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University of Birmingham

Axial-bending interaction of high deformability FRP-confined circular concrete members

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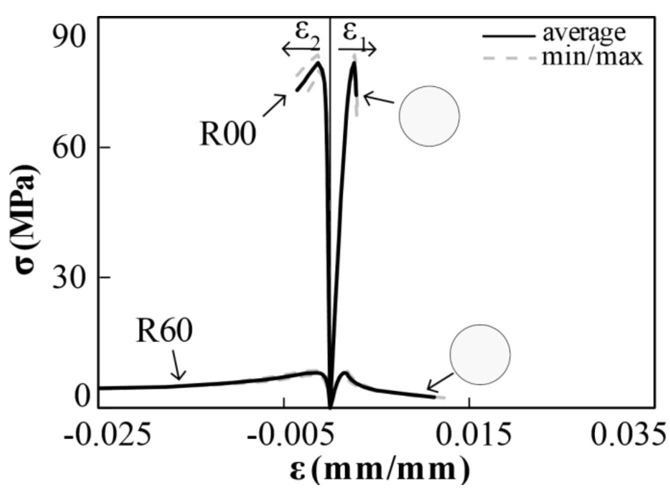
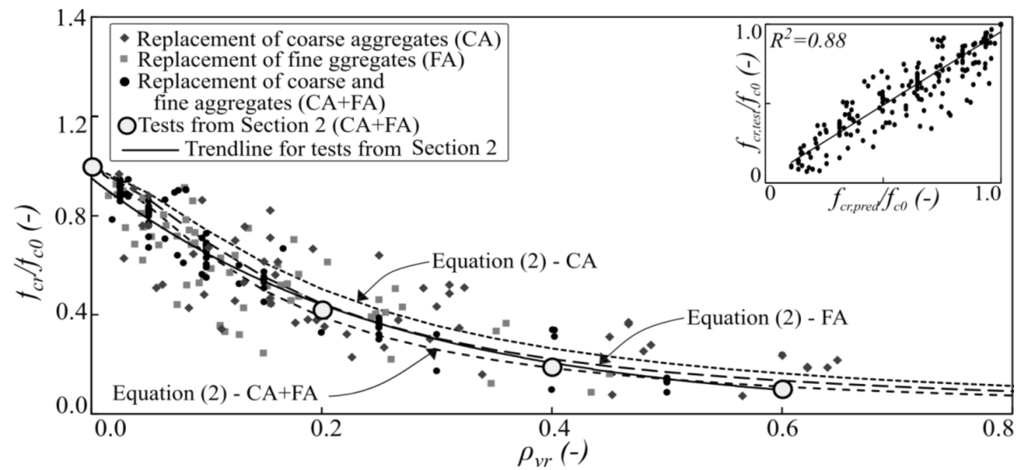
Outline

- Background
- Highly deformable concrete
- Past research
- Experimental assessment
- Analytical considerations
- Conclusions

Deformable concrete / Rubberised Concrete (RuC)

- *Main characteristics*
  - replacement of mineral aggregates with rubber
  - reduction of mechanical properties
  - softer crushing in compression/ increased post-peak ductility



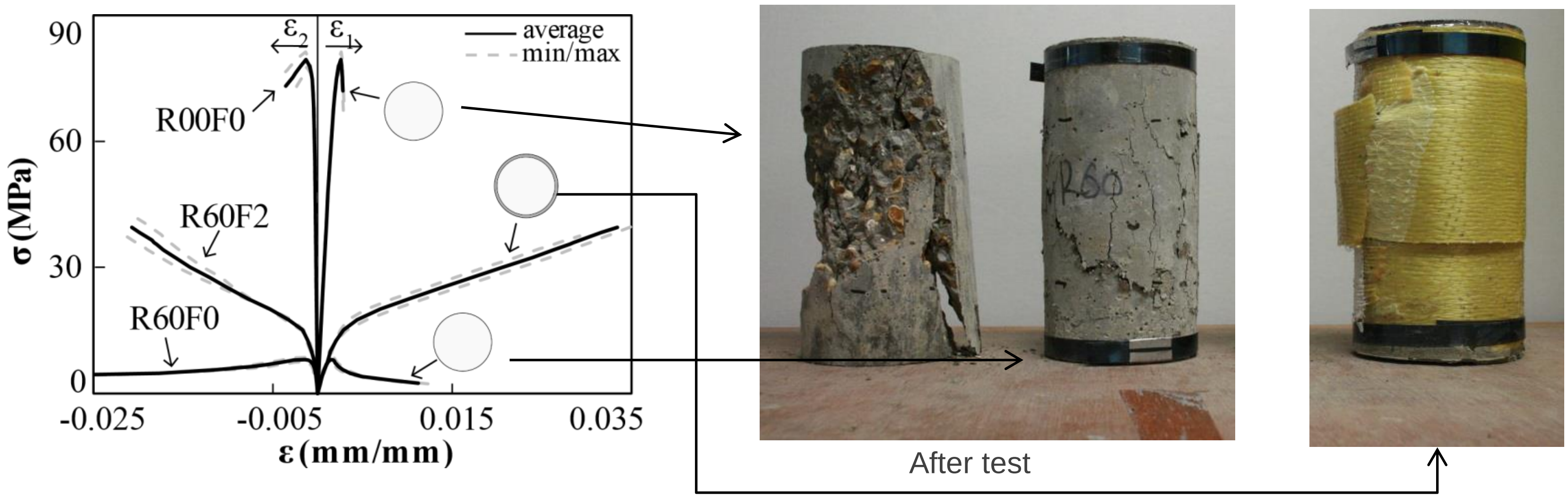


  - potential benefit in beam-column members, members subjected to low axial loads, etc.

Bompa DV, Elghazouli AY, Xu B, Stafford PJ, Ruiz-Teran AM. *Experimental assessment and constitutive modelling of rubberised concrete materials.* Construction and Building Materials. 2017 Apr 15;137:246-60.

High deformability concrete / Confined Rubberised Concrete (CRuC)

- *Main characteristics*

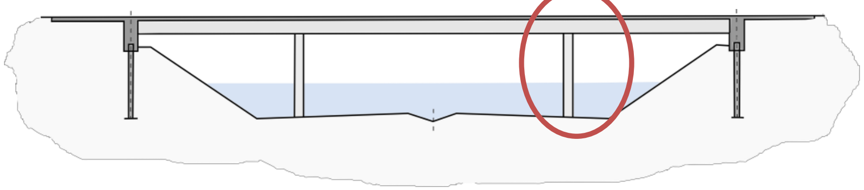


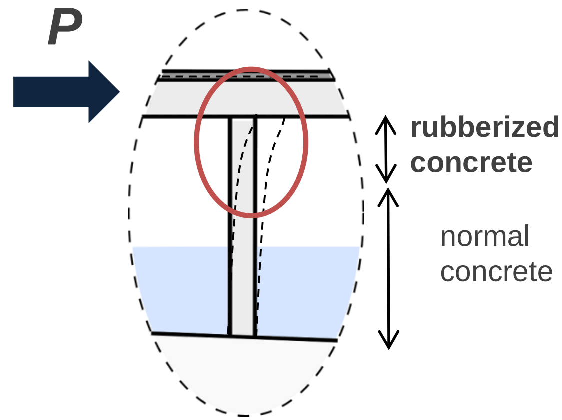
- Use of FRP confinement to control lateral expansion of cylinders by wrapping with 2-3 AFRP sheets
- (e.g.) replacement of 60% FA and 60% CA (lightweight)
- f_{c0}=70 MPa, f_{cr} = 7.5 MPa, f_{ccr} = 55 MPa
- Significantly higher deformability vs conventional concrete
- Ultimate axial strains ε_{cu}>5…8% (f-> number of layers)
- up to +20 times current ε_{cu} included in codes

Bompa DV, Elghazouli AY. *Creep properties of recycled tyre rubber concrete*. Construction and Building Materials. 2019 Jun 10;209:126-34.

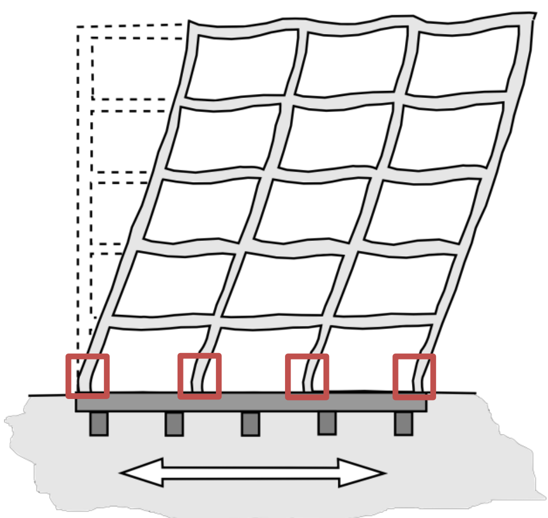
Confined Rubberised Concrete (CRuC)

- *Potentials applications*
  - *integral bridges*

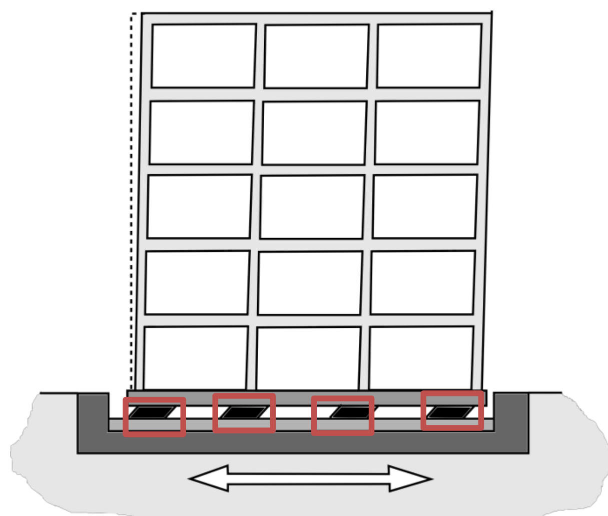




  - *buildings under seismic action*



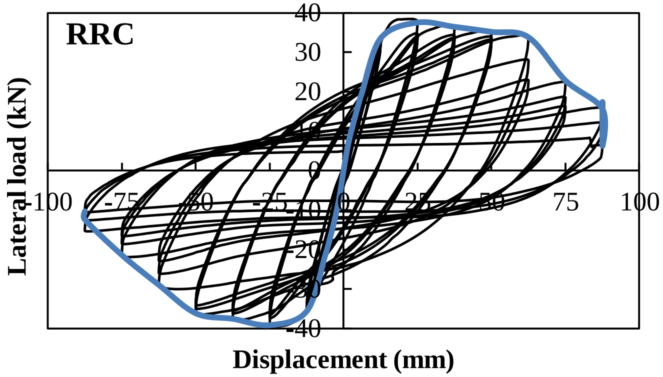
plastic hinge regions

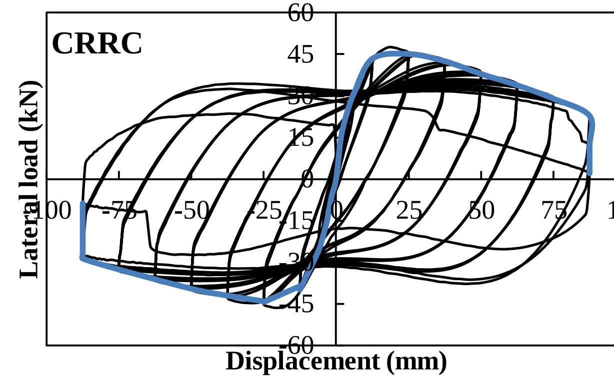


base isolation systems

Confined Rubberised Concrete (CRuC)

- *Previous tests*

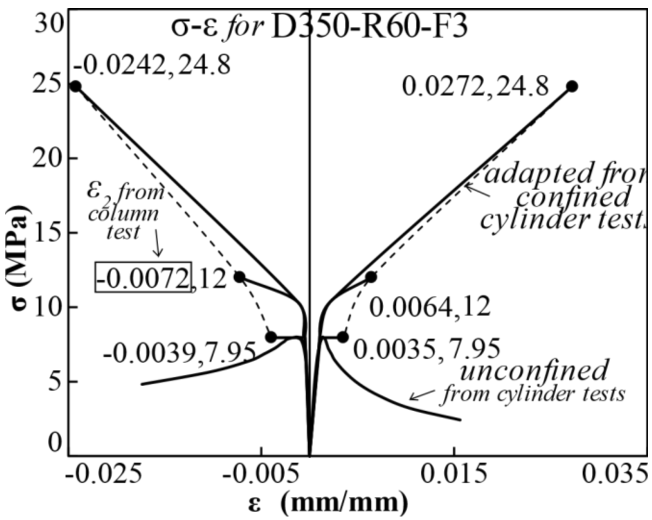


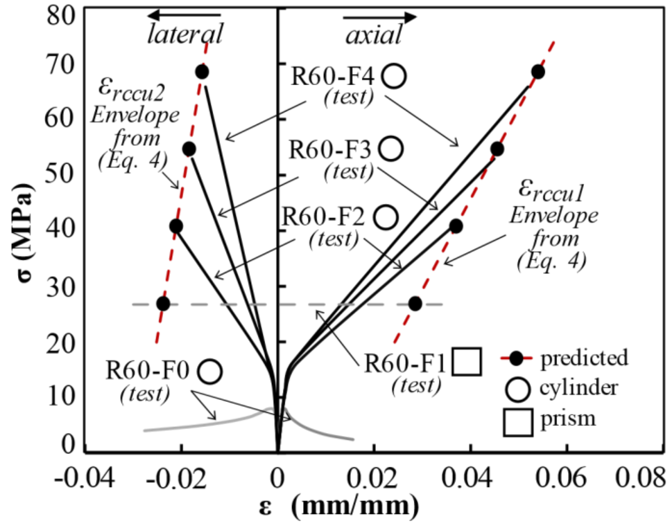


Elghazouli AY, Bompa DV, Xu B, Ruiz-Teran AM, Stafford PJ. *Performance of rubberised reinforced concrete members under cyclic loading*. Engineering Structures. 2018 Jul 1;166:526-45.

Confined Rubberised Concrete (CRuC)

- *Previous tests*
  - *Uniaxial tests on cylindrical samples*





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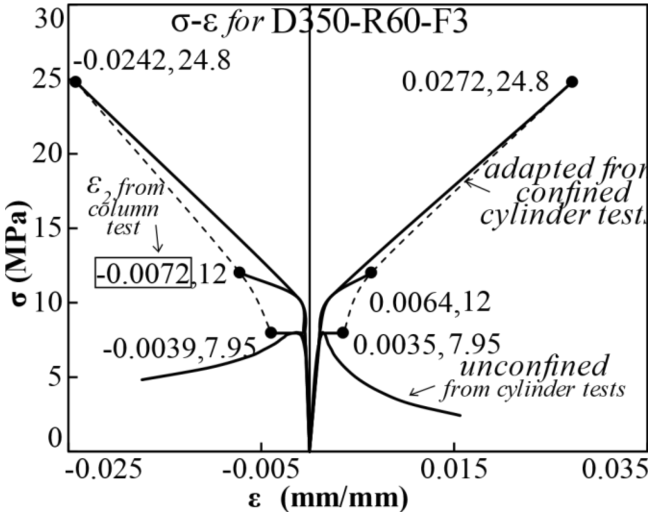
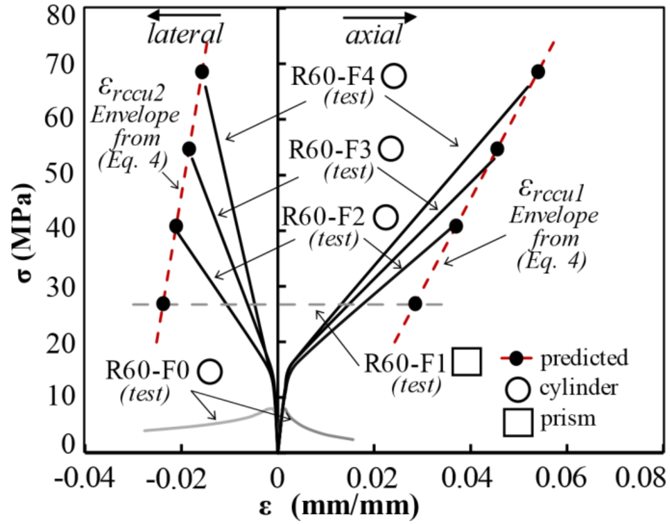
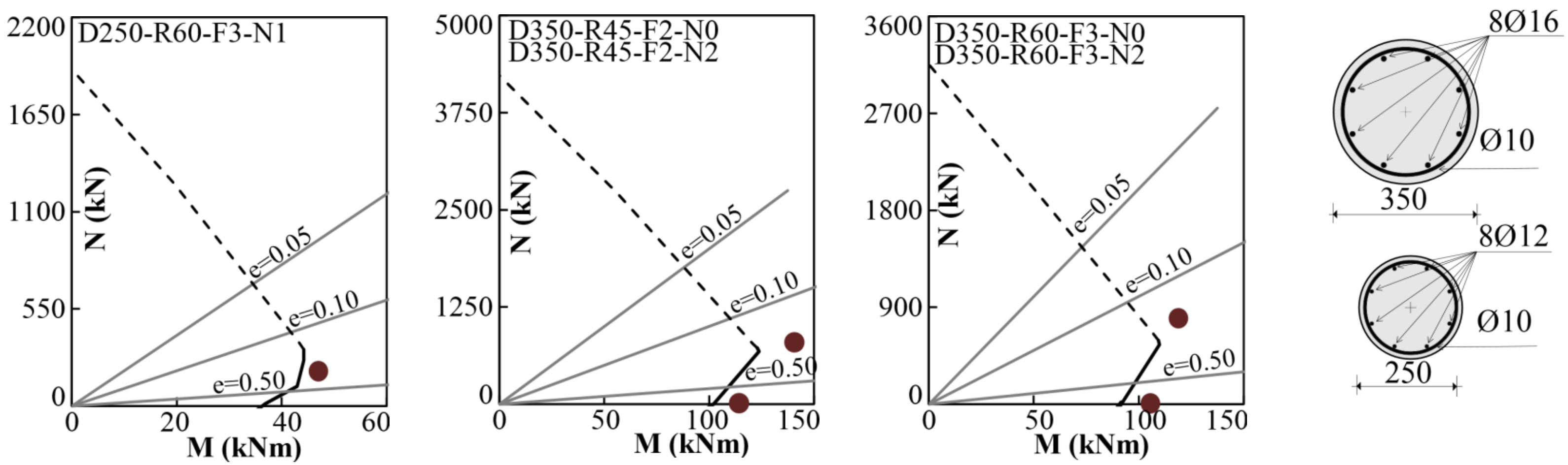




  - *Axial-bending interaction from structural tests:*



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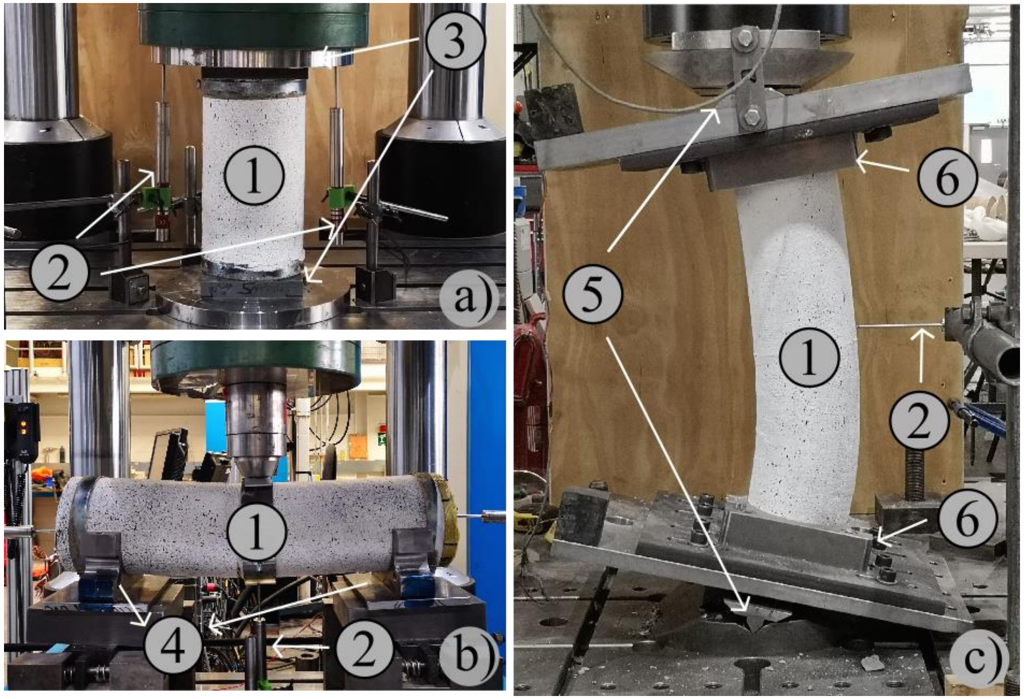
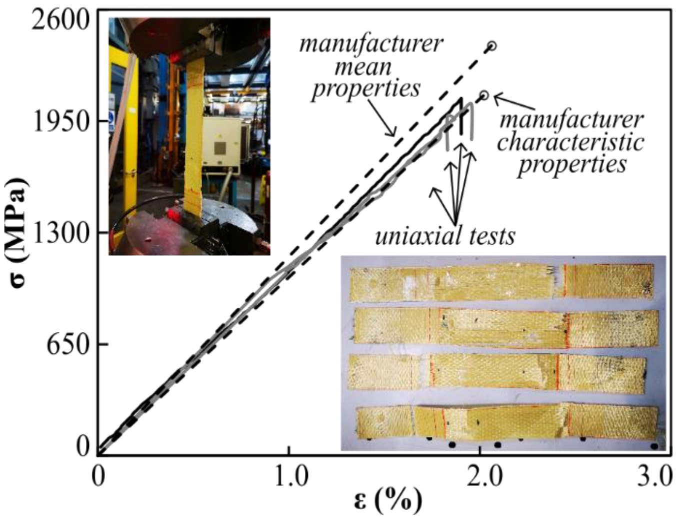
Axial-bending interaction

- *Testing arrangements*

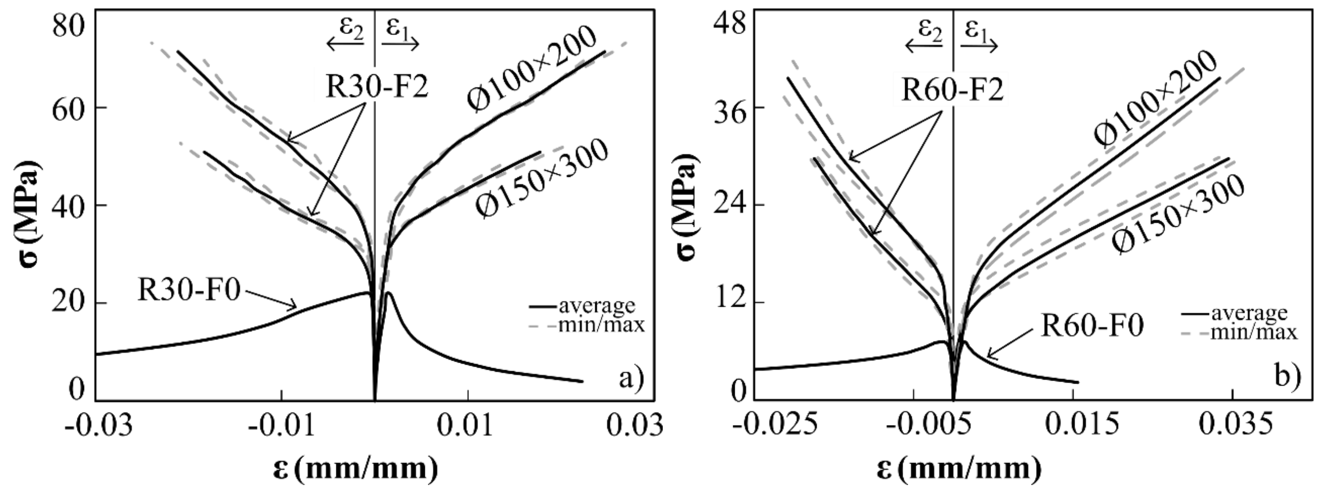


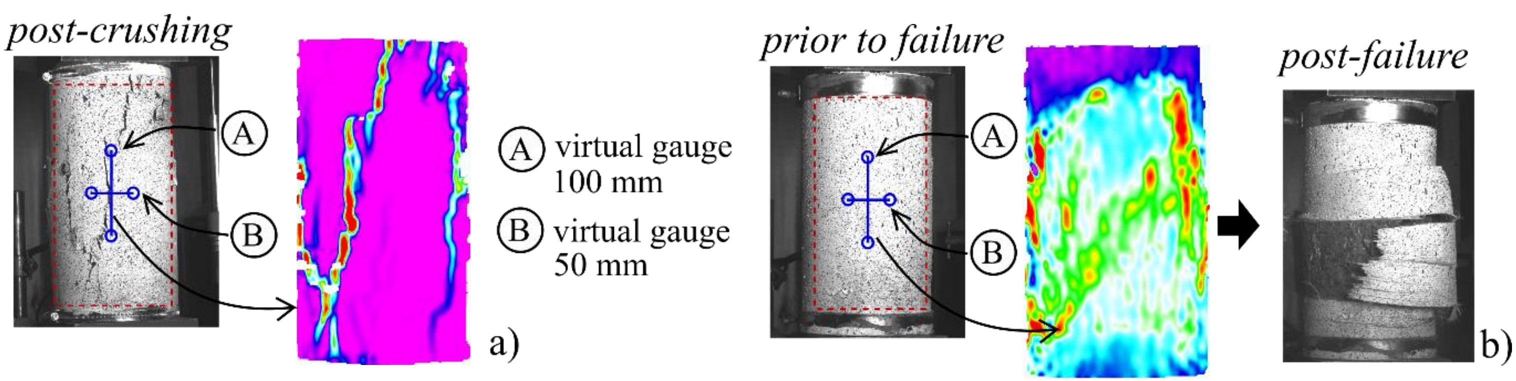


- more than 40 tests on Ø100 cylinders with R0, R30 and R60, and 0-4 AFRP layers
- more than 20 tests on Ø150 mm tests under: axial compression, eccentric compression, three point bending
- uniaxial coupon tests on aramid FRP samples

Uniaxial compression: test results

- *jacket thickness-to-member diameter (t/D)*





Uniaxial compression: test results

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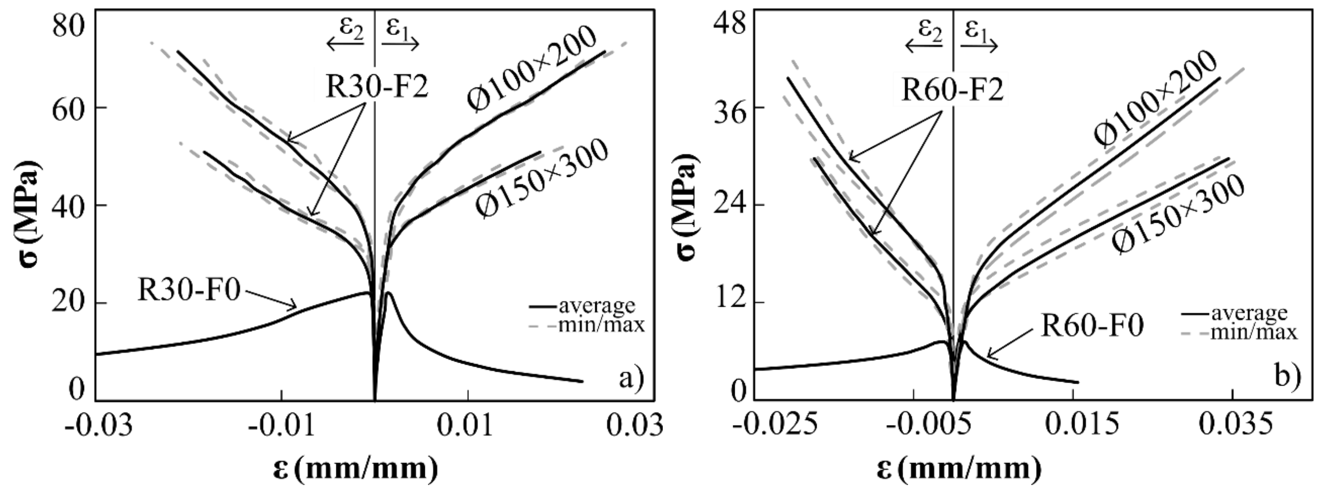
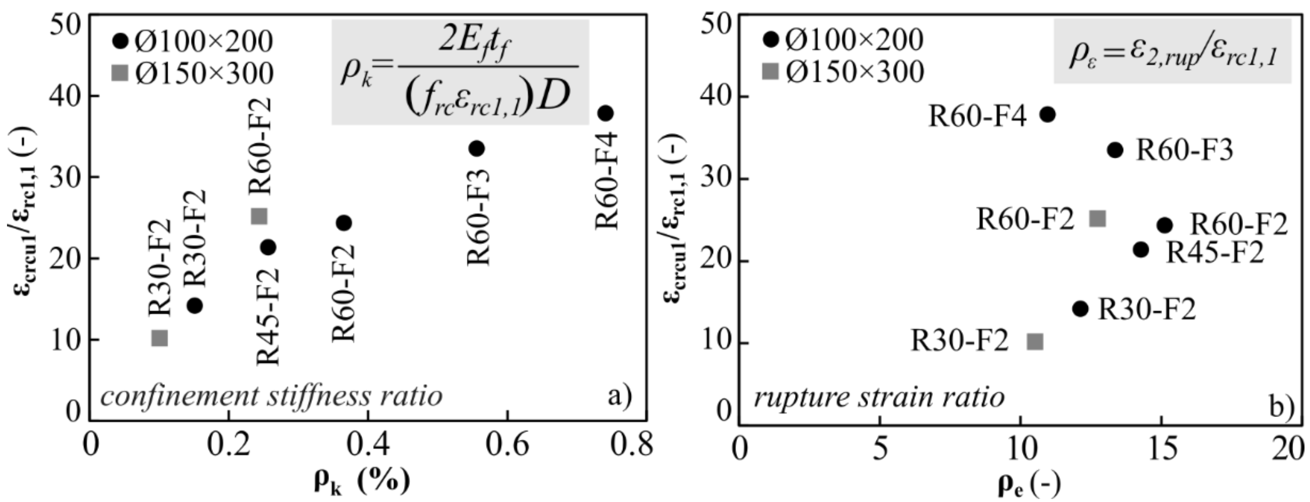
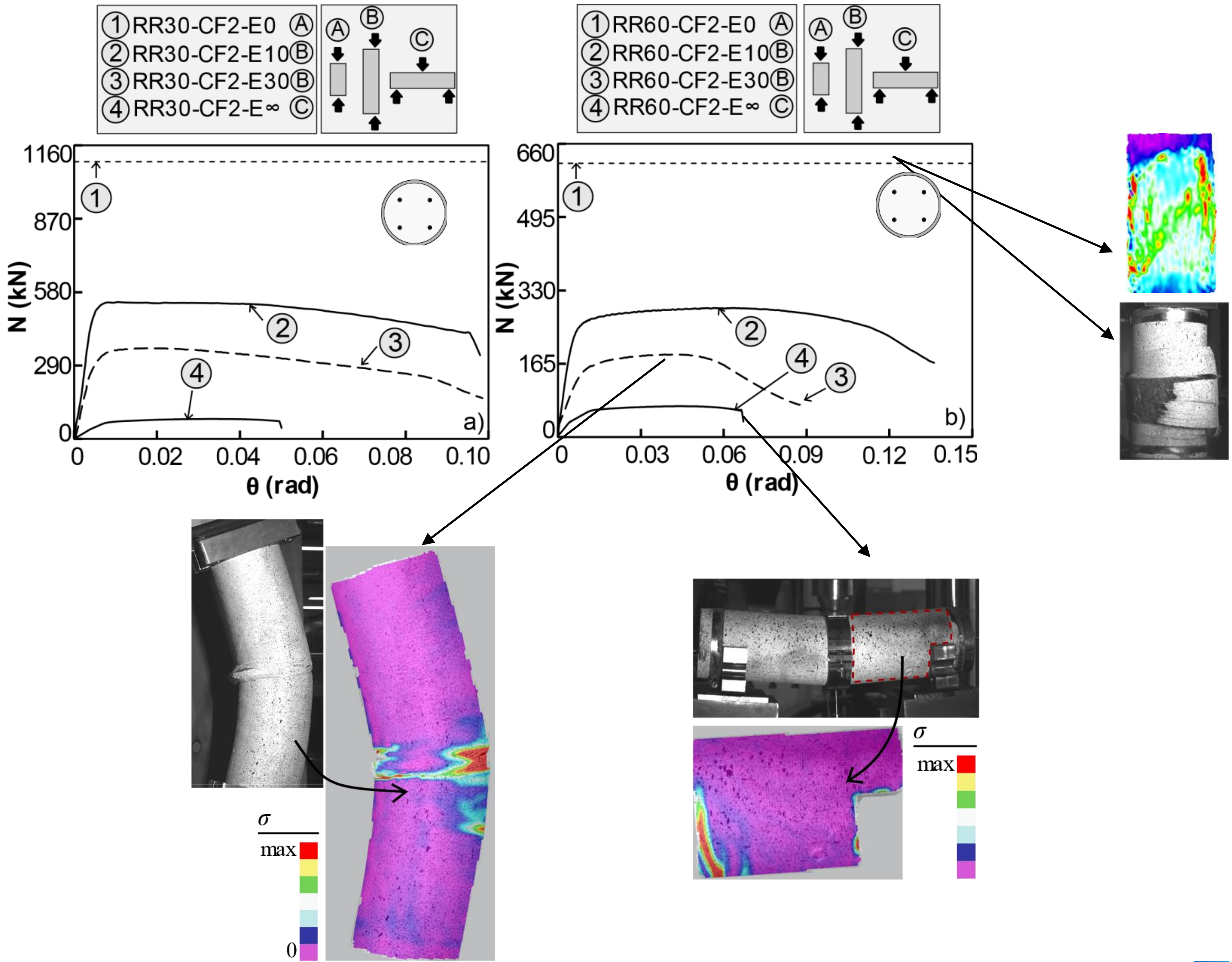


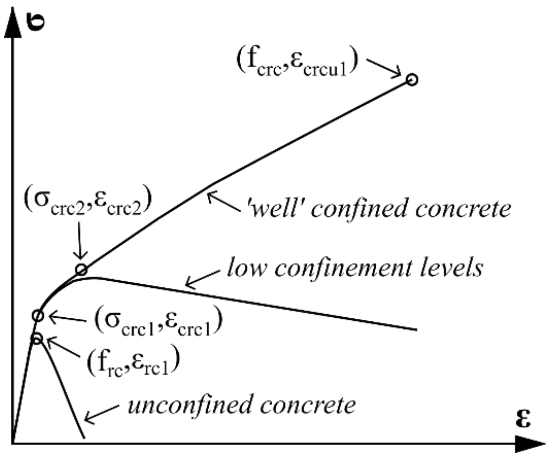
- *confinement stiffness ratio ρ_k, and rupture strain ratio ρ_ε.*



Eccentric compression and bending: test results

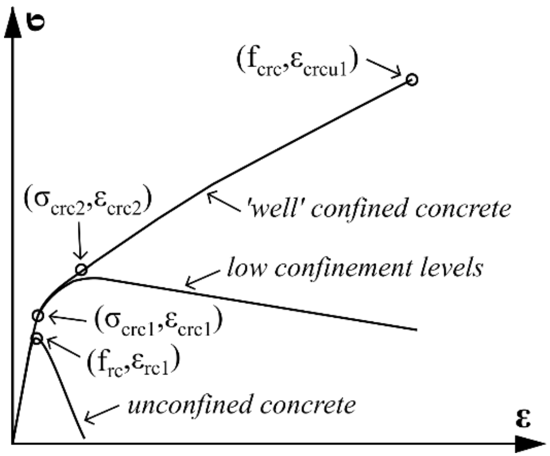


Assessment: uniaxial compression



Bompa DV, Elghazouli AY, *Response of reinforced rubberised concrete members under combined loading conditions*., Imperial College London, 2018

Assessment: uniaxial compression



- *design-oriented model*

$$f_{crc} = f_{rc} + k_1 \kappa_l \varepsilon_{fu}$$

$$k_1 = 4(1-\rho_{vr}) - \left[0.05 f_{rc}(t_f / D)^{0.15}\right]$$

$$\kappa_l = f_l / \varepsilon_{fu}$$

$$f_l = 2E_f t_f \varepsilon_{fu} / D$$

$$f_{rc} = \frac{1}{1+2(1.5\lambda\rho_{vr})^{3/2}} f_{c0}$$

$$\lambda = \left(2.43 \to d_{g,repl} \in (0,5), 2.90 \to d_{g,repl} \in (0,d_{g,max}), 2.08 \to d_{g,repl} \in (5,d_{g,max})\right)$$

$$\varepsilon_{crcu1} = \left[1 + k_2 (\kappa_l / f_{rc})^{1/2} (\varepsilon_{fu} / \varepsilon_{cr1})^{5/4}\right] \varepsilon_{cr1}$$

$$k_2 = \frac{1+1.25\rho_{vr}}{5(1+7\rho_{vr})\left[1+100(t_f \times f_{rc})/(D \times f_{crc})\right]}$$

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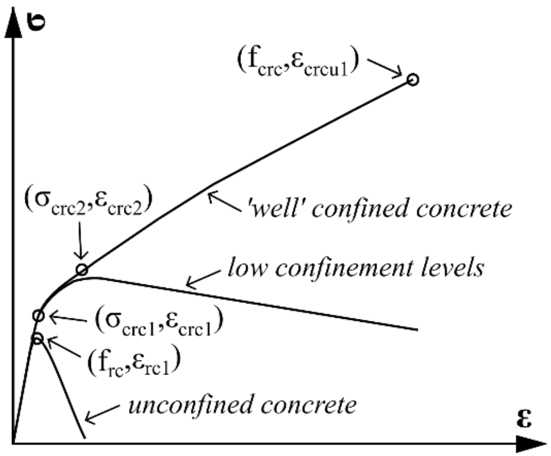
Assessment: uniaxial compression



- *design-oriented model*

$$f_{crc} = f_{rc} + k_1 \kappa_l \varepsilon_{fu}$$

$$k_1 = 4\left(1-\rho_{vr}\right) - \left[0.05 f_{rc}\left(t_f / D\right)^{0.15}\right]$$

$$\kappa_l = f_l / \varepsilon_{fu}$$

$$f_l = 2E_f t_f \varepsilon_{fu} / D$$

$$f_{rc} = \frac{1}{1+2\left(1.5\lambda\rho_{vr}\right)^{3/2}} f_{c0}$$

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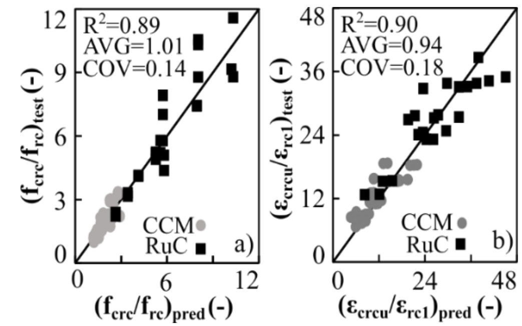
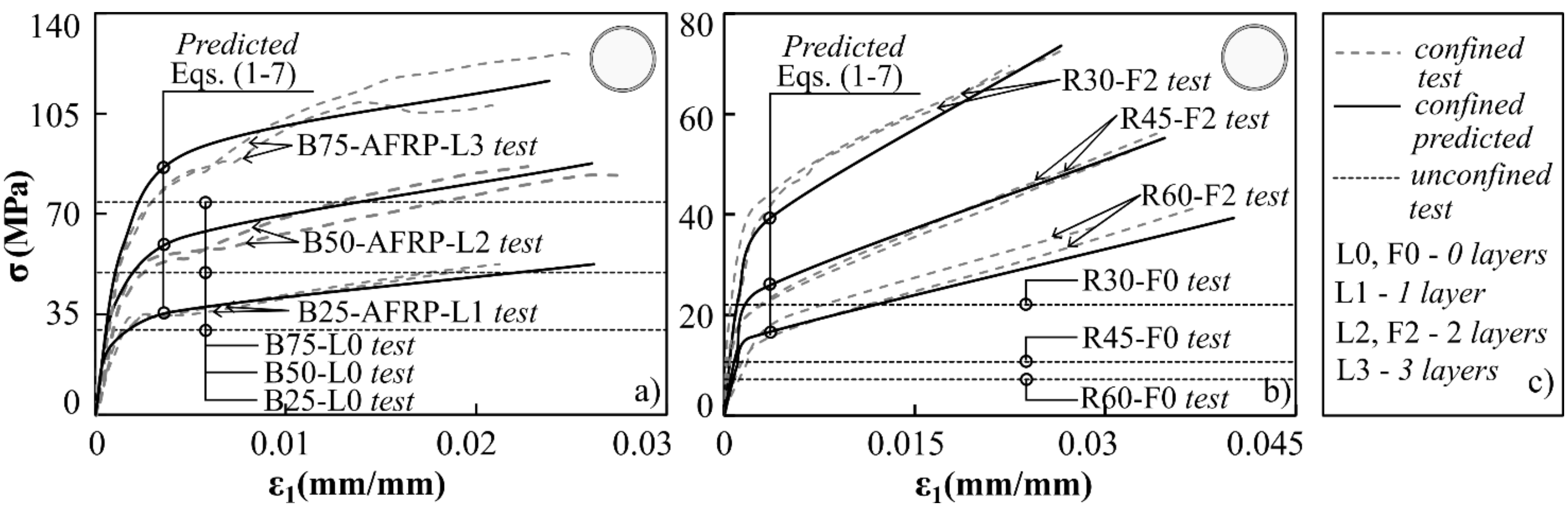
$$\varepsilon_{crcu1} = \left[1 + k_2\left(\kappa_l / f_{rc}\right)^{1/2}\left(\varepsilon_{fu} / \varepsilon_{cr1}\right)^{5/4}\right]\varepsilon_{cr1}$$

$$k_2 = \frac{1+1.25\rho_{vr}}{5\left(1+7\rho_{vr}\right)\left[1+100\left(t_f \times f_{rc}\right)/\left(D \times f_{crc}\right)\right]}$$





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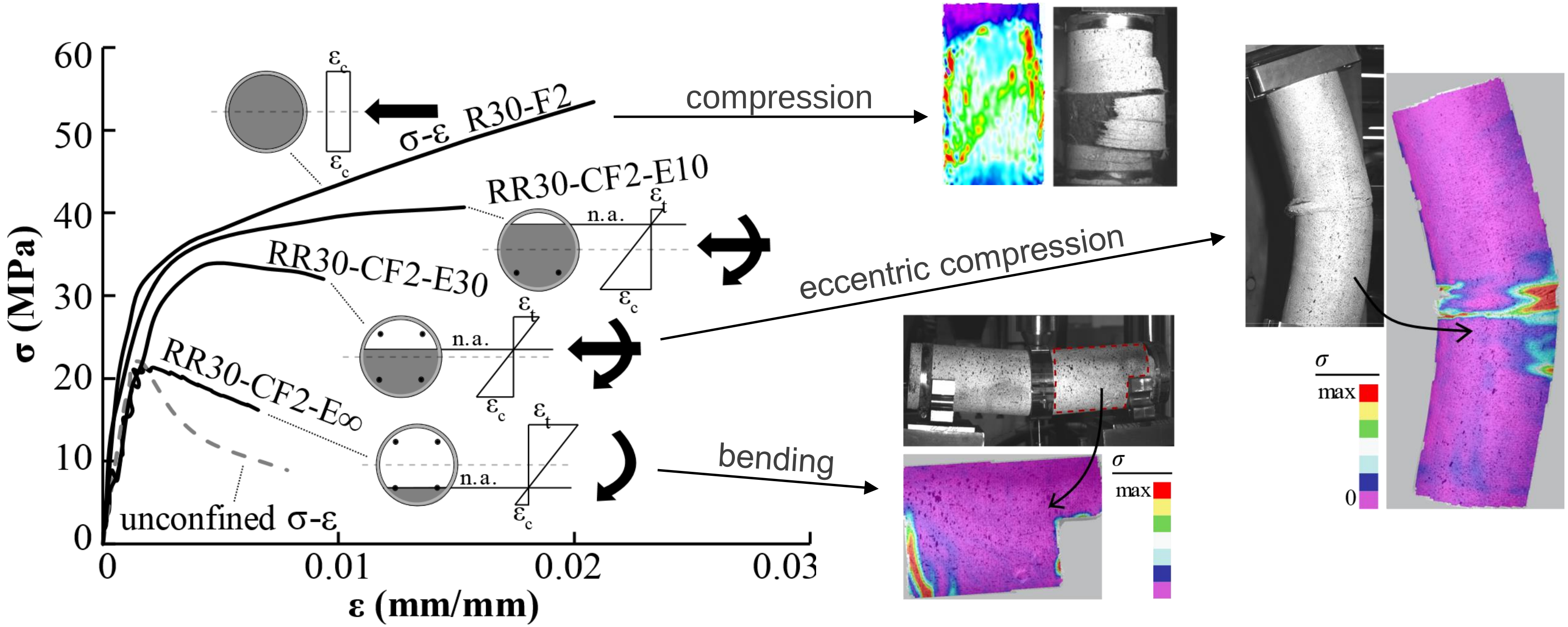
Assessment: axial-bending interaction



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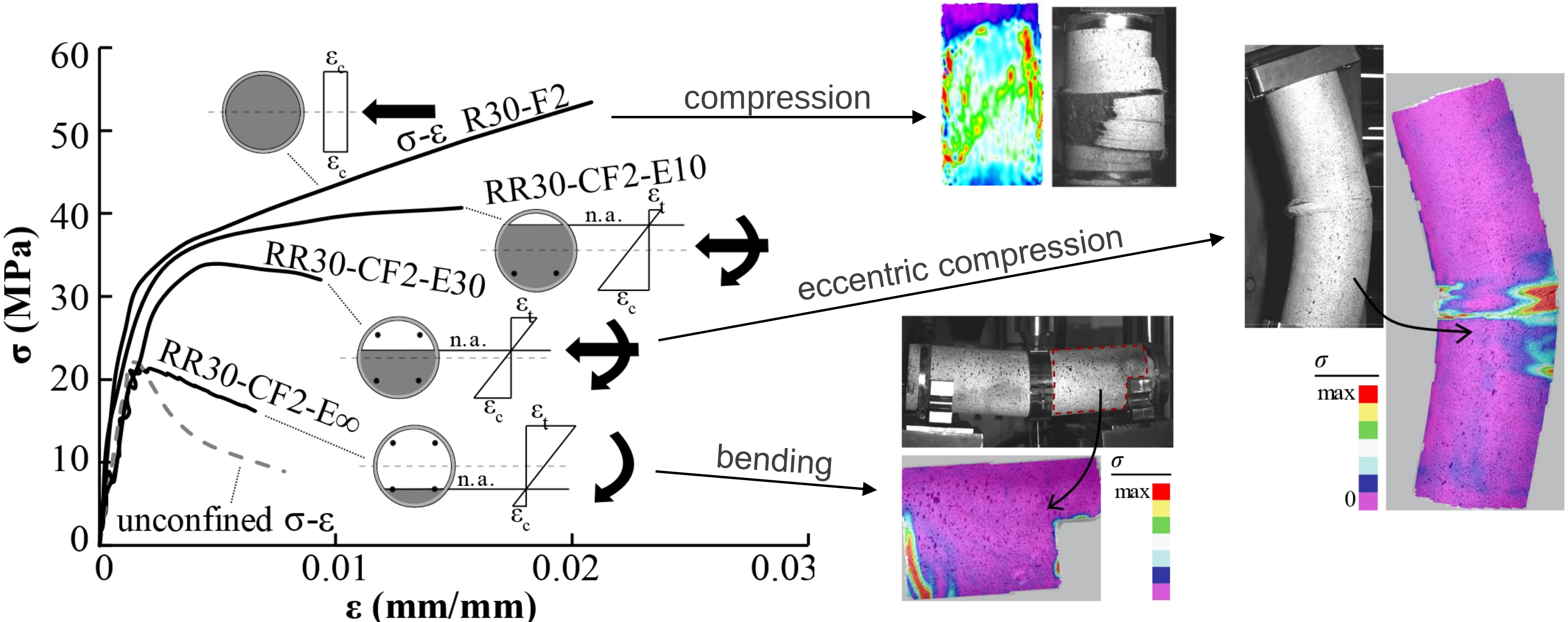
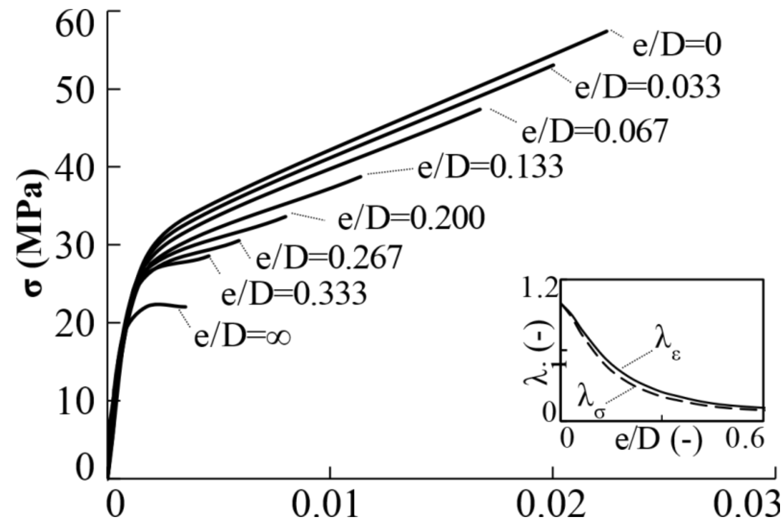


- *account for eccentricity*

$$\lambda_i = 1/\left[1+\eta\left(e/D\right)^{3/2}\right]$$

$$\eta = \begin{vmatrix} (1.25/100) \rightarrow \lambda_i = \lambda_\sigma \\ (1.0/100) \rightarrow \lambda_i = \lambda_\sigma \end{vmatrix}$$



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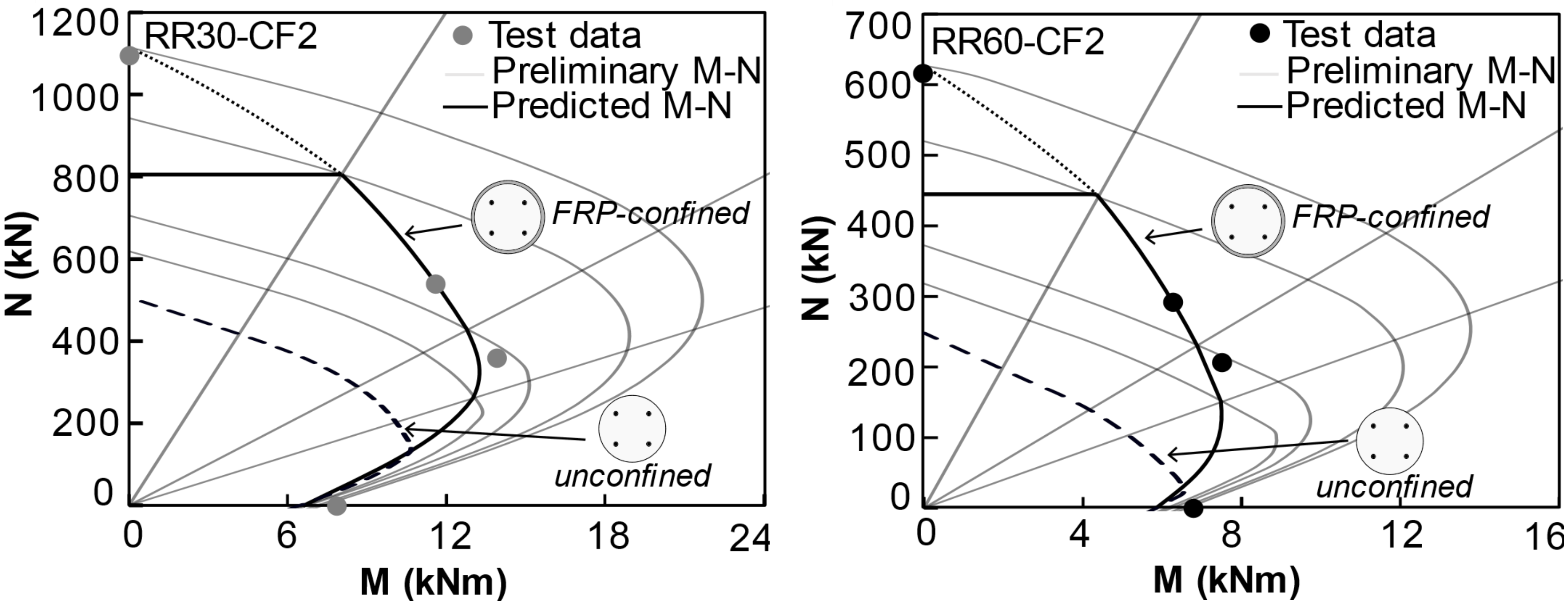

Concluding remarks

- experimental response of structural reinforced rubberised concrete members subjected to a wide range of combined axial-bending loading conditions
- FRP-confined rubberised concrete is characterised by a bilinear response, with the initial stiffness typically identical to that of the unconfined concrete; the proportionality limit and transition region are influenced by the rubber content
- the externally confined members reached reliable ultimate rotations with values multiplied by a factor of ten, for relatively small eccentricity, in comparison to similar unconfined members, but with no influence for pure bending
- a set of design expressions for the complete uniaxial constitutive response, as well as a variable confinement procedure for the full-strength interaction diagrams of circular members