aci VIRTUAL CONCRETE CONVENTION

Anchorage of Large High-Strength Headed Reinforcing Bars

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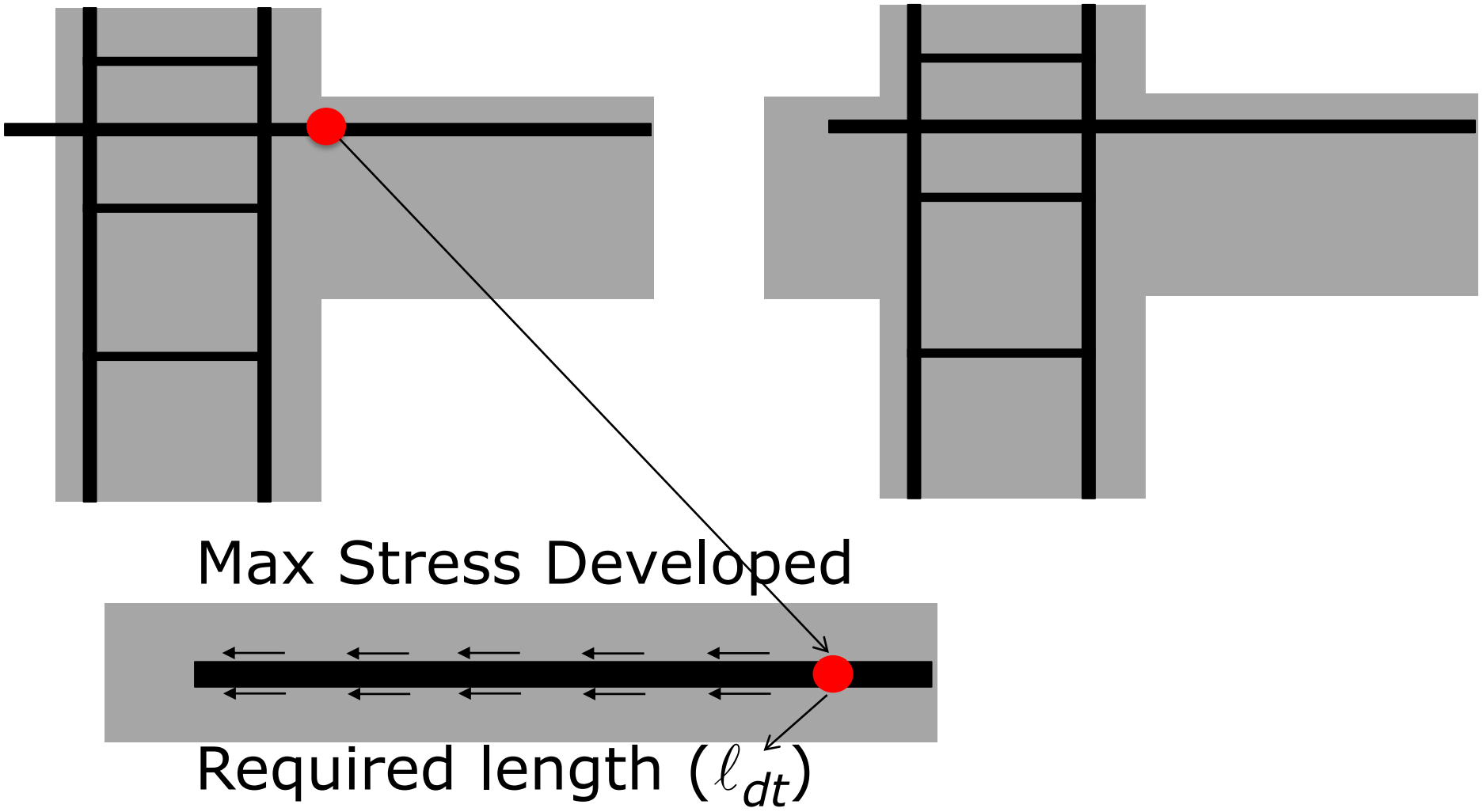
Presentation Outline

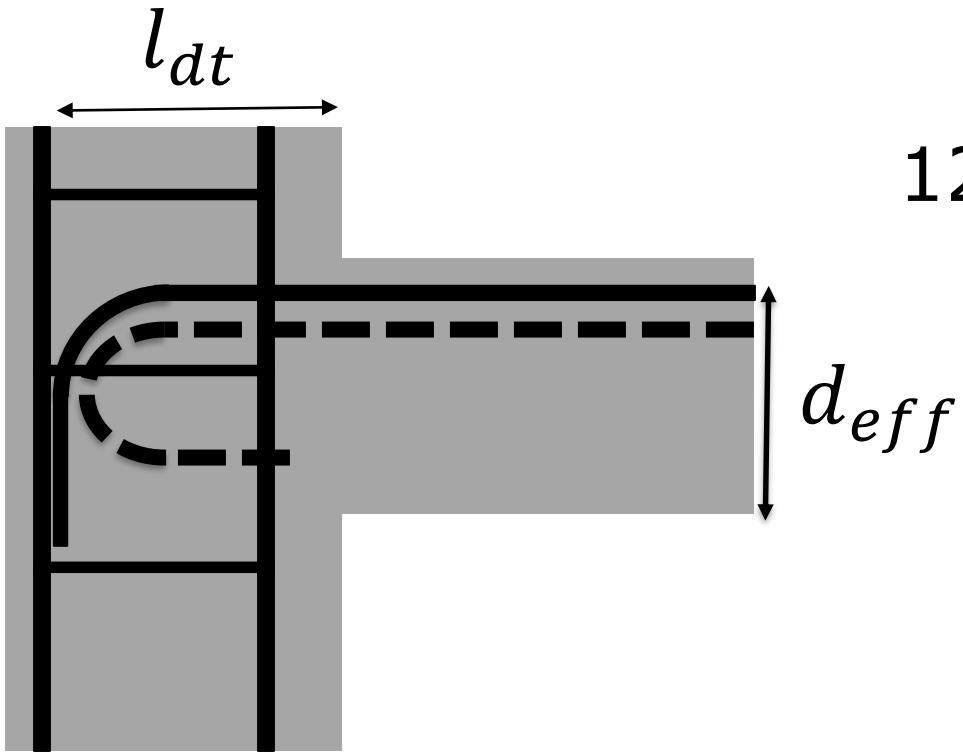
- Introduction
- KU Studies and Findings
- Current Project
- Future Research

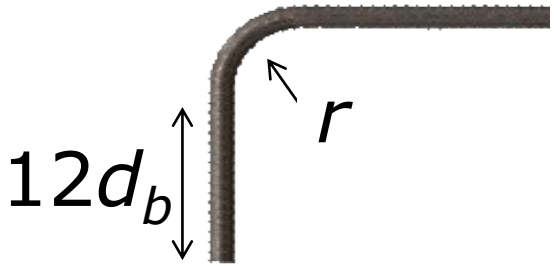
Development Length and Dimensional Restriction



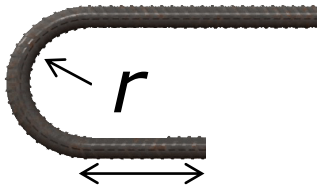
Standard Hooked Bars

- Use hooked bars (180 and 90 degrees)





90 degrees



$4d_b \geq 2.5$ in.

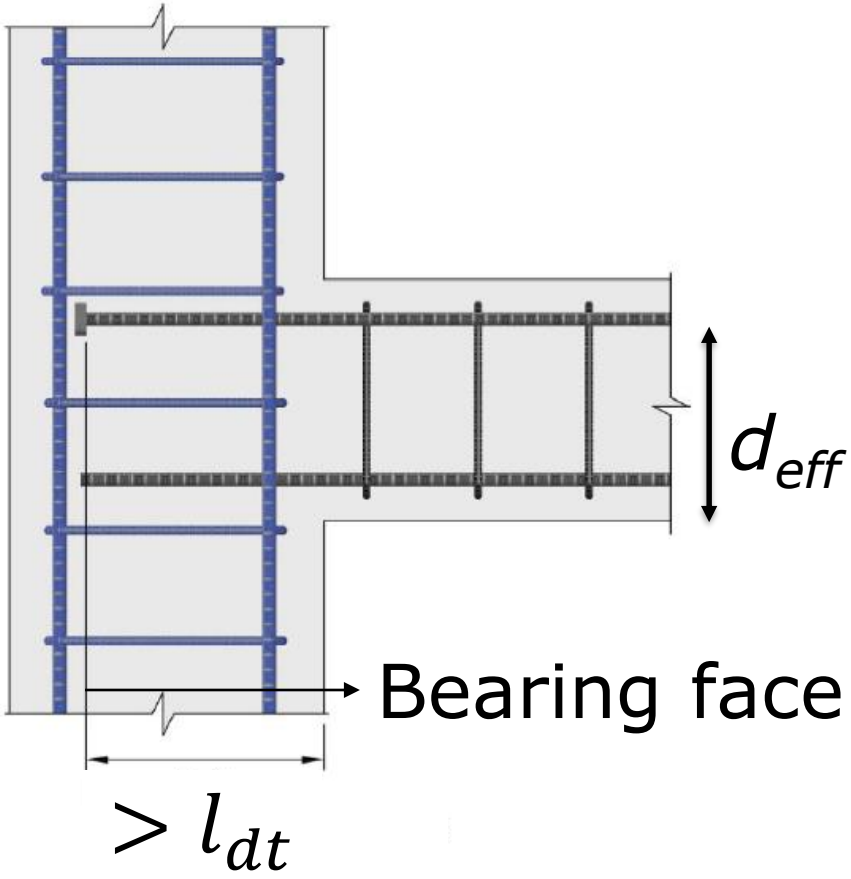
180 degrees

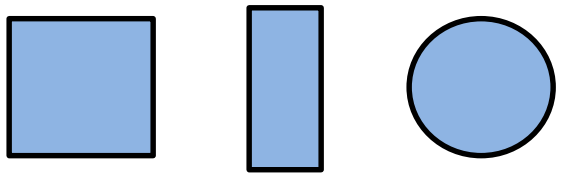
Problem with Hooked Bars

Source: https://www.sefindia.org/forum/files/beam_column_joint_2_321.jpg

Headed Bars

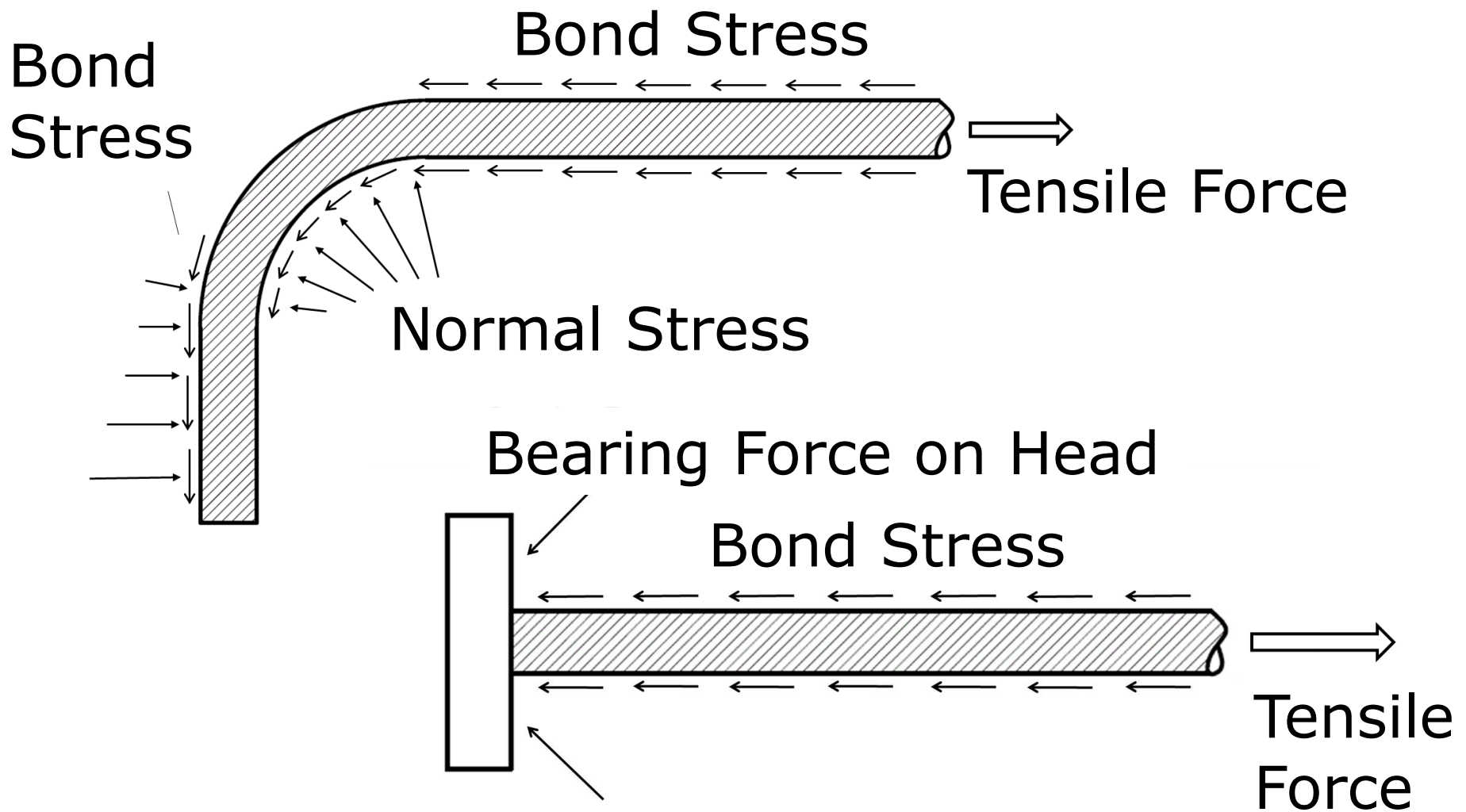
- Why headed bars?



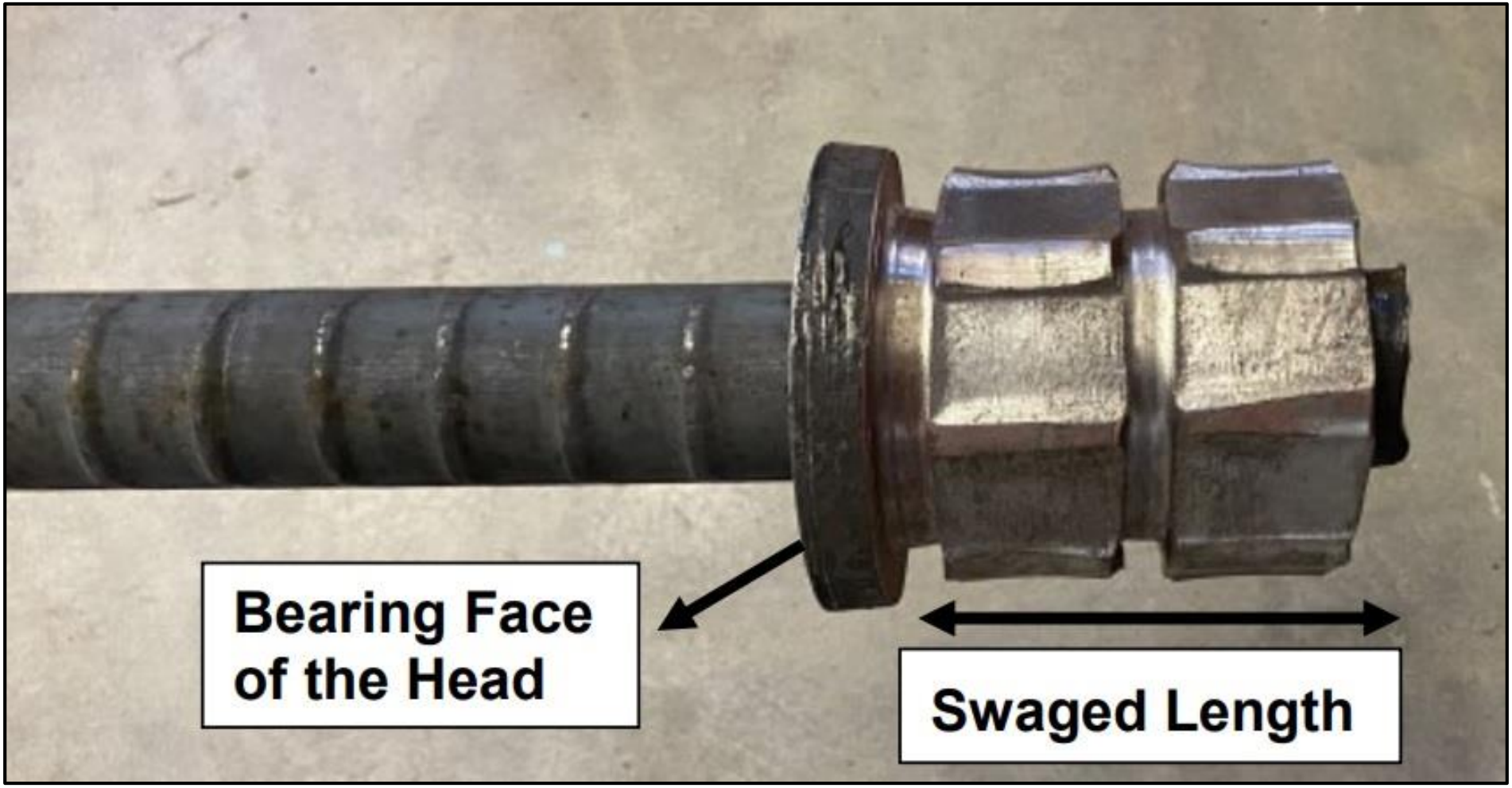


Different head shapes

Hooked Bars Vs. Headed Bars



Headed Bars

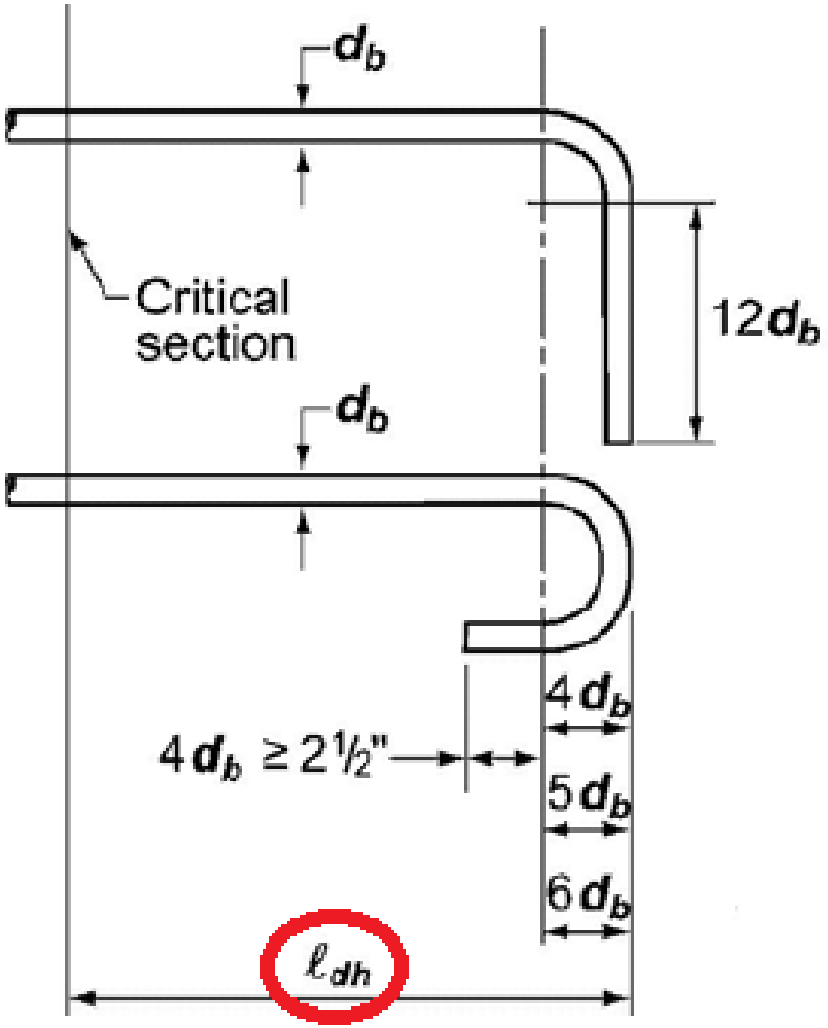


ACI 318-14: Hooked Bars

$$\ell_{dh} = \left(\frac{\Psi_e \Psi_c \Psi_r f_y}{50\lambda\sqrt{f_c'}} \right) d_b$$

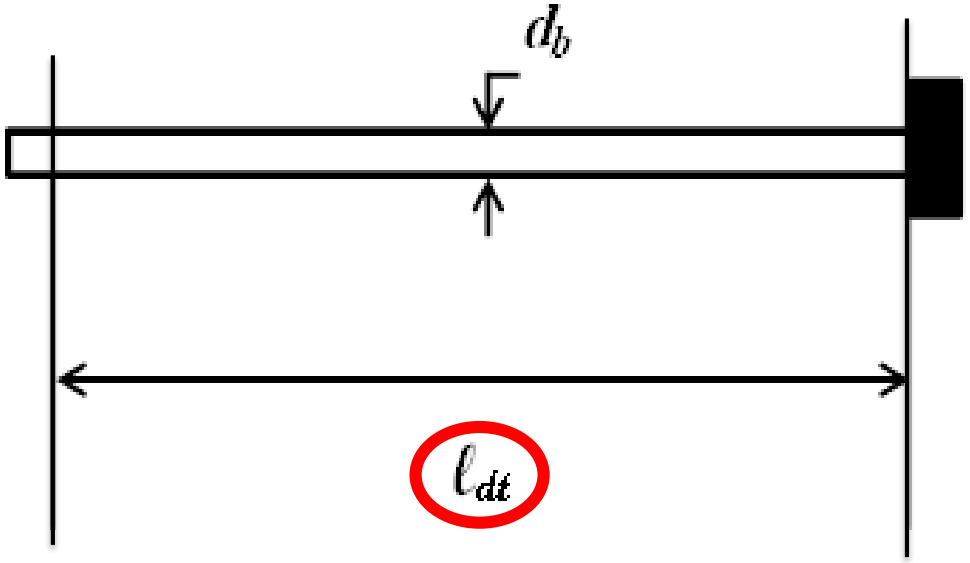
Limits

- 80 ksi for f_y
- 10 ksi for f_c'



ACI 318-14: Headed Bars

$$\ell_{dt} = \left(\frac{0.016 \psi_e f_y}{\sqrt{f_c'}} \right) d_b$$



Limits

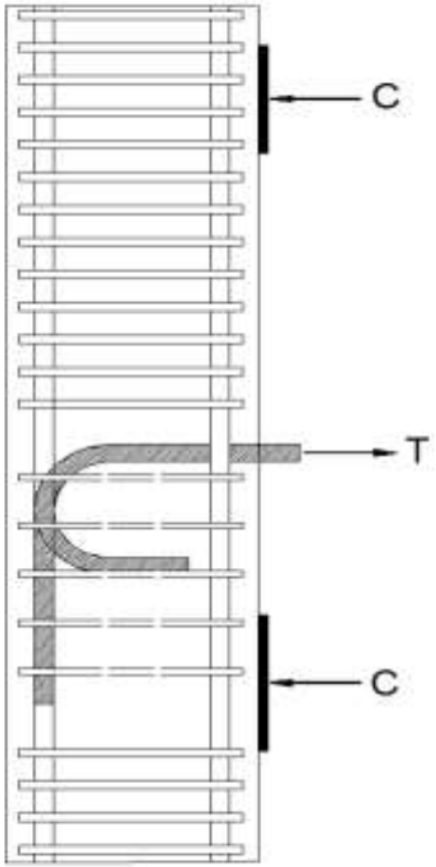
- 60 ksi for f_y
- 6 ksi for f_c'

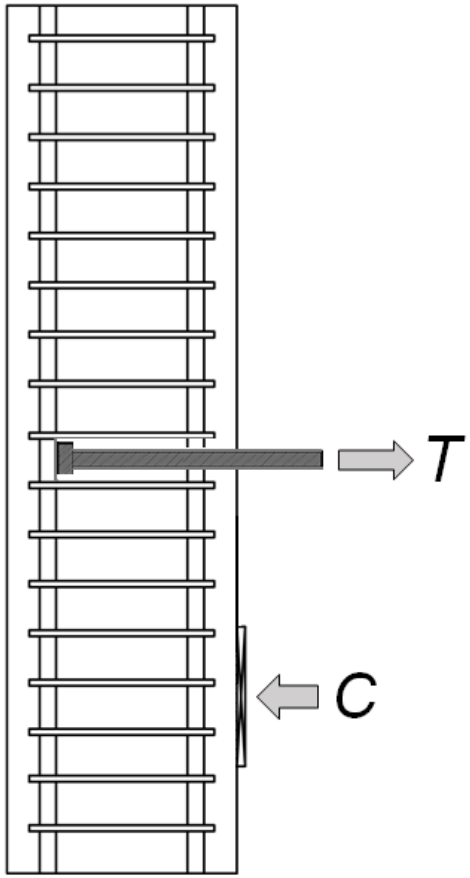
Previous KU Studies: Scope

1. Expand the understanding of the anchorage behavior
2. Develop new design provisions

Previous KU Studies

- 2012 to 2016:300 Hooked bar and 202 Headed bar Simulated Beam-Column Joint Specimens





KU Study Findings

- Hooked and headed bars behave a lot alike
- For the same embedment length, headed bars provide a higher anchorage force than hooked bars
- Closely spaced hooked and headed bars are weaker, individually, than widely spaced hooked and headed bars
- Hooked bars with 90° and 180° degree bends have similar anchorage strengths

KU Study Findings

- ACI 318-14 provisions overestimate contribution of concrete strength to anchorage strength with $\sqrt{f_c'}$ term; it can be better represented by ${f_c'}^{0.25}$
- Confining reinforcement increases anchorage strength of hooked and headed bars
- Descriptive equations for anchorage of hooked and headed bars based on tests on No. 5, No. 8, and No. 11 bars

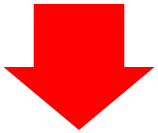
ACI 318-19 – Development Length

Hooks $$\ell_{dh} = \left(\frac{f_y \psi_e \psi_r \psi_o \psi_c}{55 \lambda \sqrt{f_c'}} \right) d_b^{1.5}$$

Heads $$\ell_{dt} = \left(\frac{f_y \psi_e \psi_p \psi_o \psi_c}{75 \sqrt{f_c'}} \right) d_b^{1.5}$$

Current KU Study: Scope

Expand the available data on the anchorage strength of No. 14 and No. 18 hooked and headed bars



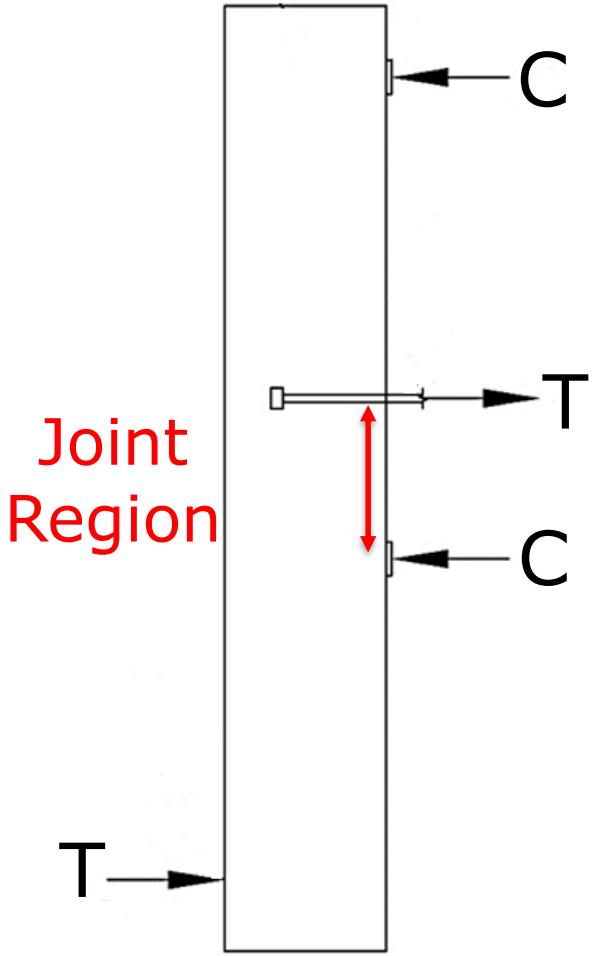
Use the experimental results to propose design criteria for No. 14 and No. 18 bars

Beam Column Joints: Specimen Design

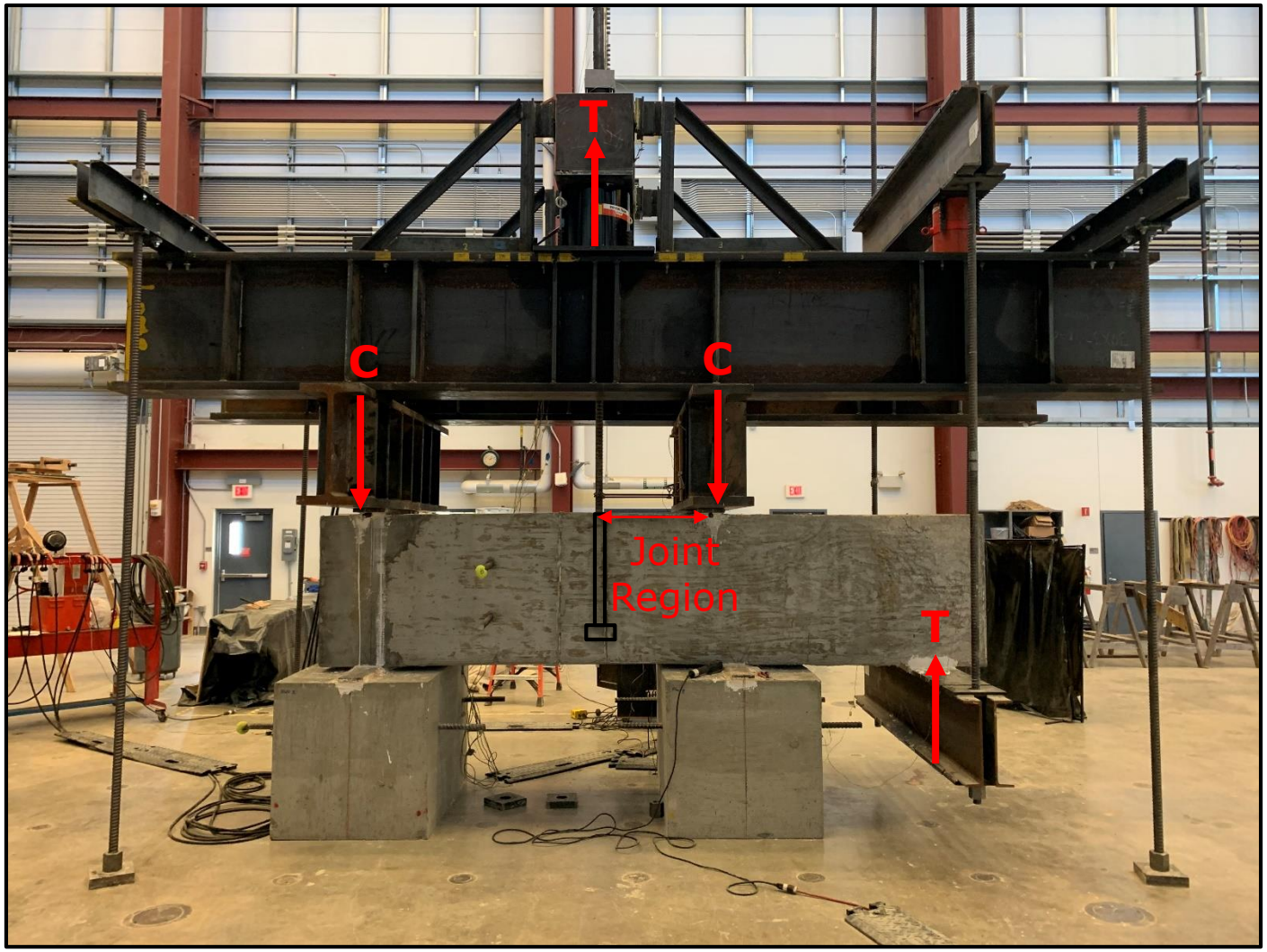
- Simulated beam-column joints same as the previous studies and designed so the anchorage failure occurs in the joint region
- Key Variables
  - Embedment length
  - Number and spacing of bars (widely and closely spaced)
  - Area of confining reinf. in the joint region
  - Bar size
  - Concrete strength: 5 to 15 ksi
  - Stress of test bars up to 150 ksi

Beam Column Joints: Testing Frame

- Forces Applied on the Specimen from the Reaction Frame



Beam Column Joints: Testing Frame



Beam Column Joints: Test Results

- No. 14 Bar Specimens

  - Concrete strength: 5-13 ksi
  - Bar stress: up to 150 ksi
  - Bar spacing: 18 in. (widely-spaced)
  - Embedment length: 22.7 to 35.8 in.
  - Confining reinforcement: with and without

Beam Column Joints: Test Results

- No. 14 Headed Bar Specimens –Results

Specimen	f'_c (psi)	Confining Reinforcement	T/T_h
14-3	8510	Without	1.04
14-4	7700	With	1.00
14-15	6190	Without	1.07
14-16B	7500	With	0.85
14-16C	6470	With	0.91
		Average:	0.97

Beam Column Joints: Test Results

- No. 14 Hooked Bar Specimens –Results

Specimen	f'_c (psi)	Confining Reinforcement	T/T_h
H14-1	12980	Without	1.09
H14-2	13010	With	1.19
H14-3	8100	Without	1.05
H14-4	7570	With	0.91
		Average:	1.06

Beam Column Joints: Test Results

- No. 14 Bar Specimens – Failure Mode

Beam Column Joints: Test Results

- No. 14 Bar Specimens – Failure Mode

Future Research

- Finish No. 14 hooked and headed bar tests with widely and closely spaced bars
- Design and fabricate No. 18 hooked and headed bar specimens

Summary

- The need for obtaining experimental data on large-diameter hooked and headed bars
- Current study on the anchorage strength of No. 14 and No. 18 bars and the results matching fairly close to previous tests
- The future plan for the ongoing study

Thank You!