Present Research into Concrete Bridges at the University of Bath

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Inadequate Anchorage

Poor reinforcement anchorage is a common cause for shear assessment failures of older bridges in the UK

There is often a significant effect on the assessed shear capacity

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EPSRC
Engineering and Physical Sciences Research Council

PARSONS BRINCKERHOFF

HIGHWAYS AGENCY

Jon Shave, Steve Denton and Tim Ibell

Effects of Poor Anchorage (BD44/95)

Poor anchorage

↓

Conservative, empirical or semi-empirical rules of thumb

↓

Significant theoretical reduction in assessed structure strength

Reduced concrete shear capacity if $L<12\phi$

+

No shear enhancement at short shear spans if $L<20\phi$

+

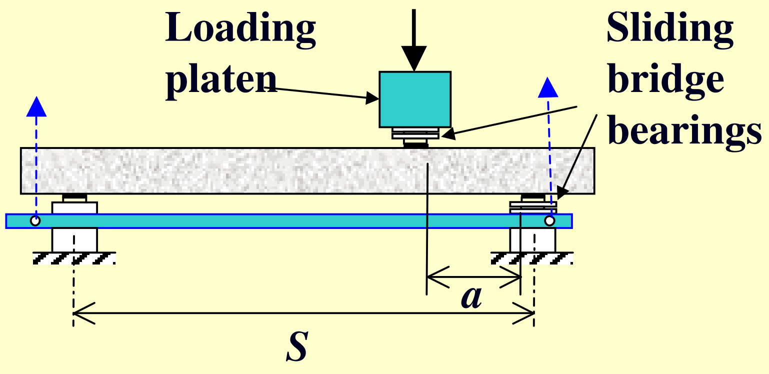
Shear stirrups ineffective at low anchorage

New Approach Requirements

- **Rational (based on sound theory)**
- **Realistic (accurate and consistent with test data)**
- **Compatible with existing approach (converges to existing fully-anchored situation)**

Experimental Investigation

- Laboratory Testing
  - Shear tests on beams and slabs



Test set-up

Parameters

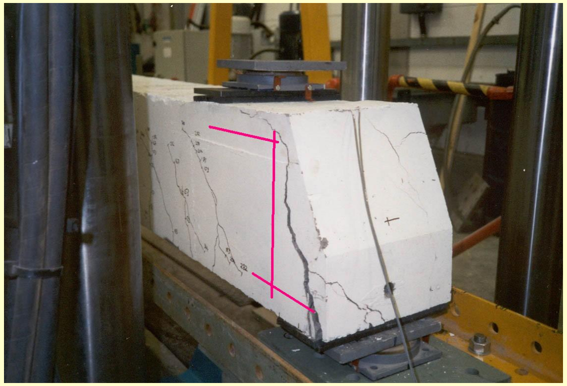
– **Varying anchorage lengths *L***

– **Other parameters varied in the tests:**
  - **Stirrups**
  - **Transverse slab reinforcement**
  - **Compression reinforcement**
  - **Shear span**
  - **Reinforcement type**
  - **Bar diameter**
  - **Member width**
  - **Discrete/continuous bearings**

Additional Case-Specifics

Some real structures required no strengthening.

The research led to a direct saving of at least £400,000.



Saving already many times more than the cost of the research.

Projected savings associated with assessment of remaining bridge stock much greater.

Experimental Findings

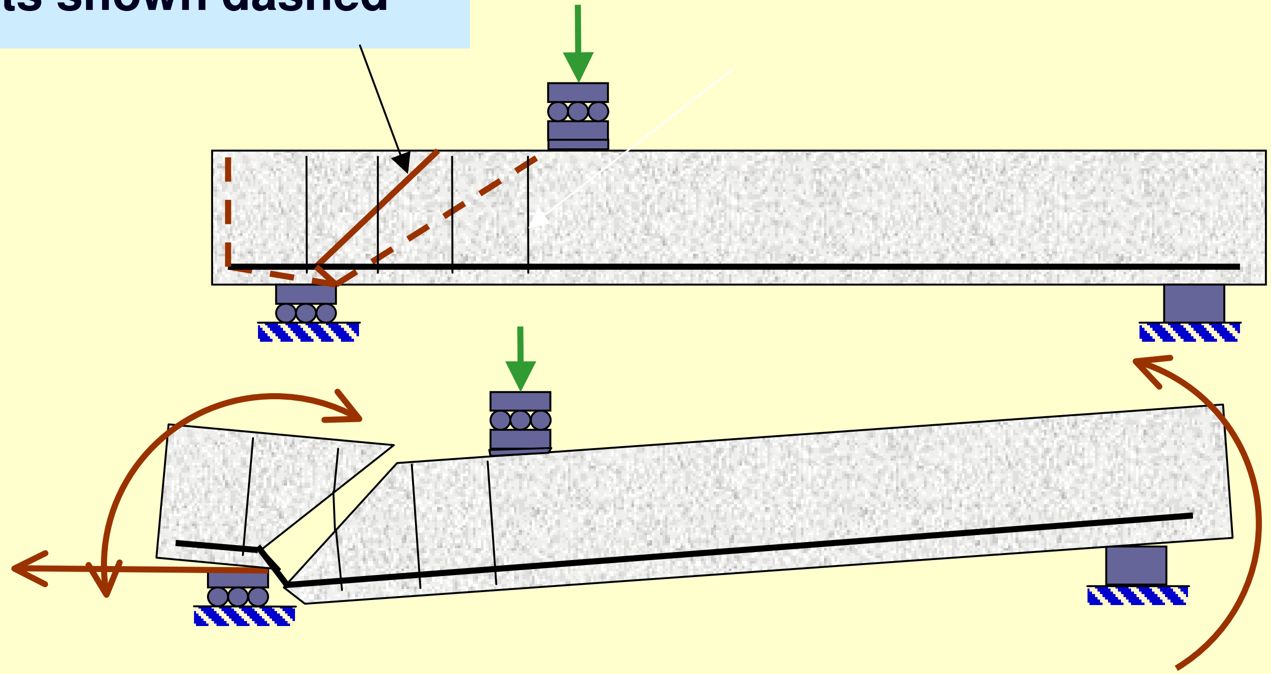
	Current Standard (BD44/95)	Test results
Concrete component	Reduction at low anchorage	Less sensitive to anchorage than previously considered
Shear enhancement at short shear spans	None at anchorage lengths $L<20\phi$	Shear enhancement observed even at low anchorage lengths
Stirrups	Ineffective at low anchorage	Shear capacity increased by stirrups, even at low anchorage
Bar type	Concrete shear capacity independent of bar type	Deformed bars significantly more effective than plain round bars at low anchorage

Theoretical Modelling

- Plasticity theory
  - Upper- and Lower-Bound Models
  - Ductility
  - Effectiveness factors
  - Particularly useful for assessment of concrete structures

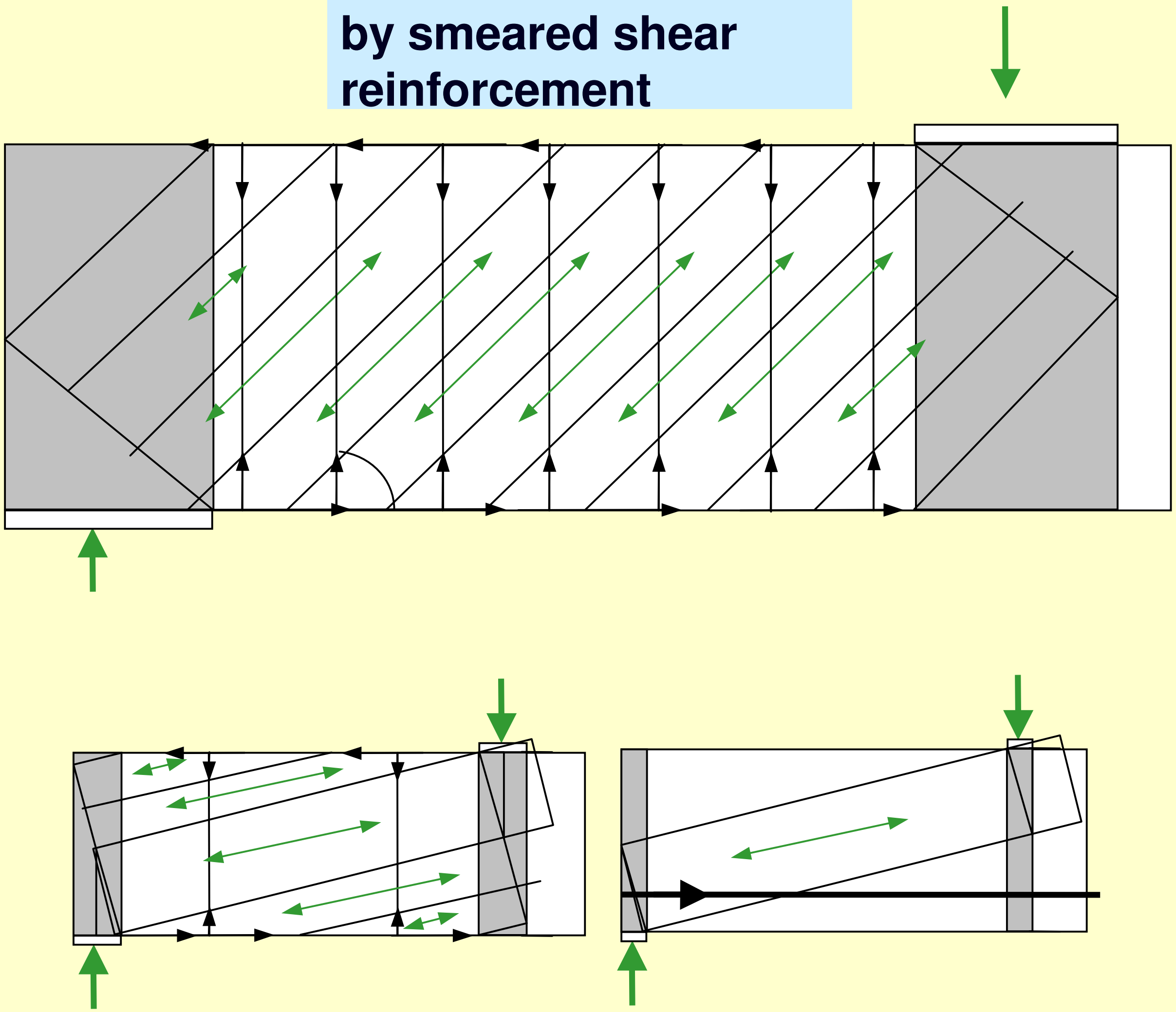
Upper-Bound Approach

Bilinear discontinuity optimised between limits shown dashed

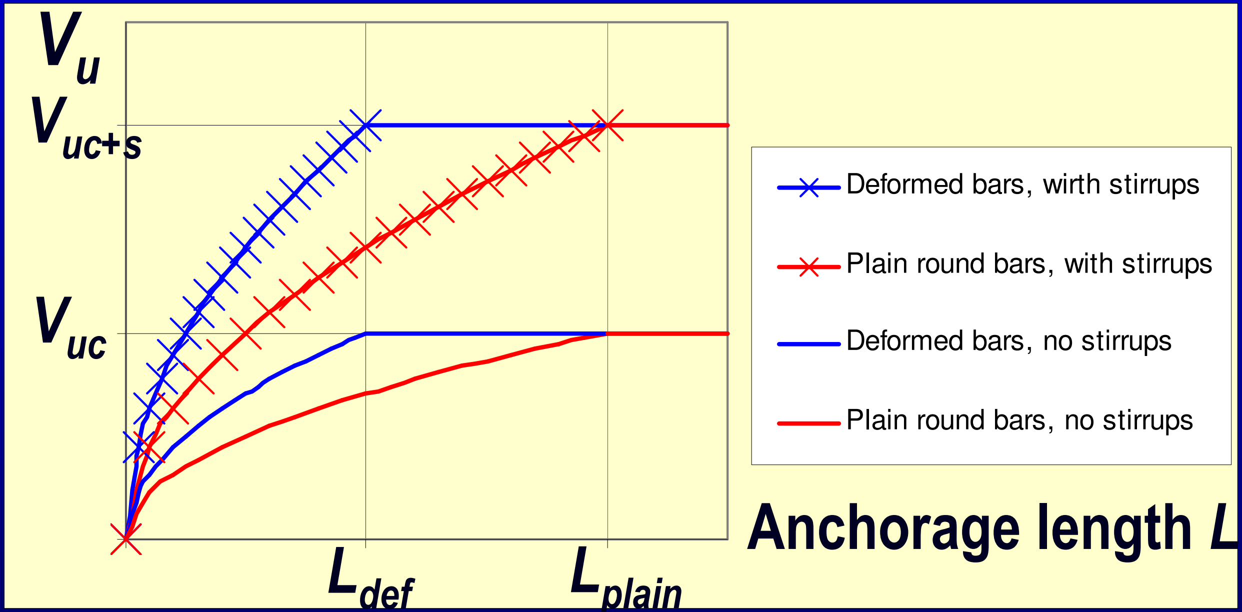


Lower-Bound Approach

Vertical forces carried by smeared shear reinforcement



Predictions



$$V_u \propto \sqrt{F_{ub}}$$

Proposed Assessment Method

Shear capacity

$$V_u = \Gamma V_{u\max}$$

Fully anchored shear capacity *including shear enhancement and shear reinforcement*

Reduction factor to account for low anchorage

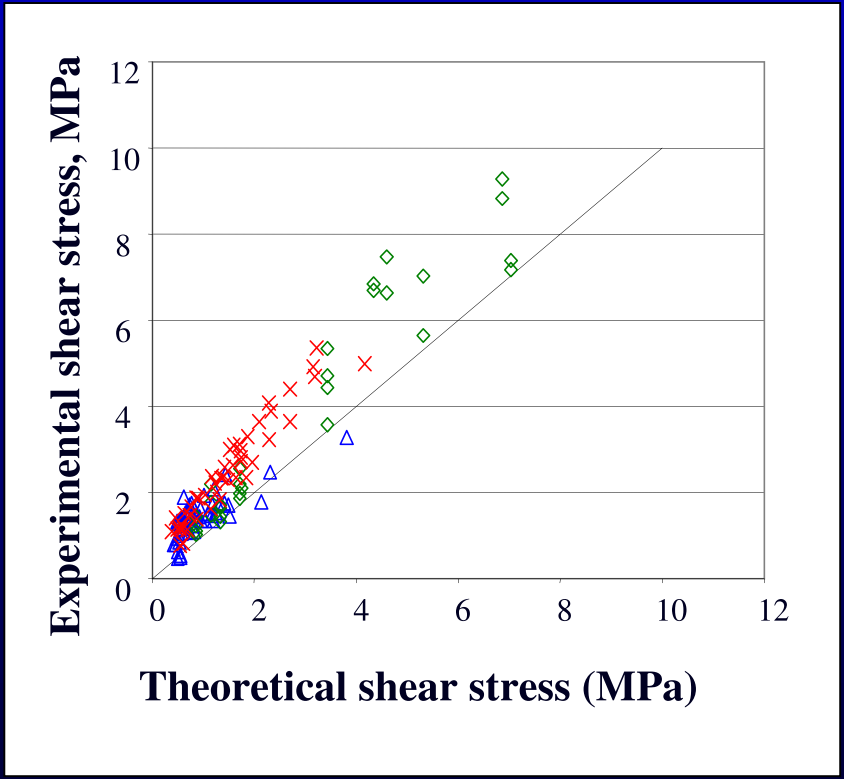
Anchorage force at support

Factor accounting for increased bond strengths due to transverse pressure

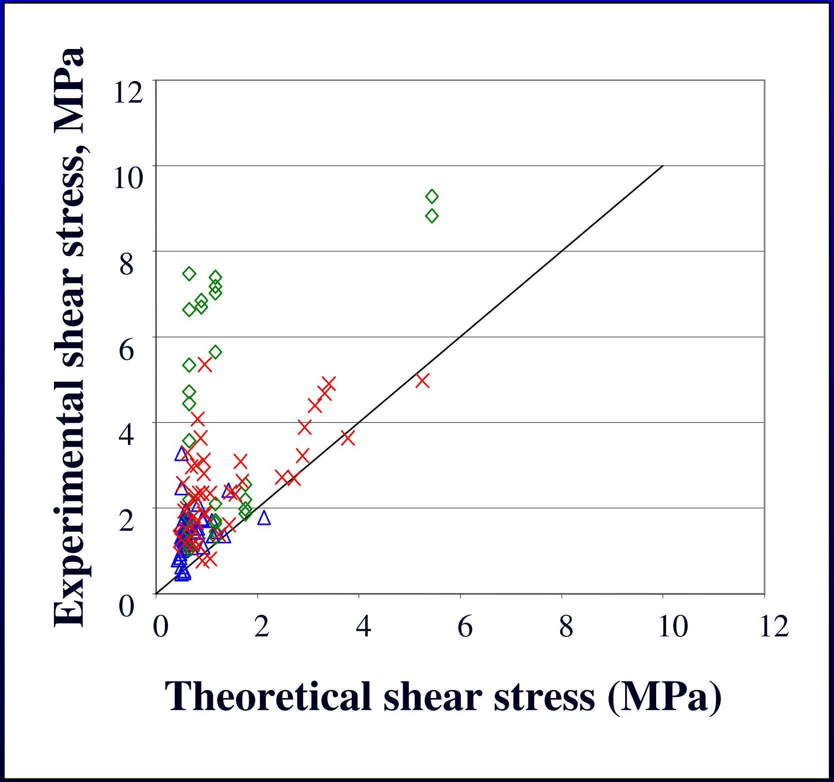
$$\Gamma = \sqrt{\frac{\alpha_s F_{ub}}{F_{ub\max}}}$$

Anchorage force required to give fully anchored shear capacity

Correlation and Calibration



New Proposed Method



Existing BD44/95 Method

Updated Version of Concrete Society Report TR55

In 2000, TR 55 first document to provide advice on use of FRP to strengthen concrete structures

Presently several documents, and updated TR 55 required

Updated version due for release in 2004

John Clarke, Antony Darby, Tim Ibell, Steve Denton, Sam Luke and Neil Farmer

General Areas of Updating TR55

1. Case studies
2. Review of partial safety factors
3. Inclusion of impact, blast and vandalism

Specific Areas of Updating TR55 - Flexure

1. Eradicate 'balanced-moment' approach to flexural strength capacity calculations
2. Anchorage lengths when steel has yielded
3. Anchorage devices to be included
4. Curved soffits
5. Near-surface mounted (NSM) reinforcement

Specific Areas of Updating TR55 - Shear

1. Present model for maximum stress in U-wrap systems (prior to peeling) based on ultimate strain capacity of the FRP. Needs to be re-examined fundamentally.
2. Strain limit of 0.004 seems sensible for aggregate interlock considerations.
3. Further limit given by half of FRP strain capacity, related to average strain in the FRP (zero at top, fully stressed at bottom).

Specific Areas of Updating TR55 - Columns

1. Flexure and axial compression considered separately. Should be treated together.
2. Guidance on rectangular and square columns required.
3. Approach to be based on that of Teng et al., involving a shape factor to allow for partial confinement of concrete.
4. Testing urgently required in this field.

Specific Areas of Updating TR55 – New Sections

1. Design flow charts, rather than specific examples.
2. Decision flow charts, providing information on which type of strengthening to employ.
3. Emerging technologies, at research stage and at prototype stage, including

   Post-tensioned systems, FRP anchorages, Concrete masonry walls, Blast resistance (ULS and SLS), Steel-reinforced polymers, Moment redistribution, Deep embedded bar, Prestressed CFRP straps, Mechanical fastening, Hybrid systems, Torsional strengthening, Life expectancy, Whole-life costing.

Curved-Soffit Strengthening

- Either global or local concave curvature of soffit
- FRP wet lay-up or pre-cured laminate attempts to straighten under tension
- Possibility of premature failure
- Would anchoring the FRP help?

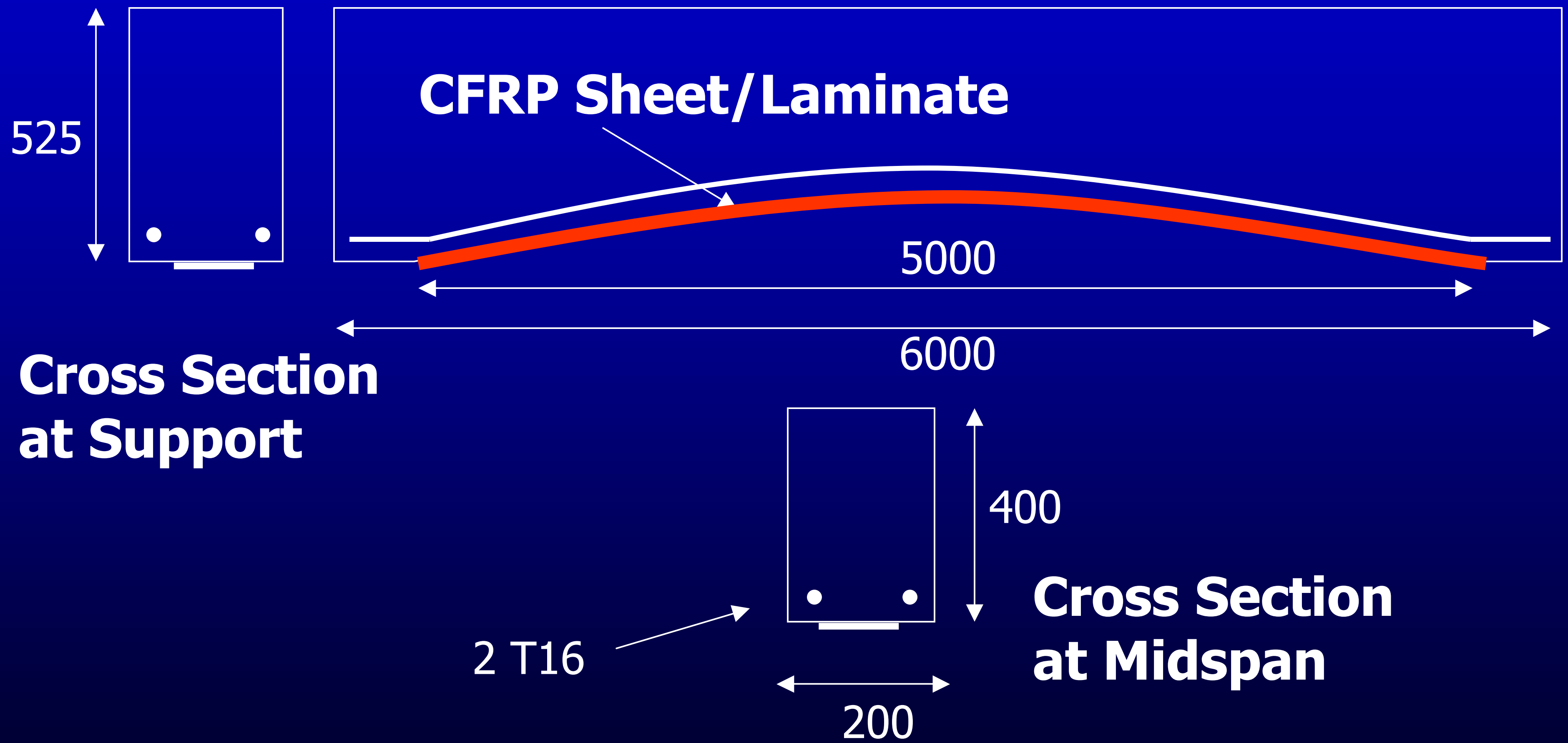
Nagaraj Eshwar, Tony Nanni, Steve Denton & Tim Ibell

Acceptable Limits

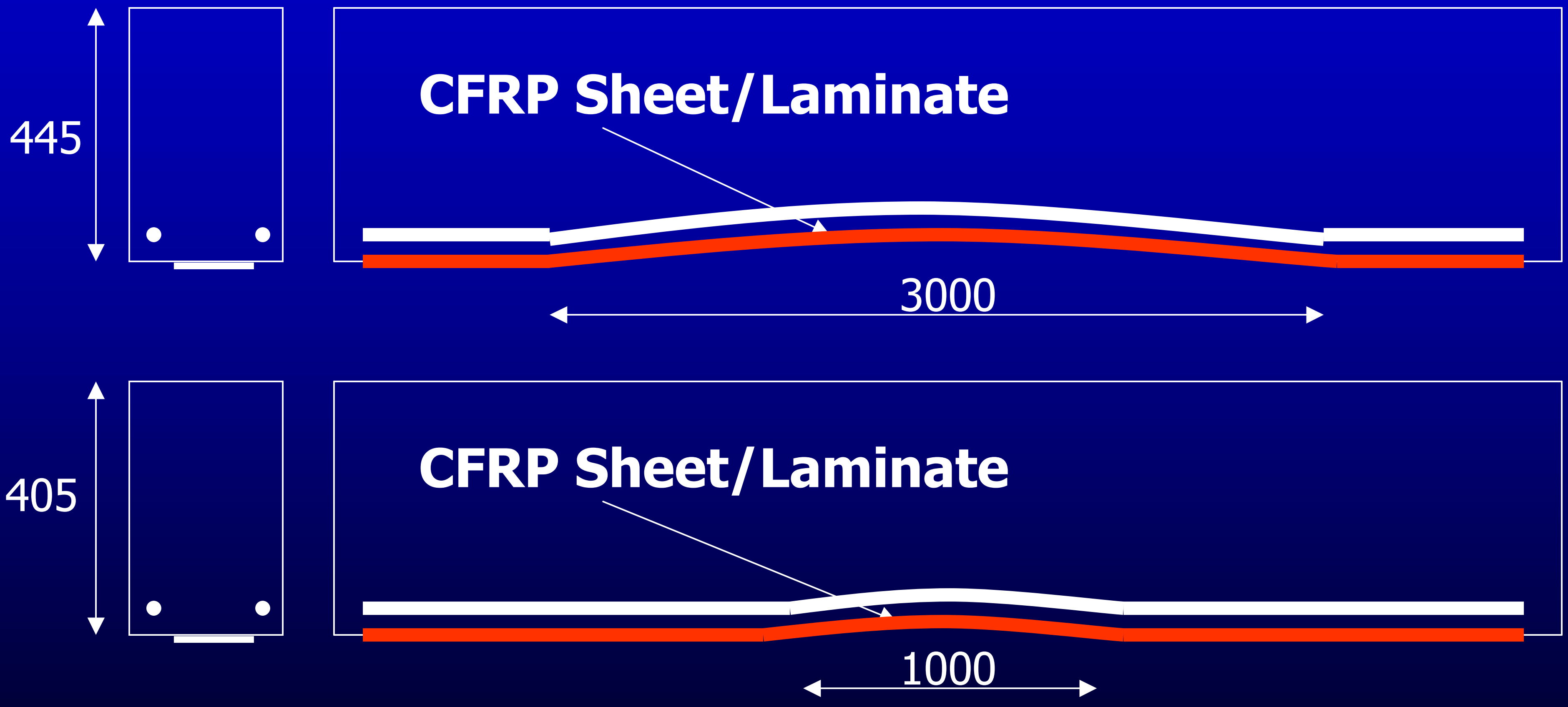
- Is maximum allowable limit of 5mm per metre unevenness (TR55) acceptable?

Curved Soffit

Global Curvature

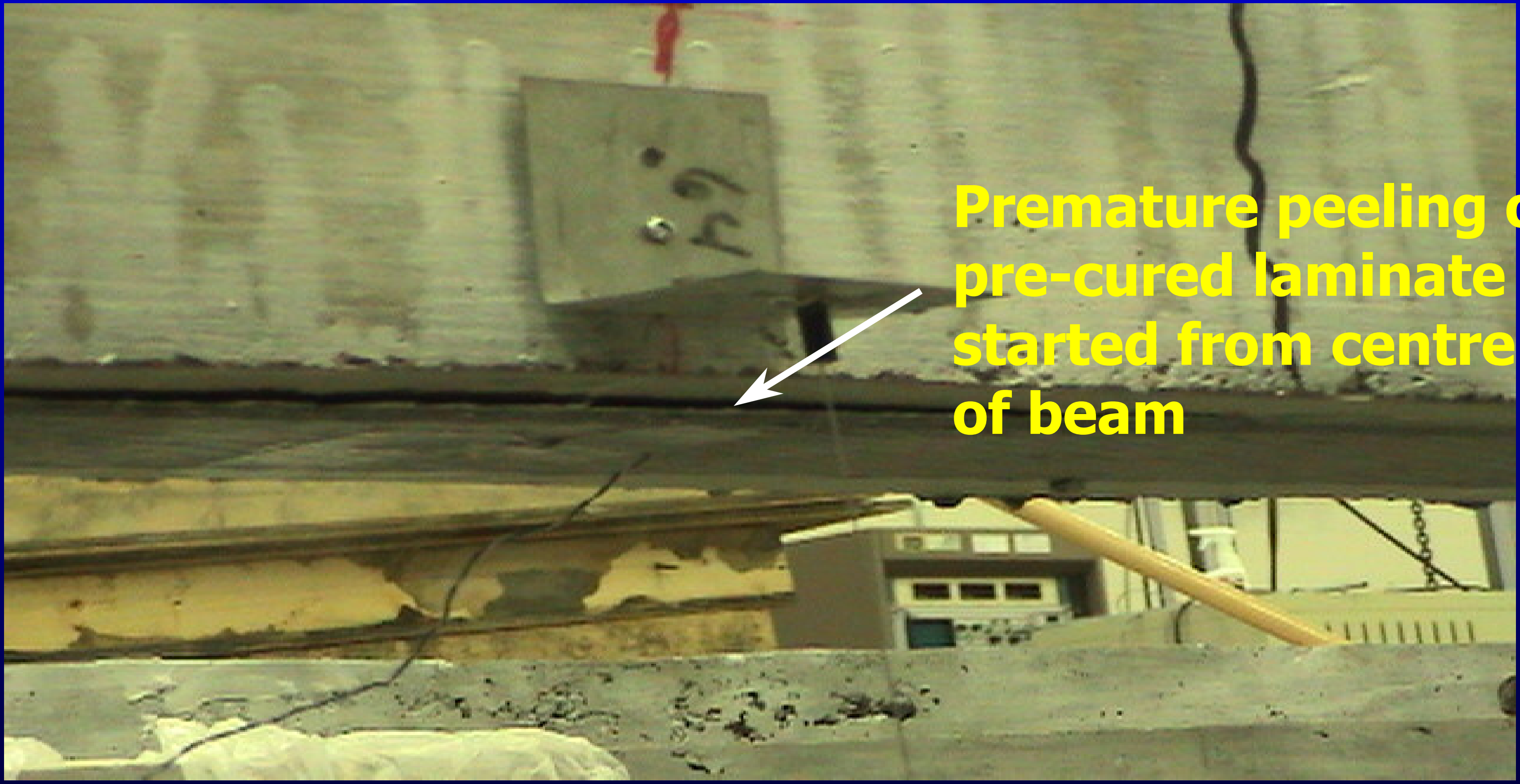


Local Curvature



Installation Procedure

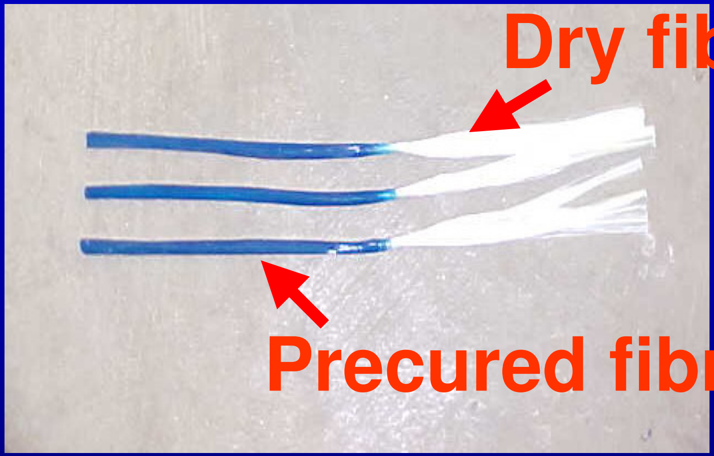
Testing Procedure

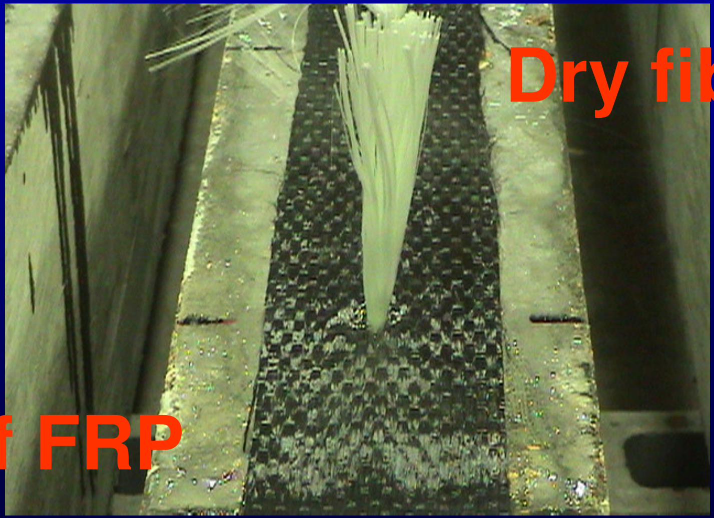


Premature peeling of pre-cured laminate started from centre of beam

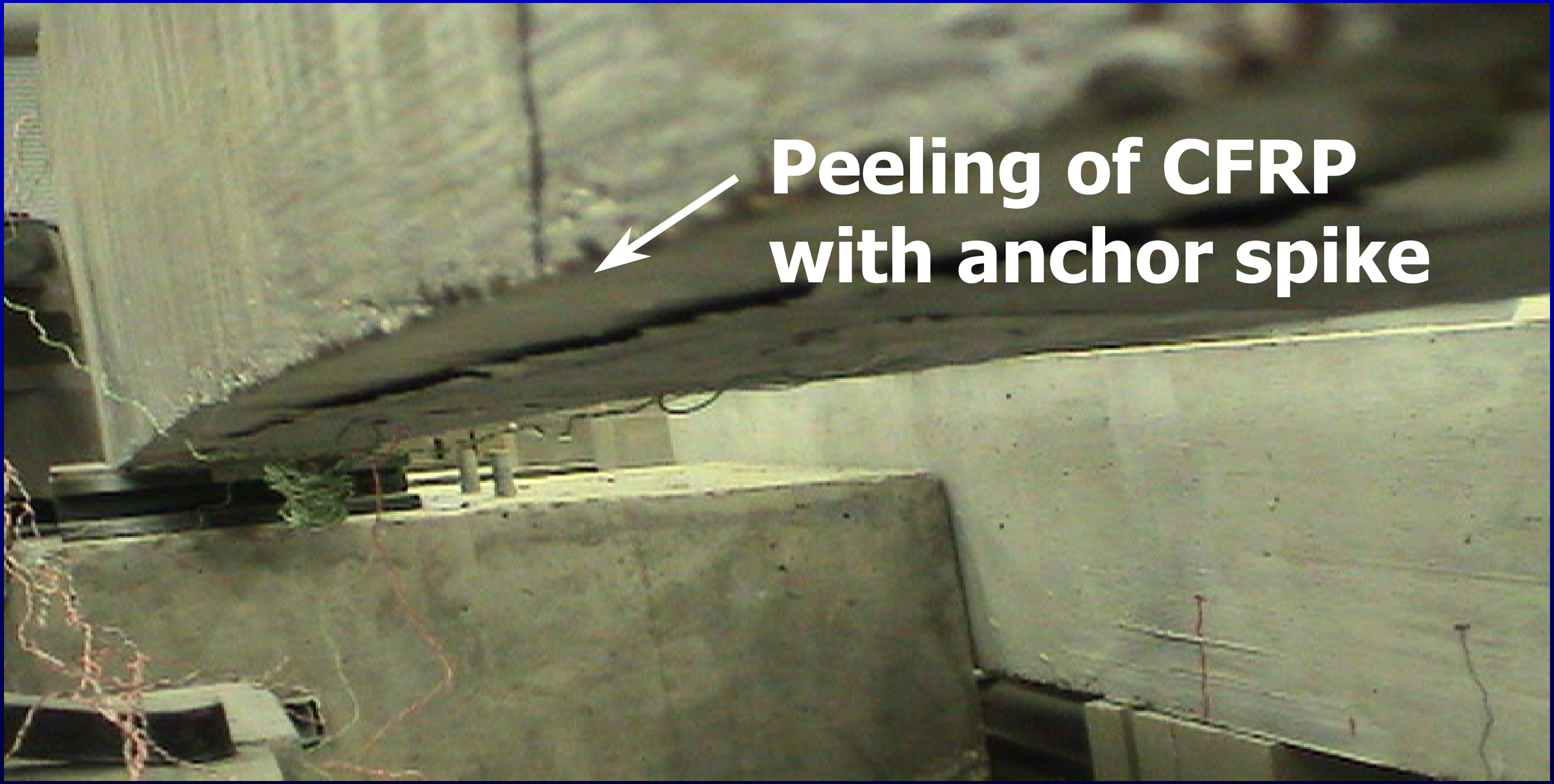
Failures

Spike Fibres

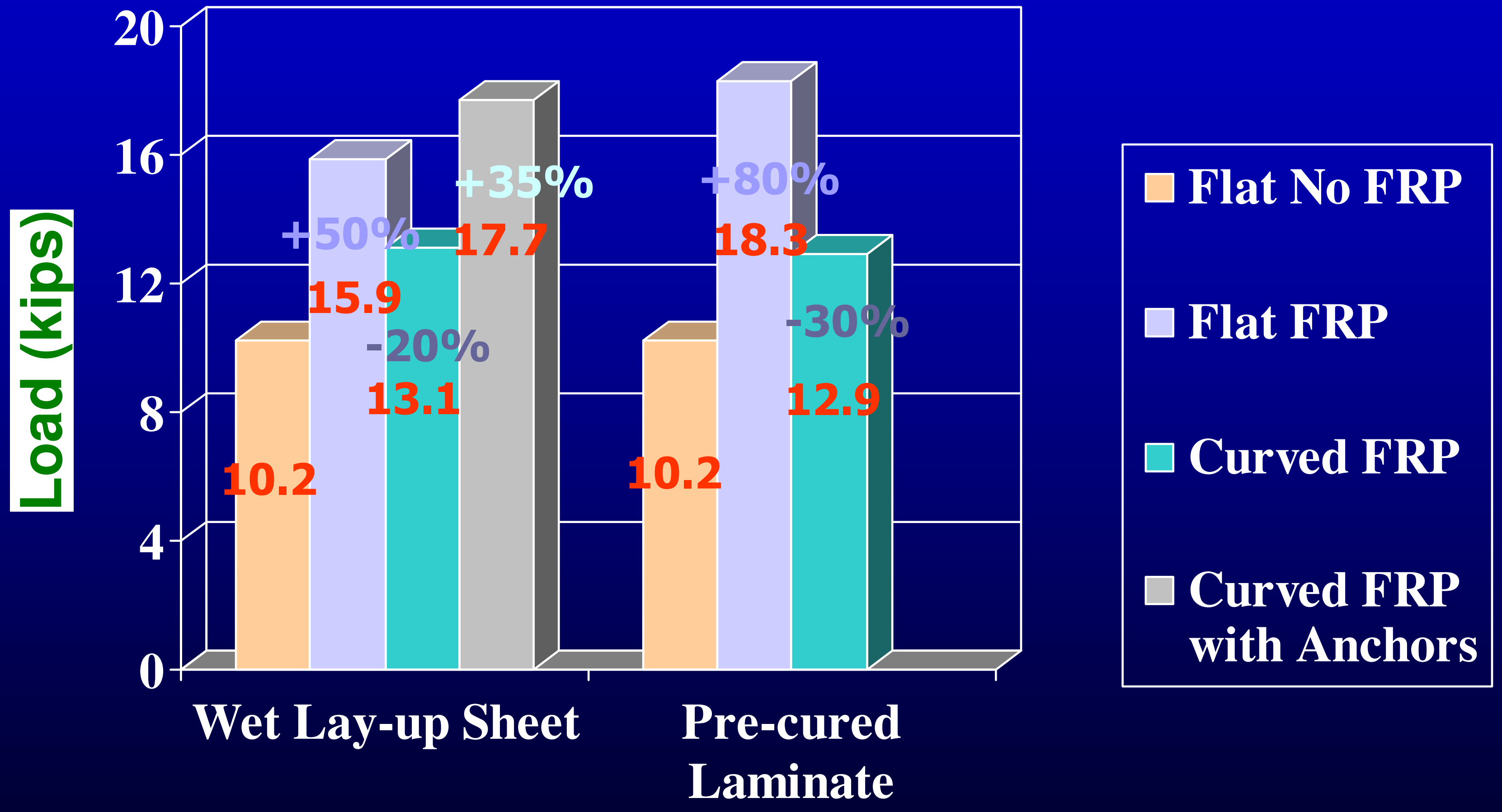




Effectiveness of Anchors



Test Results



Shear Strengthening of Slabs or Hidden Beams

Existing strengthening option

Insert threaded steel bars through deck and bolt on end plates

- **Requires access to both soffit and top of the bridge**
- **Expense of stainless steel and the required isolation from existing bars to avoid corrosion**

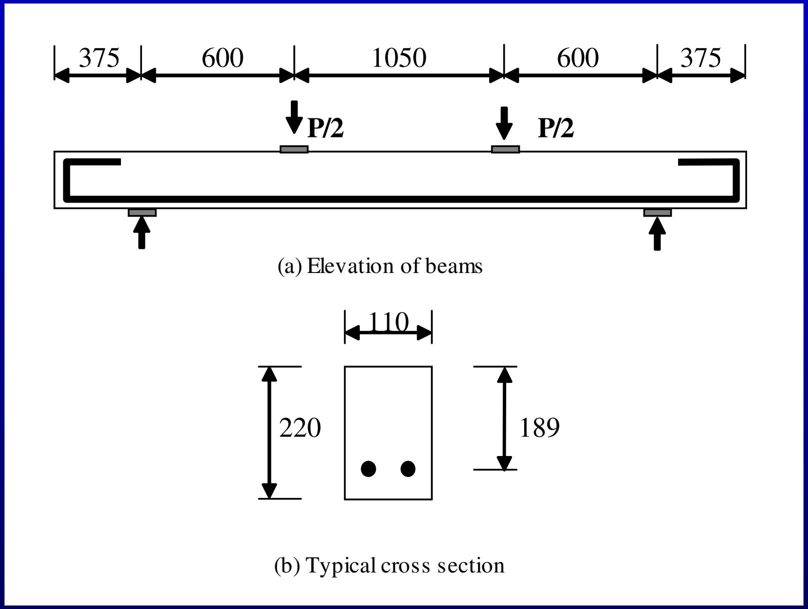
Pierfrancesco Valerio and Tim Ibell

Shear Strengthening of Slabs or Hidden Beams

Proposed strengthening option

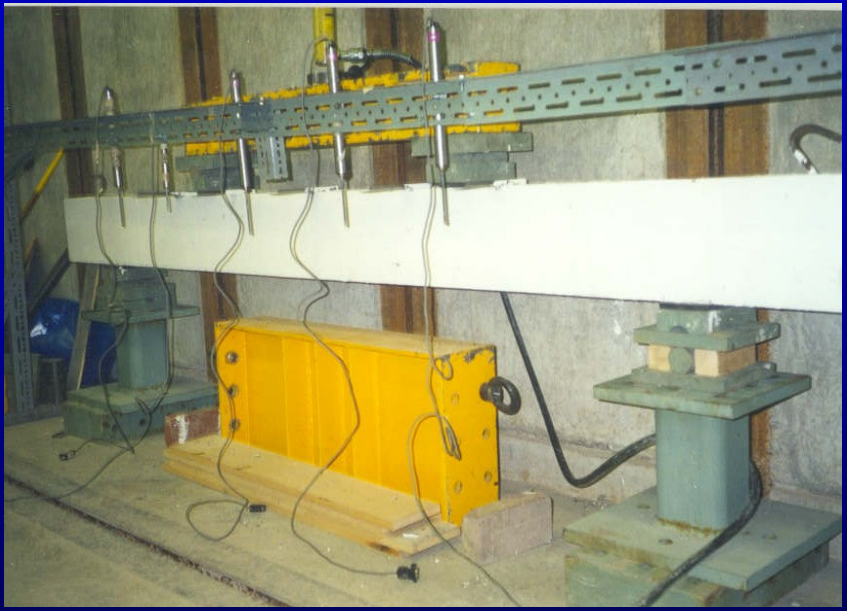
- **Vertical holes drilled into the deck from the soffit level**
- **FRP or steel bars inserted**
- **Bars embedded in place using epoxy resin injected under pressure**

Experimental Investigation



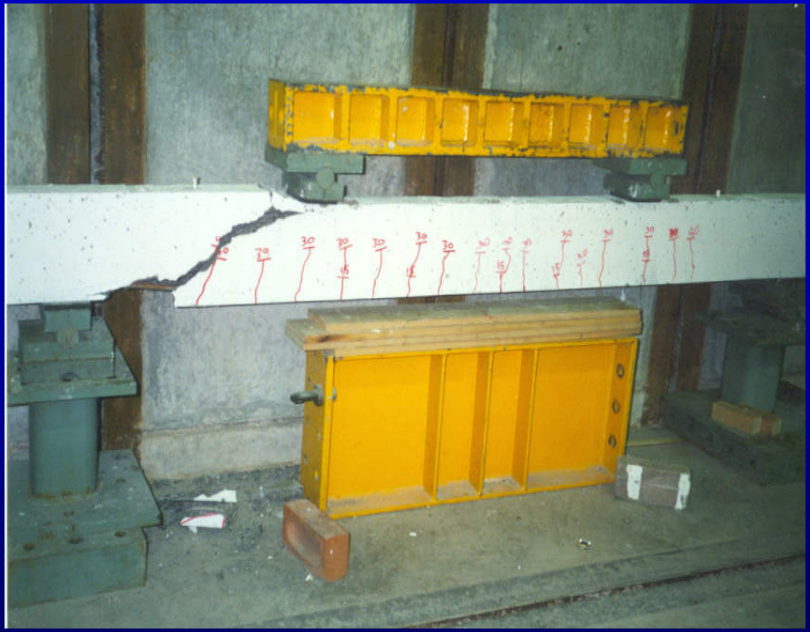
(a) Elevation of beams

(b) Typical cross section



- Ten beams tested under four point loading
- Each beam of the same cross section and longitudinal reinforcement

Test Results



- Beams with 0 to 2 transverse bars failed in shear
- Beams with 3 to 5 transverse bars failed in flexure

Present Follow-up

- EPSRC-funded project, in collaboration with Network Rail, to formulate a realistic 3-D shear assessment tool for continuous beam-bridges
- Develop a minimal-disruption shear strengthening scheme for such bridges, including solution of practical issues

Additional On-Going Research

- FRP strengthening under live load
- Mechanical fastening of FRP to concrete soffits
- Redistribution of moment in FRP-strengthened schemes
- Rectangular column strengthening
- Piezoresistivity of CFRP plates
- Whole life costing models for FRP strengthening
- Life expectancy models for FRP
- Non-principal axis bending effects in FRP plate