

# Shear Behaviour of Fin Plates to Tubular Columns at Ambient and Elevated Temperatures

Mark Jones

*Research Student, University of Manchester, UK*

Dr. Yong Wang

*Reader, University of Manchester, UK*

**EPSRC**

Engineering and Physical Sciences  
Research Council



# Presentation

- Research background
- Current connection design guidance
  - Fin-plate
  - Hollow & concrete-filled tubular (CFT) columns
- Test results
  - Ambient
  - Elevated temperature
- Potential new approach to calculation of connection ultimate strength

---

# Background

- Fin-plate connections a common solution for CFT-beam connections
- Research into such connections not advanced for fire engineering design
- In fire situations catenary action will occur if joints sufficiently robust
- Little current physical data re. such connections to CFTs, especially circular columns

# Eurocode 3 Guidance; Fin-plate under shear and bending

Plate Shear Resistance:

$$V_{pl,Rd} = A(f_y / \sqrt{3})$$

Incorporating plastic moment resistance:

$$M_{V.Rd} = M_{pl.Rd} \left( 1 - \left[ \frac{2V_{Sd,fin}}{V_{pl,Rd}} - 1 \right]^2 \right)$$

And:

$$M_{V.Rd} = V_{Sd,fin} \cdot L$$

# Current Design Guidance for CFT Component

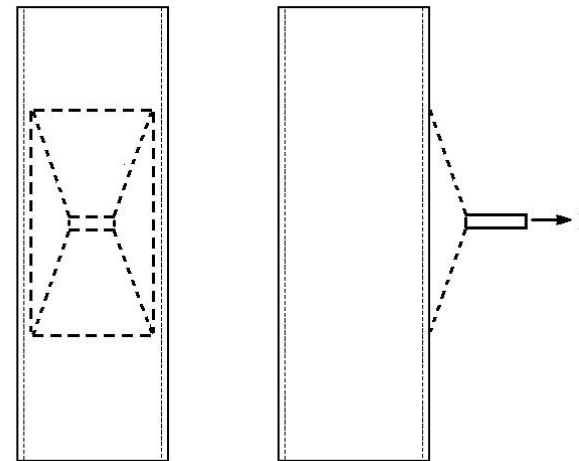
1. Punching shear check

$$t_f < \left( \frac{F_{u,0}}{F_{y,p}} \right)$$

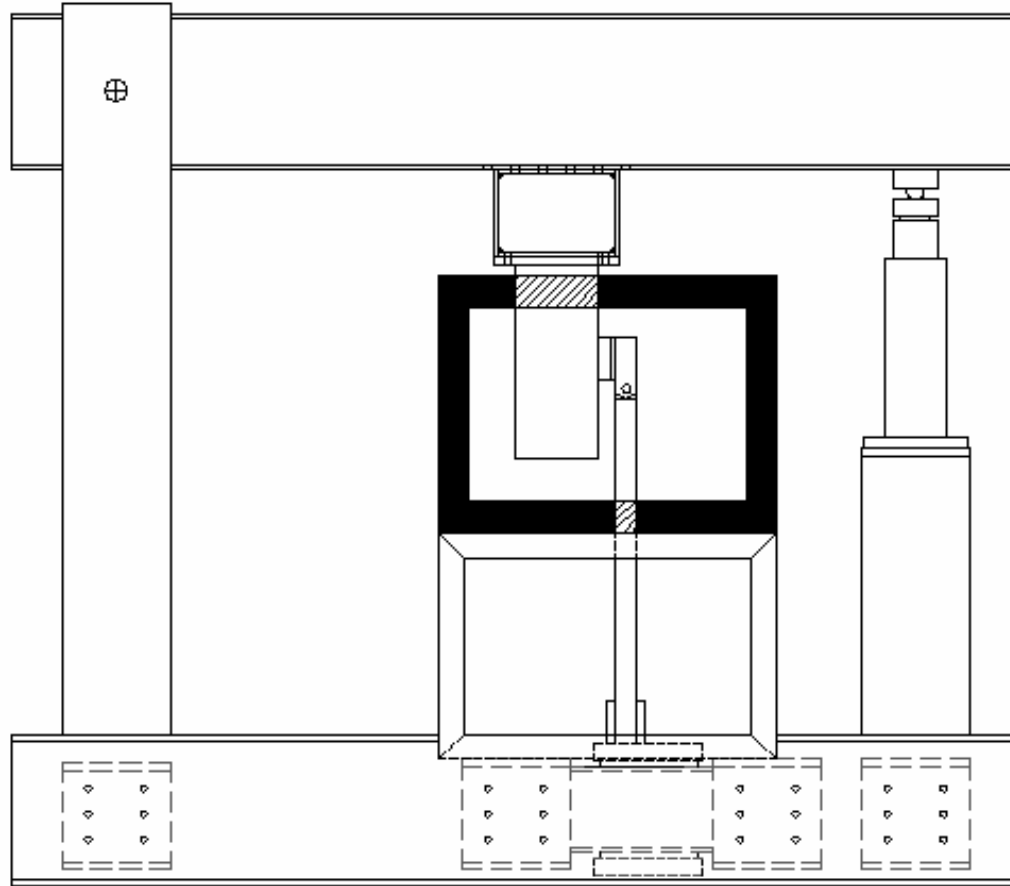
2. Shear yield strength adjacent to welds

$$V_{Sd} \leq 2V_{pl.Rd.local} = 2A_v (f_y \sqrt{3}) / \gamma_{M0}$$

- CIDECT guidance for connections to hollow RHS tubes only
- Hollow tube guidance based on curve-fitted yield line analysis
- Deformation limits imposed
  - $3\%b_0$  for tensile force
  - $\Phi < 0.1$  rad. for bending case



# Experimental Test Program



Test rig

- Specimens represent fin-plate connections under shear and bending force
- Load imparted at one end of rig
- Connection anchored such that rotation allowed
- Electric kiln surrounding specimen used for steady-state tests at temperature

# Test Rig

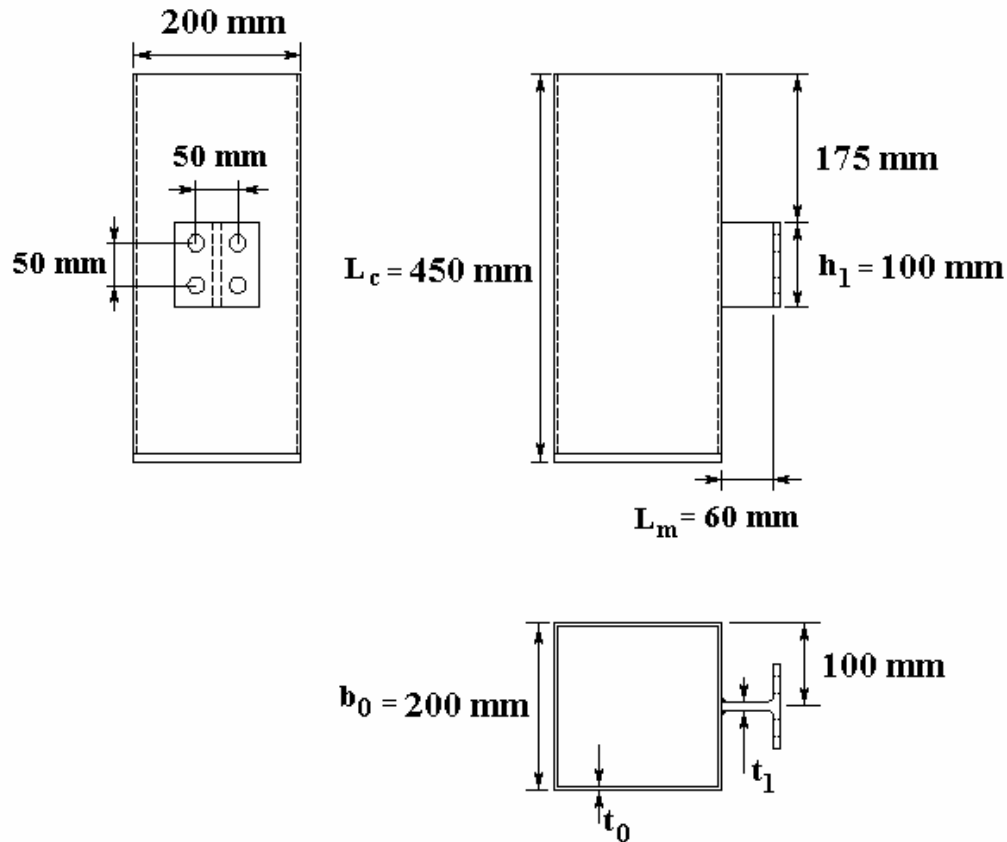


Hinge allows rotation



Roller base allows lateral movement

# Test Specimens



## Specimen classification

- SFS – square concrete-filled sections
- CFS – circular concrete-filled section
- CHS – circular hollow sections
- SHS – square hollow sections

## Other test variables

- Column thickness,  $t_c$ , 5 or 12.5mm
- Fin-plate thickness,  $t_f$ , 6 or 10mm
- Lever arm, 30 or 60mm
- Temperature, 400 - 600 °C

# Failure Modes

Failure mode (a)



Failure of fin-plate due to bending and shear

Failure mode (b)



Tear-out of column face around the weld

# Ambient Test Results

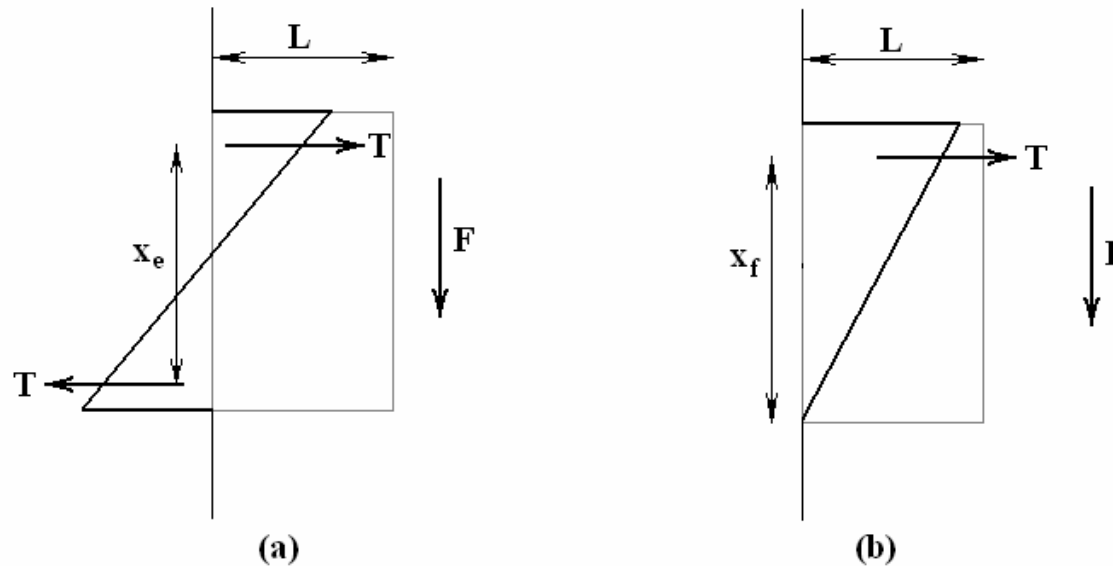
Tests	Difference	Failure mode effect	Load effect
A1 & A5	A1 – CFT A5 – hollow	(a) (b)	36% increase in load due to concrete in-fill
A2 & A4	A2 – CFT A4 – hollow	(b) (b)	28% increase in load due to concrete in-fill
A3 & A4	A3 – $t_f = 6\text{mm}$ A4 – $t_f = 10\text{mm}$	(a) (b)	38% increase in load with thicker fin-plate

# Observations

Considering test pairs 1 & 5 and 2 & 4;

Variable is presence of concrete in-fill...

Idealized strain  
along connection  
length



For a given  $F$ ,  $T$  is less & therefore CFT fails at higher load

# Fin-plate theory alone...?

Test no.	Test failure load, $T_L$ (kN)	Theoretical failure load, $F_L$ (kN)	$T_L/F_L$
A1	94.6	125.3	0.755
A3	92.5	125.3	0.738

- Fin-plate guidance alone insufficient
- Strength of column side is influential re. failure load and mode even if failure mode is in the fin-plate

# Elevated Temp. Test Results

Test No.	Column Type	Temp. (°C)	Column, $t_c$ (mm)	Fin-plate, $t_f$ (mm)	Failure Load (kN)	Failure Mode
T1	CFS	400	5	6	130.7	(a)
T2	CFS	600	12.5	6	51.1	(a)
T3	CFS	600	5	6	49.6	(a)
T4	CFS	500	12.5	6	85.5	(a)
T5	SFS	400	5	6	133.8	(a)
T6	SFS	600	5	6	53.3	(a)
T7	CFS	600	5	10	67.4	(b)
T8	CFS	400	5	10	133.4	(b)

---

# Experimental Conclusions

- A number of tests have been performed upon fin-plate connections to CFT columns under shear load
- Concrete in-fill modifies load transfer mechanism to column face, changing relative strength of column face
- Connection failure mode depends on relative strengths of connection components
- The change in mechanism influences failure load and failure mode

# Referring back...

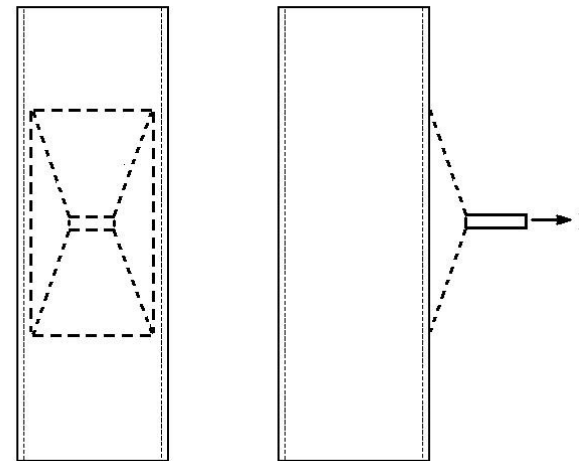
1. Punching shear check

$$t_f < \left( \frac{F_{u,0}}{F_{y,p}} \right)$$

2. Shear yield strength adjacent to welds

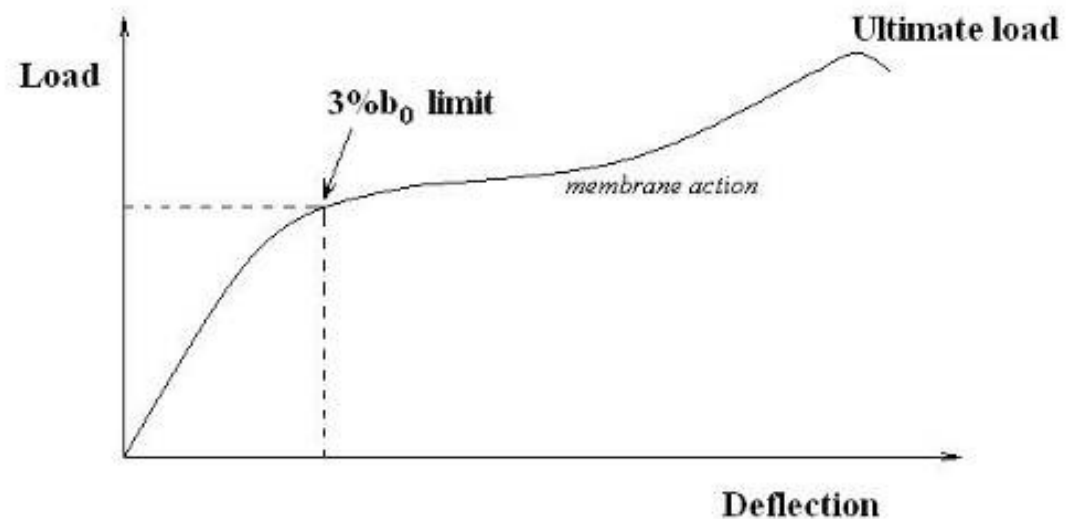
$$V_{Sd} \leq 2V_{pl.Rd.local} = 2A_v (f_y \sqrt{3}) / \gamma_{M0}$$

- CIDECT guidance for connections to hollow RHS tubes only
- Hollow tube guidance based on curve-fitted yield line analysis
- Deformation limits imposed
  - $3\%b_0$  for tensile force
  - $\Phi < 0.1$  rad. for bending case

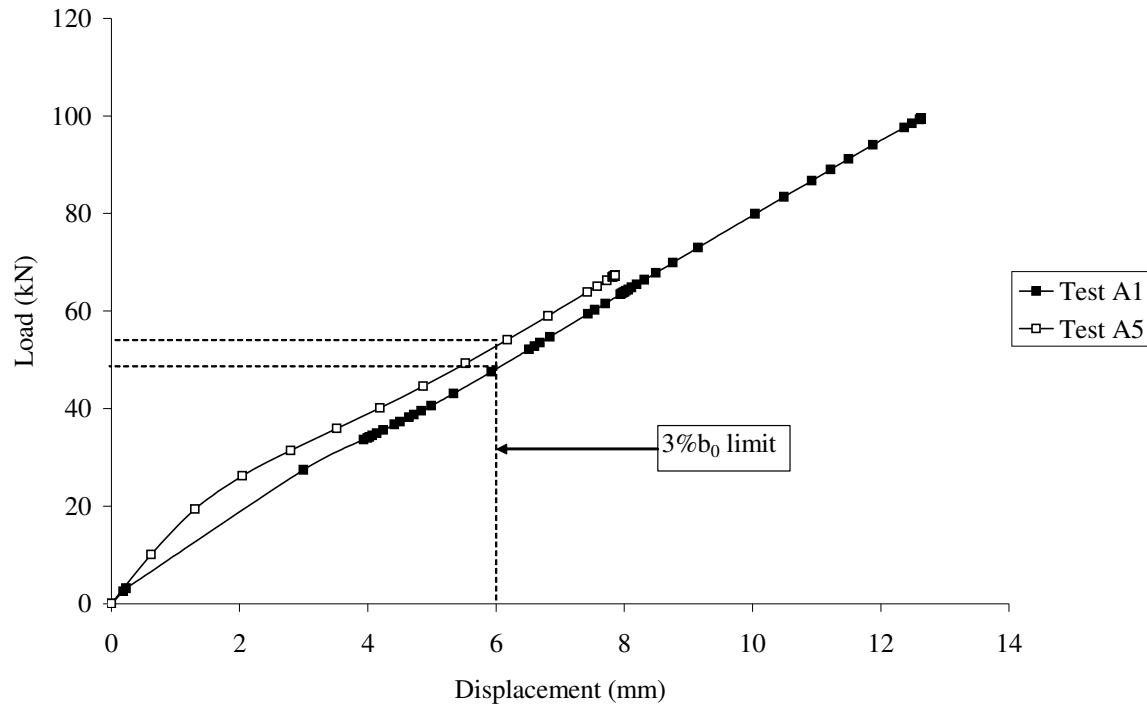


# Shortcomings of current guidance

1. Load at deformation limit calculated, not ultimate load
2. Yield lines may not actually develop
3. Membrane action may result in higher ultimate loads and deformations



# Deformation limits: test examples



A1 – CFT column

- 8 %b<sub>0</sub>
- 0.27 rads.

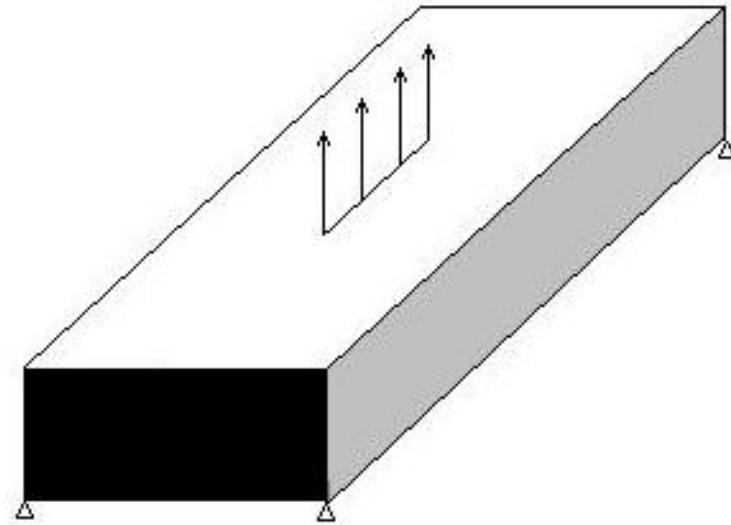
A5 – Hollow column

- 13 %b<sub>0</sub>
- 0.28 rads.

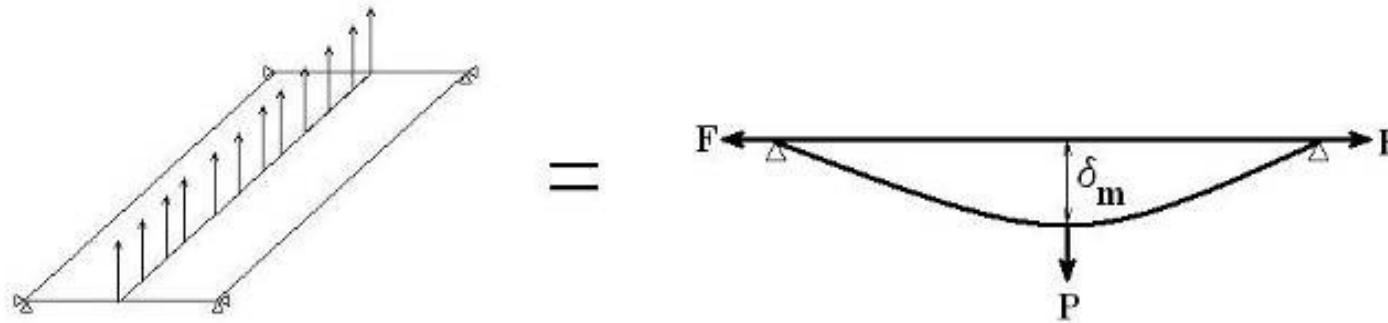
- Failure load greater than that at 3%b<sub>0</sub> limit.
- Connections more robust than current guidance allows for.

# Starting point...

- Simplest loading situation is tensile force only
- Column side walls restricted by concrete in-fill
- Area of column face above and below connection is influential



# Establishing basic principles



$$F \cdot \delta_m = \frac{P \cdot L}{4}$$

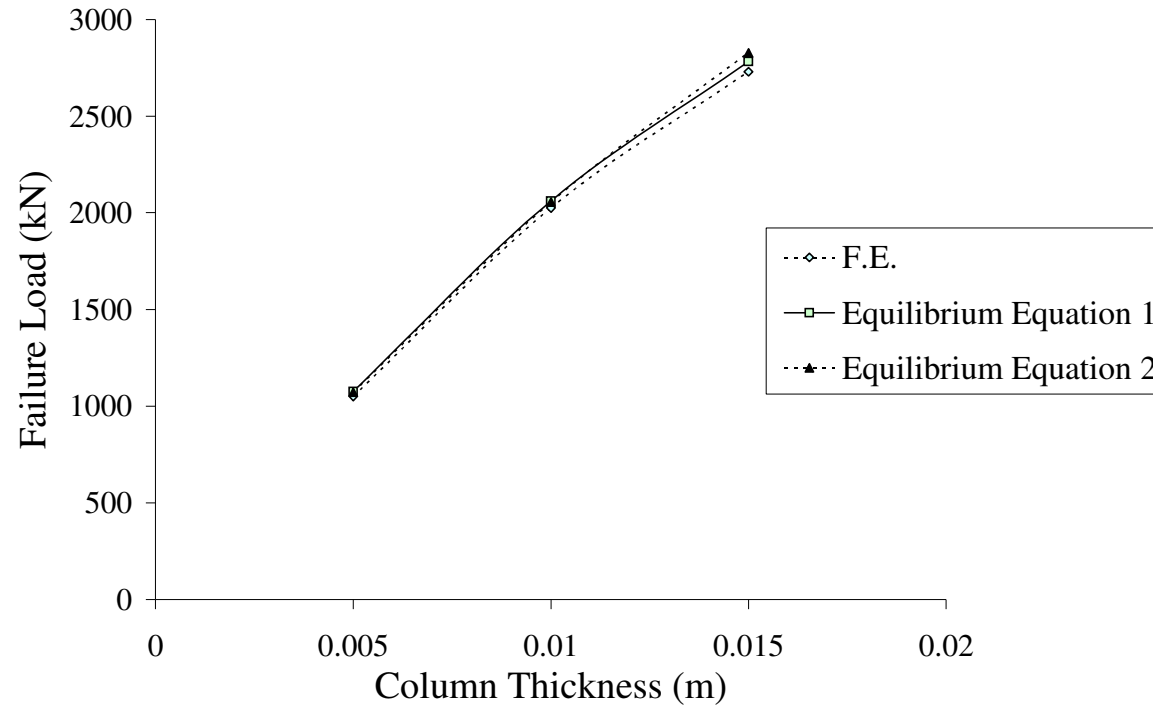
Equilibrium equation

$$2F \cdot \Delta L_m = P \cdot \delta_m$$

Work method

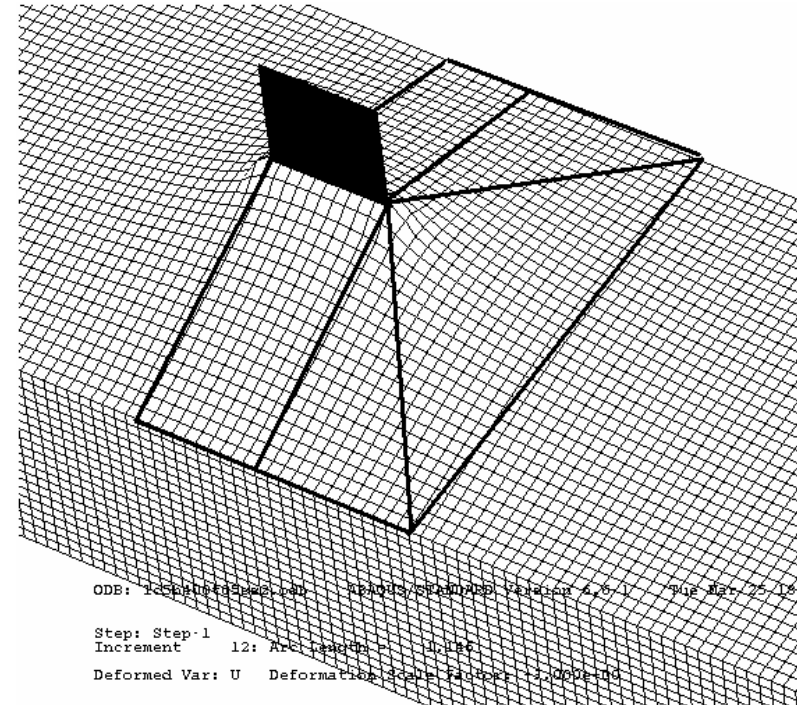
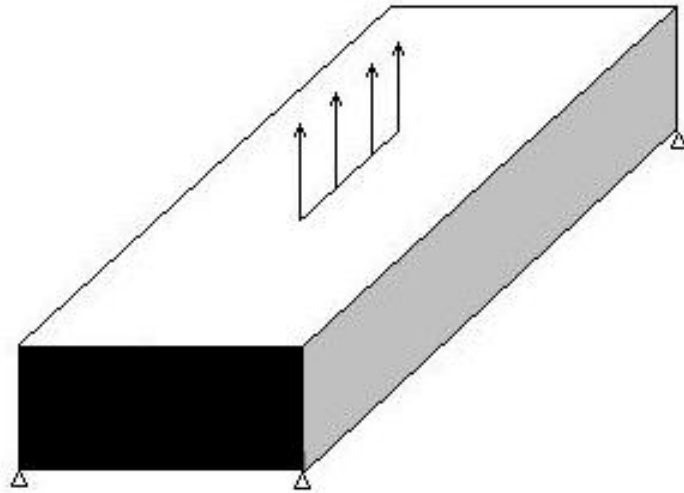
**Derive expression from equilibrium equations  
by treating the plate as beam under point  
load**

# Results for plate only



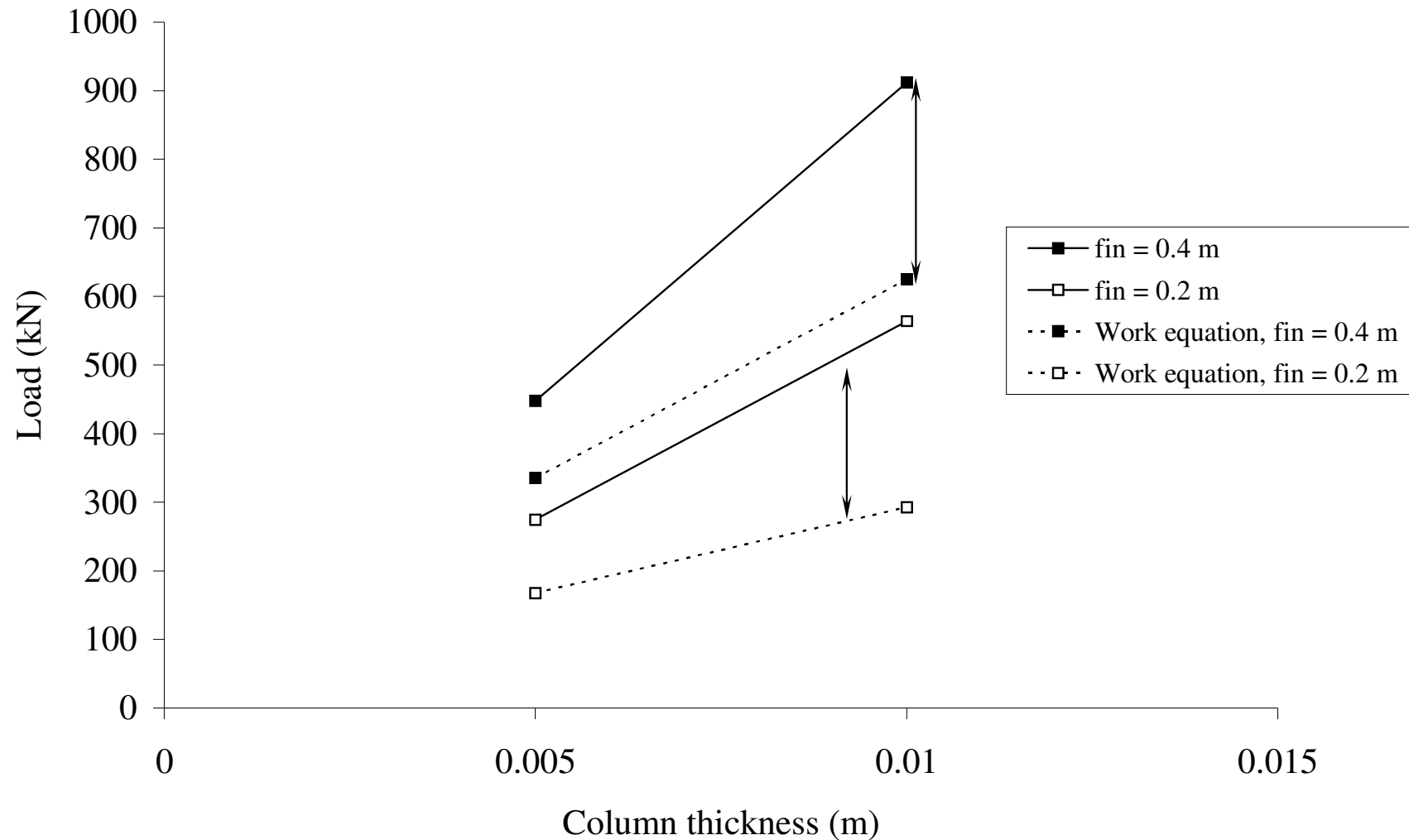
- Equations work well when considering the full-length plate connection
- Work equation is therefore suitable for adoption

# Extension of procedure

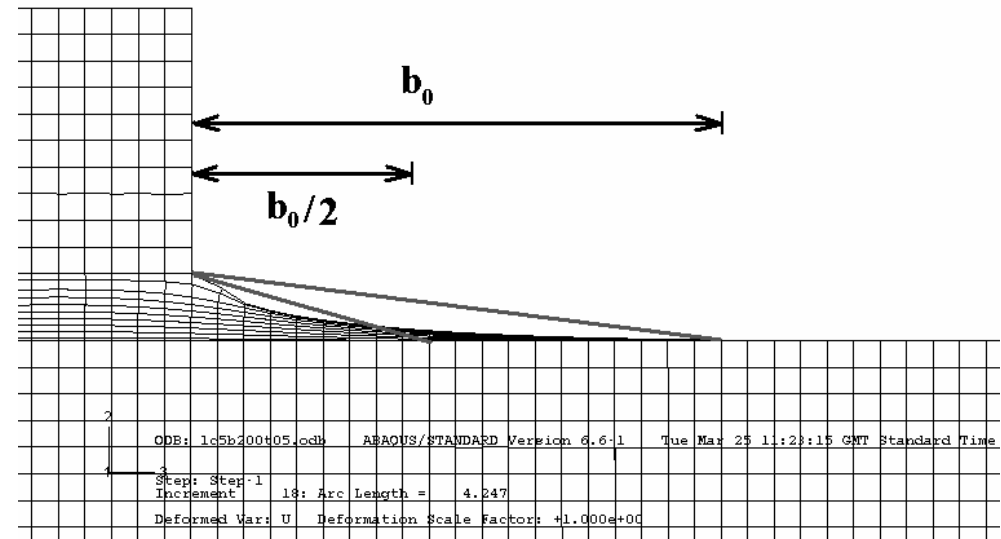
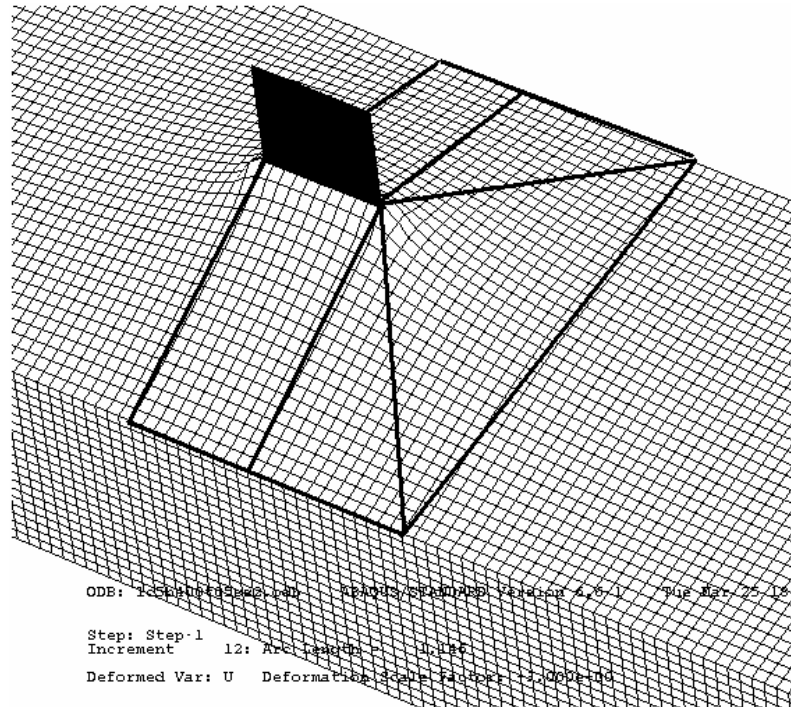


Decide upon deformation mechanism and apply work equation along the lines

# Long columns, short fin-plates...

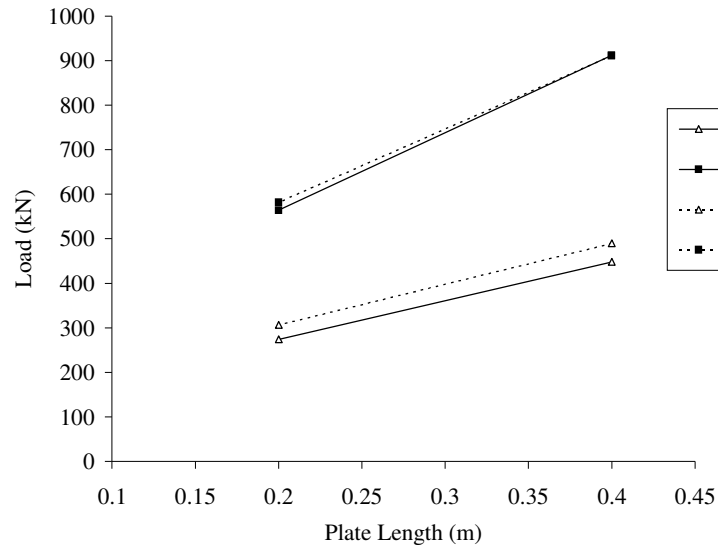


contd. ...

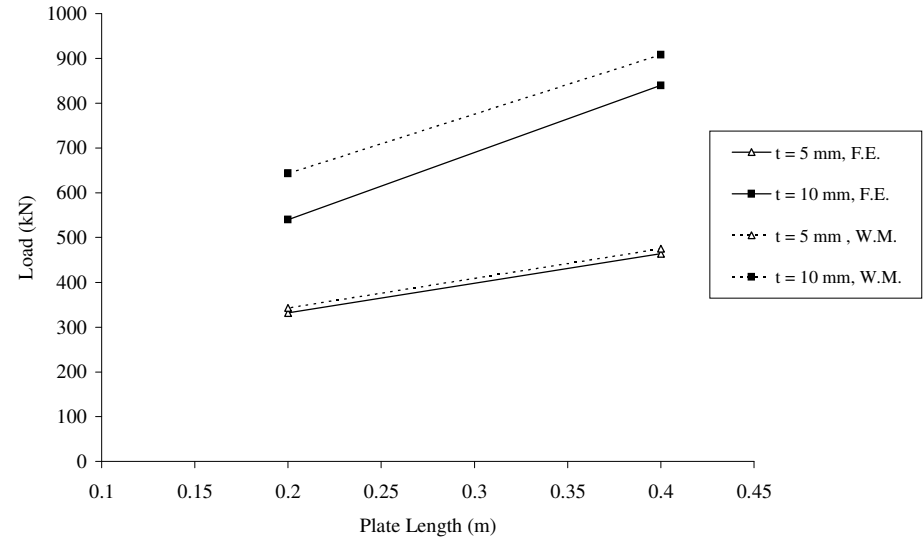


- Zone assumed to extend  $b_0/2$  above and below connection
- Linear internal work force and  $\Delta L$  distributions assumed

# First approximation...



$b_0 = 0.4 \text{ m}$



$b_0 = 0.6 \text{ m}$

- 1<sup>st</sup> approximation is slightly greater than F.E. result
- Estimate of internal work along diagonal yield lines requires revision
- Difference is consistent, indicating method may be correct

---

# Unresolved issues...

- Deflection,  $\delta_m$ , currently obtained from F.E. results
- Internal work distribution along diagonal yield lines requires approximation
- Adapting method to connections under bending and shear force

---

Thank you