number of girder lines, N_L,**

> $\lambda L_c = \sqrt{\dfrac{K_{g,bending}}{K_{c,torsion}}} = \sqrt{\dfrac{2N_L(3EI_g/L_g)}{(G_cJ_c/L_c)}}$

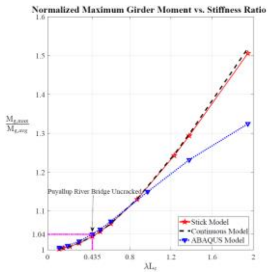
Analysis Outline

- **3D ABAQUS Model**
- **Frame Model**
- **Continuous Model**

Continuous Model Conclusions



Analysis Results: Effect of stiffness ratio



$$\lambda L_c = \sqrt{\frac{2N_L(3EI_g/L_g)}{(G_cJ_c/L_c)}}$$

Stiff cap beam

Flexible cap beam

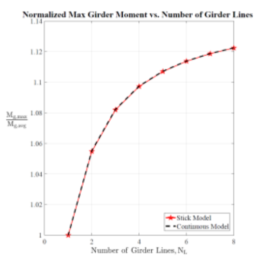
Analysis Conclusions

> **Girder moments almost uniform in WA system.**

> **Can reduce number of extended strands .**

- **Better constructability, especially in curved bridges, where extended strands not parallel.**
- **Better resistance to group breakout (fewer strands in group).**

Analysis Results: Effect of no. of girder lines.



Overall Conclusions

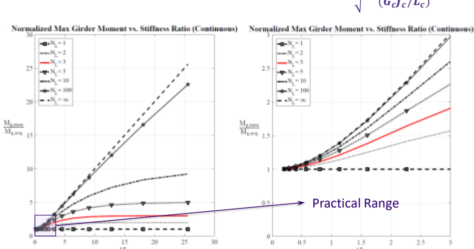
> **A strand chuck, with no bearing plate, is sufficient for transferring local bearing stresses.**

> **The CCD method can be used to design against group breakout failure.**

> **Distribution of girder bending moments is essentially uniform for WSDOT bent cap systems. Max no. of extended strands can be reduced.**

Variation of Number of Girder Lines and Stiffness Ratio

$$\lambda L_c = \sqrt{\frac{2N_L(3EI_g/L_g)}{(G_cJ_c/L_c)}}$$



Asymptotic to N, majority of moment is resisted by interior girders – for a case when the girders are much stiffer than the CB

Stiff CB

Flexible CB

Thank you!