Advanced Modelling of Reinforced Concrete Structures
Using ATENA Interface to GiD

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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 specialists

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

ETH Zurich, Prof. Marti 2006 – shear slabs

1st place

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

1st place

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

1st place

ATENA analysis by Dr. Joop den Uijl, Delft
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  $P_{\text{exp}} = 685 \text{kN}$  (Collins, M.P., Bentz, E. 2015)

ATENA simulation  $P_{\text{sim}} = 745 \text{kN}$
WEST

ATENA - winner of the contest

EAST
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
CASH Benchmark - ATENA cycled analysis

![Graph showing force vs. displacement comparison between experiment and model.](image-url)

- Force [MN]
- Displacement [mm]

- Experiment
- Model
Crack width > 0.1 mm

CASH Benchmark - cycled analysis
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

- Geometric model: reinforcement as line entities
- FE model:
Generalized Constraint Condition

Condition for nodal displacement

\[ u_R = \sum \alpha_i u_i \]

Coeff. \( \alpha \) equal to shape function values

\[ \alpha_i = h_i(r, s, t) \]

Natural coordinates \( r, s, t \) calculated from:

\[ X_R = \sum h_i(r, s, t) X_i \rightarrow r, s, t \]
Safety Assessment of Olkiluoto 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

ratio = \frac{x_i}{h}
Containment safety during accidents
Liner anchorage verification
Simulation of Nuclear Containment Safety – Olkiluoto 3

Accident load

Safety factor 3.5

Internal Pressure [MPa]

Radial Displacement [mm]

Radial displ @ z=23 m
Radial displ @ z=10 m
CERVENKA CONSULTING

May 8-9, 2008
GID Conference

Liner Anchoring

Analyzed segment
Steel liner anchoring verification by computer simulation
Liner buckling due to LOCA - Olkiuoto

- Studs
- L-anchors
- Deflection

Initial imperfection
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
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

**Chemomechanical model**
- Stress, strain, damage
- Load bearing capacity

**Cl transport for induction stage**
- Induction time, cracking, spalling
- Remaining reinforcement

**Propagation stage**
- 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, $C_{\text{crit}}=0.4\%$
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

![Graph showing chloride concentration and reduction of reinforcement over time](image)

- Corrosion starts, Spalling of concrete cover
- Cracking of concrete cover
- Patching of concrete cover
- Corrosion with direct contact with environment 30 μm/year
- Measured reduction after 79 years
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
Global assessment of ULS

![Graph showing relative load with respect to UDL/6 vs. displacement at level 103, 382.49 m.]

- Crack Width
  - Ced1 [m]
  - Values: 0.00715, 0.00030, 0.00026, 0.00021, 0.00017, 0.00013, 0.0001, 0.00009, 0.00004, 0.00001

- Deformation scale: 10
- Time: 35.0000
- ATENA x64 V. 6.0.0.15118 mod
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