# Punching Shear Capacity of Plate Dowel Joints for Slabs-on-Grade

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# Outline

- Introduction to Dowels
- Tapered Plate Dowel (TPD)
- Experimental Investigation & Results
- Punching Shear Capacity Prediction

# Acknowledgment

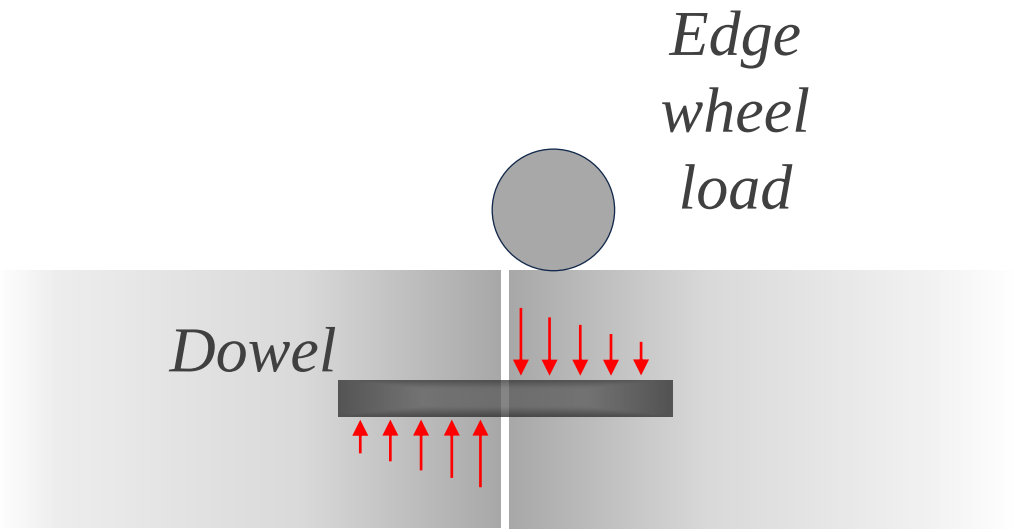

- This research was funded by **ITW Commercial Construction North America (CCNA)**
- All tests were run at **ITW's laboratory** in **Lake Forest, IL**

# Introduction to Dowels

# Dowels

- **Application:**
  - load transfer across joints (shear)
  - Limit differential deflection between slabs

- **Geometry/properties:**
  - Diameter (if round): 0.75” to 1.5”
  - Length: 18”
  - Epoxy coated (corrosion)
  - Smooth surface (sliding)




# Why Dowels

## Input:

- 15-inch airfield slab
- Airbus A350-900 @ 300.1 ton

## LTE 0% (no dowel):

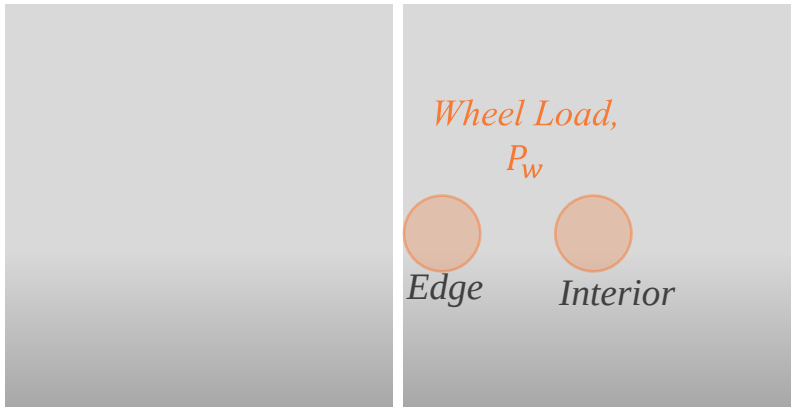
- Load: 70,800 lb.
- Interior stress: 408 psi
- **Edge stress: 770 psi**

## LTE 75% (doweled)

- Load: 44,300 lb.
- Interior stress: 408 psi
- **Edge stress: 480 psi**

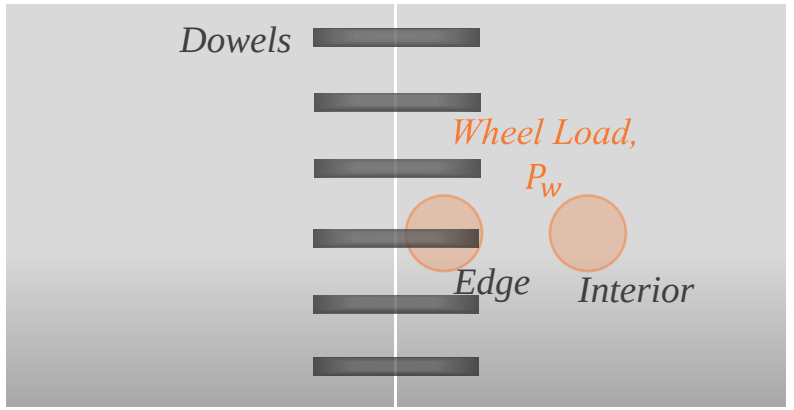
**LTE 0%**

*Plan View*




**LTE 75%**

*Plan View*

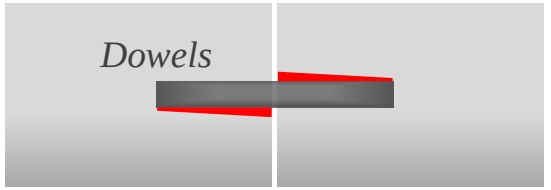


# Problems with Dowels *(ACPA, 2010)*

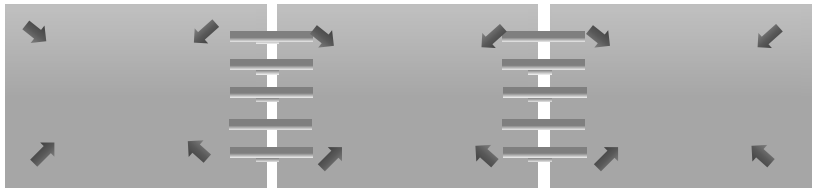
1. Steel corrosion
2. Loss of effectiveness stemming from looseness
3. Panel cracking from dowel misalignment
   - Due to restraint stresses

**Epoxy coat:**

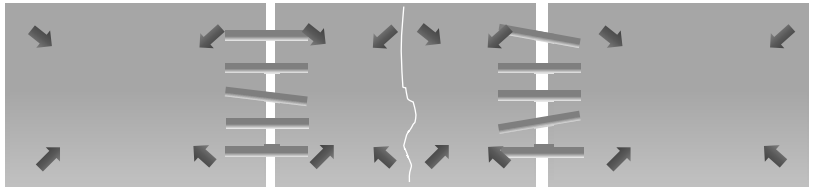
**Repeated Loading:**




**Case I:** *Aligned Prismatic Dowels*



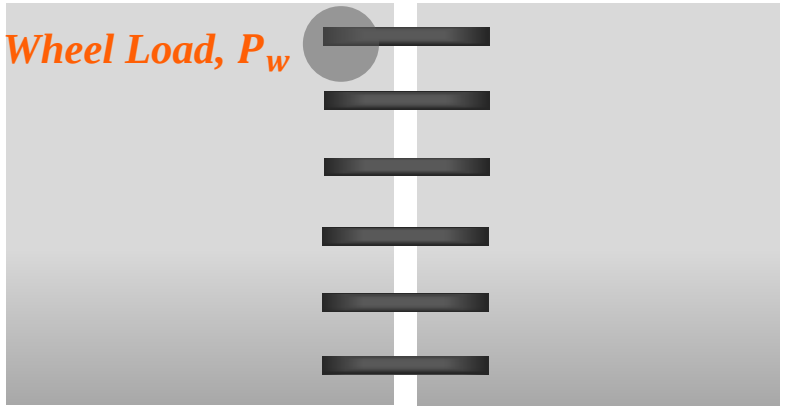
**Case II:** *Misaligned Prismatic Dowels*



After Contraction

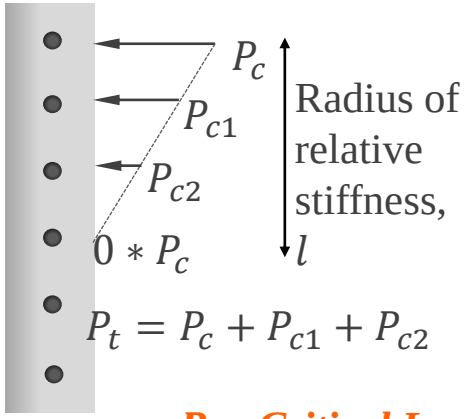
# Group Dowel Action

## Plan View




## Side View

*lateral cross section*

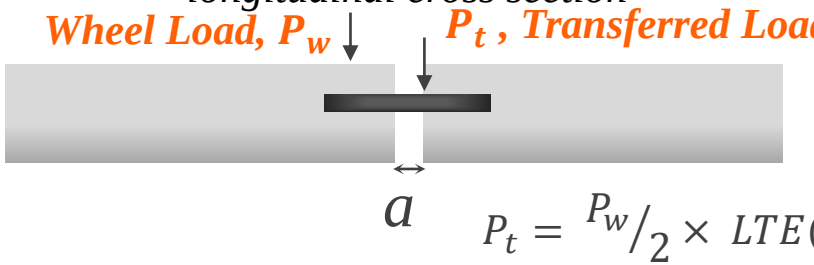



$$P_t = P_c + P_{c1} + P_{c2}$$

***$P_c$ , Critical Load***

## Side View

*longitudinal cross section*




$$P_t = {}^{P_w}/_{2} \times LTE(\%)$$

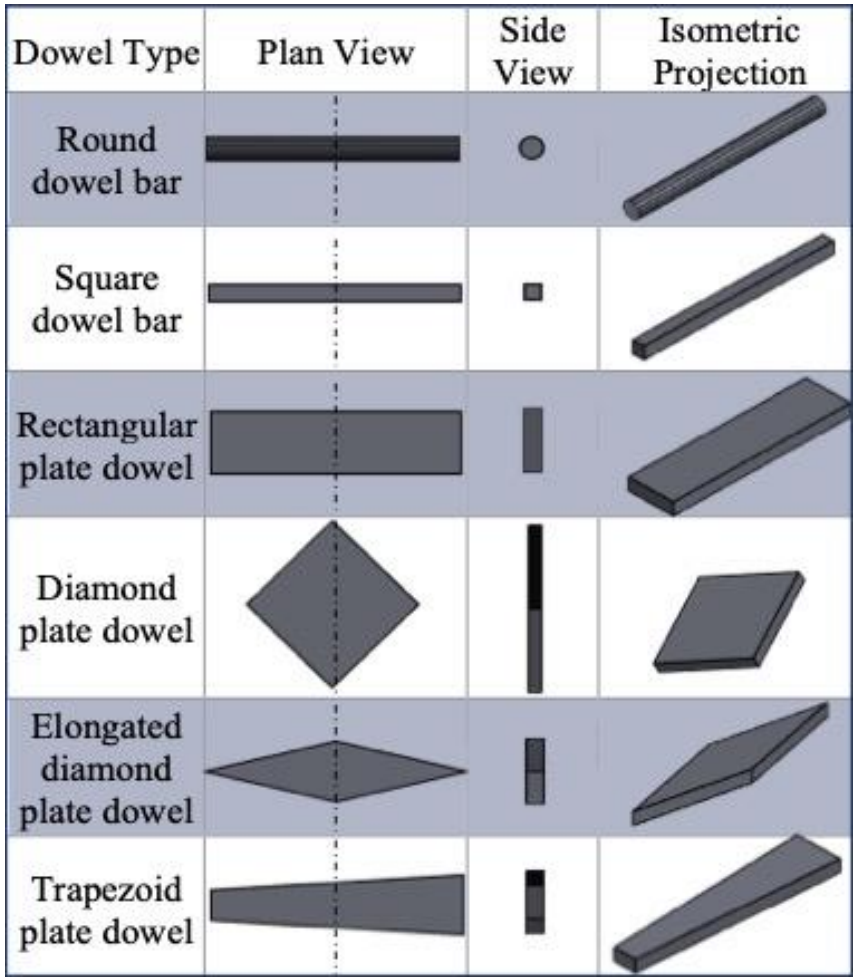
As proposed in FHWA Report #: ***FHWA-RD-88-068*** (1989)

*a*

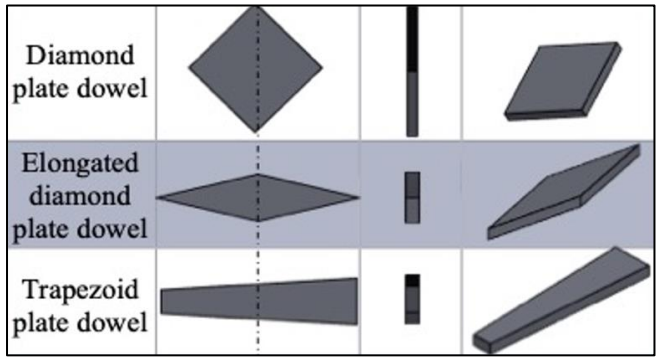
# Tapered Plate Dowels (TPD)

# Two main groups of dowel geometries:

- **Bar dowels (long prismatic beams)**
  - Round
  - Square
- **Plate dowels (Prismatic & non-prismatic)**
  - Rectangular
  - Diamond
  - Tapered (EDD, TRAP, etc.,)

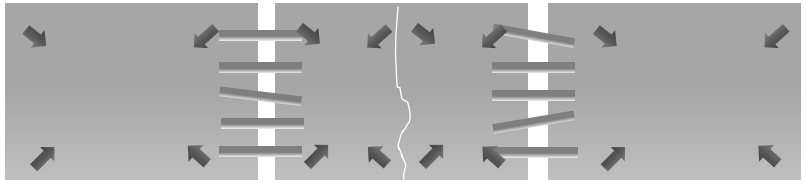


# Tapered Plate Dowels (benefits)

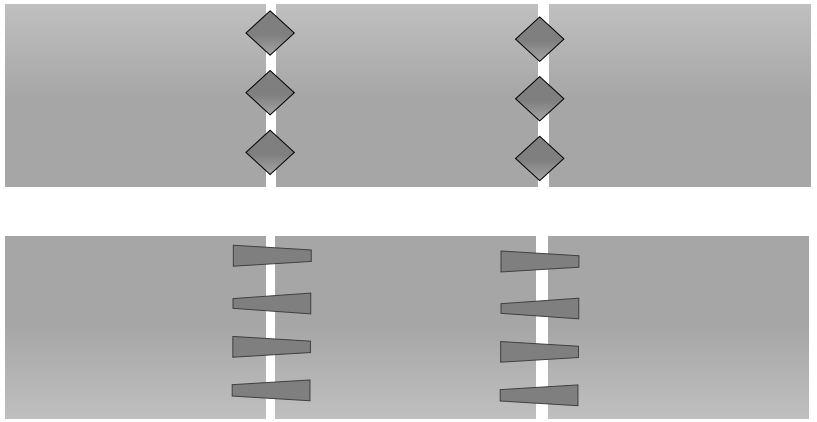



1. **Larger load bearing area**
   - Reduced bearing stress
2. **Placed closer to slab corner *(ACI 360R-10) :***
   - Round dowels – 12” from joint intersection
   - Plate dowels – 6” from joint intersection
3. **Allow free movement of slabs**
   - Reducing early age restraint induced cracking

**Case II:** *Misaligned Prismatic Dowels*



**Case III:** Non-Prismatic (Tapered) Plate Dowels



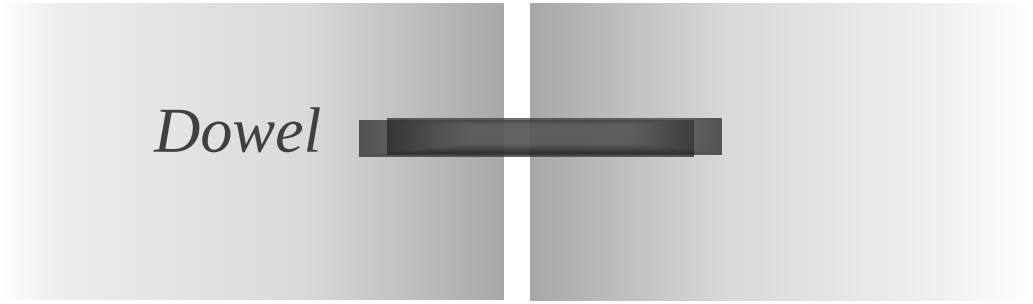
**After Contraction**

# NCHRP Report 637 (2009)

*Guidelines for Dowel Alignment in Concrete Pavements*

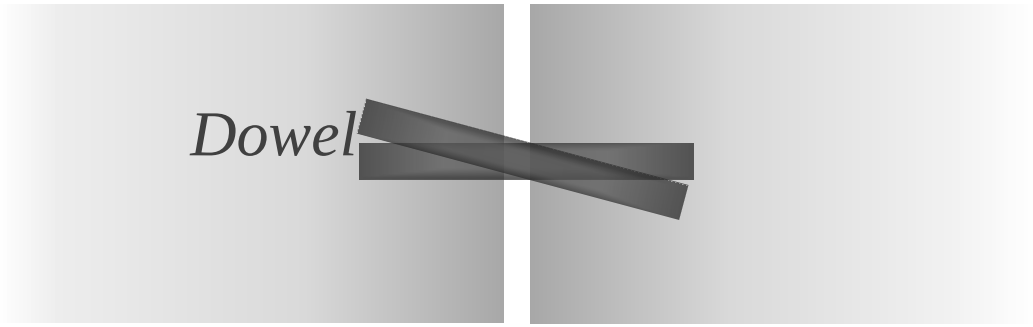
**Data from 60 project sites**

***Longitudinal Misalignment***



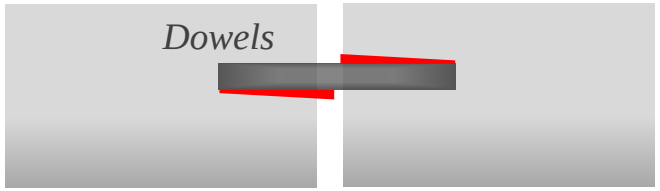

- Average: 0.86”
- Between 1.5” and 2” (~17%)

***Horizontal skew & Vertical tilt***




- Between 0.25” and 0.50” (~30%)
- >0.5” (~10%)

# Critical Dowel Responses




1. Differential deflection (slabs)
2. Bearing stress (concrete) ← *Plate Dowels perform better*
3. Dowel flexure
4. Dowel shear

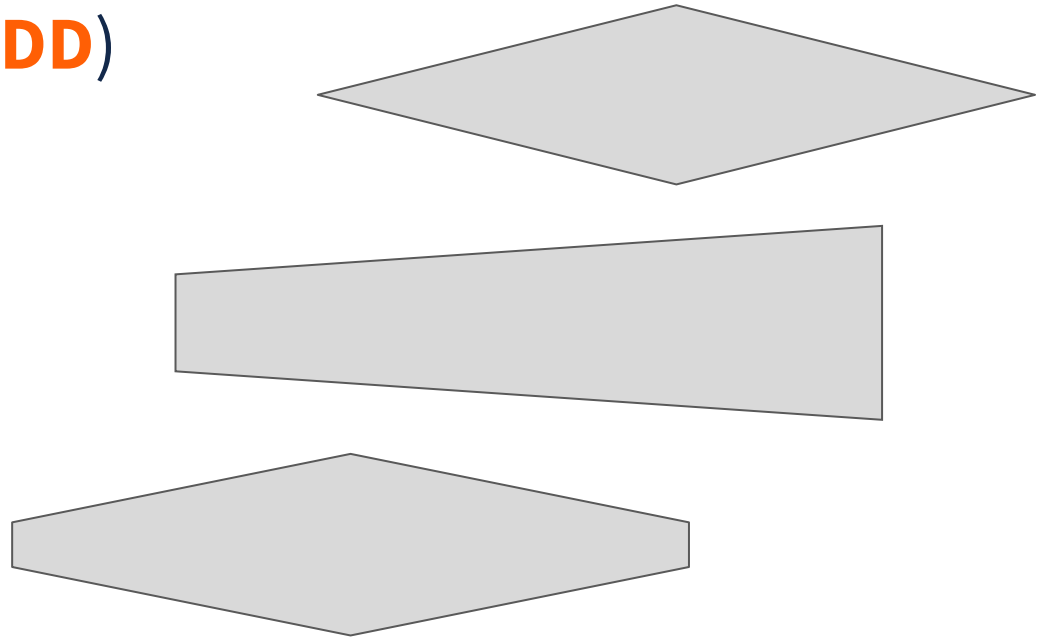
5. Punching shear(concrete) ← *Round Dowels perform better*

# Experimental Analysis & Results

# Tapered Plate Dowel Testing (I)

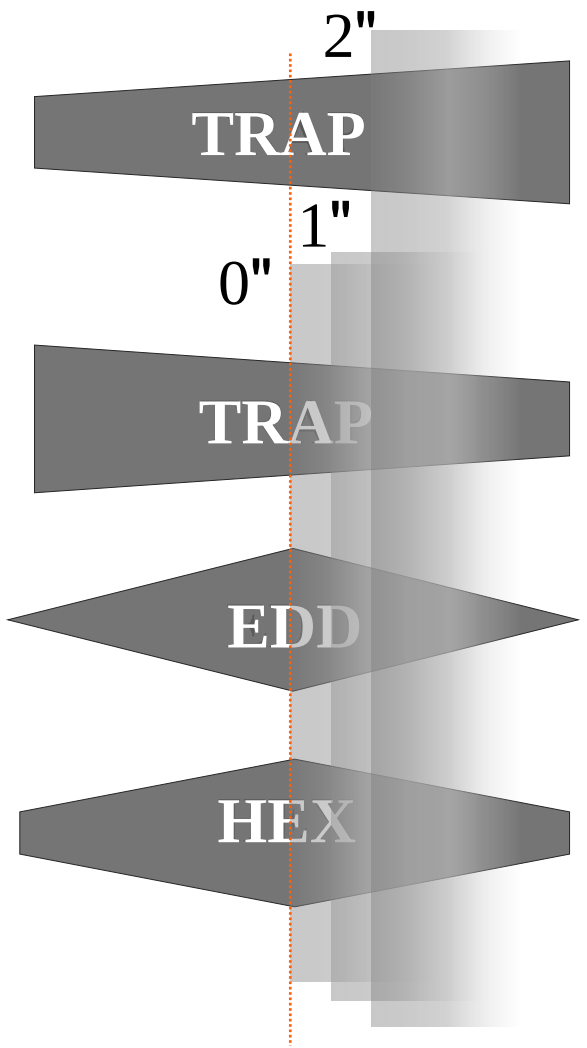
## Three Dowel Types:

1. **Elongated Diamond Dowel (EDD)**
2. **Trapezoid Dowel (TRAP)**
3. **Hexagonal Dowel (HEX)**



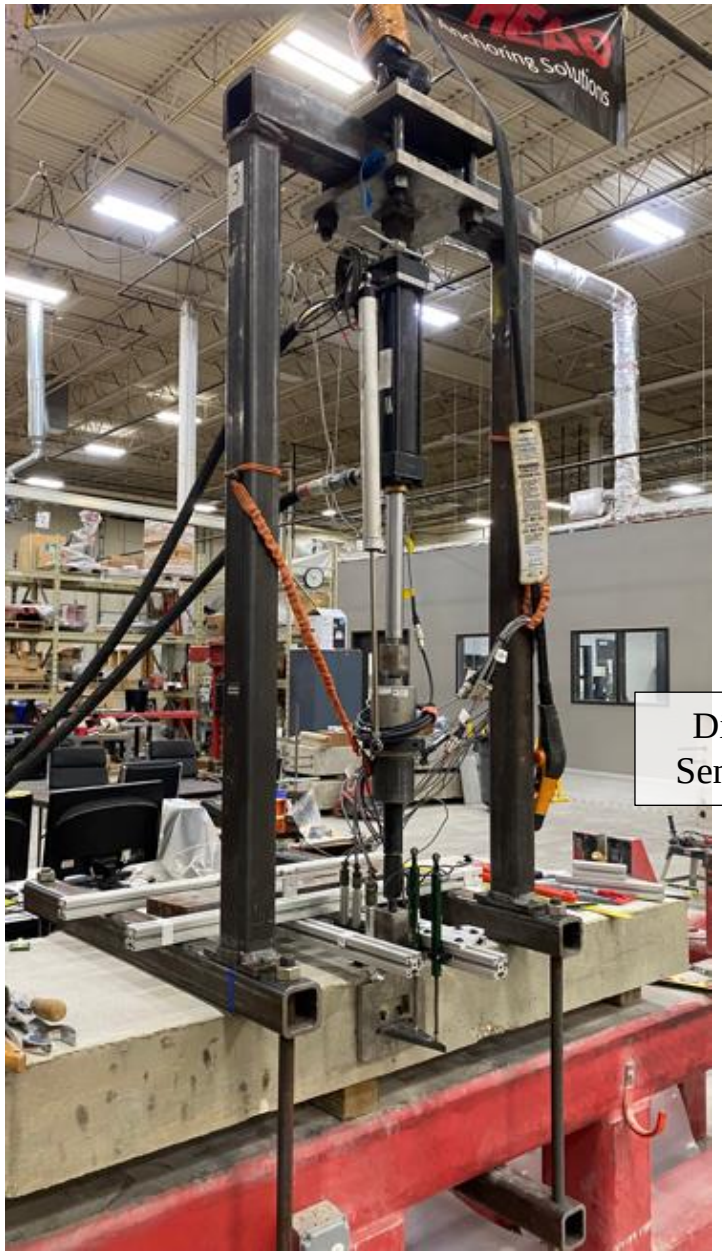
# Tapered Plate Dowel Testing (II)

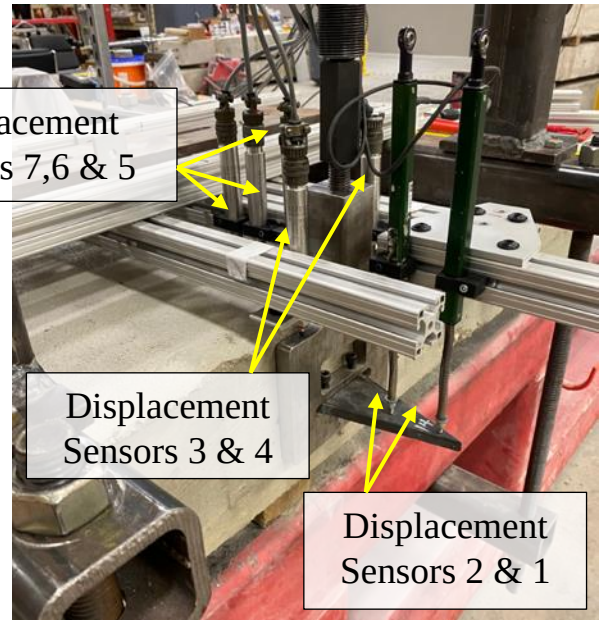
- **One end of dowel embedded in concrete**
- **Dowels embedded @ 0”, 1”, and 2” offset joints**



# Tapered Plate Dowel Testing (III)

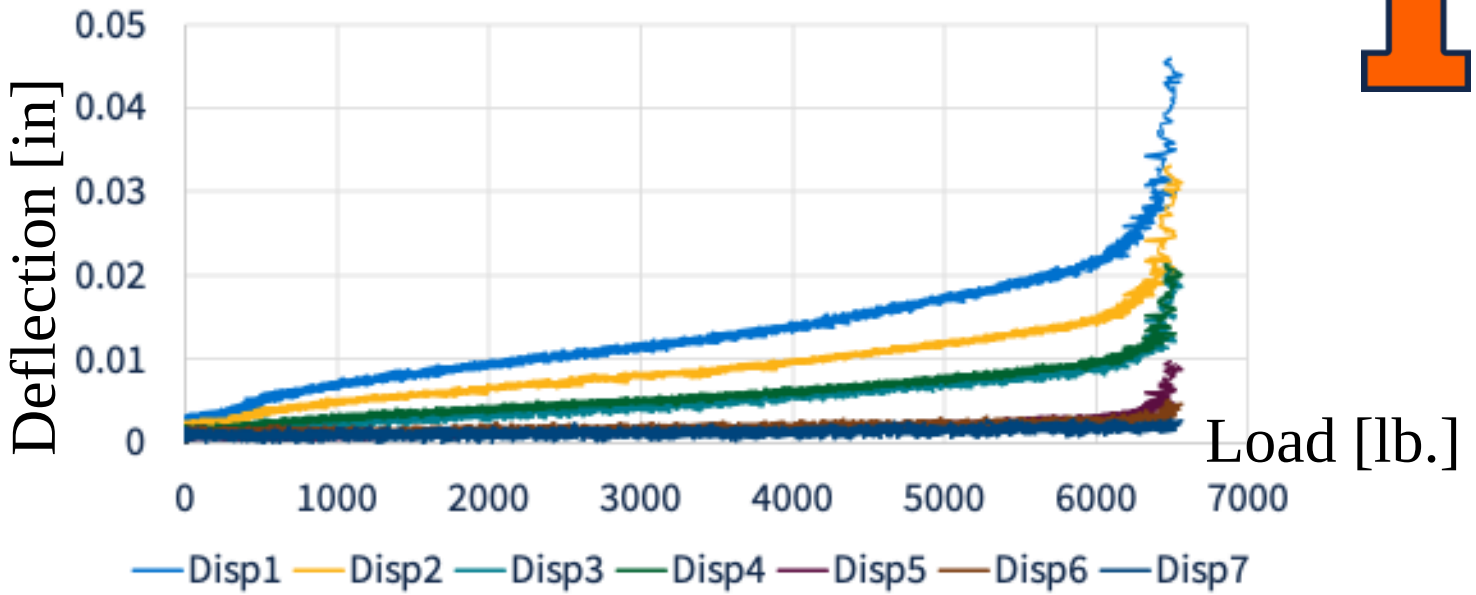
- Cyclic loading:
  - 5000 cycles
  - 2000 lb. maximum load
  - 200 lb. min. load





# Tapered Plate Dowel Testing (III)

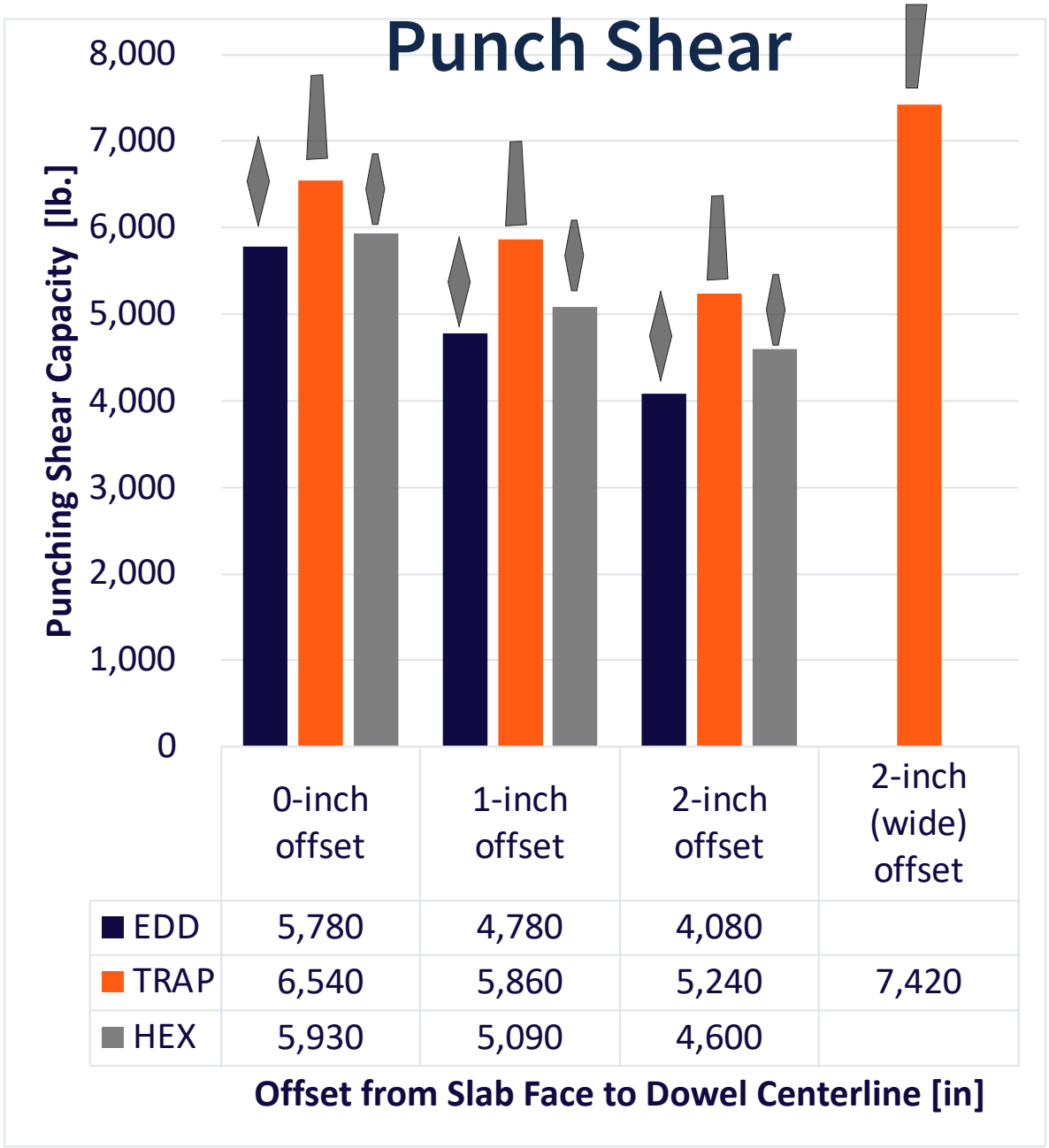
- Cyclic loading:
  - 5000 cycles
  - $P_{max}$ = 2000 lb.
- Static load test to failure at end of fatigue cycles




# Results: Punch Shear Capacity

**Punch Shear Capacity:**

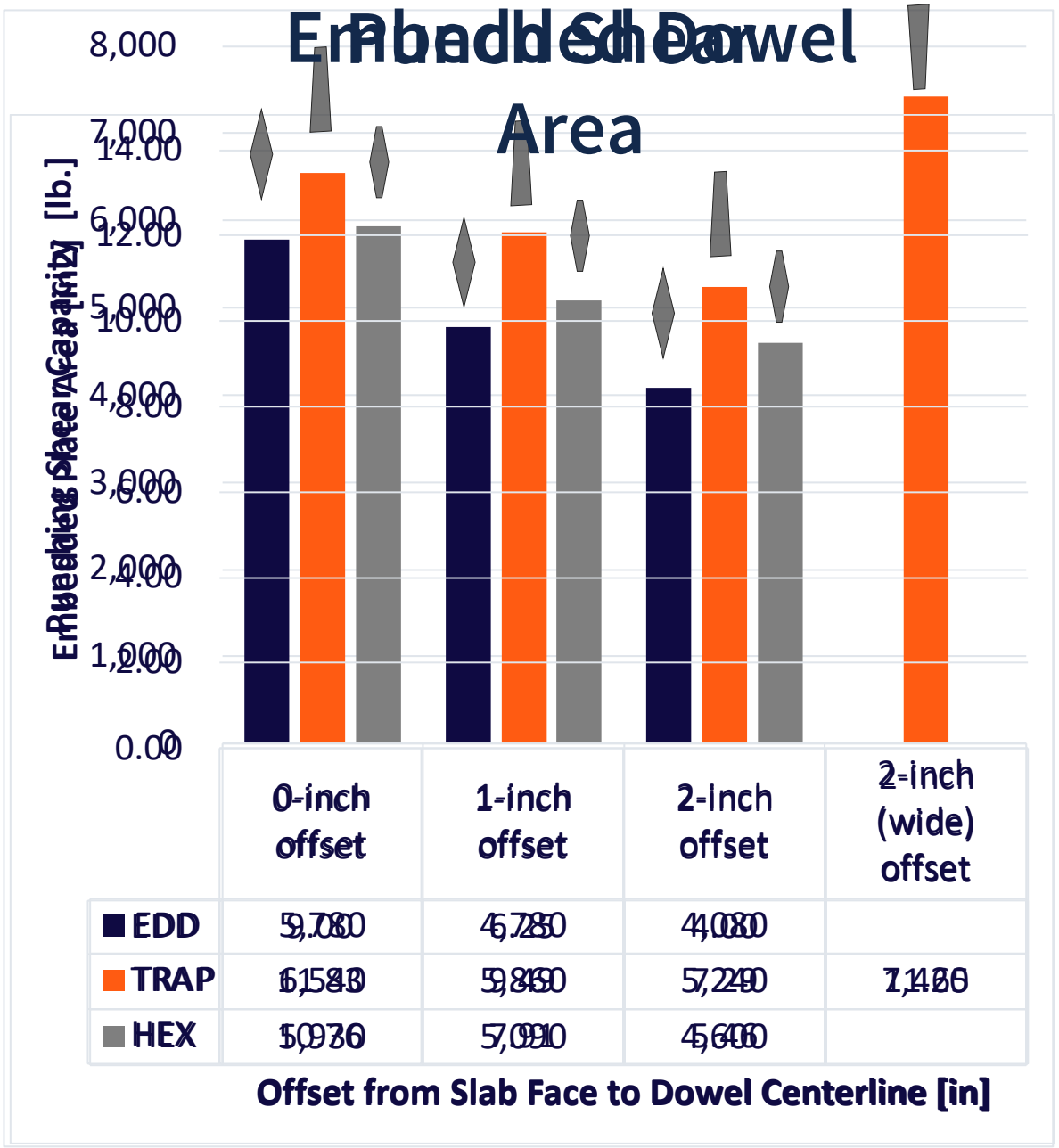
- **TRAP @ 0” offset:**
  - 7% higher than HEX
  - 13% higher than EDD
- **TRAP @ 2” offset:**
  - 14% higher than HEX
  - 28% higher than EDD
- **TRAP (*wide end*) @ 2” offset:**
  - 61% higher than HEX
  - 82% higher than EDD



# Results: Punch Shear Capacity

## Plate Dowel Areas:

- **TRAP: 28.5 in²**
- **HEX: 21.5 in²**
- **EDD: 18 in²**

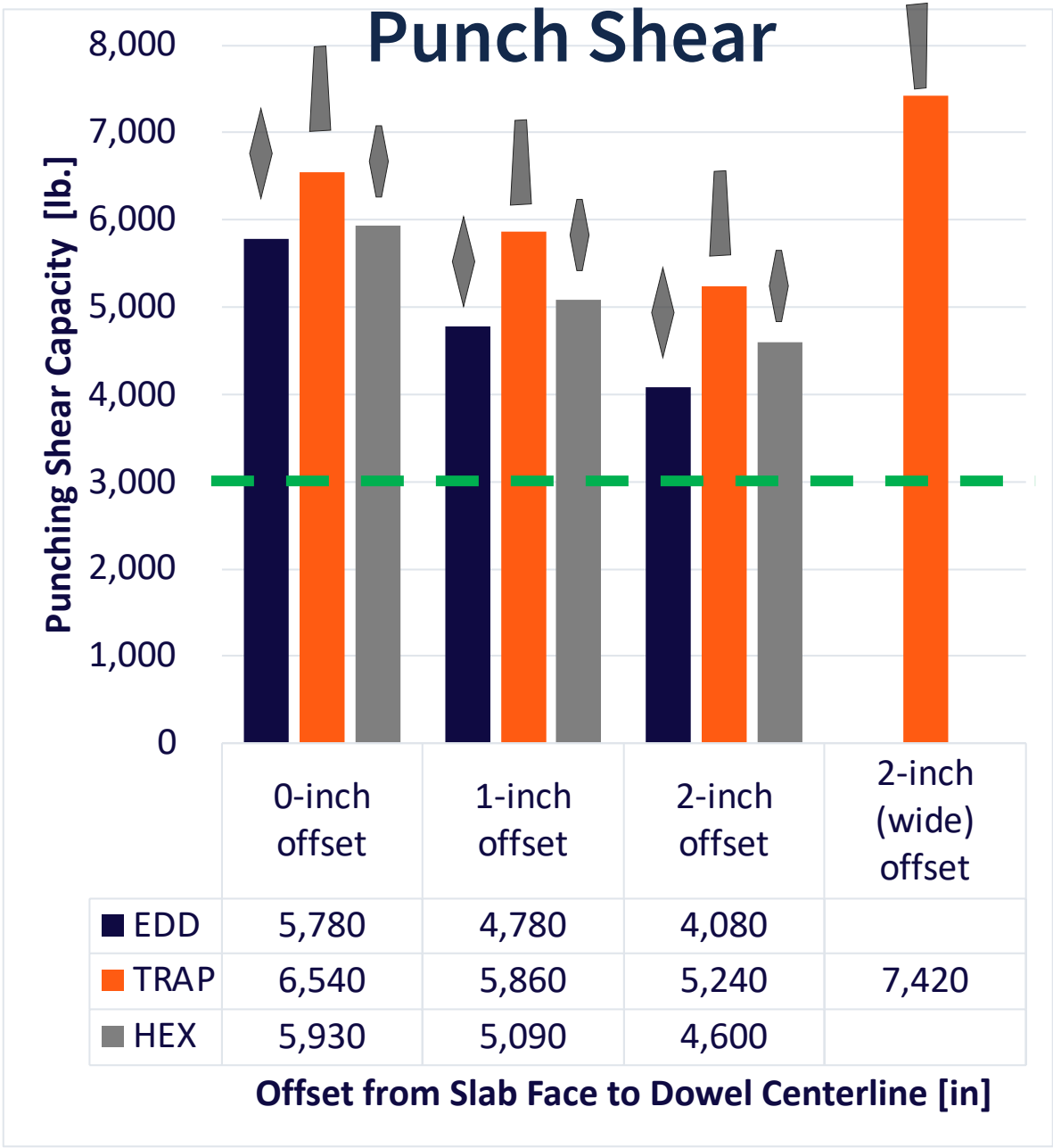


# Punch Shear Capacity

**Assume:**

- 5-ton forklift
- Single dowel load $P_c$ = 3,000 lb.

**What if 1/4” or 3/8” thick dowel?**




| | 0-inch offset | 1-inch offset | 2-inch offset | 2-inch (wide) offset |
|---|---|---|---|---|
| EDD | 5,780 | 4,780 | 4,080 | |
| TRAP | 6,540 | 5,860 | 5,240 | 7,420 |
| HEX | 5,930 | 5,090 | 4,600 | |

# Punching Shear Capacity Prediction

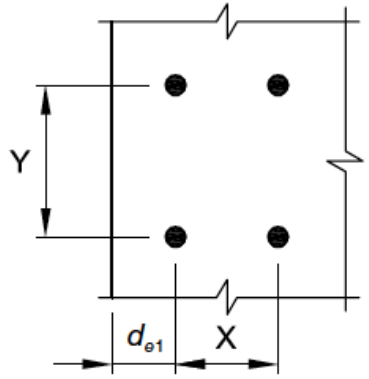
# Shear Punch Prediction Equation - *Adaptation*

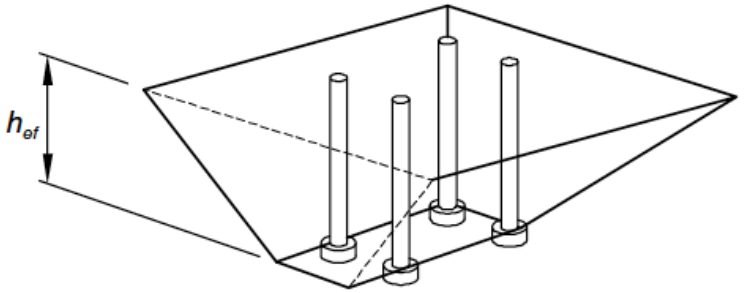
- **PCI Design Handbook** *Precast and Prestressed Concrete* **(2010 – 7th Edition)**
  - Concrete Tension Strength
  - Breakout $\varphi N_{cb}$

$$\varphi N_{cb} = \varphi C_{bs} A_N C_{crb} \Psi_{ed,N} \Psi_{ec,N} \qquad \text{(Eq. 6-3)}$$

$\varphi$ = strength-reduction factor
$C_{bs}$ = breakout strength coefficient
$A_N$ = projected surface area for a stud or group of studs, in$^2$
$h_{ef}$ = effective embedment depth, in
$C_{crb}$ = cracking coefficient
$\psi_{ed,N}$ = edge distance modification factor
$\psi_{ec,N}$ = eccentricity factor

**Case 2: Free edge on one side**

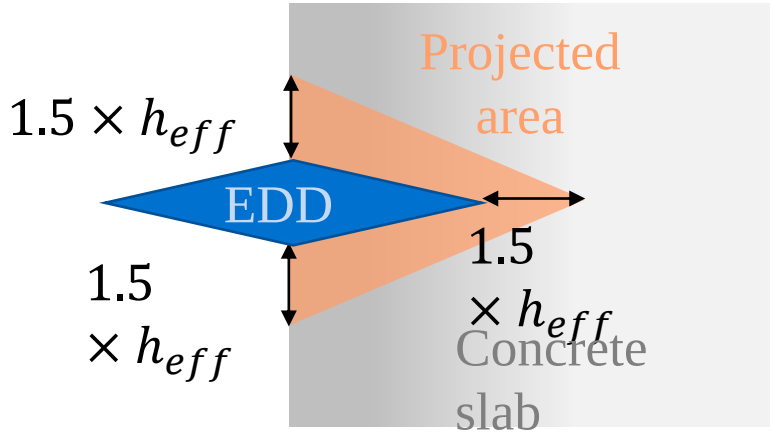


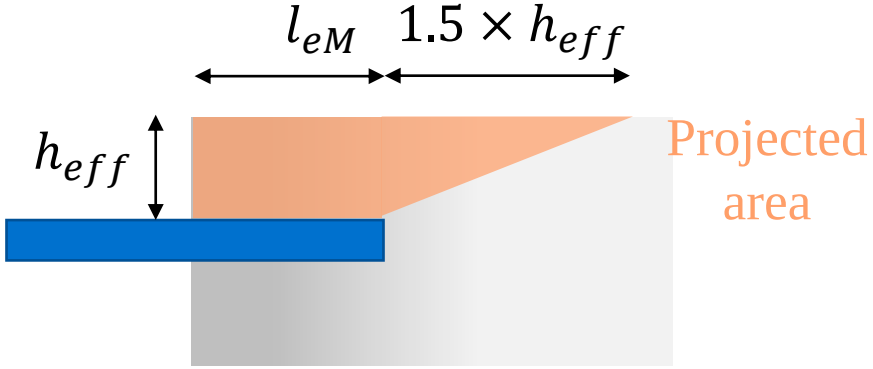
# Projected Surface Area, $A_N$

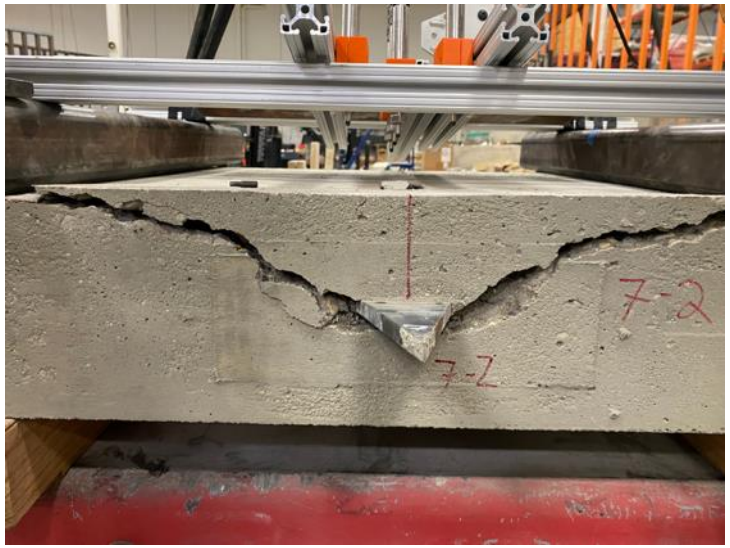
## assume valid for a TPD

***Plan View:***




***Side View:***



# Punch Shear Prediction – 81 specimens - 2017/2021

EDD *2021*

TRAP *2021*

HEX *2021*

TRAP *2017*

DD *2017*

$$\emptyset N_{cb} = \emptyset C_{bs} A_N C_{crb} \Psi_{ed,N} \Psi_{ec,N}$$

$$\emptyset N_{cb} = 2.45 \left(\frac{f'_c}{h_{eff}}\right) \left(2\, h_{eff} l_{em} + h_{eff} b_{eff} + 3 h_{eff}^2\right) \left(\frac{1}{1 + \frac{l_{em}}{9\, h_{eff}}}\right)$$

| Testing Result ID | No. of Tests | Joint Offset Level [in] | Concrete Compressive Strength, $f'_c$ [psi] | Concrete Cover Depth, $h_{eff}$ [in] | Dowel Embedment Length, $l_{em}$ [in] | Effective Dowel Width, $b_{eff}$ [in] | Average Test Punch Shear Capacity [psi] | Predicted Punch Shear Capacity [psi] | Error |
|---|---|---|---|---|---|---|---|---|---|
| E4-7 | 3 | 0 | 4100 | 3.25 | 6.228 | 1.5 | 5780 | 5527 | -4% |
| E4-7-1" | 3 | 1 | 4100 | 3.25 | 5 | 1.29 | 4780 | 5082 | 6% |
| E4-7-2" | 2 | 2 | 4100 | 3.25 | 4 | 1 | 4080 | 4665 | 14% |
| P4-7 | 3 | 0 | 4100 | 3.38 | 5.95 | 1.95 | 6538 | 5787 | -11% |
| P4-7-1" | 1 | 1 | 4100 | 3.38 | 4.71 | 1.855 | 5860 | 5000 | -15% |
| P4-7-2" | 1 | 2 | 4100 | 3.38 | 3.88 | 1.81 | 5239 | 5042 | -4% |
| P4-7-2"w | 3 | 2 (wide) | 4100 | 3.25 | 4.53 | 3.26 | 7420 | 5405 | -27% |
| H4-7 | 3 | 0 | 4100 | 3.25 | 5.65 | 1.85 | 5934 | 5428 | -9% |
| H4-7-1" | 3 | 1 | 4100 | 3.25 | 4.66 | 1.725 | 5092 | 5073 | 0% |
| H4-7-2" | 1 | 2 | 4100 | 3.25 | 3.68 | 1.475 | 4595 | 4654 | 1% |
| P3-6-N-R2 | 4 | 0 | 2083 | 2.72 | 5.28 | 1.75 | 3350 | 3101 | -7% |
| P3-6-N-R3 | 5 | 0 | 4457 | 2.81 | 5.81 | 1.755 | 5034 | 4862 | -4% |
| P3-6-W-R2 | 4 | 0 (wide) | 2250 | 2.88 | 5.89 | 2.525 | 3982 | 3687 | -7% |
| P3-6-W-R3 | 5 | 0 (wide) | 4457 | 2.84 | 6.28 | 2.52 | 5158 | 5222 | 1% |
| P4-8-N-R2 | 5 | 0 | 2083 | 3.81 | 5.3 | 1.97 | 5540 | 4537 | -18% |
| P4-8-N-R3 | 5 | 0 | 5137 | 3.76 | 6.28 | 2.005 | 8135 | 7433 | -9% |
| D2-6-R3 | 5 | 0 | 4650 | 2.94 | 3.1 | 3.125 | 8588 | 8924 | 3% |
| D2-6-P-R3 | 5 | 0 | 5086 | 2.86 | 3.34 | 3.125 | 8588 | 8672 | 1% |
| D3-8-R3 | 5 | 0 | 4911 | 3.81 | 3.2 | 3.125 | 8588 | 8117 | -6% |
| D3-8-P-R3 | 5 | 0 | 5086 | 3.79 | 3.29 | 3.125 | 8588 | 8033 | -7% |
| D6-10-R3 | 5 | 0 | 5168 | 4.63 | 3.26 | 3.11 | 9200 | 8267 | -10% |
| D6-10-P-R3 | 5 | 0 | 5189 | 4.56 | 3.14 | 3.125 | 8588 | 8082 | -6% |

| Error | < 10% |
|---|---|
| 10% < \| Error \| < 20% | |
| 10% < \| Error \| | |

| Average Error: | -4% |
|---|---|

# Findings

# Findings

1. **Offset TPD joints significantly reduce punch shear capacity**

2. **Punching shear in TPDs is sensitive to:**
   - Concrete strength
   - Embedded length
   - Effective width
   - Concrete Cover

3. **TRAP dowels showed highest punching shear**

4. **Single Taper Dowels (asymmetric about joint) retain high punch shear in one end of dowel with offset**

5. **PCI precast/prestressed concrete breakout eqn. successfully adapted for predicting punch shear of TPDs.**

# Thank You

## Questions?

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