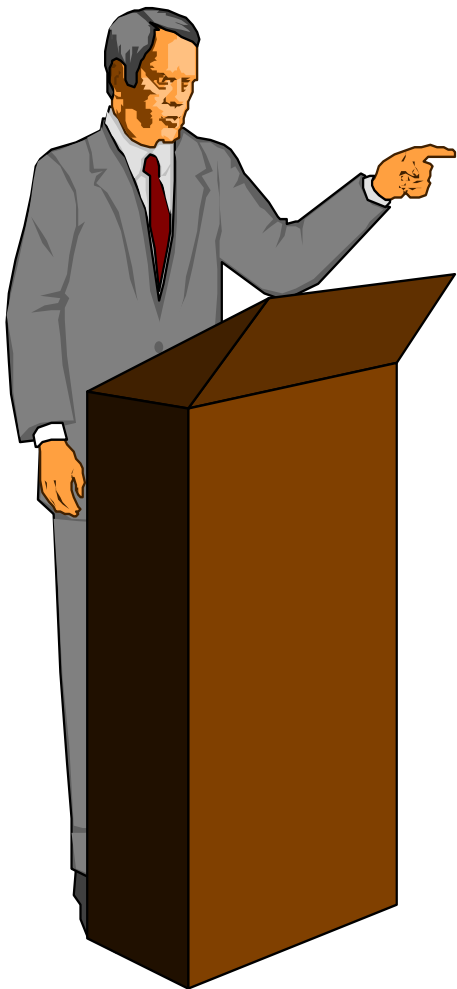


# Flexural and Punching Shear Design of FRP RC Flat Slabs



**Dr Abdel Wahab El-Ghandour**

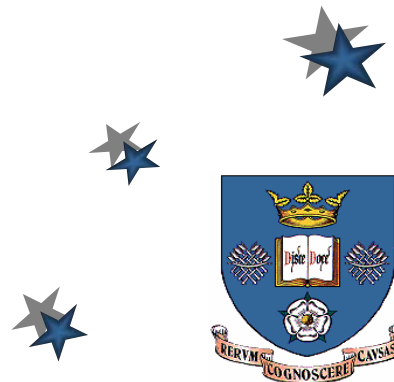
*Lecturer (Ain Shams Univ.)*

**Dr Kypros Pilakoutas**

*Reader (Univ. of Sheffield)*

**Professor Peter Waldron**

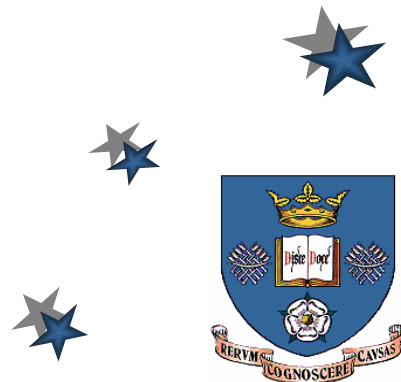
*Professor (Univ. of Sheffield)*



# Outline



- ◆ **Context of Work**
- ◆ **Experimental Program**
- ◆ **Finite Element Verification**
- ◆ **Parametric Study**
- ◆ **Flexural Design Guidelines**
- ◆ **Punching Shear Design Guidelines**
- ◆ **Conclusions**



# Context Of Work



- **Eurocrete Project**

- *Aim:* **Durable FRP Reinforcement**
- *Partners:* **9 Companies + University of Sheffield**
- *Funds:* **5.6 million ECU**

- *fib TG 9.3 + ConFibreCrete Research Network*

- *Aim:* **Design Guidelines**
- *Members:* **Over 40 International Experts**
- *TMR:* **11 Institutions from 9 EC Countries**
- *Funds:* **1.3 million Euro**

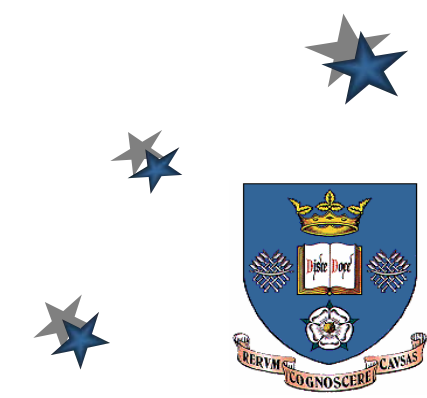
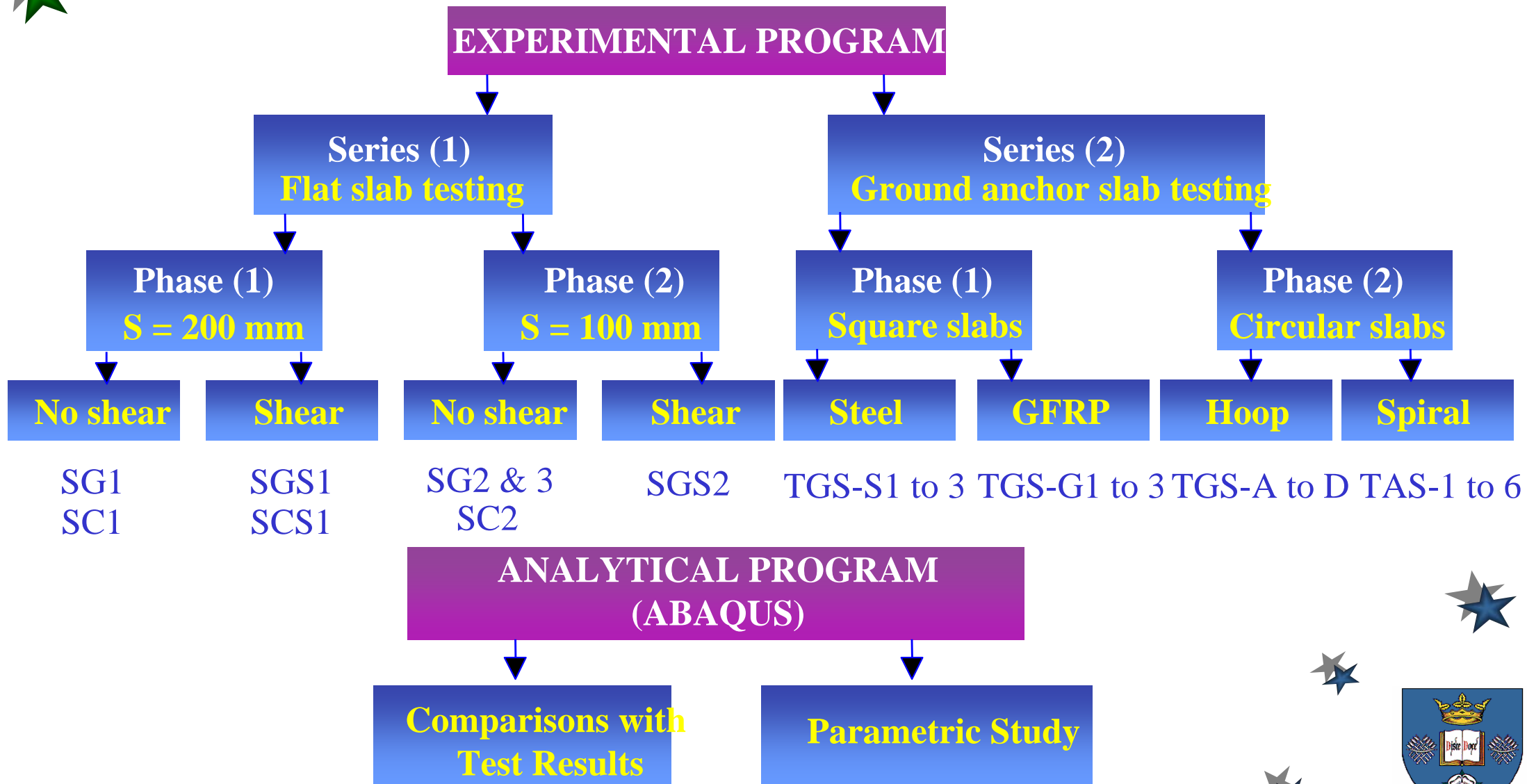


# Work Done @ Sheffield (on FRP Rebar)



- ◆ **RC Beams: Flexure, Shear, Bond & Ductility**
- ◆ **RC Slabs: 2-D Flexure, Punching Shear, Bond**
- ◆ **Sub-elements: Tensile strength, Bond**
- ◆ **Development of Design Guides and Philosophy**
- ◆ **Various Case Studies on Precast Concrete Elements**
- ◆ **Design of New Structural Elements / Applications**

# Work on FRP RC Slabs





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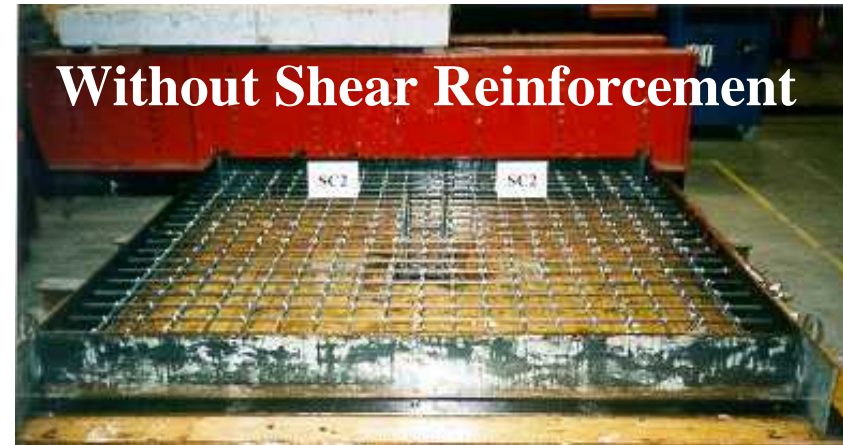
# Experimental Program

## Slab Details



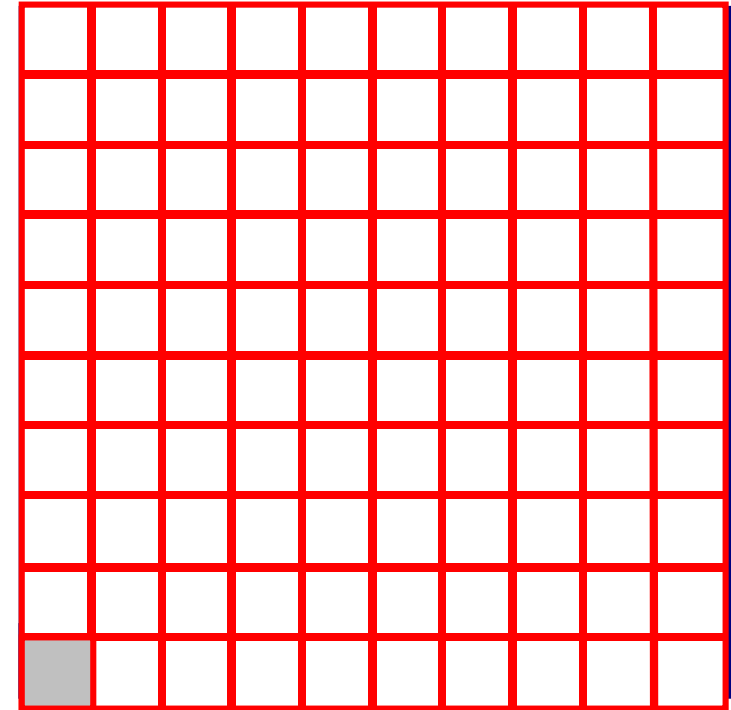
### First Series

### Second Series



## Sensitivity Study

- ◆ Element Type
- ◆ Mesh Sensitivity
- ◆ Integration Points
- ◆ Support Conditions
- ◆ Reinforcement Model
- ◆ Concrete Model



Mesh (C): 20 × 20 elem.

- Uniaxial Compressive Stress-Strain Curve
- Initial Compressive Young's Modulus
- Ratio of Uniaxial Comp. to Tensile Strength
- Tension Stiffening
- Shear Retention

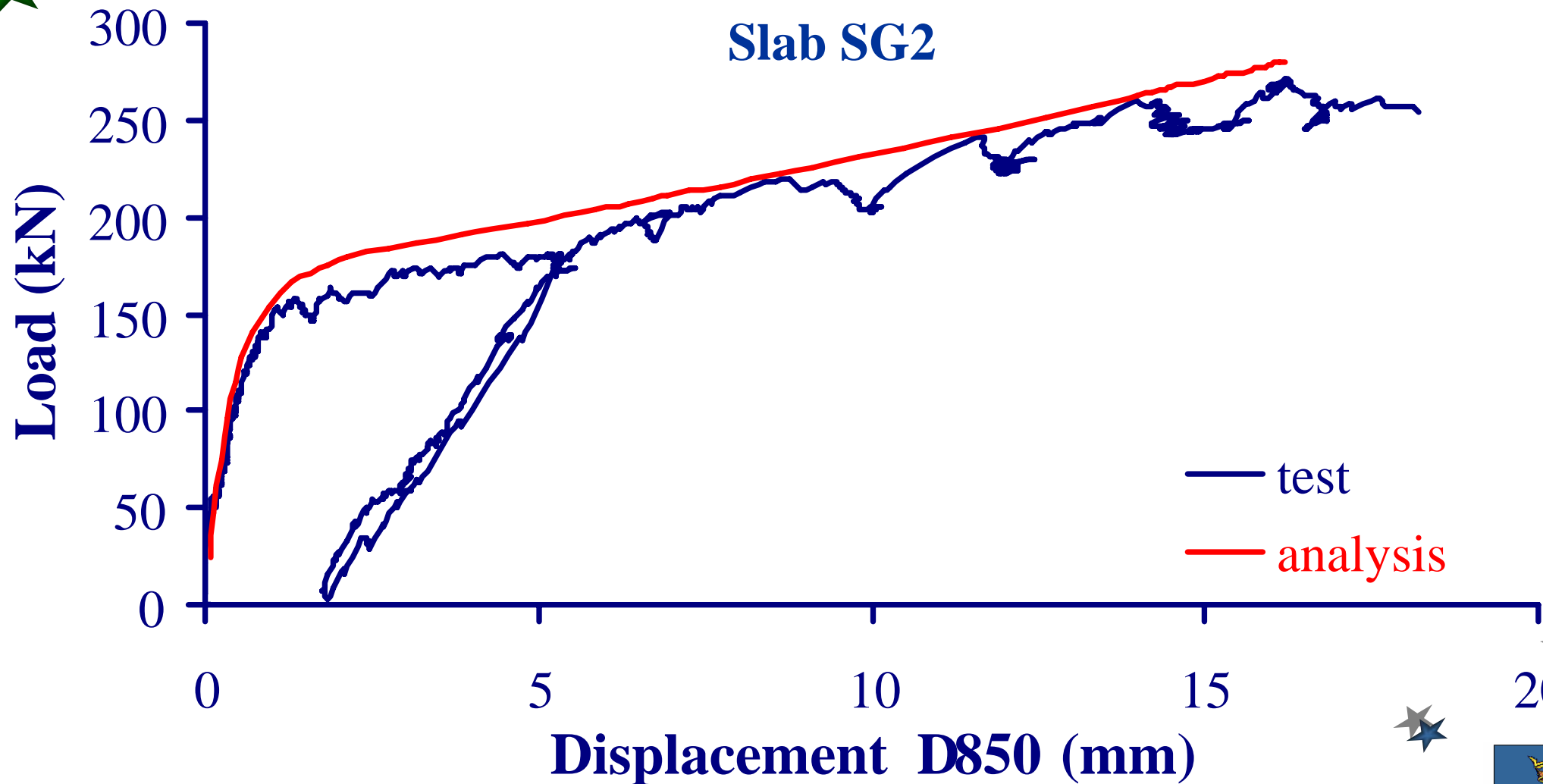


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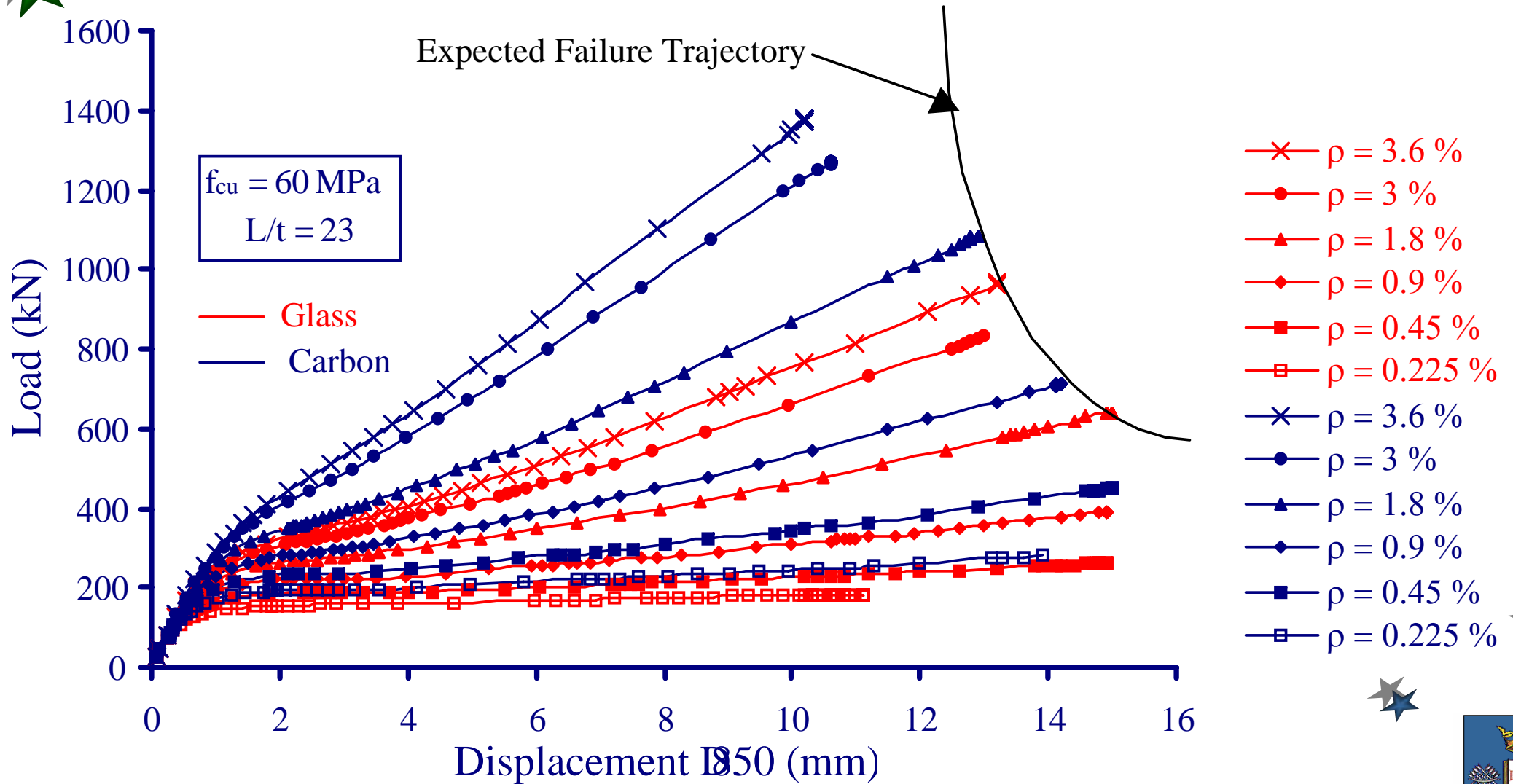


# FEA Verification

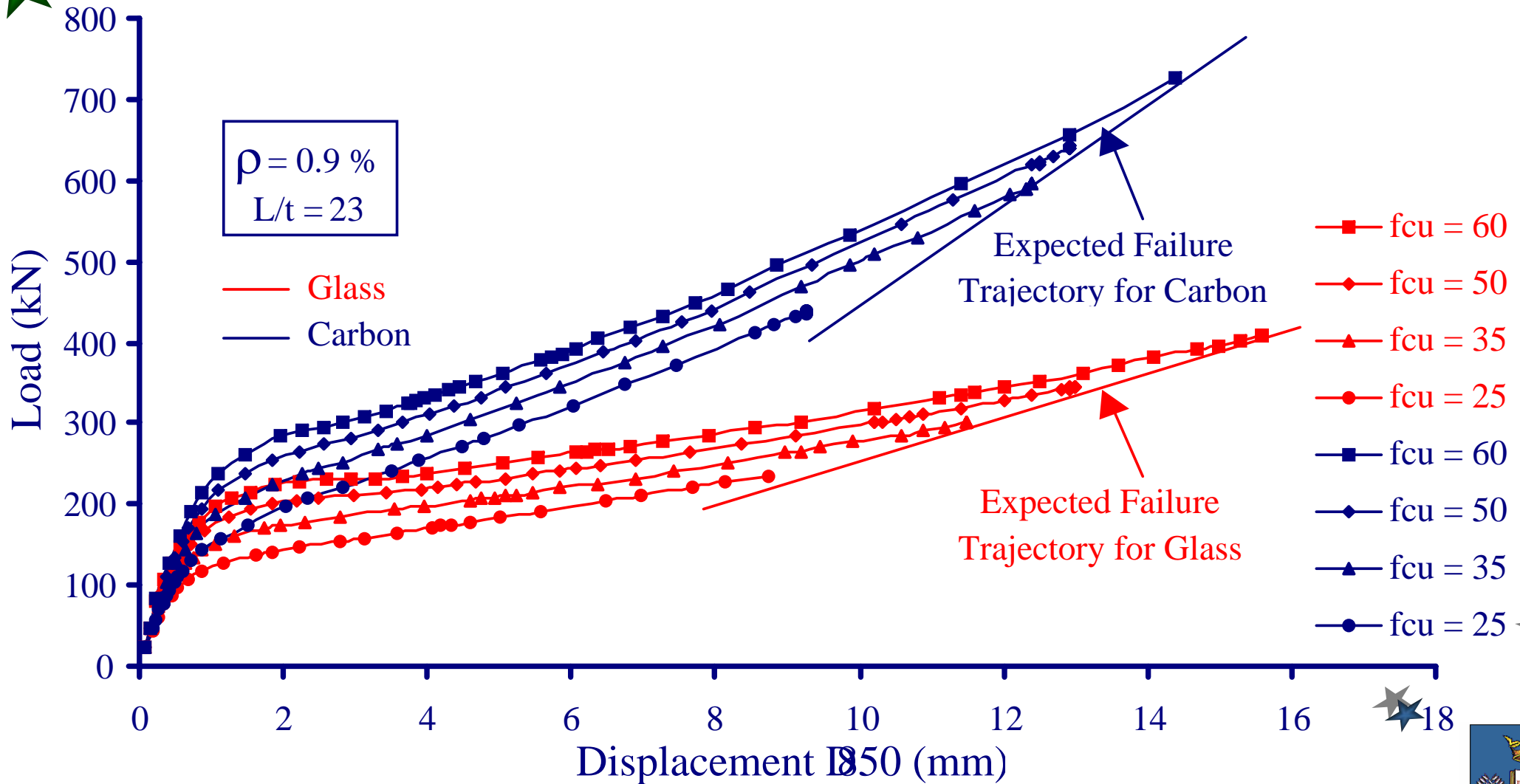
## Comparisons with Test Results



# Parametric Study Reinforcement Ratio

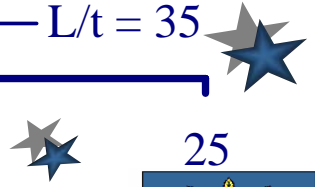
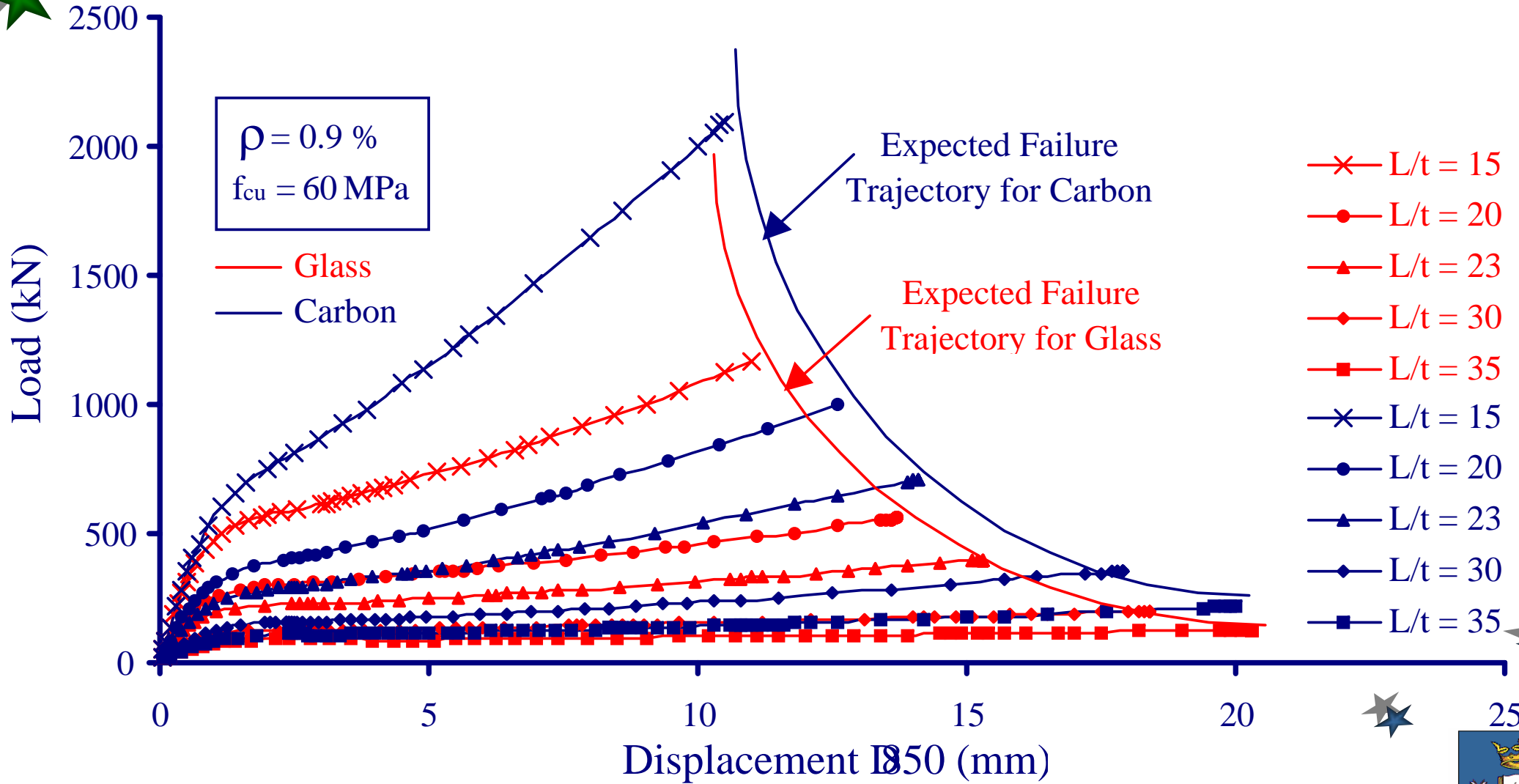


# Parametric Study Concrete Grade



# Parametric Study

## Span to Depth Ratio



# Flexural Guidelines Design Equation

$$(L/t) = 24.2 (250/\Delta r)^{1.9} (E_p/99000)^{0.1} (f_{cu}/40)^{-0.44}$$

Parametric Study CFRP RC Slabs

Ultimate Loads

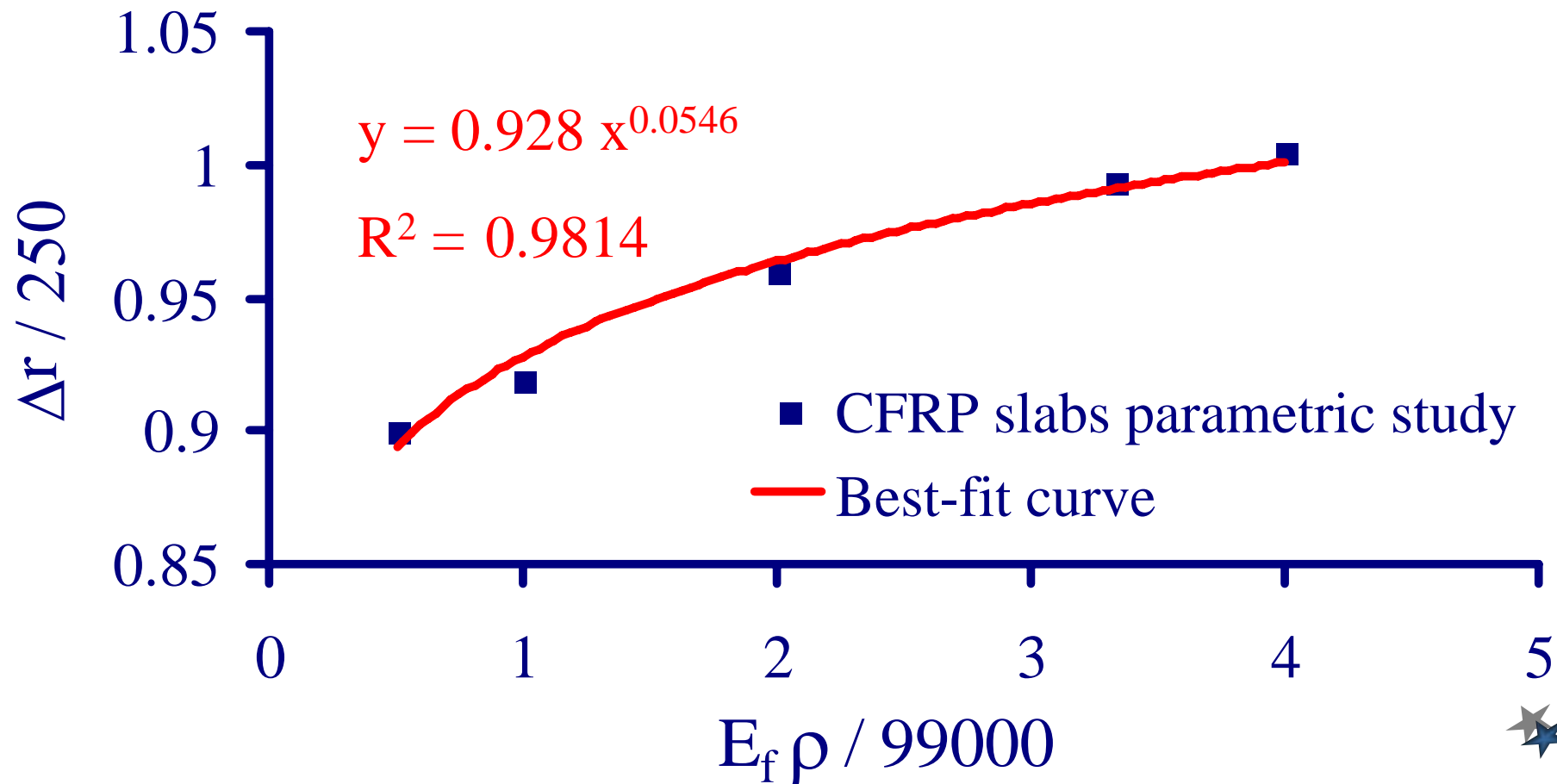
Service Loads = Ultimate Loads / 1.6

Service Loads + FEA Load-Deflection curves → Service Deflections ( $\delta_{ser}$ )

$$\delta_{ser} = L / \Delta r$$

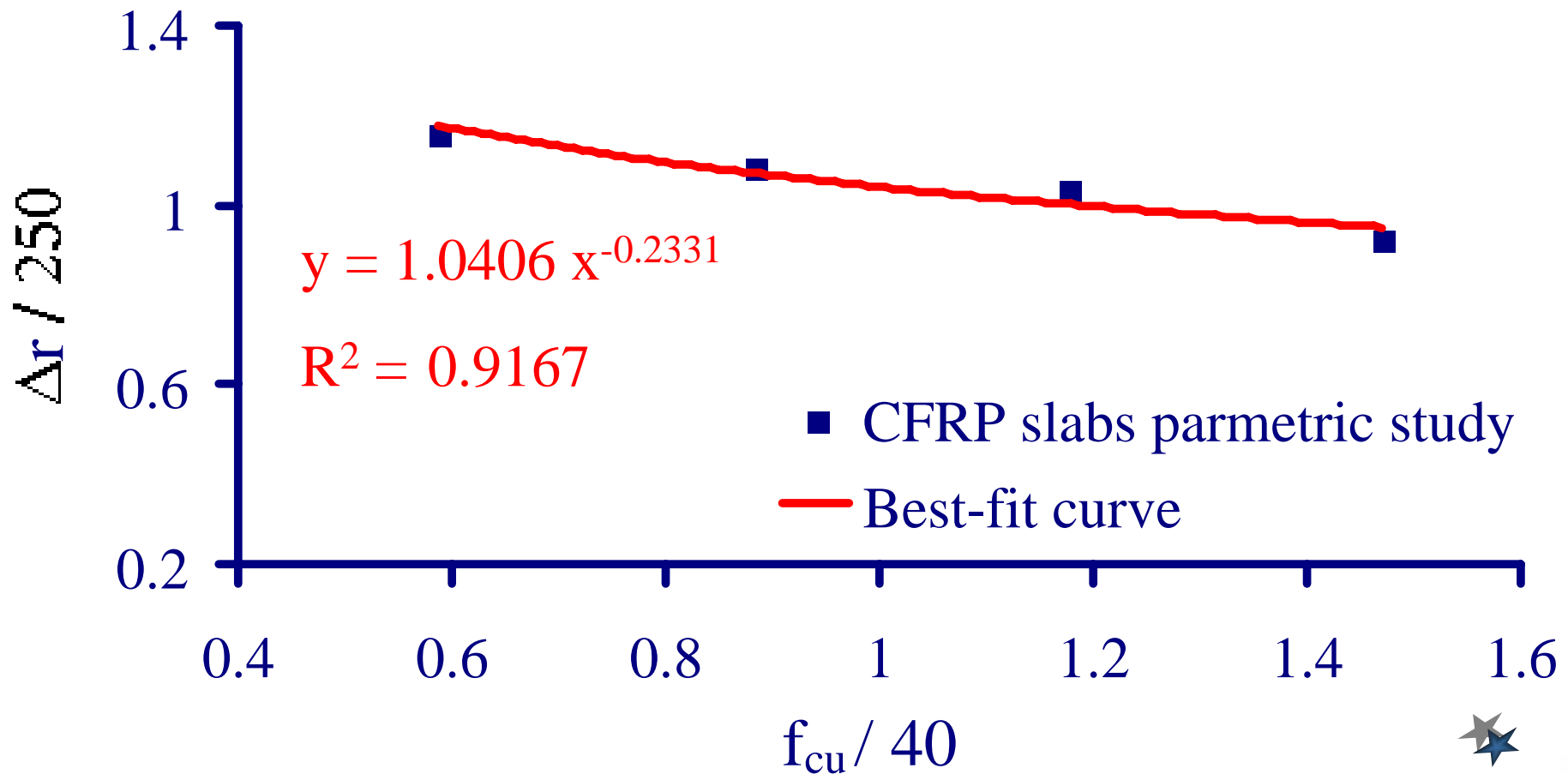
# Flexural Guidelines

## Derivation of Design Equation



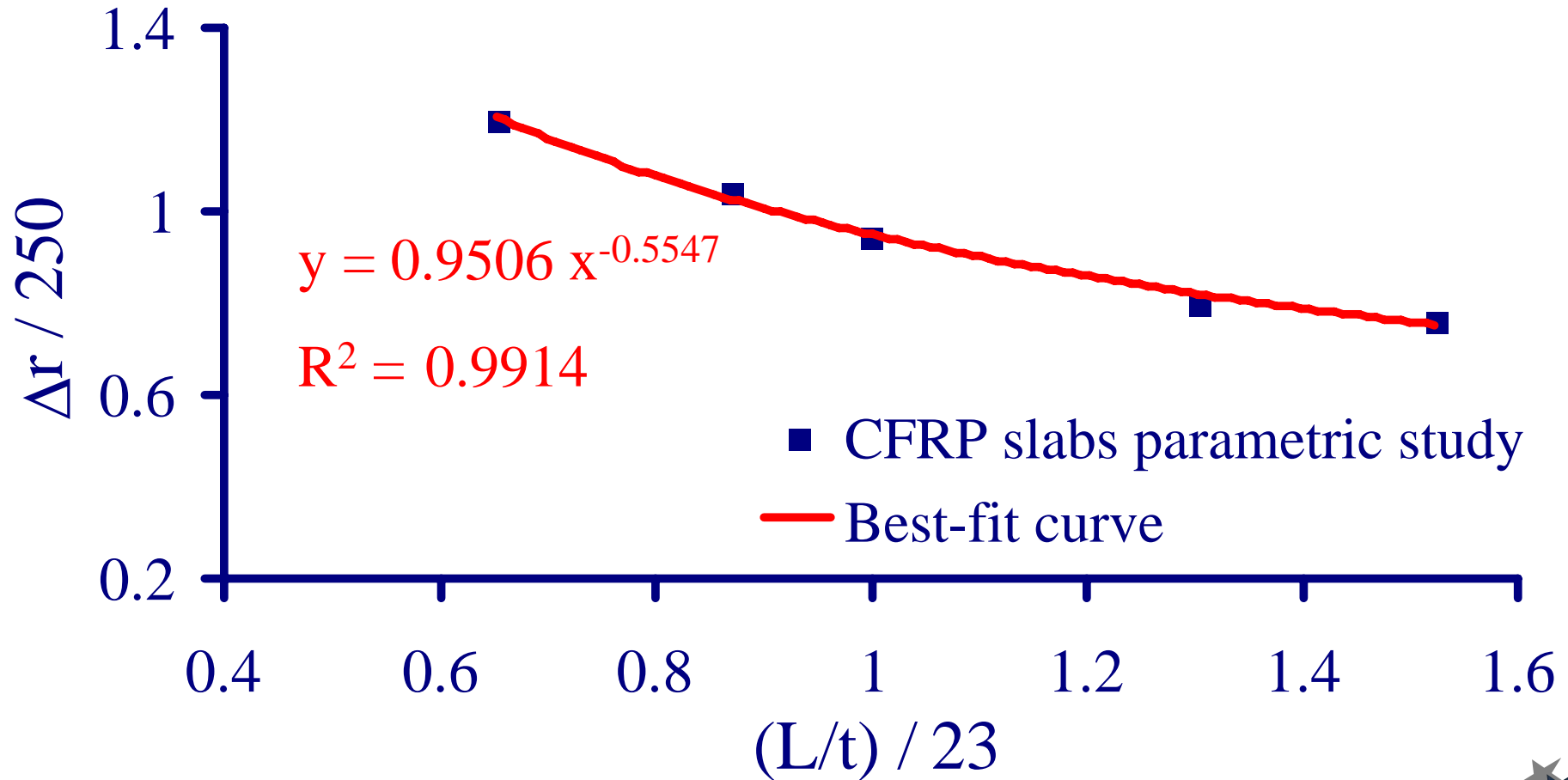
# Flexural Guidelines

## Derivation of Design Equation



# Flexural Guidelines

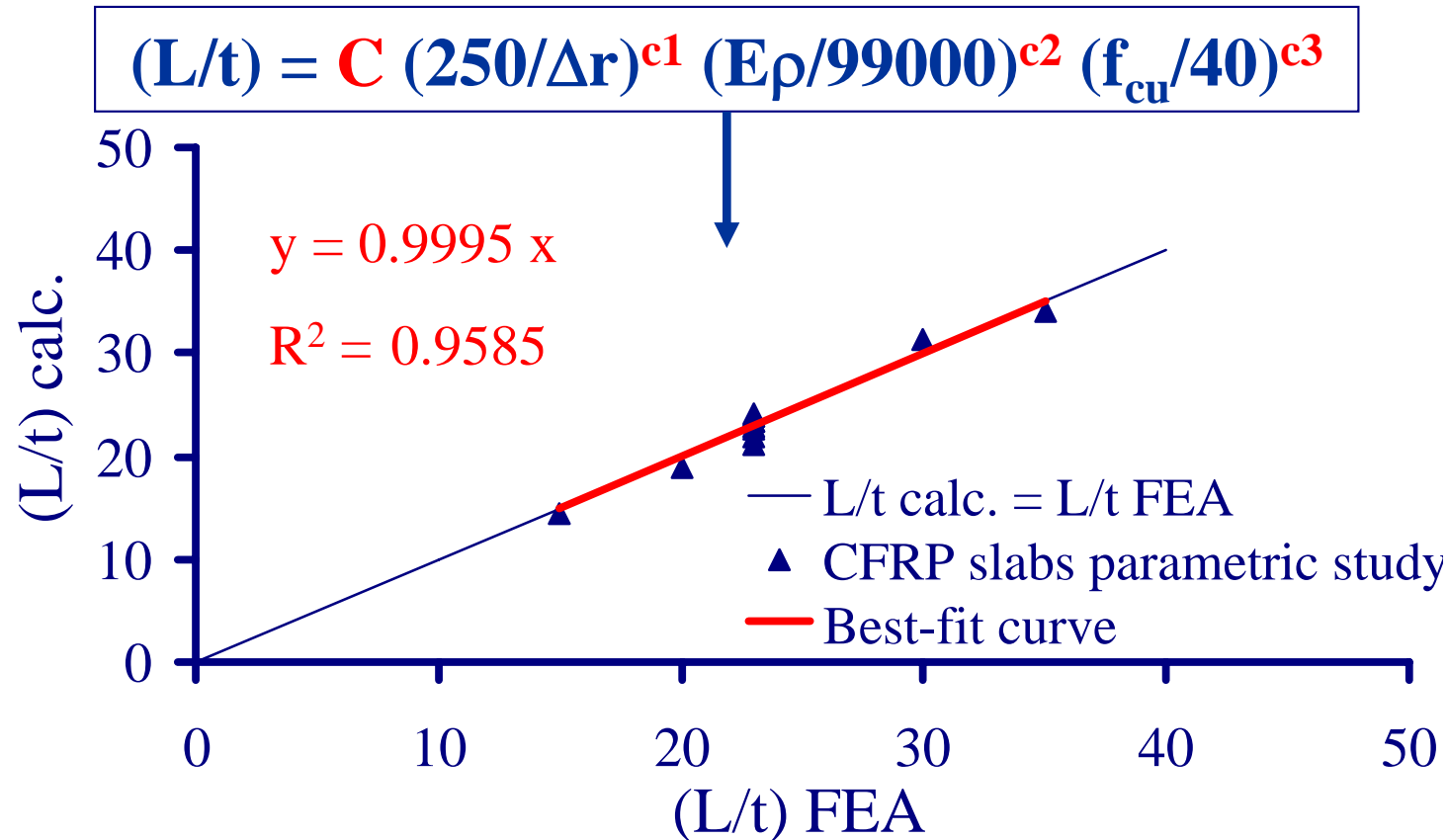
## Derivation of Design Equation



$$(\Delta r / 250) = 0.918 (E_p / 99000)^{0.0546} (f_{cu} / 40)^{-0.2331} [(L/t) / 23]^{-0.5547}$$

# Flexural Guidelines

## Derivation of Design Equation



$$(L/t) = 24.2 (250/\Delta r)^{1.9} (E_p/99000)^{0.1} (f_{cu}/40)^{-0.44}$$

# Punching Shear Guidelines

## Failure Patterns (2<sup>nd</sup> Series)



**Section through Slab SG3  
at Failure**



**Section through Slab SC2  
at Failure**



**Section through Slab SGS2  
at Failure**

# Punching Shear Guidelines

## Concrete Shear Resistance

### *Predictive Approaches*



### Strain Approach

$$v_c = (100 A_e / b_v d)^{1/3} (400 / d)^{1/4} (0.27) (f_{cu})^{1/3} ,$$

$$A_e = A_{FRP} (E_{FRP} / E_{steel})$$

### Modified Approach

$$v_c = (100 A_e / b_v d)^{1/3} (400 / d)^{1/4} (0.27) (f_{cu})^{1/3} ,$$

$$A_e = A_{FRP} (E_{FRP} / E_{steel}) (\phi)$$

$$\varepsilon = \varepsilon_{FRP} / \varepsilon_{yield\ steel}$$

$$\text{when } \varepsilon_{FRP} = 0.0045, \phi = 1.8$$

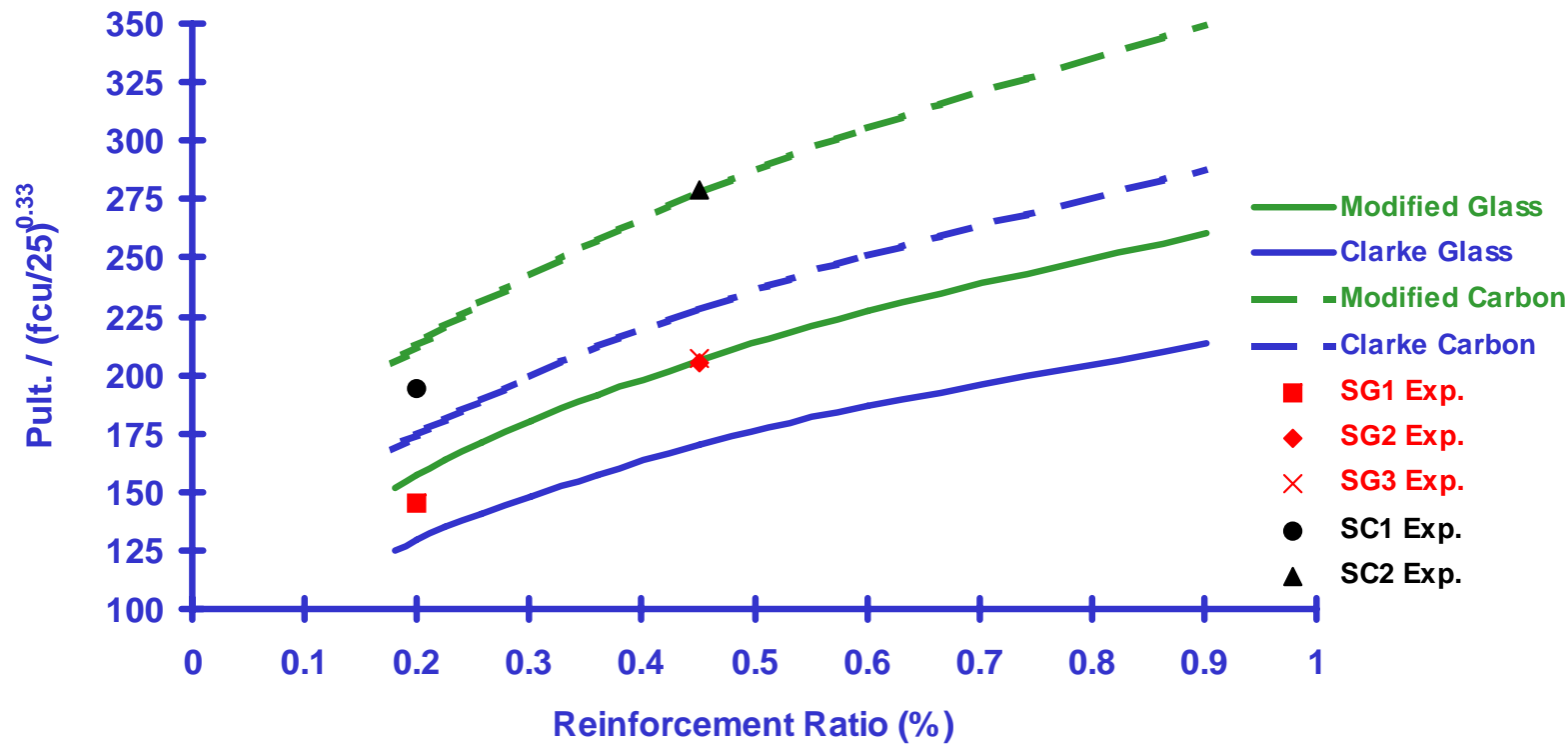


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# Punching Shear Guidelines

## Concrete Shear Resistance

### Normalised Exp. & Pred. Capacities (BS 8110)



### Strain Approach

$$v_c = (100 A_e / b_v d)^{1/3} (400 / d)^{1/4} (0.27) (f_{cu})^{1/3}, \text{ where } A_e = A_r (E_r / 200)$$

### Modified Approach

$$v_c = (100 A_e / b_v d)^{1/3} (400 / d)^{1/4} (0.27) (f_{cu})^{1/3}, \text{ where } A_e = A_r (1.8E_r/200)$$





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# Punching Shear Guidelines

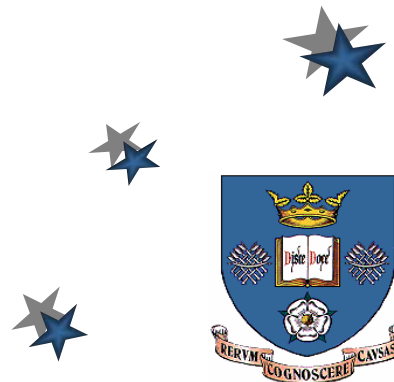
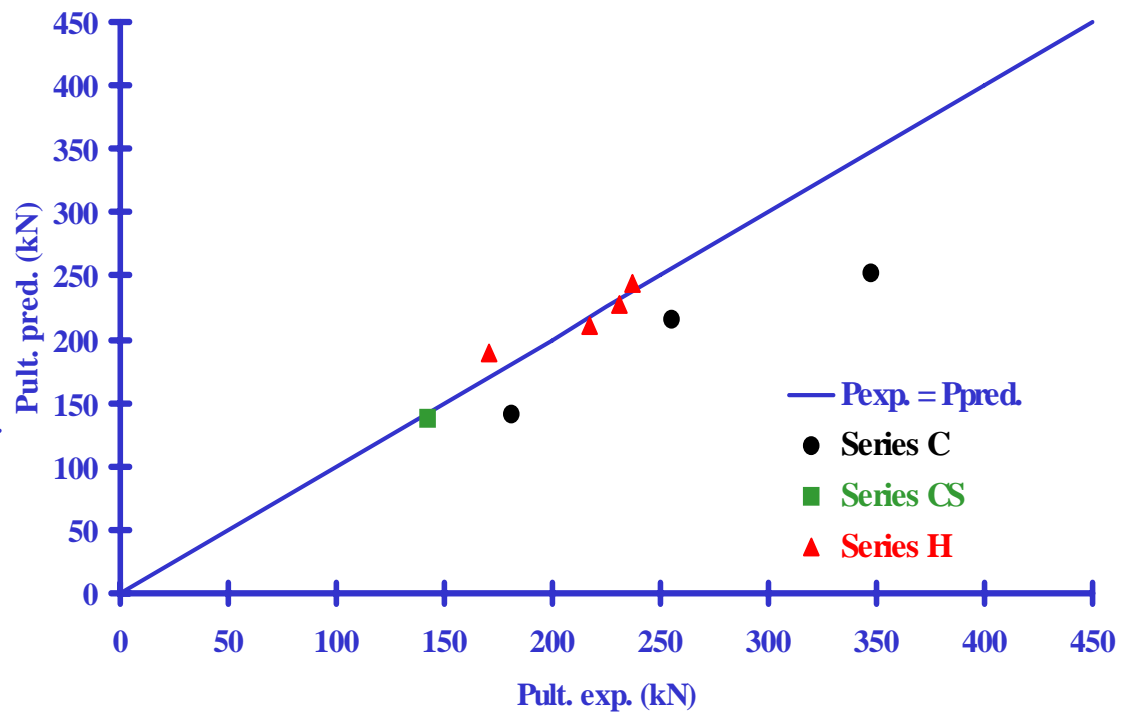
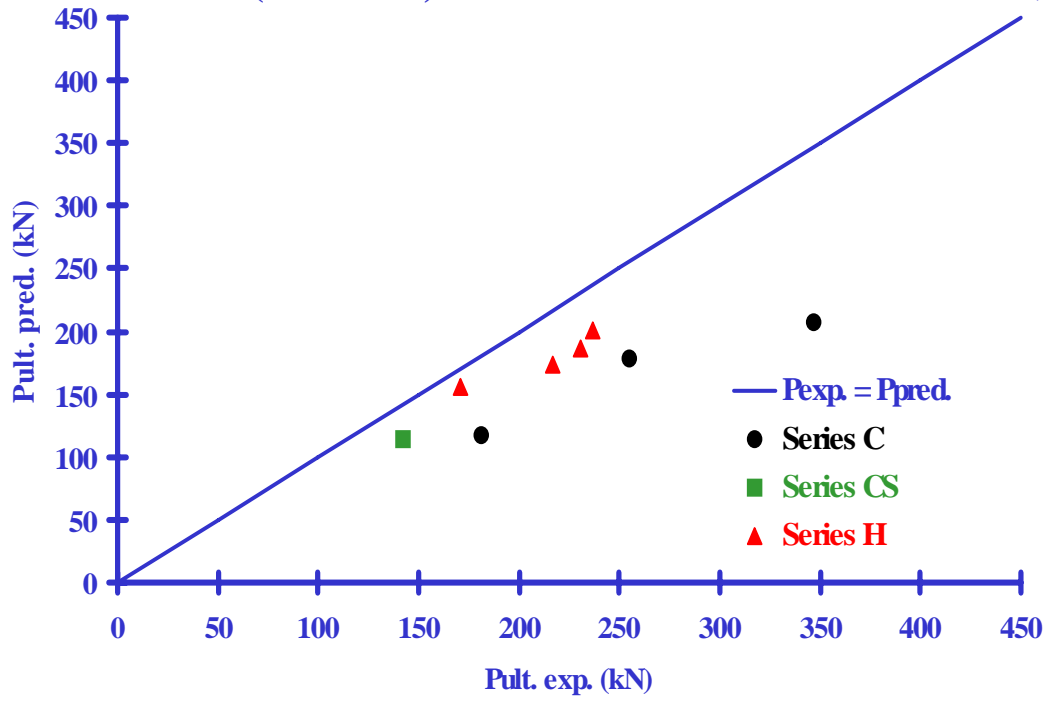
## Concrete Shear Resistance

### Verification of the Modified Approach (BS 8110)



**MODIFIED  
APPROACH  
(BS 8110)**

**STRAIN APPROACH  
(BS 8110)**



# CONCLUSIONS

- **Flexural Design Guidelines**
  - **FEA can predict flexural deformations**  
(though convergence problems encountered)
  - **Main parameters influencing deflections** ( $L/t$ ,  $E$ ,  $\rho$ ,  $f_{cu}$ )
  - **General Design Equation proposed** [ $L/t = f(\Delta r, E, \rho, f_{cu})$ ]
- **Punching Shear Design Guidelines**
  - **Strain App. is conservative**
  - **Modified App. offers good predictions** ( $\phi = 1.8$ )