Concrete foundations for pipes and turbines
FE modelling of complex 3D geometries in ZSoil

Rafal OBRZUD
GeoMod Ing. SA, Lausanne
robrzud@geomod.ch
Content

- **Pumped-storage power plant in the Valais Alps: Nant de Drance (CH)**
  
  **Client:** Alpiq, CFF-Energie et FMV
  
  **General contractor:** AF-Colenco
  
  **General project of cavernes:** BG Ingénieurs-Conseils SA

- **A new penstock in hydraulic power plant in Monthey (CH)**
  
  **Client:** CIMO (CH)
  
  **General project:** CETP (CH)
Nant de Drance: Pumped-storage power plant in the Valais Alps

Geneva lake

Valais

Martigny

Facts:
From ~2017:
6x150MW pump turbines

Machine cavern:
- Length = 184m
- Width = 32m
- Height = 52m
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland
Project Nant de Drance

3D view of the construction site

**Facts:**
Two 1.7km power tunnels and vertical wells of 2470m
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil

Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland

2D & 3D modeling of cavern excavation project presented during ZSoil Day 2011

Constitutive model and parametric studies

Application of mesh tying technique

FE discretization of the excavation stages
3D modeling for a concrete turbine support

Goals and requests:

Evaluation of stresses for reinforcement dimensioning

Including effects of:

- concrete shrinkage
- temperature changes
- different combination of static, hydraulic and pseudo-static loads
3D modeling: Preparatory phase

Generation 3D model with a CAD software
3D modeling: Generation of macromodel in separated files

Assembling macromodel components

If necessary, use of NODAL LINKS option in order to ensure continuity of displacements and temperature
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland

Final mesh for analysis of turbine support

Loads from upper part of the structure

Stage 4

Stage 3

Stage 2

Stage 1

B8-EAS15 (3D)
Continuum for structures elements were used
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland
Stator foundation and pseudo-static loads

Simulations included:

- Effect of *intrinsic shrinkage* and concrete cooling effect
- 10 different load combinations

Static (machine weight) and pseudo-static loads (functioning of machines) applied to:
- Rotor foundation
- Stator foundation

Hydraulic loads applied to:
- Turbine spiral
- Suction pipe
Steel spiral and hydraulic forces

- Steel spiral
- Steel rings
- Armoring
- Prestressed steel bolts
- Hydraulic pressure inside the spiral
Principal stress increment due to hydraulic pressure

Results averaging disabled speeds up model analysis
Principal stresses developed due to shrinkage of concrete

Filling concrete around the suction pipe

Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland
Shear stress due to pseudo-static loading

Stator foundation

Each element was analysed in terms of:
- Principal stresses
- Shear stresses
Goals:

Evaluation of stresses for reinforcement dimensioning

Evaluation of deformations of the new structure under full hydraulic loading and temperature variations
A new penstock in hydraulic power plant in Monthey

General view

Nouvelle usine électrique en 1910

Existing power station

Newly constructed penstock

Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland
A new penstock in hydraulic power plant in Monthey

Projected view

Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland
A new penstock in hydraulic power plant in Monthey

Longitudinal section
3D modeling: importing *.dxf file

finding the most complicated point in the model
Starting from generating subdomains around the most complicated point of the model is highly recommended.
3D modeling: Generating subdomains

Macromodel expanding with simultaneous virtual meshing
3D modeling: Generating subdomains

Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil

Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland

View from the top

- Junction
- Outflow 1
- Outflow 2
- Outflow 3
- « Small » channel
- Sluiceway

Small channel
Sluiceway
Outflow 1
Junction
Outflow 2
Outflow 3
Hypothèses: Maillage 3D du point fixe PF VII
Géométrie de PF VII et du voisinage fournis par le bureau CETP: «CETP_34_CIMO_PFVII-CENTRALE-CANAL FUITE.dwg»

1. Pipe - diameter [mm] Thickness [mm]
   1 – 1500/1600 20
   2 – 1500/1800 20
   3 – 1800/1350 20
   4 – 1800/1200 20
   5 – 1350/1200 14
   6 – 1200 14
   7 – 1200 14
   8 – 1200 14
   10 – 1200/1000 14
   11 – 1000 14
   13 reinforcement 70

Steel: E= 200GPa, v = 0.3
Concrete foundations for pipes and turbines

– FE modelling of complex 3D geometries in ZSoil

Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland

Annexe 1.8

Hypothèses:

Maillage 3D du point fixe PF VII

Géométrie du système des interfaces

- Soil / Concrete $\phi=20^\circ$, $c=0$
- PFVII / Existing structure $\phi=40^\circ$, $c=0$
- Pipe / Concrete $\phi=40^\circ$, $c=0$
- Concrete / Soil $\phi=20^\circ$, $c=0$
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland

Hydraulic loads applied in the penstock

Hydraulic pipe specific weight

Stiffeners

Pressure due to closure of Valve 1
Pressure due to closure of valve 2
Pressure due to closure of valve 3 et 4

Deformed pipe under hydraulic pressure (amplified deformation 2000x)

Outlet

Chamber

Hydraulic pressure
Modeling stiffeners: Role of stiffeners

- to stiffen penstock in sensitive zones (bifurcations, changes of curvature)
- to prevent from relative movements between pipe and foundation

Stiffeners modeled with BEAM elems

LINK INTERFACE NODE option

Relative movements prevented
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland

Principal stresses $\sigma_1$ for combination of loads: all valves open
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland

Principal stresses $\sigma_1$ for combination of loads: all valves open
Principal stresses $\sigma_1$ for combination of loads: all valves open and $\Delta T = -10^\circ C$
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland

Principal stresses $\sigma_1$ for combination of loads: all valves open

Section F-F
Concrete foundations for pipes and turbines – FE modelling of complex 3D geometries in ZSoil
Rafal Obrzud, GeoMod SA
31.08.2012, Lausanne, Switzerland

Absolute displacements and deformations of foundation for combination of loads: all valves open

Possible gap
Thank you for your attention ...

GeoMod® 2012