IPHA Technical Seminar 2015

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Transmission length and shear capacity in hollow core slabs

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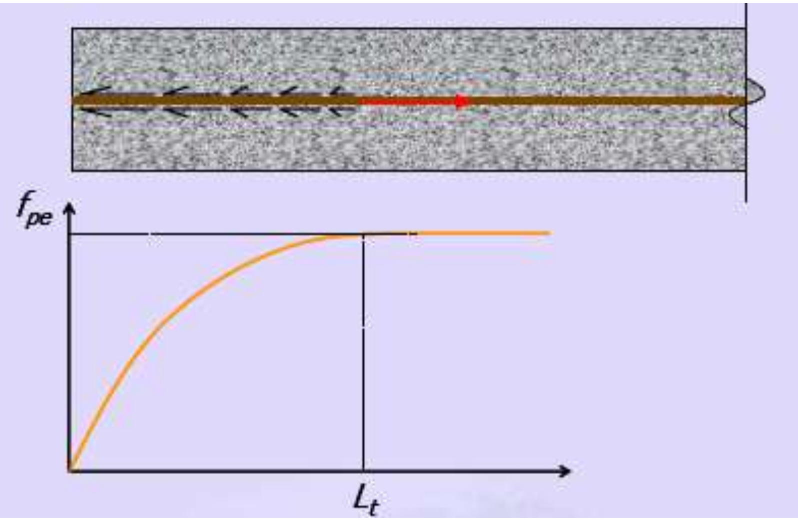
IPHA
INTERNATIONAL PRESTRESSED
HOLLOWCORE ASSOCIATION

in cooperation with
StruSoft

Background

Transmission length L_t is the length required to develop full prestress.



Reduced prestress within this zone reduces shear capacity.

Increased transmission length also extends the region of reduced prestress at holes and notches.

Historical increase in transmission length

CP110 L_t = 30 ϕ for strand

B8110 (C30 cube strength at transfer)
L_t = 44 ϕ for helical strand and L_t = 73 ϕ for indented wire.

EC2 (C25/30 cylinder/cube strength at transfer)
Design length = 1.2 x basic length l_{pt}
l_{pt2} = 70 ϕ for helical strand and l_{pt2} = 110 ϕ for indented wire.

Are these values valid for prestressed hollow core floor units made by slipforming/extrusion and then cut to length?

- Research carried out at Nottingham University in 2010-11 funded by UK PFF (Precast Flooring Federation) and supported by 4 manufacturers
- To measure real transmission lengths L_t and shear capacities $V_{Rd,c}$ in prestressed hcu and present relationship between them

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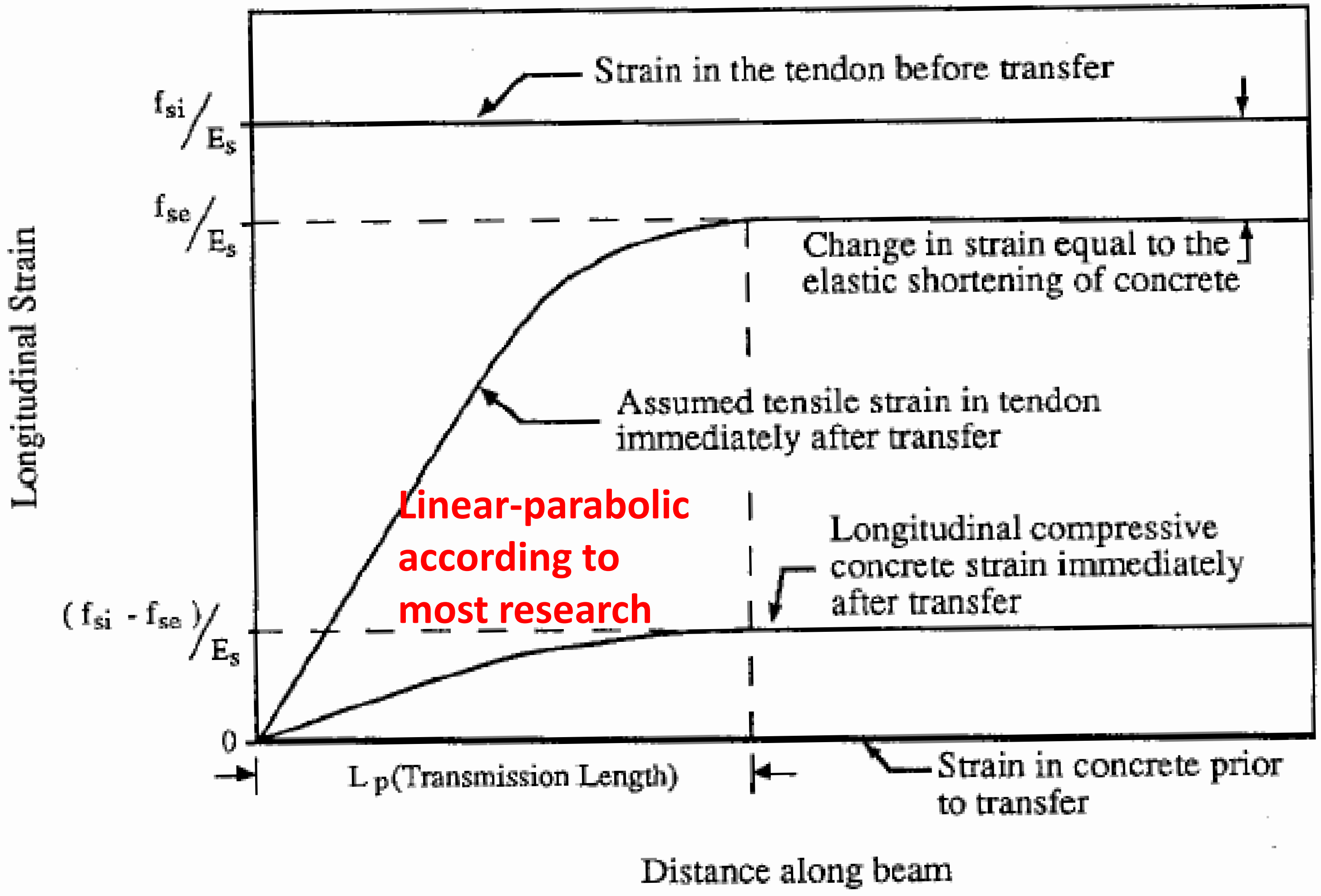
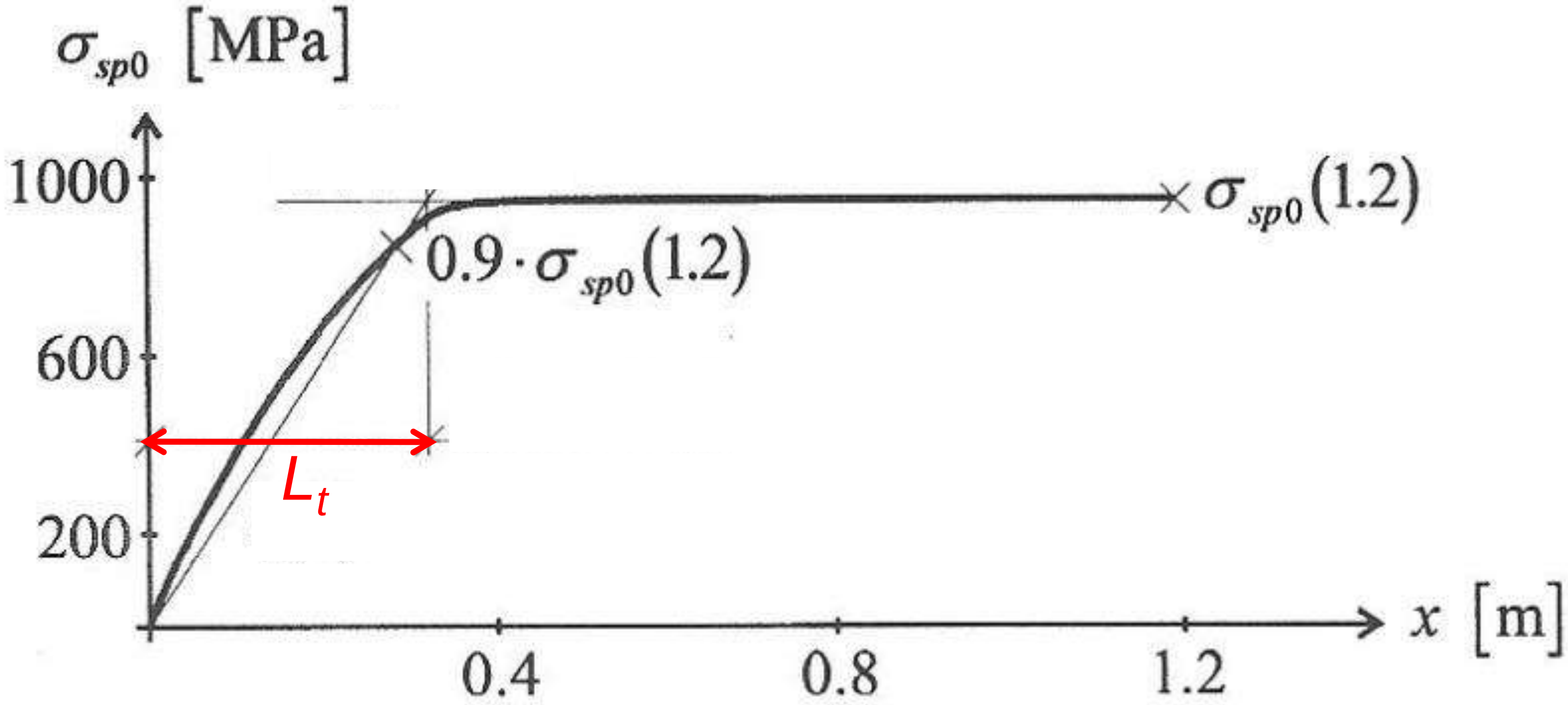
- To measure real transmission lengths L_t and shear capacities $V_{Rd,c}$ in prestressed hcu and present relationship between them
- Definitions and values from some codes
- Experiments: transmission length and shear capacity
- Comparison of tests vs code values
- Modified equation for $V_{Rd,c}$ in terms of L_t



Linear-parabolic according to most research

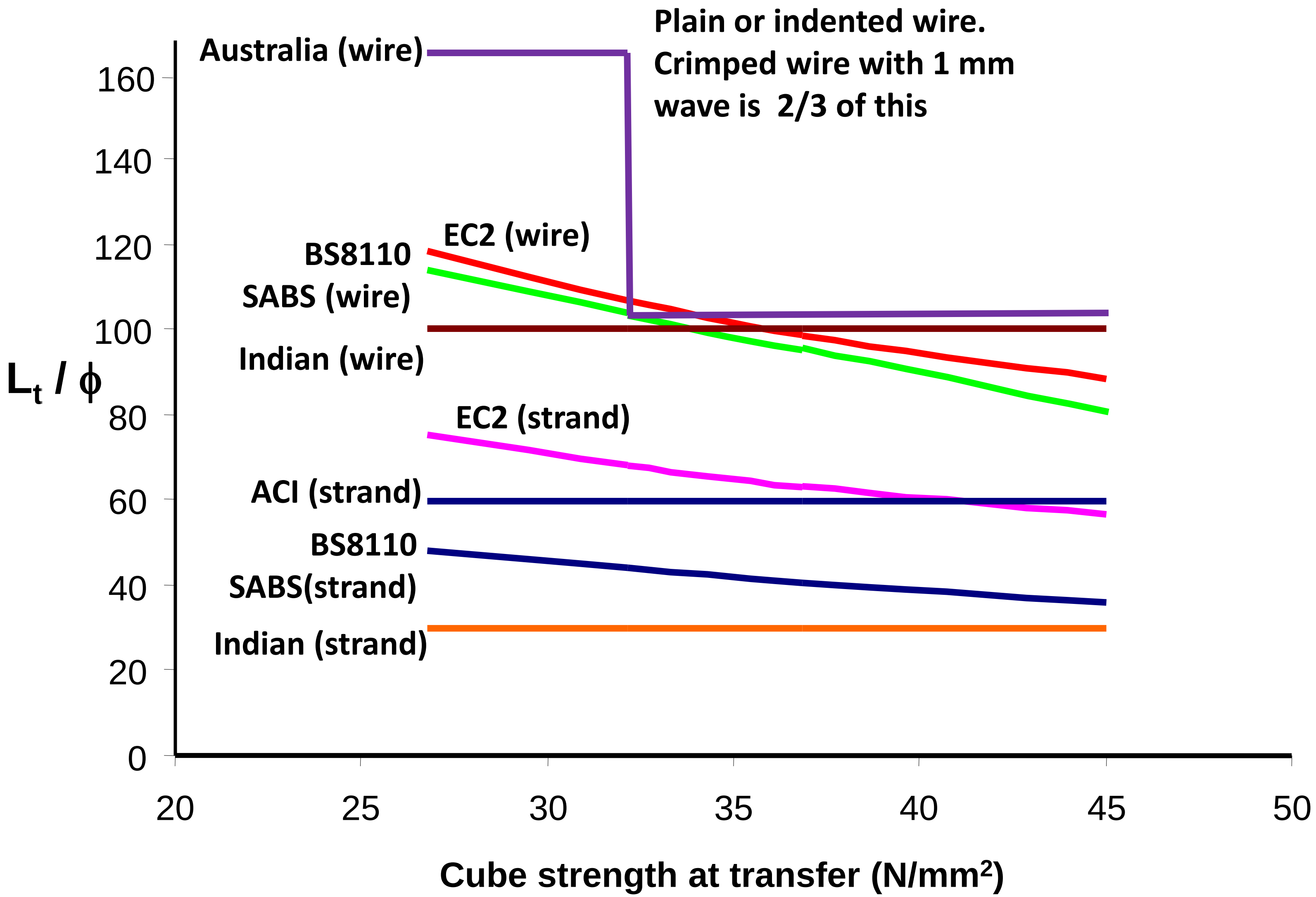
Figure 2.2 Longitudinal Strains in the End Zone Before and Immediately After Prestress Transfer (adapted from Figure 2.11 of Chandler (1984))



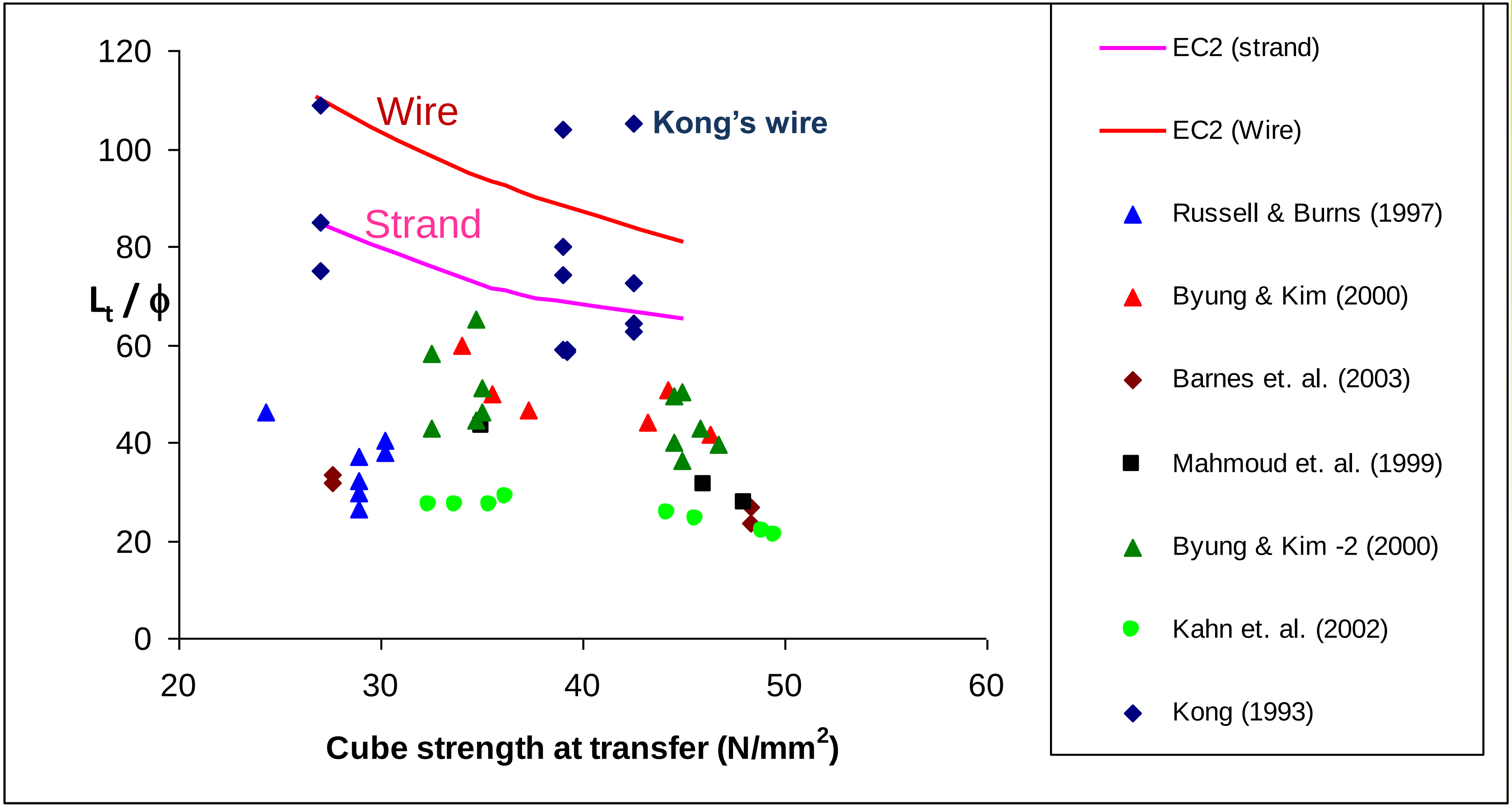
Definition of transmission length

CEB-FIP Guide to Special Design Considerations for Precast Prestressed Hollow Core Floors (1999)

Values from EC2 and other international codes

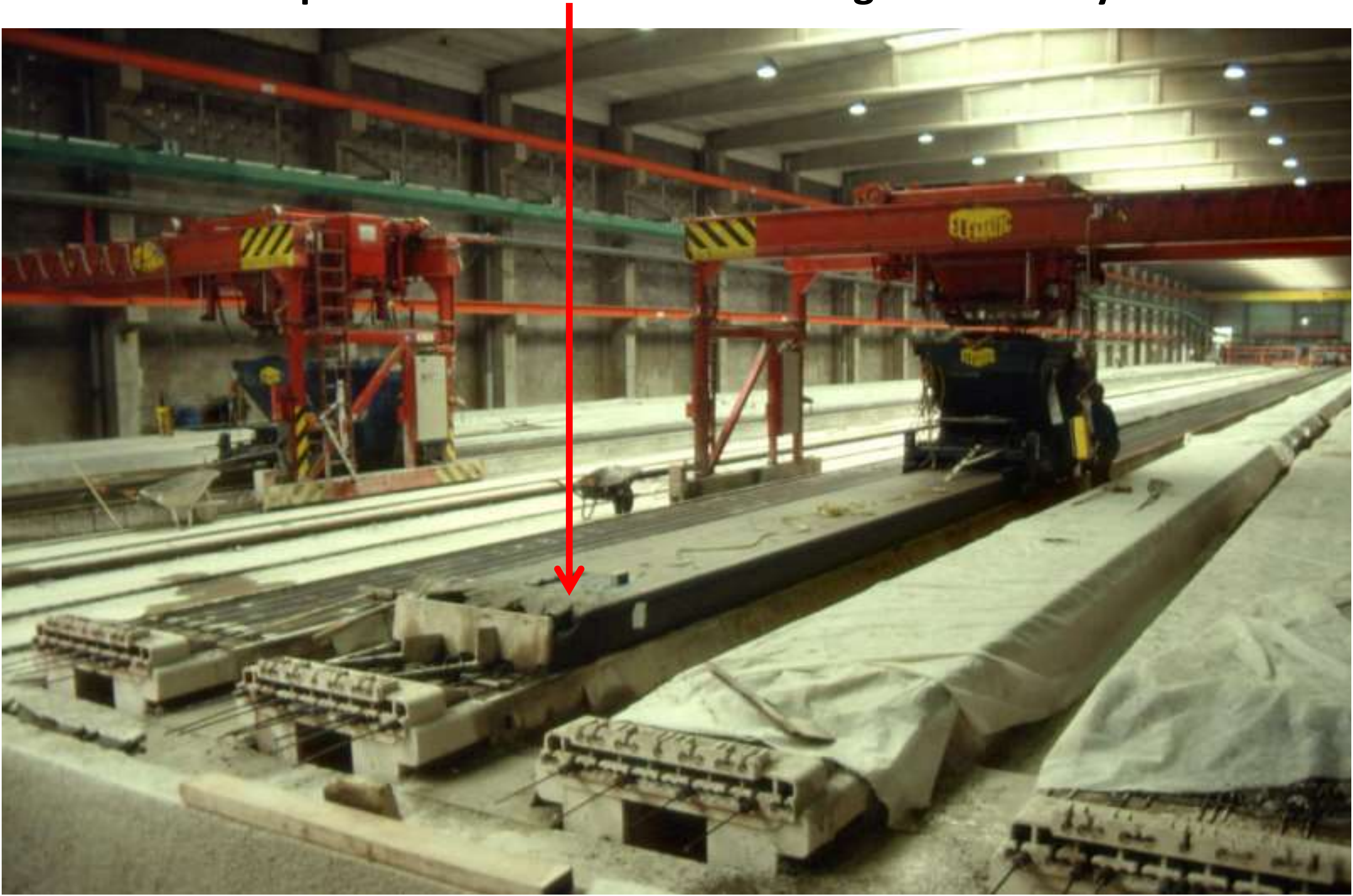

Plain or indented wire. Crimped wire with 1 mm wave is 2/3 of this

Comparison of transmission length with research results shows EC2 exceeds nearly all the data



Cast end *vs*. cut ends.

Are the basic expressions for transmission length for freshly cast ends?



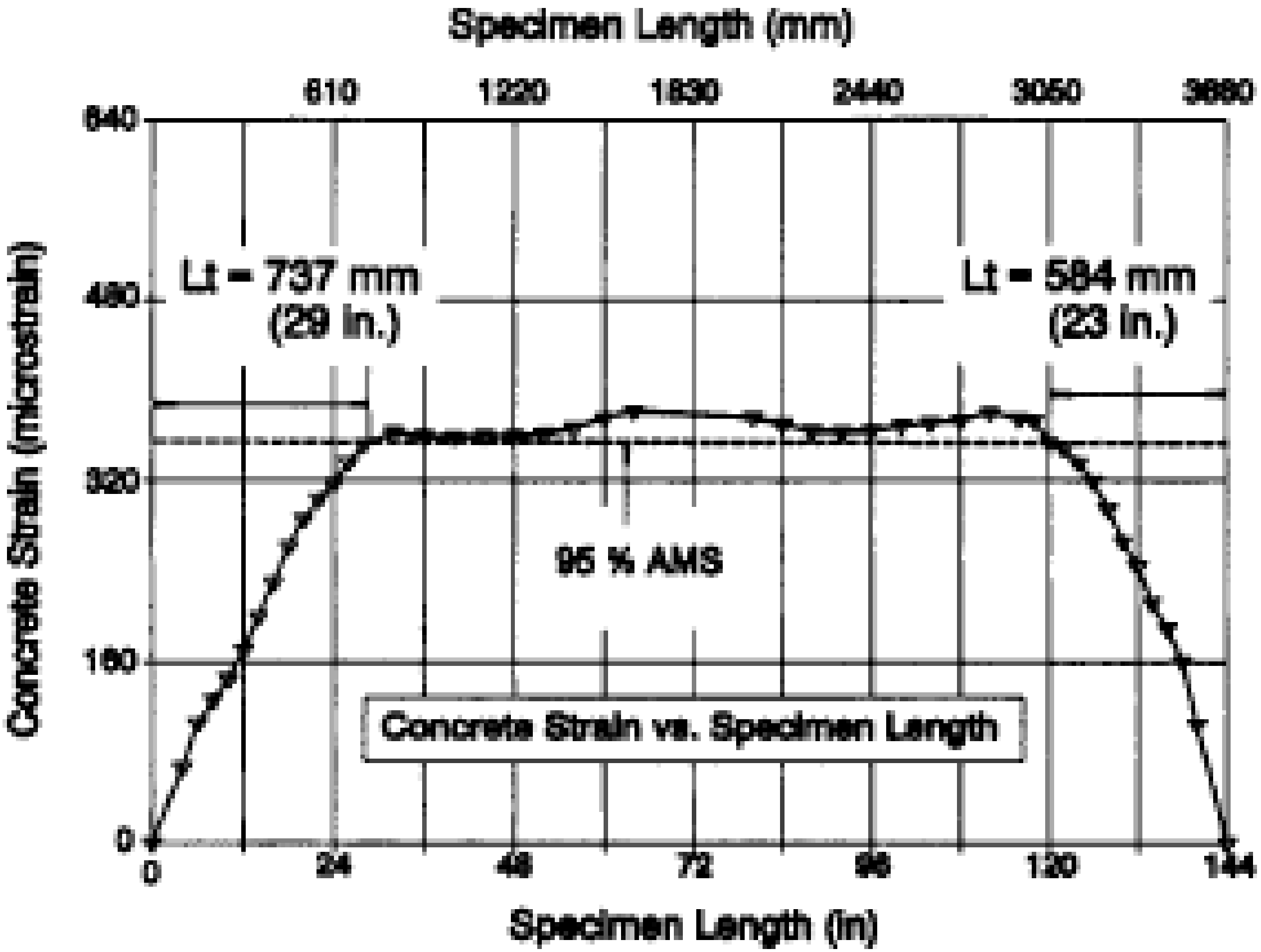
Cast end *vs*. cut ends.

.. or at a cut end where the prestress is interrupted, rather than developing from a cast end?

Cast end *vs*. cut ends.

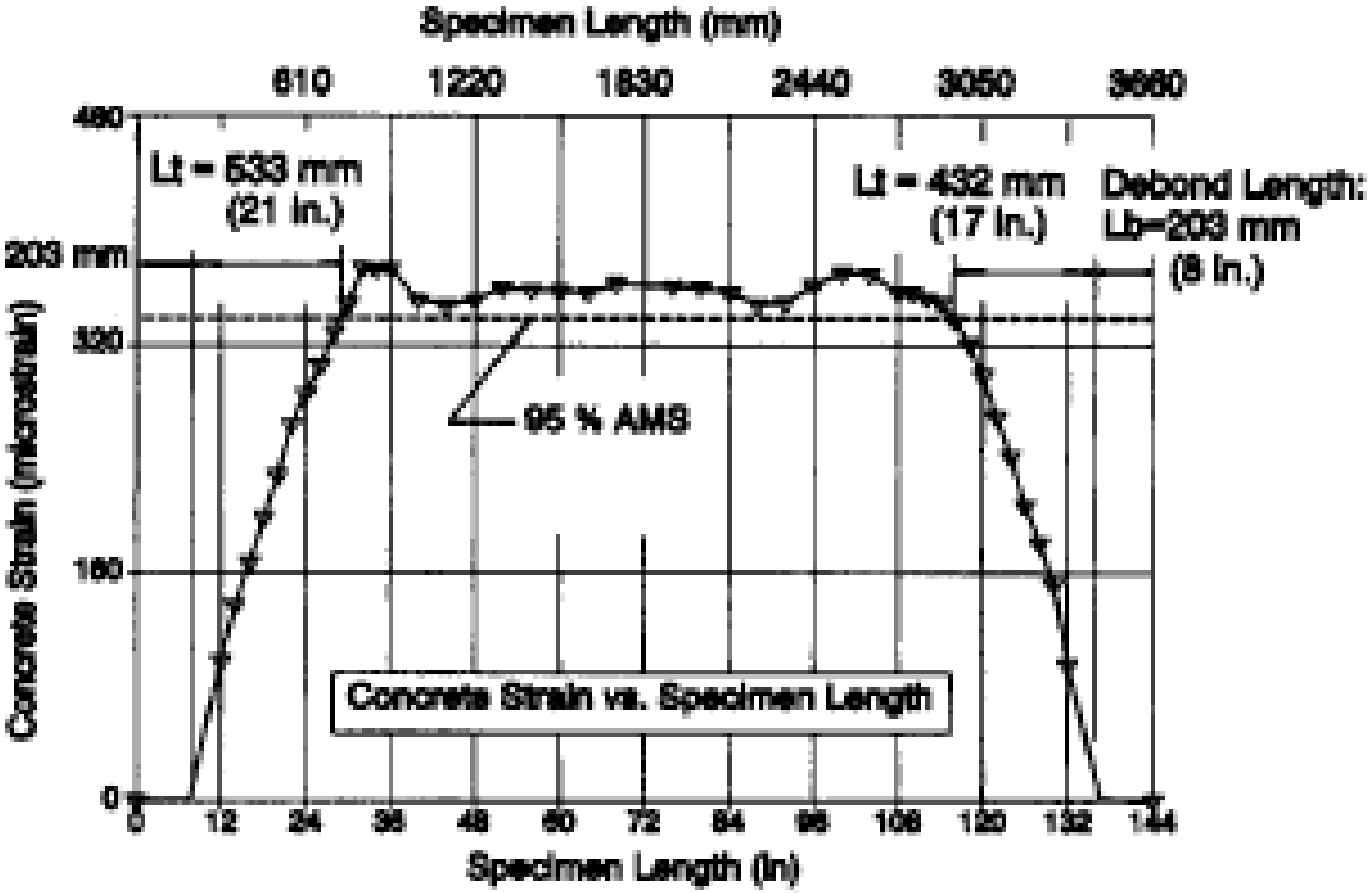
Results from prestressed beams show 26% reduction for cut rather than cast.

Bruce W. Russell *et.al.*, Measurement of Transfer Lengths on Pretensioned Concrete Elements, Journal of Structural Engineering, May 1997.



and a 23% reduction.

Although the exact details are not known, and are certainly not applicable to hollow core slabs, it's worthy of further investigation.



Experimental programme

To : measure L_t in hcu using 5 mm, 5 and 7 mm wire, and 9.3 mm strand

To : compare results with “basic” values, i.e. using actual material and geometric data, without PSF

To : compare with EC2 design values

To : L_t in T beams (from beam and block floors) 5 mm wire with ‘cast’ and ‘cut’ ends

To : ultimate load test in shear

To : correlate shear capacity with L_t

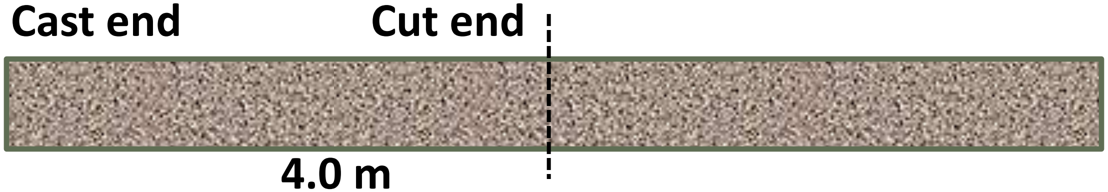
To : determine a value of L_t that will give same basic shear capacity as in tests, and use this to propose a reduction factor for L_t in the EC2 equation for shear capacity

Hollow core slabs 4.0 m long x 600 mm wide x 150 mm deep

Tarmac Precast – 5 mm wire (W)
Coltman Precast – mixed 5 and 7 mm wire (M)
Creagh Concrete – 9.3 mm strands (S)

Cast T beams were 4.0 m long x 135 mm wide x 225 mm deep

Hanson Building Products – 5 mm wire (TB)

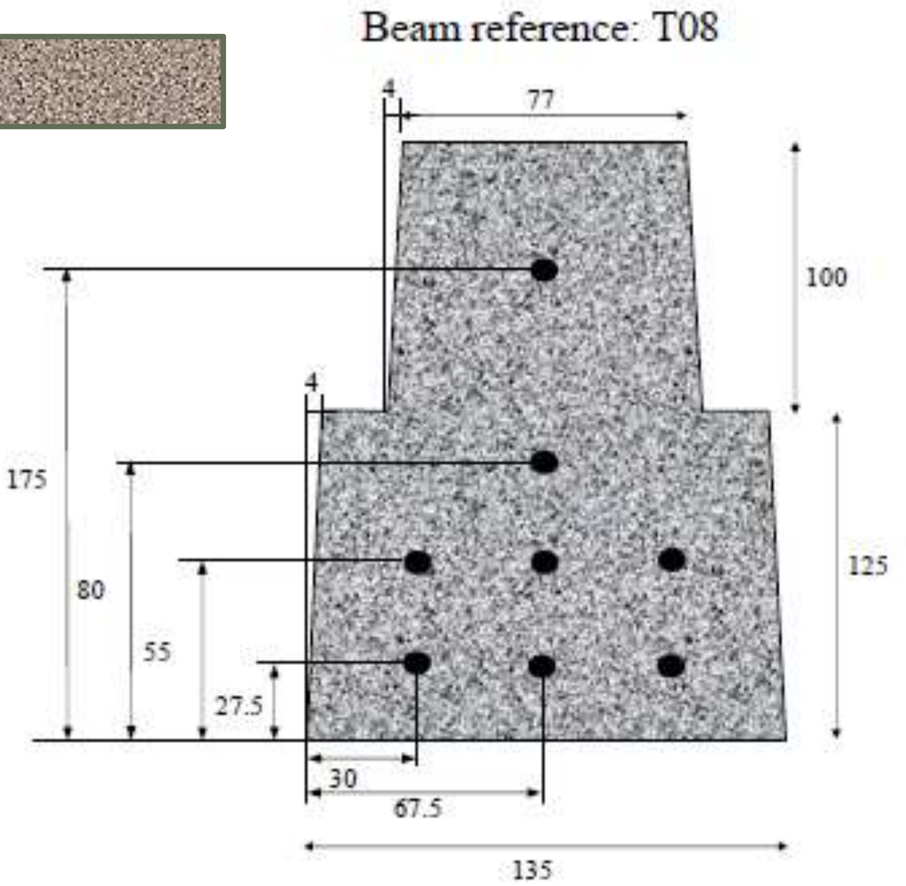


Cast end

Cut end

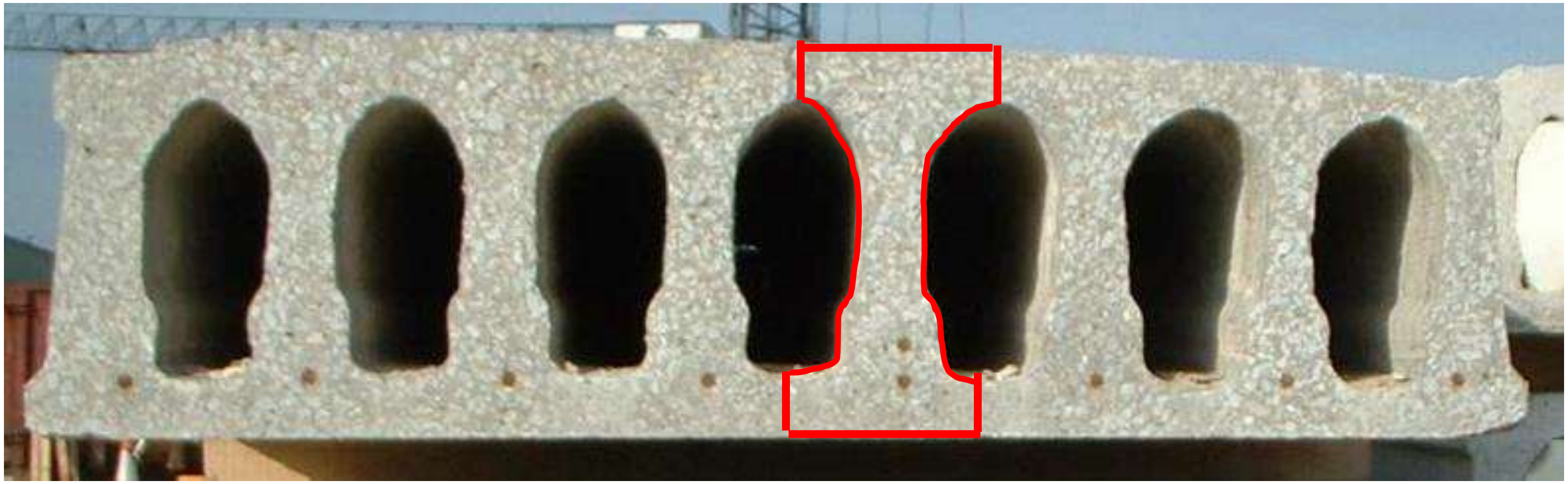
4.0 m

8.0 m as cast



X-beams were 4.0 m long x 100 mm wide x 150 mm deep, longitudinally cut from 600 mm wide hollow core

Coltman Precast Ltd. 7 and 5 mm wire (X)



1 no. 7 mm wire and 1 no. 5 mm wire

Step 1

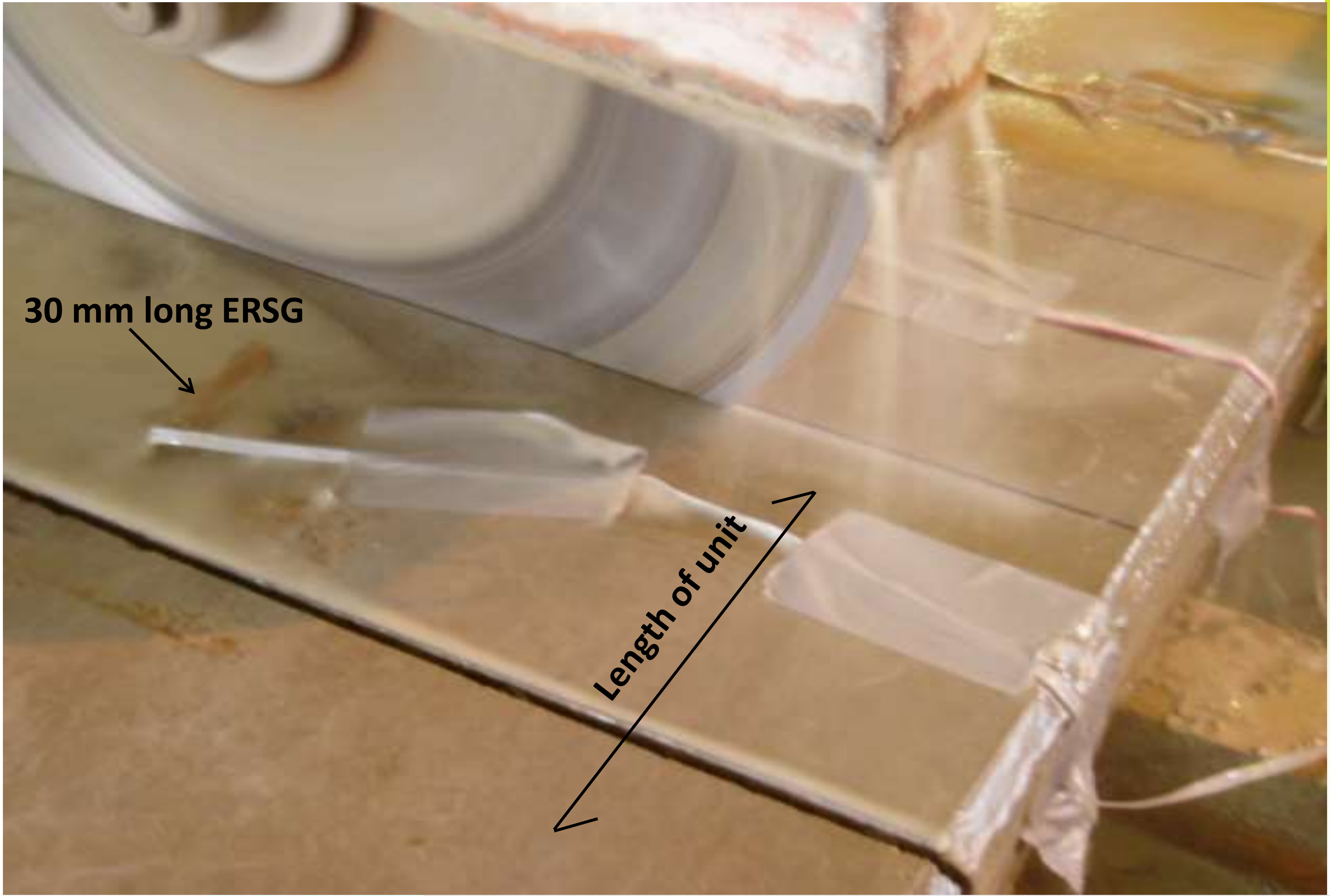
Transmission length was measured using the "trepanning" method.

Attach strain gauges to the soffit of the units.

Distances = 300, 450, 600, 750 and 900 mm.

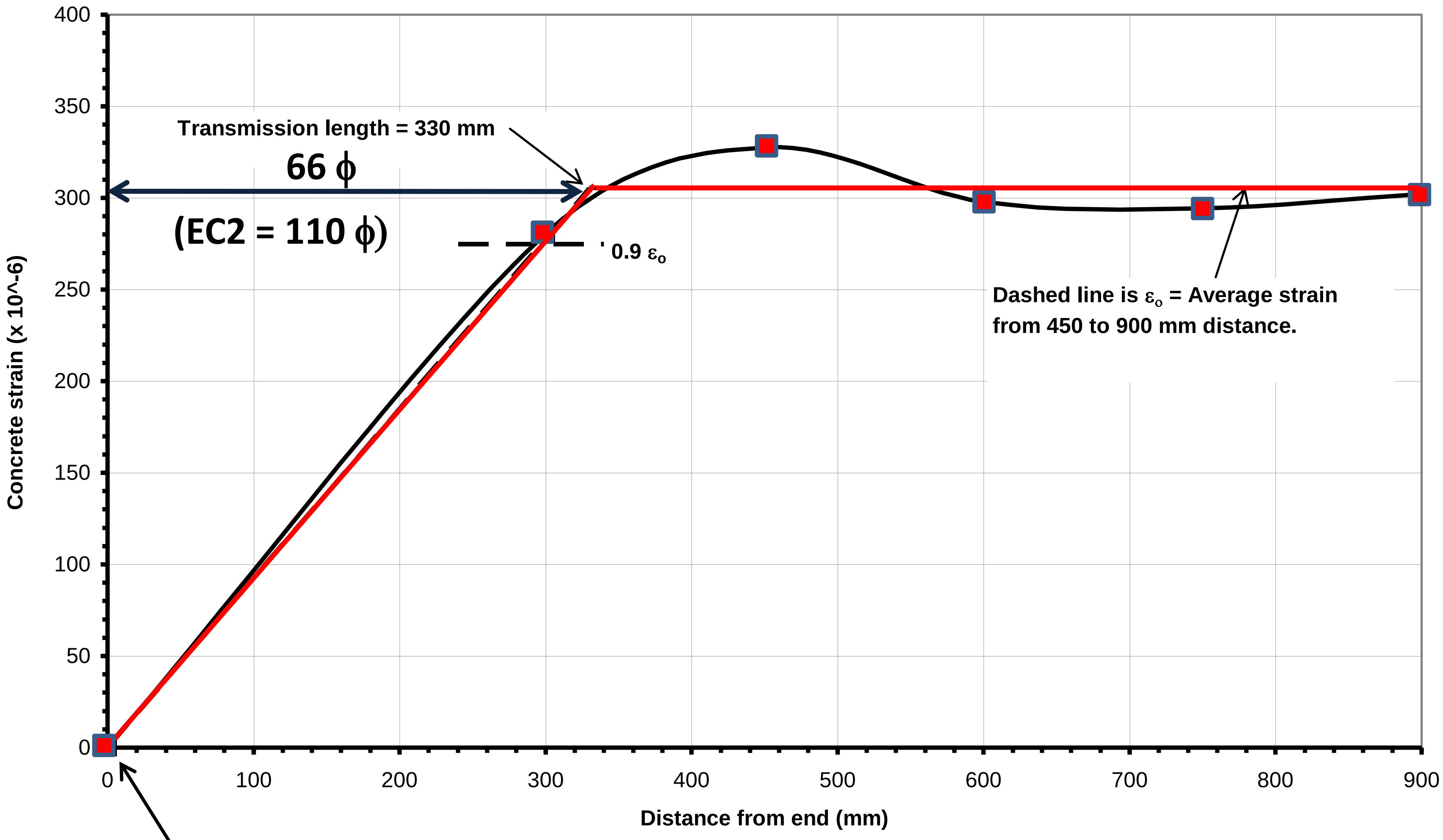
Cut the gauges out, thus releasing the pre-strain, and measure the difference.

Plot the strain profile and deduce L_t using the CEB-FIP 90% rule.



1 hour relaxation and take the readings

Transmission length for hollow core with 5 mm wire - HCU W1



Transmission length = 330 mm

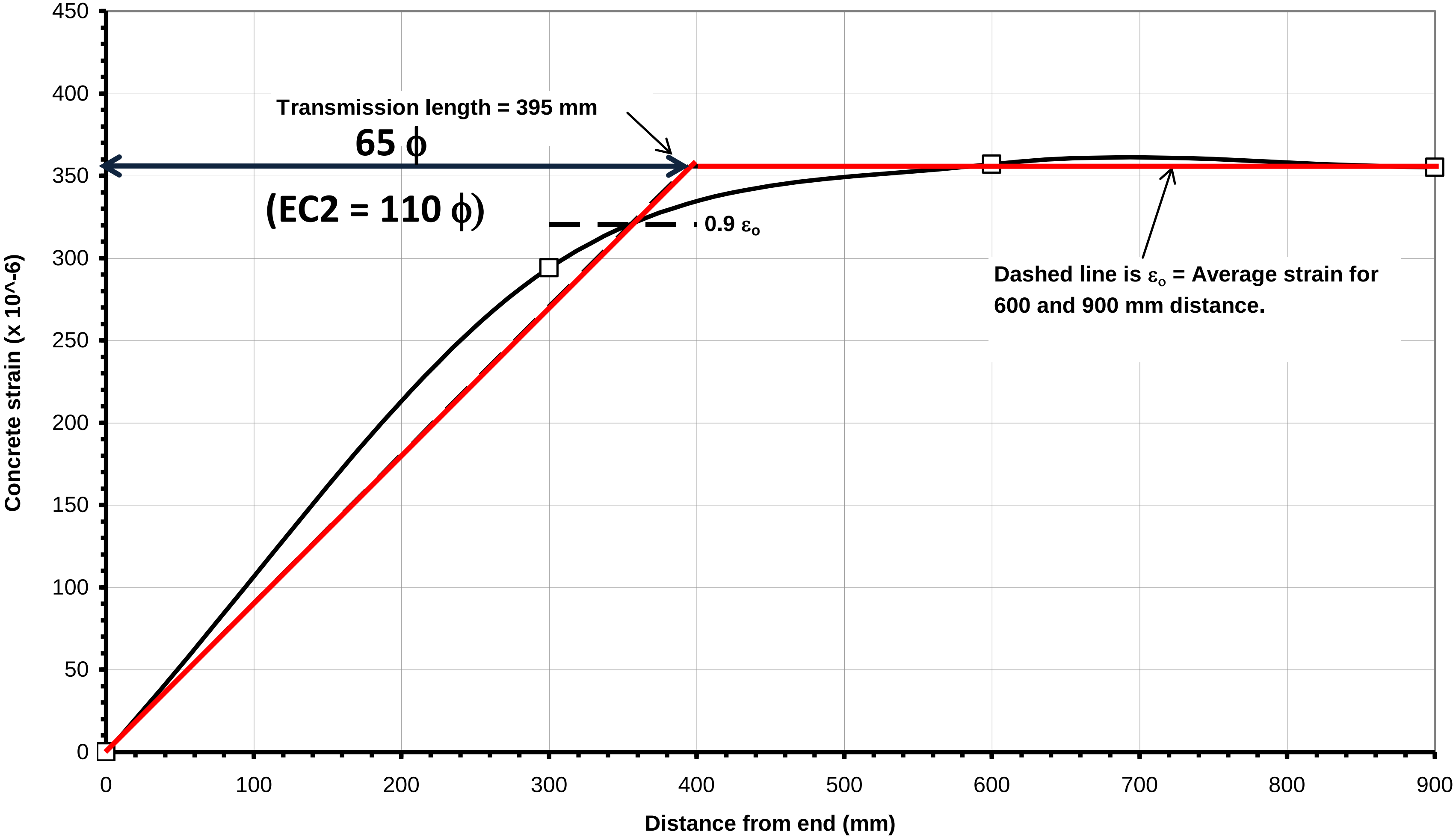
66 ϕ

(EC2 = 110 ϕ)

Dashed line is ε_o = Average strain from 450 to 900 mm distance.

Assumed zero, though it may have a small strain at the end ?

Transmission length for hollow core with mixed 7 and 5 mm wire - HCU M2



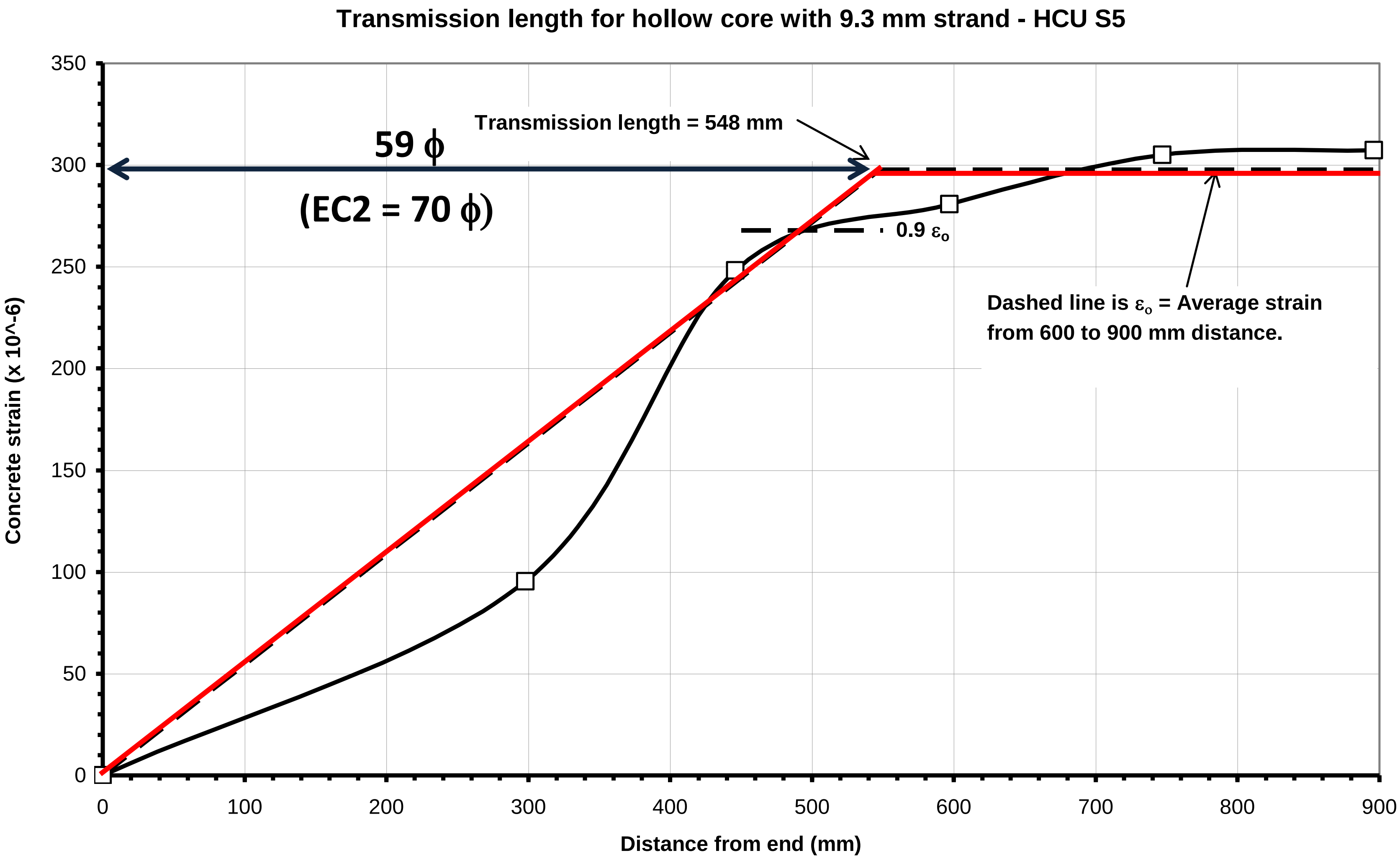
Transmission length = 395 mm

65 ϕ

(EC2 = 110 ϕ)

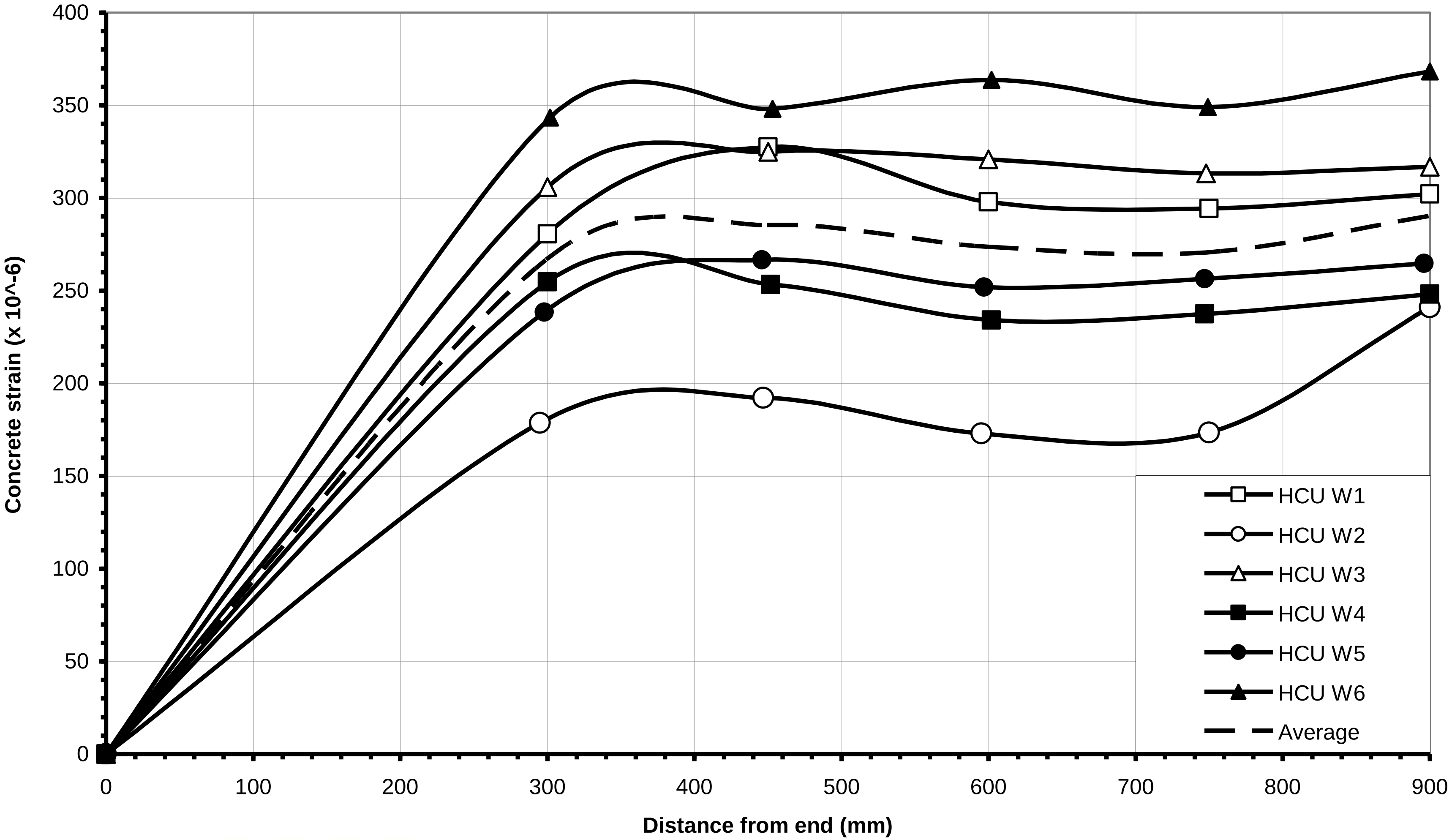
0.9 ε_o

Dashed line is ε_o = Average strain for 600 and 900 mm distance.

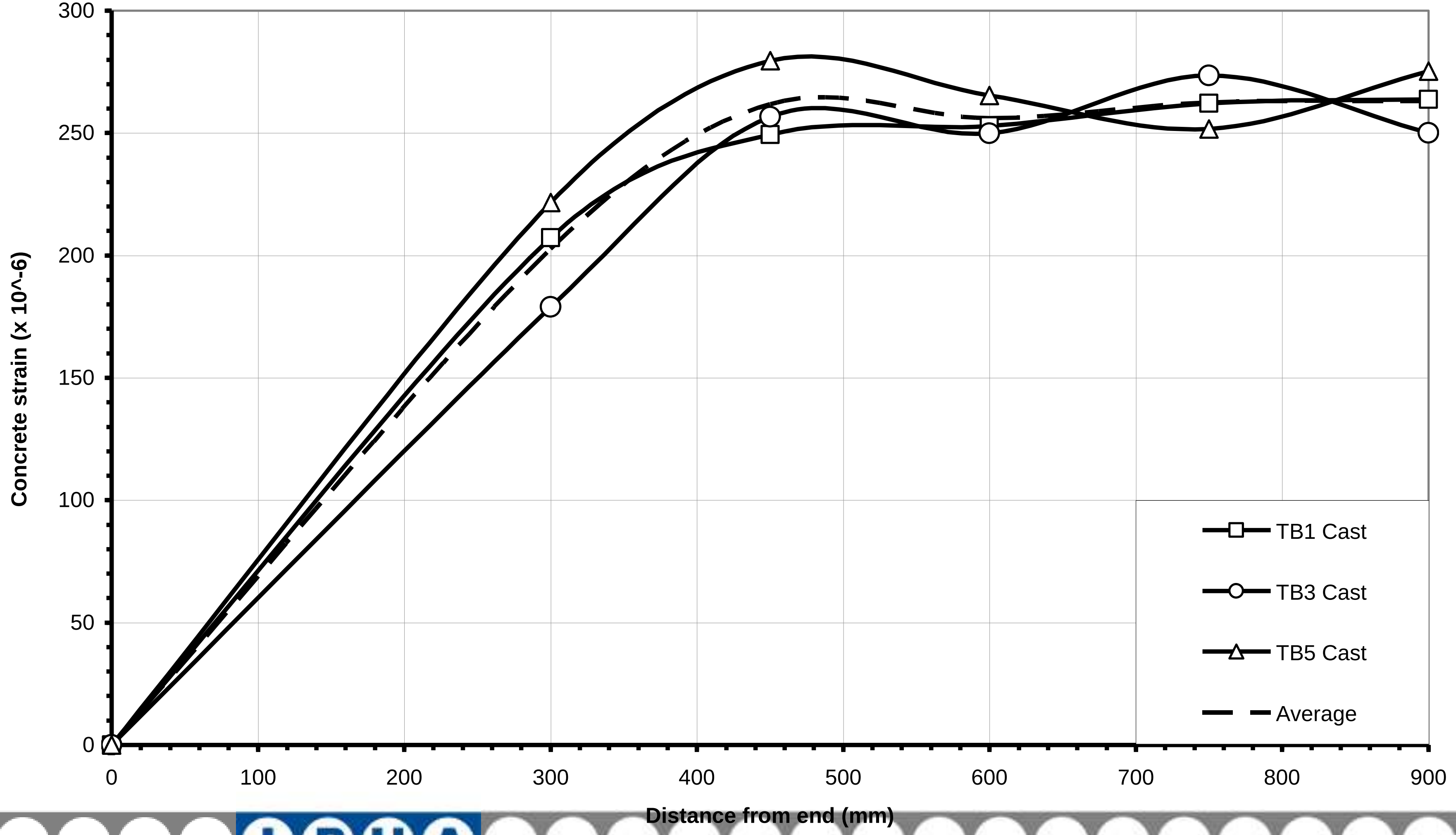


More difficult to obtain strain output and reliable data

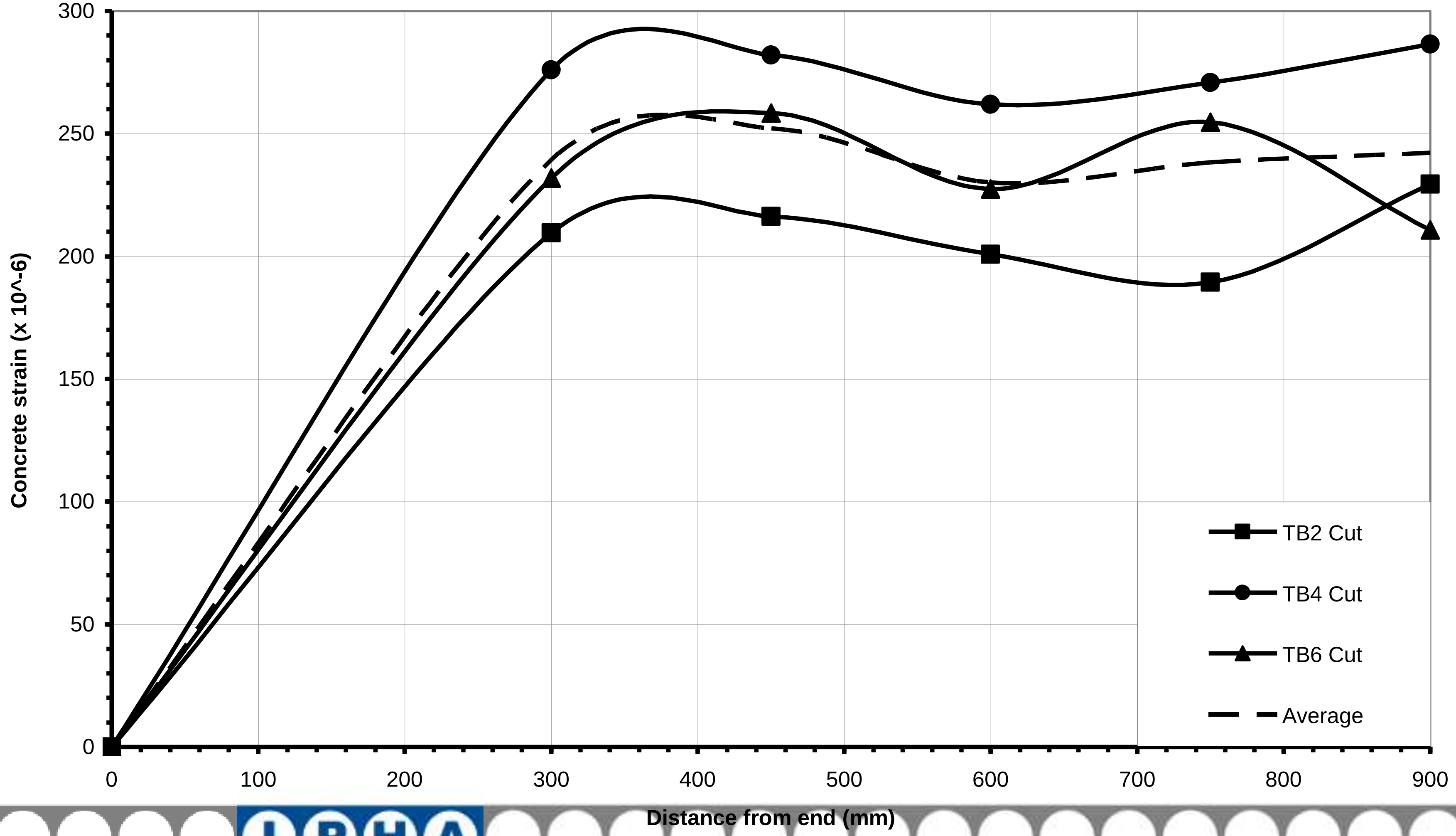
All results for 5 mm wire slabs.
Wide variation in strain output, but consistency in transmission length, 56 ϕ to 65 ϕ , mean = 62 ϕ



T beams with cast ends.
Transmission length mean = 80 ϕ



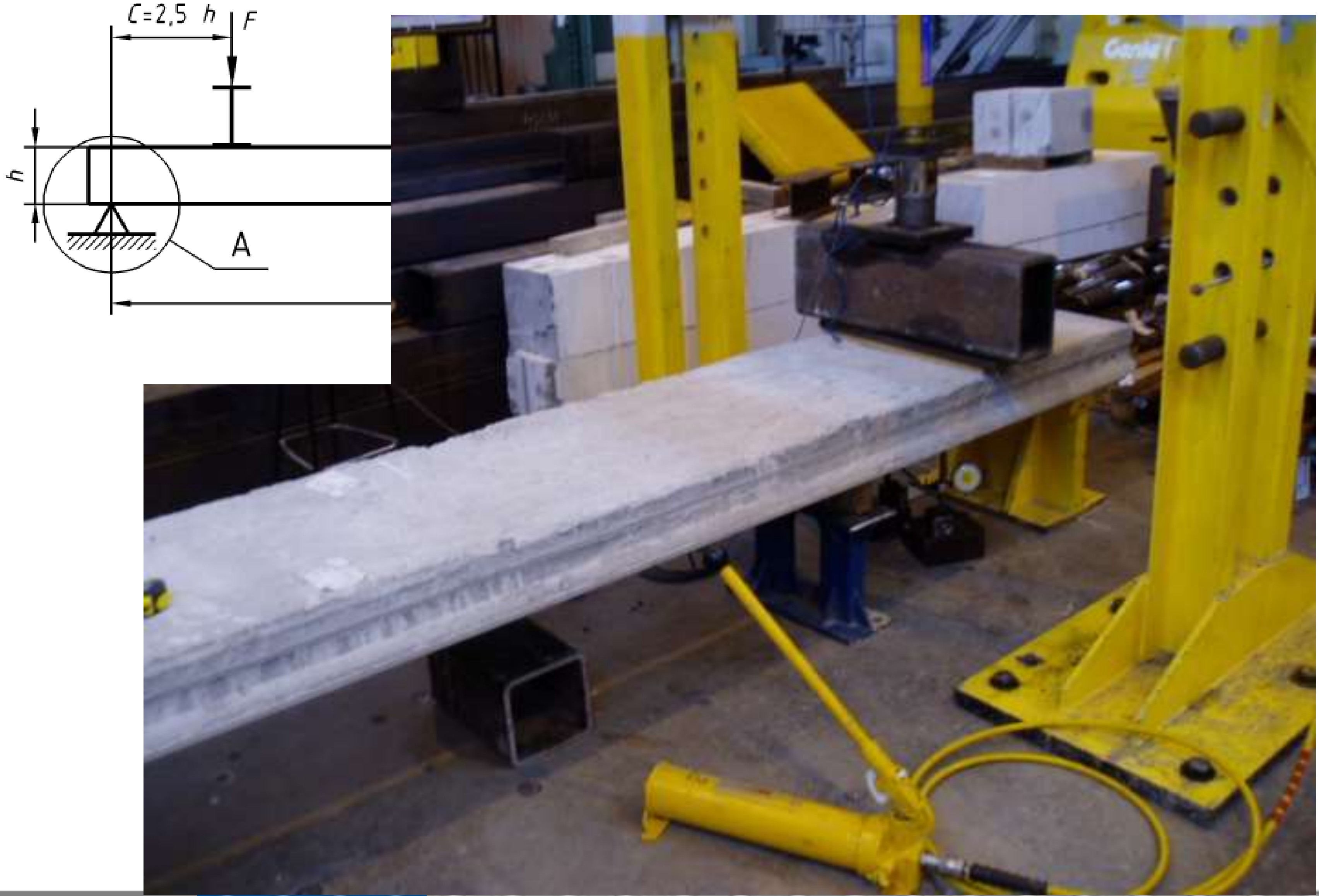
T beams with cut ends.
Transmission length mean = 59 ϕ
26% reduction



Unit type	Test L_t mm	L_t / dia ratio	Basic L_{pt} mm	Design L_{pt2} mm	Ratio L_t / L_{pt}	Ratio L_t / L_{pt2}
Hollow core 5 mm wire	313	63	317	618	0.99	0.51
Hollow core mixed 7 and 5 mm wire	380	63	346	593	1.10	0.64
Hollow core 9.3 mm strand	491	53	338	611	1.45	0.80
T beams 5 mm wire	347	69	286	520	1.21	0.67
X beams mixed 7 and 5 mm wire	369	62	340	593	1.09	0.62
Averages of transmission ratios					1.16	0.65

Transmission length values and ratios

Step 2 – ultimate shear tests to EN1168, Annex J




48
47
22.3
11.5

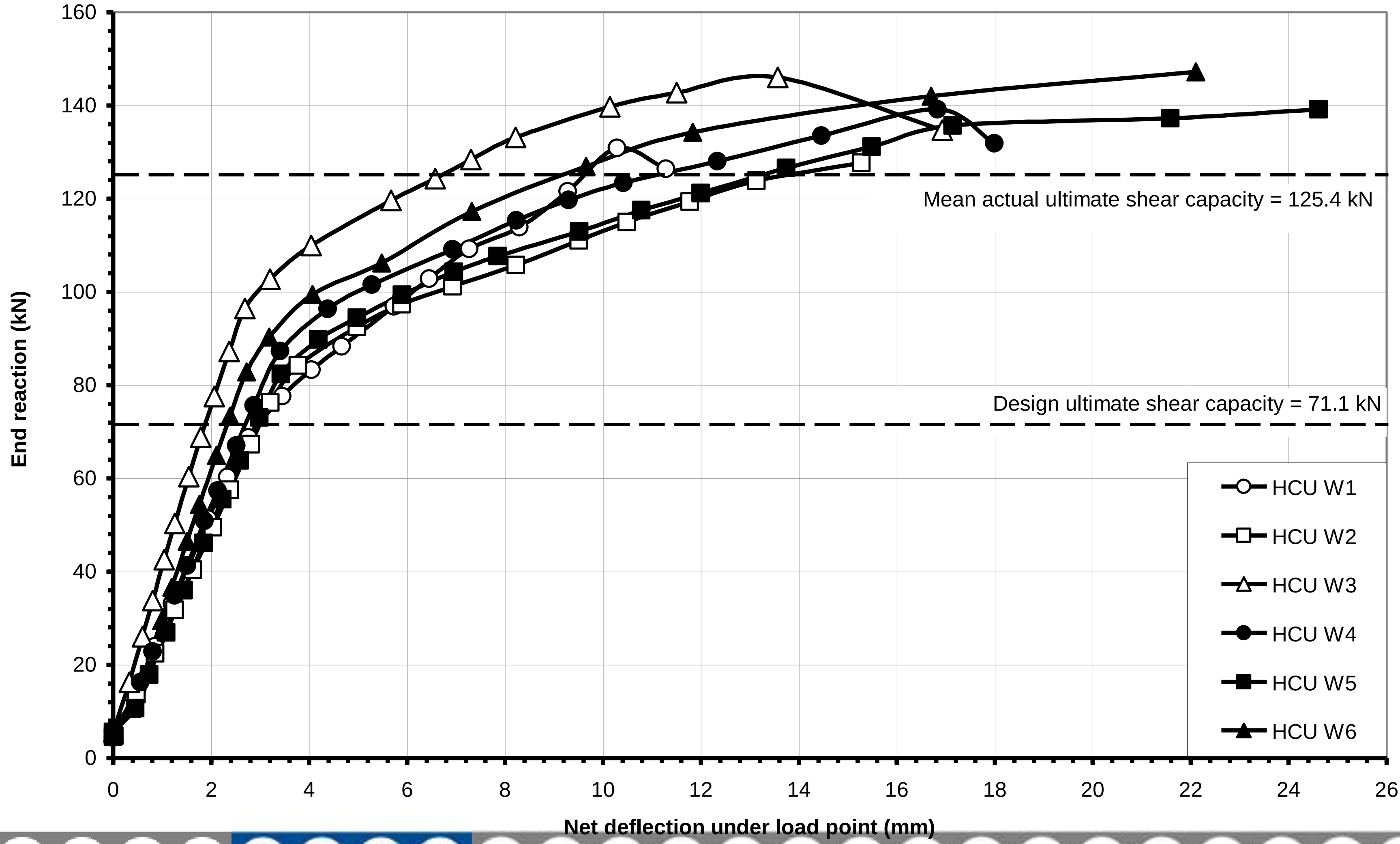
Units containing 9.3 mm strand had wide webs relative to their flexural strength, and it was not possible to produce a true shear failure, even with a/h ratio = 1.8

Shear tests with 5 mm wire

Actual $V_{Rd,c}$ = using measured strength, geometry, no PSF = 125.4 kN

Design $V_{Rd,c}$ = using EC2 design equations and values = 71.1 kN

Mean test value = 138.4 kN



Comparison of test v code values

$$V_U = \frac{I\,b_w}{S}\sqrt{{f_{ctm}}^2 + \frac{L_x}{L_{pt}}\,\sigma_{cp}\,f_{ctm}}$$

Unit type	Test V_{Ed} kN	Basic V_U kN	Design $V_{Rd,c}$ kN	Ratio V_{Ed} / V_u	Ratio $V_{Ed} / V_{Rd,c}$
Hollow core 5 mm wire	138.4	125.4	71.1	1.10	1.95
Hollow core mixed 7 and 5 mm wire	97.5	89.8	47.2	1.09	2.07
Hollow core 9.3 mm strand	63.8	111.1	65.3	~~0.57~~	~~0.98~~
T beams 5 mm wire	81.9	70.1	40.0	1.17	2.05
X beams mixed 7 and 5 mm wire	16.8	15.2	7.9	1.10	2.13
Averages of shear force ratios				1.01	1.88

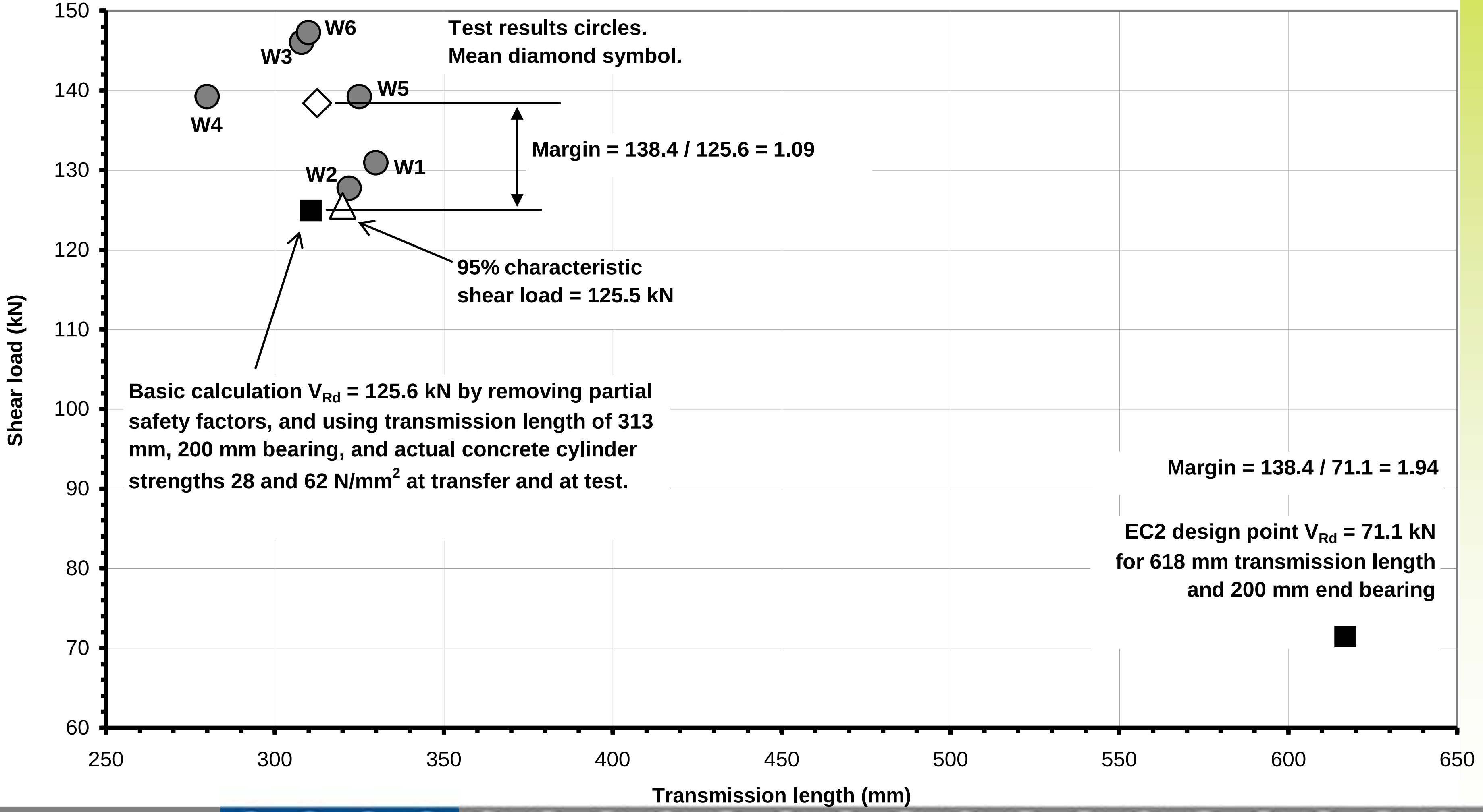
Summary of shear tests and shear load to shear capacity ratios

1.11 and 2.05 ignoring

Step 3

Shear capacity vs transmission length

Hcu 5 mm wire



Test results circles.
Mean diamond symbol.

Margin = 138.4 / 125.6 = 1.09

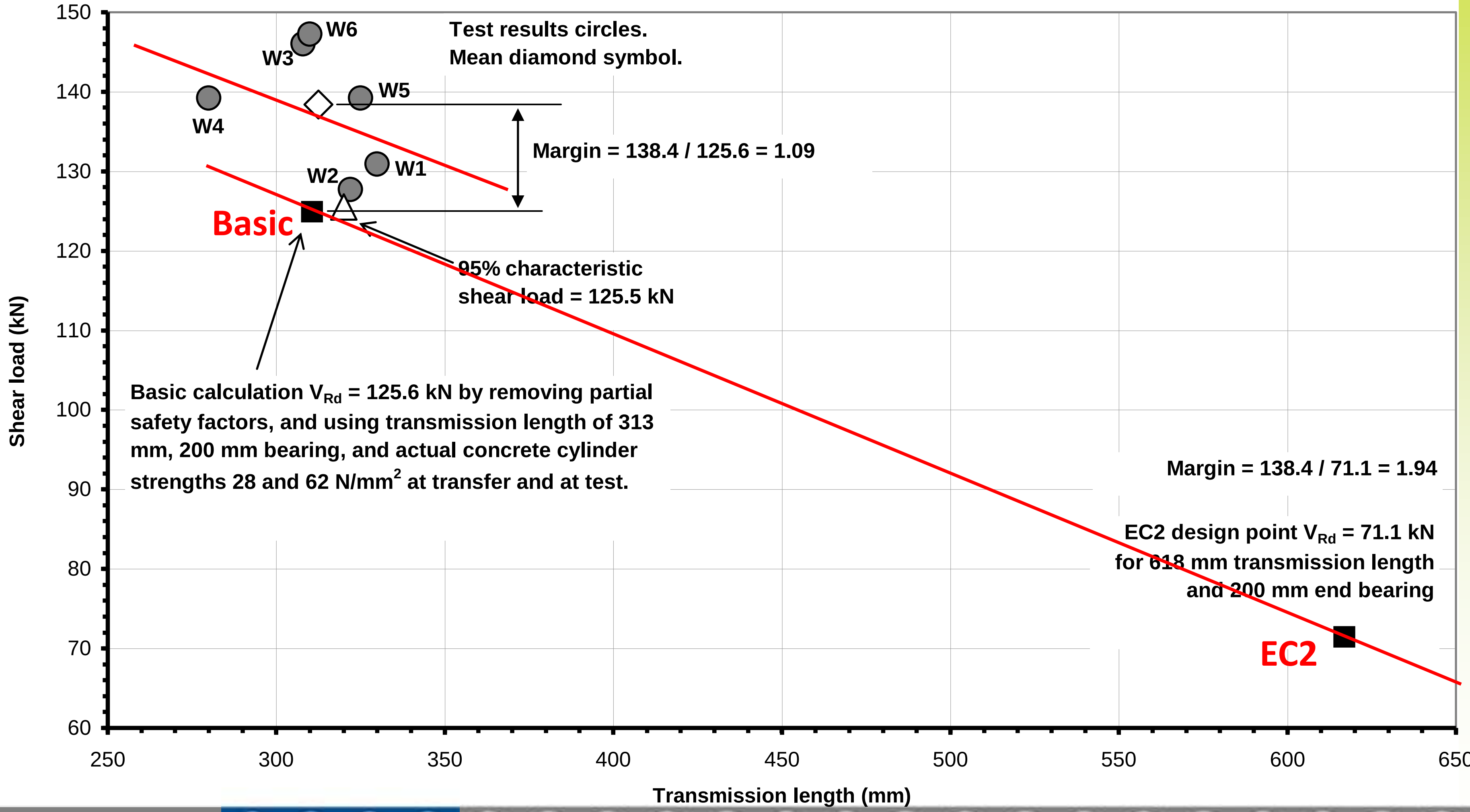
95% characteristic shear load = 125.5 kN

Basic calculation V_{Rd} = 125.6 kN by removing partial safety factors, and using transmission length of 313 mm, 200 mm bearing, and actual concrete cylinder strengths 28 and 62 N/mm^2 at transfer and at test.

Margin = 138.4 / 71.1 = 1.94

EC2 design point V_{Rd} = 71.1 kN for 618 mm transmission length and 200 mm end bearing

Trend lines are close to parallel suggesting test results follow same *regime* as calculated values



Test results circles.
Mean diamond symbol.

Margin = 138.4 / 125.6 = 1.09

95% characteristic shear load = 125.5 kN

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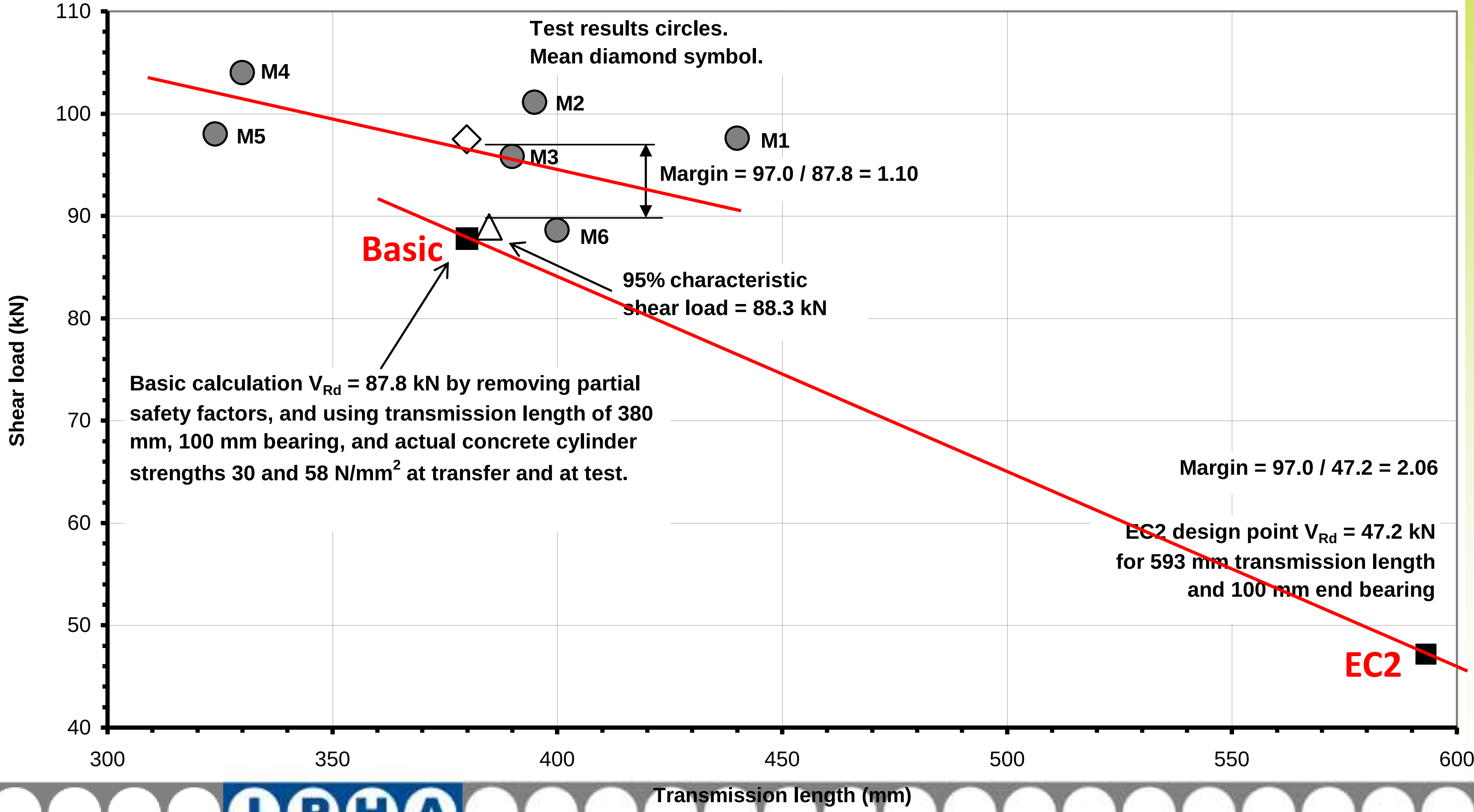
Margin = 138.4 / 71.1 = 1.94

EC2 design point V_{Rd} = 71.1 kN for 618 mm transmission length and 200 mm end bearing

Hcu mixed 7 and 5 mm wire



Test results circles.
Mean diamond symbol.

Margin = 97.0 / 87.8 = 1.10

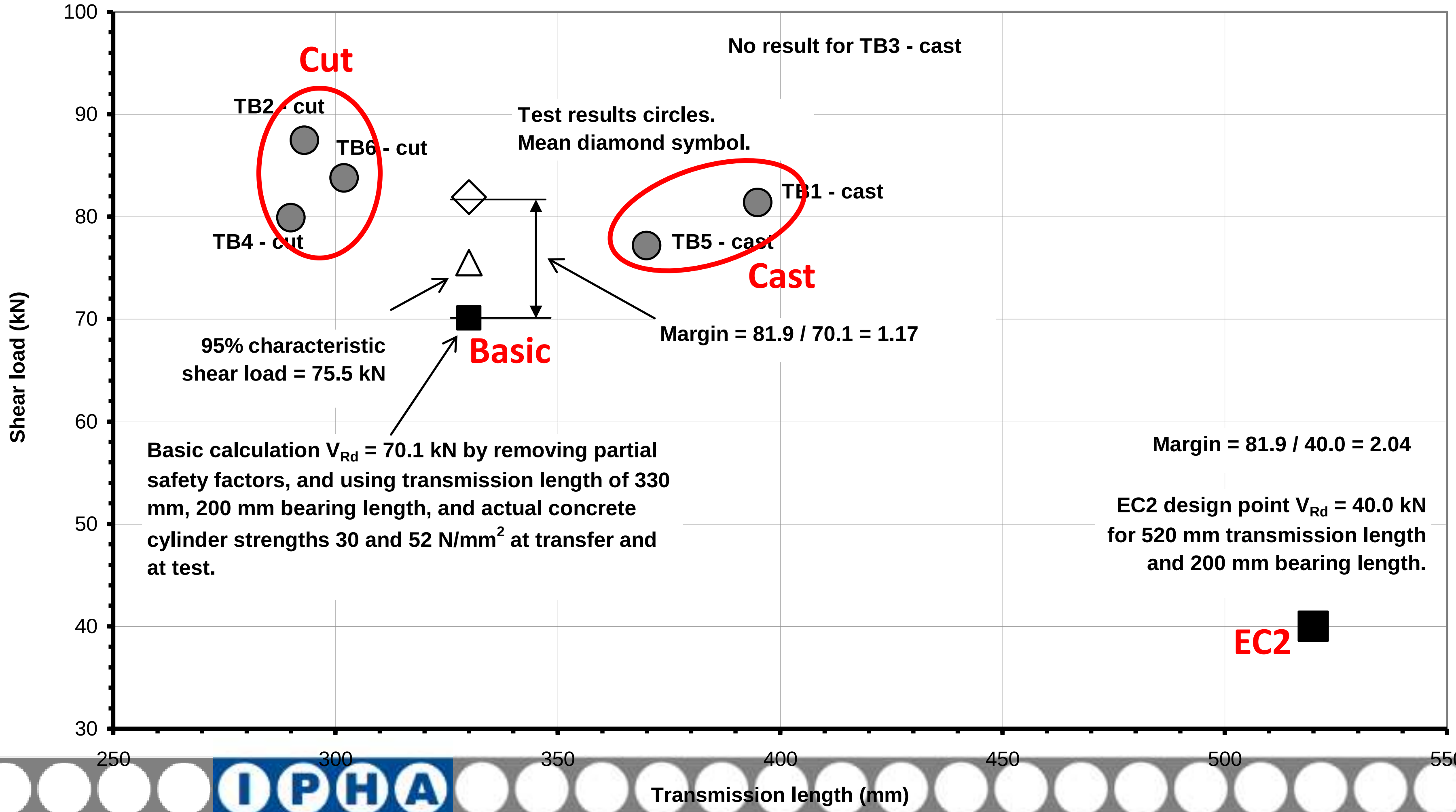
95% characteristic shear load = 88.3 kN

Basic calculation V_{Rd} = 87.8 kN by removing partial safety factors, and using transmission length of 380 mm, 100 mm bearing, and actual concrete cylinder strengths 30 and 58 N/mm^2 at transfer and at test.

Margin = 97.0 / 47.2 = 2.06

EC2 design point V_{Rd} = 47.2 kN for 593 mm transmission length and 100 mm end bearing

T beams 5 mm wire



No result for TB3 - cast

Test results circles.
Mean diamond symbol.

95% characteristic
shear load = 75.5 kN

Margin = 81.9 / 70.1 = 1.17

Basic calculation V_{Rd} = 70.1 kN by removing partial safety factors, and using transmission length of 330 mm, 200 mm bearing length, and actual concrete cylinder strengths 30 and 52 N/mm^2 at transfer and at test.

Margin = 81.9 / 40.0 = 2.04

EC2 design point V_{Rd} = 40.0 kN
for 520 mm transmission length
and 200 mm bearing length.

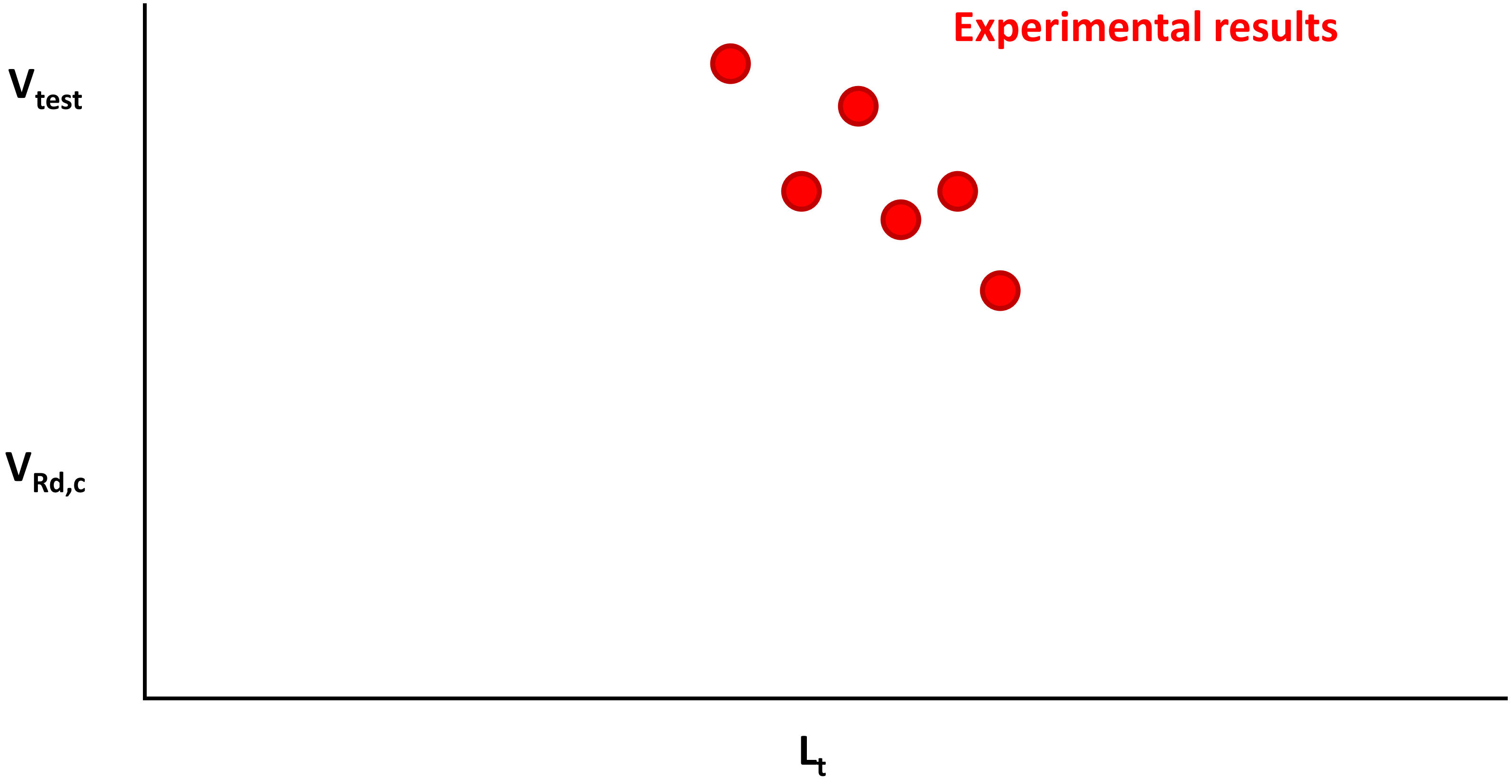
Step 4

Modified equation for $V_{Rd,c}$ based on tests and analysis

Step 4

Simulation

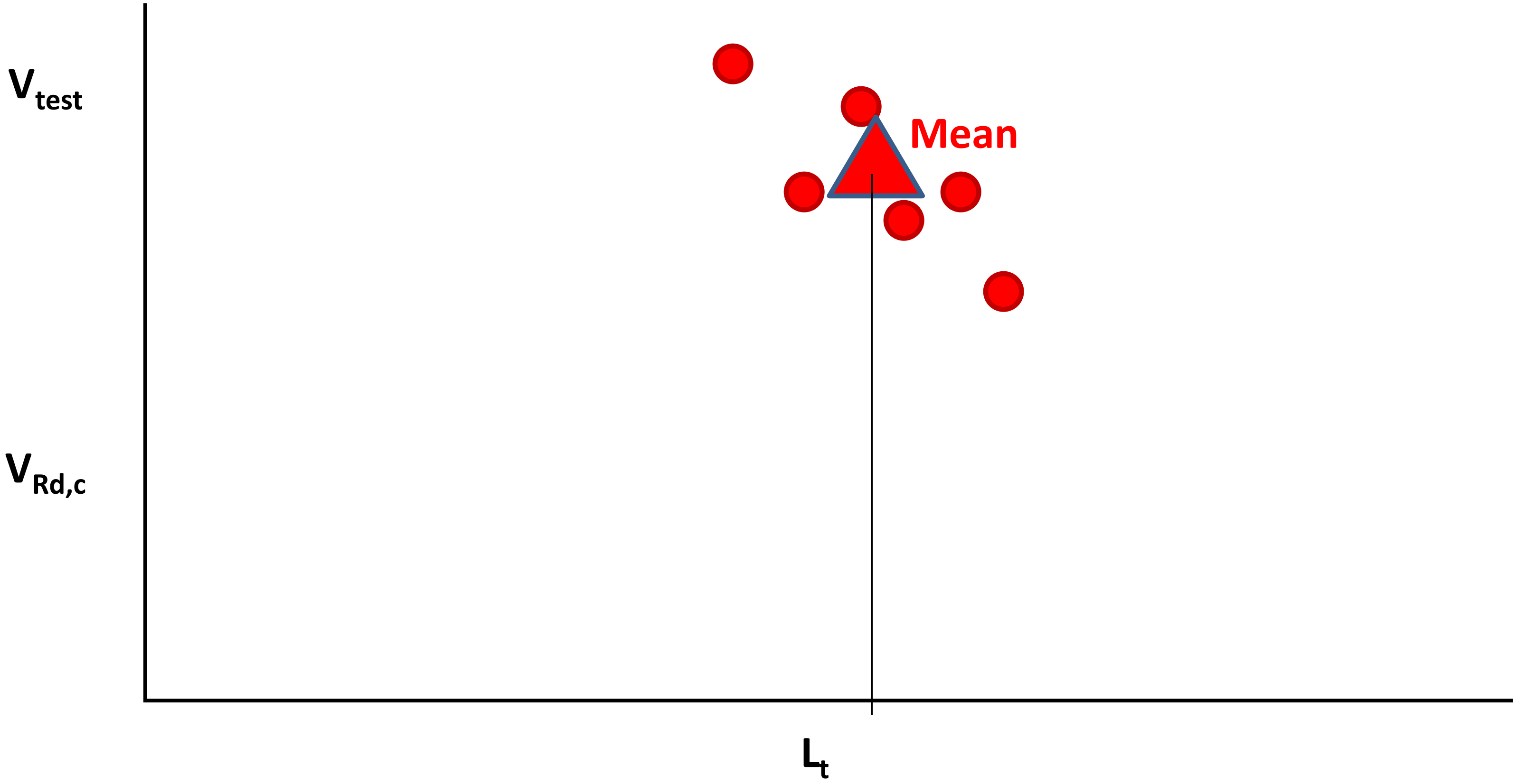
Shifting the transmission length



Step 4

Simulation

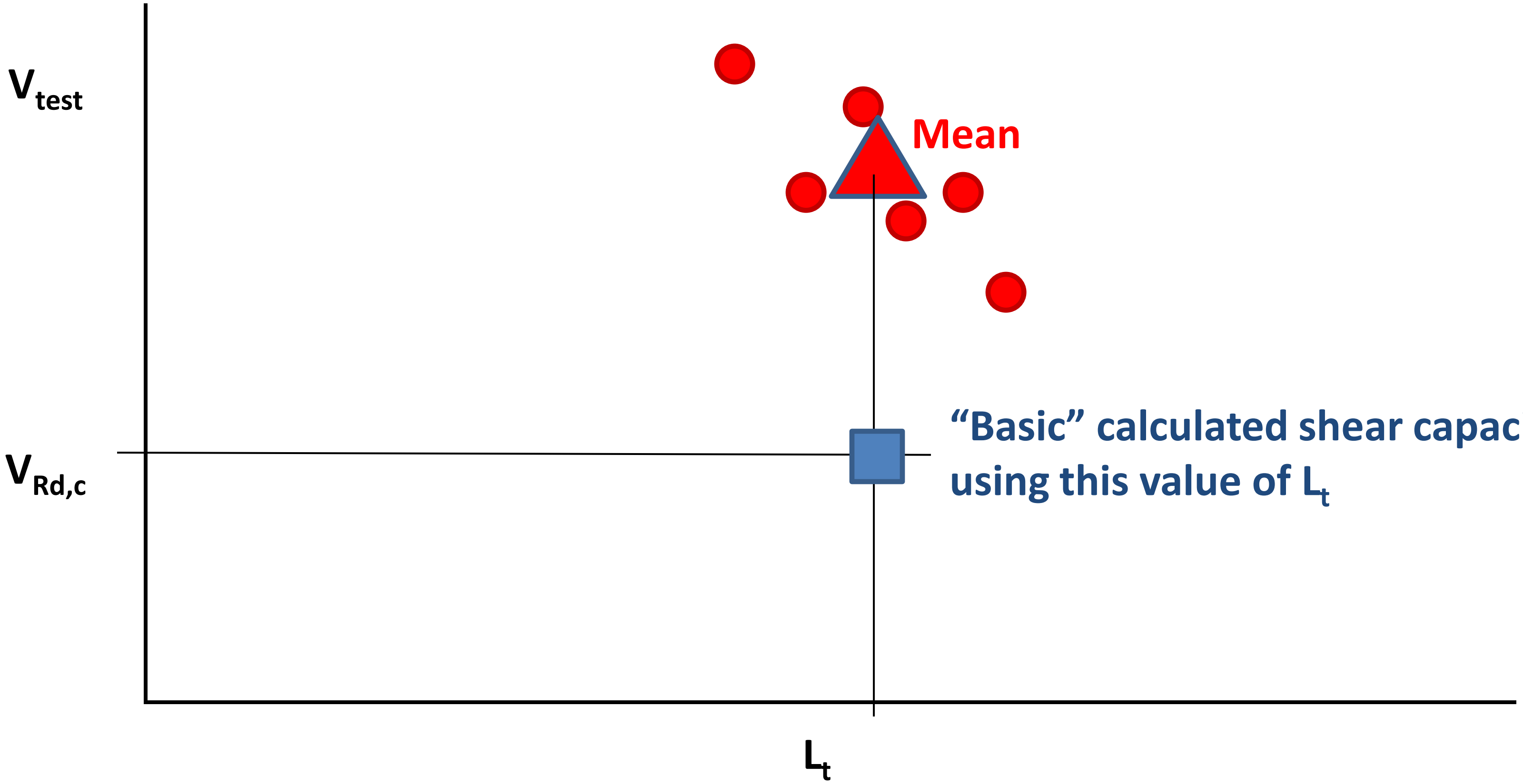
Shifting the transmission length



Step 4

Simulation

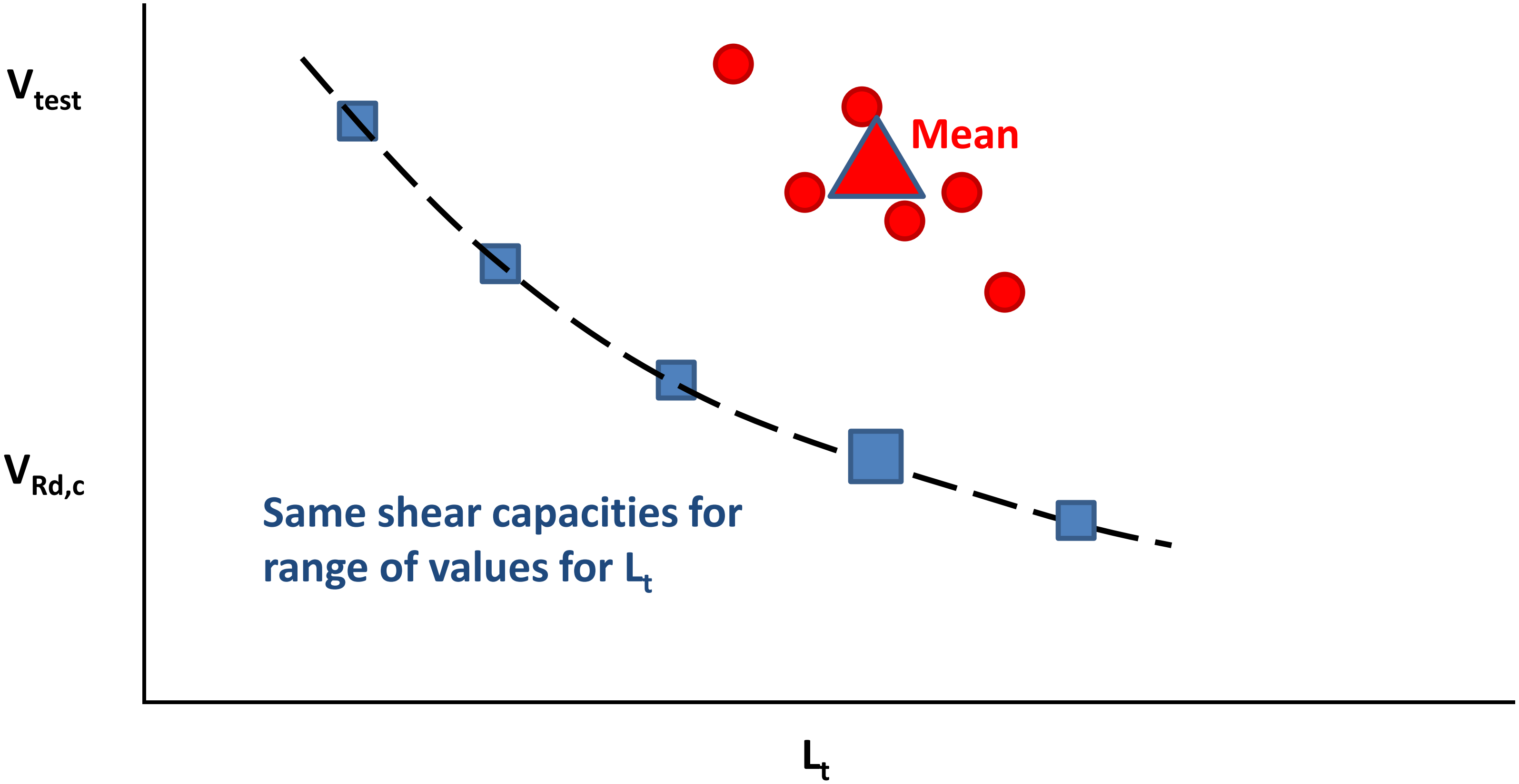
Shifting the transmission length



Step 4

Simulation

Shifting the transmission length

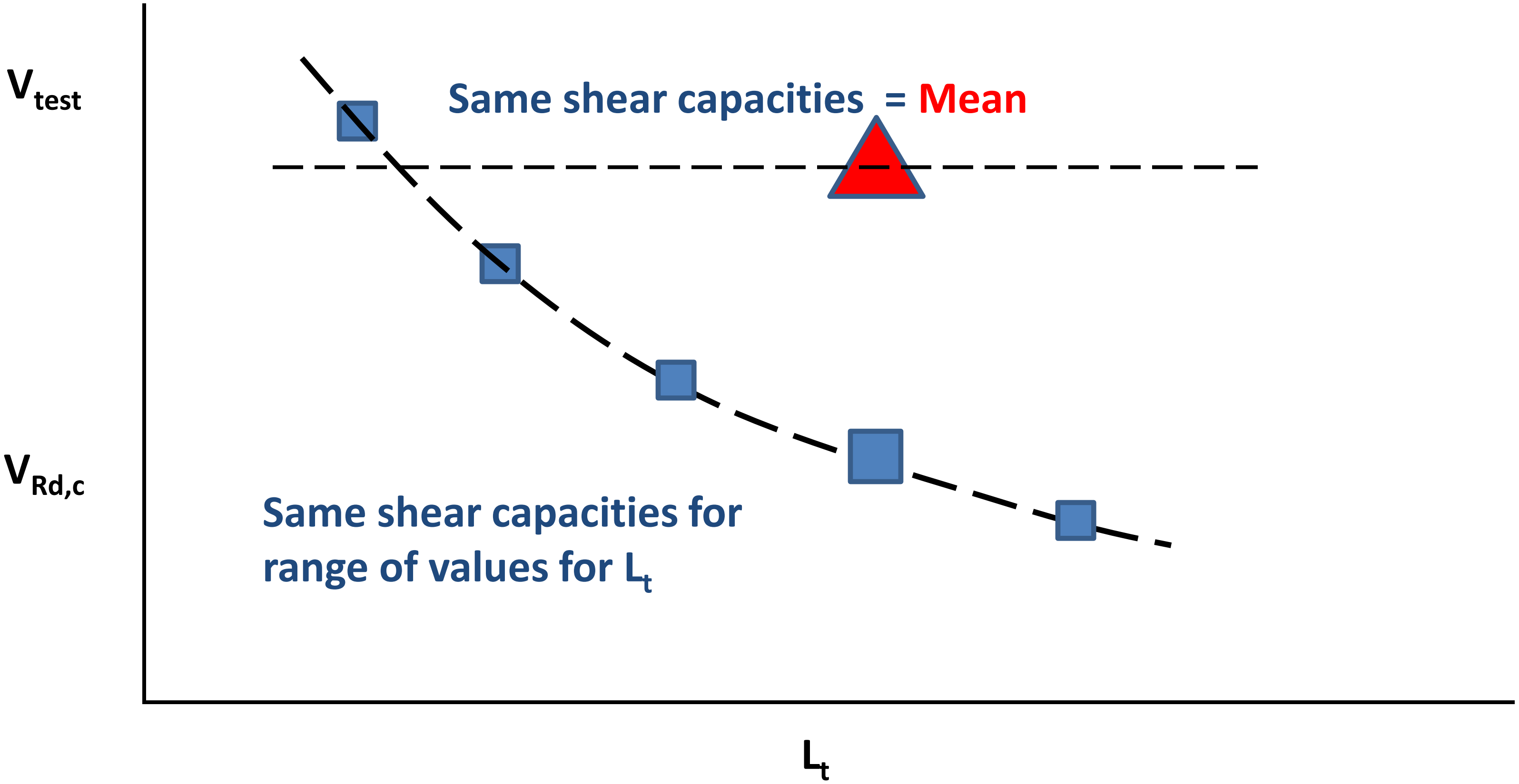


Same shear capacities for range of values for L_t

Step 4

Simulation

Shifting the transmission length



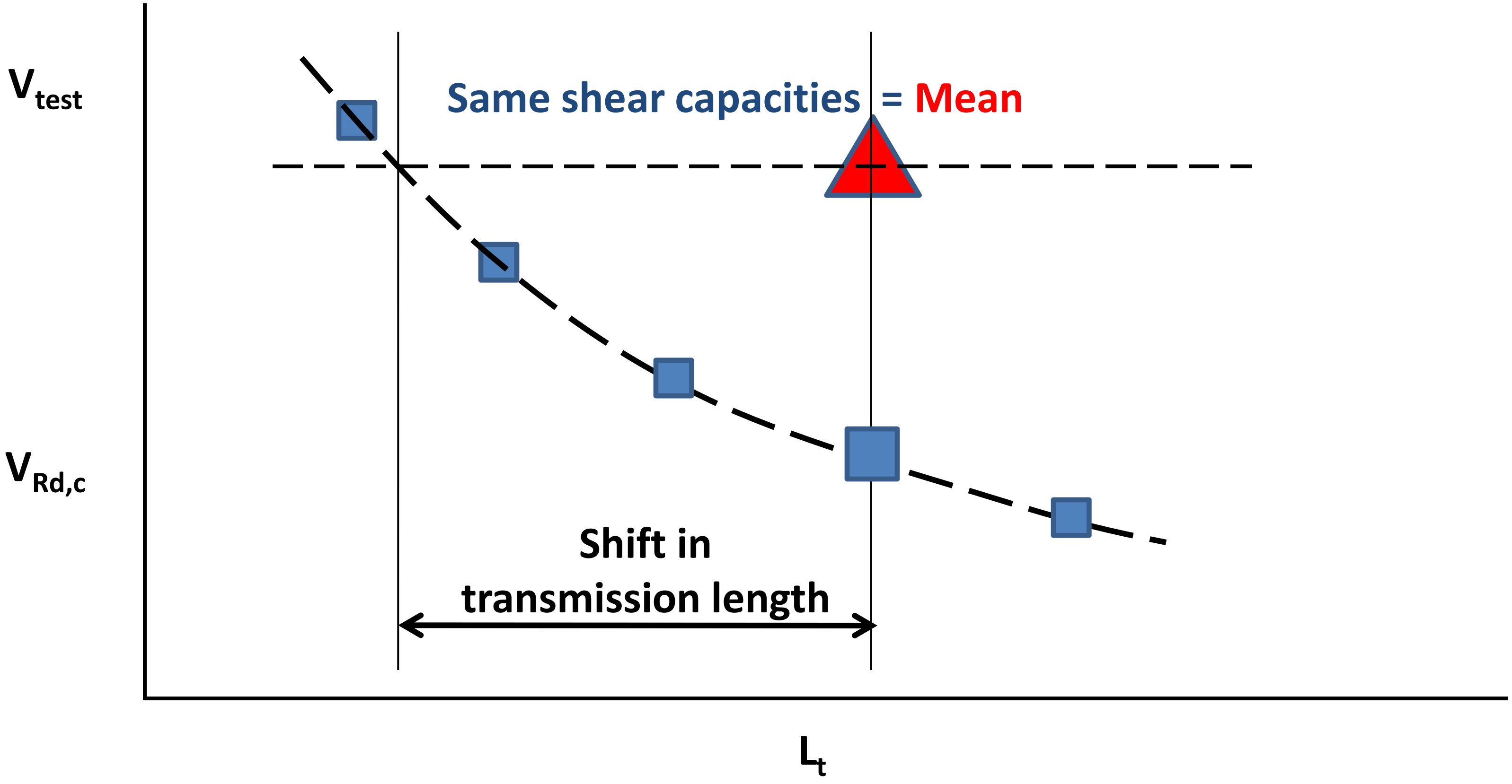
Same shear capacities = Mean

Same shear capacities for range of values for L_t

Step 4

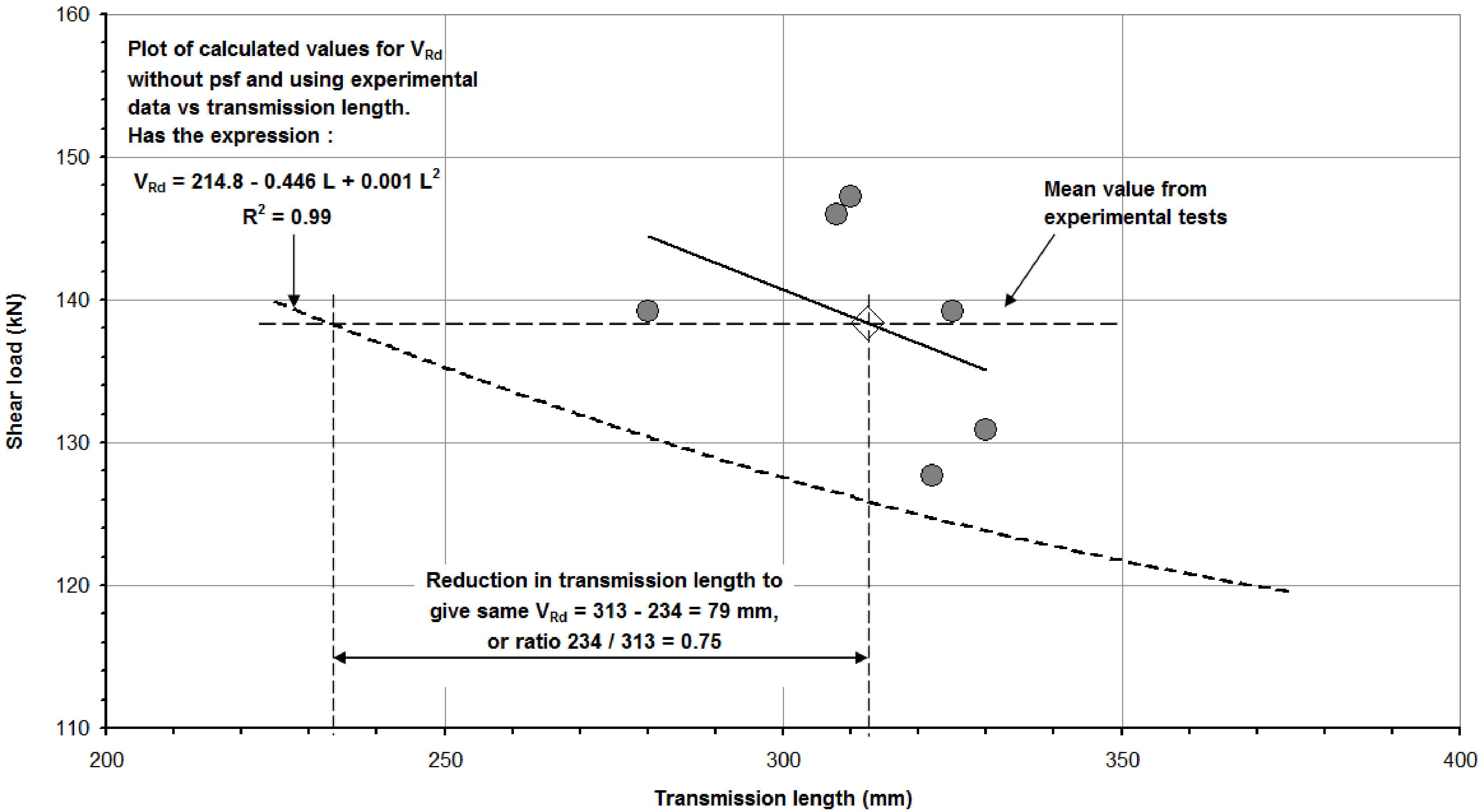
Simulation

Shifting the transmission length



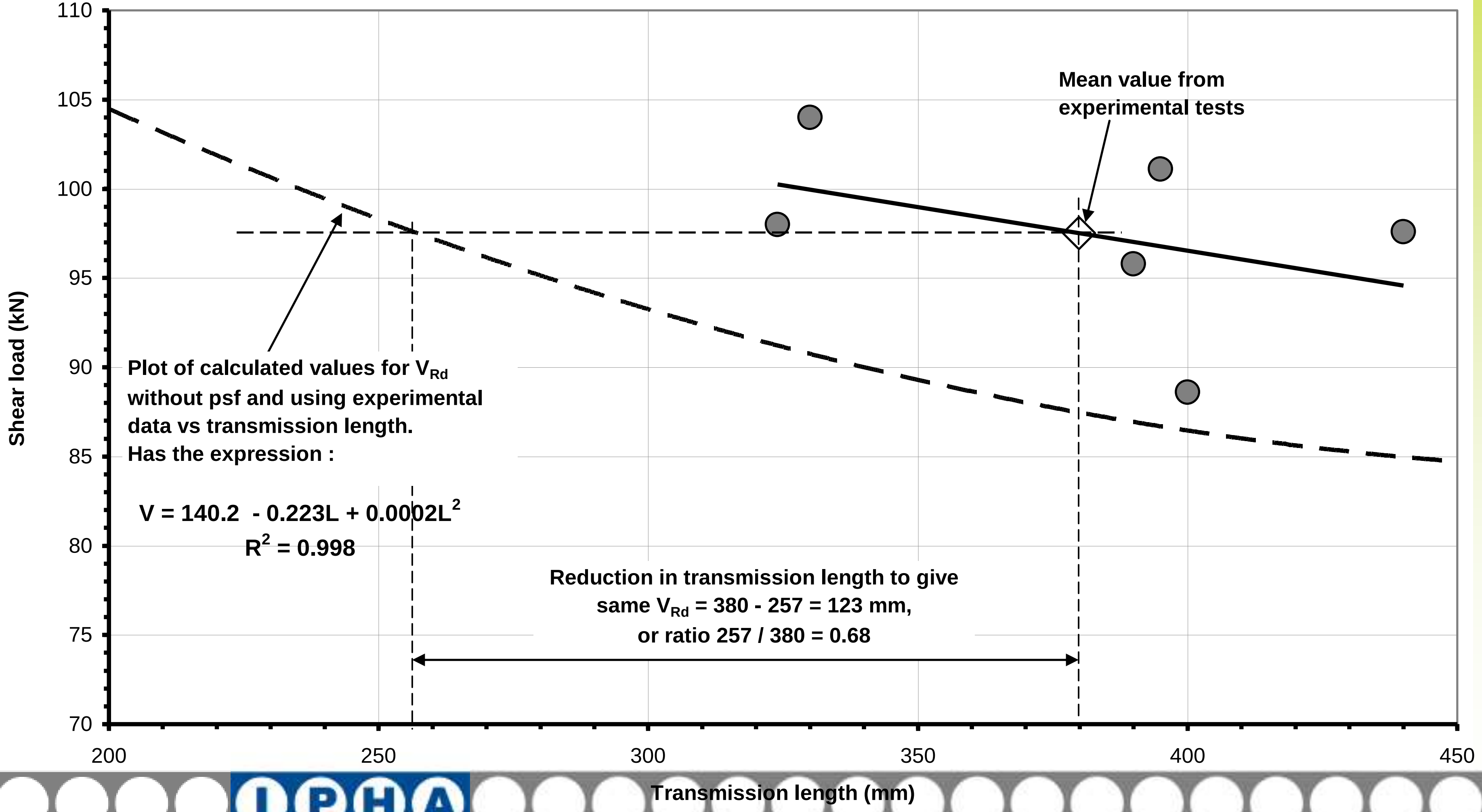
Hollow core units pretensioned using 5 mm wire.

Shift = 79 mm or ratio = 0.75



Hollow core units pretensioned using 7 and 5 mm wire

Shift = 123 mm or ratio = 0.68



Plot of calculated values for V_{Rd} without psf and using experimental data vs transmission length.
Has the expression :

$$V = 140.2 - 0.223L + 0.0002L^2$$
$$R^2 = 0.998$$

Reduction in transmission length to give same V_{Rd} = 380 - 257 = 123 mm, or ratio 257 / 380 = 0.68

Unit type	Test $V_{Ed,mean}$ kN	Basic V_U kN	Test L_t mm	Shifted L_t mm	Ratio of shifted / test L_t
Hollow core 5 mm wire	138.4	125.4	313	234	0.75
Hollow core mixed 7 and 5 mm wire	97.5	89.8	380	257	0.68
Hollow core 9.3 mm strand	63.8	111.1	491	No result	
T beams 5 mm wire	81.9	70.1	347	202	0.61
X beams mixed 7 and 5 mm wire	16.8	14.8	369	240	0.65
Averages of shifted ratios					0.67

Shifted values for transmission lengths

$$V_{Rd,c} = \frac{I\, b_w}{S} \sqrt{f_{ctd}^{\,2} + \frac{L_x}{0.67\, L_{pt}}\, 0.9\, \sigma_{cp}\, f_{ctd}}$$

Unit type	Test $V_{Ed,mean}$ kN	Basic V_U kN	Test L_t mm	Shifted L_t mm	Ratio of shifted / test L_t
Hollow core 5 mm wire	138.4	125.4	313	234	0.75
Hollow core mixed 7 and 5 mm wire	97.5	89.8	380	257	0.68
Hollow core 9.3 mm strand	63.8	111.1	491	No result	
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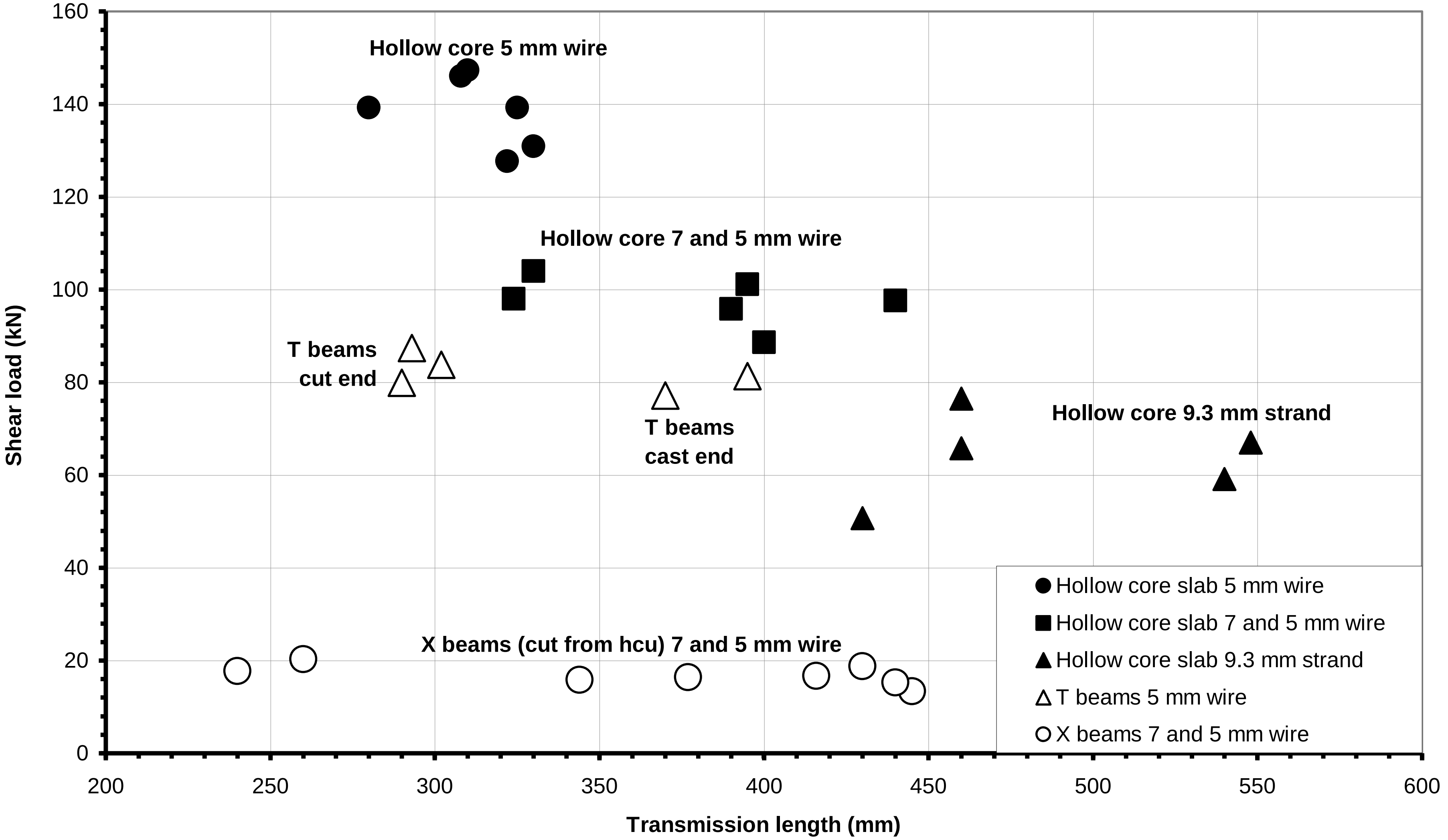
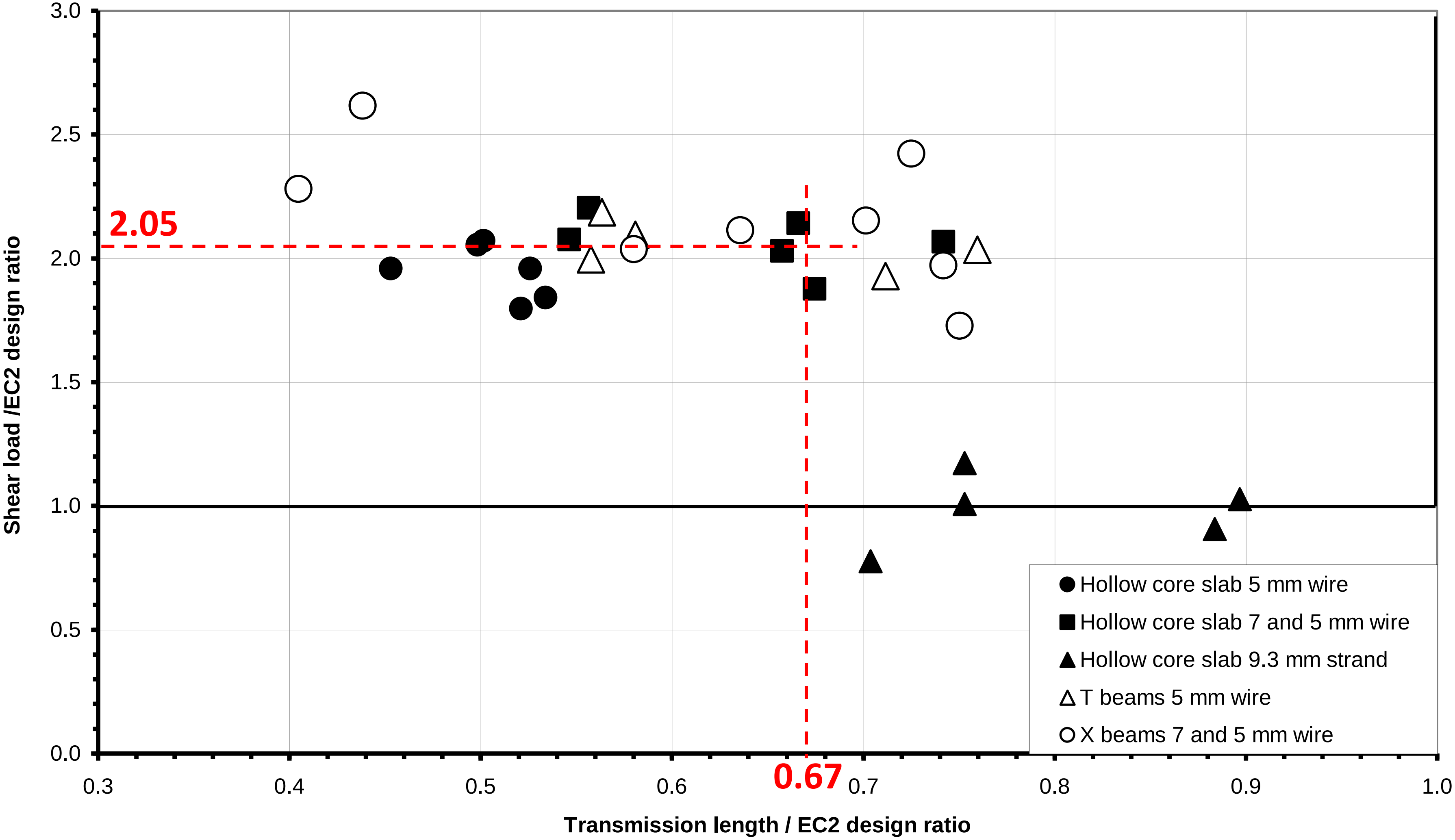
Averages of shifted ratios					$\boxed{0.67}$

Shifted values for transmission lengths



Final summaries – raw data



Final summaries – test / EC2

Conclusions

36 tests to measure L_t and shear capacity of extruded and slipformed hollow core slabs, X beams (cut from hcu) and cast T beams.

CEB-FIP method was used to determine L_t from strain distributions.

L_t varied from 240 to 550 mm, but when normalised with respect to EC2, Part 1-1, clause 8.10.2.2, EC2 L_{pt} are between 1.3 and 2.5 times greater than measured values.

. . .

Conclusions

Ultimate test shear varied from 0.9 to 1.3 times the basic calculated capacity.

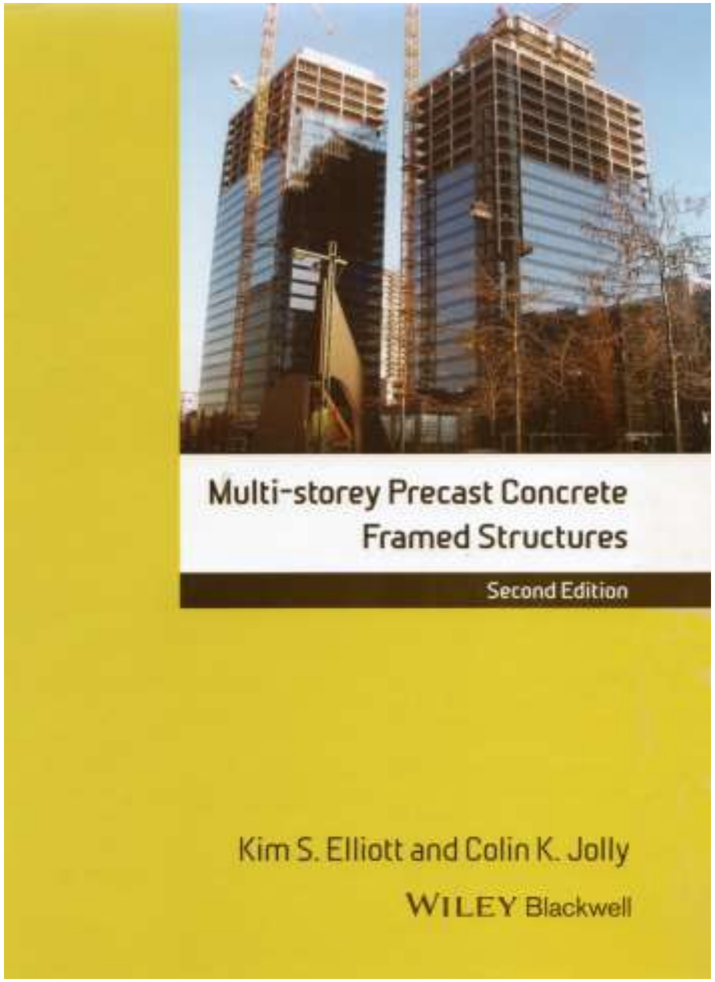
The ratio of test to EC2 $V_{Rd,c}$ = 1.7 to 2.6.

Reduction in L_t for 'cut' *v* 'cast' ends was 80ϕ to 59ϕ = 26%.
Hollow core units all have cut ends.

"Shifting" L_t to a position where test shear = calculated shear, suggests L_t may be modified by a factor between 0.61 and 0.75, leading to recommendation :

$$V_{Rd,c} = \frac{I\, b_w}{S} \sqrt{{f_{ctd}}^2 + 1.5\, \alpha\, 0.9\, \sigma_{cp}\, f_{ctd}}$$

Thank you for your attention



Multi-storey Precast Concrete Framed Structures

Second Edition

Kim S. Elliott and Colin K. Jolly

WILEY Blackwell