CompTest 2008
October 20-22
Dayton, OH

Experimental Techniques and Data Acquisition for High-Rate Loading of Composite Joints and Structures

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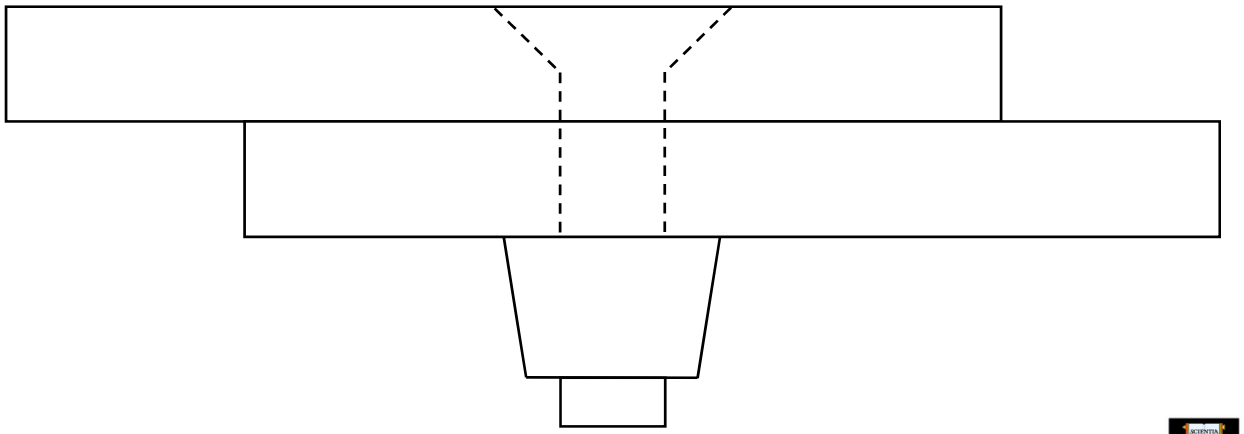
Overview

- Single fastener joint tests
  - Test fixtures
  - Data acquisition
  - Results
  - CT scan
- Simple structural tests
  - Test fixtures
  - Data acquisition
  - Results
  - CT scan
- Numerical simulation
  - Model
  - Results

Single Fastener Joint Tests: Overview

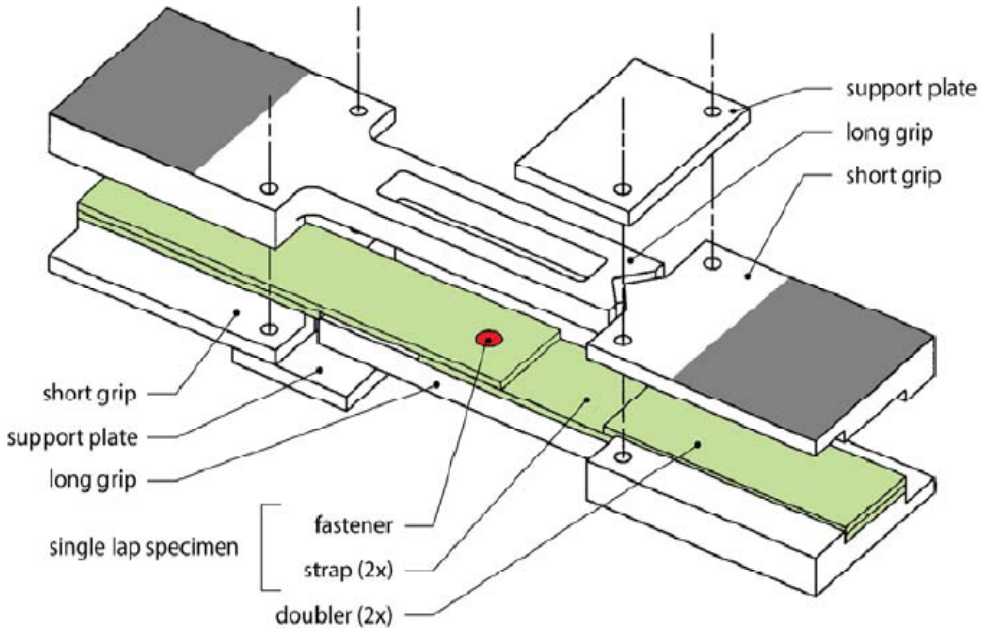
- ¼” Hi-Lok bolt
- Countersunk head type
- 16 ply quasi-isotropic laminate
- W/D, E/D = Large
- Two test geometries
  - Single-lap shear bolted joint
  - Pull-out test configuration

- 3 test loading rates
  - 0.1 m/s
  - 1 m/s
  - 10 m/s
- Hi-rate Instron tensile test rig

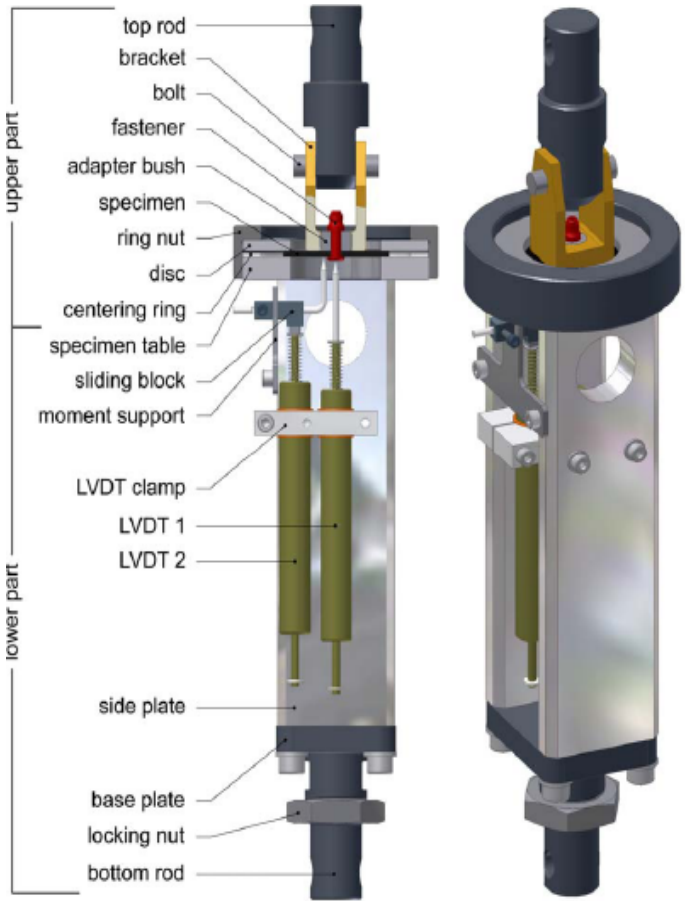


Single Fastener Joint Tests: Test Fixtures

- Common test fixtures
- Unsuitable for high-rate testing



ASTM D 5961 Bearing Test Fixture



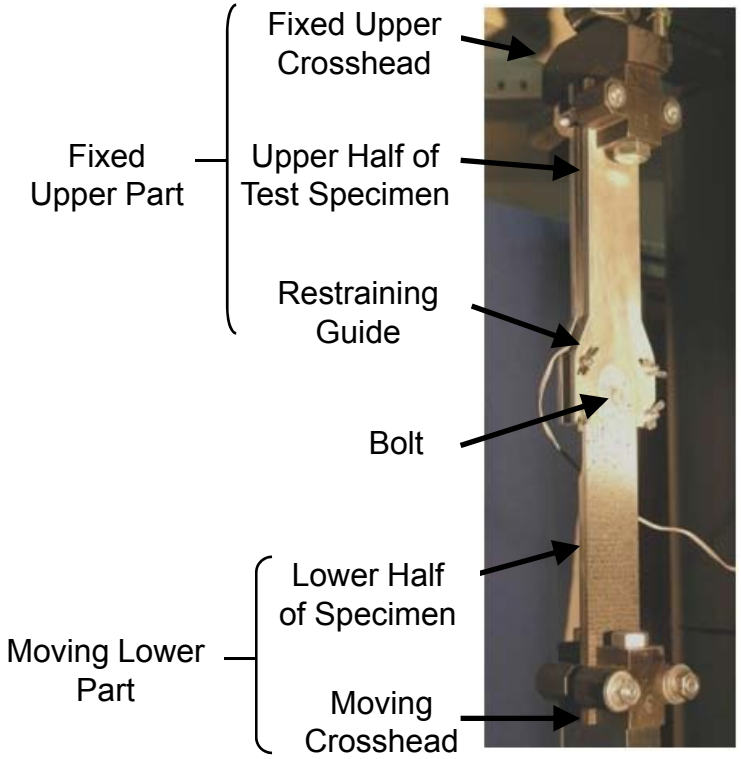
Pull-through Test Fixture

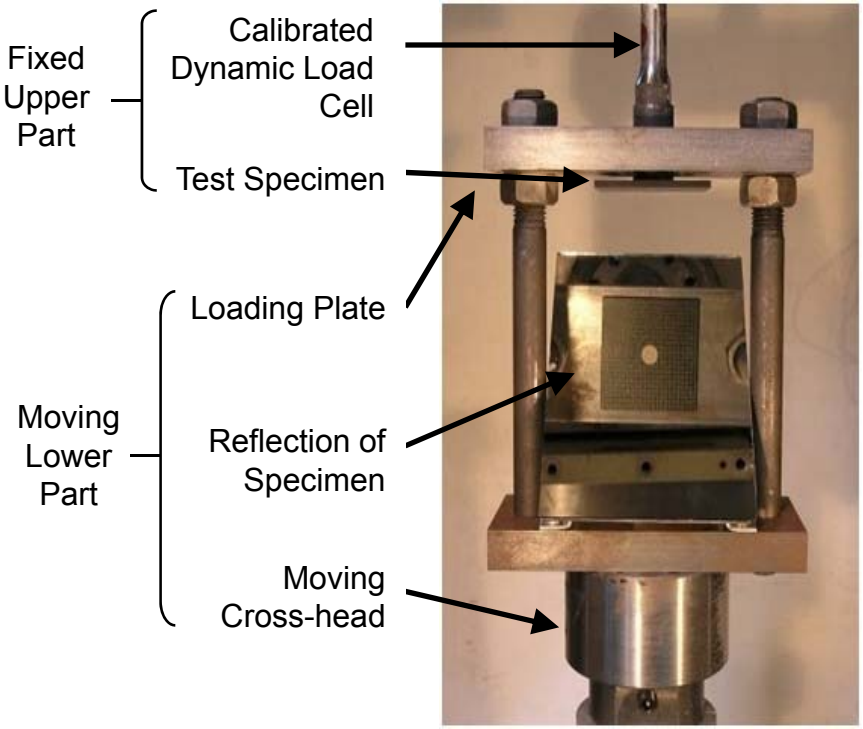
Single Fastener Joint Tests: Test Fixtures

- There are many factors to consider with high-rate test fixtures
  - Acceleration and deceleration distance of the crosshead
  - Inertia of the test fixture
  - Natural frequency of test rig sections
  - Experimental signal/noise ratio
  - High-rate tests generally cannot be stopped before ultimate failure
  - In many high-rate tests, a large amount of high energy debris is created that needs to be able to escape the test rig
- Problems with current test fixtures
  - Too much inertia
  - No allowance for acceleration and deceleration
  - Too enclosed (no exit paths for debris)

Single Fastener Joint Tests: Test Fixtures

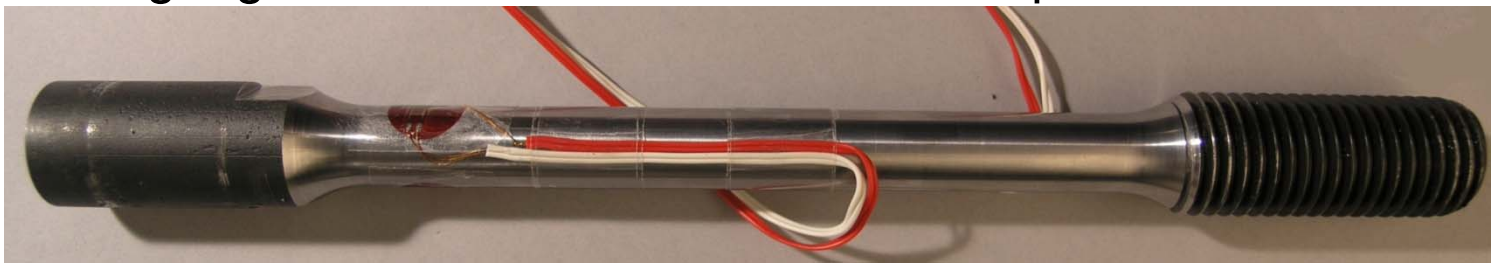
- New test fixtures allow for initial acceleration of the cross-head and have minimal weight



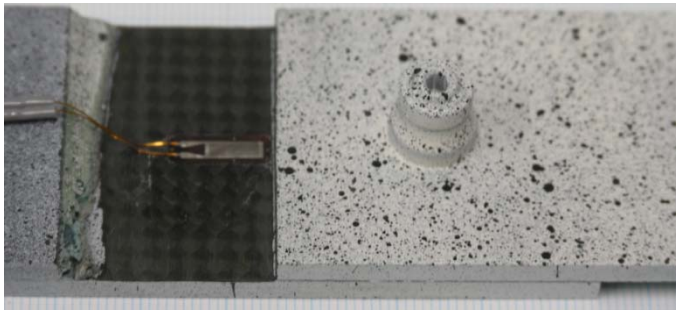


Single Fastener Joint Tests: Data Acquisition

- The cross-head load cell was not suitable for these dynamic specimens due to system vibrations and physical distance from the region of interest.
- For pull-through tests used an instrumented bar as a load cell. The strain gauge is then much closer to the test piece

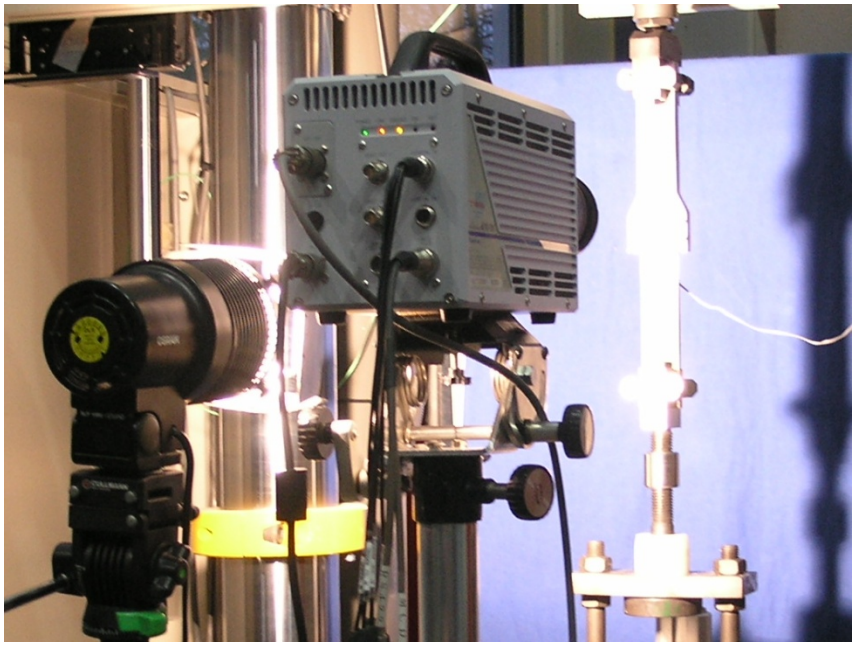


- The bearing specimens used calibrated strain gauges very close to the bolt

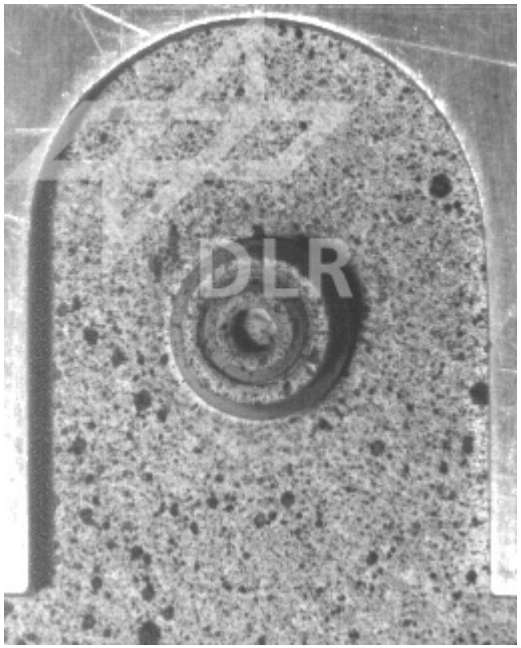


Single Fastener Joint Tests: Data Acquisition

- Specimens were filmed with a high-speed camera with maximum 3000 fps at full resolution (1024x1024) or up to 250000 fps with split resolution
- The film speed varied depending on the test loading rate
- The specimens were painted white and a black speckle pattern was applied to them for use with full field strain measurement techniques
- High intensity lighting was used to provide enough exposure for the camera CMOS sensor

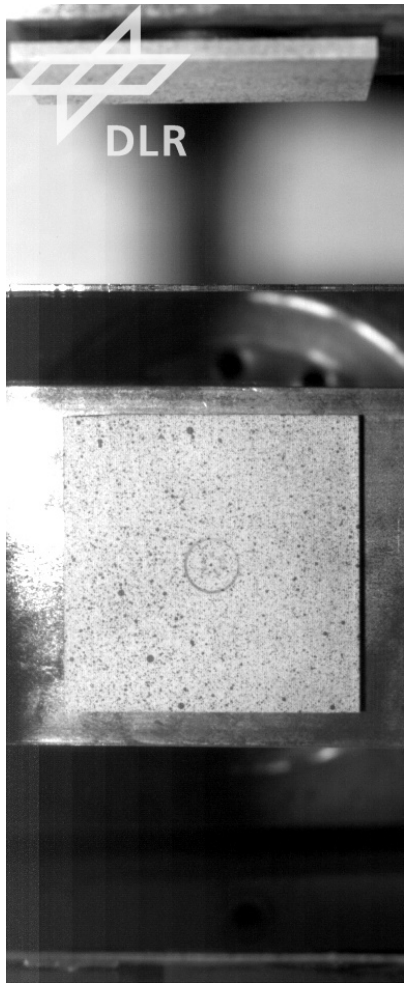


Single Fastener Joint Tests: Results



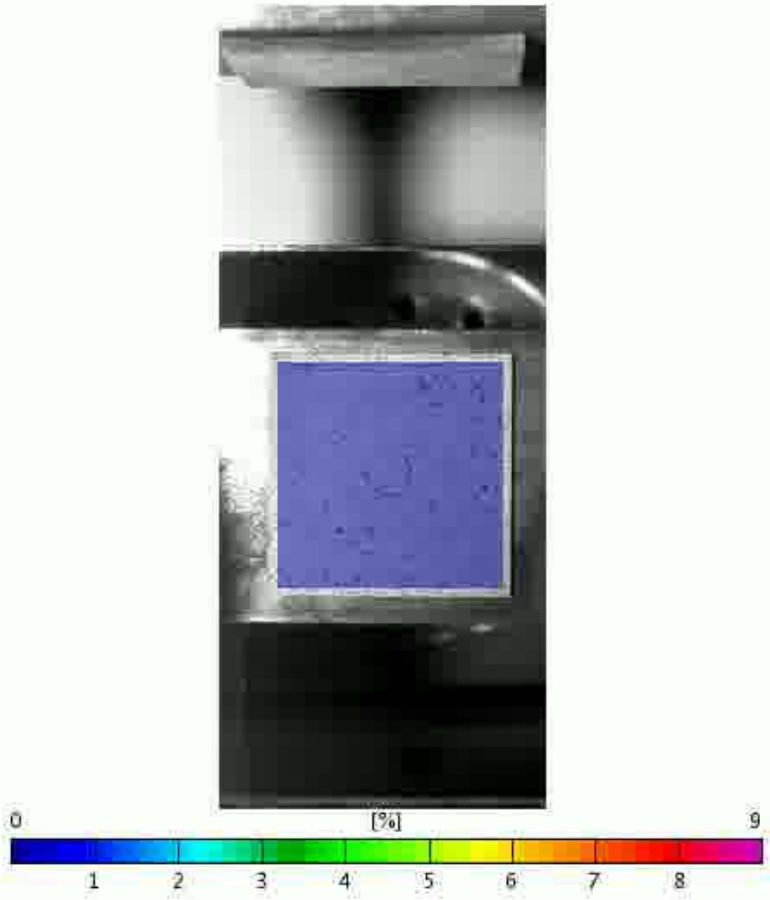
0.1 m/s shear test

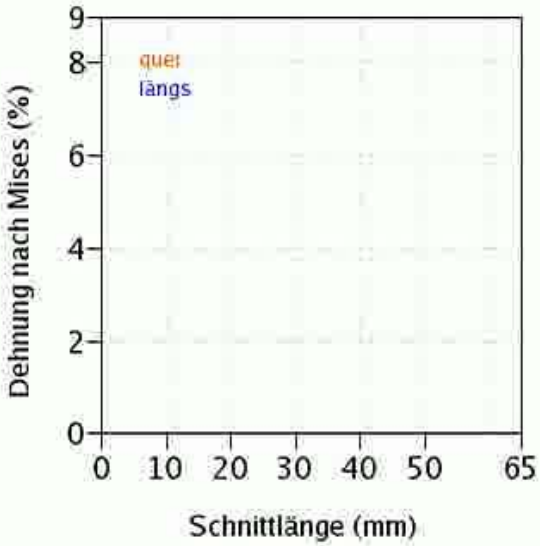
1 m/s shear test



Pull-through test

Single Fastener Joint Tests: Results





Probe: Ausreiss-Probe 6
Geschw.: 1 [m/s]
Bemerkung: -
Dehnung nach Mises (0-0)
Zeit: 0.000000s

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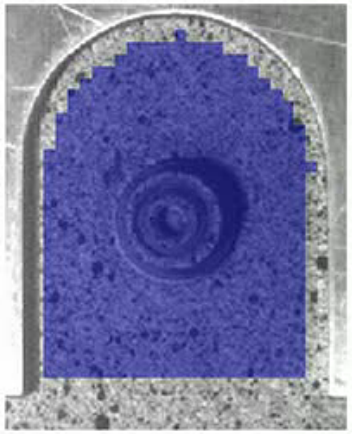
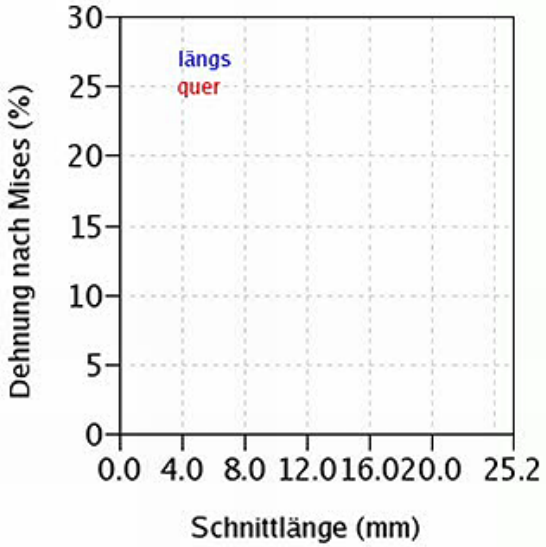
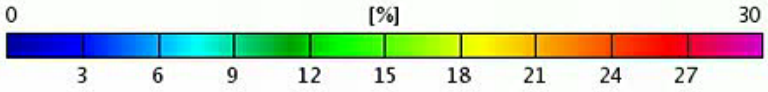
Single Fastener Joint Tests: Results

Stufe 0





Probe: Schub-Probe 1
Geschw.: 100 [mm/s]
Bemerkung: -
Dehnung nach Mises (0-0)
Zeit: 0.000000 ms



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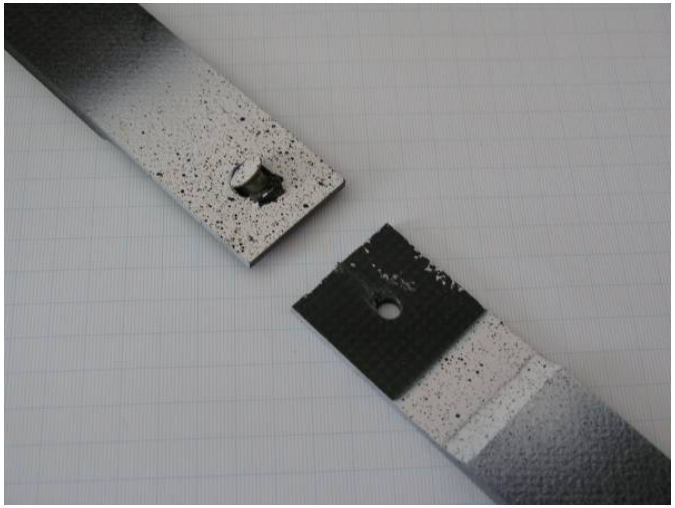
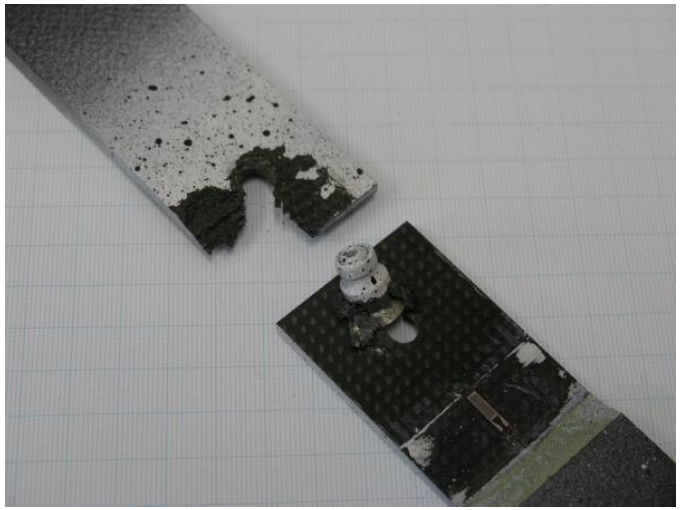
Single Fastener Joint Tests: Results

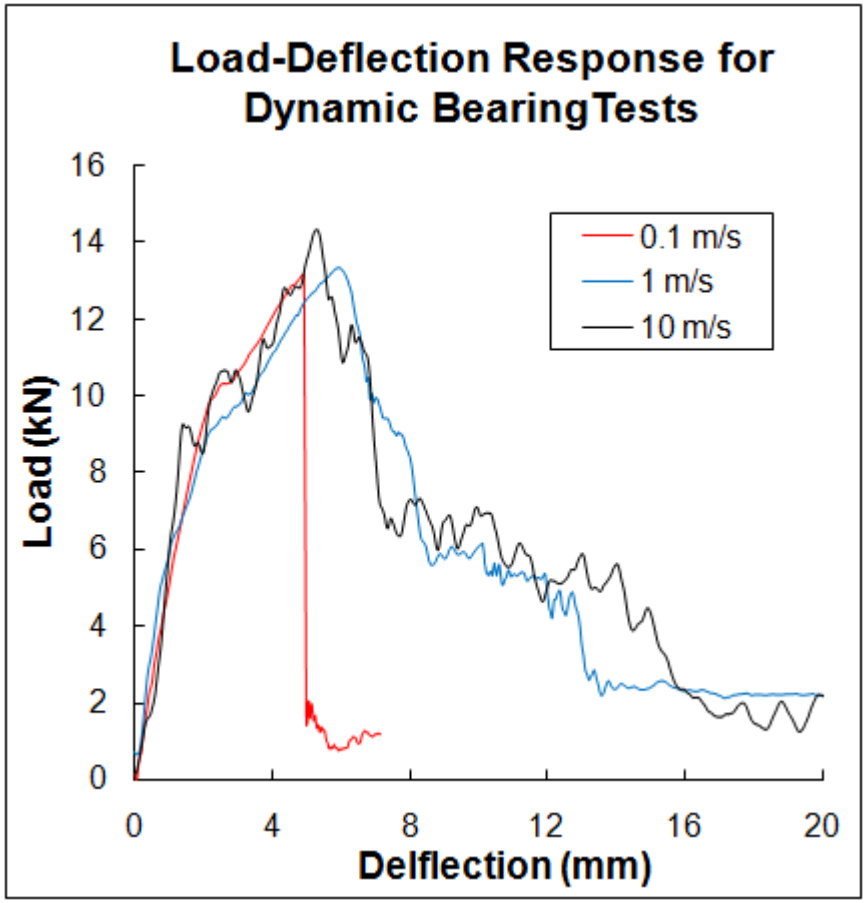


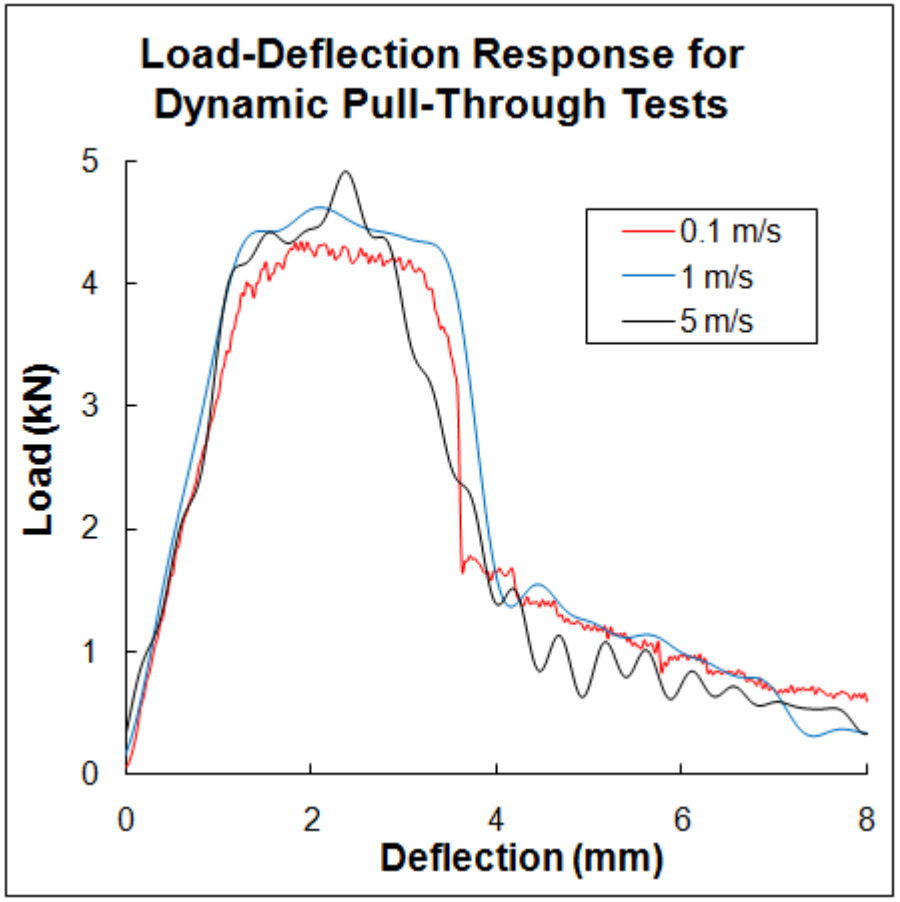


Pull-through failure (above)

Low-rate (top left) and High-rate (bottom left) bearing failure

Single Fastener Joint Tests: Results

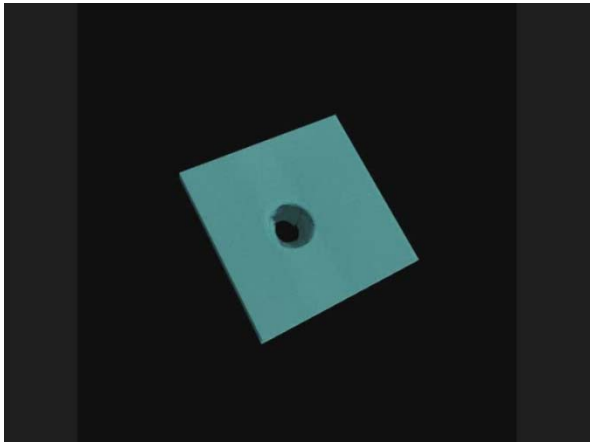




Single Fastener Joint Tests: CT Scan

- X-ray images collected non-destructively and reconstructed into 2-D slices and 3-D volumes of specimen

- 3-D volume representations can be easily manipulated into visualisations to aid understanding of failure modes

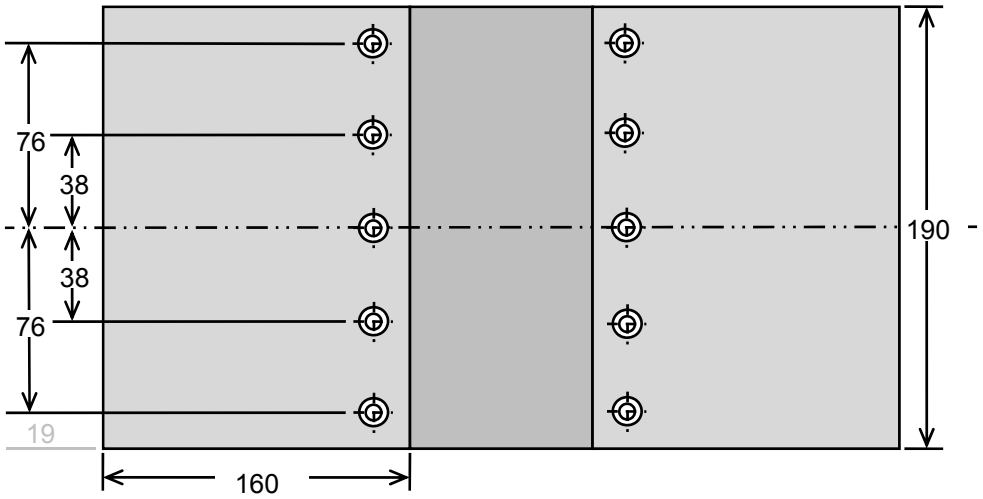


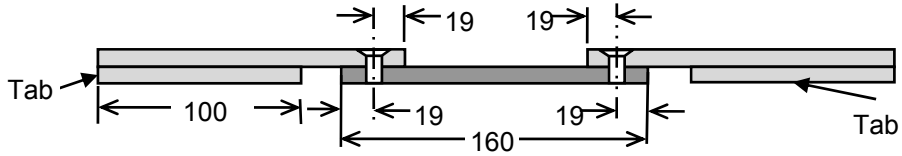
Single Fastener Joint Tests: Review

- Common bolted joint test fixtures do not lend themselves well to dynamic testing
- More suitable test fixtures have been designed
- Full field strain measurement techniques show promise for this area but must be 3D in future to capture relevant information
- No rate sensitivity for pull-through loading
- Change in failure mode between 0.1 m/s and 1 m/s loading rate for single lap shear joints

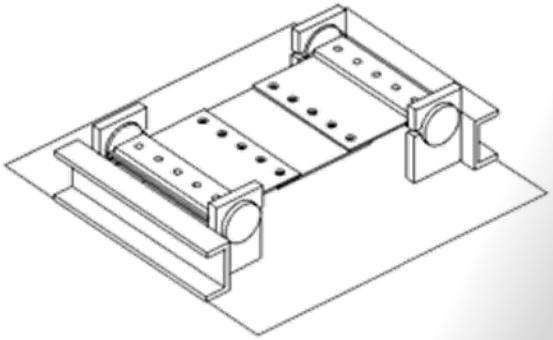
Structural Tests: Overview

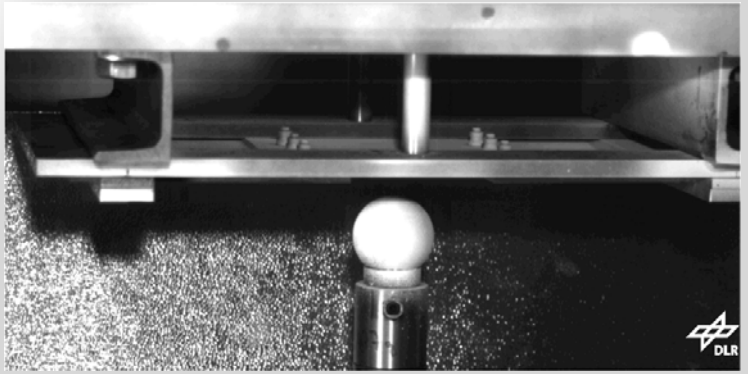
- A simple structure was created to test for rate sensitivity
- Two rows of single lap joints
- Two different loading conditions were considered for the panel
  - Line loading
  - Point loading
- Three loading rates
  - 0.1 m/s
  - 1 m/s
  - 10 m/s

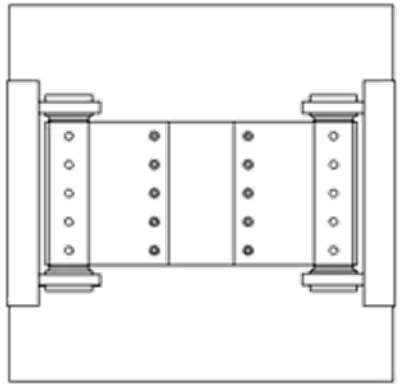




Structural Tests: Test Fixtures

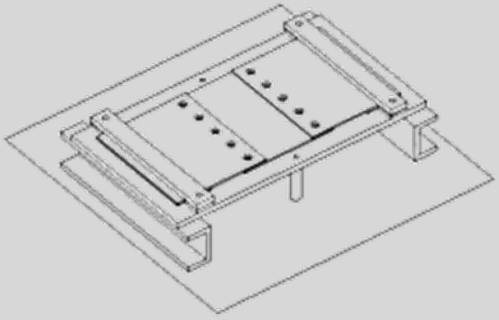


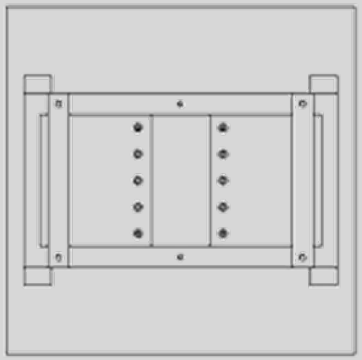




Line loaded test

Ball loaded test





Structural Tests: Test Fixtures

- Line loaded test
  - Simply supported at two ends
  - Single curvature induced in panel
  - Every bolt is loaded approximately equally
  - Deflection of panel creates large normal and shear loads on each bolt

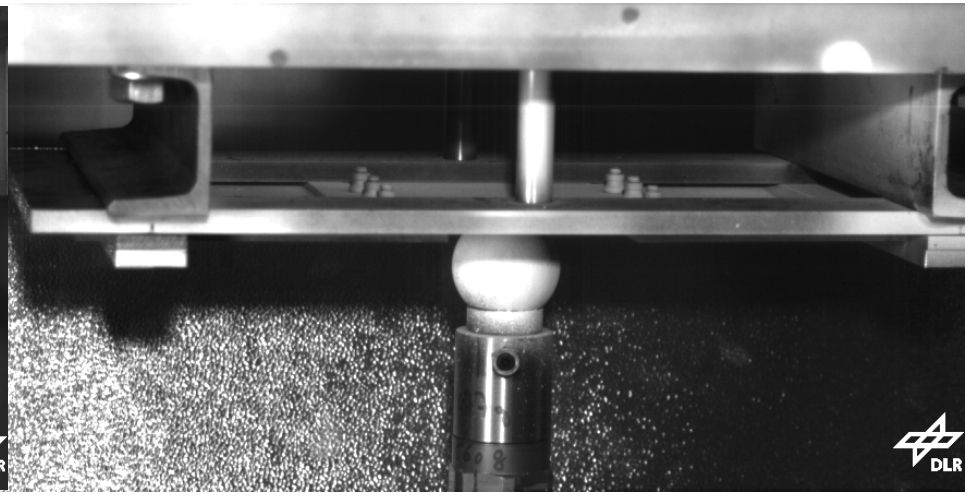
- Ball loaded test
  - Clamped on two edges, simply supported along the others
  - Point load creates double curvature in the panel
  - Each bolt experiences different normal and shear loads depending on its position in the joint

Structural Tests: Data Acquisition

- Due to the more complex loading arrangement of the structural tests it was more difficult to use calibrated strain gauges to measure forces
- Instron load cell values were used and attempts were made to filter out any delays or noise that resulted
- The tests were filmed on the same HS camera as the single fastener tests
- No full field strain measurements were attempted.

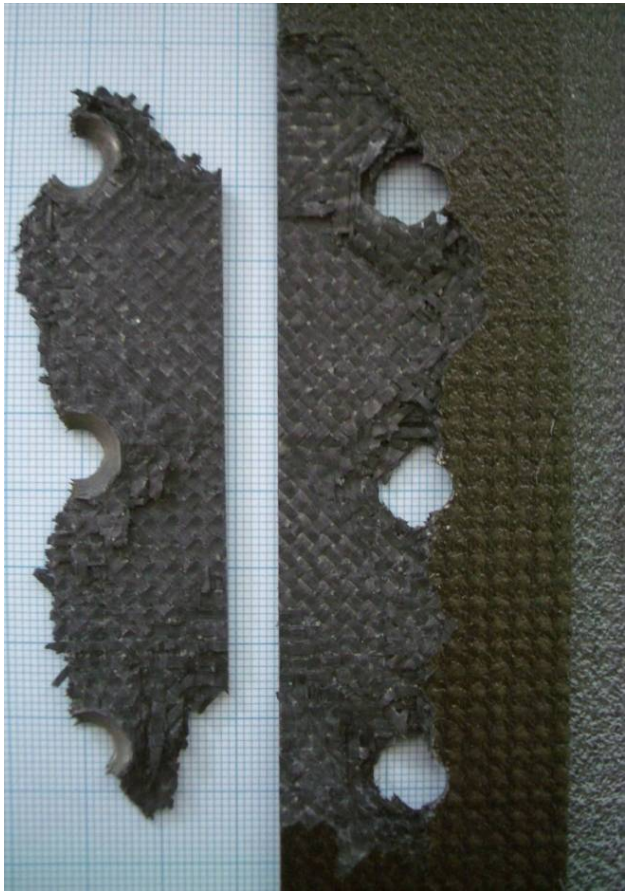
Structural Tests: Results

Line loaded test



Ball loaded test

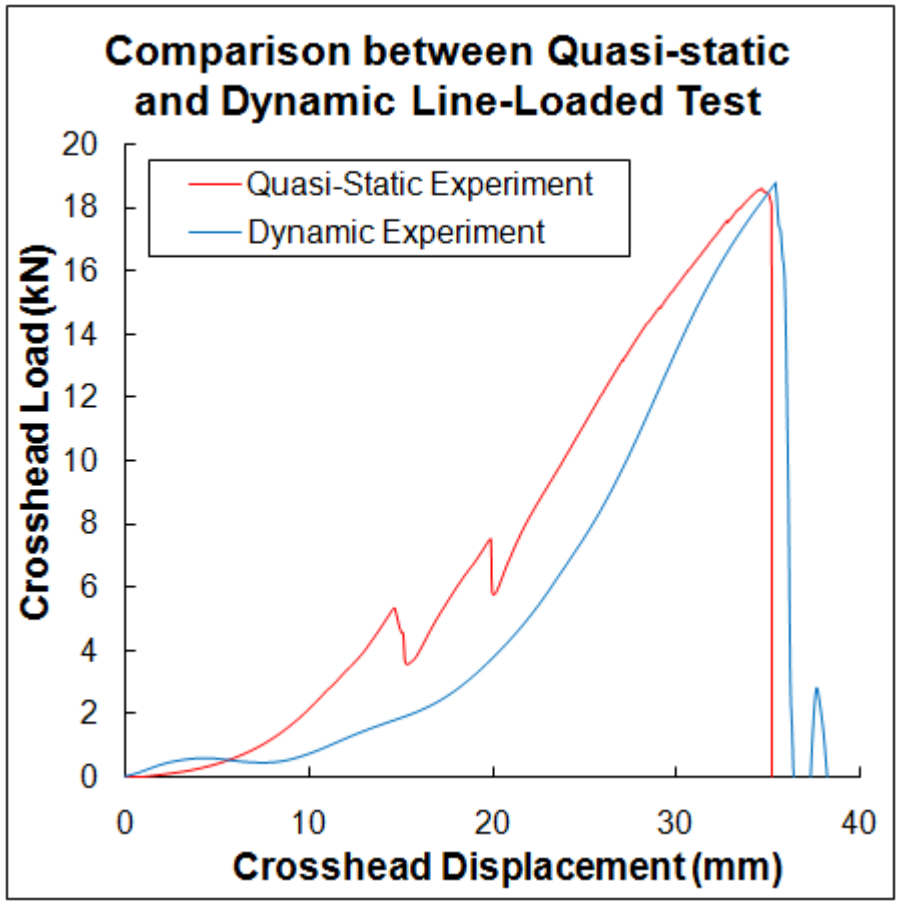
Structural Tests: Results

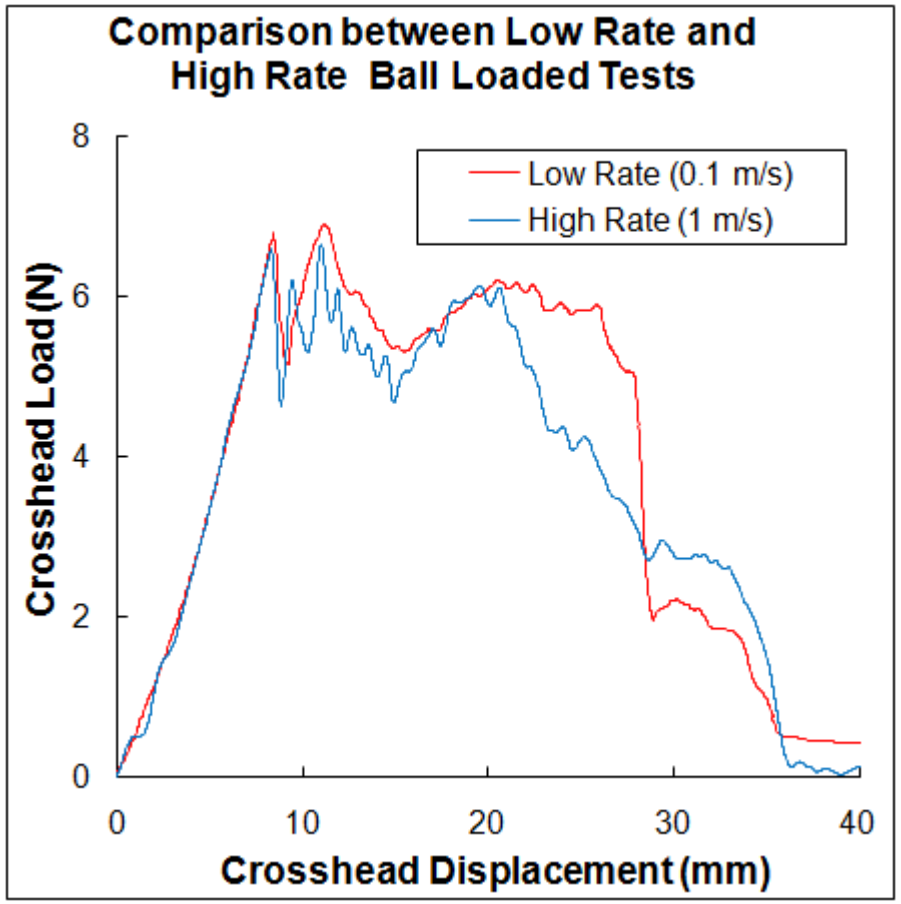


Line loaded test

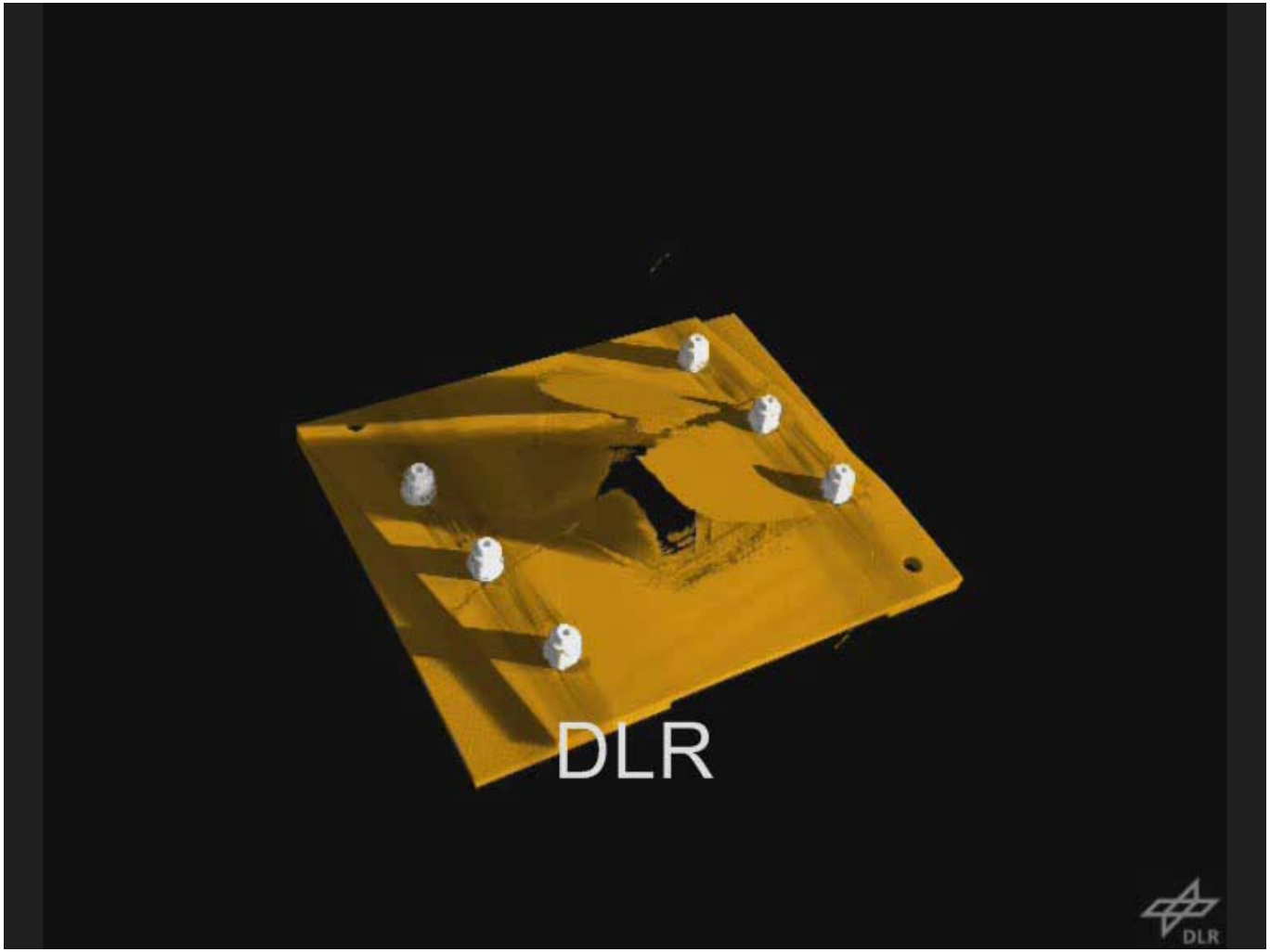
Ball loaded test

Structural Tests: Results



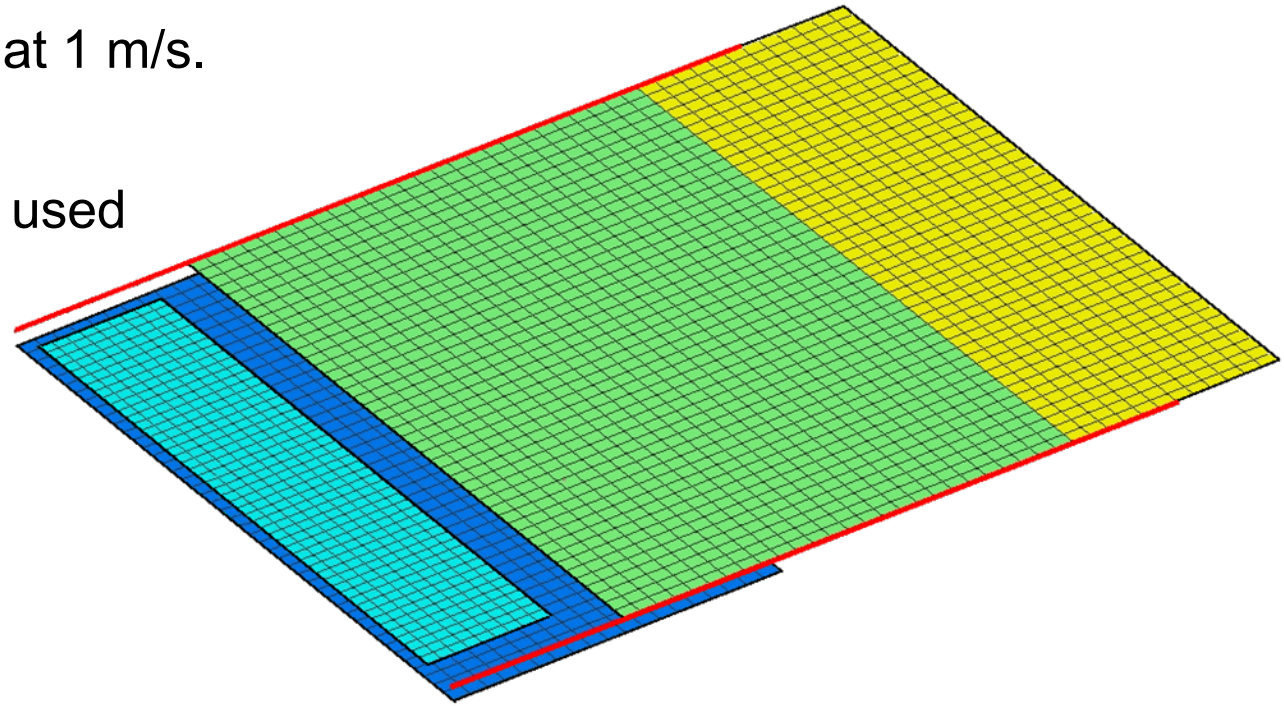


Structural Tests: CT Scan

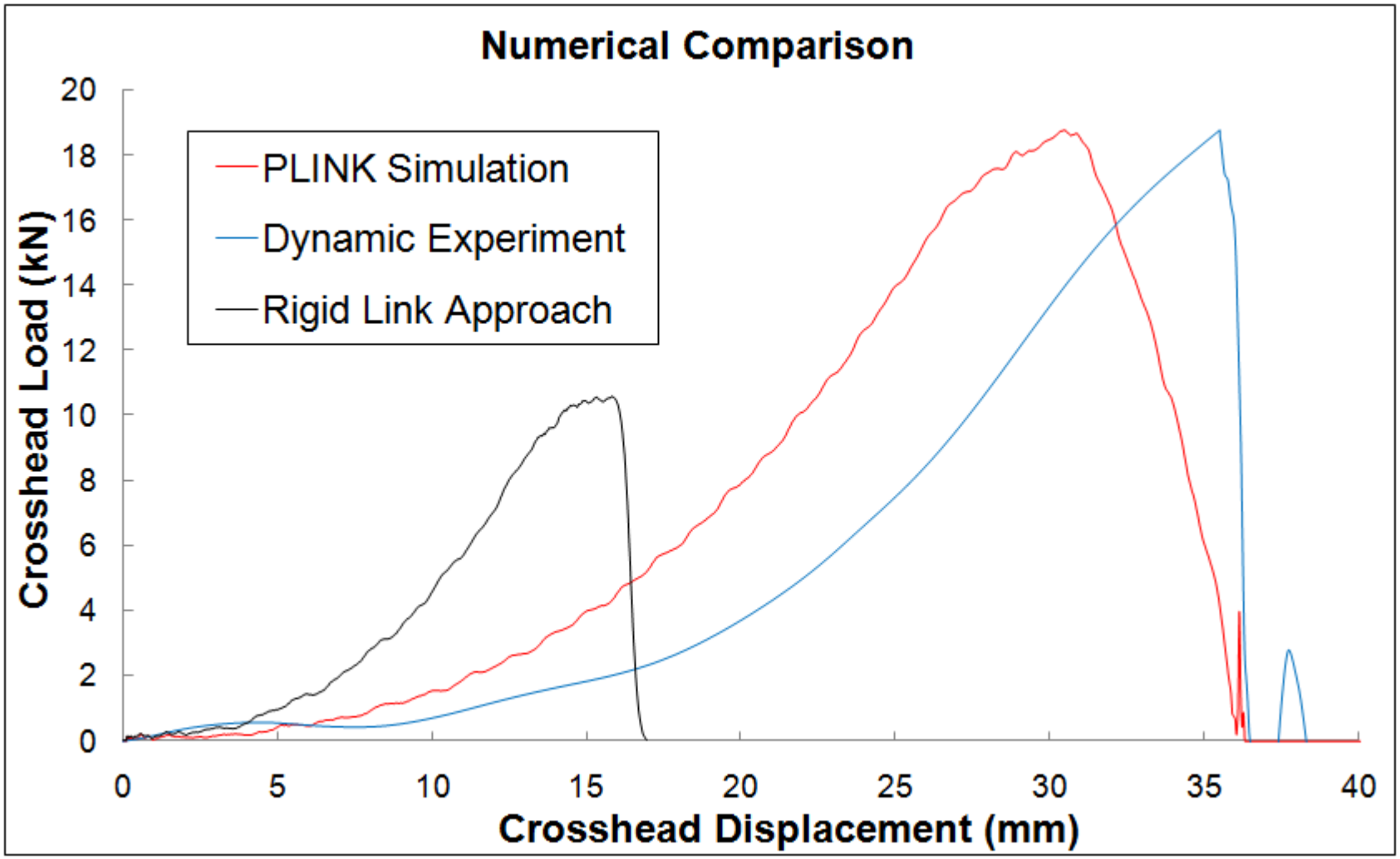


Numerical Simulation: Model

- Modelled with PAMCRASH v2006.
- 4 node quad elements.
- Material Type 131 using degenerate bi-phase Ply 0 model.
- Loading applied at 1 m/s.
- Symmetry
- PLINK elements used to represent fasteners



Numerical Simulation: Results



Key Results Summary

- New test fixture developed that were more suitable for high-rate testing
- No rate sensitivity discovered for pull-through loading of single fastener joints
- Step change in failure mode for shear loading between 0.1 m/s and 1 m/s
- No rate sensitivity discovered in the structural tests conducted
- Load realignment tends to make the joints fail in a pull-through fashion
- PLINK elements can model fastened joint far more effectively than “Tied Nodes” or “Rigid Link” approach

References

- Gunnion, A., et al., *Development of Fastener Models for Impact Simulation of Composite Structures*, in *25th Congress of the International Council of Aeronautical Sciences ICAS*. 2006: Hamburg, Germany.
- Bornschegel, T., *Experimentelle Untersuchung von Nieten in Verbundstrukturen unter Hochgeschwindigkeitsbelastungen*, in *DLR Report*. 2007.
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Acknowledgements

The authors would like to acknowledge and thank the following:

- Australian Postgraduate Awards Scheme.
- Australian Government under the “International Science Linkages” programme.
- Cooperative Research Centre for Advanced Composite Structures (CRC-ACS) and colleagues Andrew Gunnion and David Elder.
- DLR and colleagues Thomas Bornschlegel, Husam Abu El-Hija, Raouf Jemmali and Harald Kraft.