Aluminum structures exposed to blast loading

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Outline

• Blast loading
• Challenges in urban environments
• Research approach at CASA
• Blast-load research at CASA
• Computer simulations
Brief intro to blast loading

- Typical scenario in blast-resistant design of civilian buildings
- Spherical blast wave propagation
- Structure loaded by the blast overpressure
- Response dependent on the structural and loading properties
Blast mitigation

- Protection = reduce the effect of the action
- Blast mitigation = increased distance
Challenges in urban environments

- Space limitations
- Utilize the capacity of architectural materials and components
- Mitigate the effect of blast loading on buildings

Team Urbis’ concept «Adapt»
Blast mitigation

Objective:
- Avoid total structural collapse
- Protect people and critical infrastructure

Understanding the underlying physics

Pictures from Oslo Bombings 22 July 2011, NOU (2012)
Research approach

- Detailed analyses of complex full scale problems.

- Validate computational methods (material and FSI)
- Material testing and controllable small-scale experiments

Establish reliable experimental and computational frameworks
What about explosive detonations?
Experimental and numerical results

Numerical results in good agreement with experimental data
What did we actually observe?

- Reversed snap buckling (unexpected behaviour)
- Characteristic loading domain often determined based on the ratio $t_{d+}/T_n$
- Severe blast-structure interaction effects during the negative phase

Loading domain should not be determined solely based on the positive phase
Experience with high explosives

Picture from the detonation of a VBIED (400 kg TNT)
SIMLab Shock Tube Facility

17 MPa

Figure: Sketch of SIMLab Shock Tube Facility.
SIMLab Shock Tube Facility

- Alternative to explosive detonations
- Controlled, repeatable blast environment
- Planar shock wave
- Dynamic response of blast-loaded structures
Blast-load research at CASA

FIRING SECTION

DRIVER DRIVEN

0.27m 4.0m

Test specimen

Seen from the side

Seen from the driver
What did we actually observe?
What did we actually observe?
Blast-load research at CASA

![Diagram of blast-load research setup]

- **Driver** and **Driven** sections
- Aluminium inserts: 0.27m & 0.77m
- Total length: 16.20m
- TANK: ~73°
- Test specimen
- Sensors 1 & 2
- Cam 1 & Cam 2

Materials:
- Steel
- Aluminium
- Concrete
- Glass

Centre for Advanced Structural Analysis (CASA)

17
Blast-load research at CASA

Study the dynamic response of blast-loaded structures

- Material vs geometry
- Fluid-structure interaction
- Evaluation of computational methods
Aluminium plates

Study dynamic response of blast-loaded plates

- Massive plate (loading, FSI effects)
- Various blast intensities
- Evaluation of computational methods
High-speed cameras and 3D-DIC (eCorr)
Synchronized pressure and response
Possibilities with 3D-DIC (eCorr)
Possibilities with 3D-DIC (eCorr)
Possibilities with 3D-DIC (eCorr)
Aluminium plates with pre-cut defects
Aluminiumsplate with pre-cut defects
Aluminium plates with pre-cut defects

6016 – T4

$P_{r,\text{max}} = 460 \text{ kPa}$

$P_{r,\text{max}} = 620 \text{ kPa}$
Aluminium plates with pre-cut defects

\[ P_{r,\text{max}} = 460 \text{ kPa} \]

6016 - TX

- T4
  - \( t = 1.50 \text{ ms} \)

- T6
  - \( t = 1.50 \text{ ms} \)

- T7
  - \( t = 1.50 \text{ ms} \)
Computer simulations

Use the FE code EUROPLEXUS (EPX)

- Assuming symmetry (1/4 model)
- 4-node shell elements (6 mm x 6 mm)
- 3 blast intensities
- Uncoupled vs. coupled FSI approach
Coupled FSI approach

- Assuming symmetry (1/4 model)
- 1D-3D model of the tube/tank/air
- FSI-driven AMR in the vicinity of the plate
Validation of model

Numerical results in **good agreement** with experimental data

6-mm mesh size **not able** to predict failure
Adaptive mesh refinement (AMR)

- AMR using a threshold criterion
- Based on damage parameter

\[ D = \frac{1}{W_c} \int_0^p \langle \sigma_1 \rangle \, dp \]

- Refine mesh when \( D_{\text{min}} < D < D_{\text{max}} \)
- Refinements until a user-defined level
- Maximum refinement when \( D > D_{\text{max}} \)
- Controlled by GPs with the largest damage
Computer simulations
Computer simulations
Comparison to experiment (qualitative)
Comparison to experiment (qualitative)
Application in realistic scenarios
Application in realistic scenarios

Explosion dans une rame de métro

Temps : 5.7 ms