FULL-SCALE CRASH TESTING OF CARGO CONTAINERS

EXPERIMENTAL CHARACTERIZATION FOR TRANSPORT AIRPLANE CRASH APPLICATIONS

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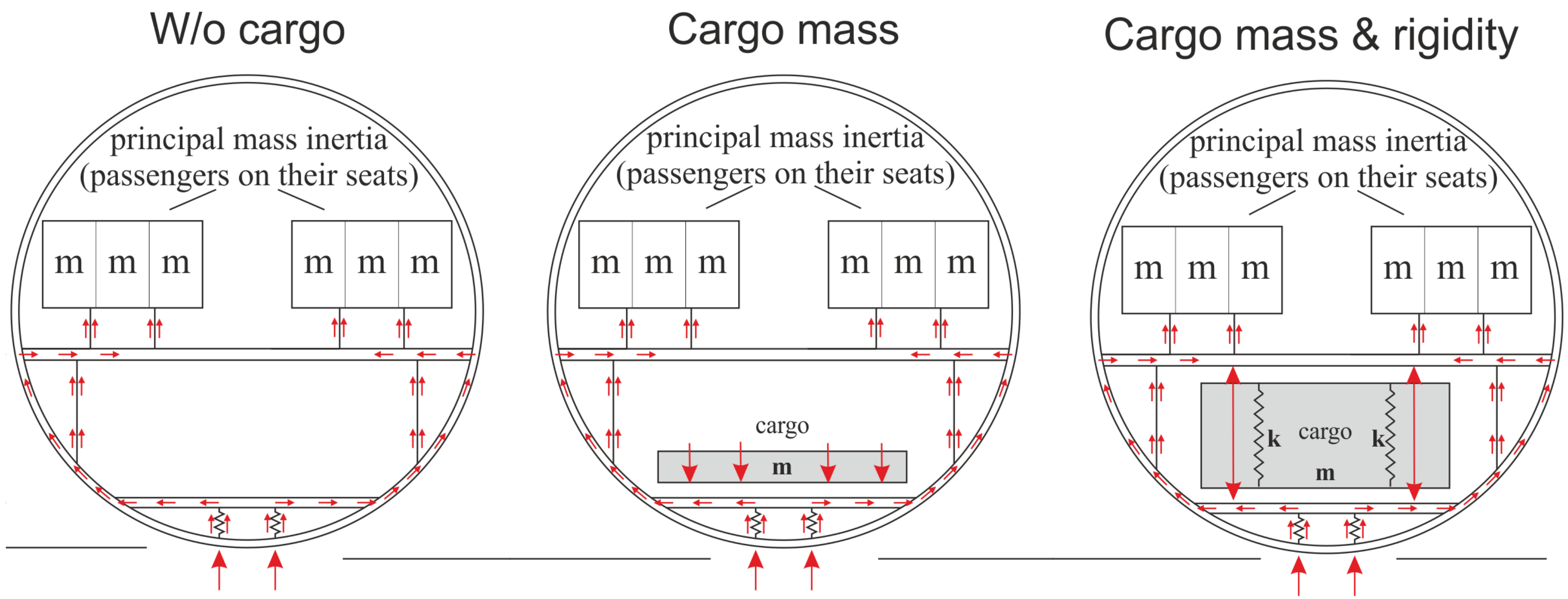
Motivation

Influence of cargo loading on crashworthiness

- **Relevant characteristics of cargo loading**
  - Cargo mass → mass inertia forces introduced in the cargo floor structure
  - Cargo rigidity → direct load path between cabin and cargo floor



Motivation

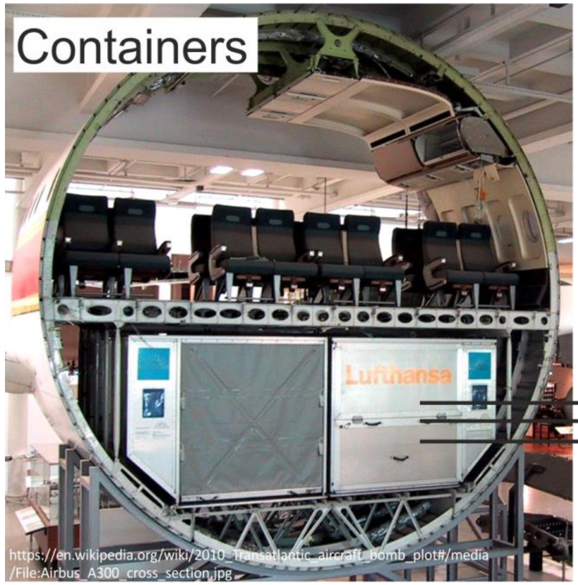
Cargo loading

- **Types of cargo loading (lower deck)**
  - Bulk
  - Container
  - Pallets
  - Miscellaneous

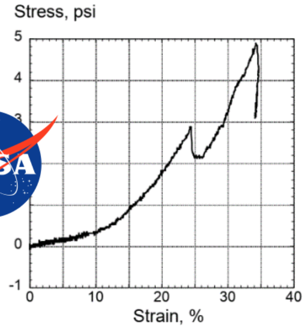
- **What is representative cargo?**
  - Bulk

    NASA performed luggage crush tests ✓ →
  - Container

    No data available in literature ✗



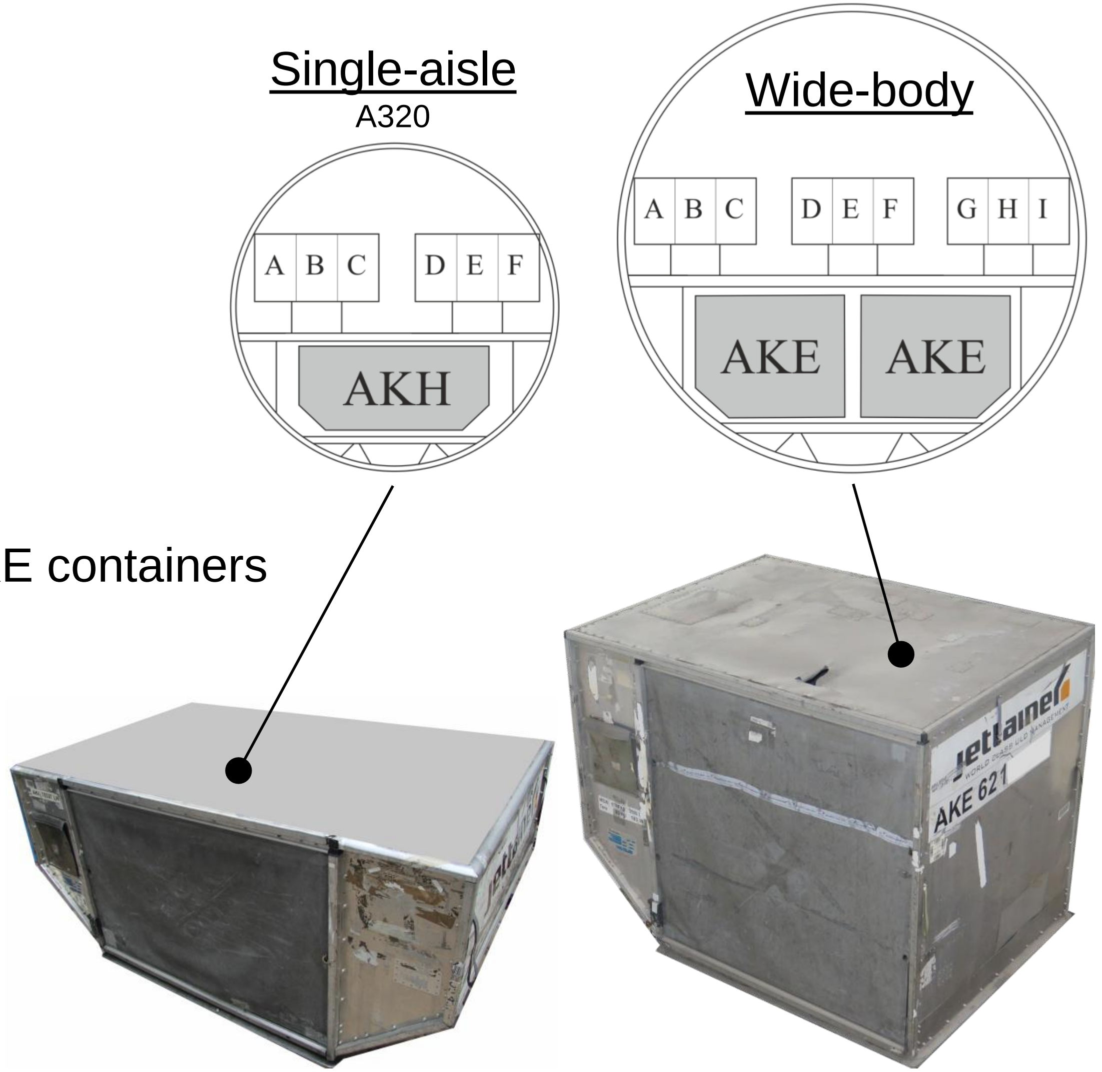
Q-s luggage crush tests (DOT/FAA/AR-02/62)
Dynamic luggage crush tests (NASA/TM-2018-219829)



Representative ULD containers

- **Selected container types**
  - LD3 (IATA: AKE)
    - Lower deck of wide-body transport airplanes
  - LD3-45 (IATA: AKH)
    - Lower deck of the single-aisle A320 family

- **Selected containers**
  - 13 used containers purchased by DLR: 4 AKH + 9 AKE containers
    - All airworthy, with negligible or minor damages
    - Same manufacturer (Driessen) and same series
  - Conventional differential design (most representative)
    - **Similar design for AKE and AKH containers, e.g. identical profile cross-sections**



Building block approach

Container characterization

- **Full-scale**
  - Drop tower tests
- **Detail level**
  - Roof corner: Cantilever bending
  - Base corner: Crushing
- **Element level**
  - Profiles: 3-point-bending
- **Coupon level**
  - Door canvas
  - Diagonal ropes
  - Bolted joints
  - Material testing

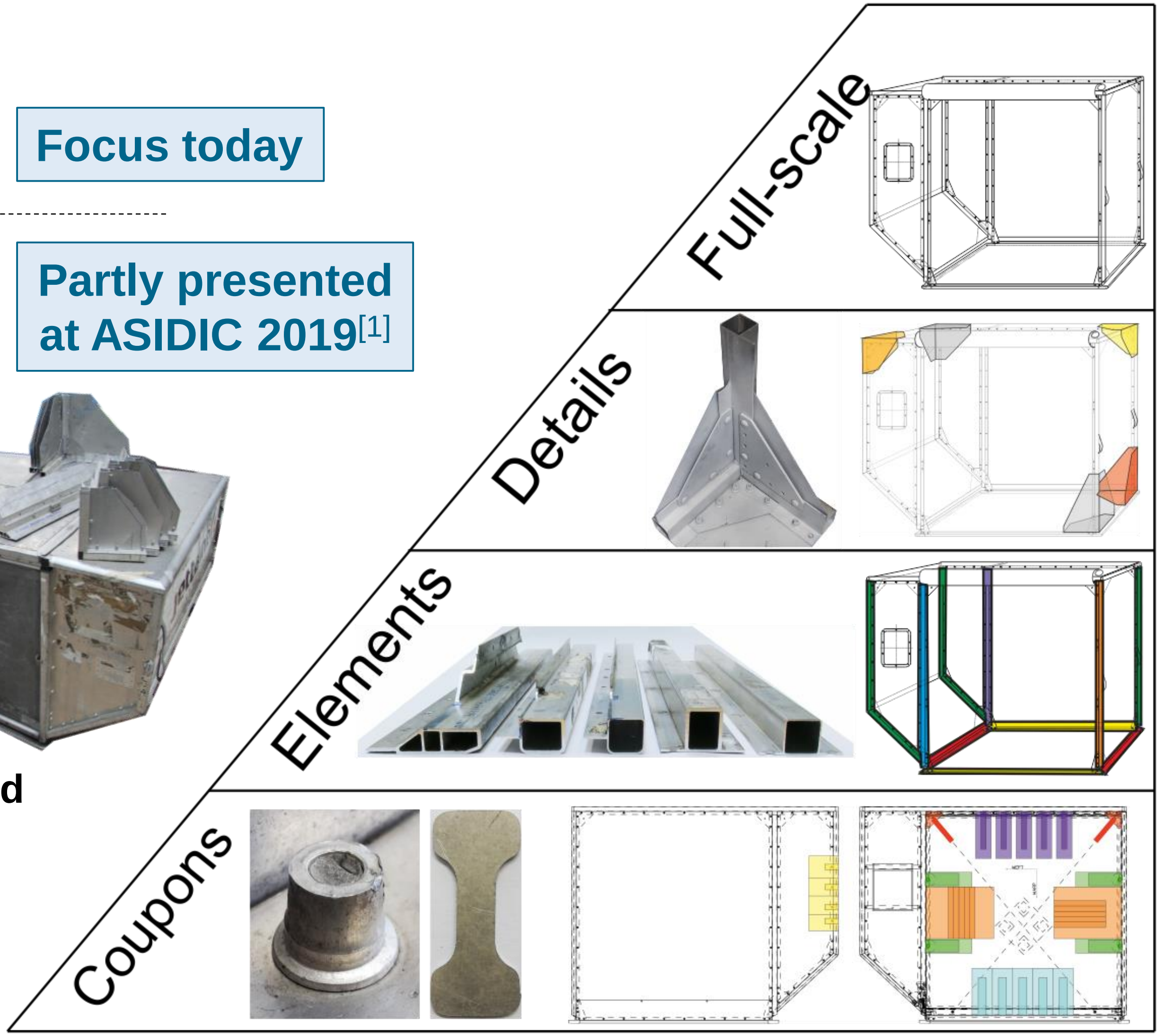
Optional,
in case data sheet
information is not
sufficient

4 x AKE
4 x AKH

Focus today

Partly presented at ASIDIC 2019[1]

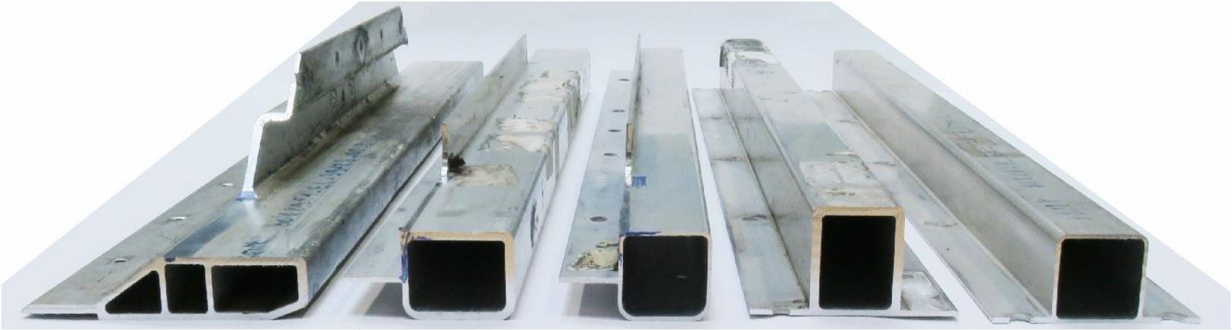
4 containers disassembled

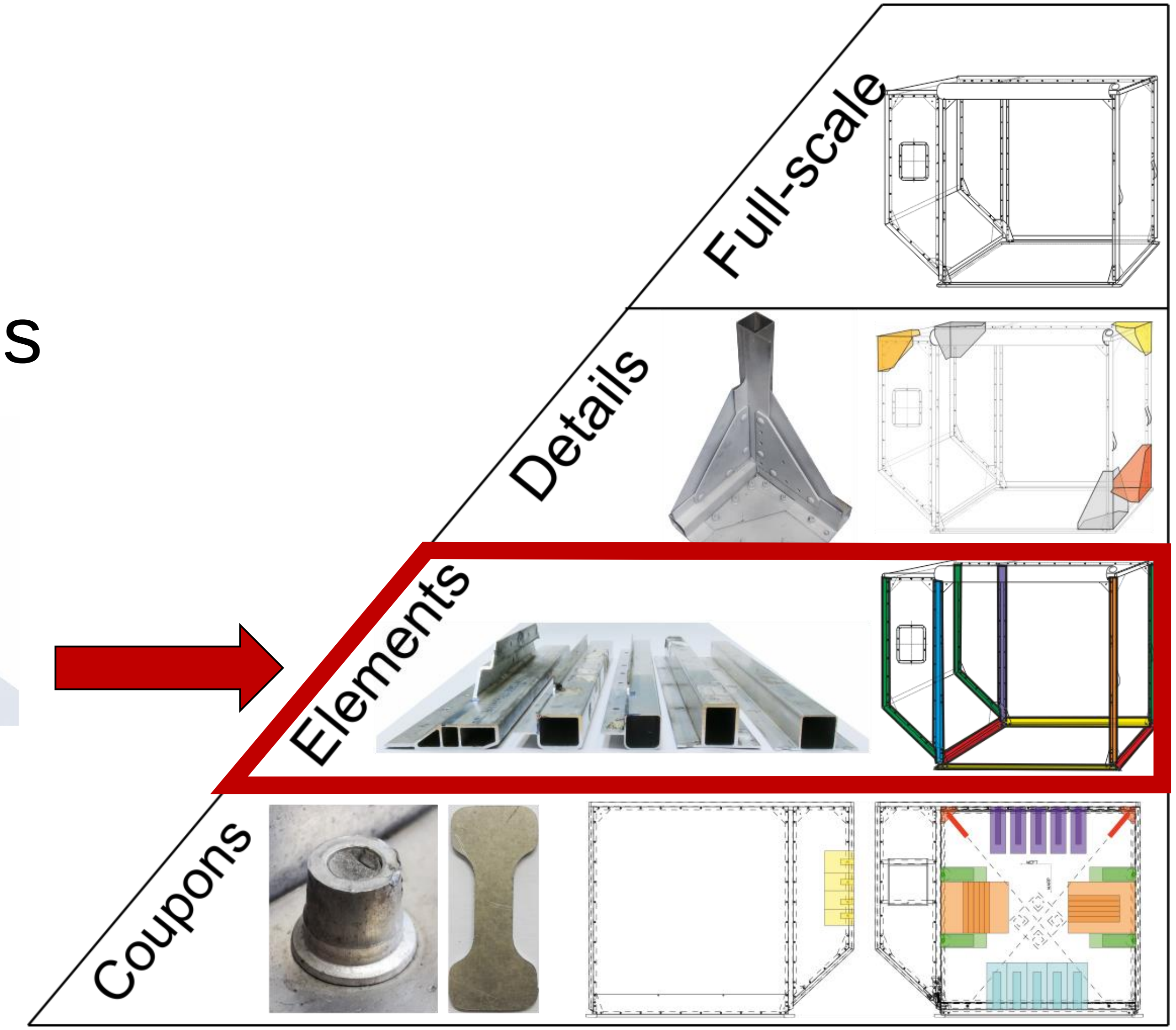


[1] M. Waimer, P. Schatrow: „Cargo Container Characterization for Airplane Crash Applications – Experimental Tests and Validation of Simulation Models", Aerospace Structural Impact Dynamics International Conference 2019, June 4-6, 2019 – Madrid, Spain

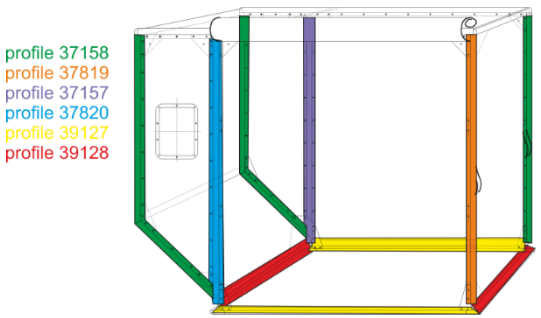
Element level

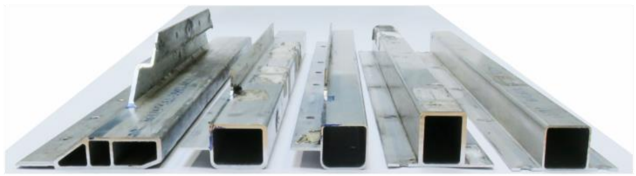
Container profile sections





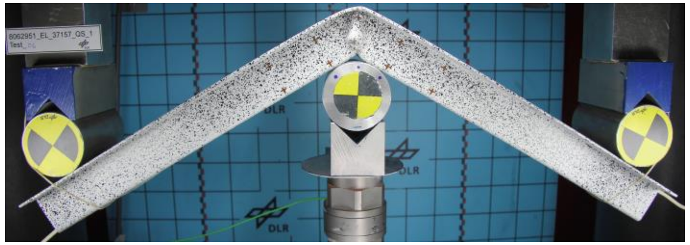
Element level
Overview

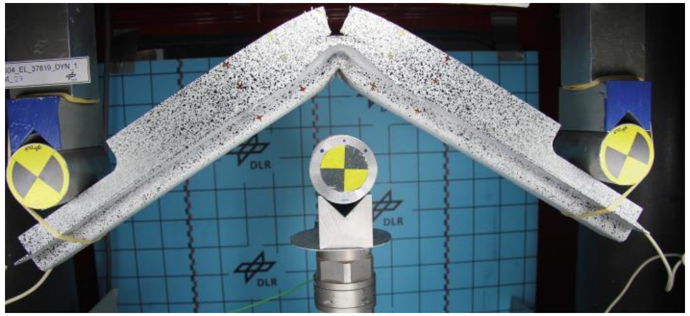


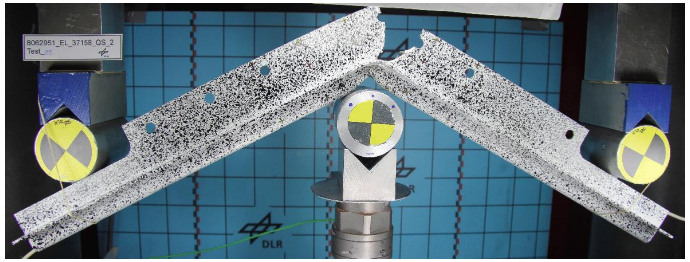


- **Experiments**
  - 3P-bending
  - Quasi-static (50 mm/min) and transient dynamic (2 m/s)
  - Servo-hydraulic high-rate test machine

- **Effects**
  - Failure behavior significantly dependent on profile design
    - Plastic hinge development
    - Rupture of tensile loaded flanges
    - Flange holes as crack initiator
  - ➔ **Good experimental data base for model validation!**
    - Plasticity & damage, element size, flange hole modeling, etc.



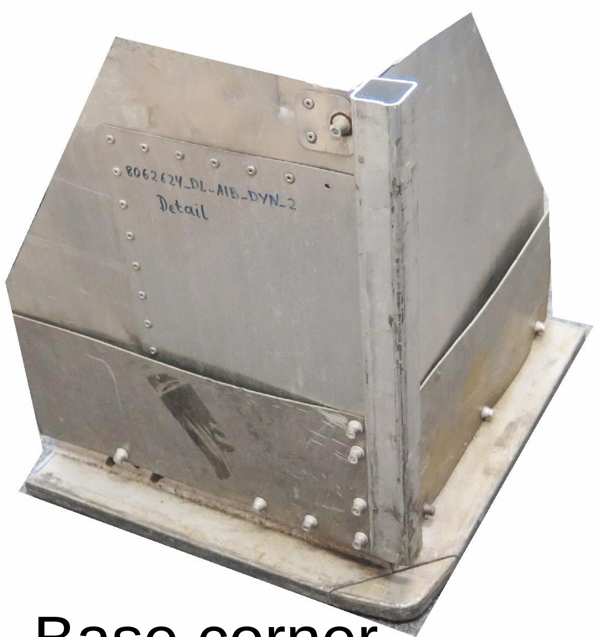




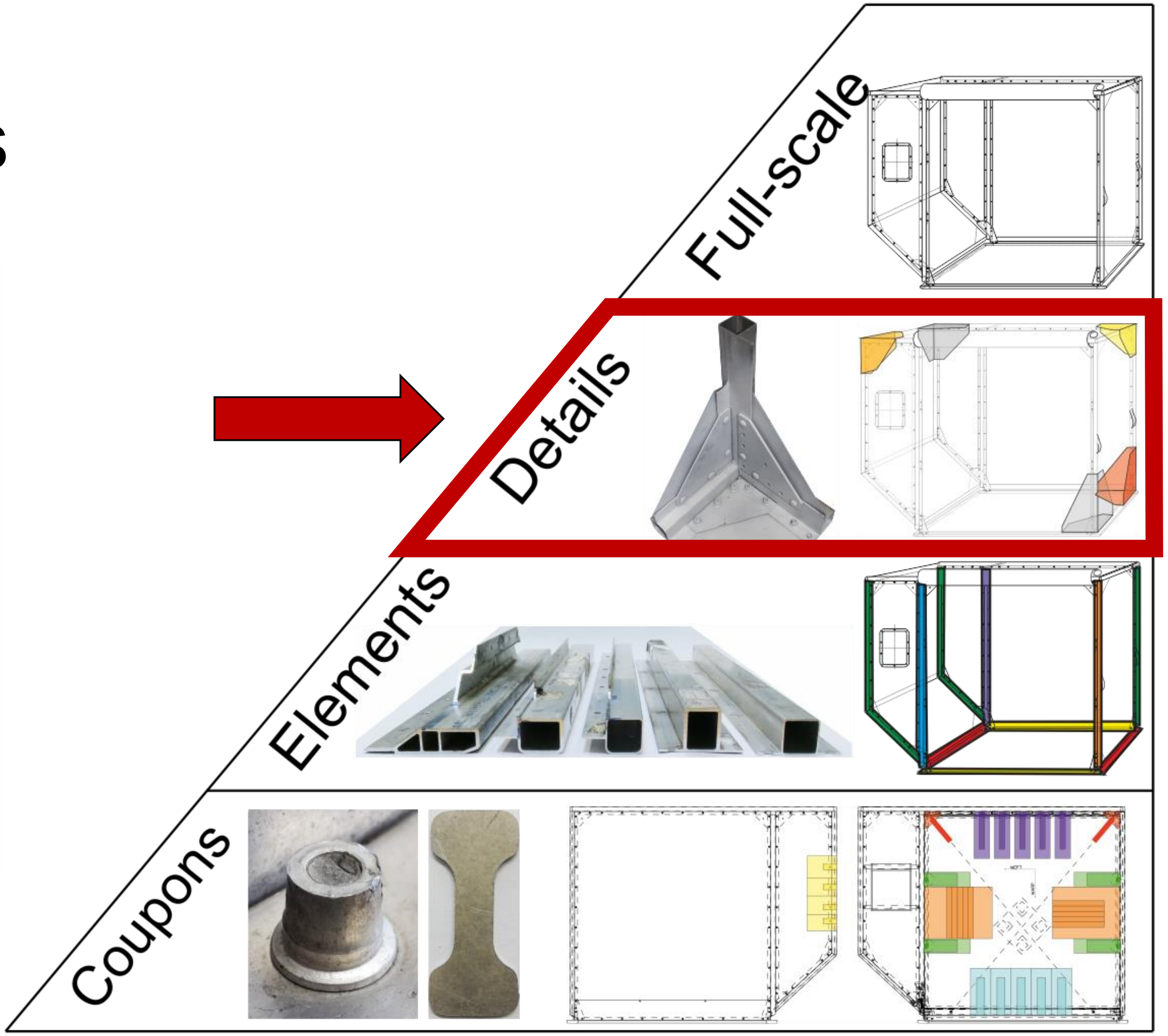
Detail level

Container corner assemblies

Roof corner

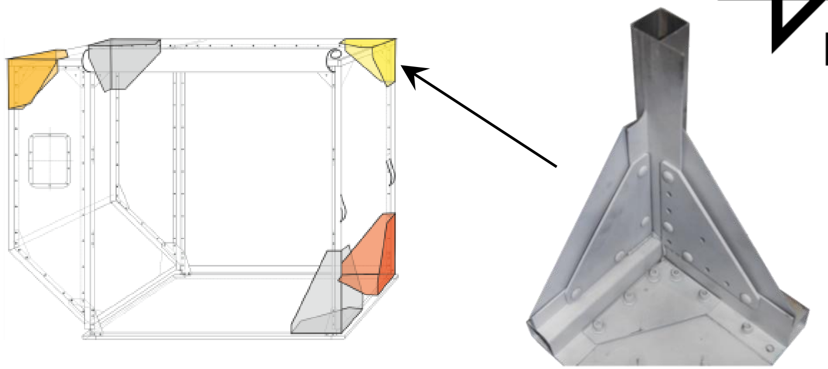


Base corner



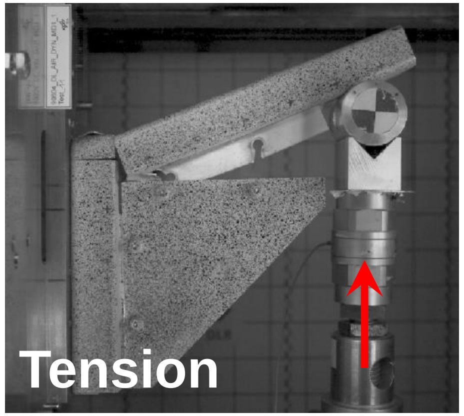
Detail level

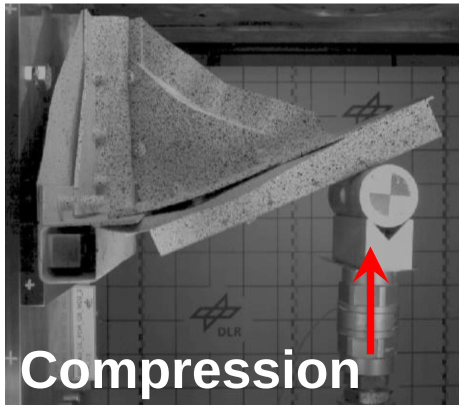
Roof corner: Overview



- **Experiments**
  - Roof corner assembly: Cantilever bending
    - Tension & compression mode
  - Quasi-static (50 mm/min) and transient dynamic (2 m/s)
  - Servo-hydraulic high-rate test machine

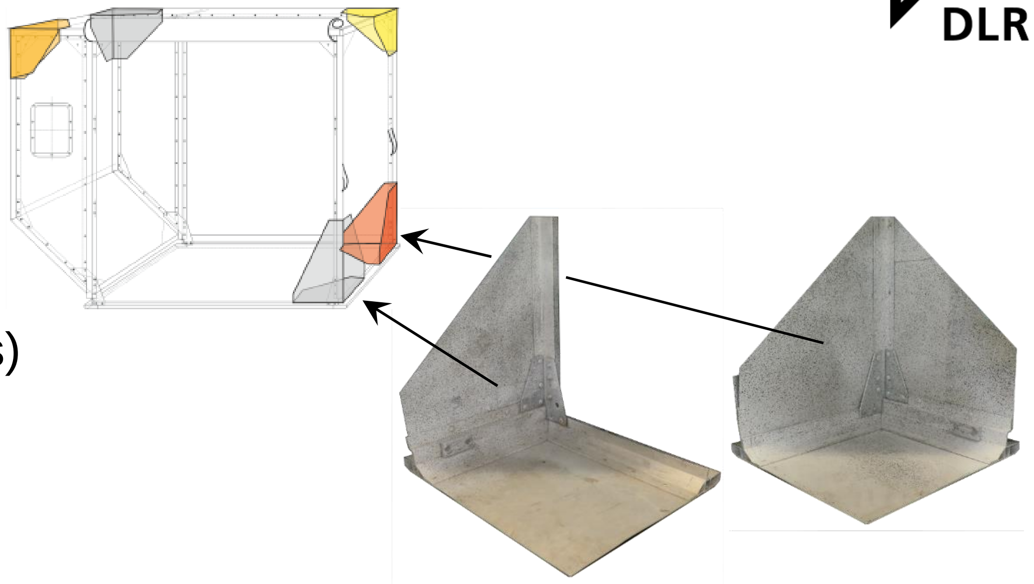
- **Effects**
  - Tension mode
    - Failure behavior driven by the bolted joints
  - Compression mode
    - Buckling of gusset, w/o bolted joint failure
  - ➔ **Good experimental data base for model validation!**
    - Fastener model, model assembly



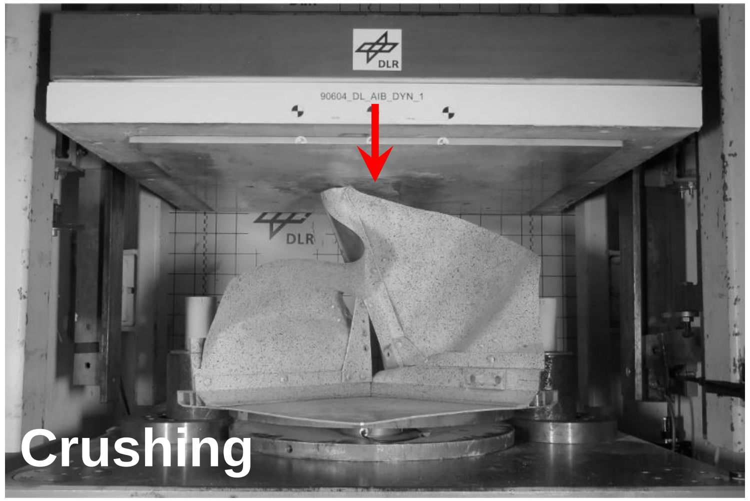


Detail level
Base corner: Overview

- **Experiments**
  - Base corner assembly: Crushing
  - Quasi-static (50 mm/min) and transient dynamic (2 m/s)
  - Universal testing machine (q-s); drop tower (dyn)

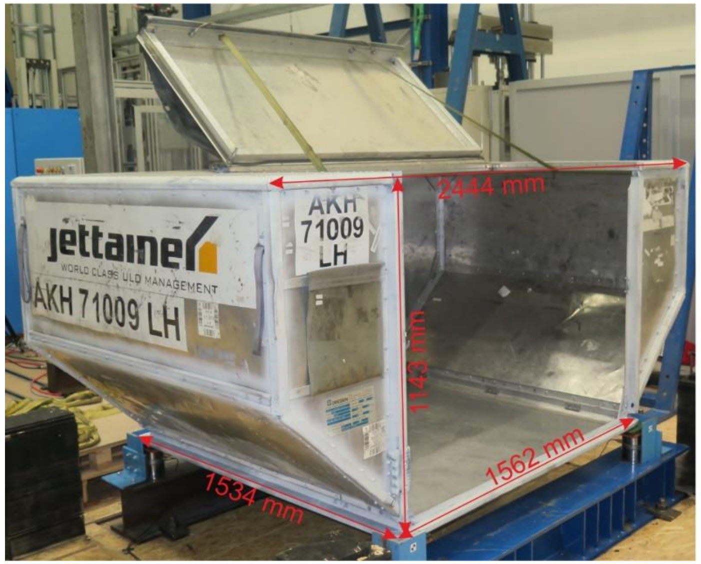


- **Effects**
  - Bolted joint failure and structural disintegration
  - Stanchion buckling after disintegration from container base
  - Peak load driven by complex structural interaction
    - Compliance in the bolted joint and stanchion contact with base → Second load path in addition to bolted joints
  - ➔ **Good experimental data base for model validation!**
    - Model assembly

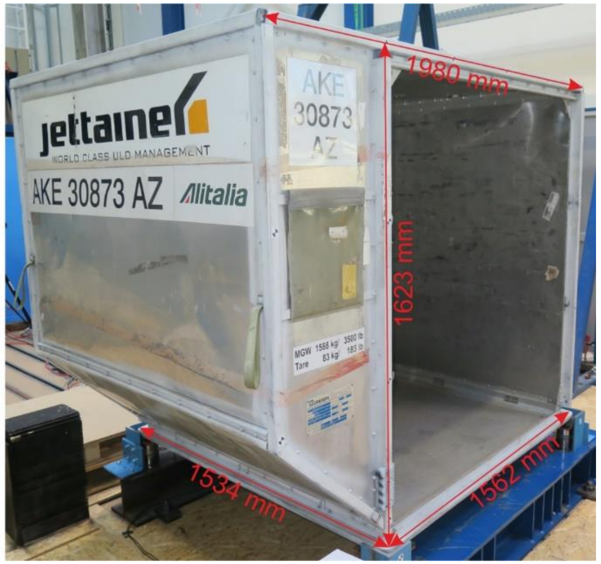


Full-scale level

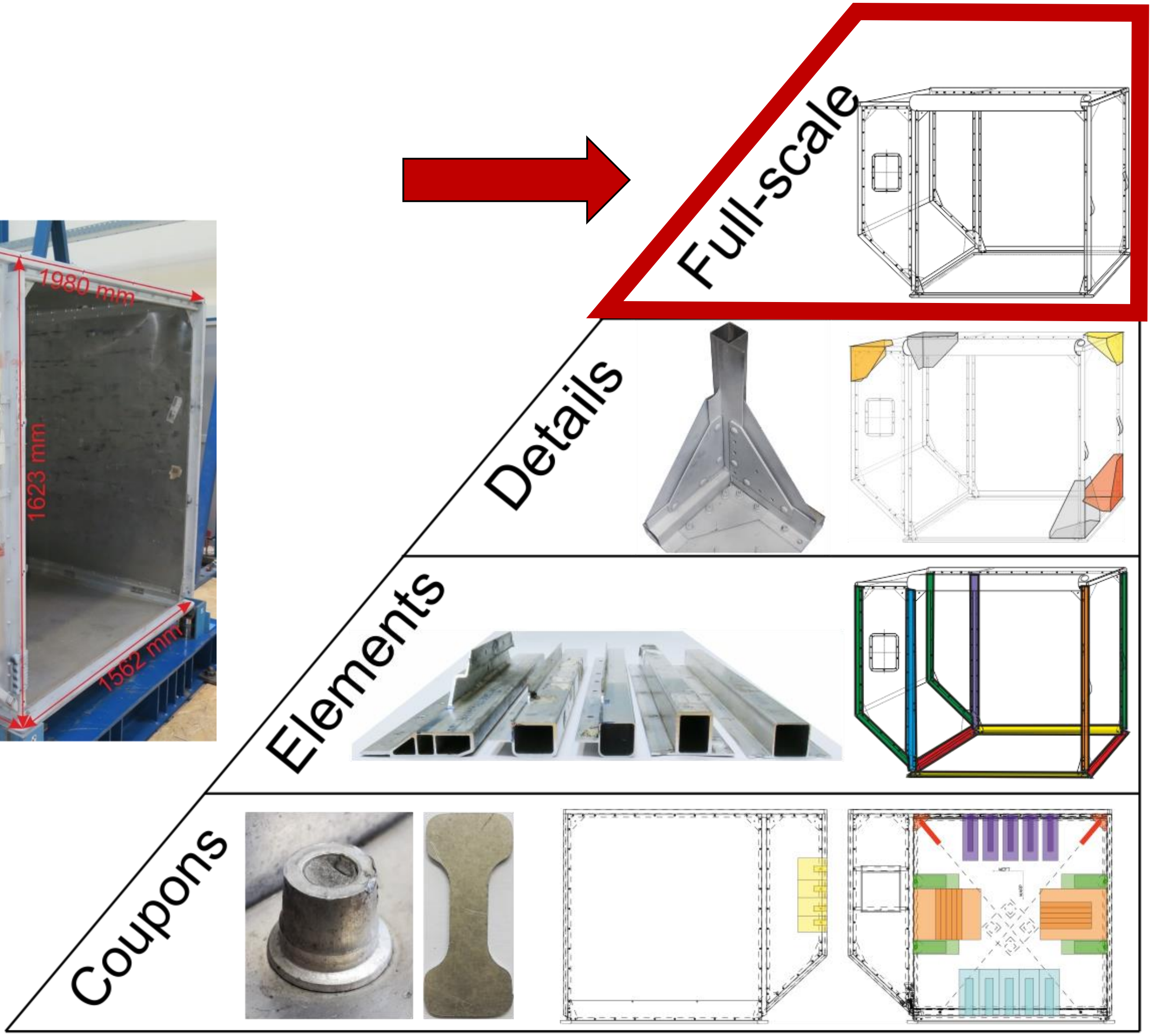
Containers



AKH type

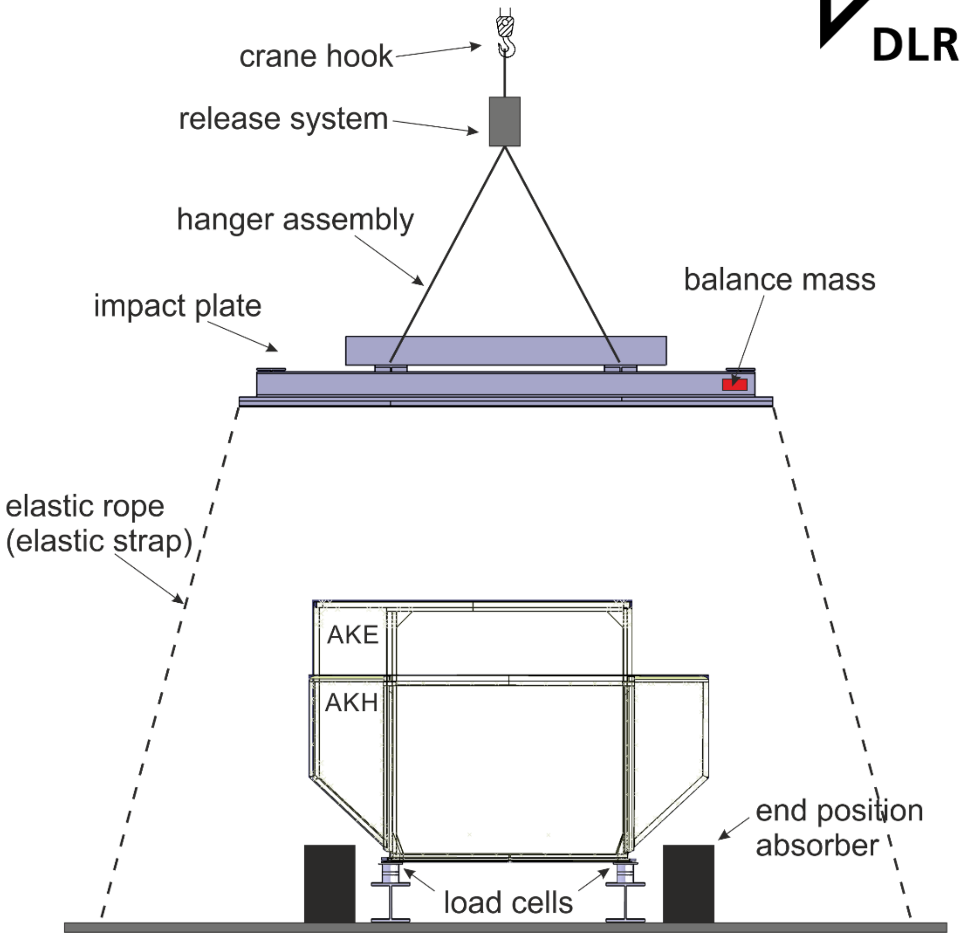


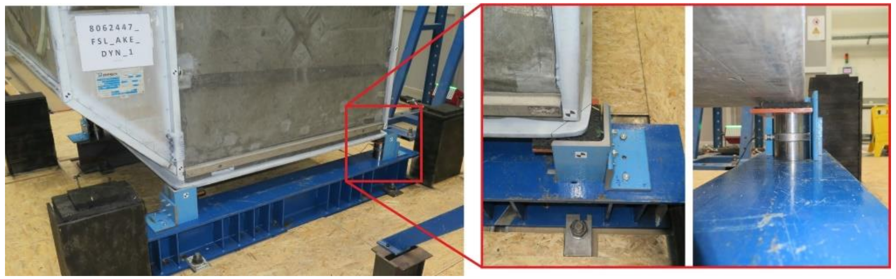
AKE type



Full-scale level
Test setup

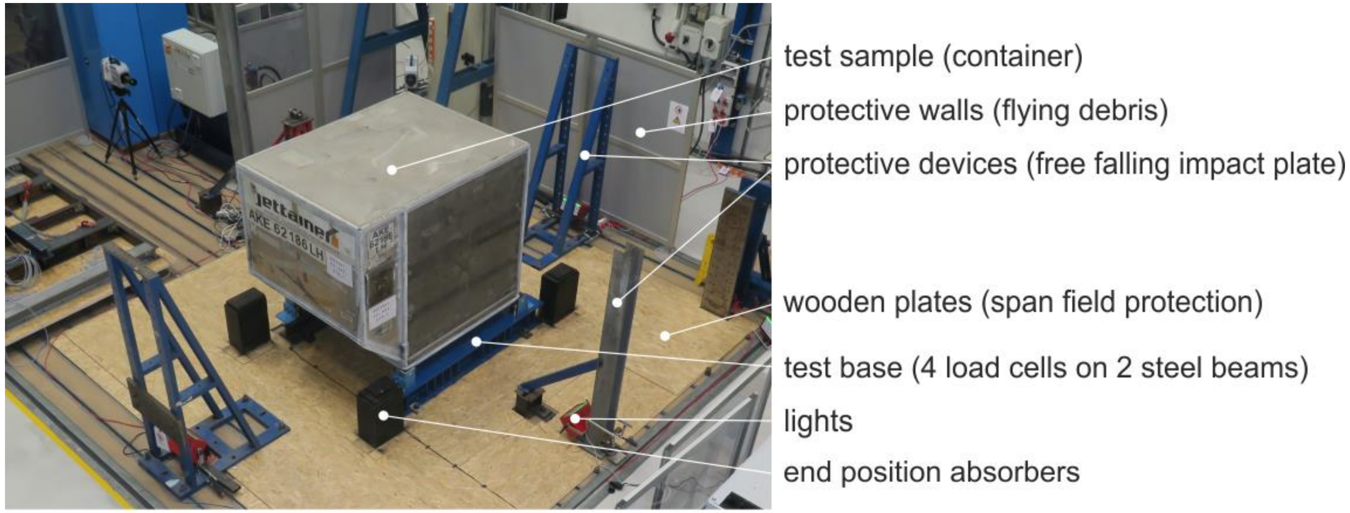
- **Drop test**
  - Temporary setup in the in-door test lab
  - Free-falling impact plate (unguided)
    - Clear boundary conditions (no compliance in guidance)
    - Pyrotechnical release system
    - Elastic ropes for automatic alignment
  - Test base
    - AKE / AKH identical base dimensions
    - Container embedded on 4 load cells
    - Boundary condition device
- **Data acquisition**
  - 4 load cells (Vertical force in each container base corner)
  - 4 high-speed cameras (Front, rear, isometric views)
  - 2 GoPros

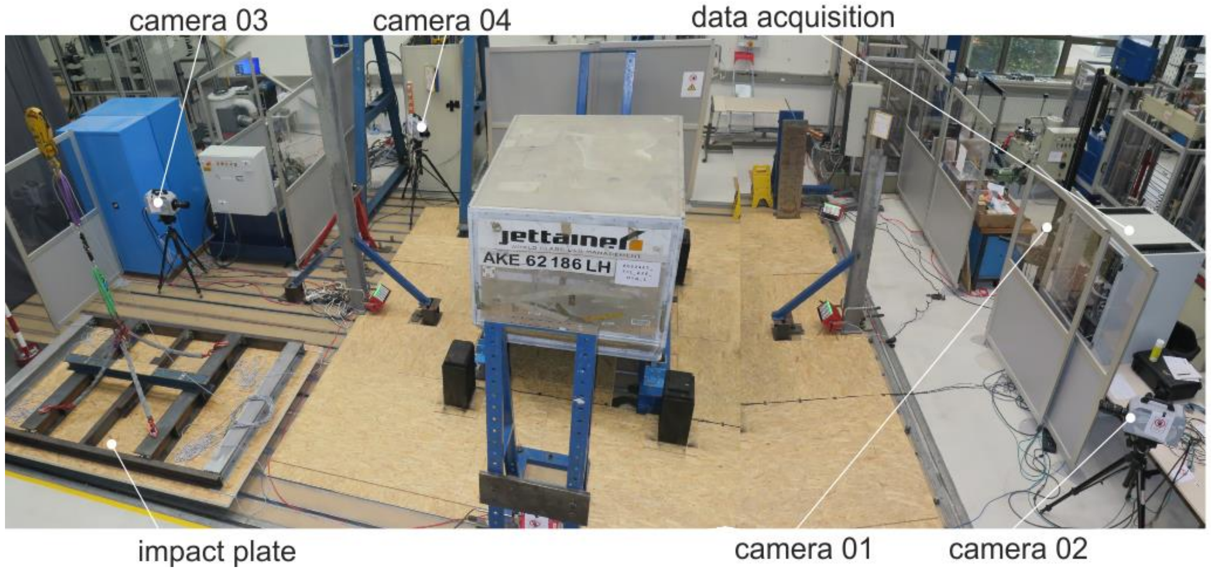




Full-scale level

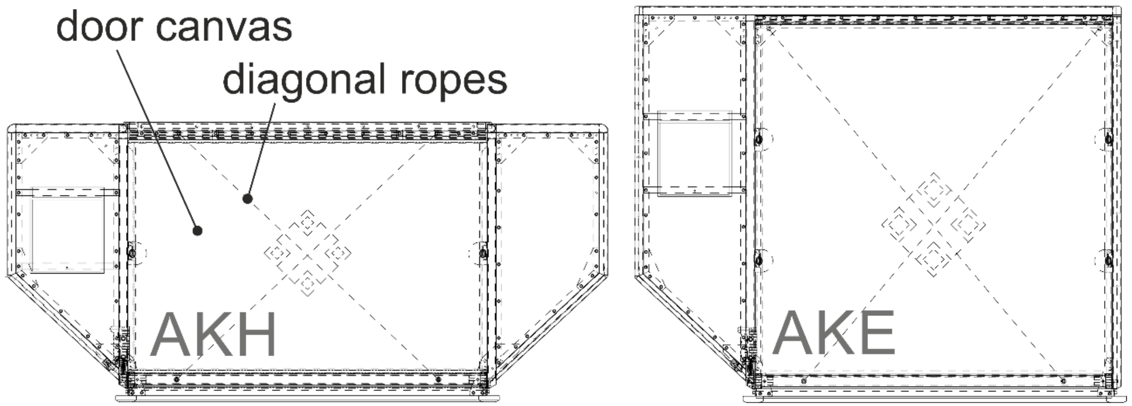
Test setup





Full-scale level
Test matrix

- **Container type (AKE & AKH)**
- **Door canvas & door diagonal ropes**
  - Relevance for finite element model
- **Container loading (Luggage)**
  - Decision to test w/o luggage (empty containers), focus on container design parameters
  - Luggage test data available for separate validation; combination of both in the finite element model
- **Impact speed: 6.7 m/s (22 ft/s)**
  - Based on pre-test simulation (energy absorption) and final impact plate mass



Test number	Container type	Door canvas & diagonal ropes	Test identifier (incl. series number)
1	AKE	with	8062447_FSL_AKE_DYN_1
2	AKE	with	8062445_FSL_AKE_DYN_2
3	AKE	without	8063050_FSL_AKE_DYN_3
4	AKE	without	8062915_FSL_AKE_DYN_4
5	AKH	with	8063189_FSL_AKH_DYN_5
6	AKH	with	7059356_FSL_AKH_DYN_6
7	AKH	without	7059334_FSL_AKH_DYN_7
8	AKH	without	8063217_FSL_AKH_DYN_8

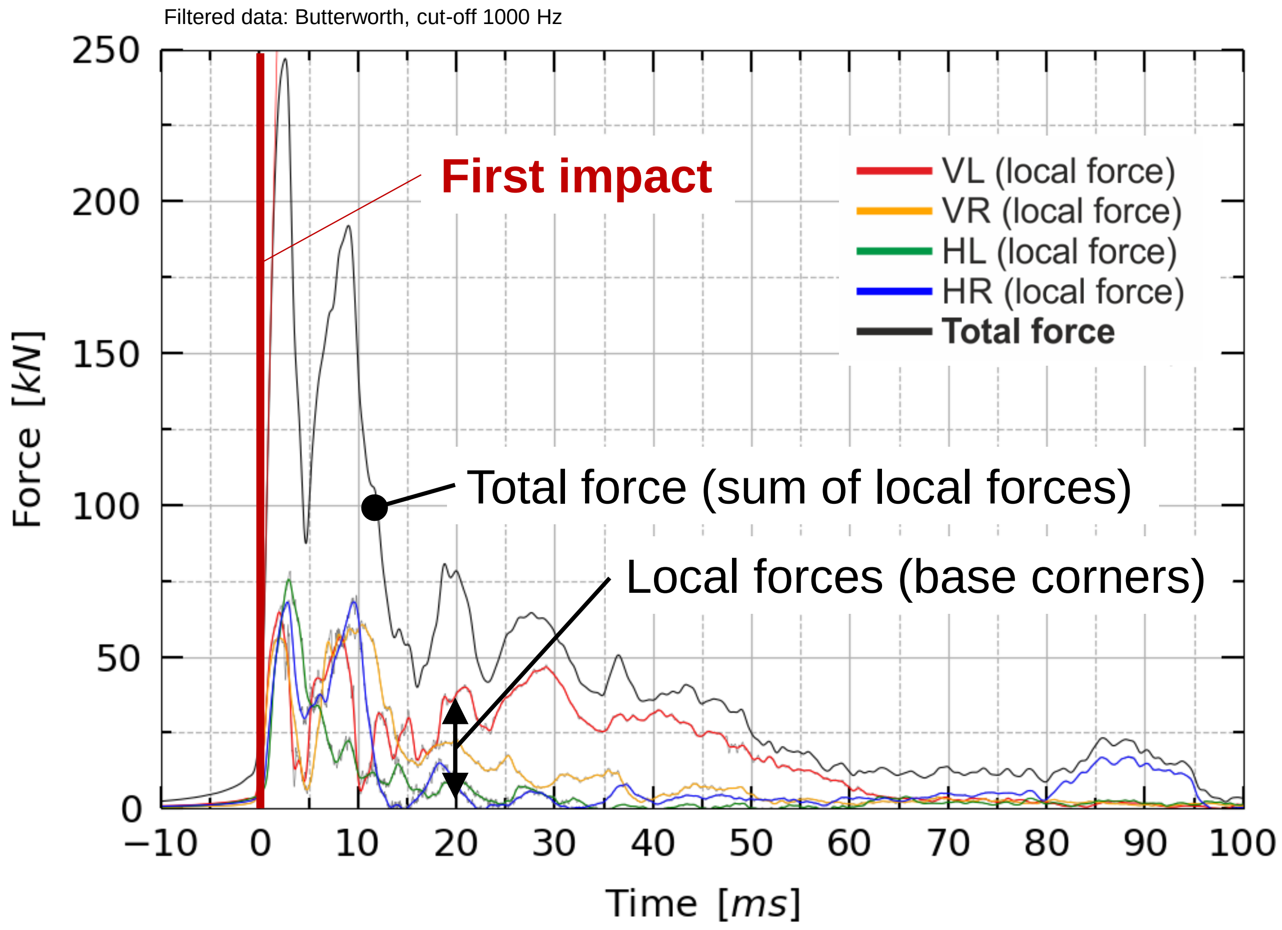
Full-scale level
Test results: AKE

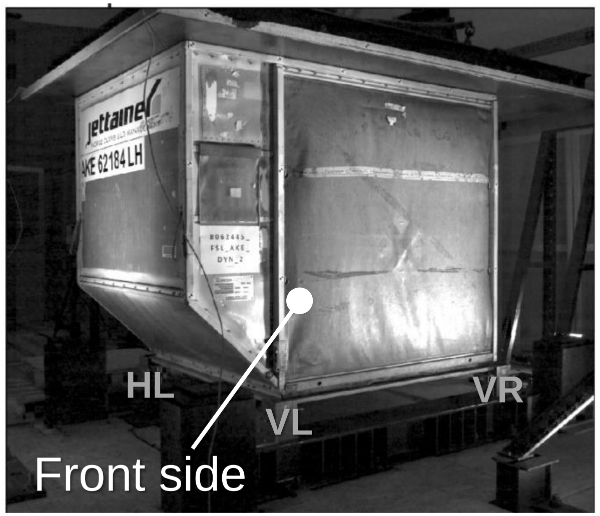
Full-scale level

Test results: AKE

Full-scale level
Test results: AKE

- AKE with door canvas/ropes (exemplarily test 02)



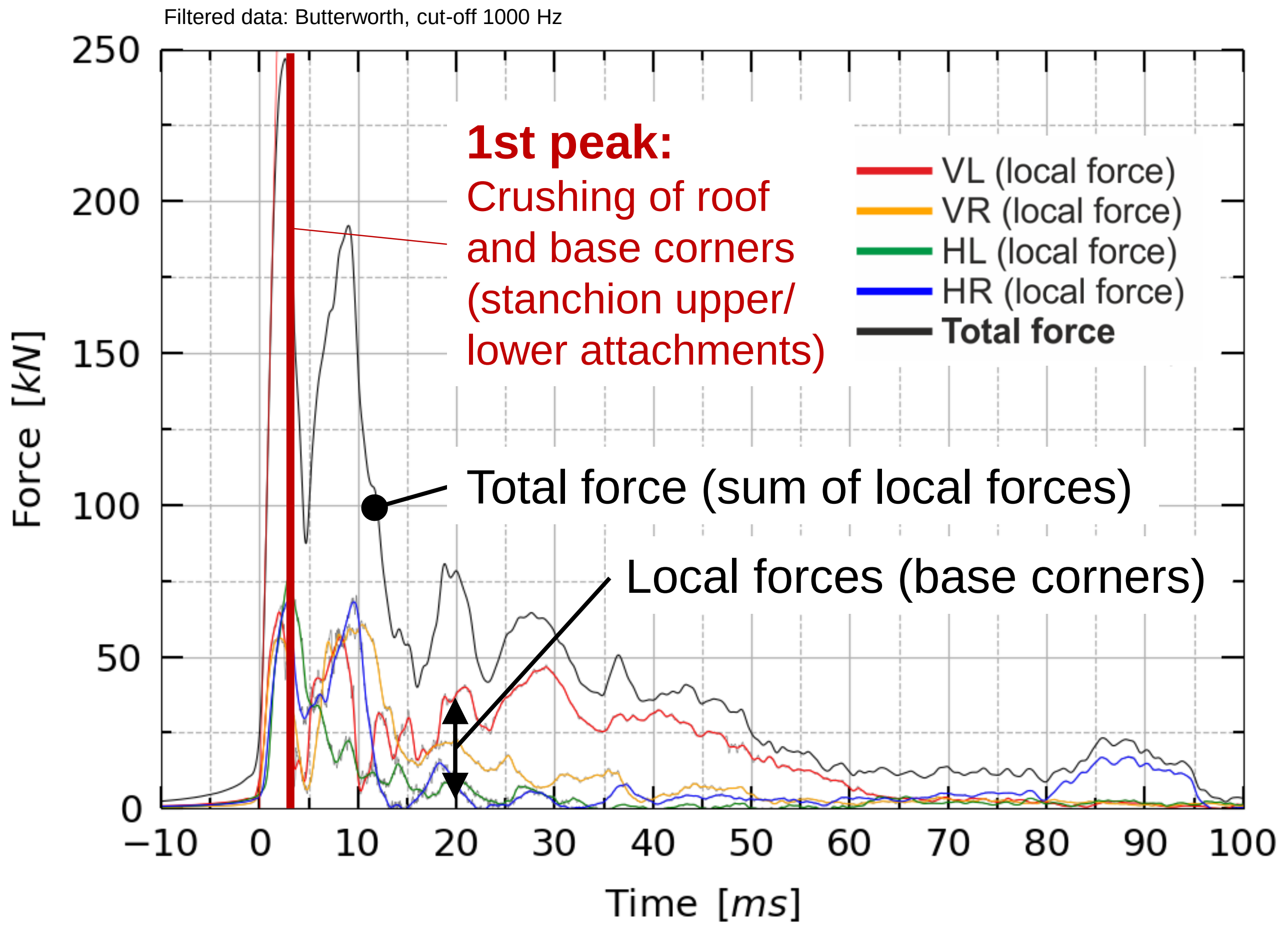


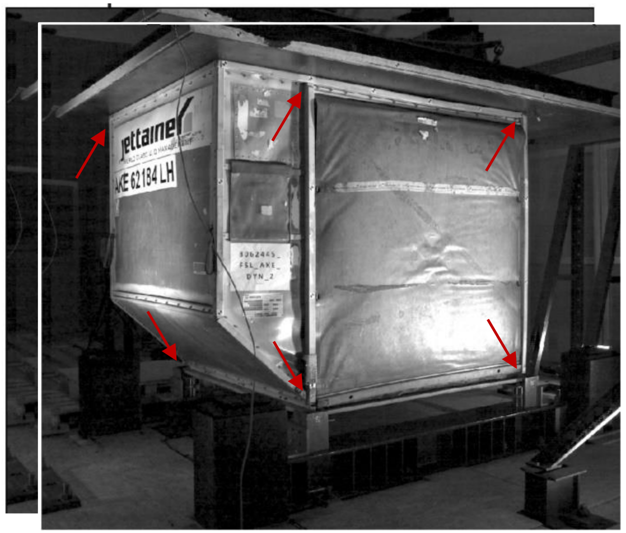
High-speed video records

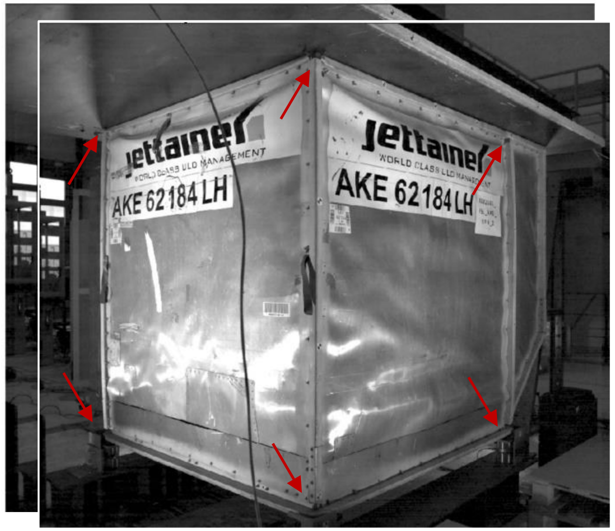
Full-scale level

Test results: AKE

- AKE with door canvas/ropes (exemplarily test 02)





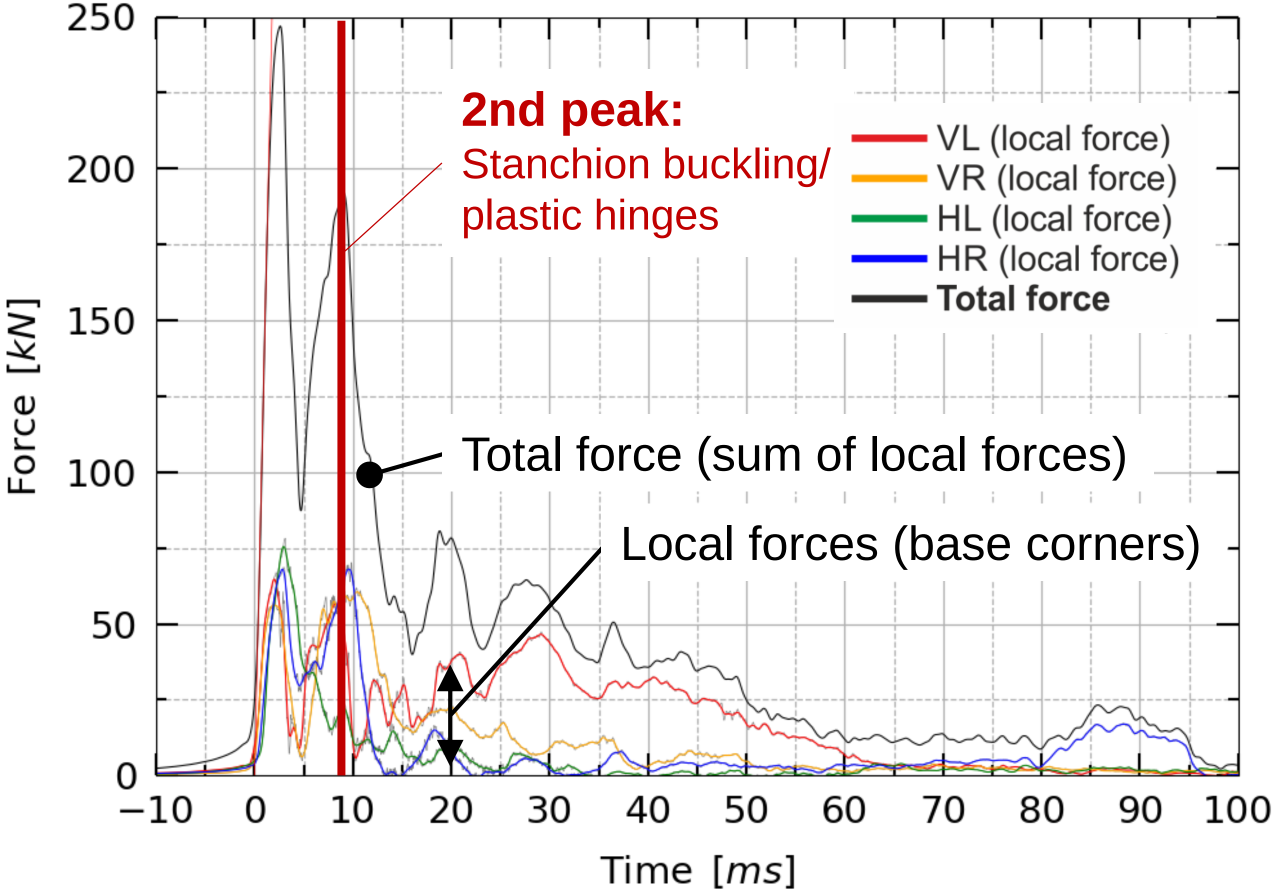


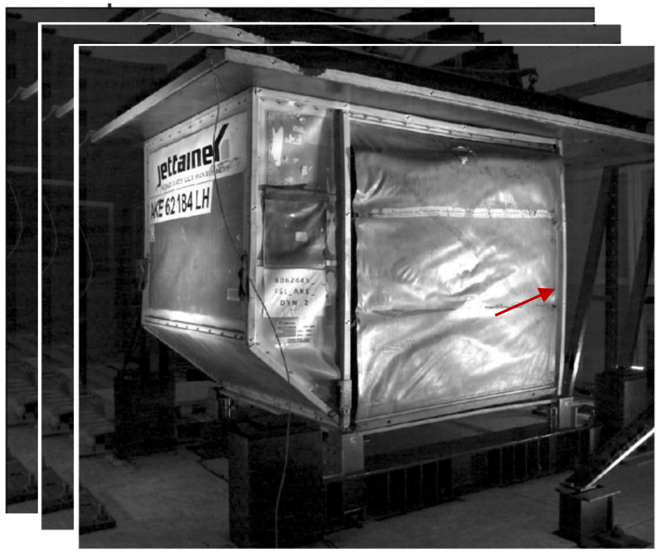
Full-scale level

Test results: AKE

- AKE <u>with</u> door canvas/ropes (exemplarily test 02)

Filtered data: Butterworth, cut-off 1000 Hz

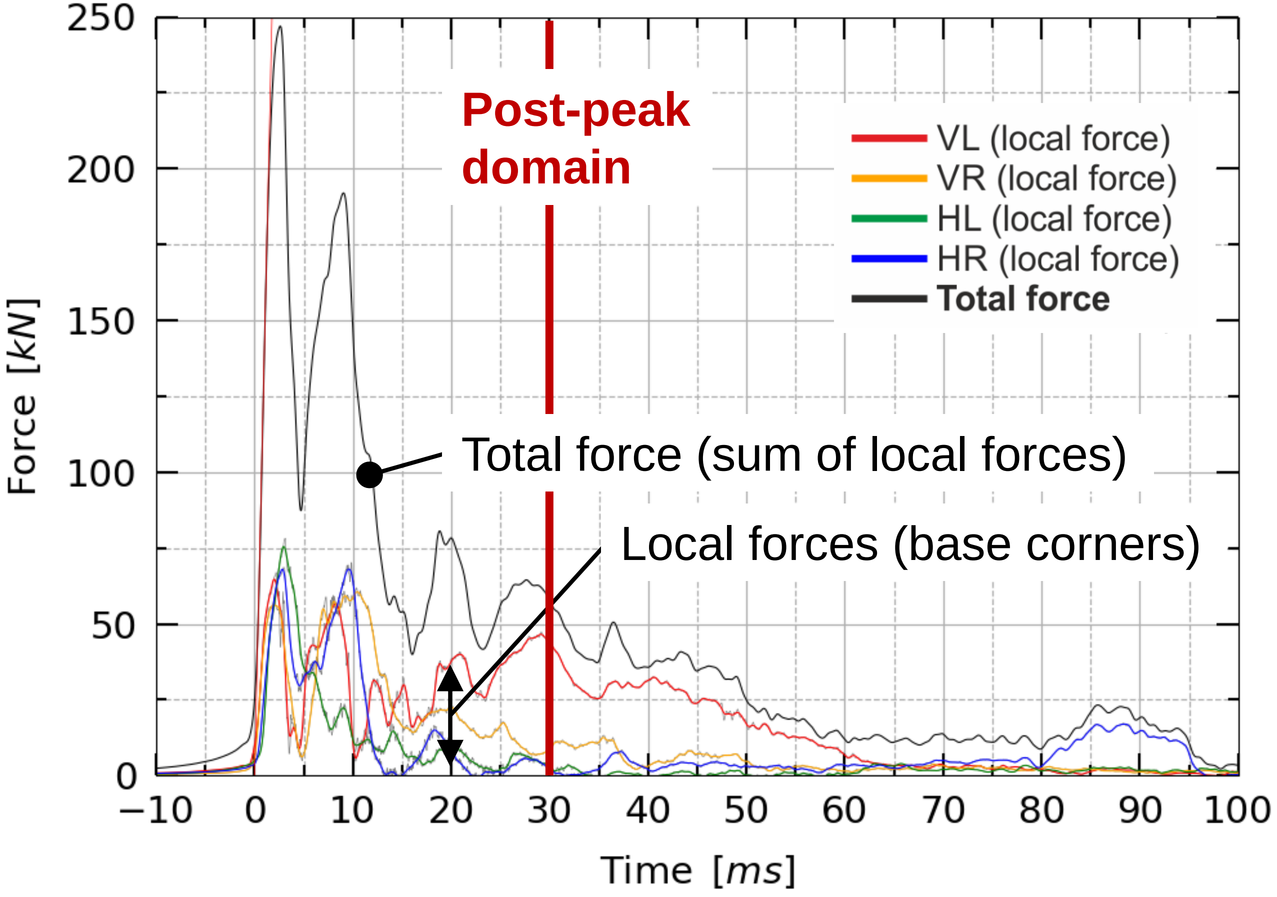




Full-scale level
Test results: AKE

- AKE with door canvas/ropes (exemplarily test 02)

Filtered data: Butterworth, cut-off 1000 Hz

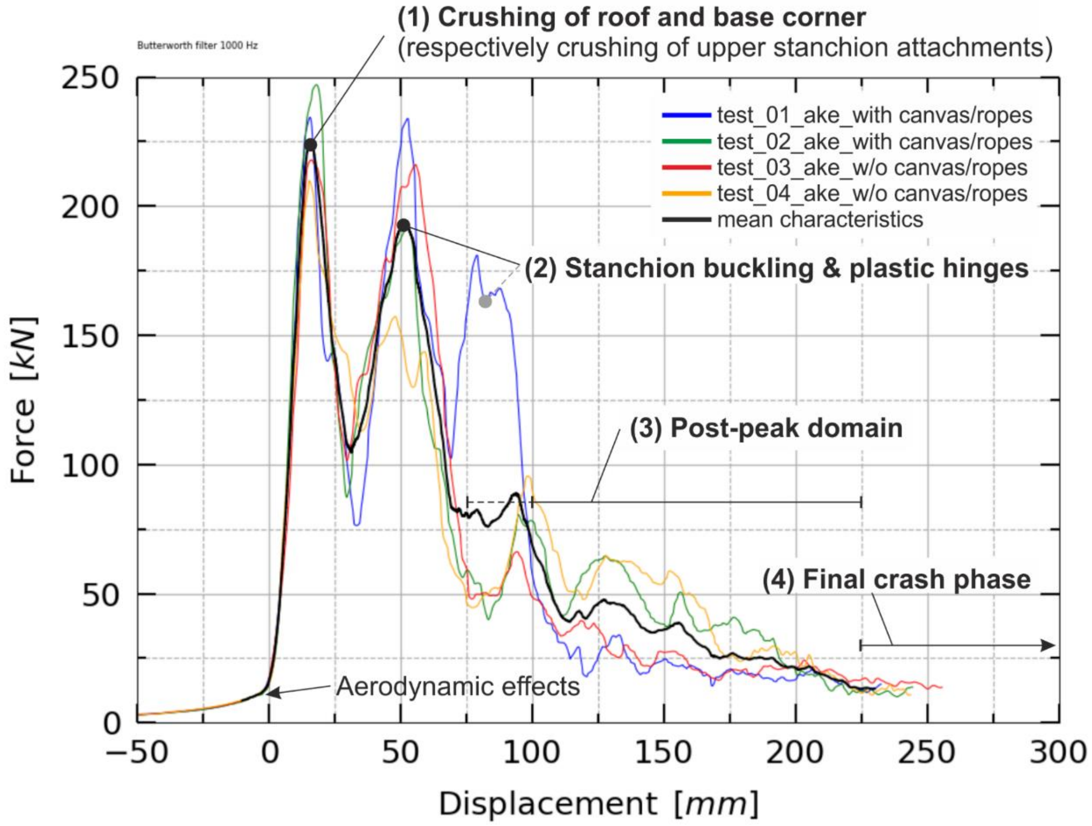


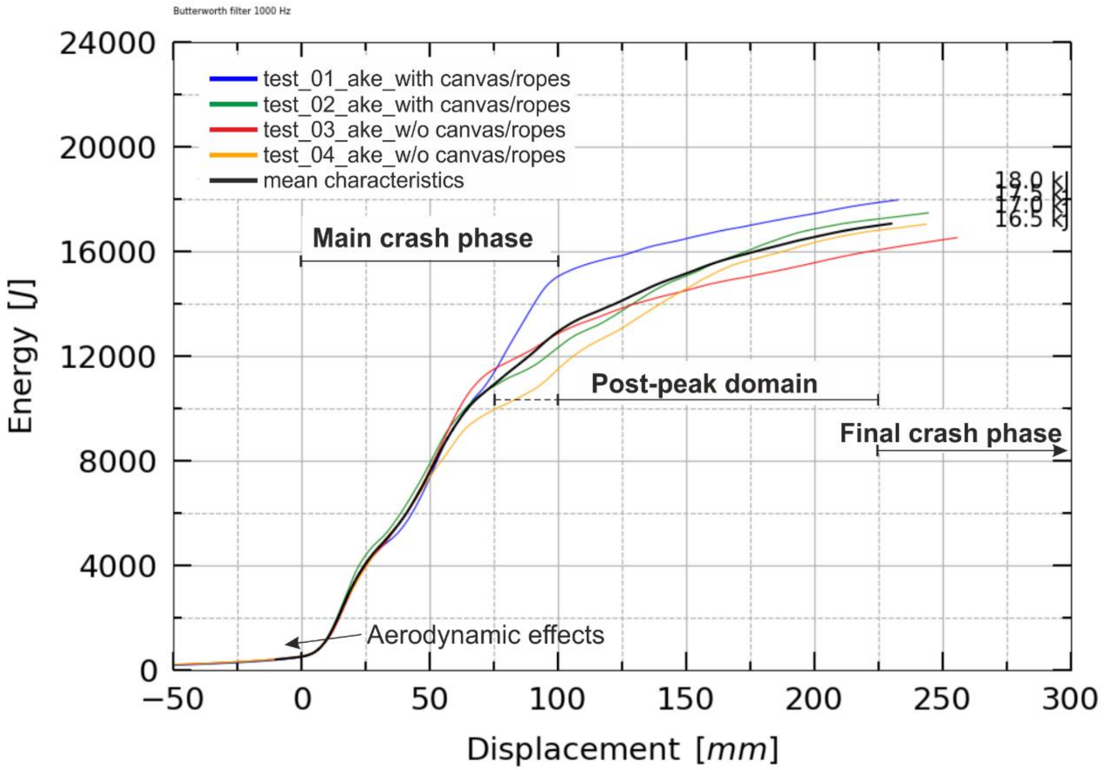
Full-scale level
Test results: AKE

- Data plots (all AKE tests)

Force-displacement correlation acc. to ISO18571
(CORAplus, test by test correlation, 0-100 mm)

Overall rating	Min	Max	Mean
AKE	0.594 (fair)	0.857 (good)	0.748 (fair)





Force: Butterworth, cut-off 1000 Hz (50 kHz sampling frequency)
Displacement: Unfiltered (5 kHZ sampling frequency)

Force: Sum of local forces (four base corners)
Displacement: Mean of local displacements (four impact plate positions)

Full-scale level

Test results: AKH

Full-scale level

Test results: AKH

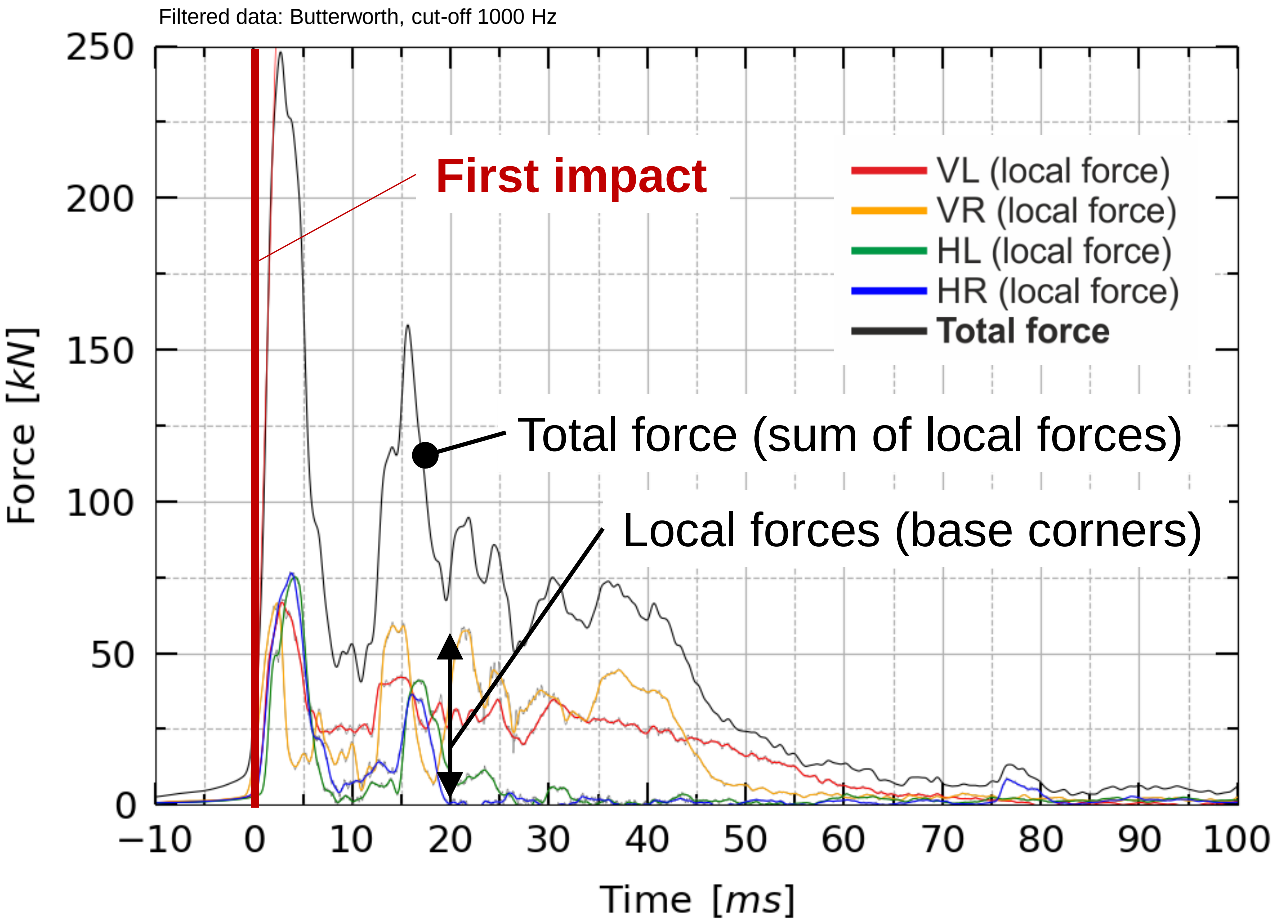
Exemplary result w/o door canvas/ropes (test 07)

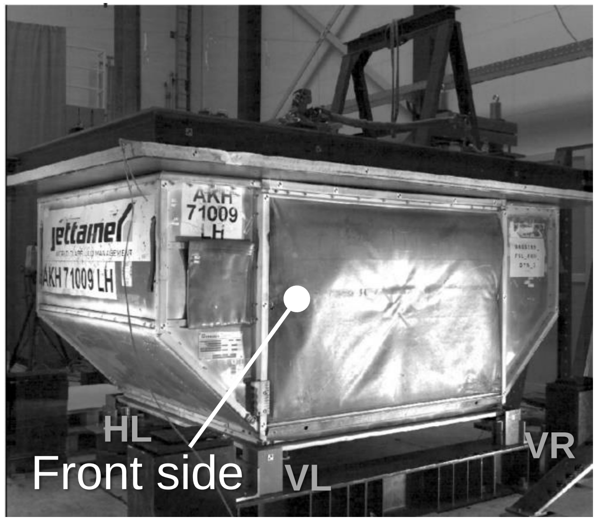
GoPro video record

Full-scale level

Test results: AKH

- AKH <u>with</u> door canvas/ropes (exemplarily test 05)

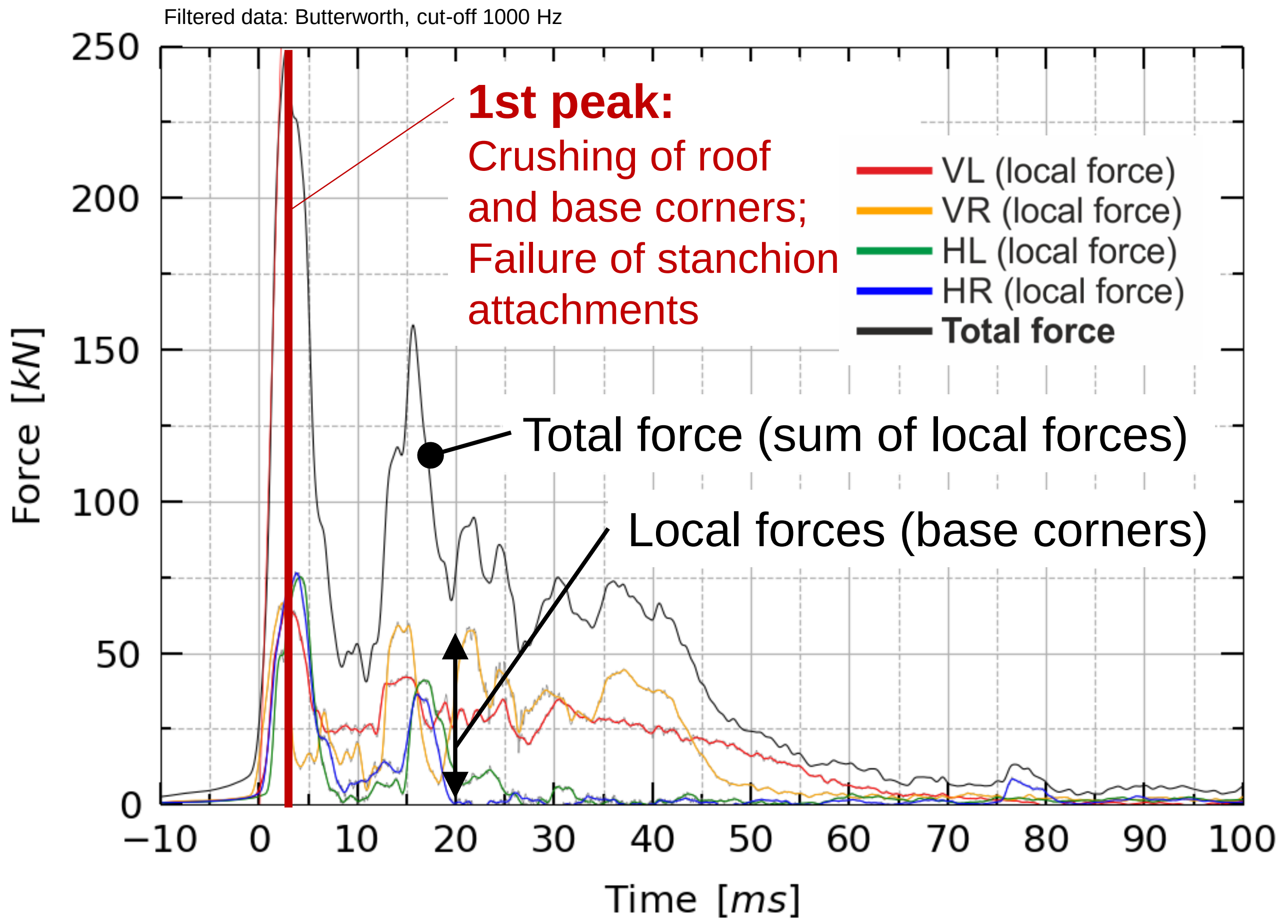




High-speed video records

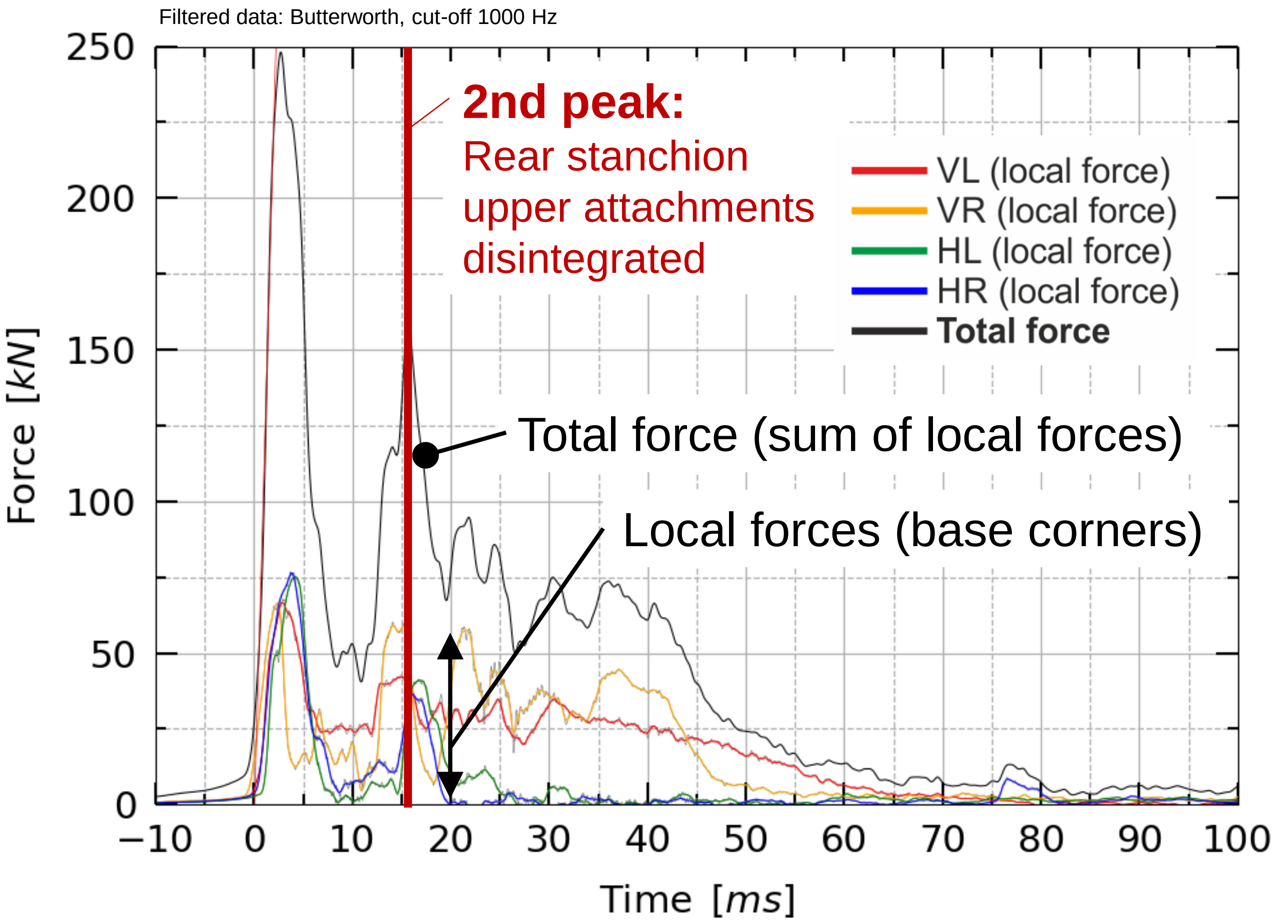
Full-scale level
Test results: AKH

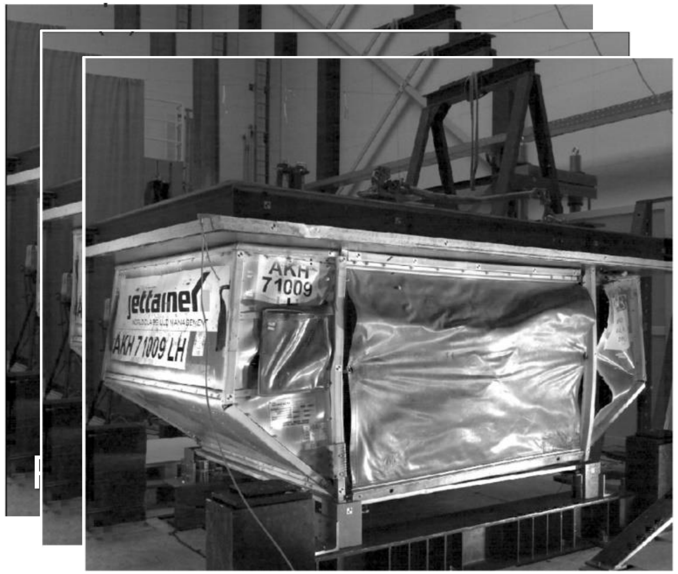
- AKH <u>with</u> door canvas/ropes (exemplarily test 05)



Full-scale level
Test results: AKH

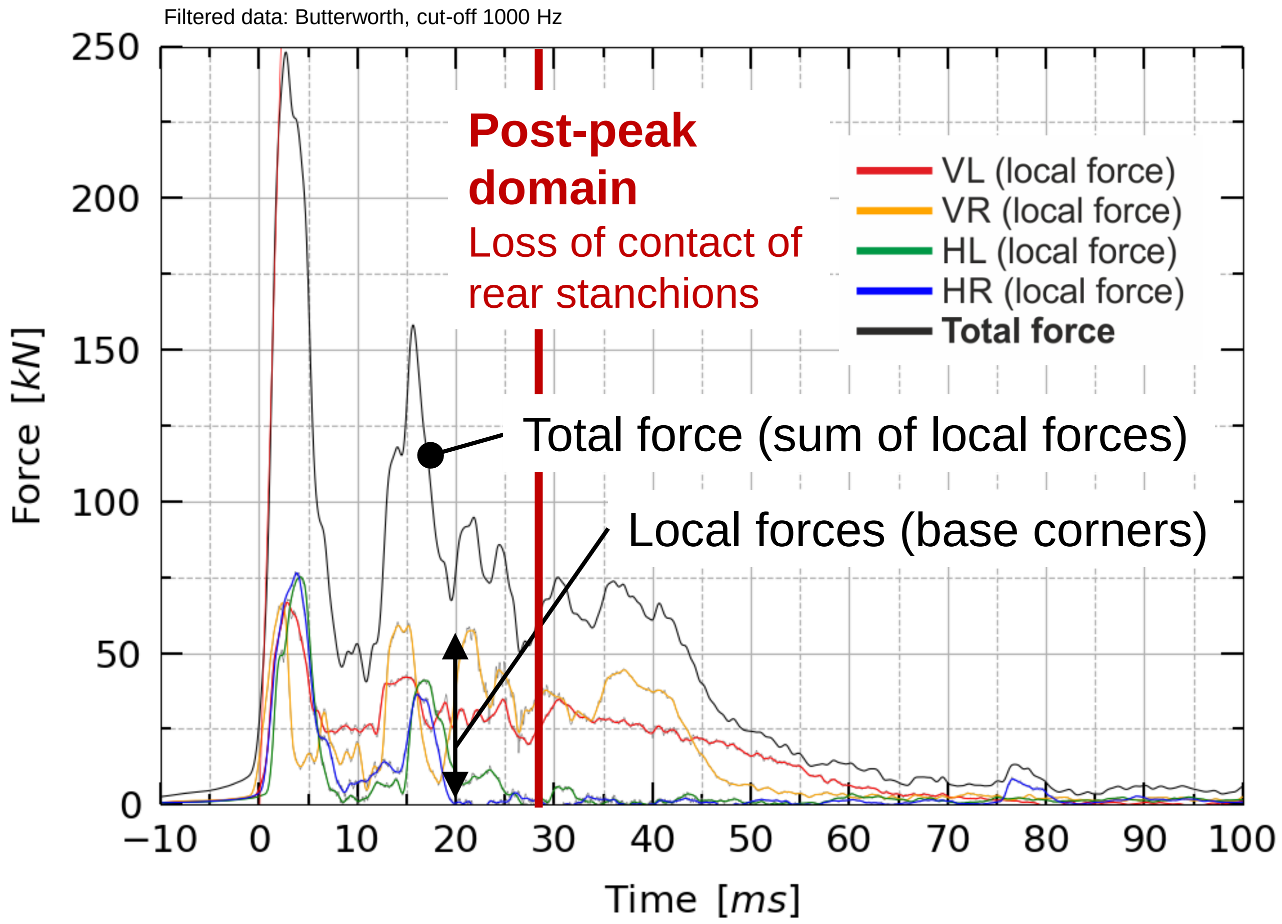
- AKH <u>with</u> door canvas/ropes (exemplarily test 05)

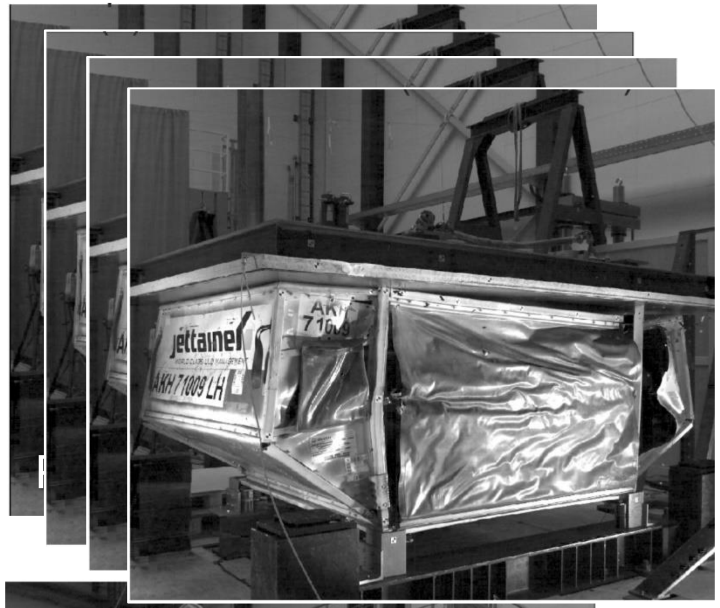




Full-scale level
Test results: AKH

- AKH <u>with</u> door canvas/ropes (exemplarily test 05)



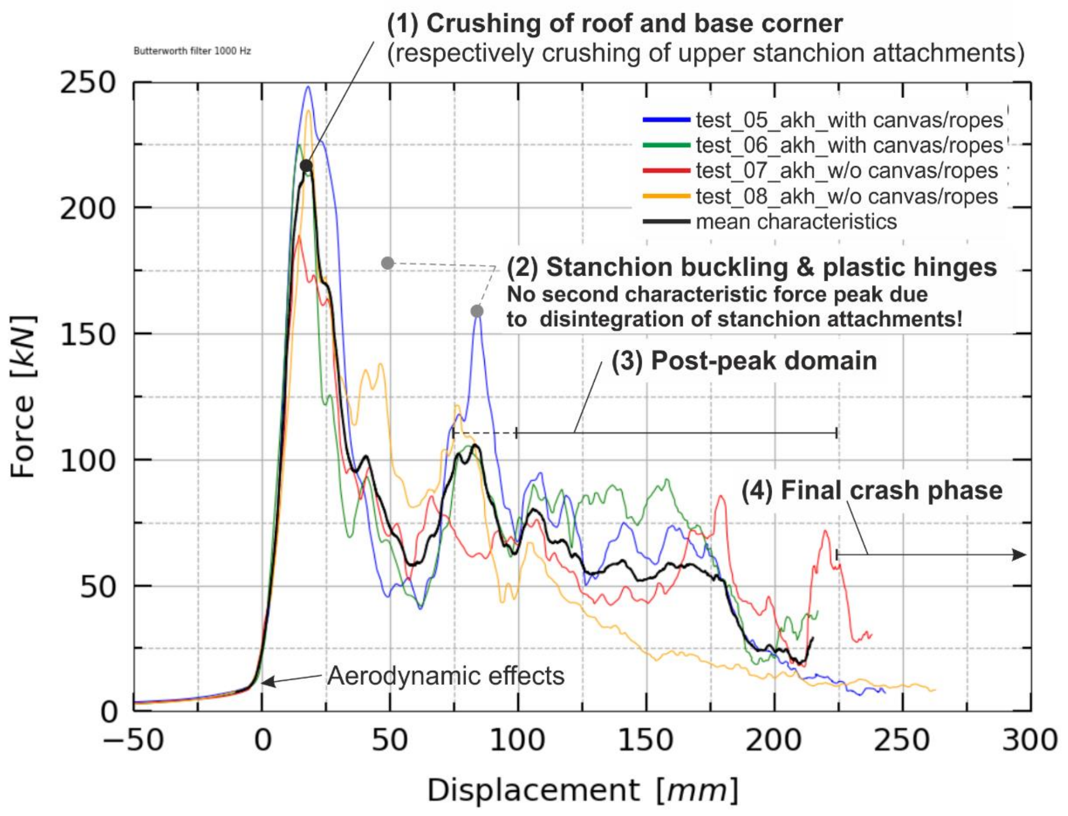


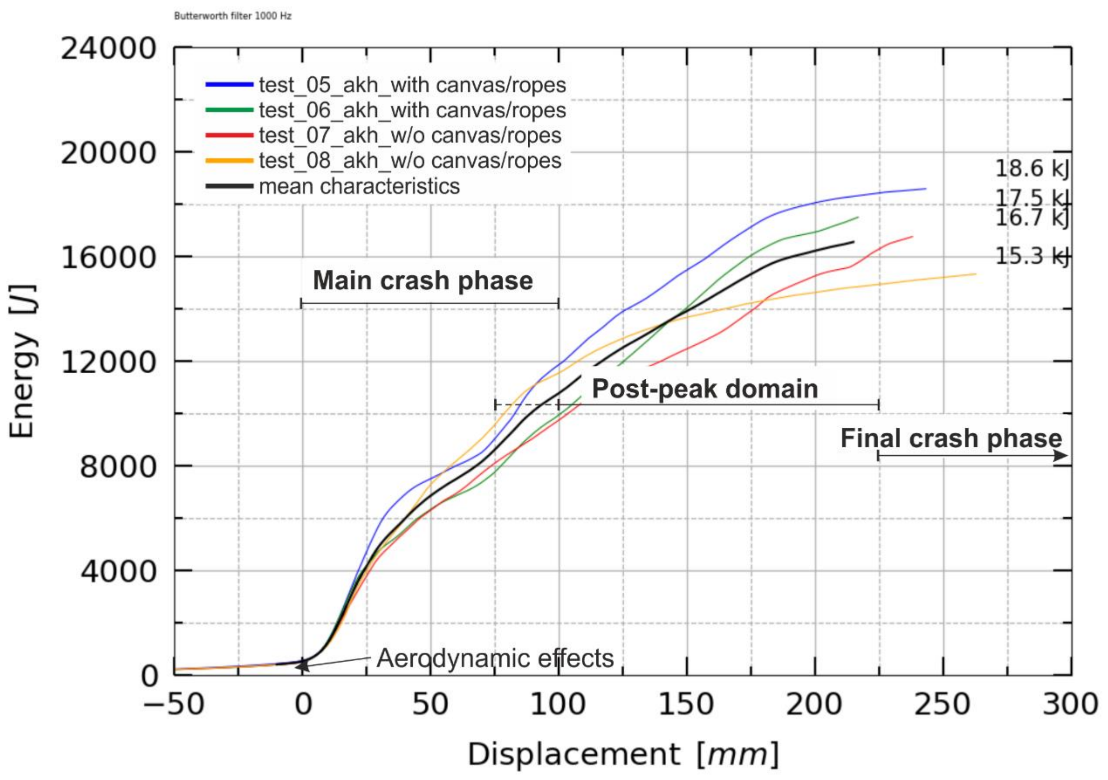
Full-scale level
Test results: AKH

- Data plots (all AKH tests)

Force-displacement correlation acc. to ISO18571
(CORAplus, test by test correlation, 0-100 mm)

Overall rating	Min	Max	Mean
AKH	0.651 (fair)	0.807 (good)	0.742 (fair)





Force: Butterworth, cut-off 1000 Hz (50 kHz sampling frequency)
Displacement: Unfiltered (5 kHZ sampling frequency)

Force: Sum of local forces (four base corners)
Displacement: Mean of local displacements (four impact plate positions)

Final outcomes

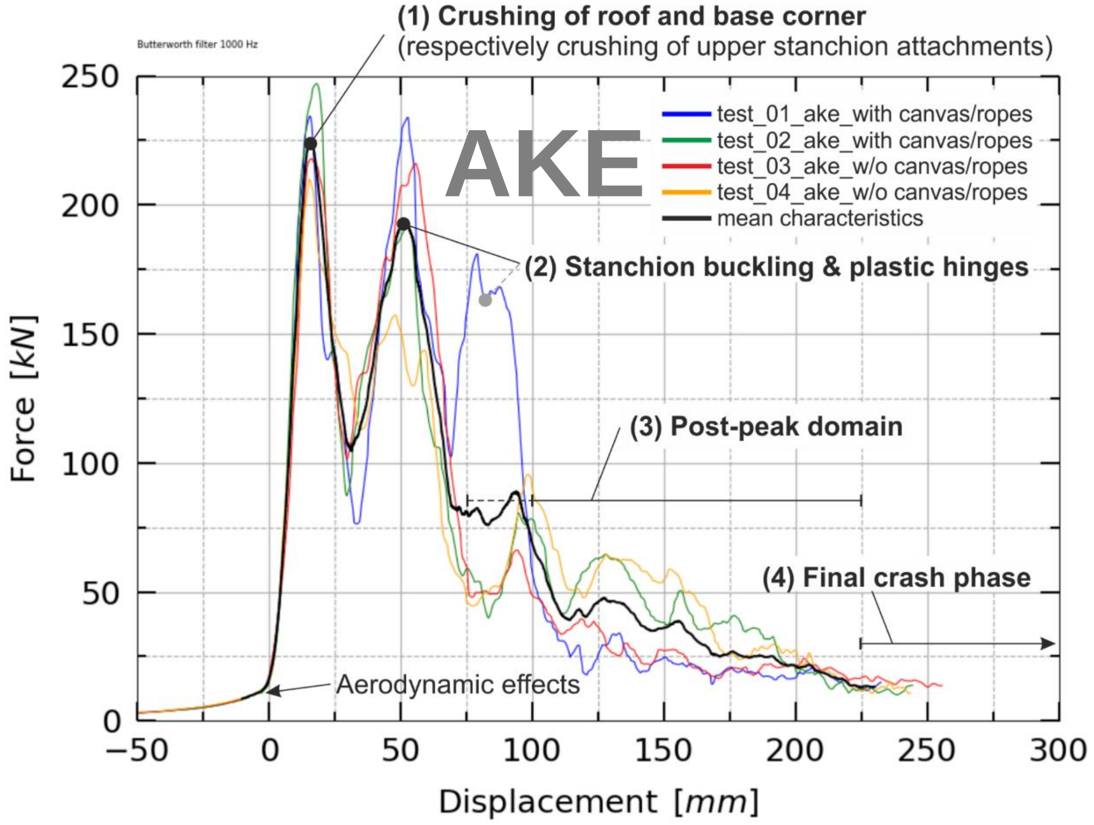
Final outcomes

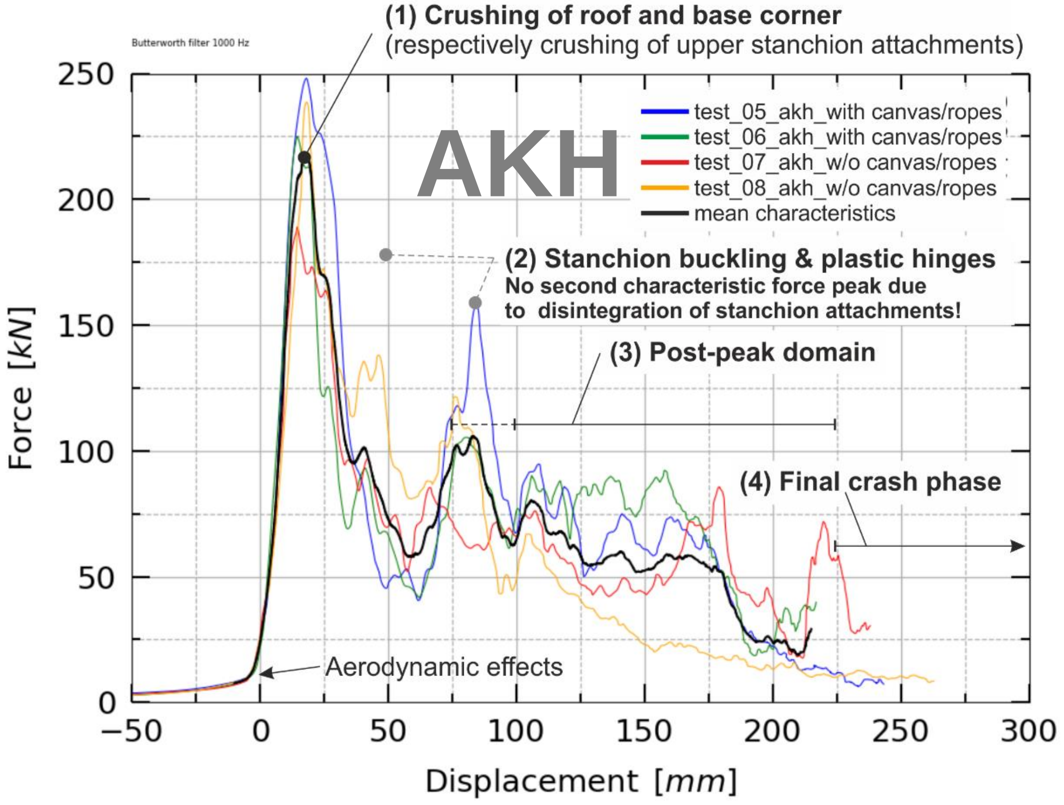
Crash characteristics under purely vertical impact conditions

Force-displacement correlation acc. to ISO18571
(CORAplus, test by test correlation, 0-100 mm)

Overall rating	Min	Max	Mean
AKE	0.594 (fair)	0.857 (good)	0.748 (fair)
AKH	0.651 (fair)	0.807 (good)	0.742 (fair)

- **Force-displacement**
  - Same general crash phases for both container types



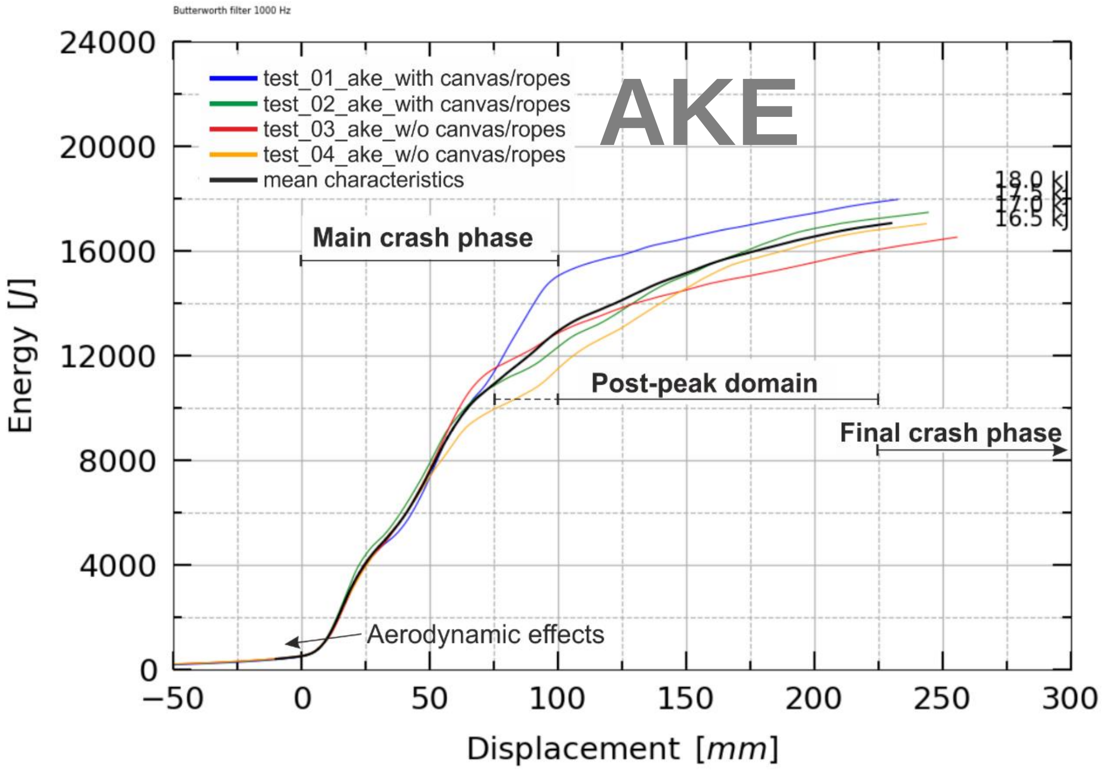


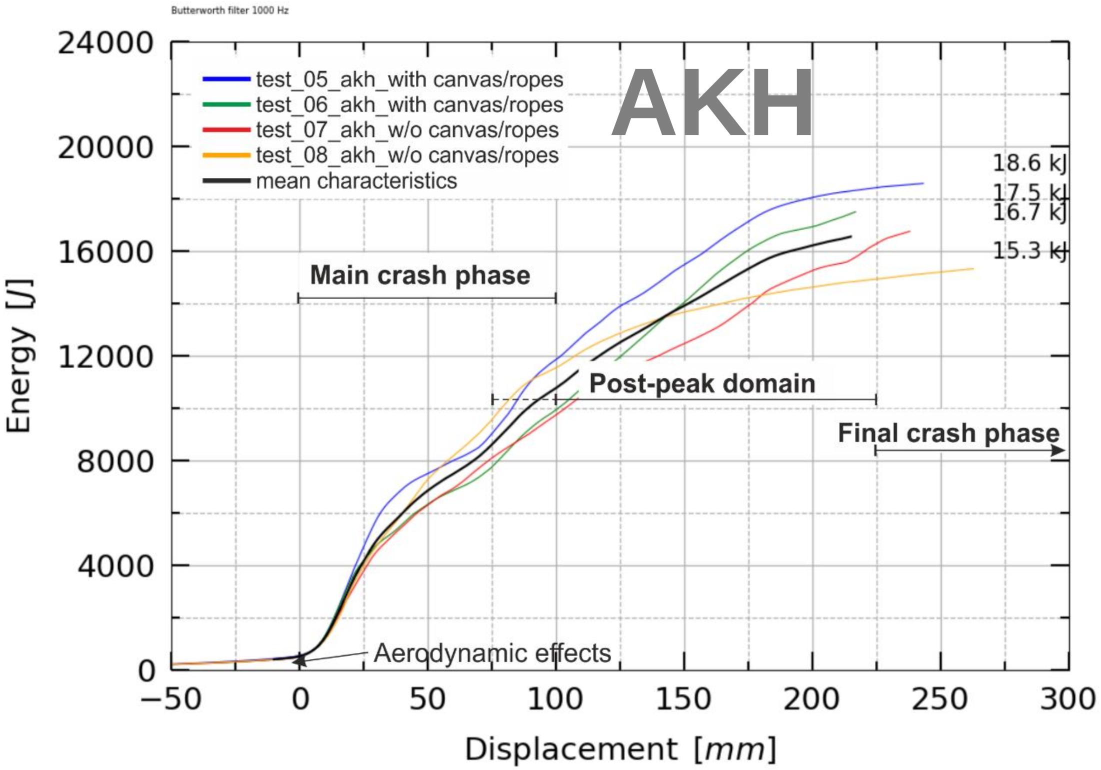
Force: Sum of local forces (four base corners), filtered data: Butterworth, cut-off 1000 Hz (50 kHz sampling frequency)
Displacement: Mean of local displacements (four impact plate positions), unfiltered data (5 kHZ sampling frequency)

Final outcomes

Crash characteristics under purely vertical impact conditions

- **Energy-displacement**
  - Total absorbed energies in the same range for both container types





Force: Sum of local forces (four base corners), filtered data: Butterworth, cut-off 1000 Hz (50 kHz sampling frequency)
Displacement: Mean of local displacements (four impact plate positions), unfiltered data (5 kHZ sampling frequency)

Final outcomes

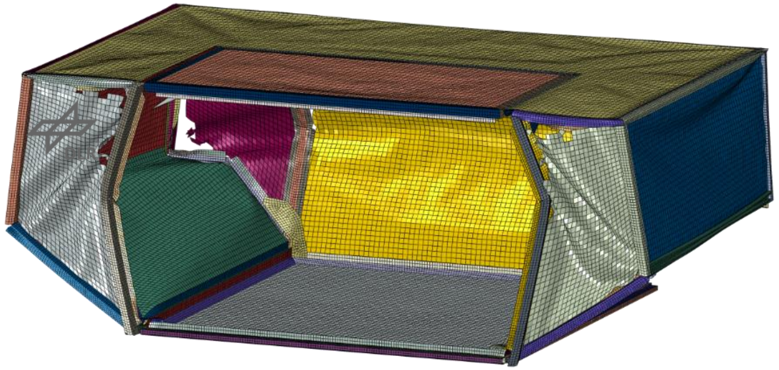
Parameter influences

- **Container type (AKE vs. AKH)**
  - Identical general crash phases for both container types
  - Initial force peak in the same range (Reasonable: Design similarities for both container types)
  - Second force peak different for AKE and AKH (AKH: Stanchion disintegration during initial force peak)
  - Post-peak domain different for AKE and AKH (different design: stanchion length and number of balconies)
  - Total absorbed energies in the same range

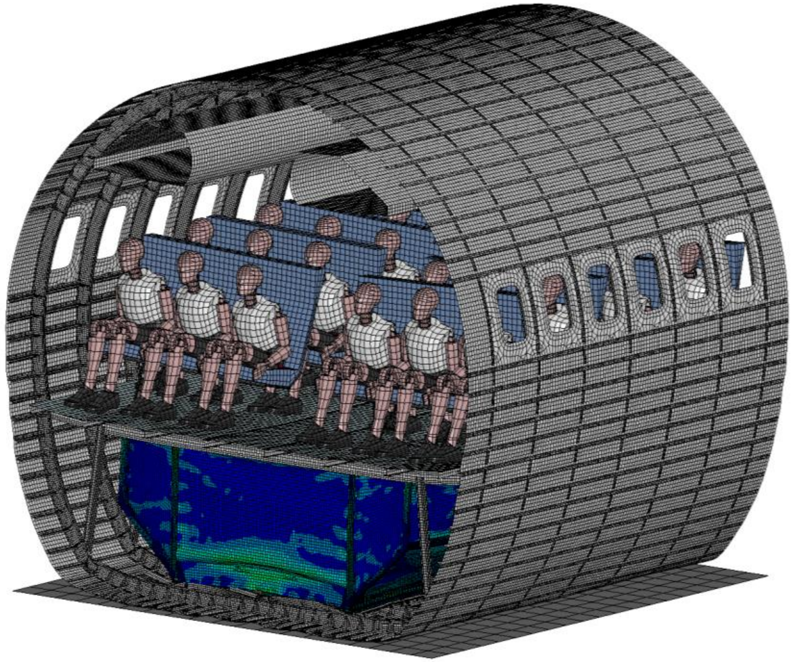
- **Door canvas & diagonal ropes**
  - Test results indicate no noticeable influence of door canvas and diagonal ropes
  - Tests in the same force-displacement range
  - No effects identified by high-speed video records or post-test inspections

Outlook

- **Finalization of research program**
  - Post-test simulations and final model validation of AKE and AKH simulation models



- **Application of container finite element models**
  - Simulation driven investigations on the effect of container loading under real-world crash conditions



Thank you for your attention!

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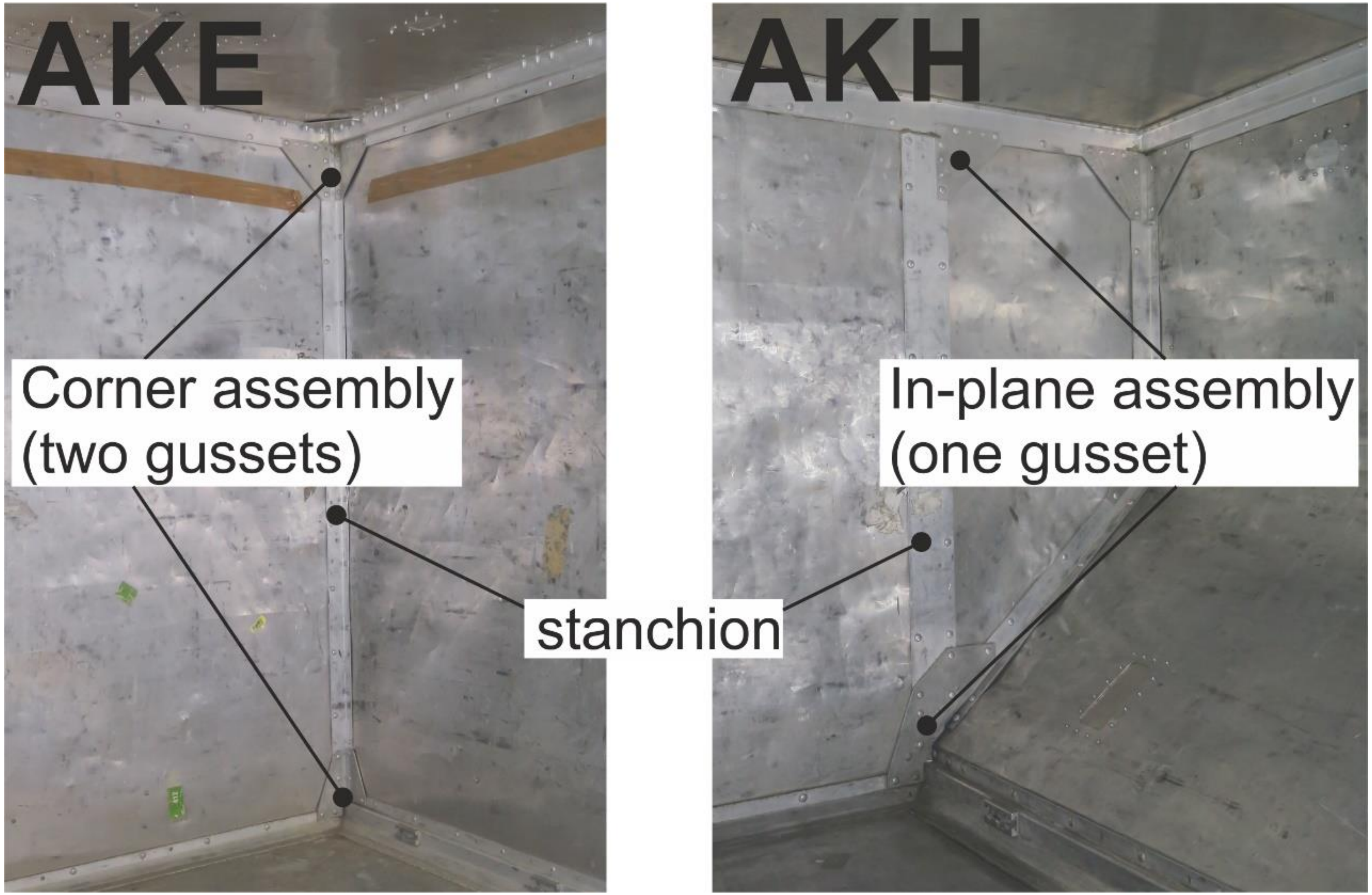
Appendix

AKE vs. AKH design



Appendix

Secondary crash effects in the balcony structure (post-peak domain)