Advanced Modelling of Reinforced Concrete Structures Using ATENA Interface to GiD

Jan Cervenka, Zdenek Janda

Červenka Consulting s.r.o., Prague, Czech Republic

Outline:

Červenka Consulting - Computer simulation (virtual testing) of concrete structures

Validation by tests and blind prediction competitions

ATENA – GID Interface – problem types, reinforcement modelling,

Practical applications

About Cervenka Consulting

Main office:

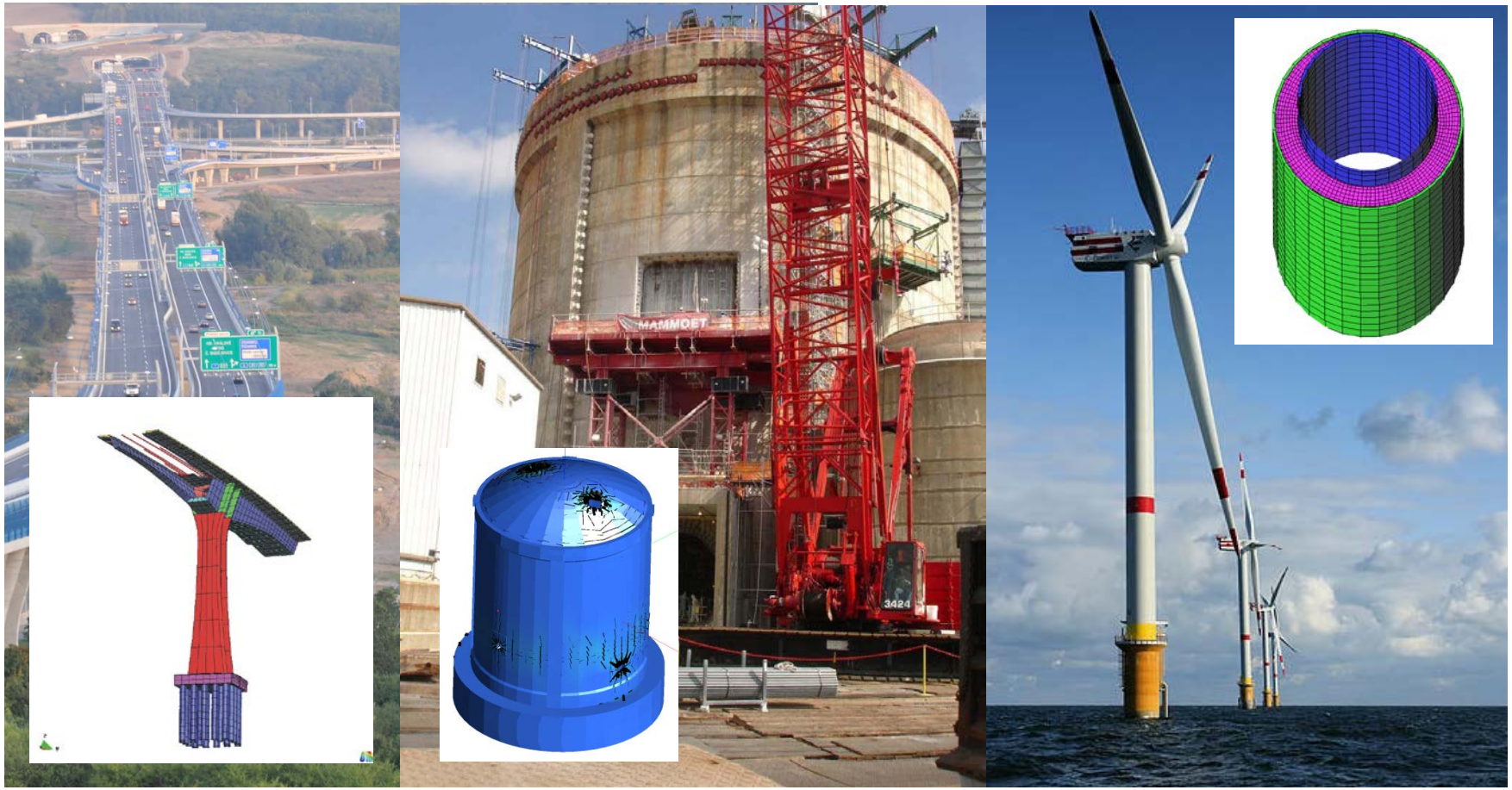
Prague, Czech Republic established 1992 by Vladimír Červenka

Staff:

20 high qualified PhD Engineers and IT specialits

Small company with broad international activities in USA, Germany, Netherlands, Switzerland, Japan, Australia, India, Emirates, Korea, China…

SCOPE: Nonlinear modelling of structures, bridges, tunnels , containments, towers, composites, connections…

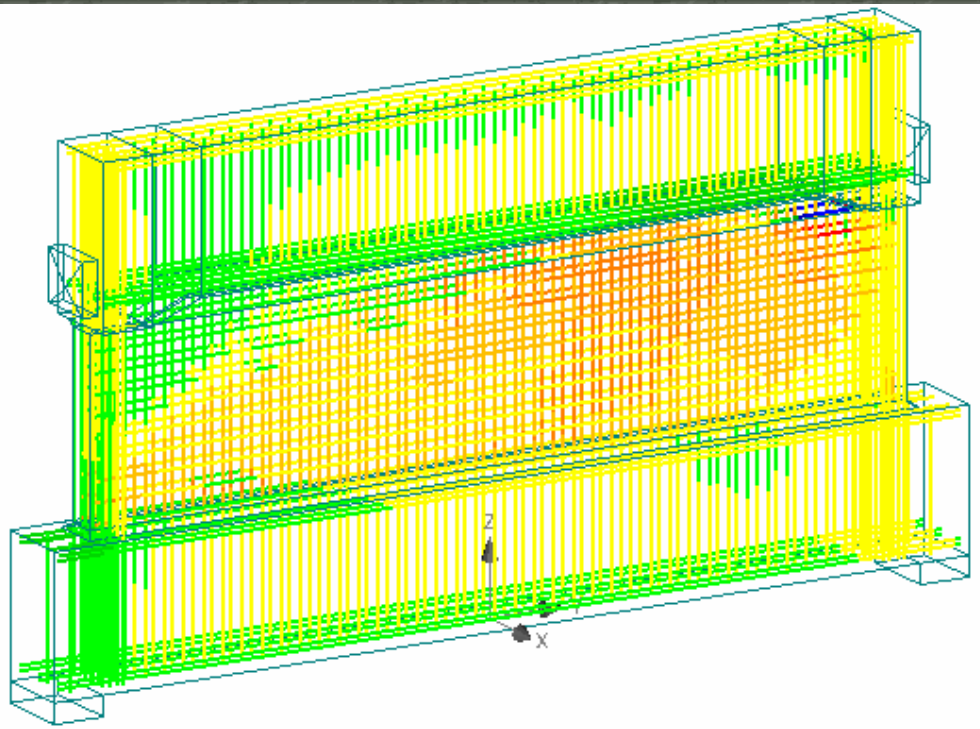


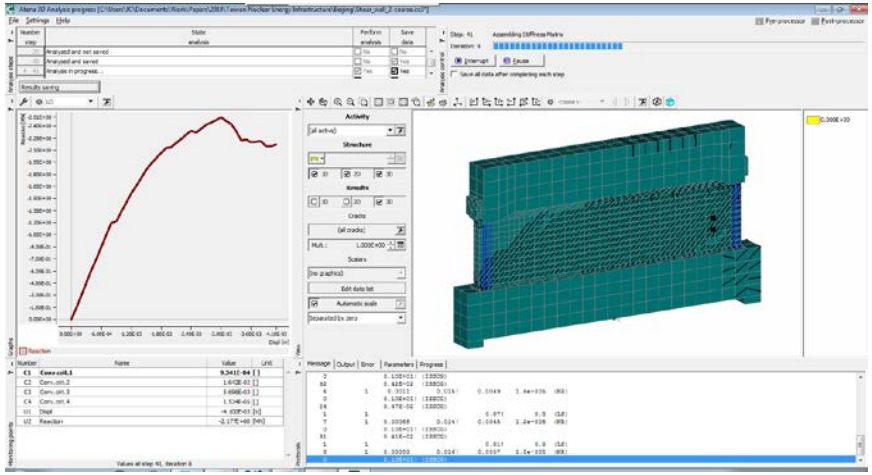
Tool:

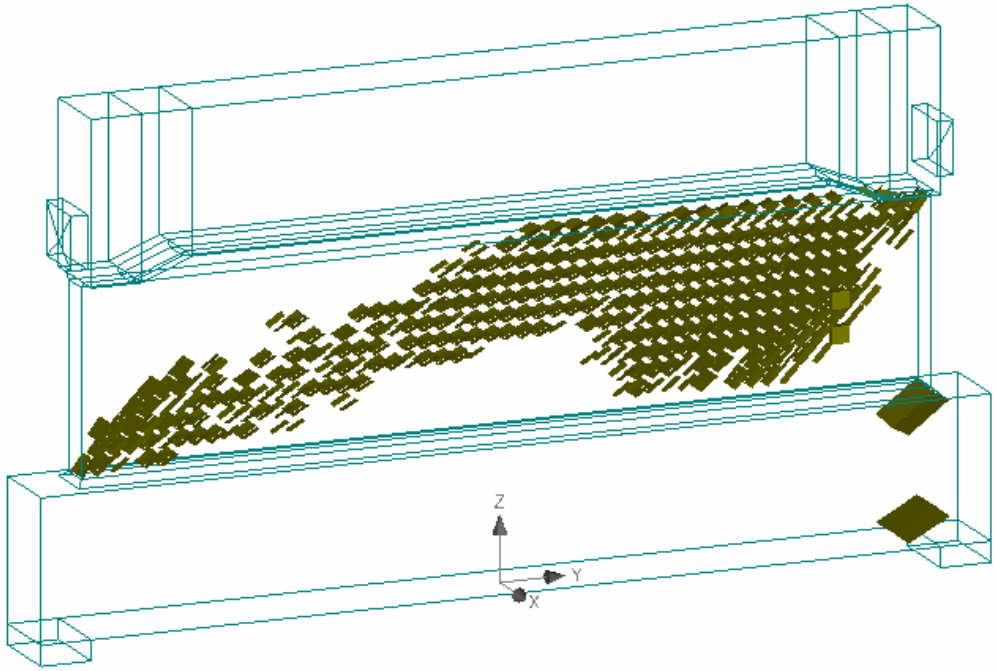
ATENA – software for simulation of structural performance of RC.

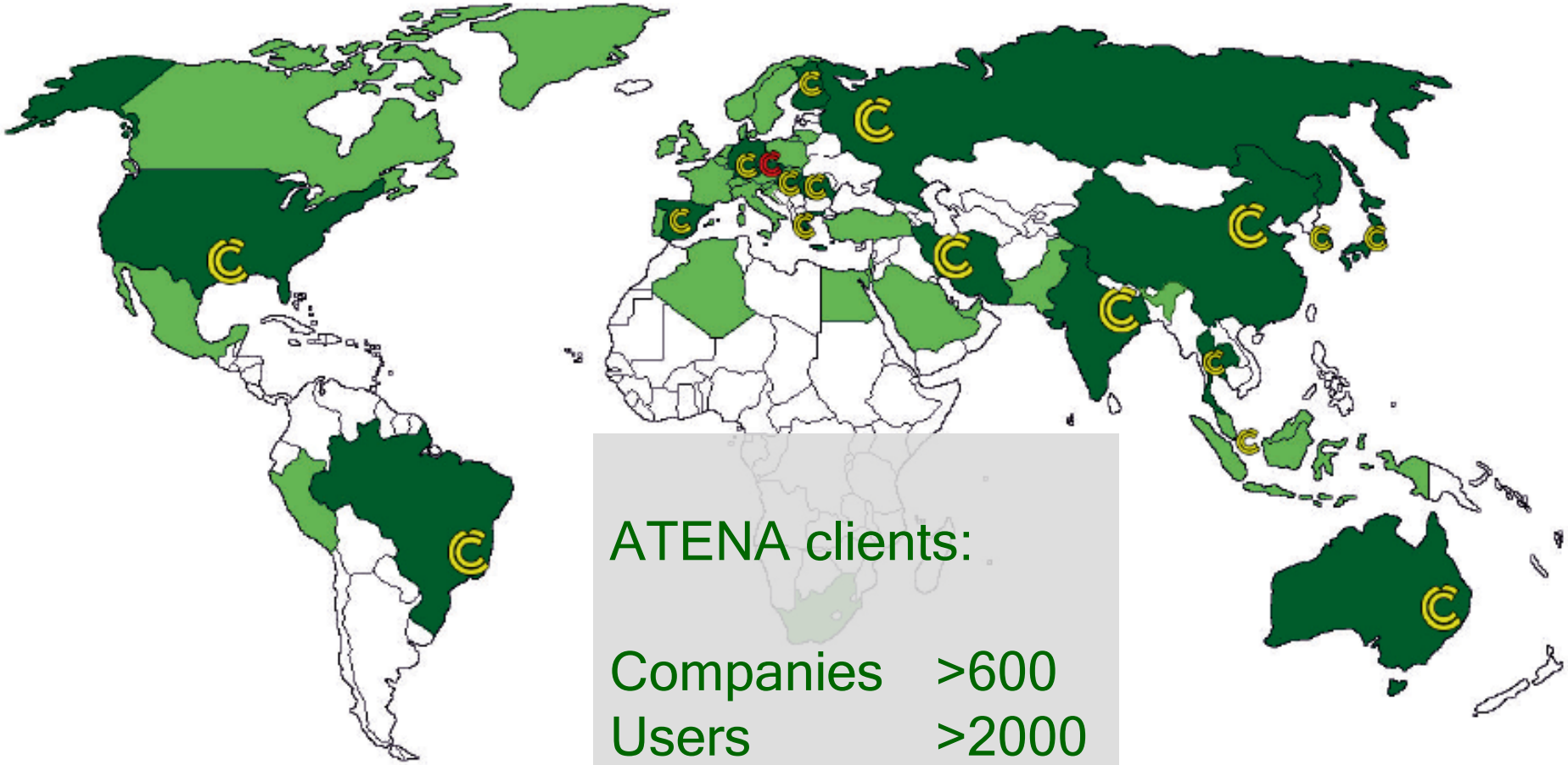
Unique:

reinforcement , cracks, run-time visualization.









ATENA clients:

Companies	>600
Users	>2000
Countries	62

ATENA material models

Concrete:
Fracture-plastic model (Menetrey-Wilam, non-associated flow rule, fracture, smeared cracks

Soil, rock: Drucker-Prager

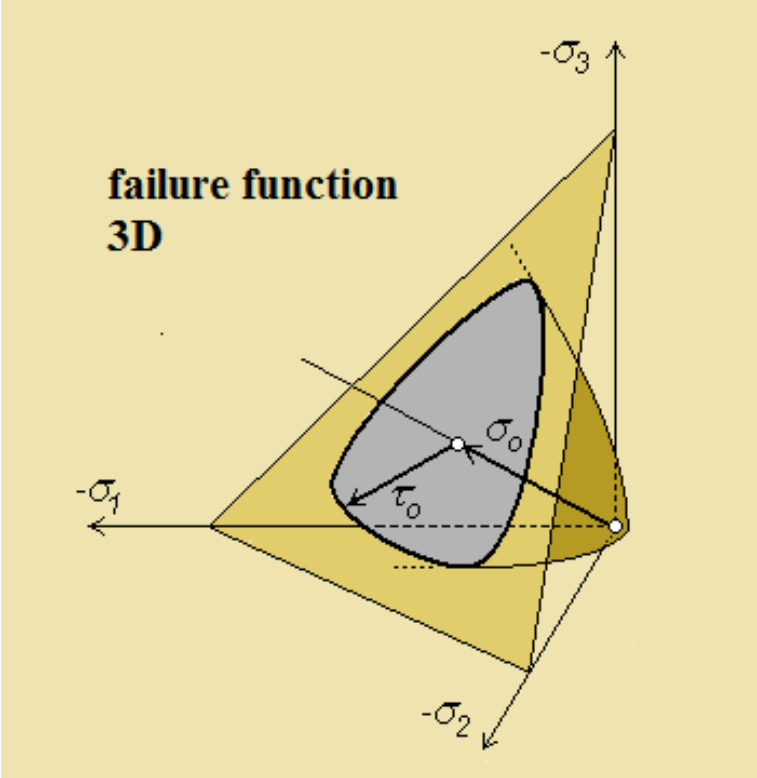
Concrete, rock, masonry: Microplane Bazant M4, M7

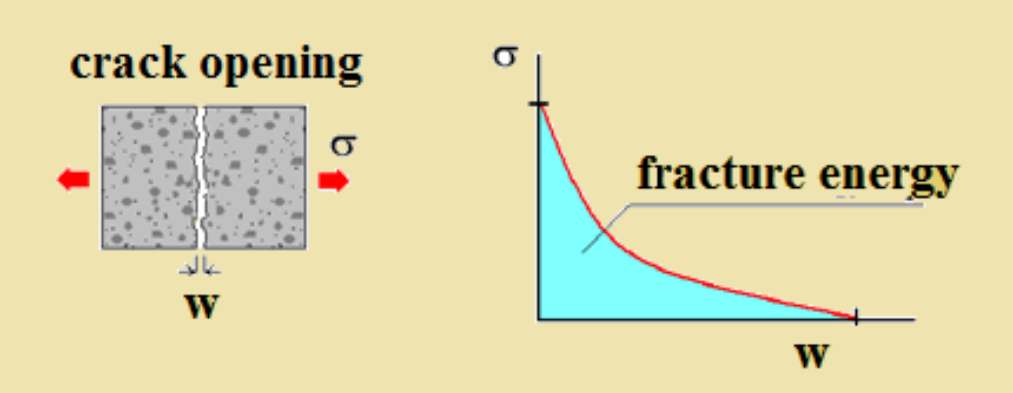
Steel: Von Mises

Time dependent models:
Transport of heat and moisture, fire, creep, corrosion

Concrete:

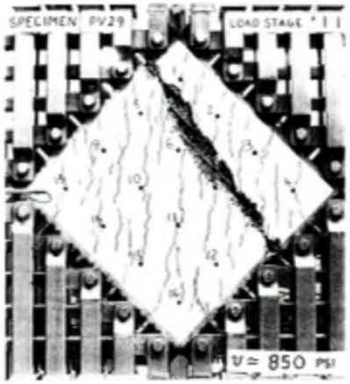
Fracture-plastic model (Menetrey-Wilam, non-associated flow rule, fracture, smeared cracks





ATENA – Blind prediction benchmarks

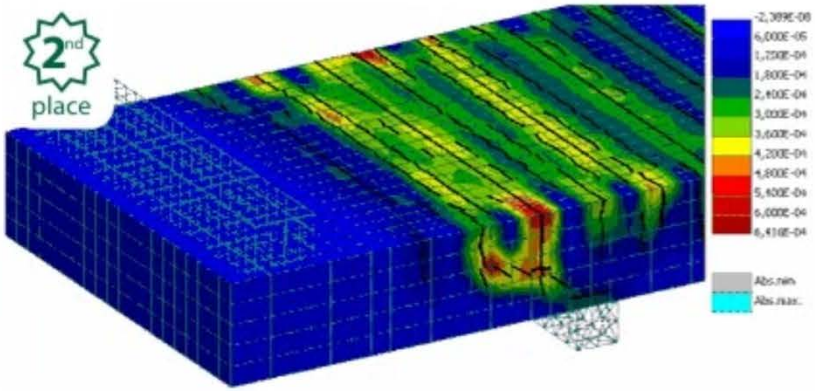
Univ. Toronto, Prof. Collins 1982 – shear panels



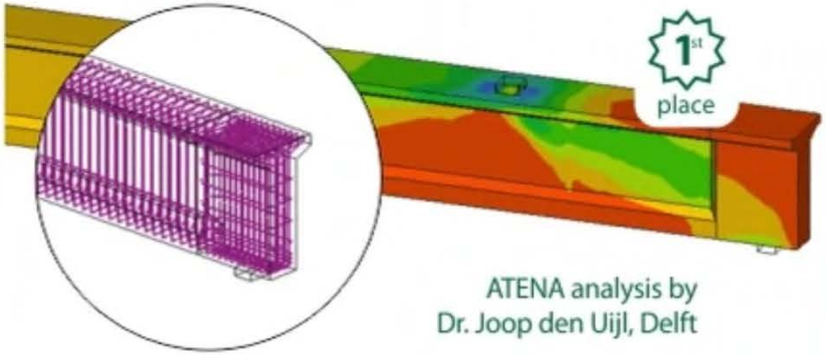
1st place

ETH Zurich, Prof. Marti 2006 – shear slabs

2nd place



Univ. Parma, Prof. Belleti, 2014 – shear beams



1st place

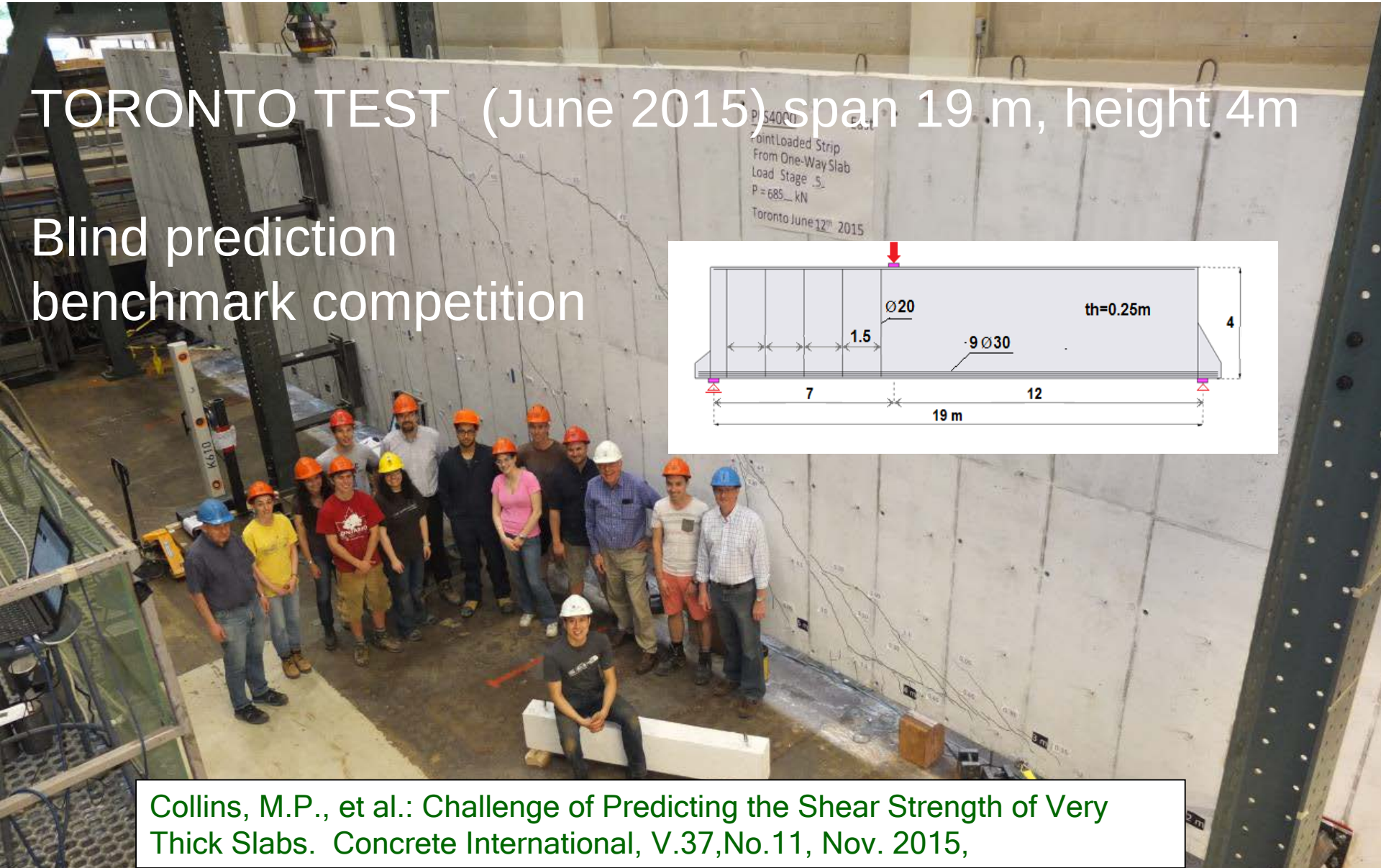
ATENA analysis by
Dr. Joop den Uijl, Delft

Univ. Toronto, Prof. Collins, 2015 – large shear beam

1st place

TORONTO TEST (June 2015) span 19 m, height 4m

Blind prediction
benchmark competition



Collins, M.P., et al.: Challenge of Predicting the Shear Strength of Very Thick Slabs. Concrete International, V.37,No.11, Nov. 2015,

East test

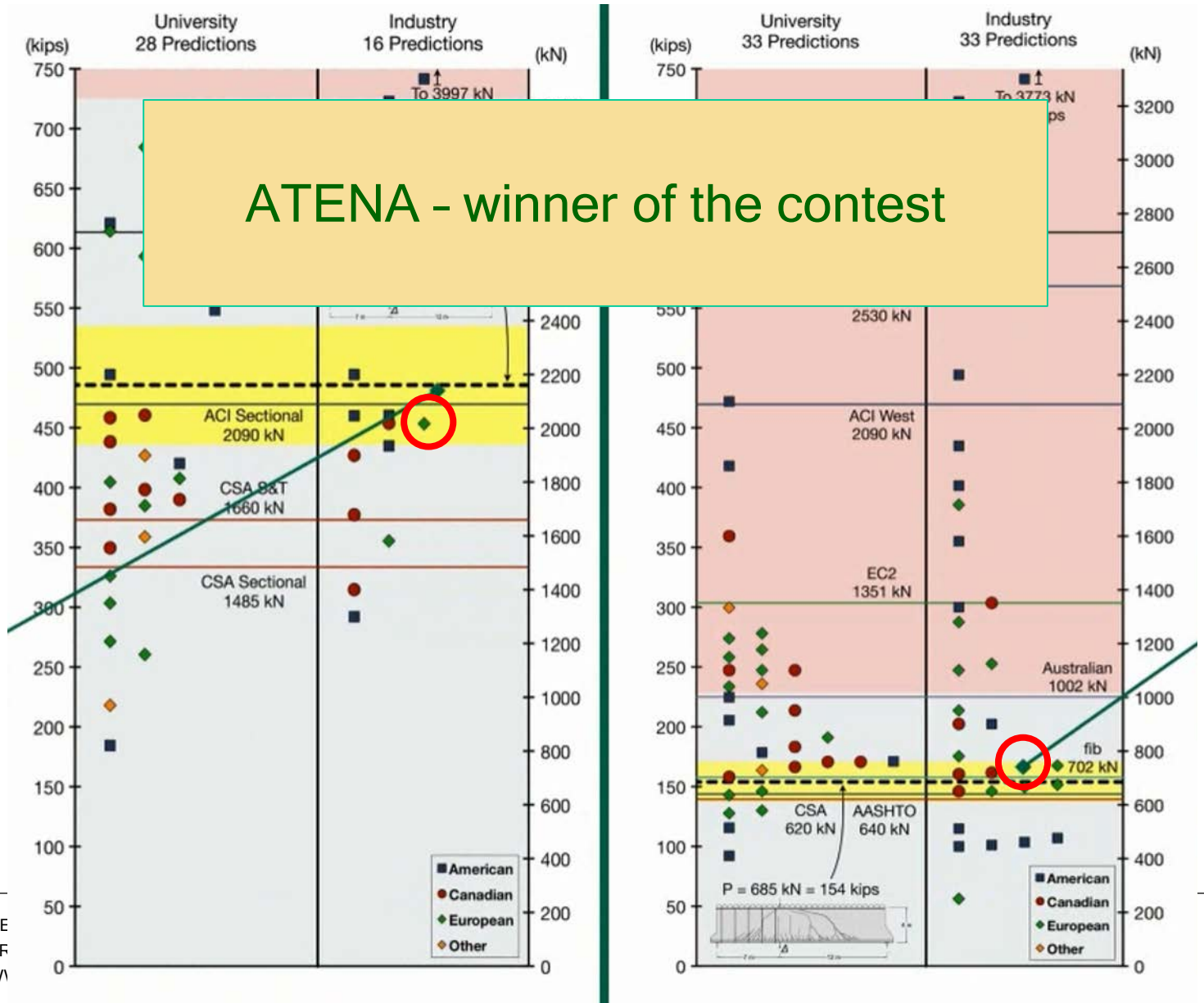
Toronto experiment P_{exp} = 685 kN (Collins, M.P., Bentz, E. 2015)

ATENA simulation P_{sim} = 745 kN

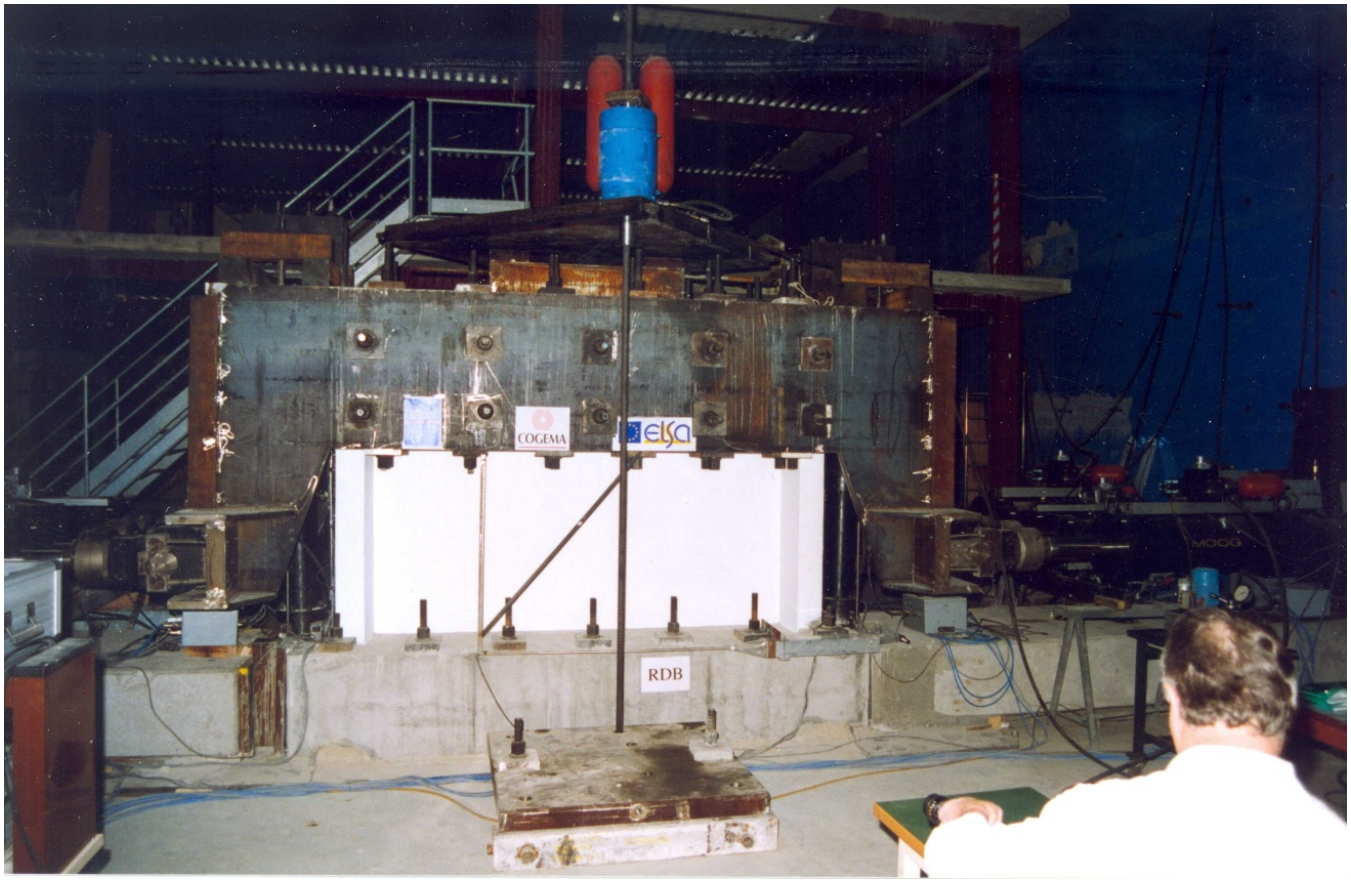
WEST

EAST

ATENA – winner of the contest



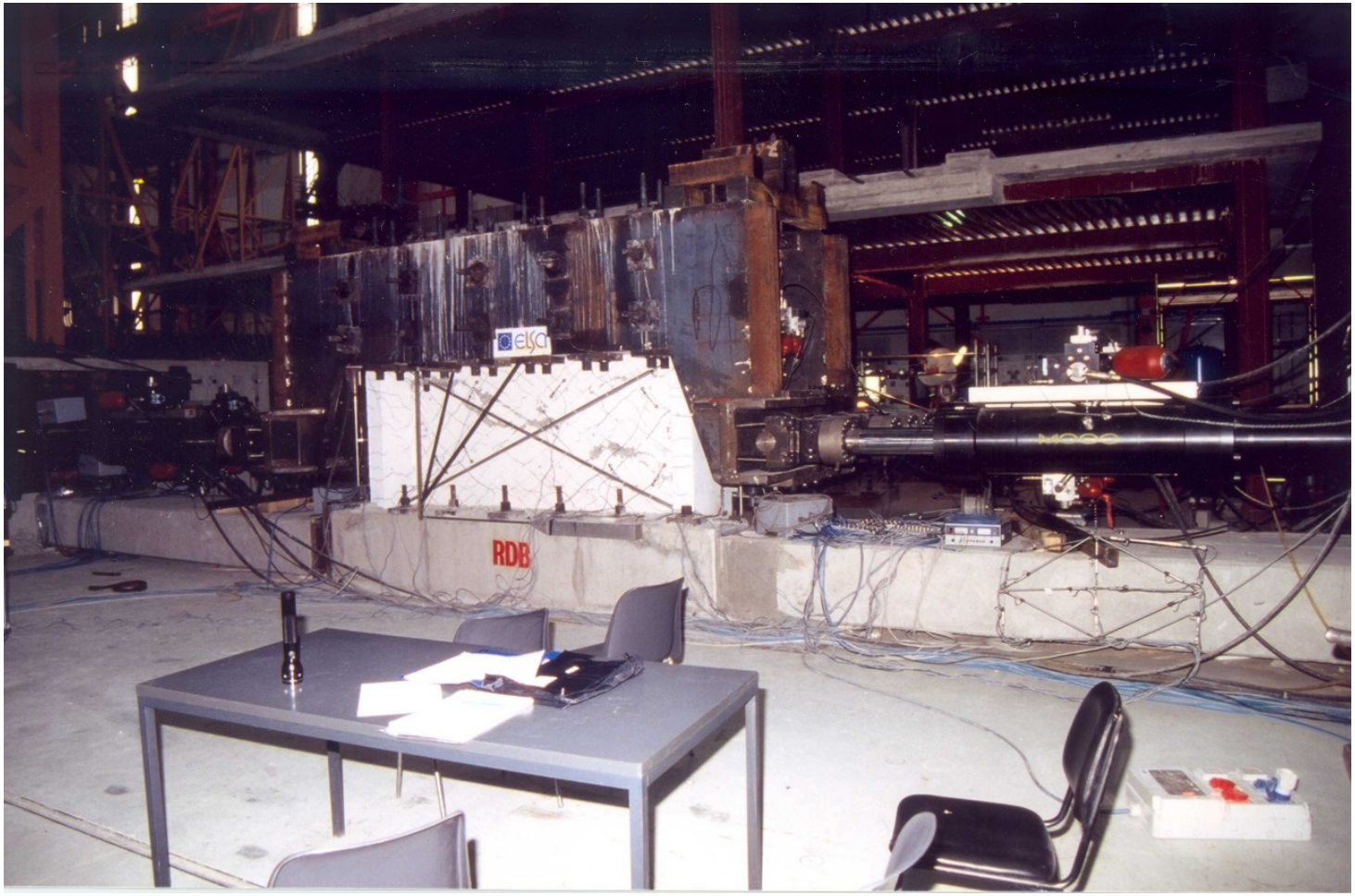
CASH - Benchmark on the beyond design seismic capacity of reinforced concrete shear walls



Phase 1 modeling of SAFE experiment,

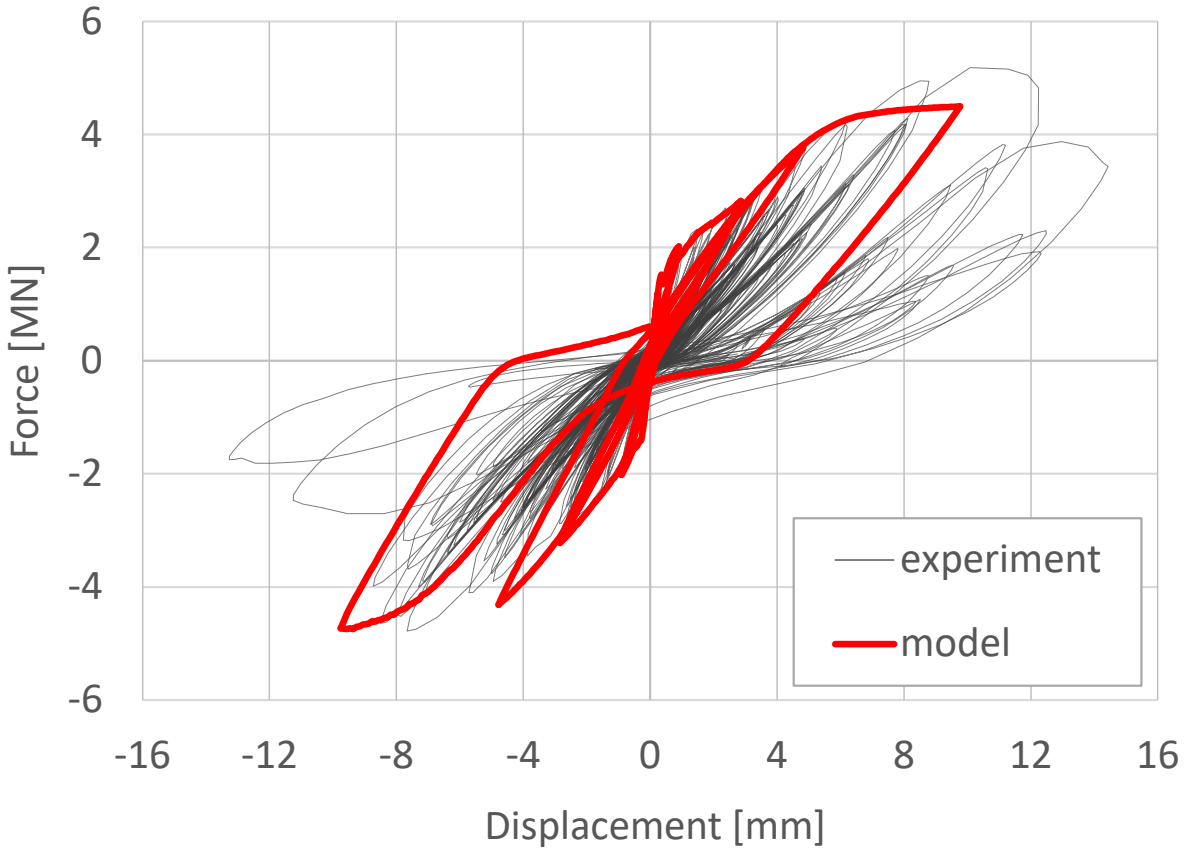
ELSA lab. 1997-98

before test



after test

CASH Benchmark – ATENA cycled analysis

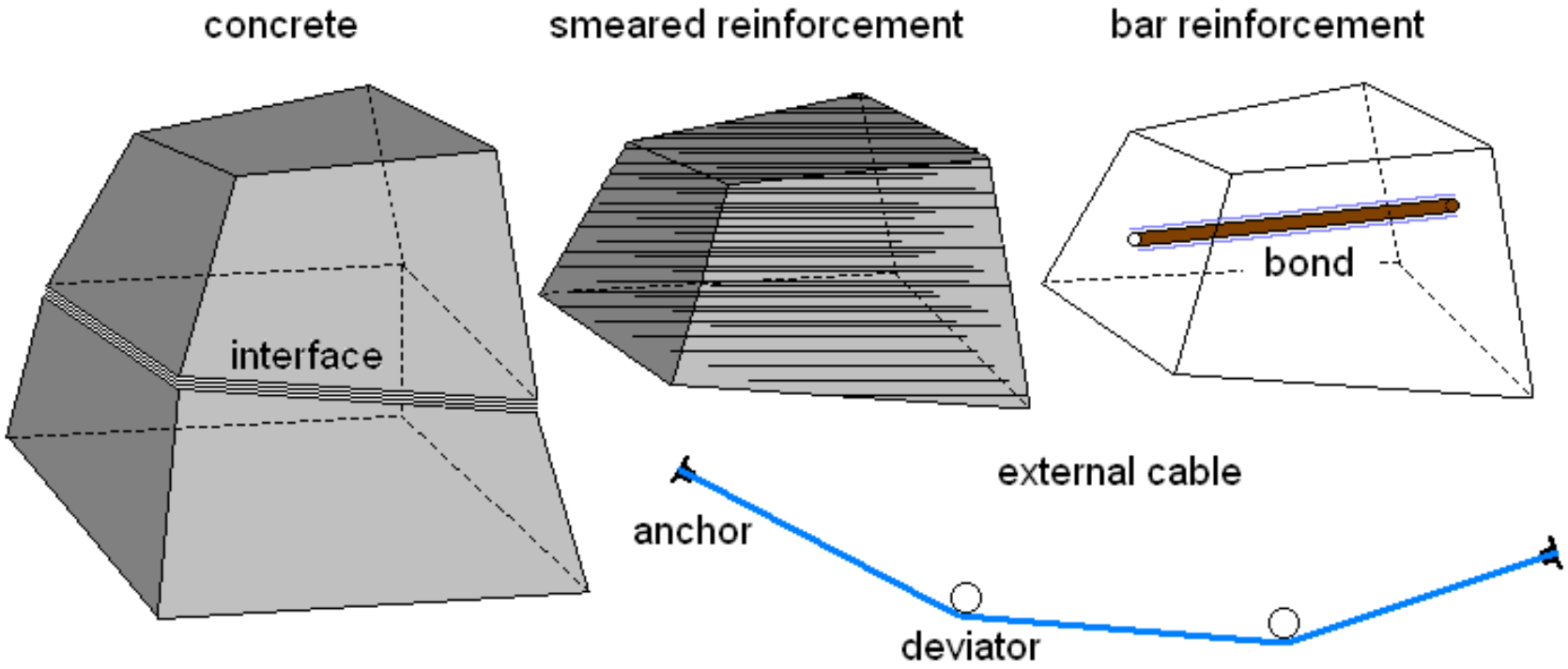


CASH Benchmark – cycled analysis

idth > 0.1 mm

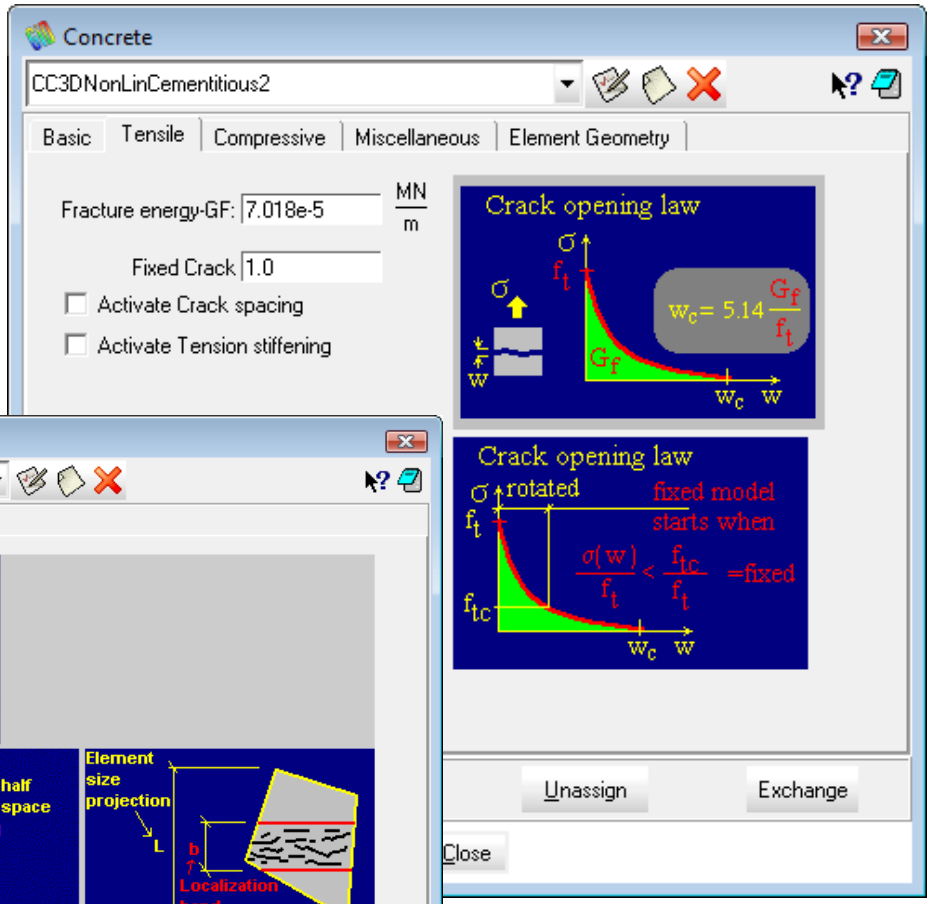
CASH Benchmark – dynamic analysis

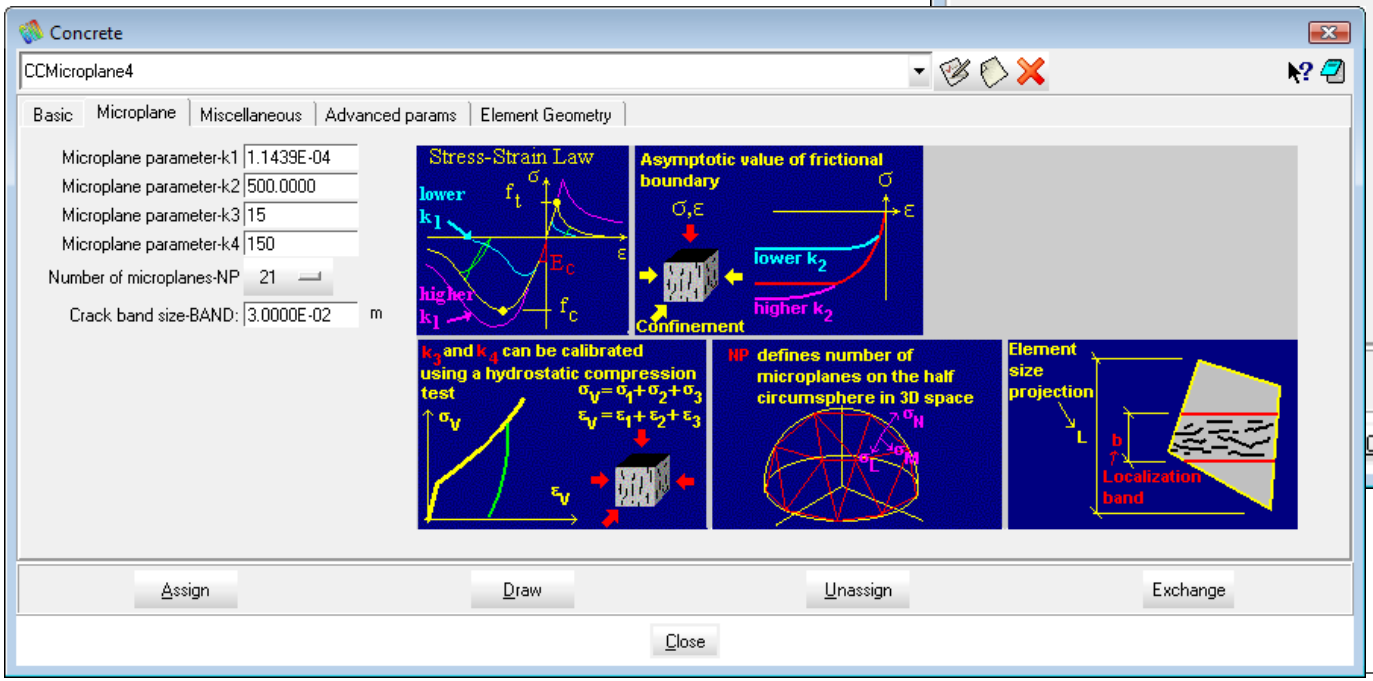
Special elements for reinforced concrete analysis



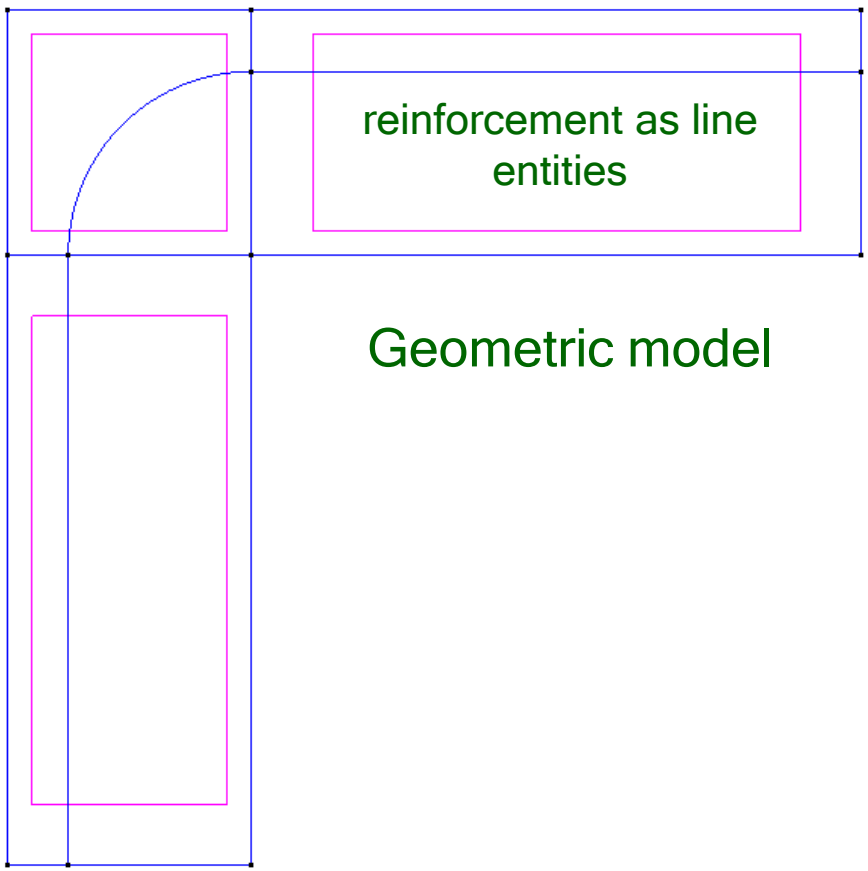
ATENA Material Models input in GiD

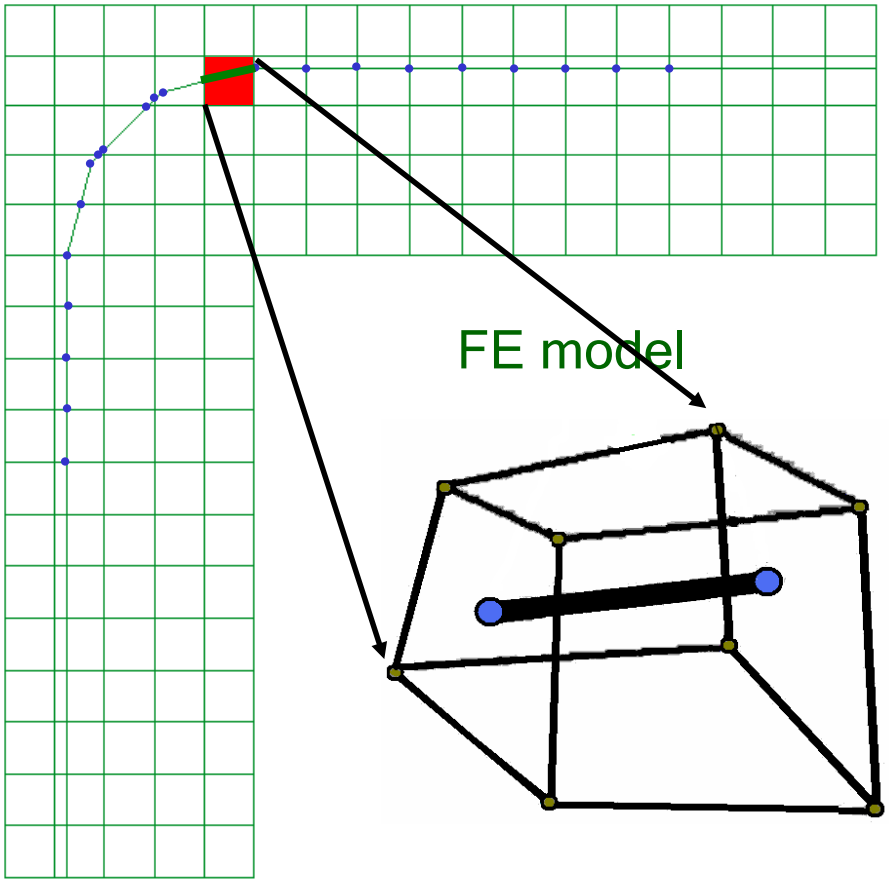
concrete
reinforcement
steel
rock/soil, interfaces



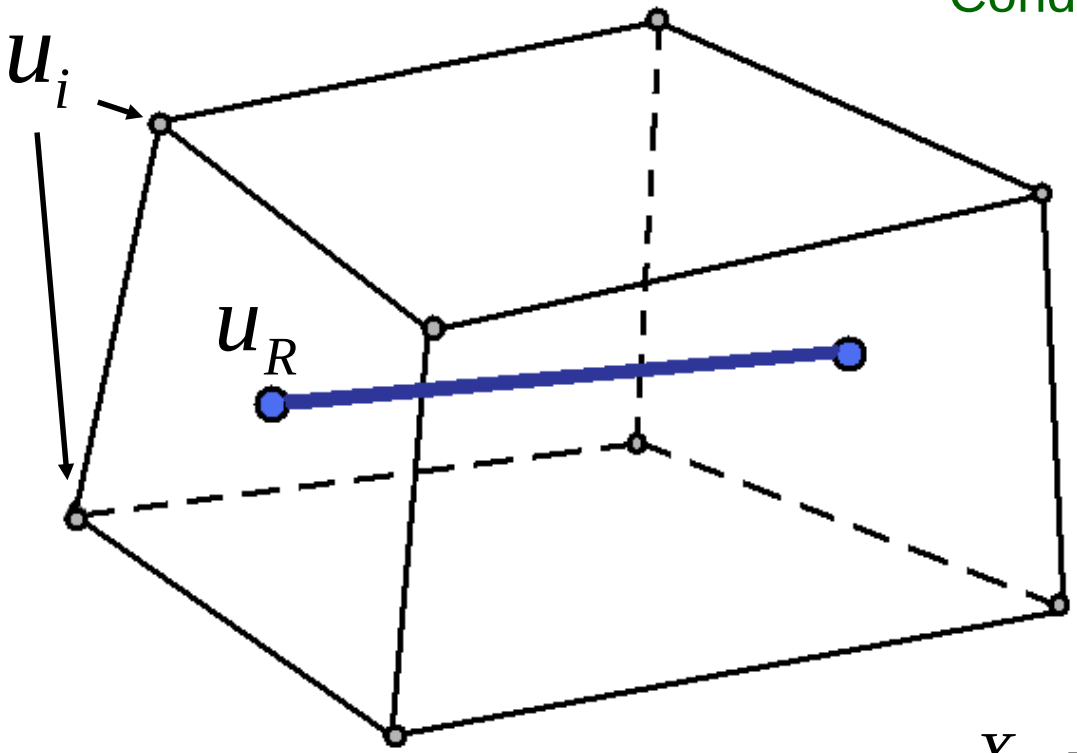


Modelling of Reinforcement





Generalized Constraint Condition



Condition for nodal displacement

$$u_R = \sum \alpha_i u_i$$

Coeff. α equal to shape function values

$$\alpha_i = h_i(r,s,t)$$

Natural coordinates r,s,t calculated from:

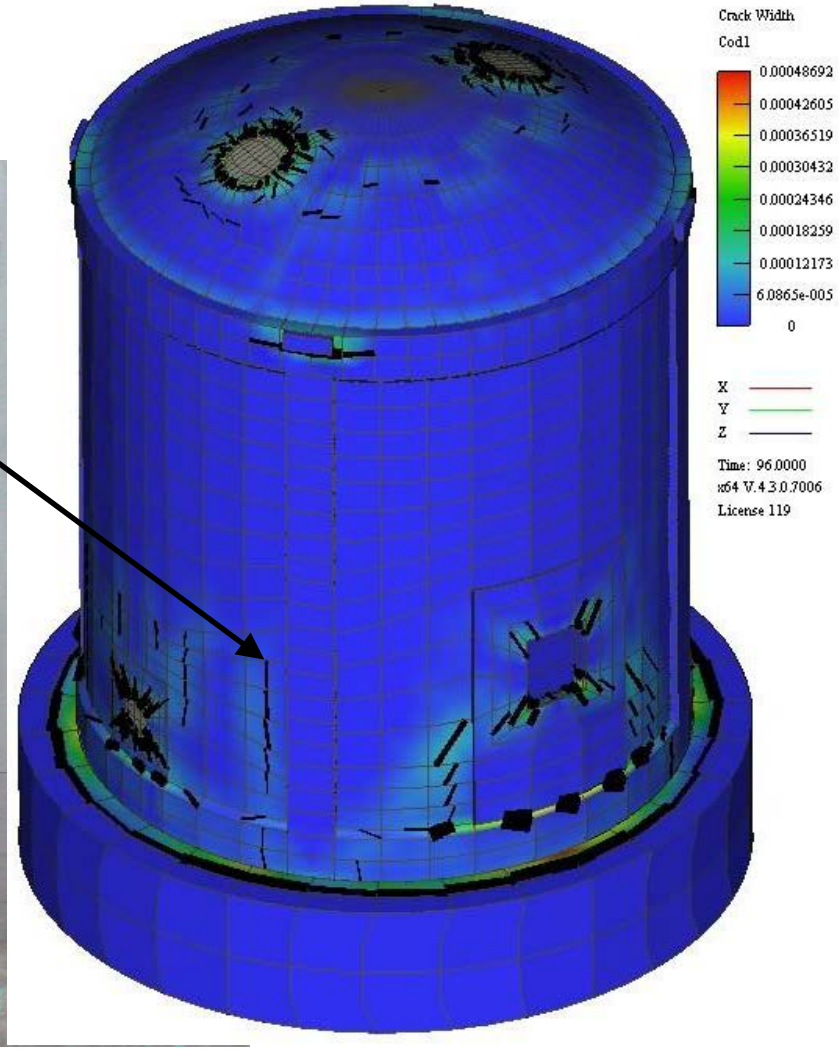
$$X_R = \sum h_i(r,s,t) X_i \quad \rightarrow \quad r,s,t$$

Safety Assesment of Olkiuoto 3 NPP - Finland

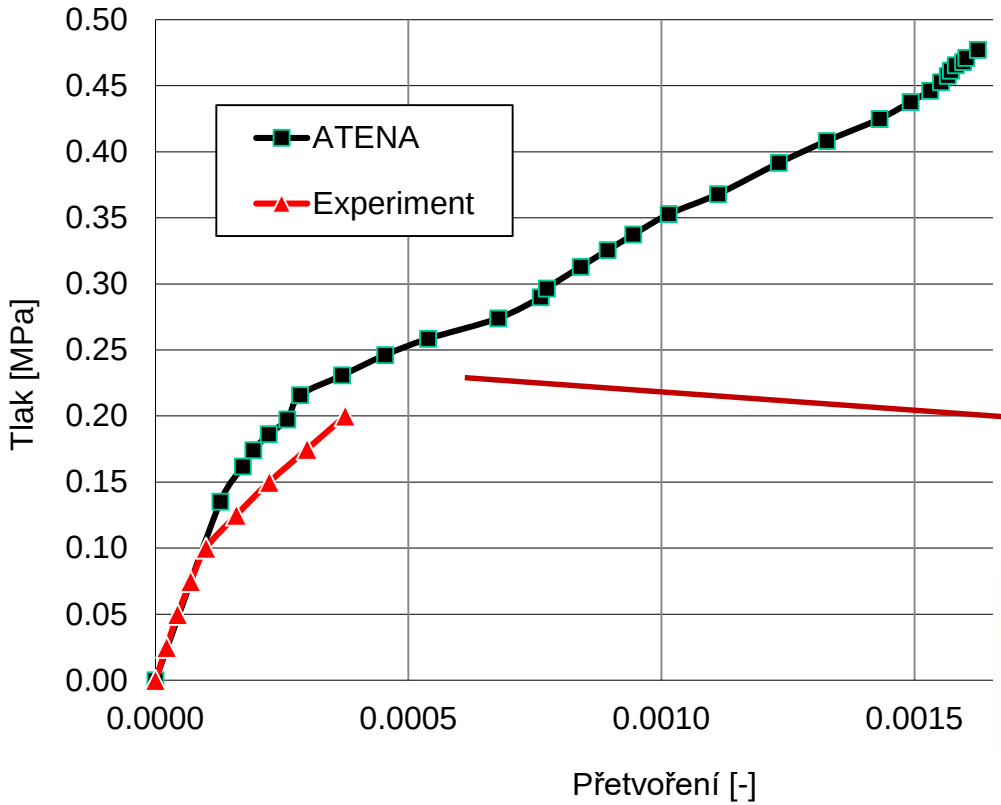
3D analyses, liner buckling

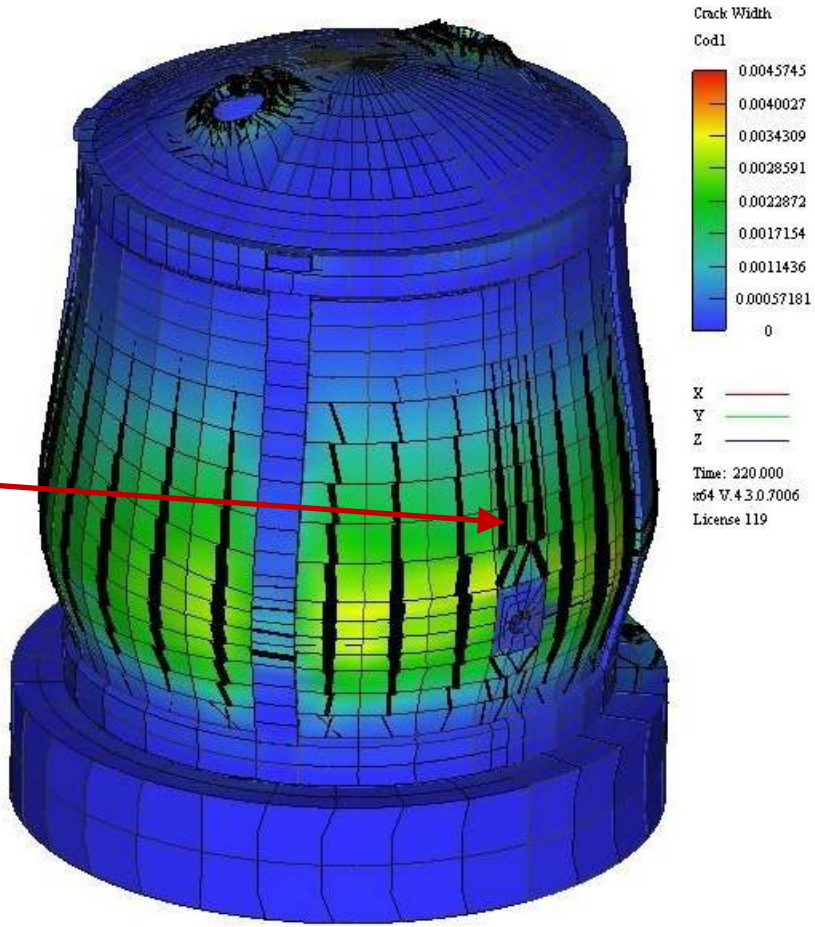
BARC, Indie, Containment Pressure Test Model 1:4

Crack Pattern at 1.4 Pd

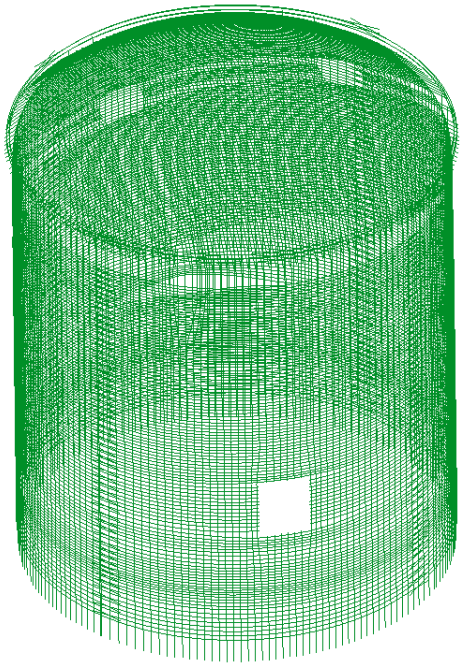


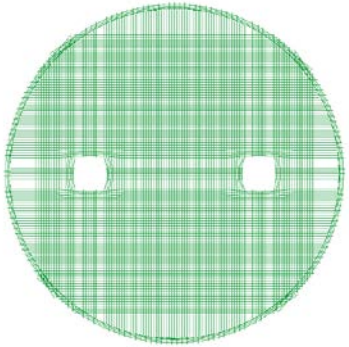
Comparison of measured and calculated concrete strains

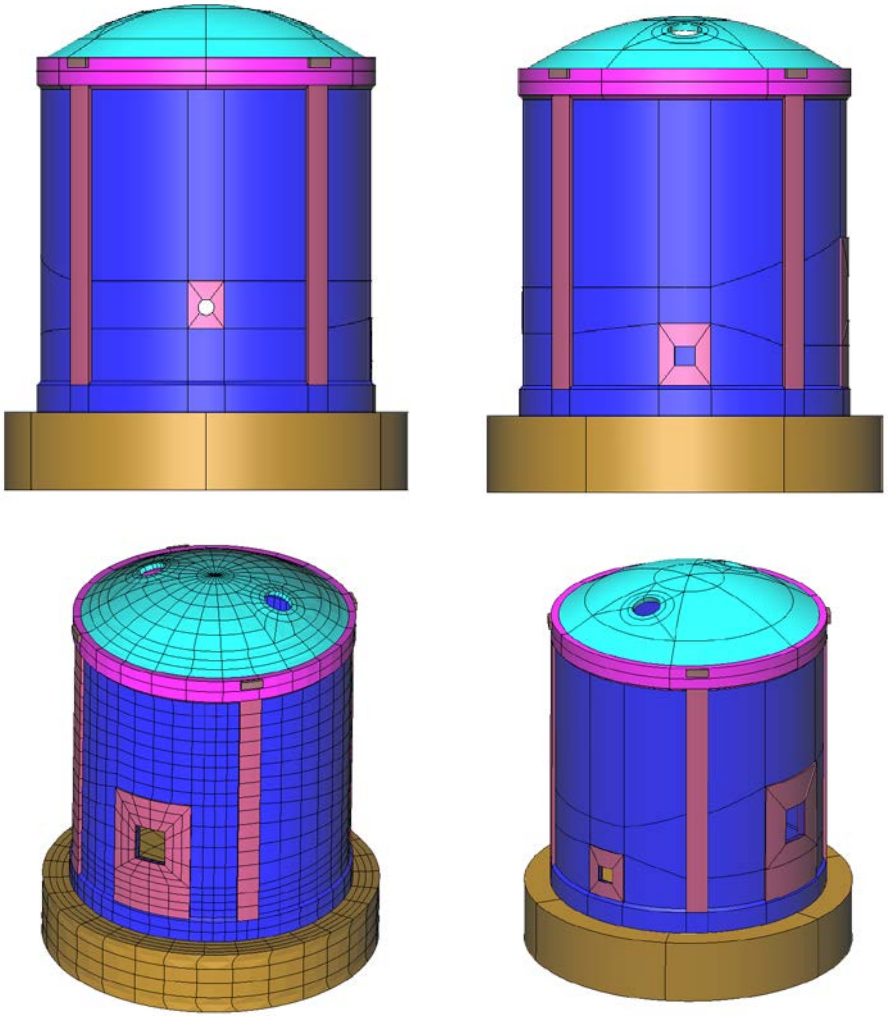




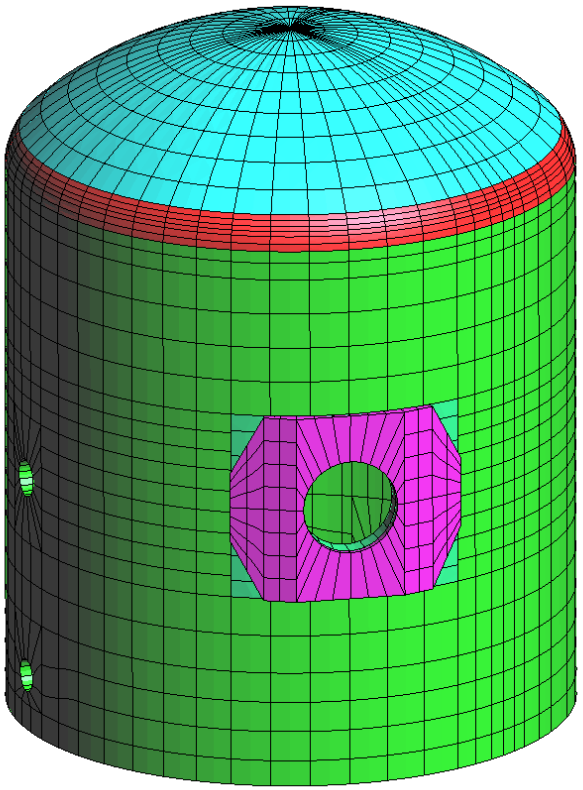
3D model



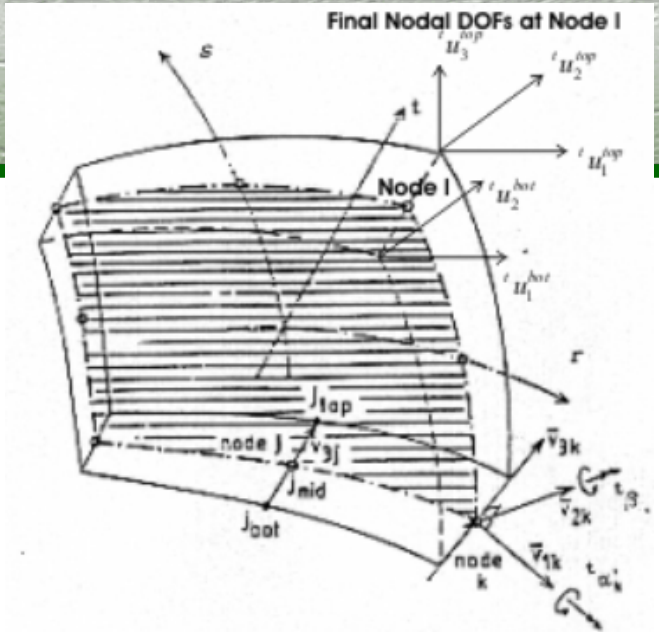




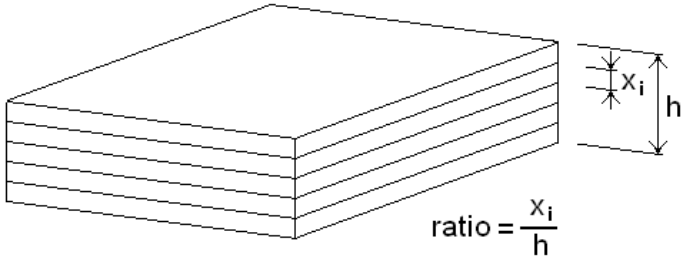
ATENA
3D shell element



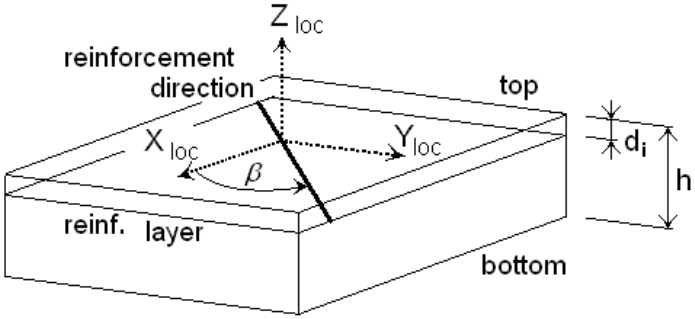
geometry



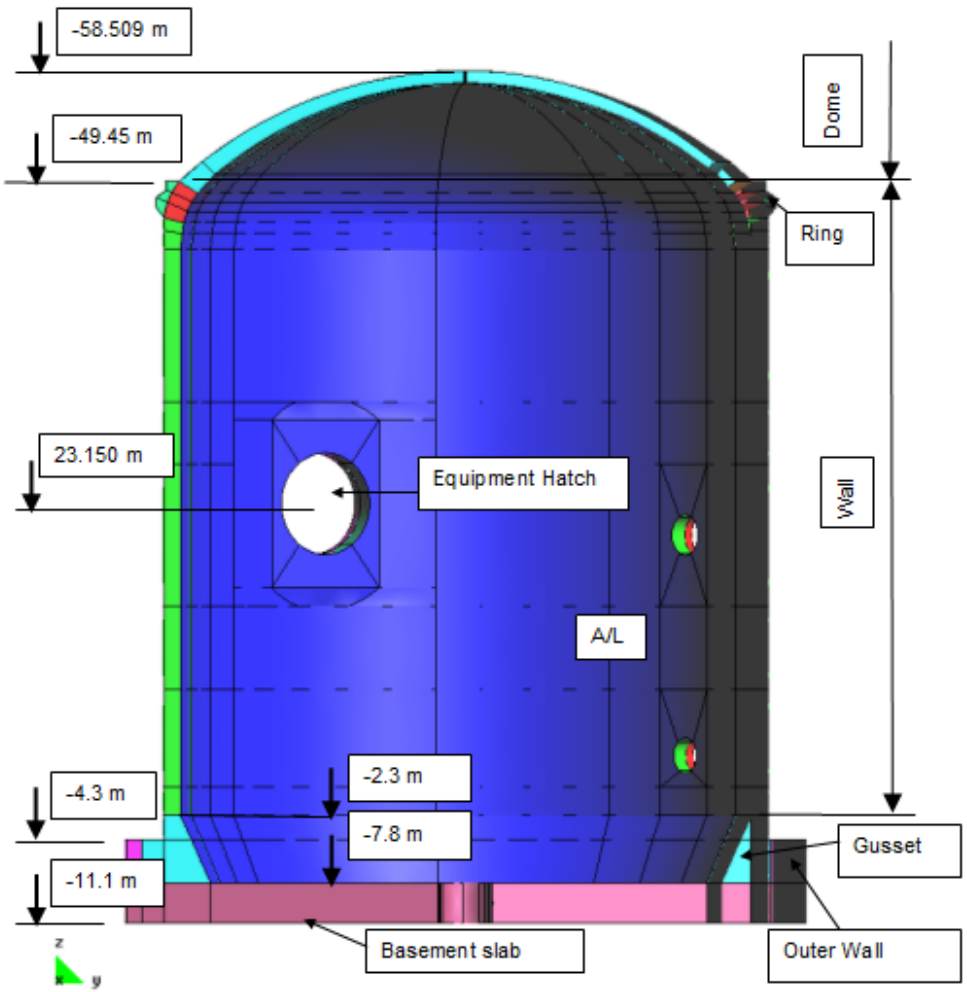
layers

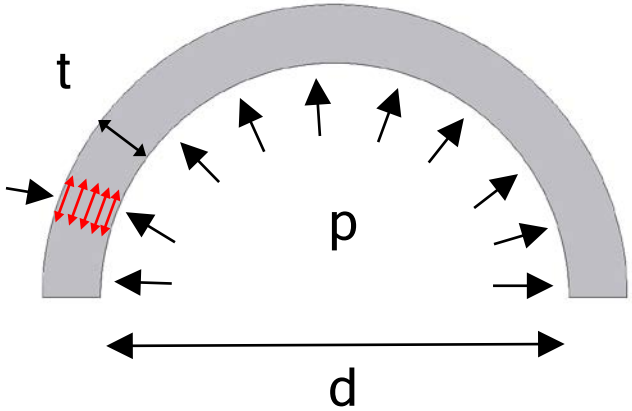


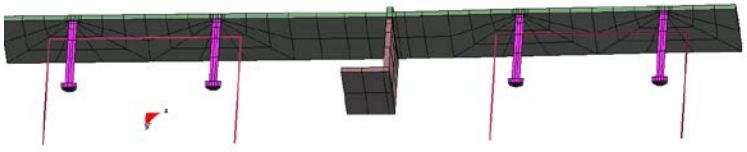
reinforcement

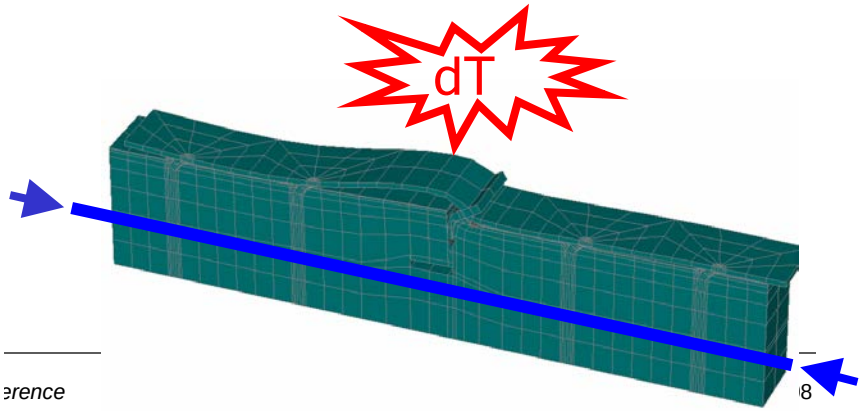


Containment safety during accidents
Liner anchorage verification

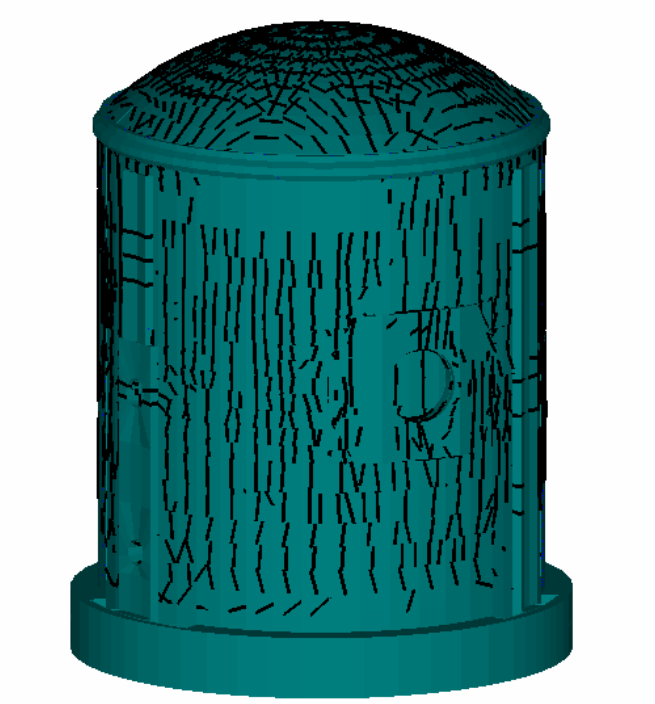


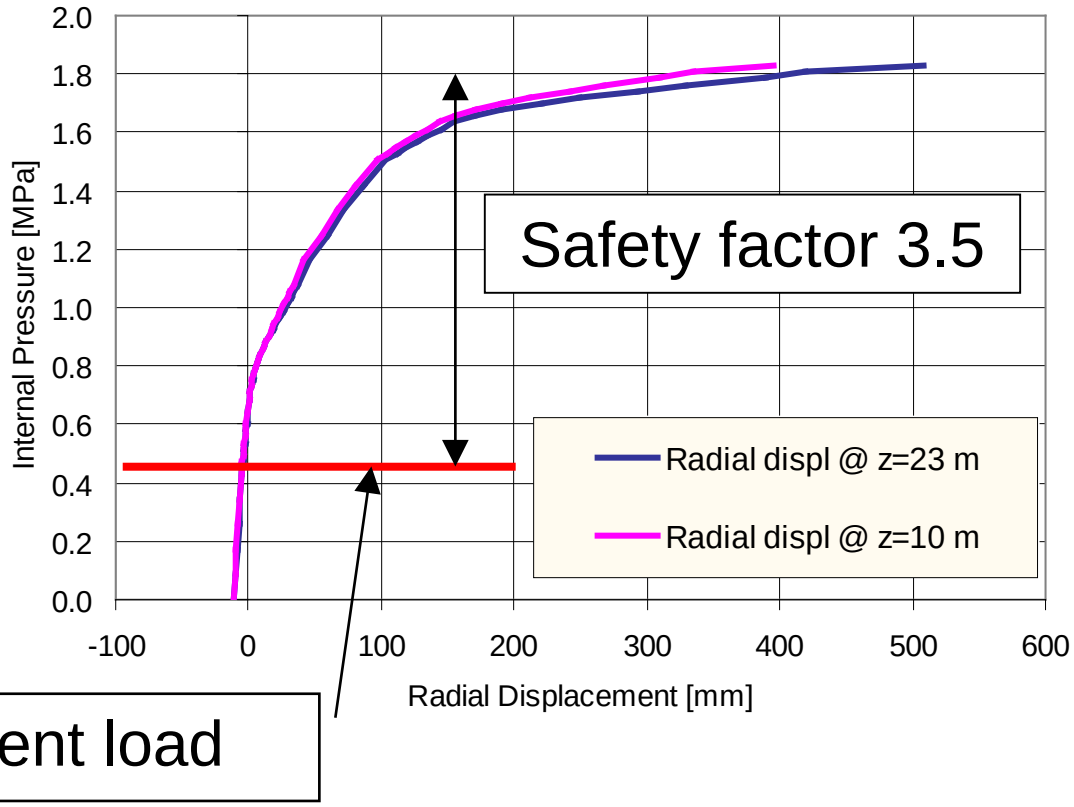




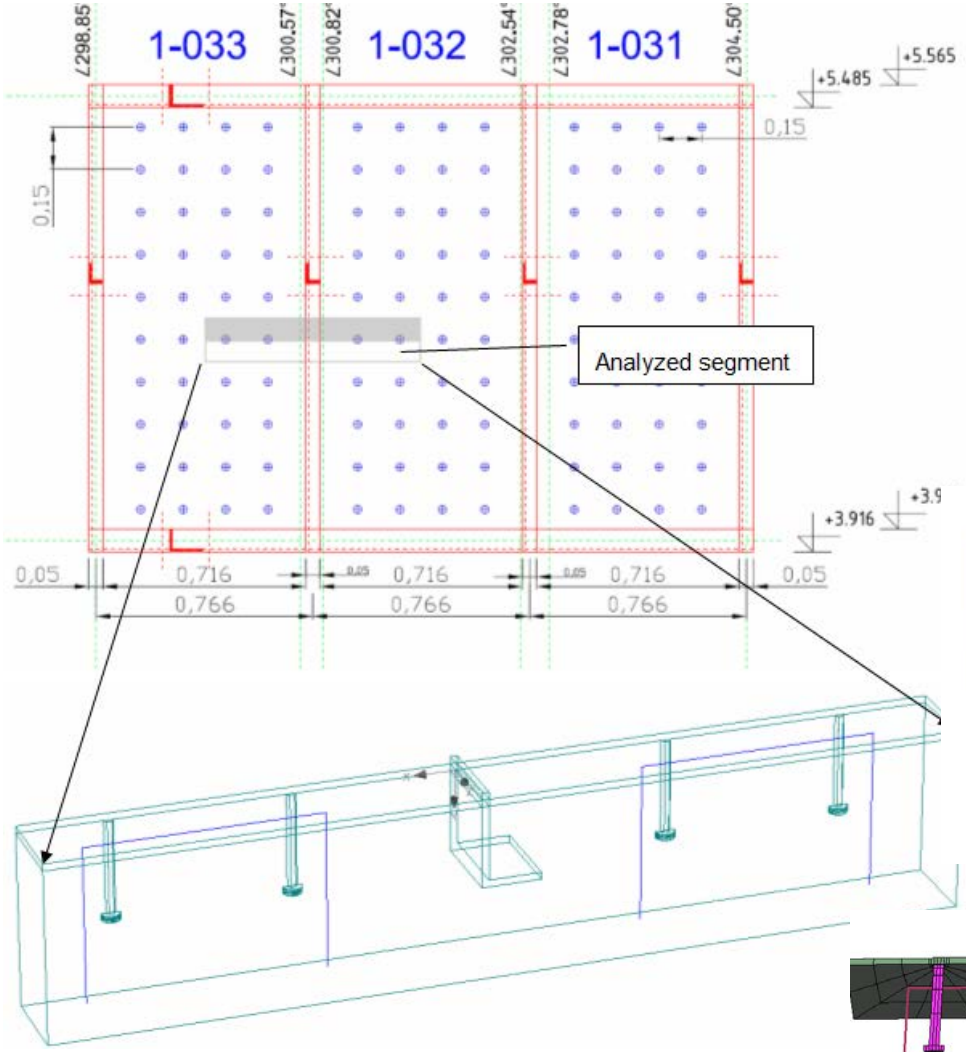


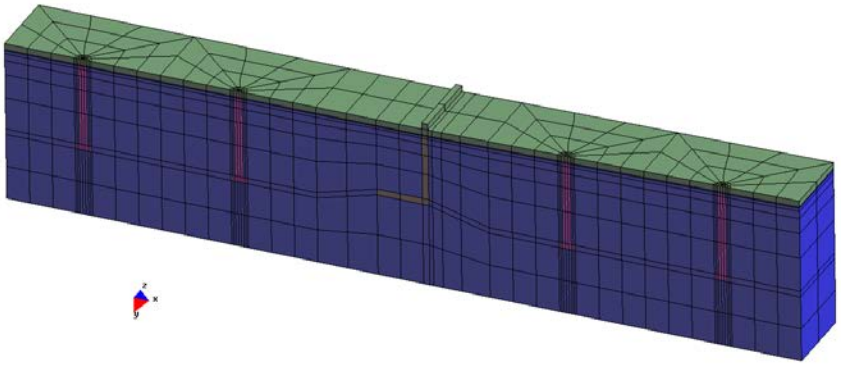
Simulation of Nuclear Containment Safety – Olkiluoto 3

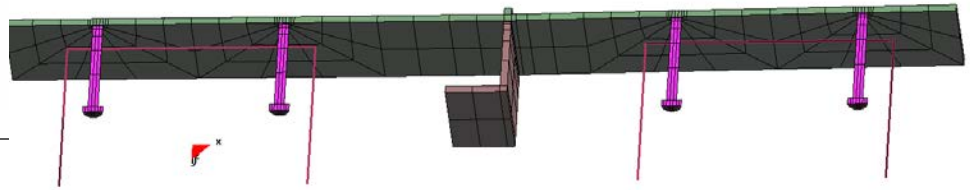




Liner Anchoring

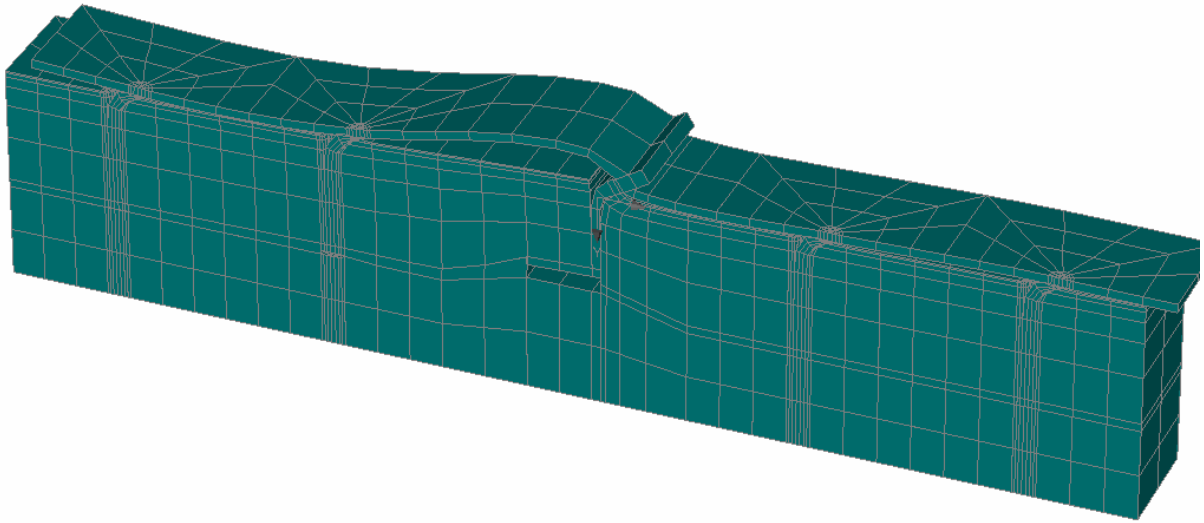


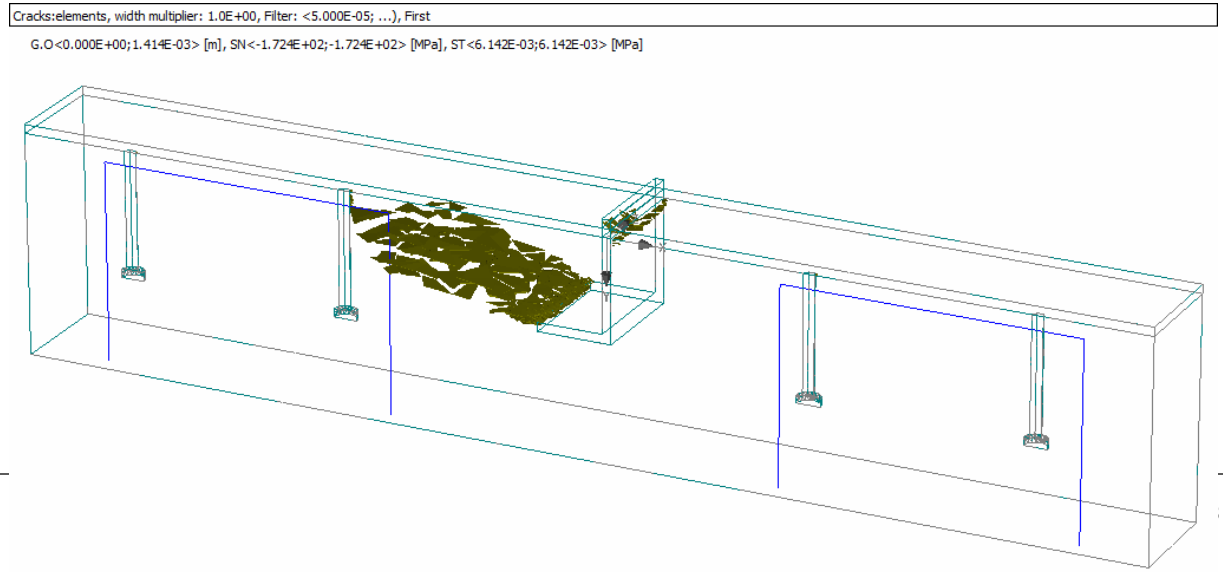




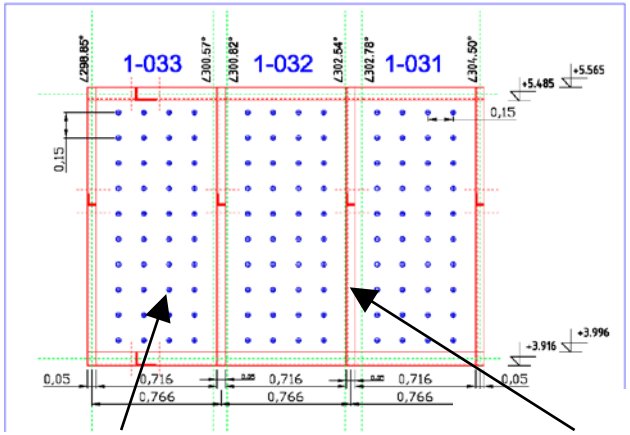
Steel liner anchoring verification

by computer simulation

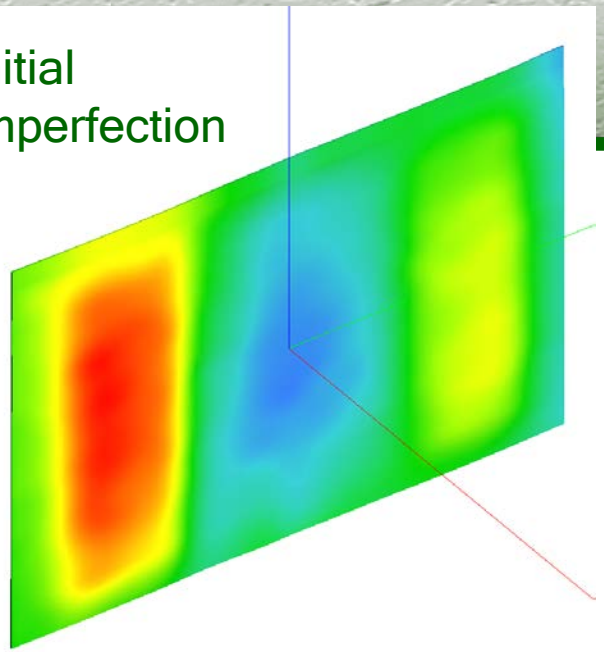




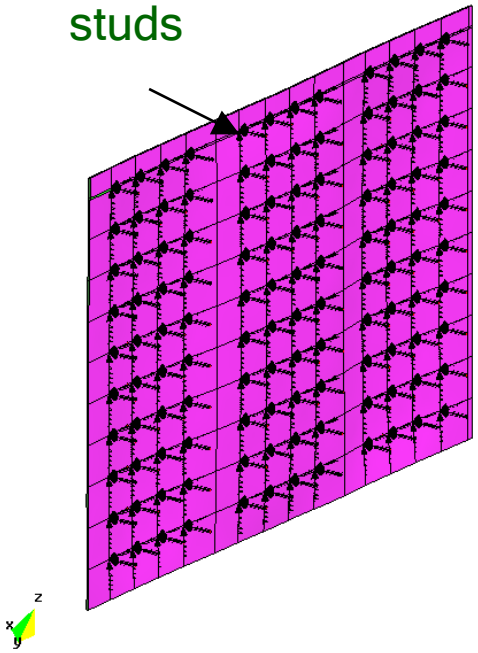
Liner buckling due to LOCA - Olkiuoto



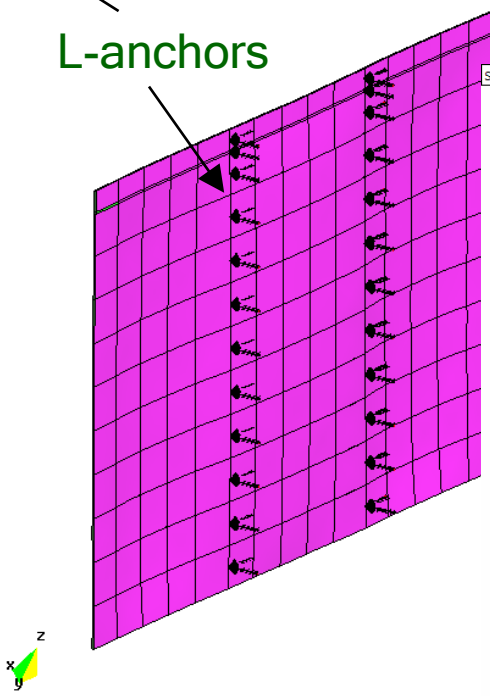
initial imperfection



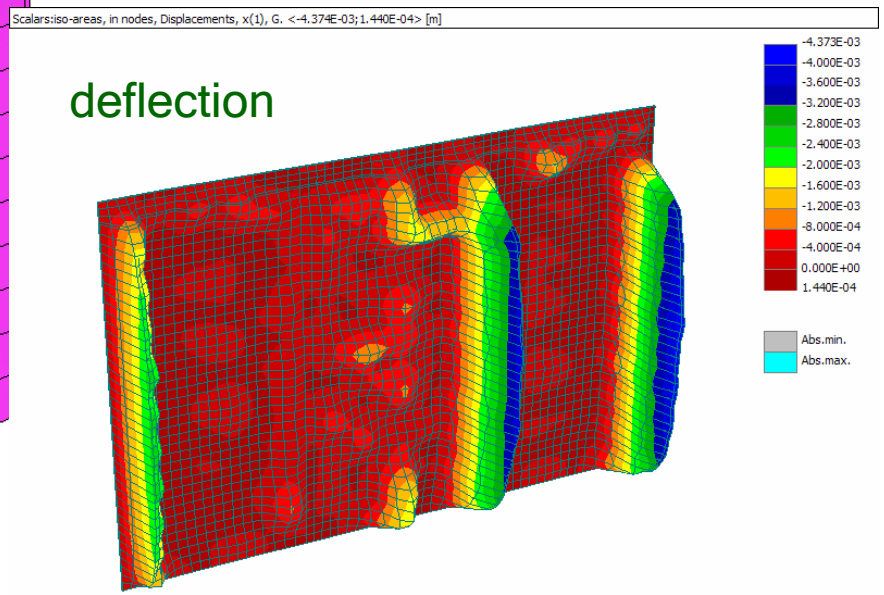
studs



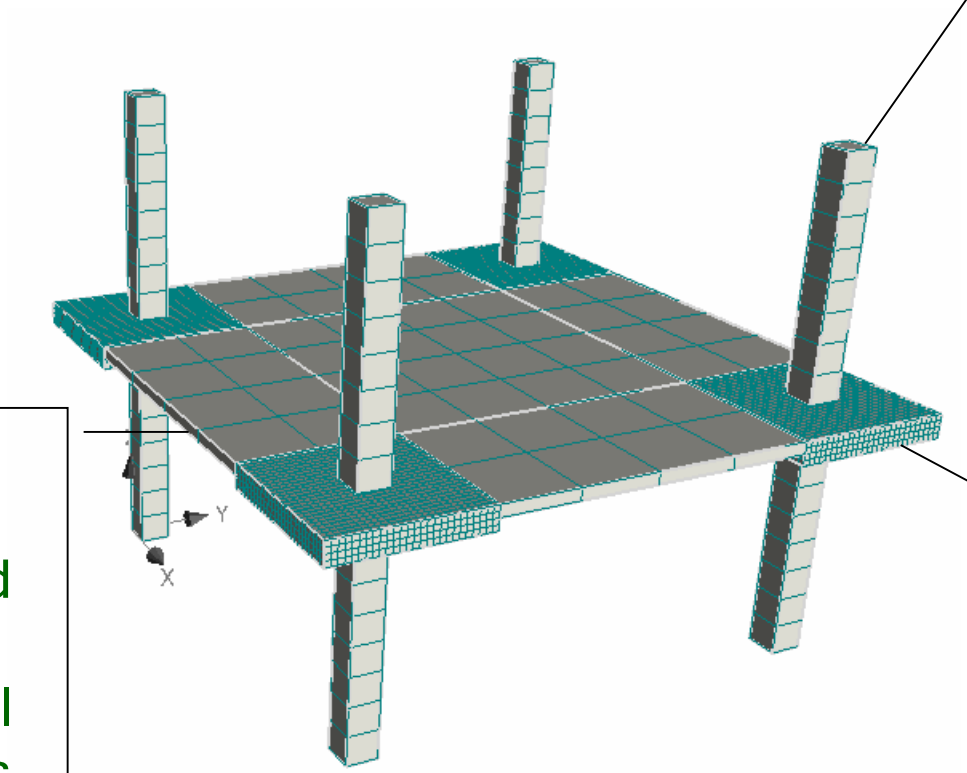
L-anchors



deflection



Advanced features in ATENA modeling
Large scale structures



Columns bending failure expected

Use beam elements with fibres

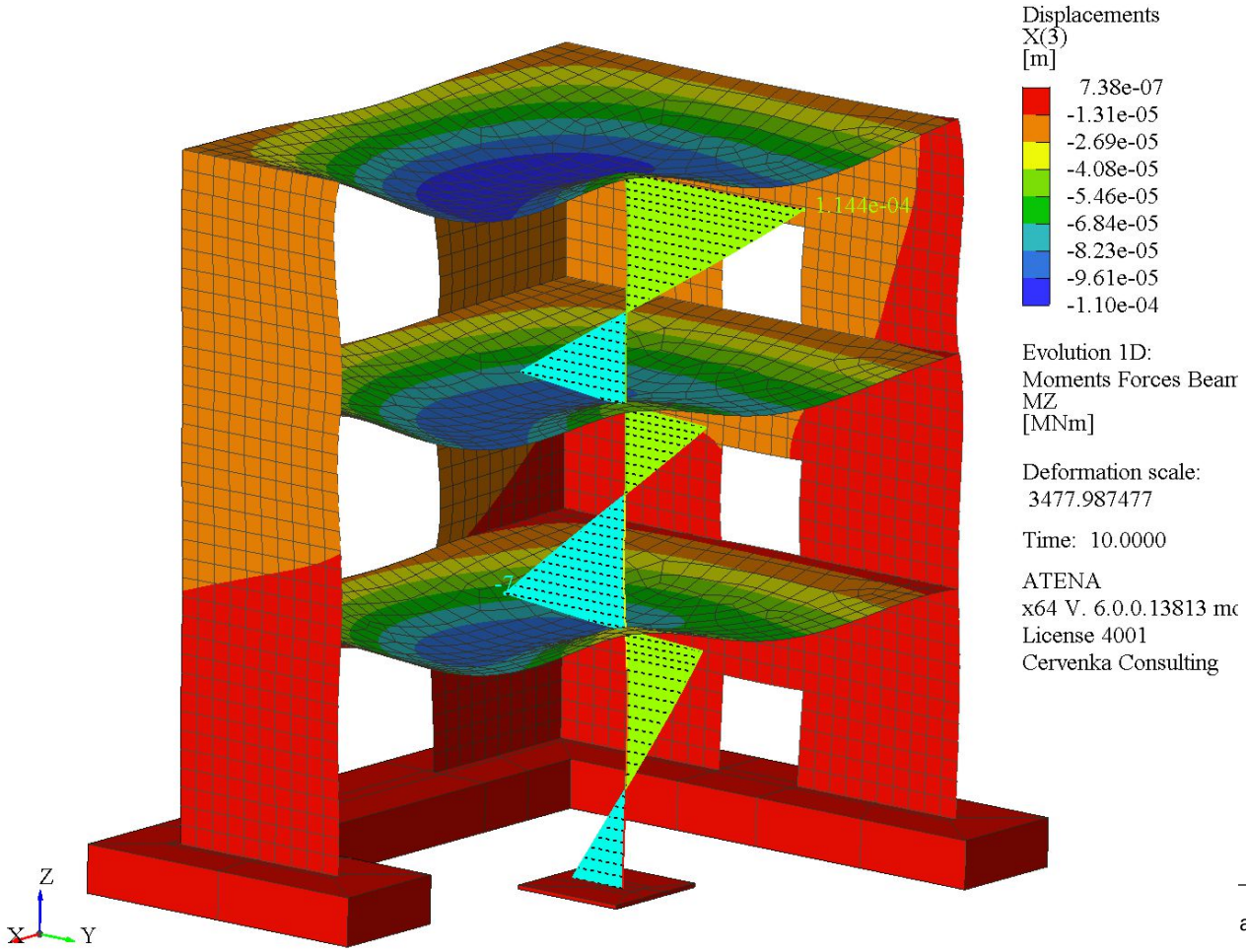
Bending failure expected

Use shell elements

Shear + bending failure

Use solid elements

Advanced features in ATENA modeling
Large scale structures, new 1D beams and 2D shells



SEISMIC ASSESSMENT OF NPP BEZNAU

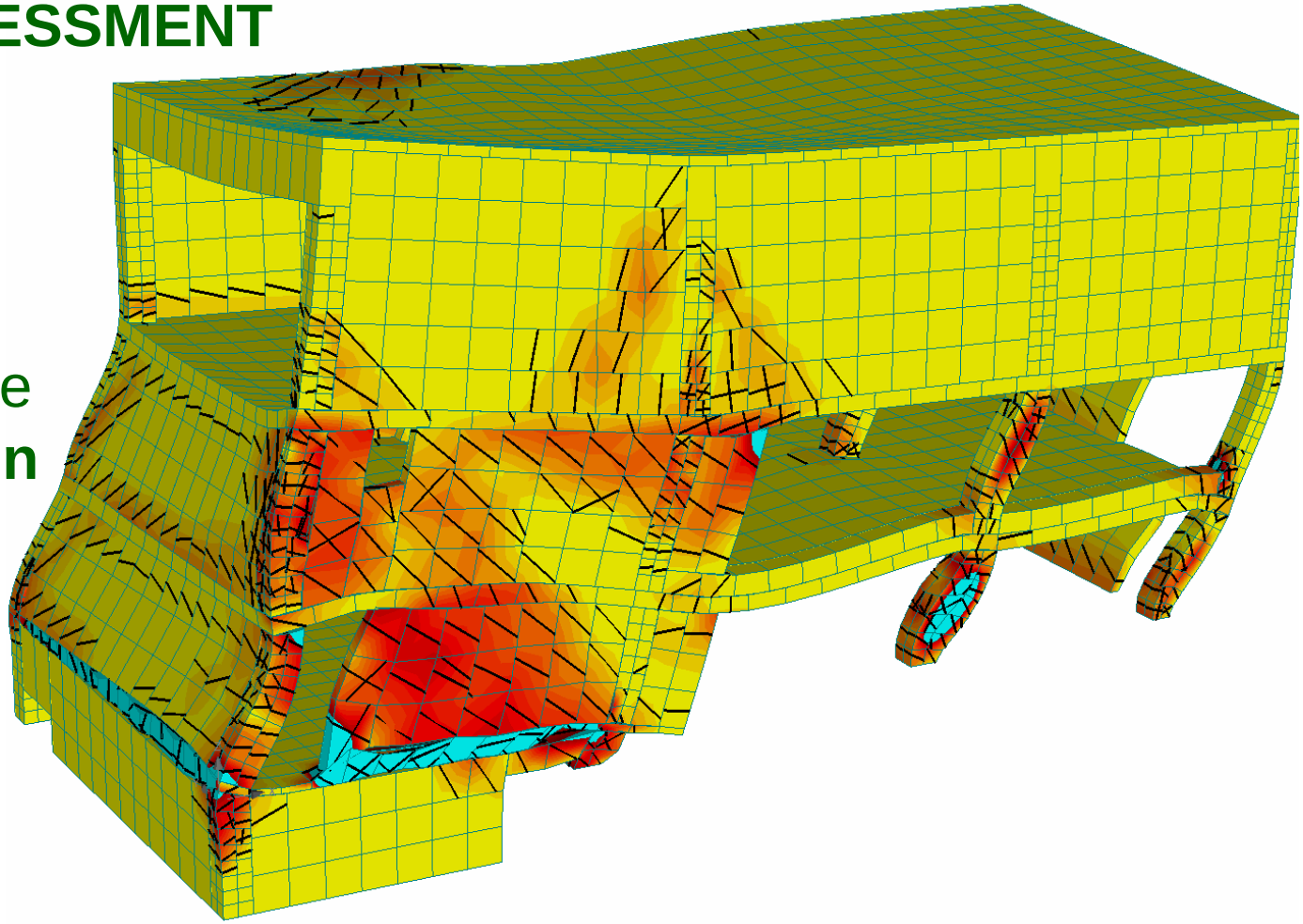
April 2012:

"European Nuclear Safety Regulators Group (ENSREG) accord special recognition to Switzerland's exceptional efforts in connection with the analysis of seismic hazards"

SEISMIC ASSESSMENT

NPP Beznau Switzerland:

deformed shape **and cracking in** pushover analysis



Concrete durability

Geometry
Dimensions
Reinforcement
Cover thickness

Material properties
Concrete (w/c)
Steel

Boundary conditions
Supports
Mechanical loads
Thermal loads
Prescribed displacements
Surface concentration

Initial conditions
Temperature
Concentration

Mechanical model

Stress, strain, damage

Load bearing capacity

Crack width

Chemo-mechanical model

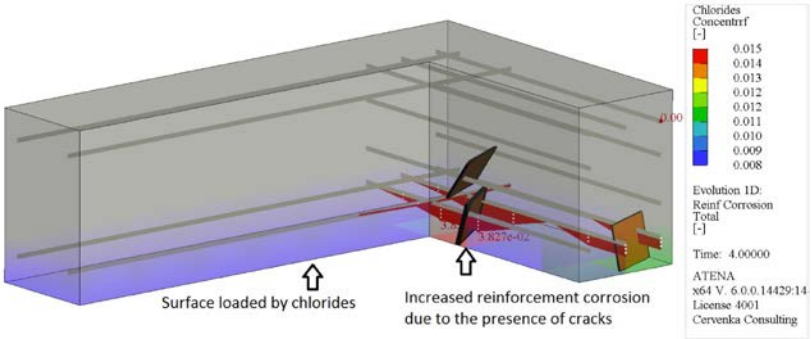
Cl transport for induction stage

Propagation stage

Induction time, cracking, spalling

Remaining reinforcement

Mechanical model



New features – durability and reinforcement corrosion

Nougawa bridge, Japan

Built 1930 in coastal area, stirrup's concrete cover 47

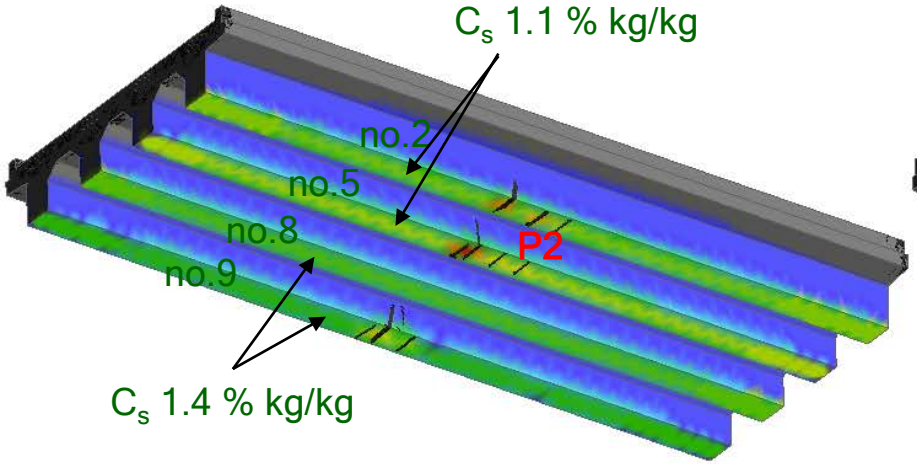
Reinforced beams, 3x4 spans @ 10.8 m = 131 m

Bars ø25.4 mm, stirrups ø9.5 mm

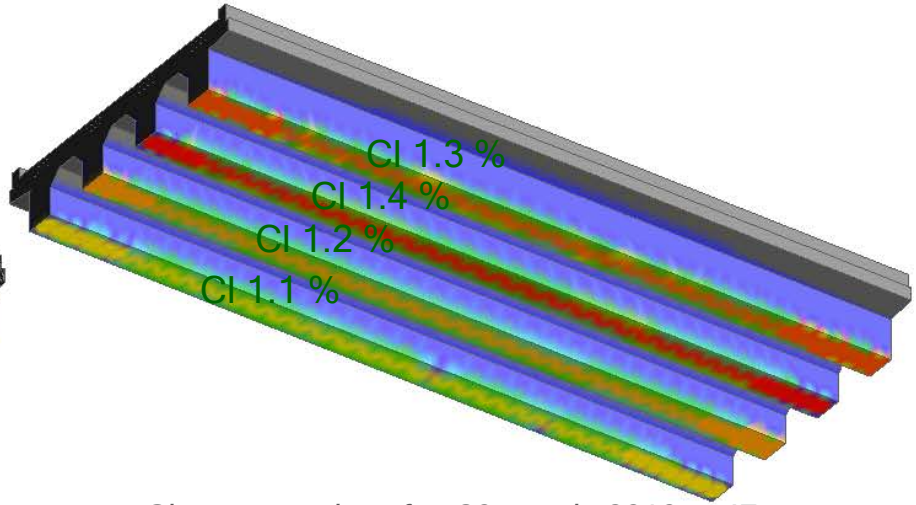
Cover restored in 1960, C_{crit}=0.4%

Two beams tested in 2009

Validated specimen, (Tanaka et al.)



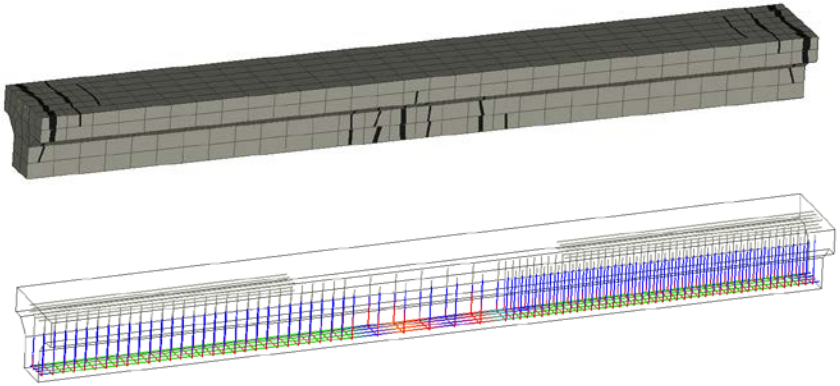
Cl concentration after 30 year in 1960 at 47 mm



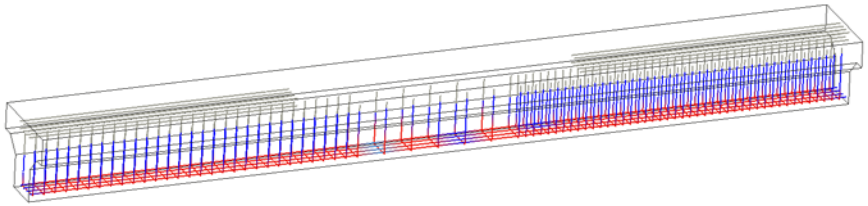
Cl concentration after 80 year in 2010 at 47 mm

Nougawa bridge, Japan

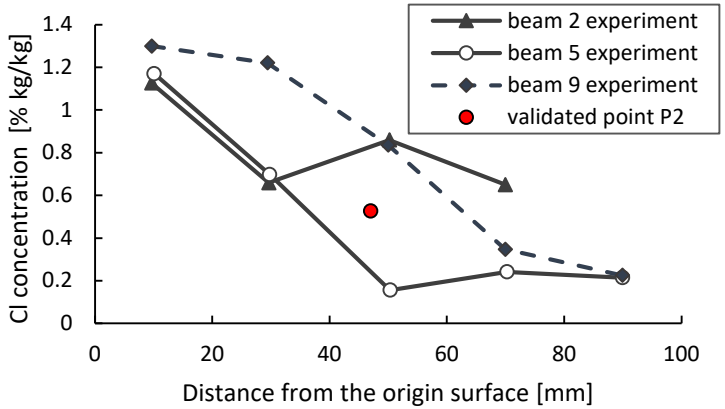
Predicted reinforcement area of 64% agrees well with the measured value of 62.5%

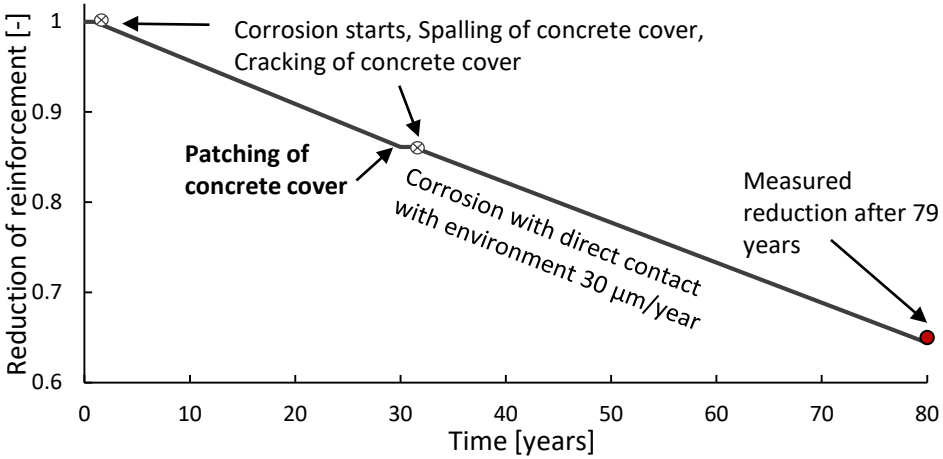


Reinforcement corrosion after 30 years in 1960



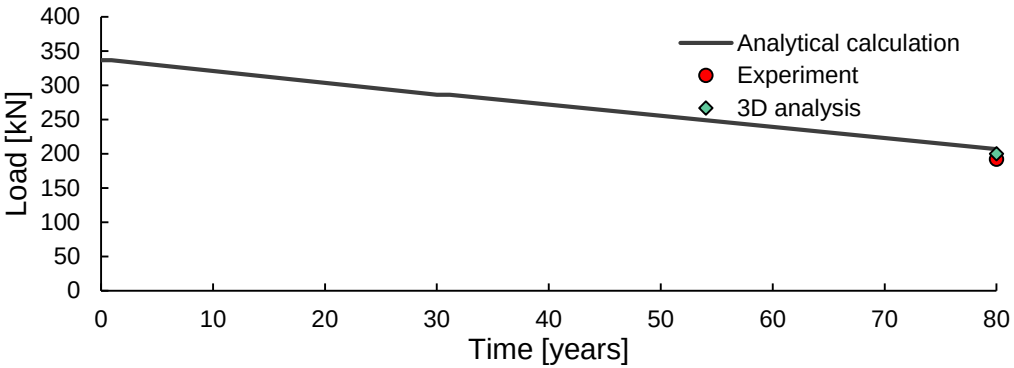
Reinforcement corrosion after 79 years in 2009

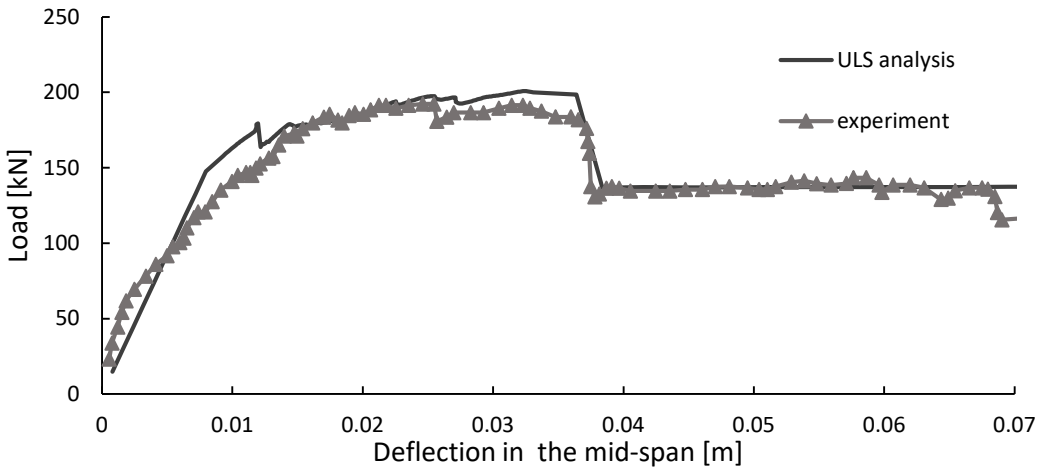


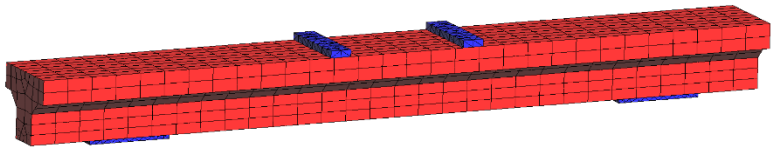


Nougawa bridge, Japan

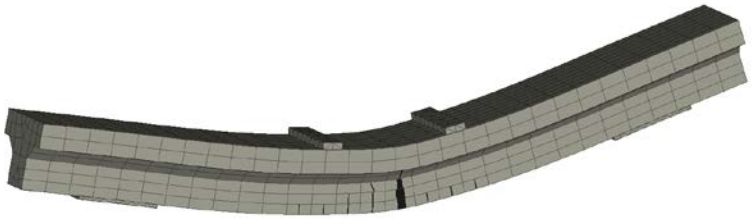
ULS analysis, 4 point bending @ 3+2+3 m



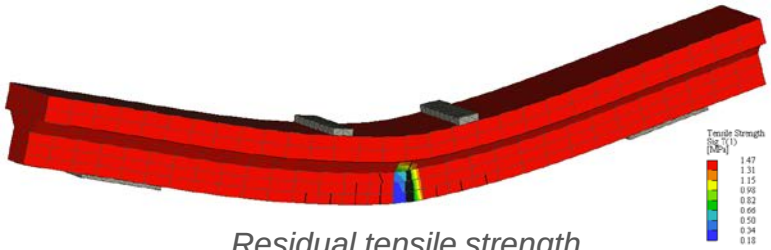




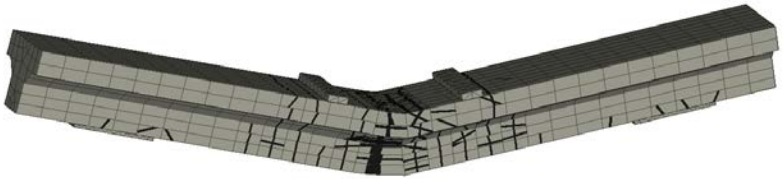
Loaded geometry of cut out beam specimen



Start of ULS analysis

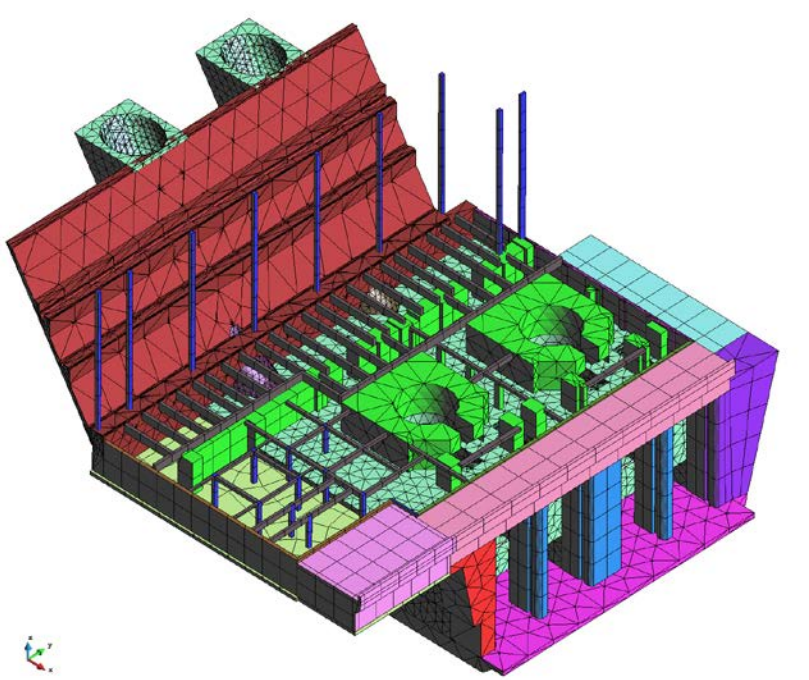


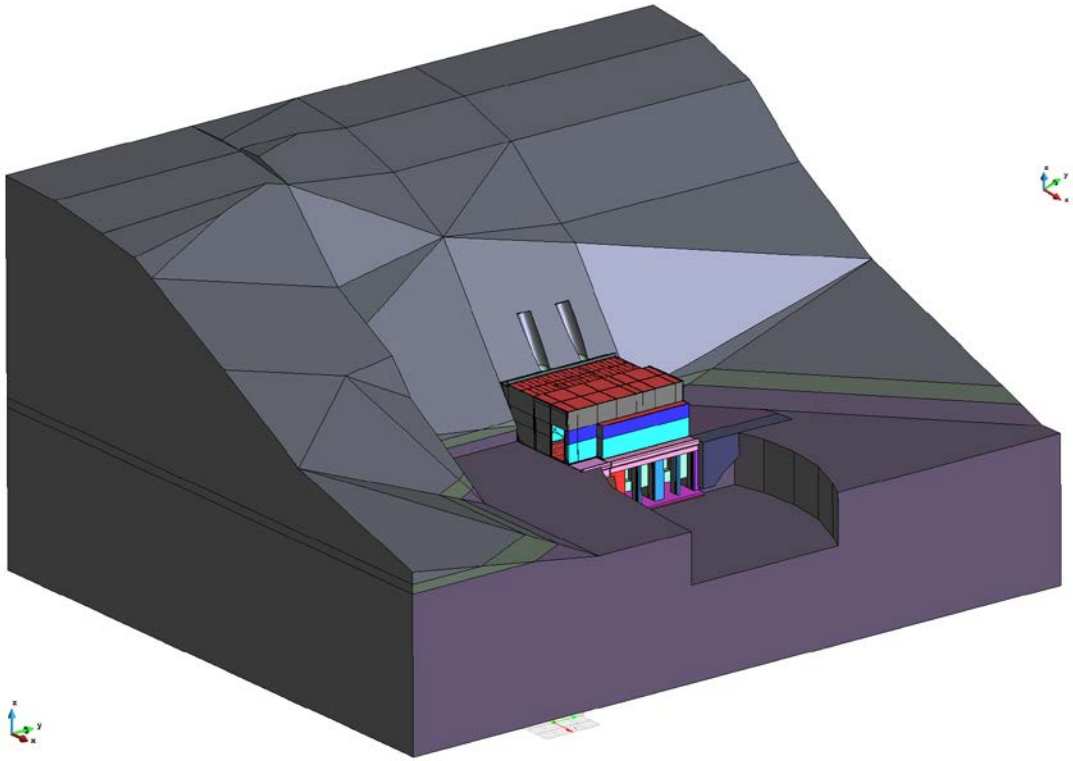
Residual tensile strength

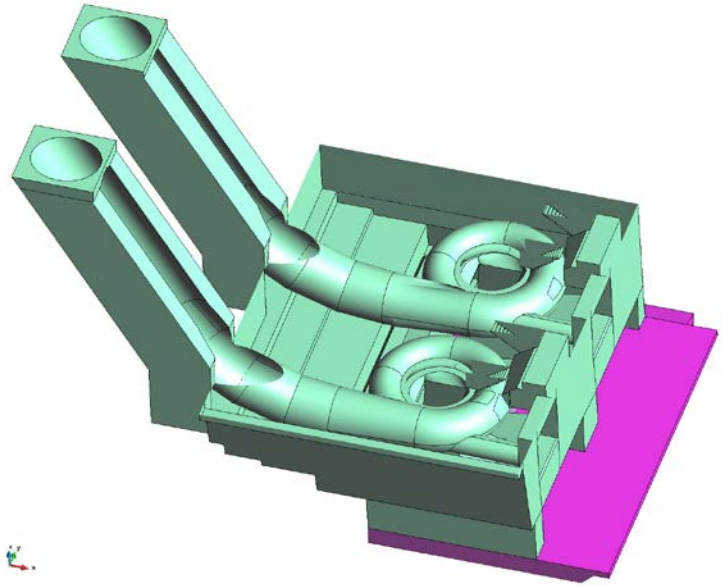


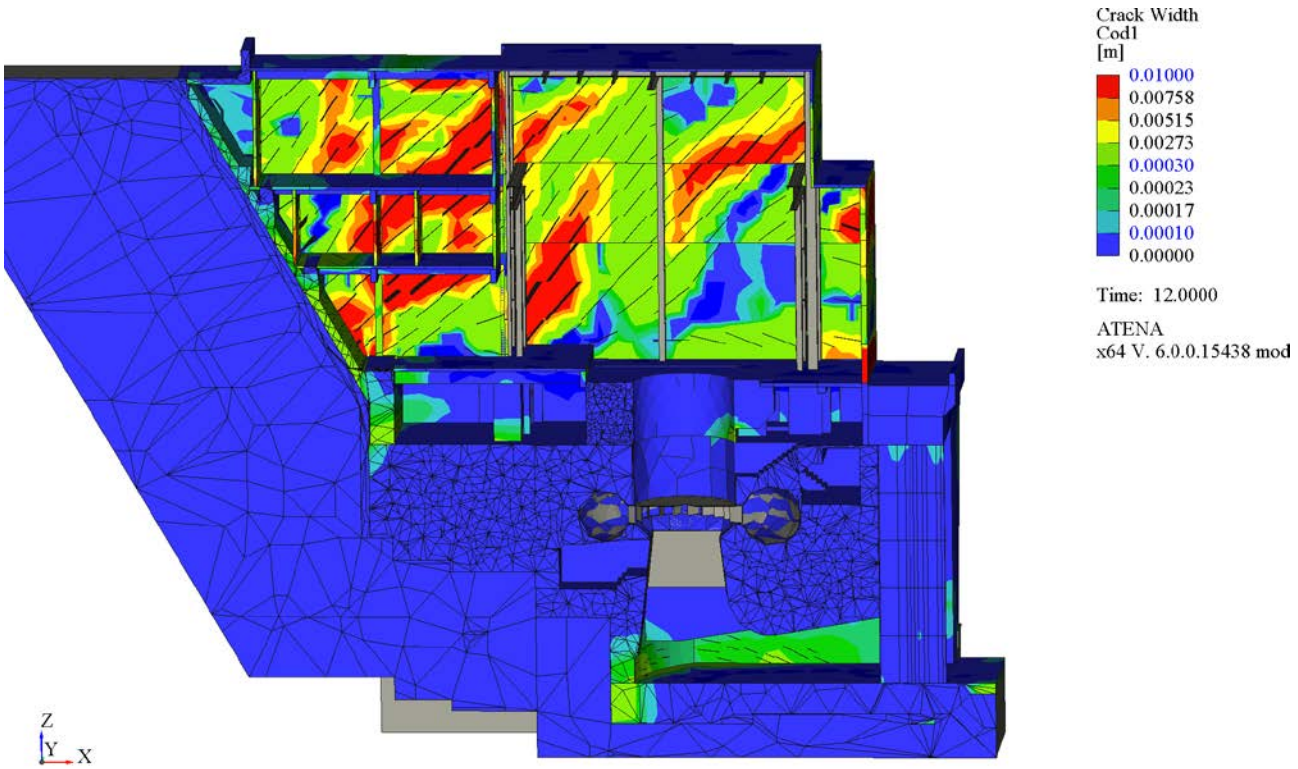
End of ULS analysis

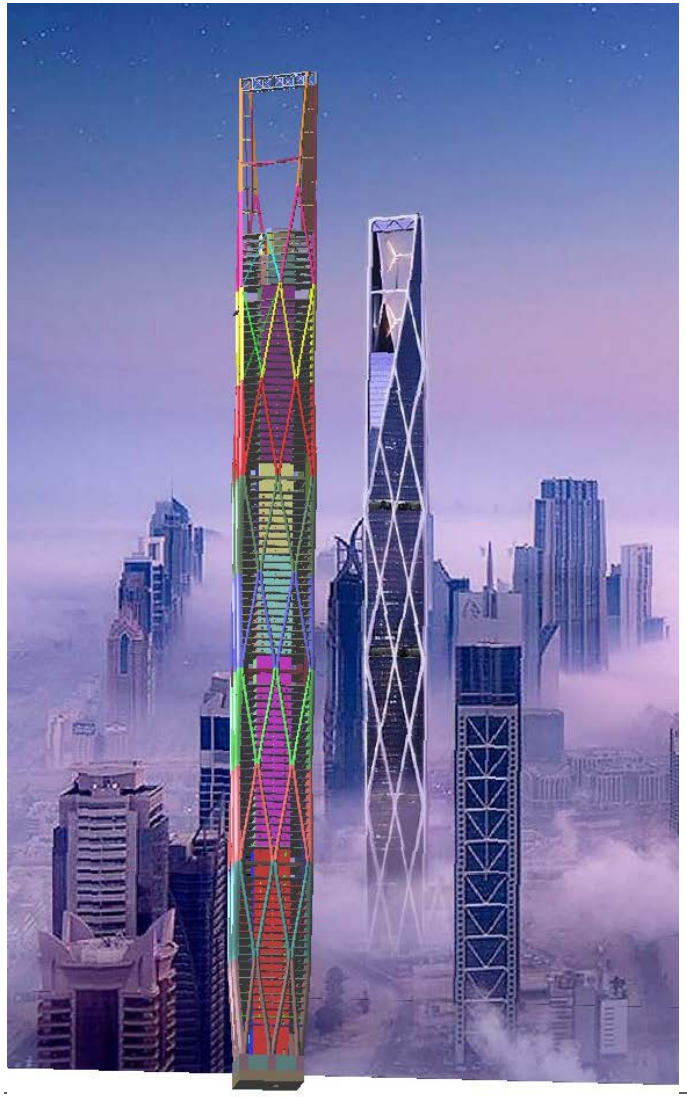
Powerhouse, Canada

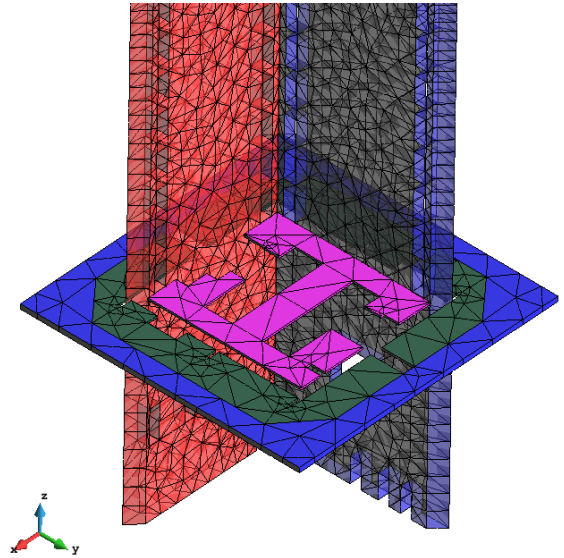


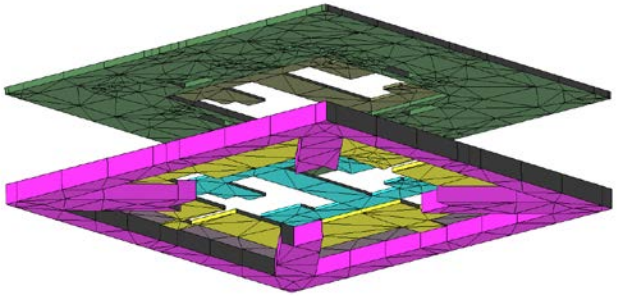


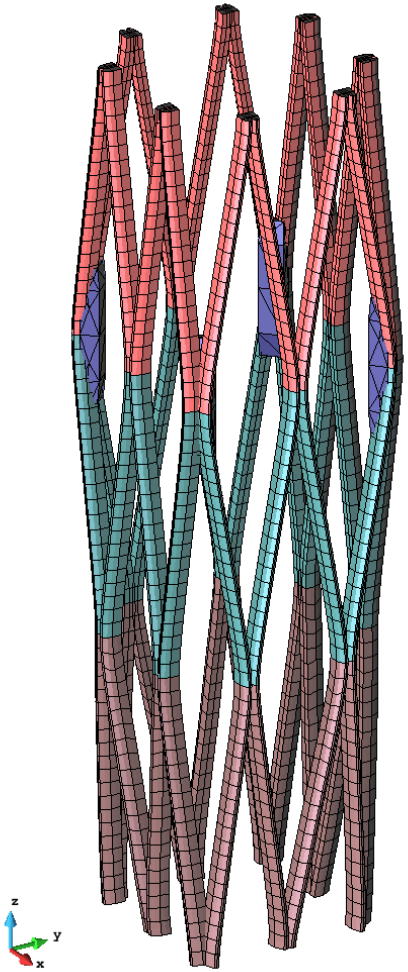



Crack Width
Cod1
[m]
0.01000
0.00758
0.00515
0.00273
0.00030
0.00023
0.00017
0.00010
0.00000
Time: 12.0000
ATENA
x64 V. 6.0.0.15438 mod
Z
Y
X

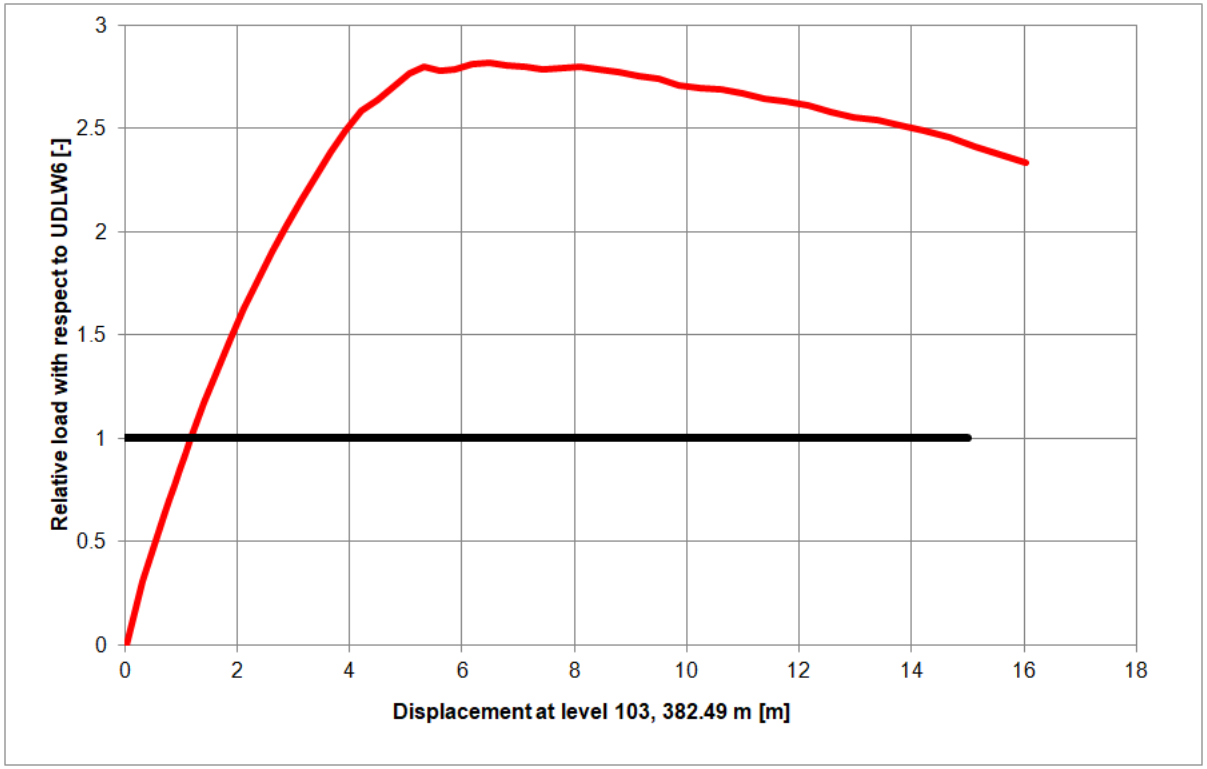


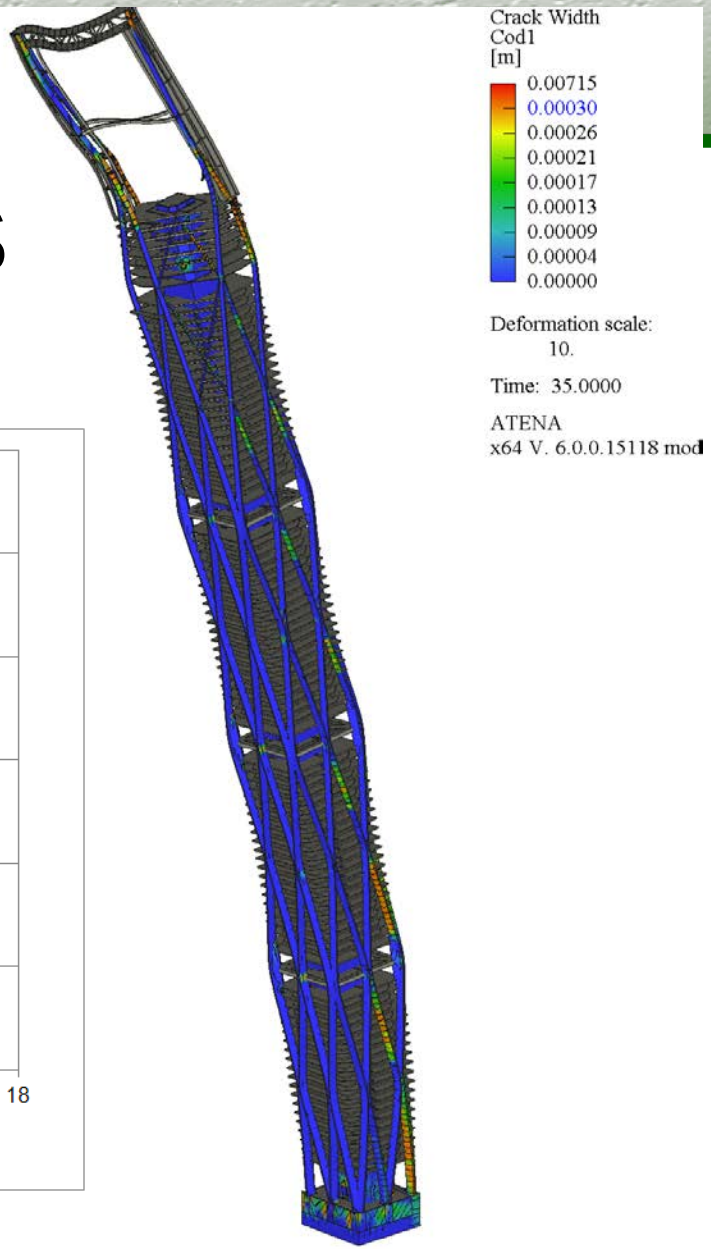

z
x
y




z
y
x

Global assessment of ULS





ATENA - GID Implementation Comments:

- GID showed to be very flexible - almost all reinforced concrete features were successfully implemented
- Instability when meshing complex and large problems. Slightly improved in newer versions
- Condition definition in intervals very time consuming, prone to error and difficult to check
- Template file *.bas combined with tcl was used to develop the interface
- GID postprocessor cannot show cracks so ATENA native postprocessor is still necessary

Thank you for your attention