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Experimental and numerical methods for external event assessment improving safety

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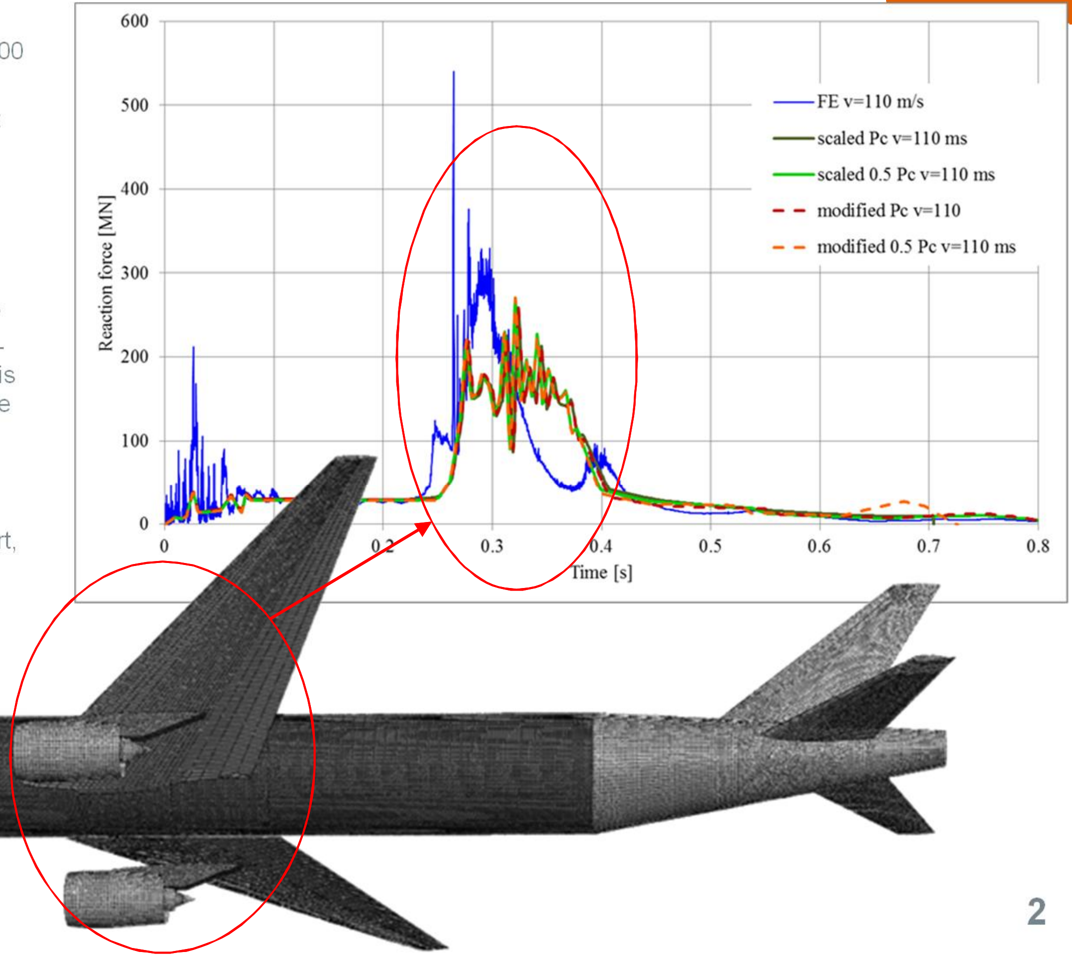
Modelling of an aircraft impact

- A detailed finite element model of Boeing 777-300 was created
  - simulation of impact against a rigid target
  - difference between the impact loading functions obtained by
    - FE model
    - analytical Riera method
  - Impact velocities of 110 m/s and 160 m/s
  - The main discrepancy: the effect of semi-hard parts like engines and landing gear is not properly included in the crushing force assumption used in the Riera approach
    - mass flow (mass distribution) is dominating
  - Otherwise, especially for the fuselage part, the loading functions were in agreement.



Impact testing

- Experimental test data is needed for validation of computational models
- 5 impact tests in ERNEST

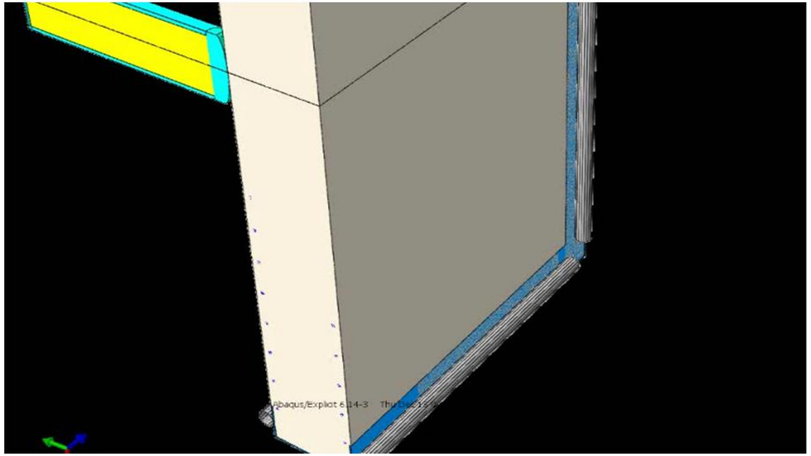
Punching & bending - type

Parameter	Test E1	Test E2
Projectile outer diameter [mm]	260	219.1
Projectile body wall thickness [mm]	5.0	6.35
Outer radius to wall thickness ratio [-]	26	17.3
Projectile mass [kg]	49.90	50.04
Impact velocity [m/s]	124.0	150.6

Punching - type

Parameter	Test E3	Test E4	Test E5
Projectile mass [kg]	47.58	47.60	47.58
Impact velocity [m/s]	102.6	104.9	104.0
Concrete compr. strength [MPa] Cube/Cyl.	57.7/55.5	57.5/51.8	57.5/49.9
Concrete splitting tensile strength [MPa]	3.35	2.77	3.26
Residual velocity [m/s]	41	42	49
Scabbing area [m^2]	0.65	0.52	0.89
Mass of detached concrete [kg]	58	67	141
Estimated just perforation velocity [m/s]	81	82	36

High speed video from Test E4

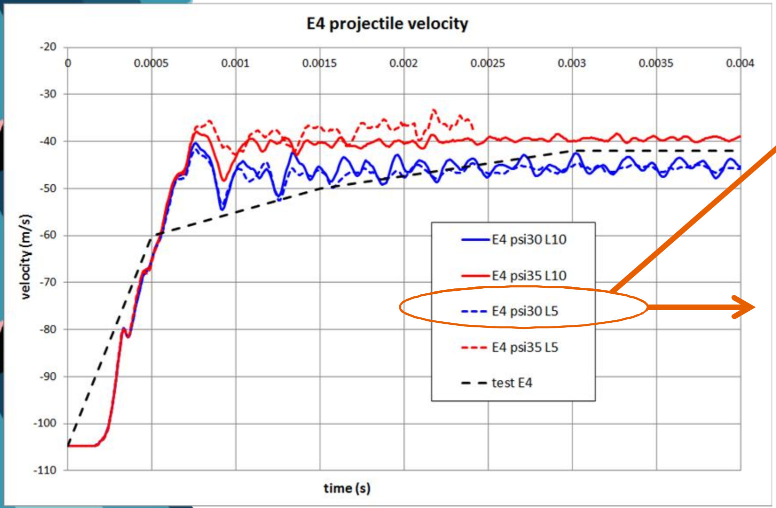


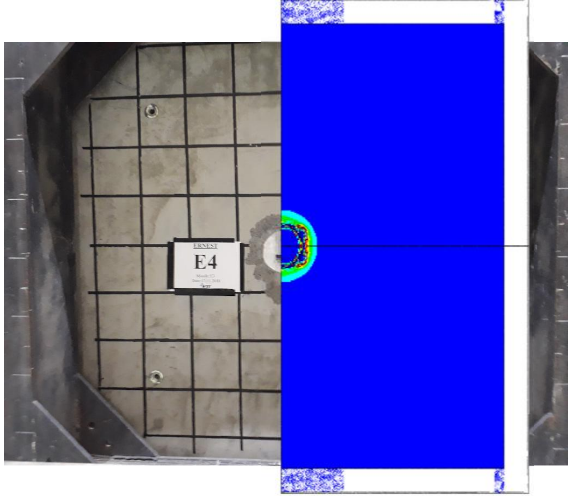
FE simulation of Test E4

Dilation angle 30°, element size 5 mm

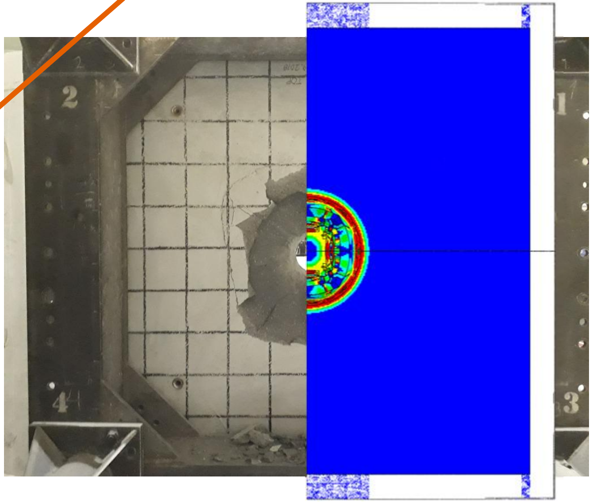
Material model development

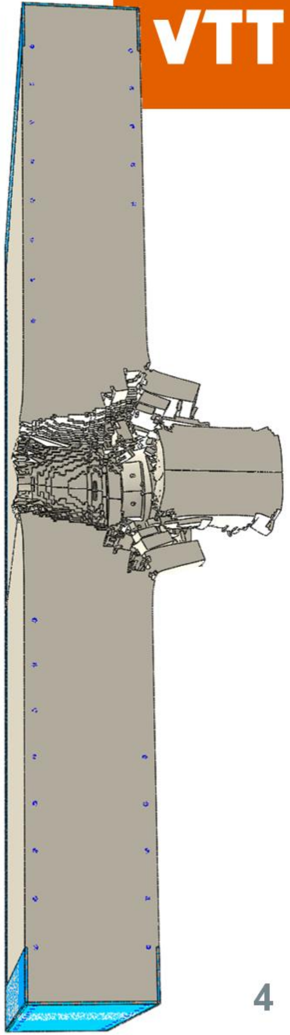
- Concrete Damaged Plasticity material model in Abaqus code
    - Triaxiality (effect of confinement)
    - Rate-dependency
    - Element removal criteria
- Sensitivity study for parameter values and element size
    - Especially sensitive to angle of dilation
- Satisfactory agreement with benchmark test results





Dilation angle 30º, element size 5 mm





Synthetic ground motion modeling (NKS / Syntagma)

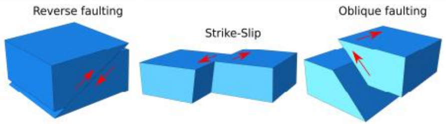
Goal: Relevance of near-field (<50km) earthquakes to safety of NPPs is high. Very few recordings in this range of distances.

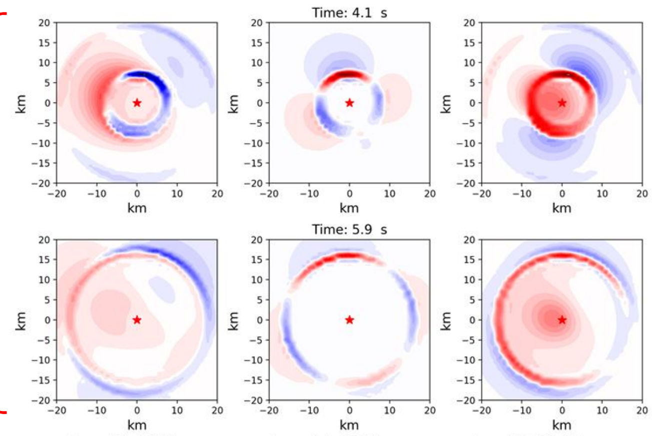
We developed a hybrid method to generate synthetic ground motions by physics-based modeling and verified the results with a GMPE developed for hard rock sites.

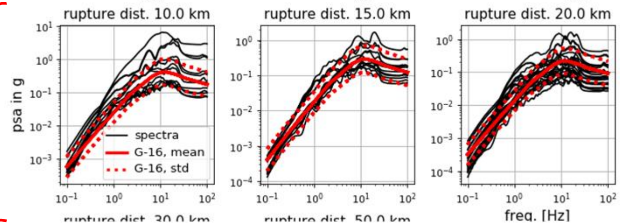
Method: Earthquake sources were generated by dynamic rupture modelling using 3DEC. Time-slip functions transferred to Compsyn, where ground motion was calculated using point source summation of kinematic slip and complete Green's function.

Ground-motion generated up to 30 km. Frequency up to 25 Hz. Spectra computed from the ground-motion and compared to the G-16 GMPE.

Moment magnitude (M_w)	Fault dip angle (deg)	Hypocenter depth (km)	Focal mechanism
4.3	30, 80, 45	2, 10	Reverse, Strike-Slip, Oblique
5.0	30, 80, 45	10	Reverse, Strike-Slip, Oblique
5.4	80, 45	10, 20	Strike-Slip, Oblique
5.5	30	10, 20	Reverse
5.6	30, 80, 45	10, 20	Reverse, Strike-Slip, Oblique







Results: Plots of ground motion at the Earth's surface from different earthquakes, used to verify the simulations qualitatively.

Response spectra computed (valid up to 25Hz), which is the limit covered in modeling. We overlap all spectra for the same magnitude (M_w) and distance (D_{rup}) with the GMPE prediction (median and ±σ)

Conclusions: Computed acceleration spectra agrees well with the G16 GMPE up to 30 km distance. Up to 30 km synthetic ground motions could be used for PSHA.

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