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Panel in–plane stiffness from vertical strain analysis in box compression test

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Introduction

- Part of project on corrugated fibreboard packaging with Centre for Postharvest and Refrigeration Research (CPRR) at Massey University
- Particular focus: Modelling to optimise design of packaging for compression loading


Motivation

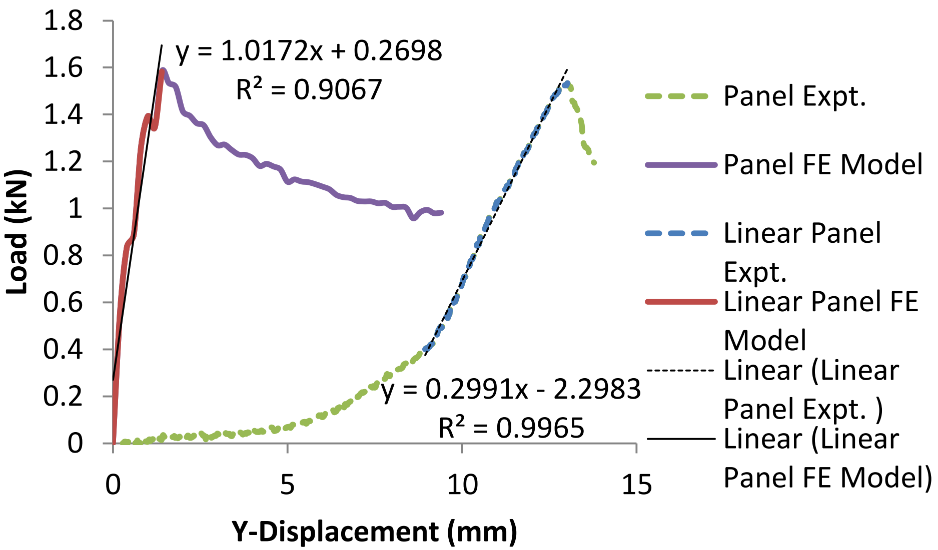
- To minimise damage to non-load bearing products, important to be able to predict package vertical compression when stacked



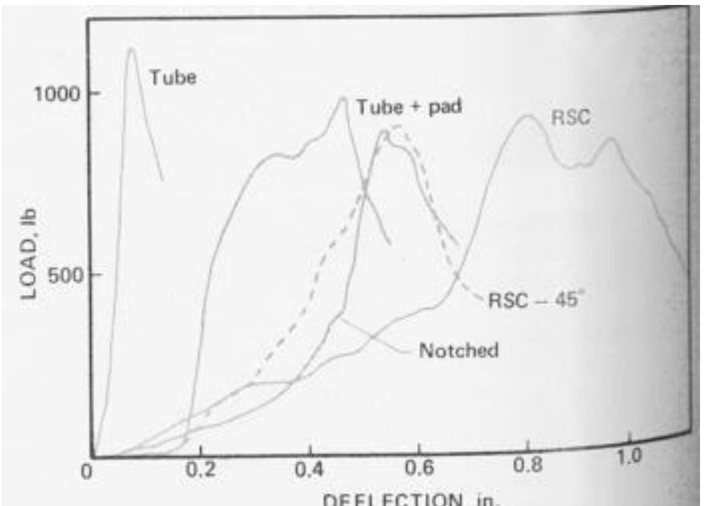
Problem Statement

- For panel specimen - experimental cross-head displacement higher than model in-plane compression, though peak force in agreement
- Box flaps and horizontal folds crushing not accounted for in model
- We need to experimentally measure displacements in panel in isolation from box flaps to verify model

Panel specimen



Prior literature



2. Typical box top-to-bottom compressive load–vertical deflection curves (1 in. = 2.54 cm, 1 lb = 4.45 N).

Peterson and Schimmelpfenning[1]

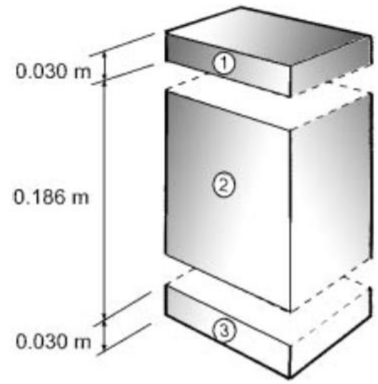
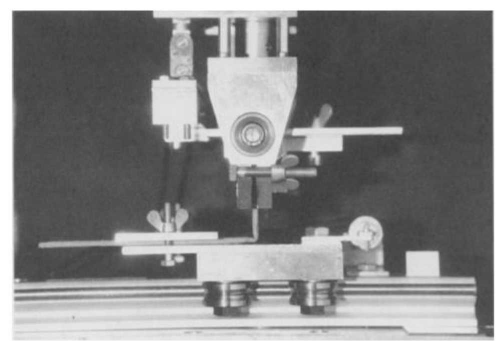


Figure 3. The segments of the paperboard package.

Beldie et al. [2]

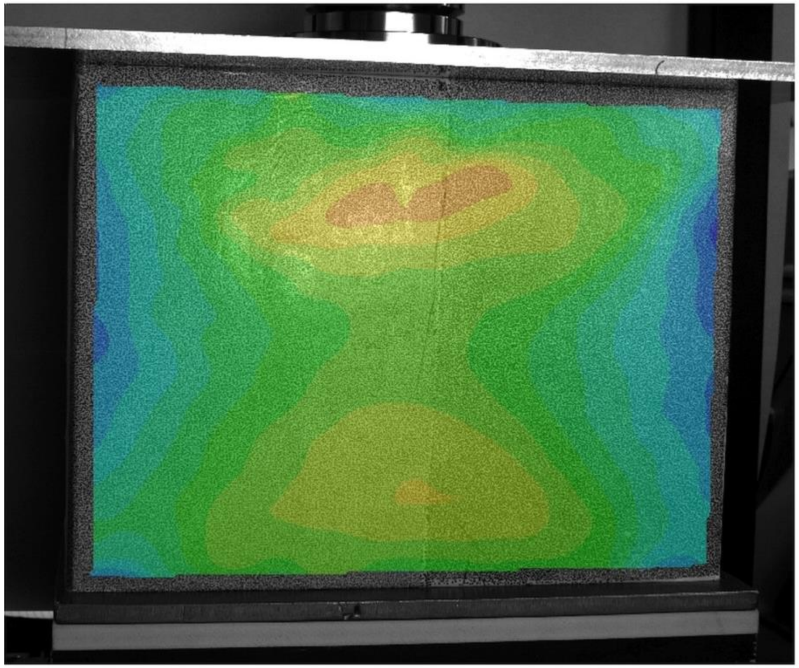


Renman[3]

Aim

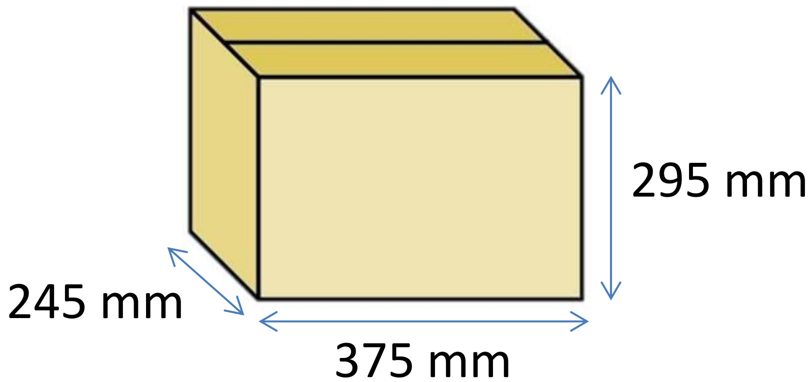
Quantify contributions of regions to overall box displacement in compression, without having to test tube sections to infer or extract in-plane panel compression

- Digital image correlation (DIC) methods are a solution

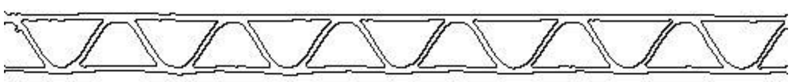


Box compression test

Material



Commercial regular slotted container

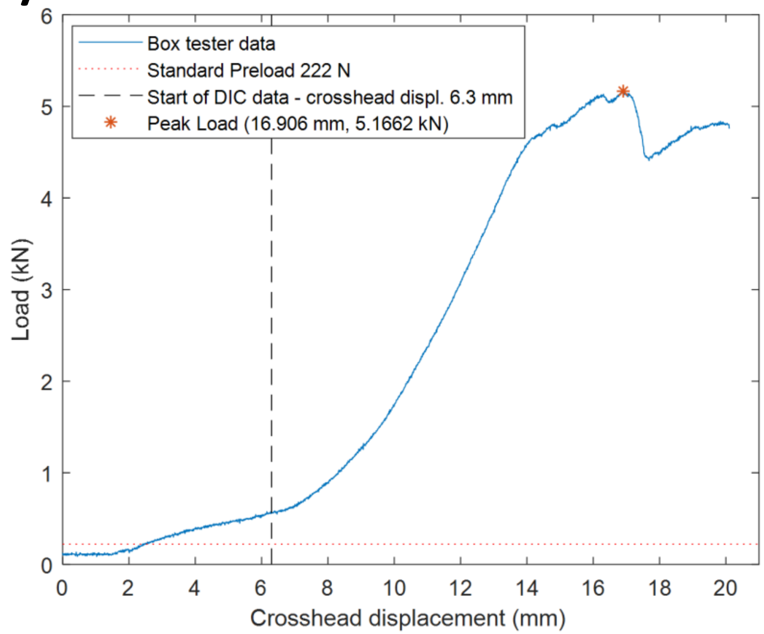


L70C single-wall C-flute corrugated fibreboard – exterior 200 g/m^2, medium 160 g/m^2, interior 250 g/m^2

Panel painted white and decal sheet with printed random speckle patterns adhered

Method

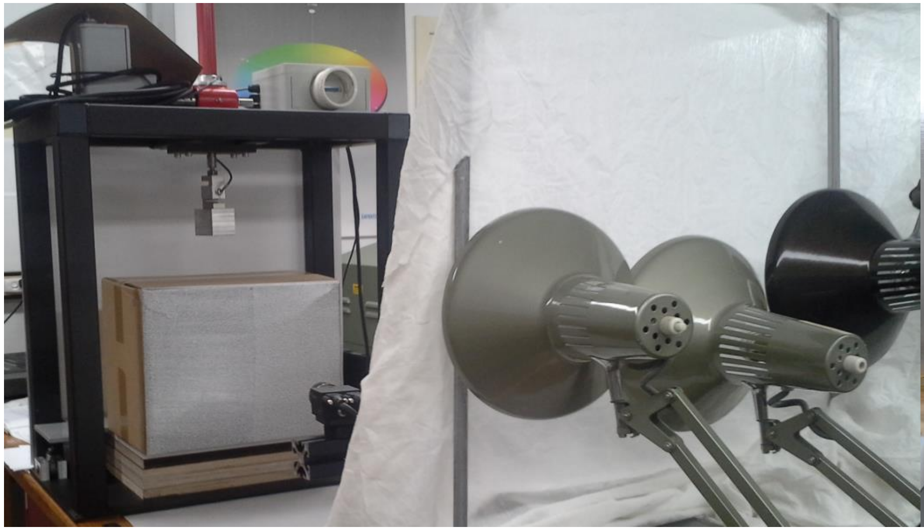
- Box compression test at 23°C, 50% relative humidity, floating upper platen ASTM D642, rate 12 mm/min



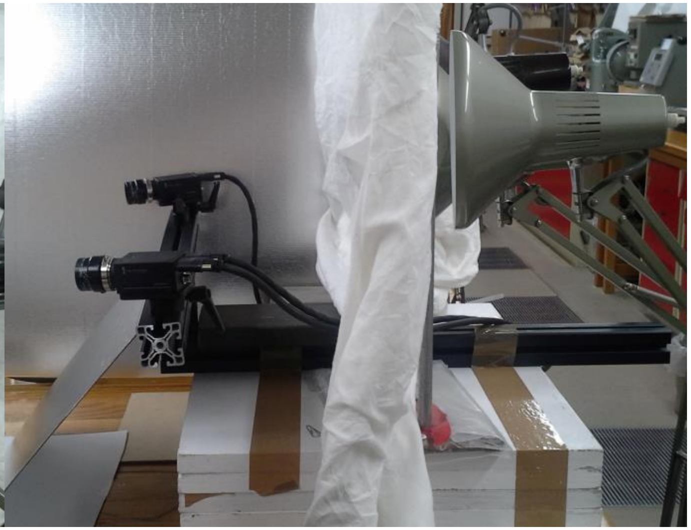
Load vs. crosshead displacement from box tester

Method

- 3D Digital image correlation (DIC) dual camera setup to capture images of panel face with speckled pattern during test



Crushed specimen with speckled panel in box tester (without platen)



3D DIC dual camera setup

Method

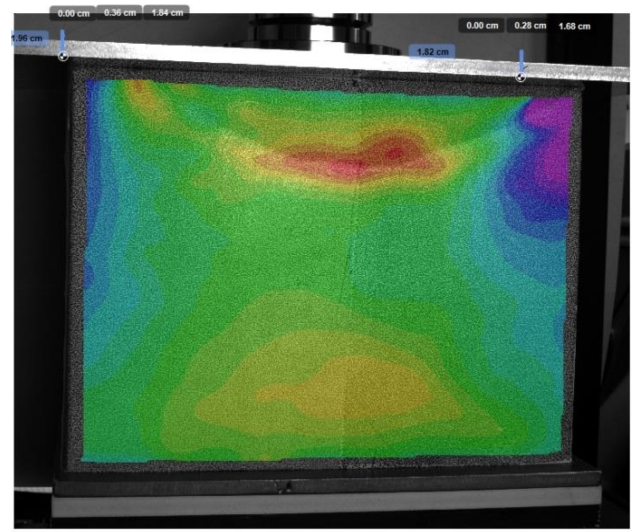
- 70 images DIC stereo images with 1 s intervals between images*
- Post-processed in Correlated Solutions' *VIC-3D* software to obtain displacement and strain data, and spatial coordinates X, Y, Z
- Data analysis in *Matlab*

  -Out-of plane displacement *W*

  -Vertical component of strain ϵ_{yy}

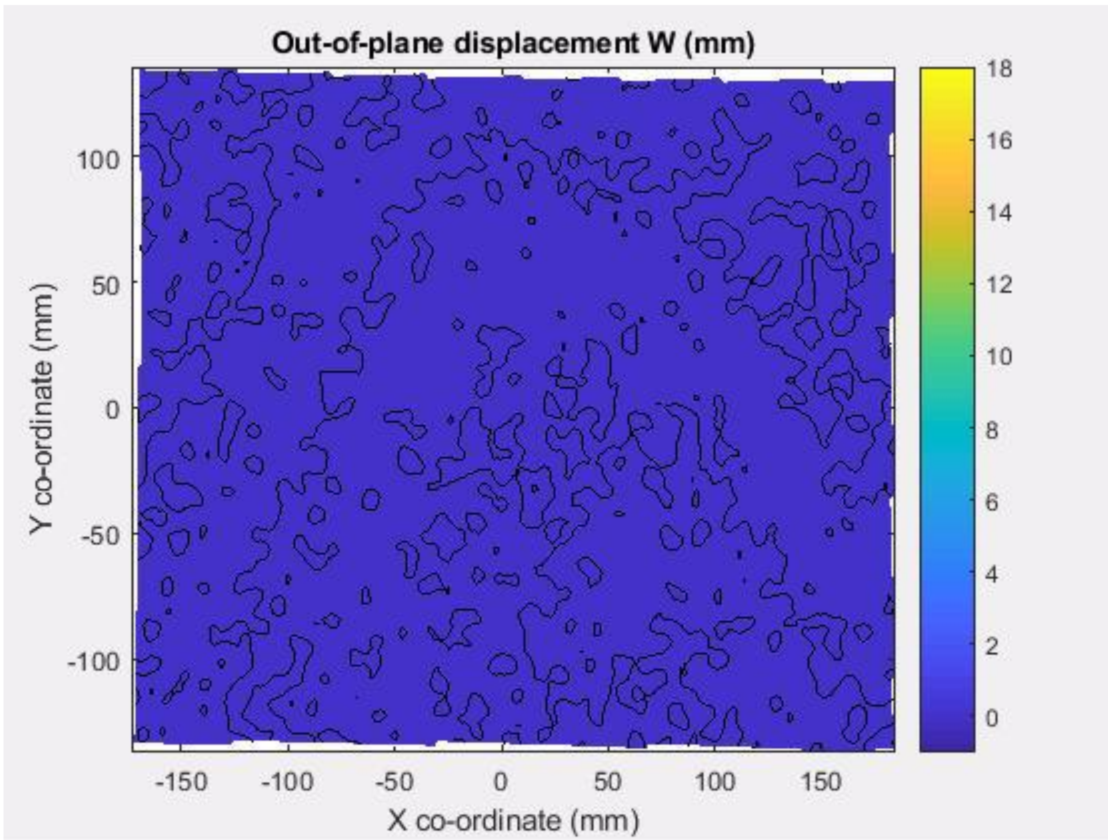
  -Vertical displacement *V*

* 0.2 mm/s crosshead displacement



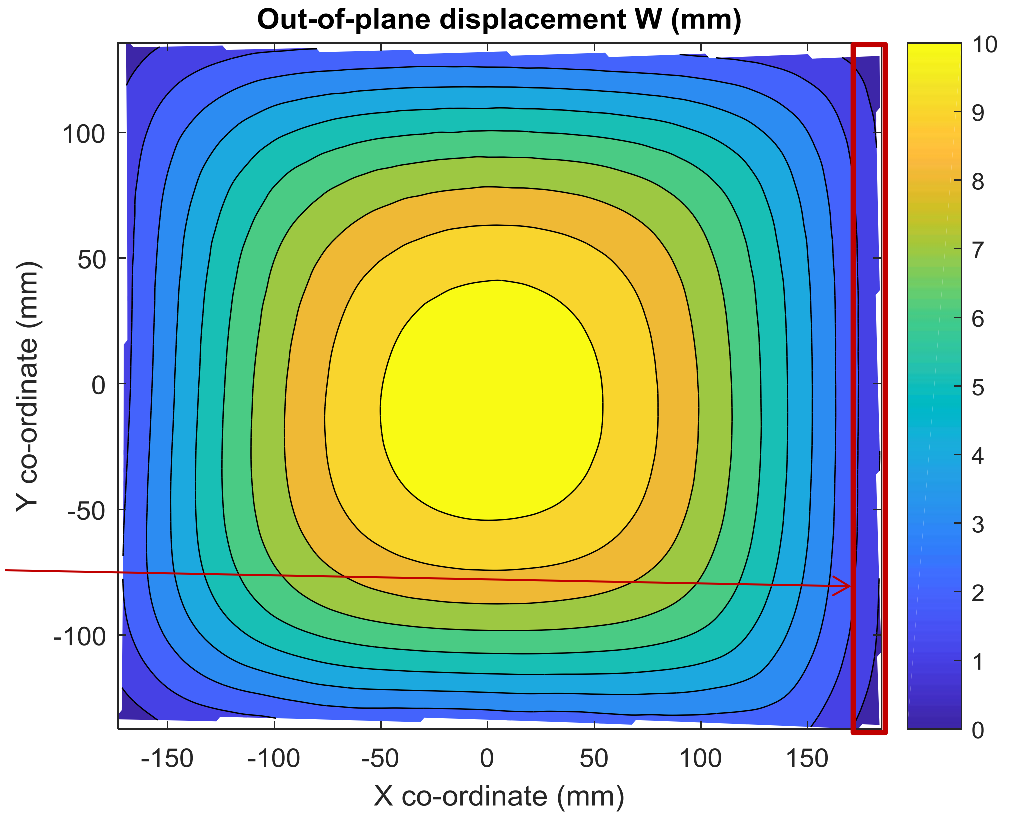
DIC image of vertical strain at max. compression

Out-of-plane Displacement



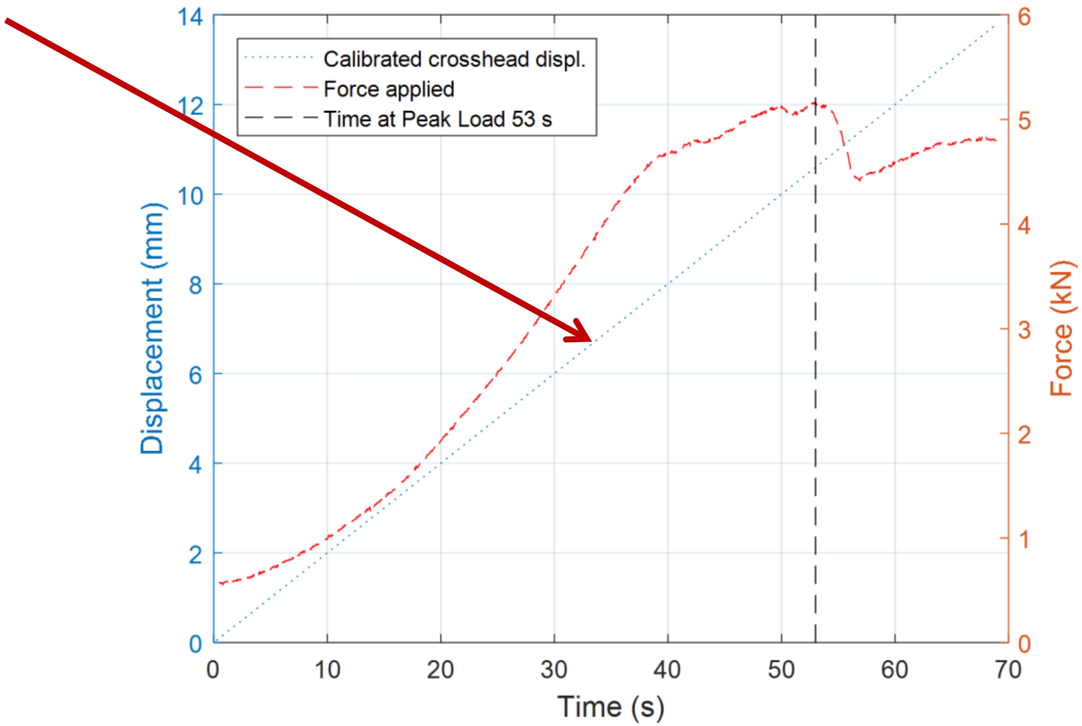
Out-of-plane Displacement

- With bowing at central region, strain from bending and compression are coupled
- Near vertical panel edges, out-of-plane displacement close to zero
- Ideal to determine in-plane compression from vertical strain data in this region

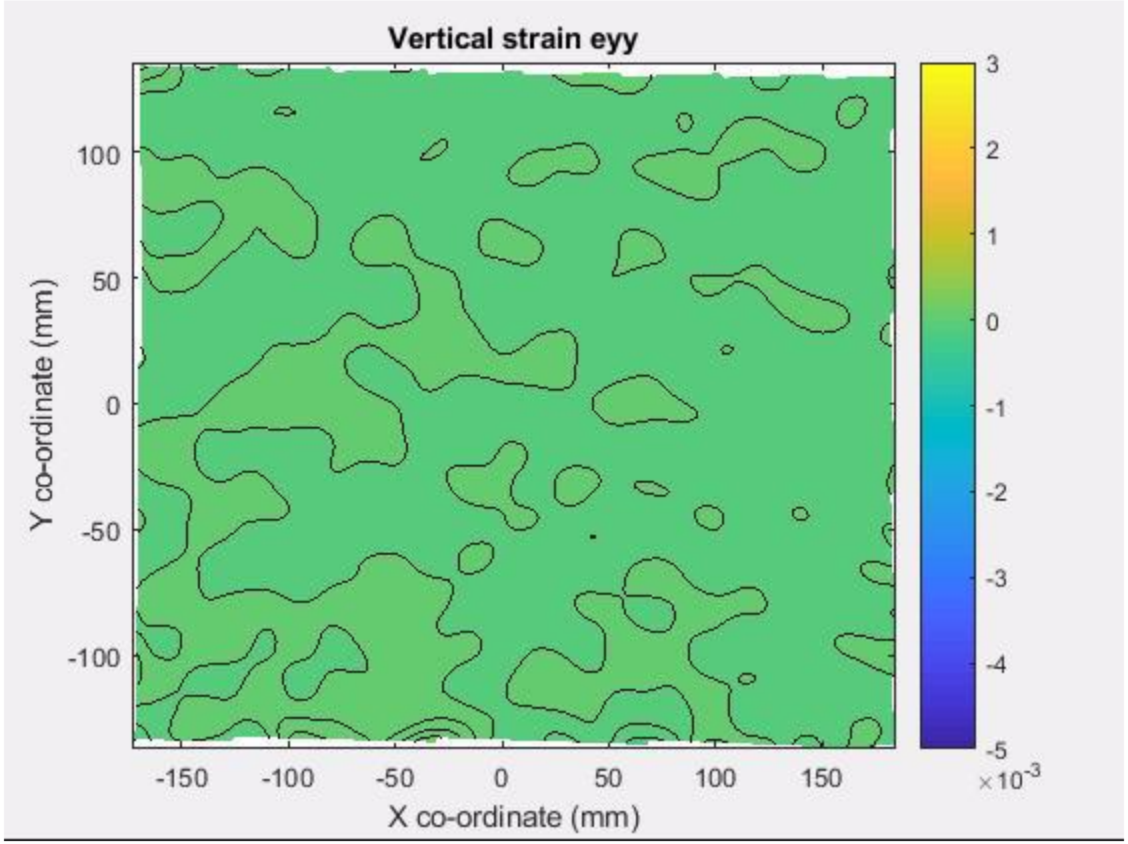


Calibrated Data

- Crosshead displacement from box tester data calibrated to start of DIC

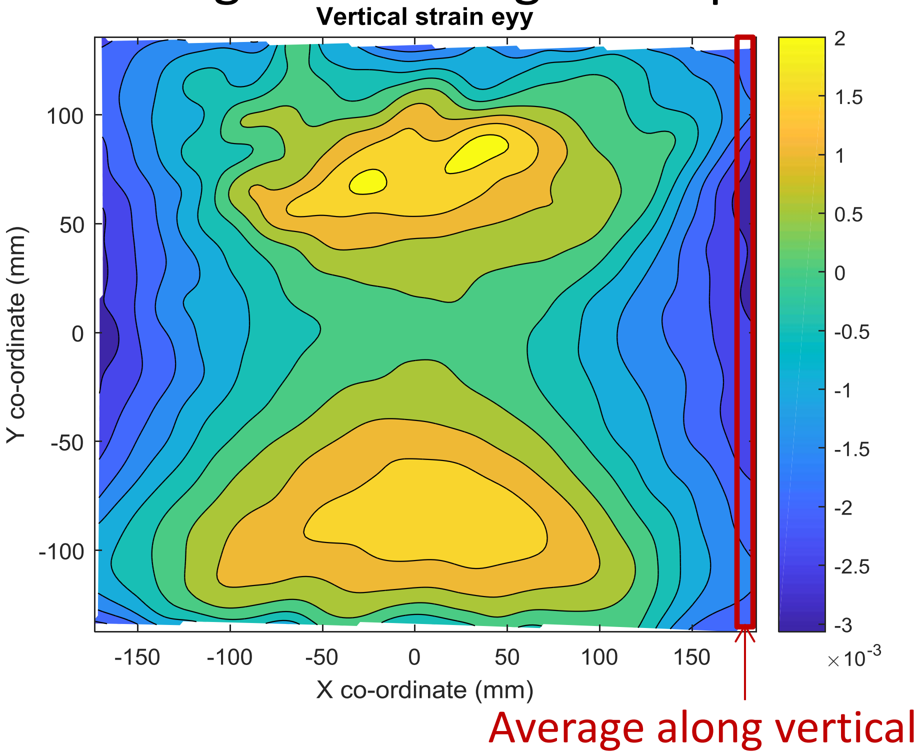


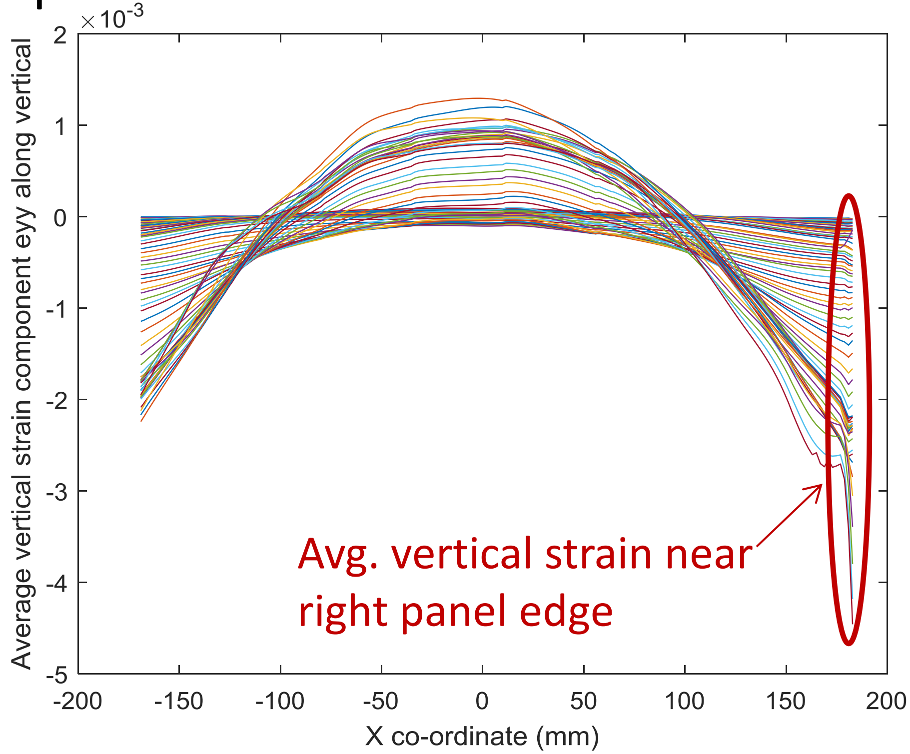
Vertical component of Strain



Averaged Vertical component of Strain

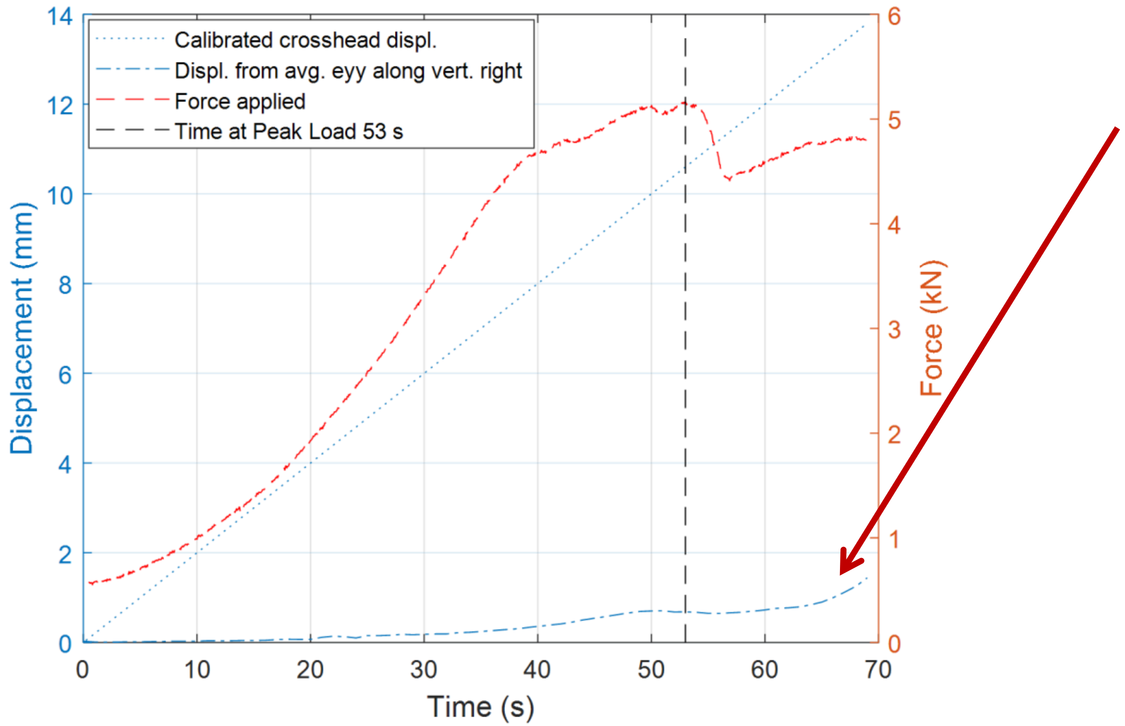
- Vertical strain averaged along vertical direction, plotted with horizontal coordinate
- Avg. vertical strain at right panel edge multiplied by initial panel height 295 mm gives in-plane compression



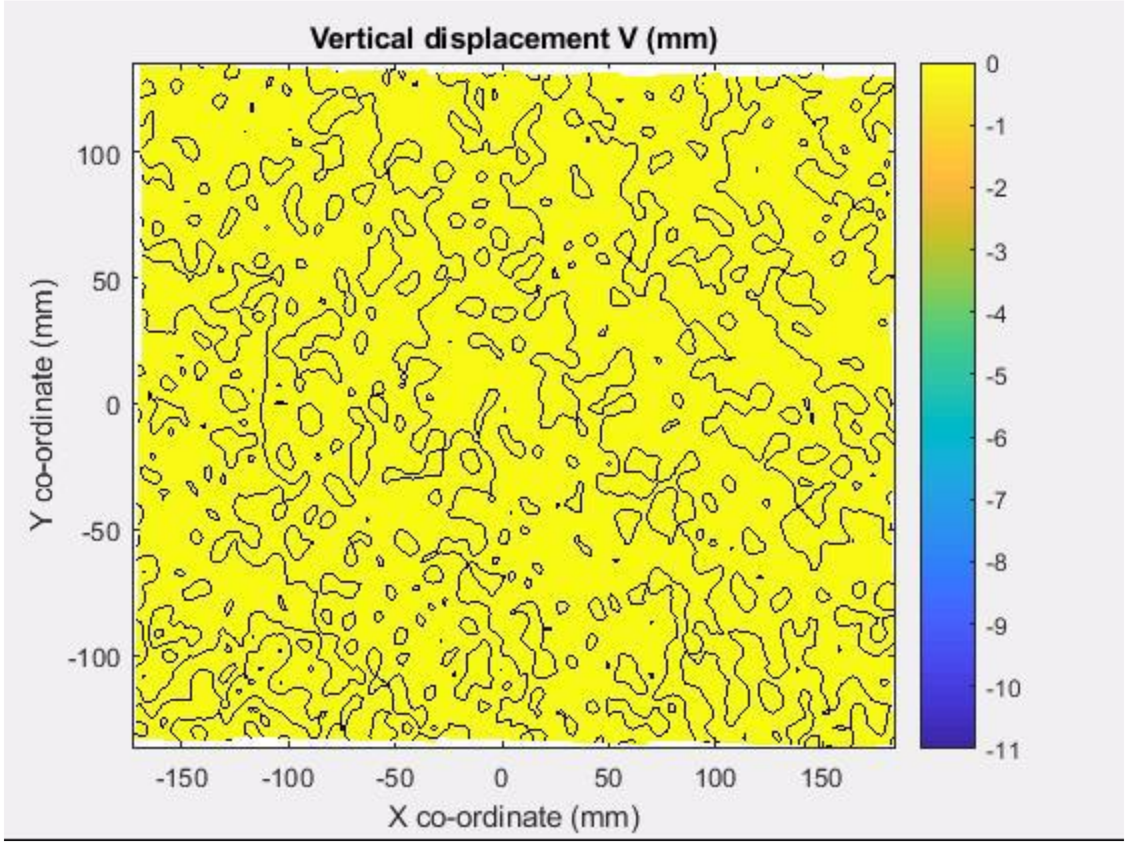


In-plane compression

- In-plane compression based on averaged vertical strain at right panel edge

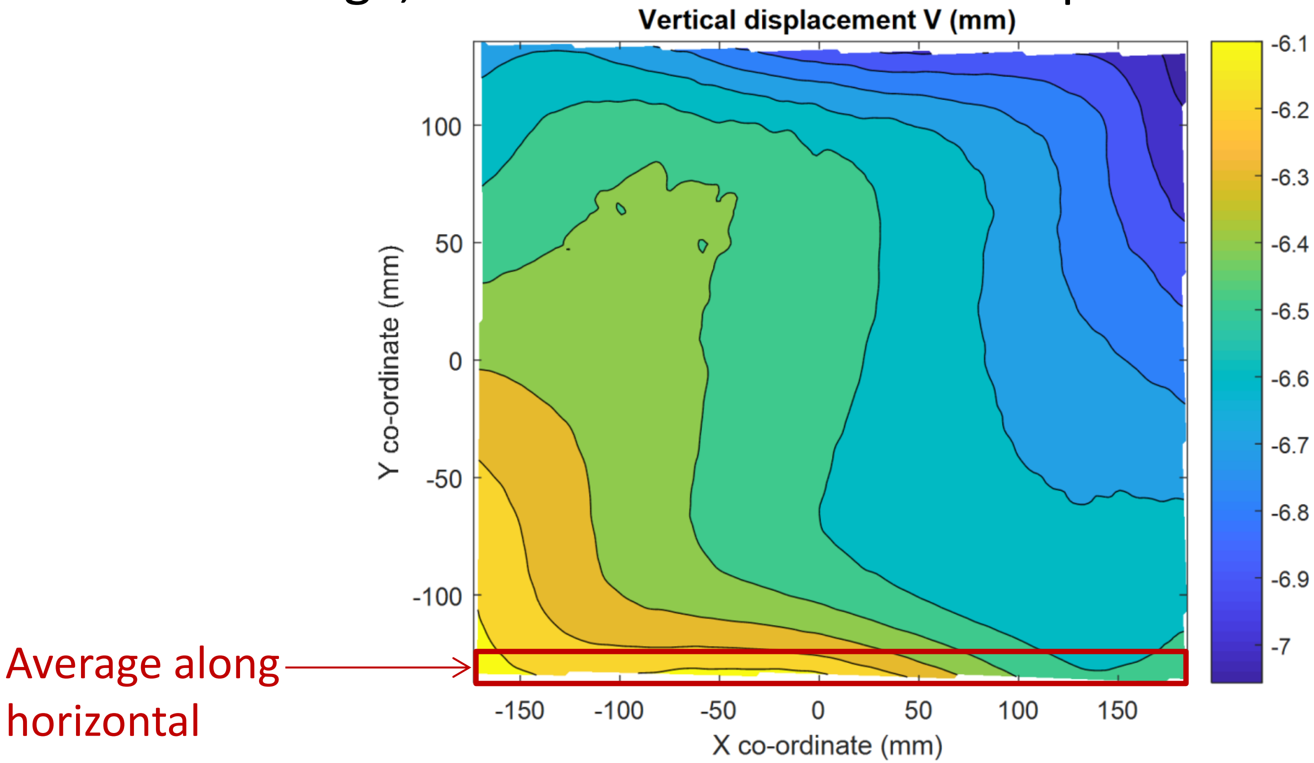


Vertical Displacement



Vertical Displacement

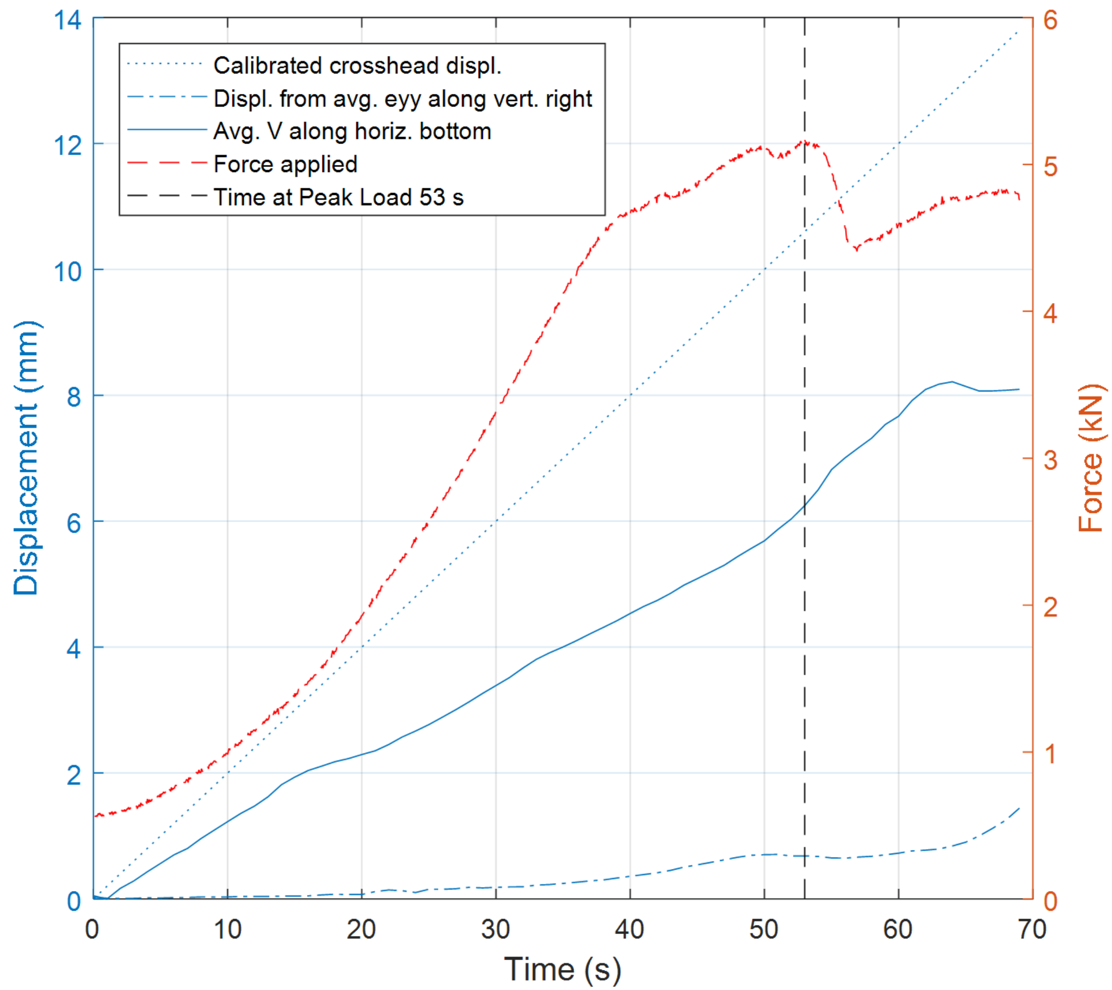
- Similar vertical displacement over panel - moved downwards with minimal in-plane compression
- Vertical displacement averaged along horizontal direction close to bottom edge, associated with bottom flaps and folds crushing



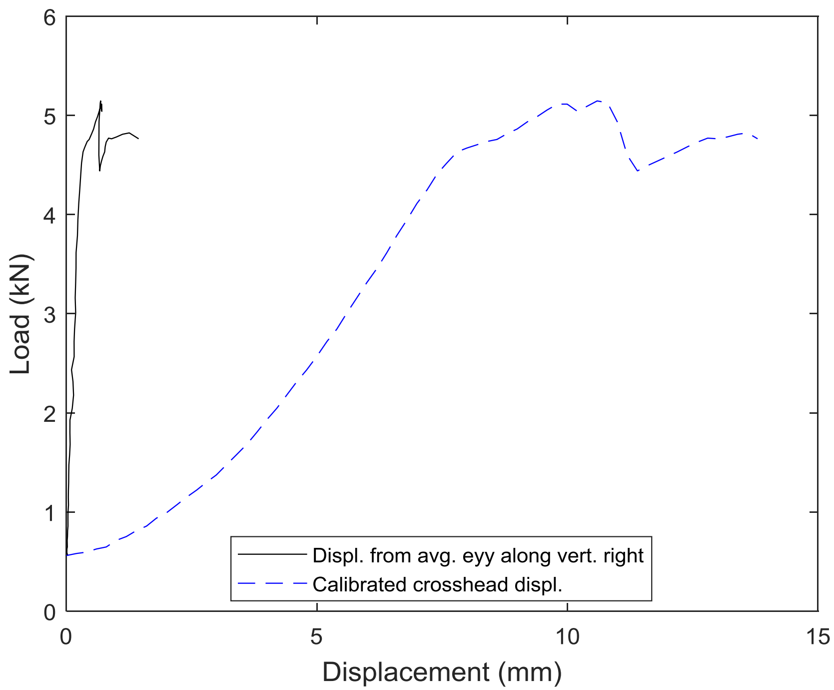
Displacement Contributions

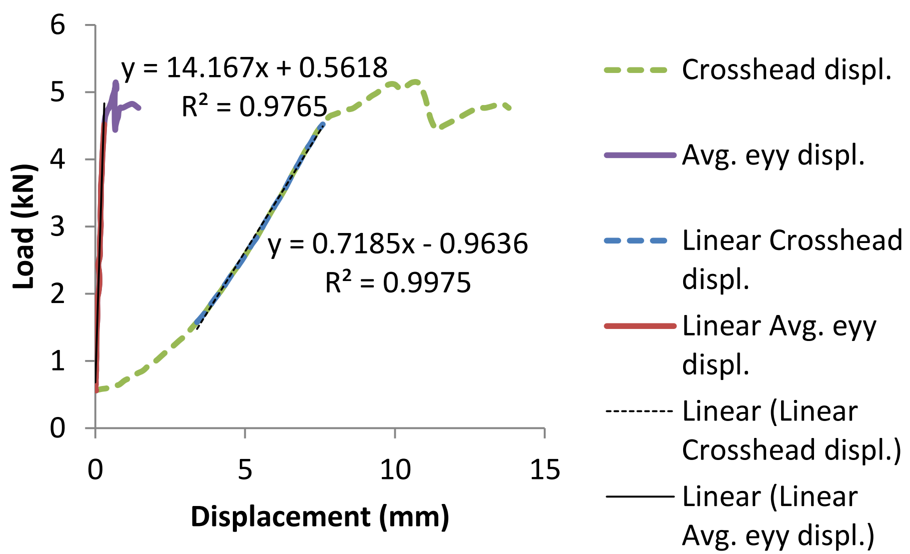
At peak load, time 53 s:

- Calibrated crosshead displacement 10.6 mm
- In-plane compression panel near the right vertical edge -0.68 mm
- Average *V* along horizontal near bottom edge -6.25 mm
- Remaining vertical displacement - top flaps and folds crushing and bowing of panel



Load – Displacement





Implications

- Compression of flaps and horizontal folds dominate shortening of box throughout test
- If interaction of package with contents is important for box design, deformation behaviour should be examined and sufficient headspace incorporated

Conclusion

- DIC enables measurement of regional contributions to overall displacement on a whole compressed box
- Measurements clearly show vertical displacement of box flaps and folds contribute most to box compression
- Agrees with results of previous studies which used tube sections to separate out various contributions to vertical displacement

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