Determination of the Stiffness Reduction Map in an Impacted Composite Panel

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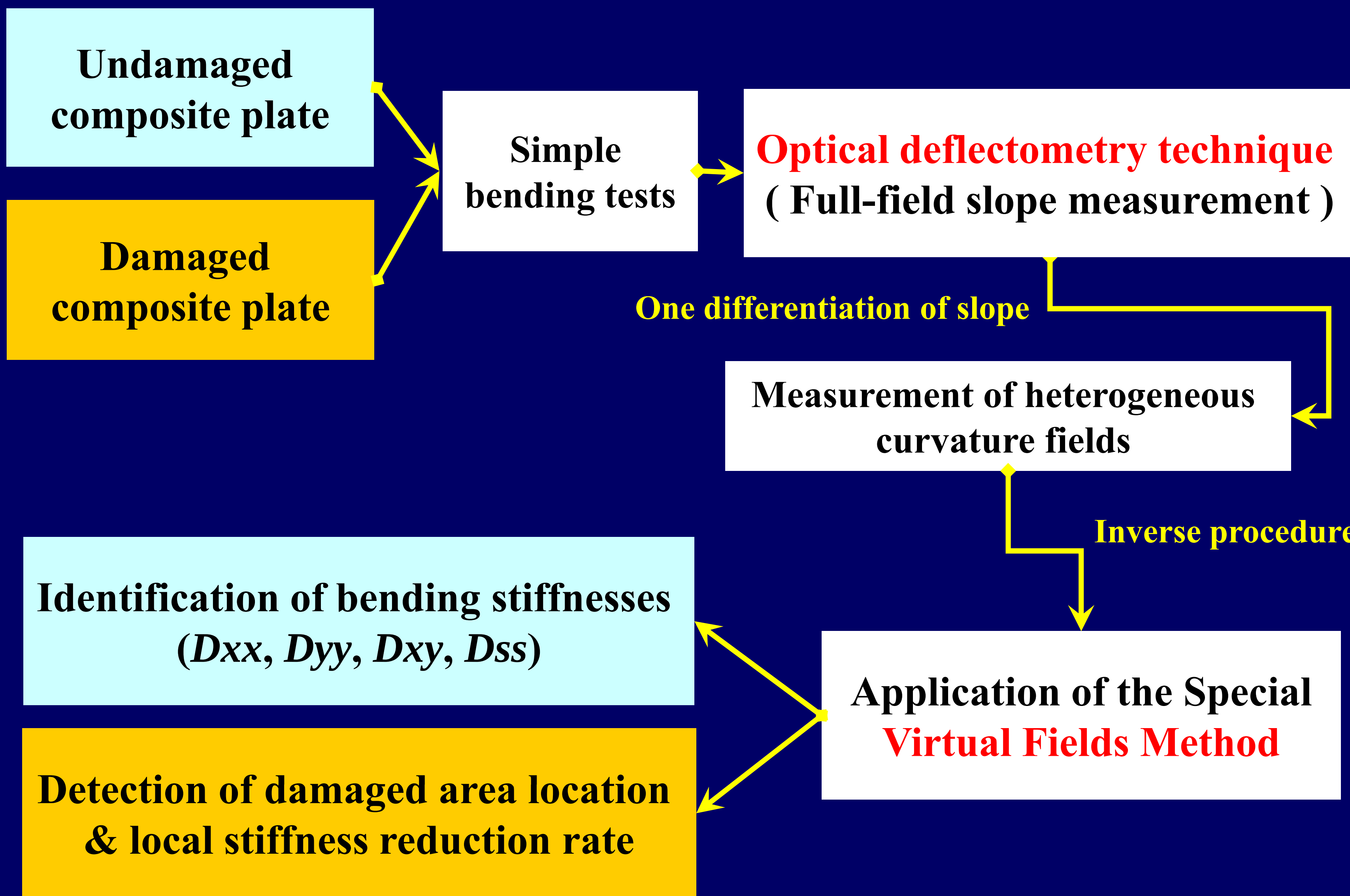
Damage in composite panels

- Relatively easy to detect (C-Scan, IR thermography etc)
- Difficult to quantify the effect on mechanical performance

Objective of the study

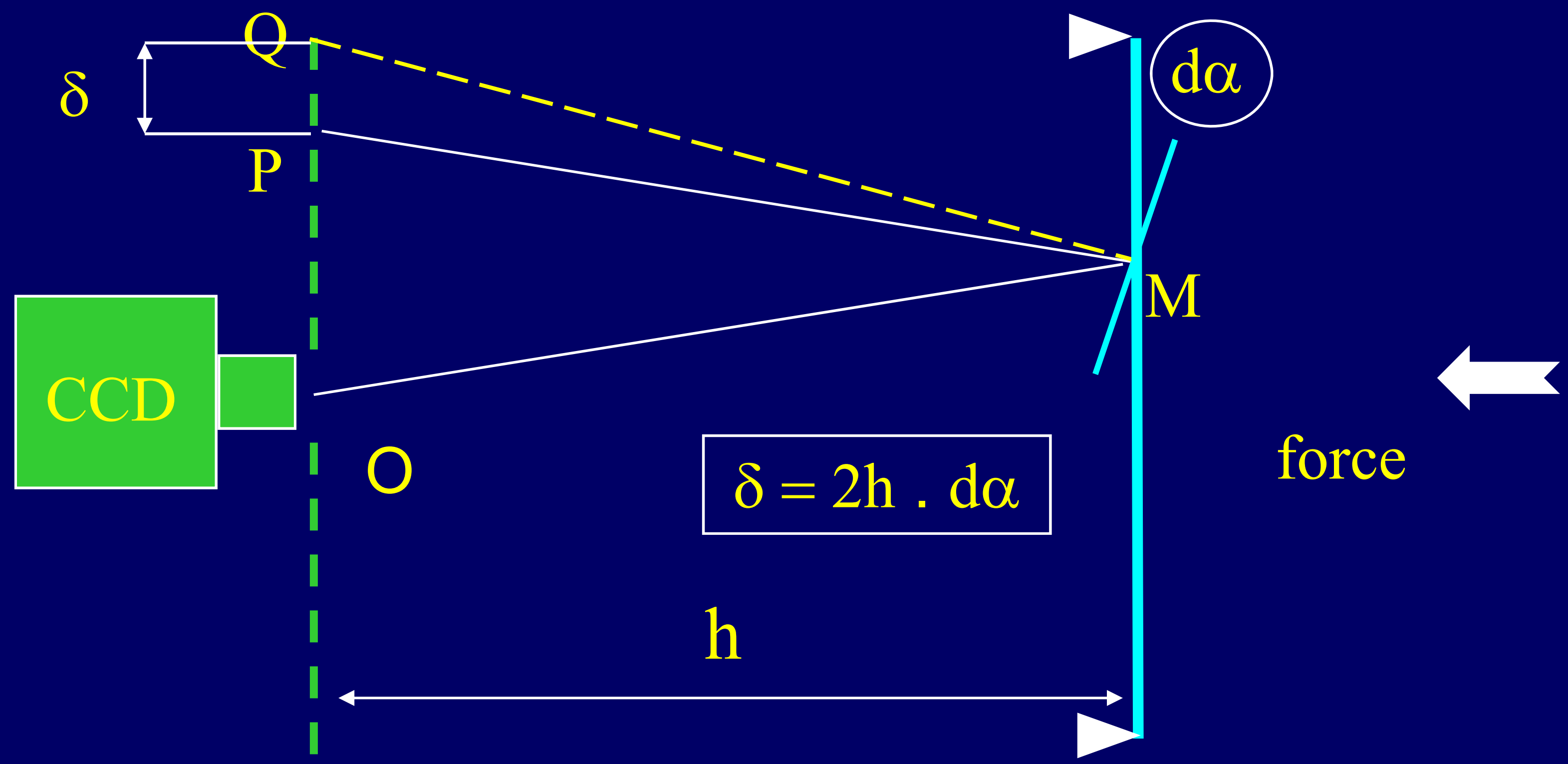
- Quantify the local loss of stiffness
  - Barely visible impact (small damage)
  - Full-field measurements
  - Virtual Fields Method
  - 2D map of stiffness reduction

Methodology



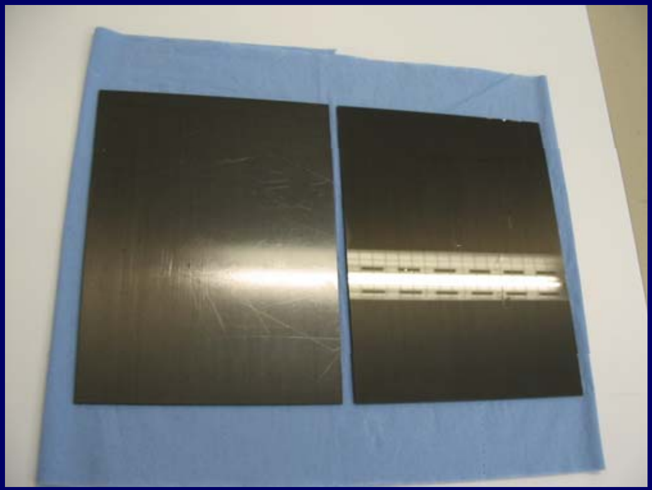
Measurement technique: deflectometry

Full-field slope measurements



$\delta \Rightarrow$ spatial phase difference $d\varphi$ ⇒ $d\alpha = d\varphi * p/(4\pi h)$

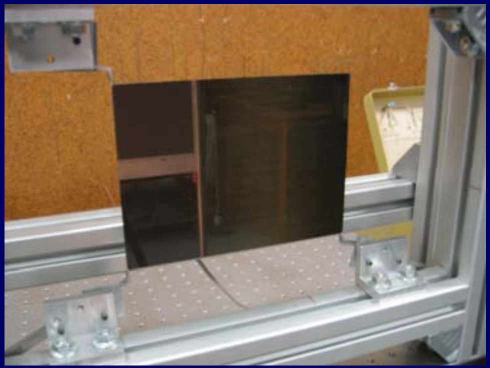
Experimental Set-up



Specimen preparation (gel coat)

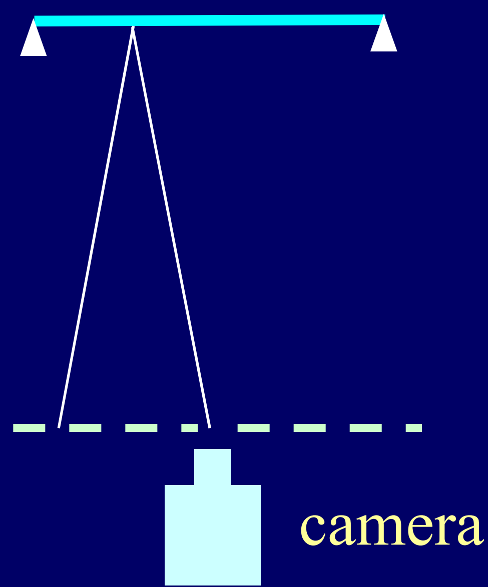
Kim J.-H., Pierron F., Grédiac M., Wisnom M.R.
A procedure for producing reflective coatings on plates to be used for full-field slope measurements by a deflectometry technique
Strain: an International Journal for Experimental Mechanics, vol. 43, pp. 138-144, 2007.

Test setup



Camera position in deflectometry

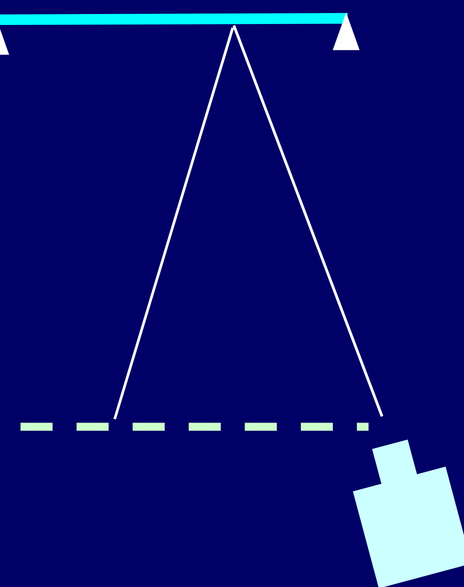
Central



- Reconstruction by spatial smoothing

  (loss of spatial resolution)
- No calibration

Offset



- No reconstruction (no smoothing)
- Calibration

Virtual Fields Method

- Continuous parameterization
  - Reduction in bending stiffness matrix:

    $$D=D^0(1-f(x,y))$$

    with D^0: undamaged bending stiffness and f: function driving the stiffness reduction (f is a polynomial of x and y)
  - Coefficients of the polynomial to be identified
  - Basic assumption: “isotropic” damage, D^0 is known

Virtual Fields Method

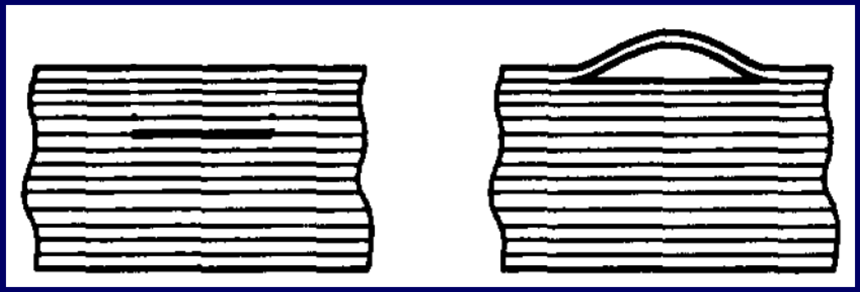
Resolution

- Linear system if D^0 is known in continuous parameterization
- Use of optimized special virtual fields*
- Extremely fast computation time
- Procedure detailed in **

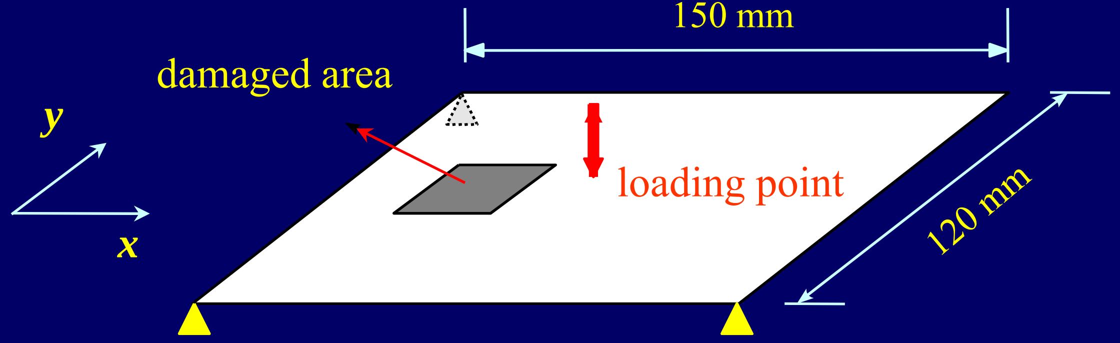
*Avril S., Grédiac M., Pierron F.
Sensitivity of the virtual fields method to noisy data, ***Computational Mechanics***, vol. 34, n° 6, pp. 439-452, 2004.

** Kim J.-H., Pierron F., Wisnom M., Syed-Muhamad K.
Identification of the local stiffness reduction of a damaged composite plate using the virtual fields method, ***Composites Part A: Applied Science and Manufacturing, vol. 38, n° 9, pp. 2065-2075, 2007***

Artificial damage

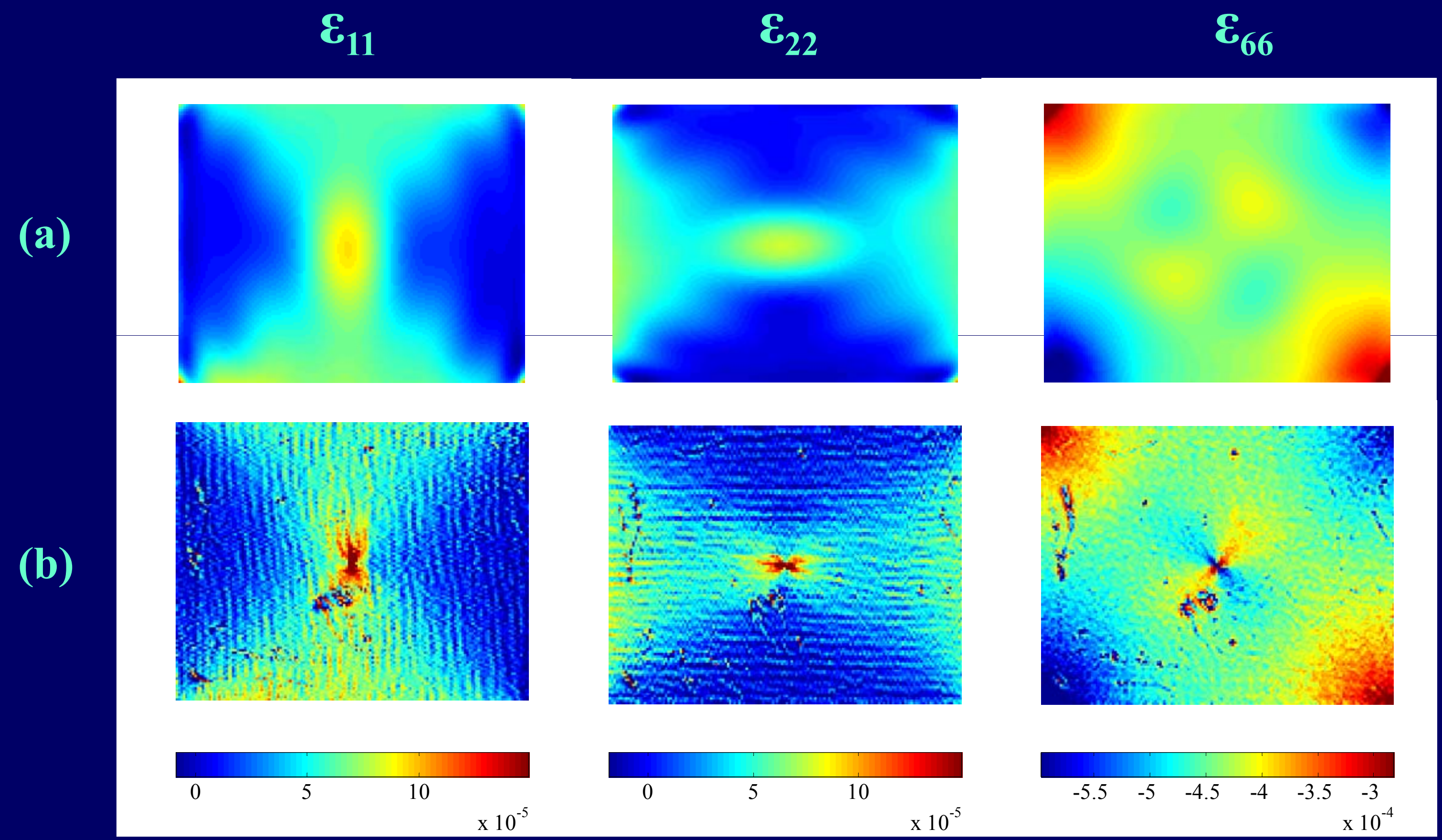


Geometry and test configuration of the damaged plate



Near-the-surface delamination

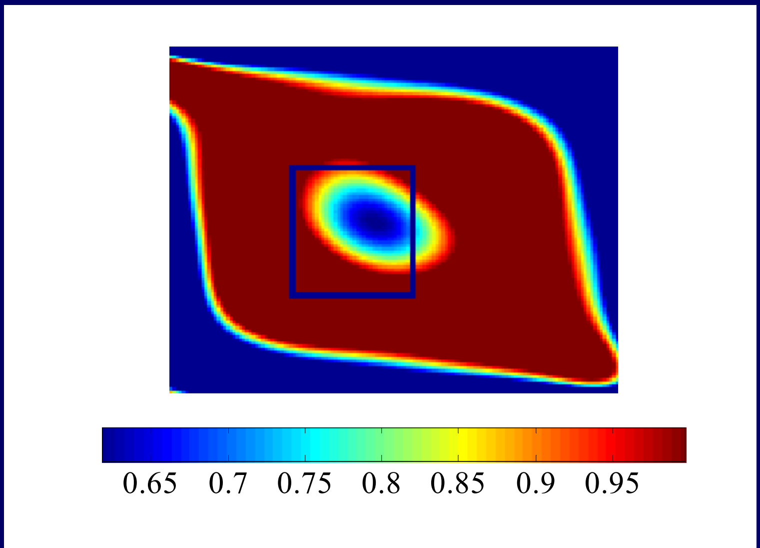
- Cross-ply carbon/epoxy plate, 2.5 mm thick (16 plies)
- FEP film between 1 & 2 and 2 & 3 surface plies
- Target is 30% reduction in D



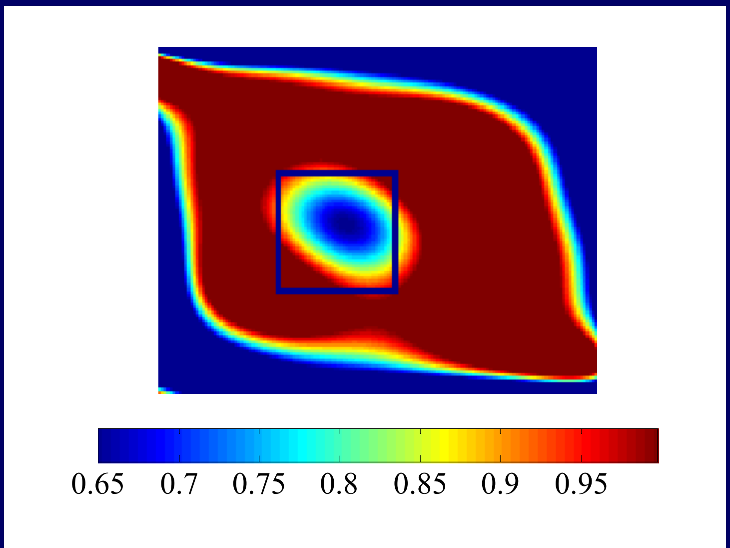
(a) central position (14th order polynomial), (b) offset position, 15N

Results: near-the-surface delamination

- Polynomial parameterization
- f(x,y): 8th order polynomial
- Load: 15 N



central position
spatial smoothing



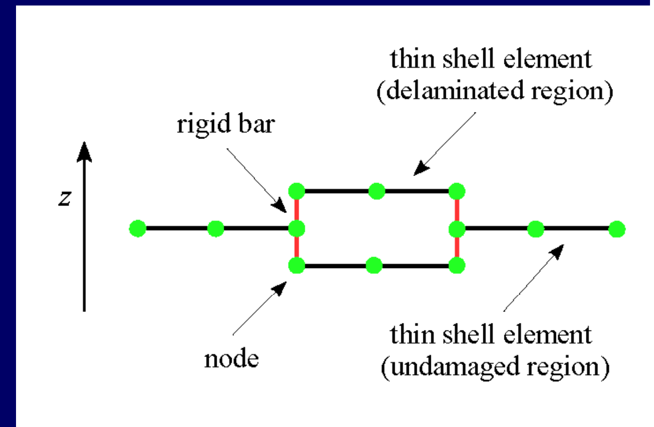
offset position
no spatial smoothing

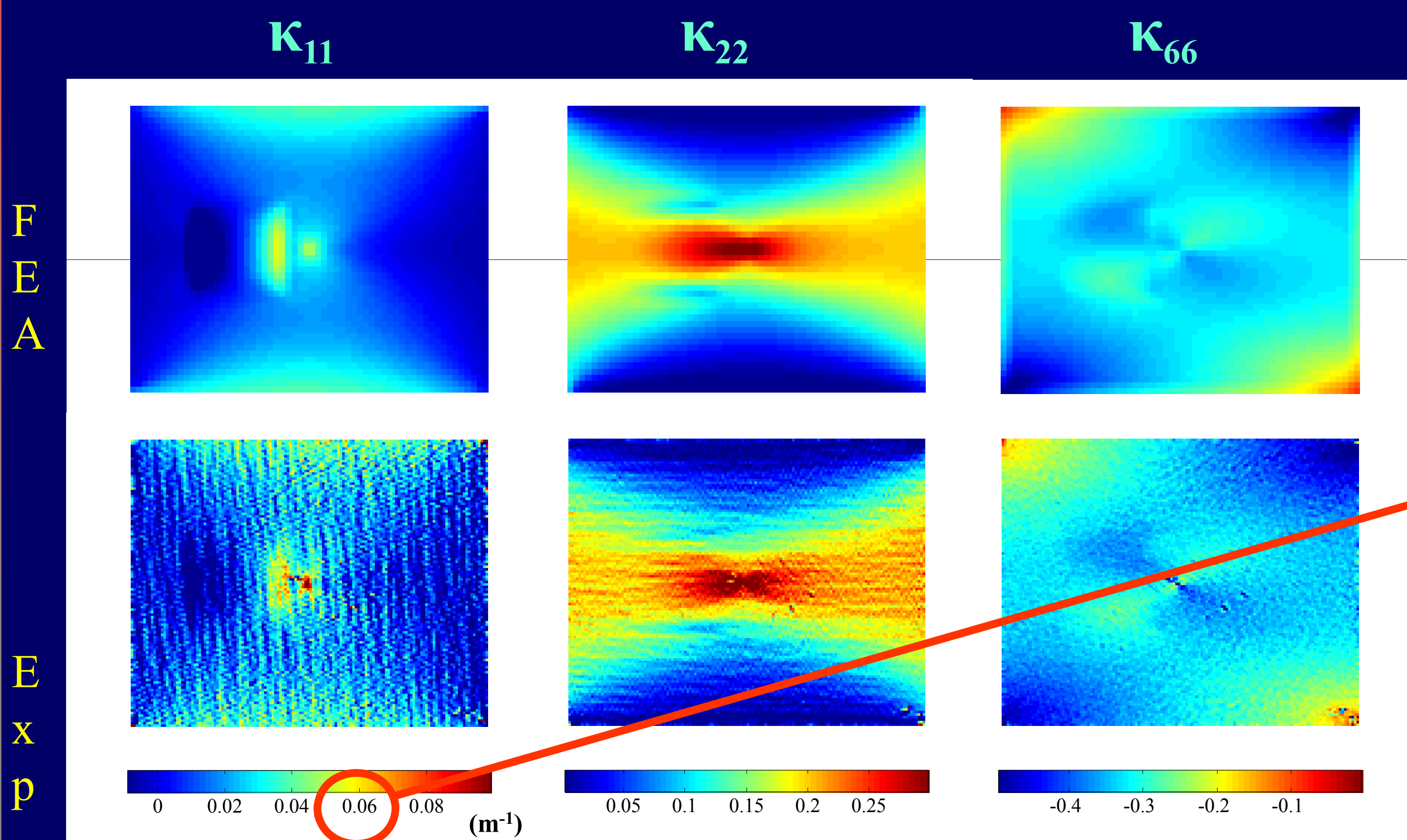
In black: exact damage location

Offset position is preferable

Mid-plane delamination

- UD carbon/epoxy, 2.5 mm thick (16 plies)
- FEP film into the mid-interface
- Offset camera position, 15N

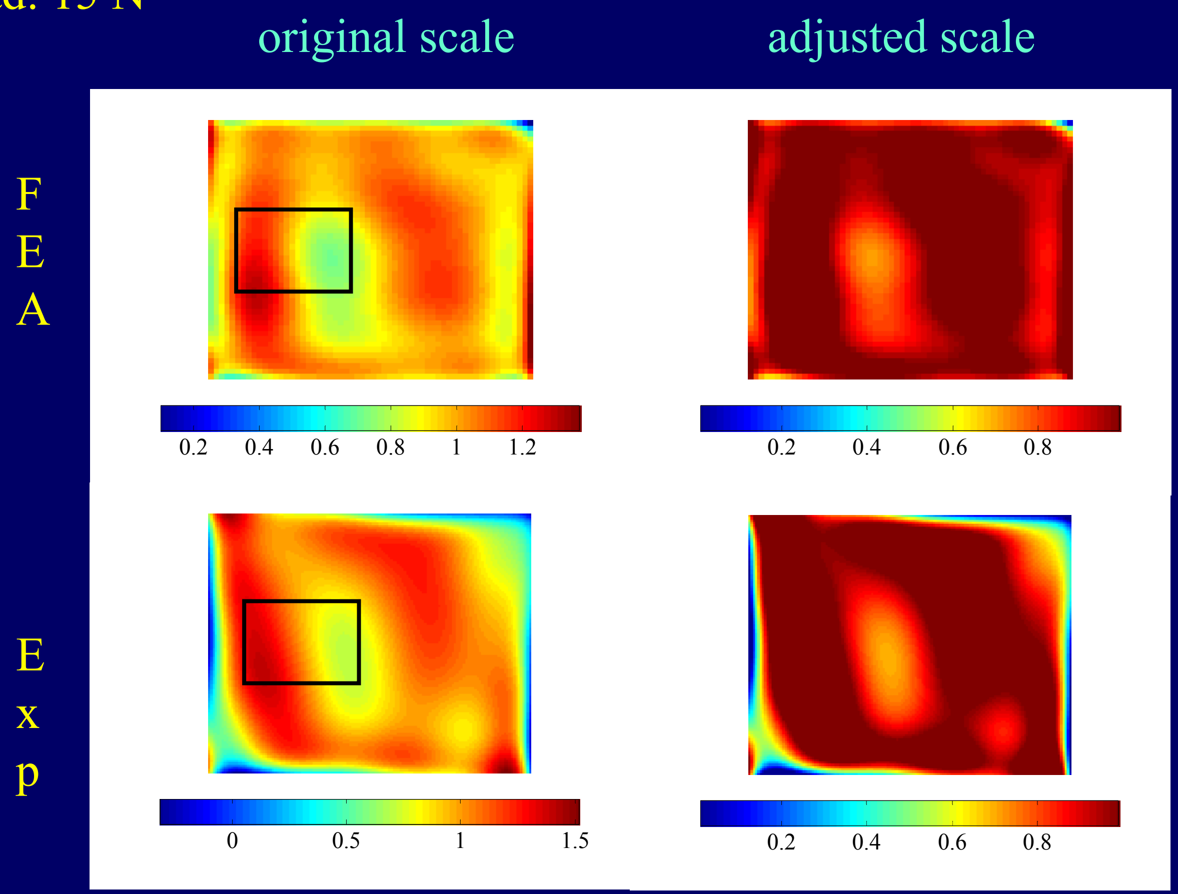




$\varepsilon_{11} = 6.10^{-5}$

Results: mid-plane delamination

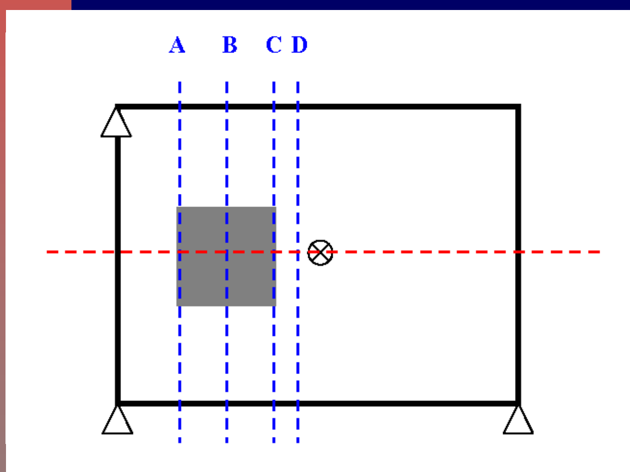
- Polynomial parameterization
- f(x,y): 8^{th} order polynomial
- Load: 15 N

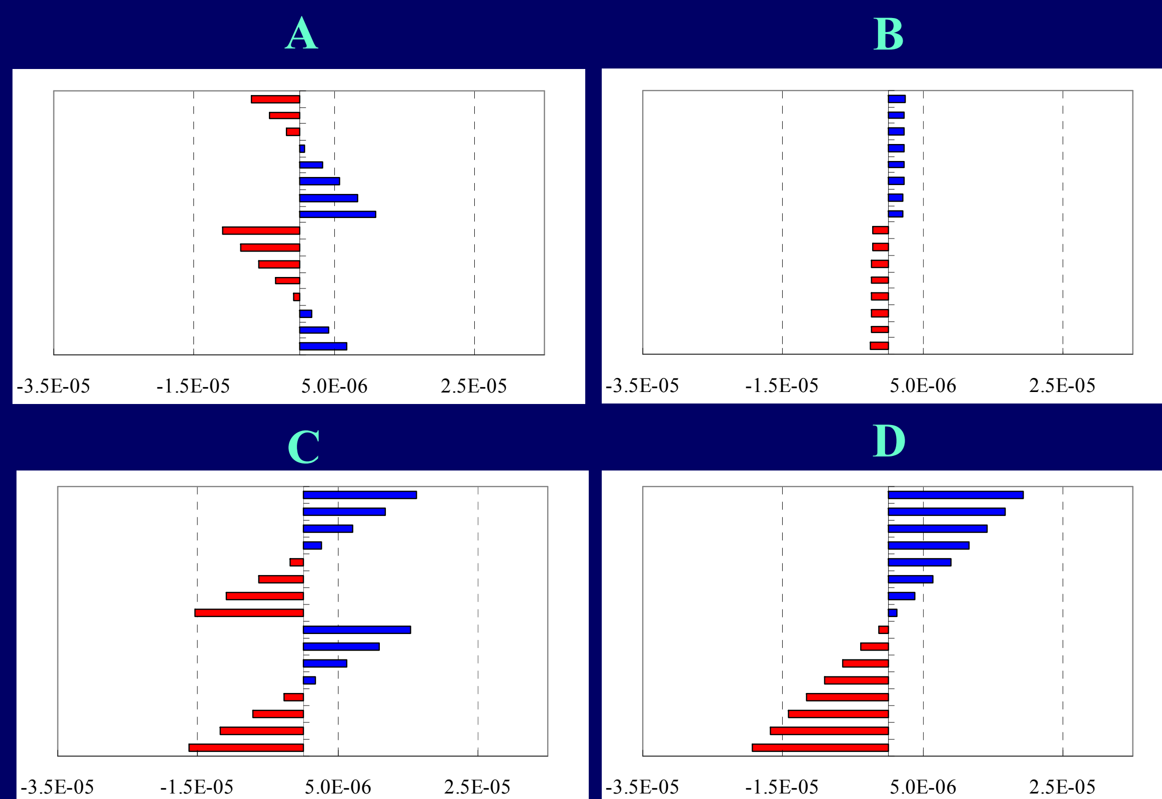


Unexpected results both in location and stiffness reduction

Results: mid-plane delamination

- Through-the-thickness strain distributions (FEA)

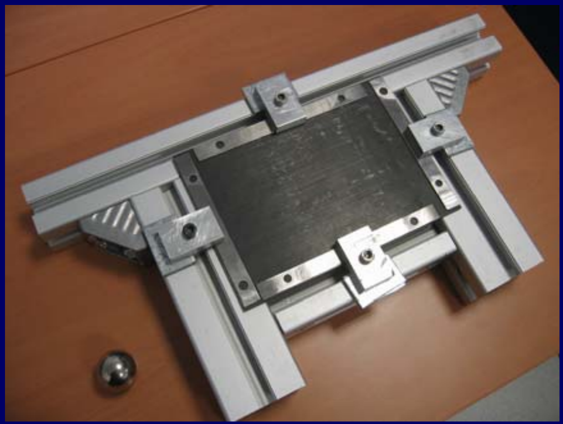


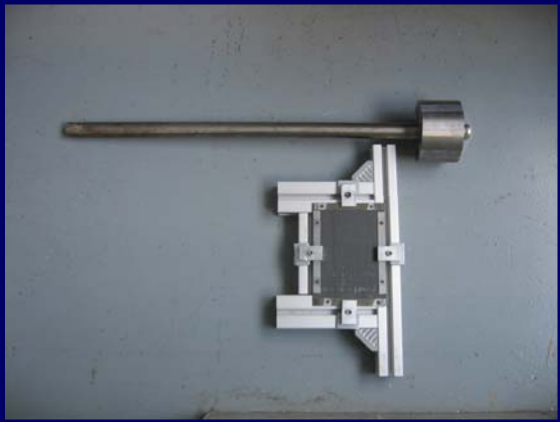


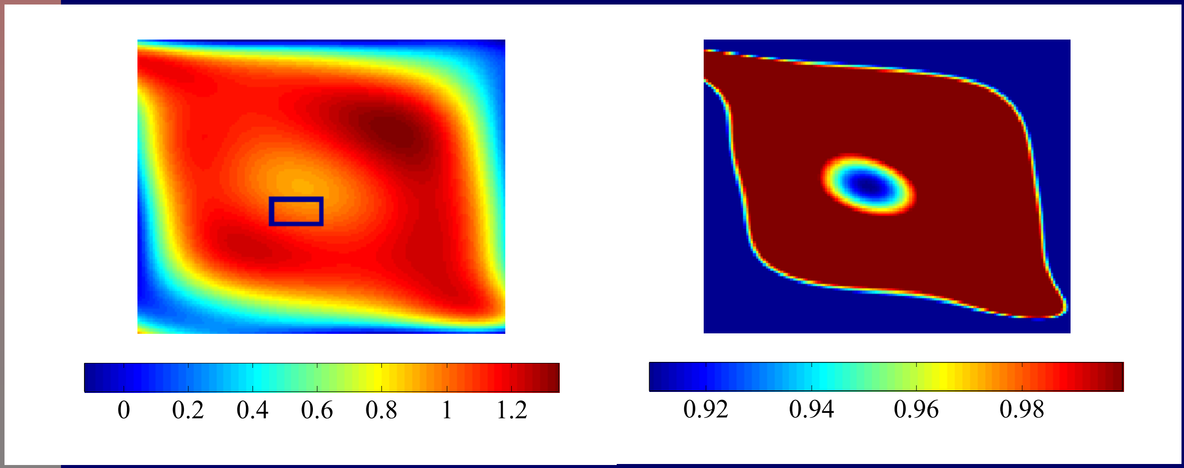
Kirchhoff plate kinematic assumption of linear through-the-thickness displacement distributions is no longer valid.

Real impact damage

- 10 kg impactor dropped on clamped plate (~20 J)
- Barely visible damage







original scale   adjusted scale

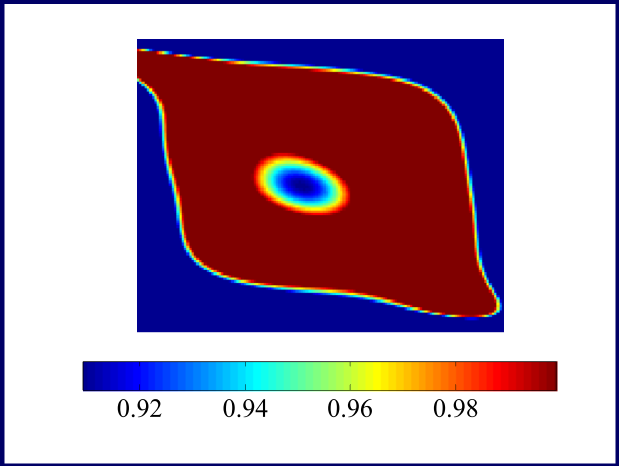
Polynomial parameterization
f(x,y): 8th order polynomial
Load: 15 N

Very small and localized stiffness reduction
Is it really a stiffness reduction or just noise?

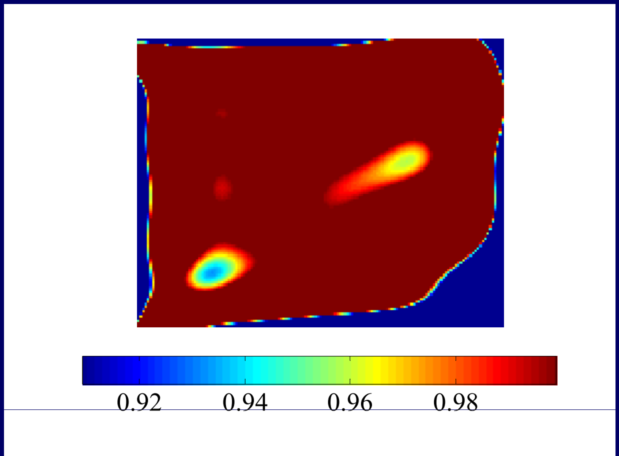
Detection threshold

- Apply procedure on an undamaged plate

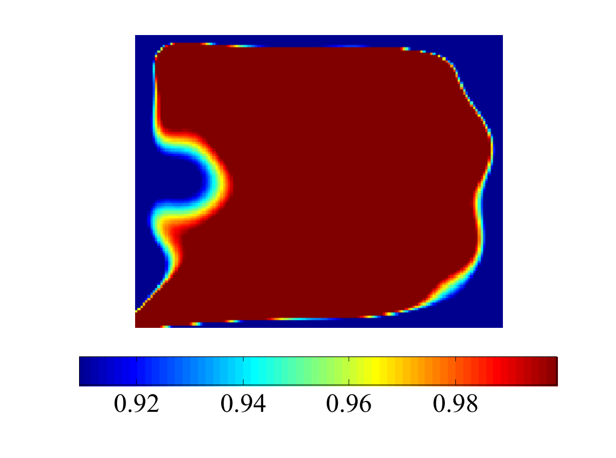
BVID



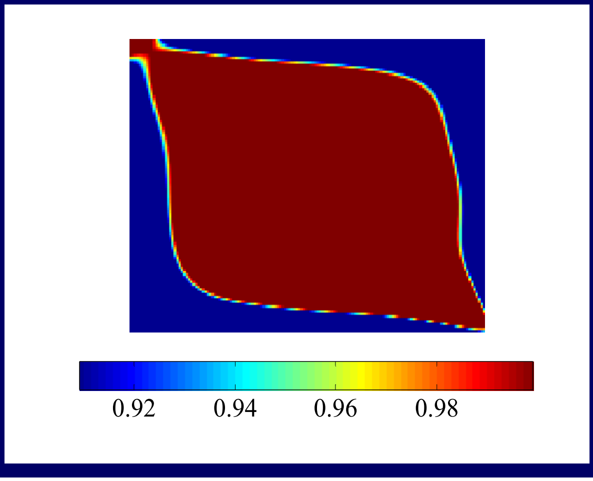
Undamaged 1



Undamaged 2



Undamaged 3



Summary

- Methodology for evaluating stiffness reduction maps in thin composite plates
- Full-field slope measurements by deflectometry
- Virtual fields method
  - Discrete or continuous
  - Linear equations: very fast resolution times!
- Target: small stiffness reduction over a very localized area
  - Barely visible damage
- Continuous approach more adapted
- Possible to couple both approaches

Future work

- Anisotropic damage
  - Combine several load cases
- Real impacted plates and curved surfaces (new PhD)