On the modeling of industrial processes

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Industry

Processes

- Set-ups
- Tooling design

Products

- Mechanical properties
- Geometrical tolerances
- Integrity requirements

Technological windows

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The Methodology

Physical Problem

Mathematical Model
(PDE + BC + IC)

Numerical Model

Results verification and validation
Engineering Applications
1. Structural analysis
2. Metal forming
3. Heat transfer and metallurgical processes
4. Computational fluid mechanics
Structural Analysis
Collapse and post-collapse of pipelines (external pressure only)

Experimental results (solid line)
Finite element curve (line and symbols)

External pressure 1.26 kg/mm²
External pressure 1.19 kg/mm²
External pressure 1.20 kg/mm²

Photo of Pipe After Testing

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Structural Analysis

Collapse and post-collapse of pipelines (pressure-bend tests)

Exp. collapse pressure 52.3MPa

Applied external pressure 50.4MPa

Bending moment vs. Average bending strain

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Structural Analysis

Collapse and post-collapse of pipelines

Sample 4: Pressure vs. Volume

P_{eo, exp} = 3970 psi
P_{eo, FEA} = 3663 psi
(-7.7%)

P_{eo, exp} = 2390 psi
P_{eo, FEA} = 2310 psi
(-3.3%)

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Structural Analysis

Collapse and post-collapse of pipelines

![Graph showing internal volume variation and external pressure with strains in percentage]

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Structural Analysis
Collapse of corroded pipes (Repsol-Bolivia)

Angular position

24 elementos  78 elementos  24 elementos

415.5 mm  312 mm  415.5 mm

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Structural Analysis

Collapse of corroded pipes (Repsol-Bolivia)

External pressure (Mpa)

Displacement (mm)

- 97.91 MPa
- 81.84 MPa
- 81.55 MPa
- 69.77 MPa
- 69.18 MPa
- 57.39 MPa
- 56.49 MPa

Analyzed node

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Structural Analysis

Salt domes

\[ \sigma_v = \gamma \]

\[ \sigma_{h1} \]

\[ \sigma_{h2} \]

Structural Analysis  Creep parameters

MATERIAL PARAMETERS 1
Young Modulus=31000 MPa
Poisson's Modulus=0.25

\[ m = -3.27 \times 10^{-1} \text{ MPa}^{-1} \]
\[ k_1 = -2.54 \times 10^{-1} \text{ MPa}^{-1} \]
\[ k_2 = -2.67 \times 10^{-1} \text{ MPa}^{-1} \]
\[ \varepsilon_{\text{am}*} = 1.21 \times 10^8 \text{ MPa d} \]
\[ G_{\text{k}*} = 1.88 \times 10^5 \text{ MPa} \]
\[ E_{\text{k}*} = 4.98 \times 10^5 \text{ MPa d} \]

Creep Hardening: Strain Hardening

MATERIAL PARAMETERS 2
Young Modulus=31000 MPa
Poisson's Modulus=0.25

\[ m = -2.54 \times 10^{-1} \text{ MPa}^{-1} \]
\[ k_1 = -1.22 \times 10^{-1} \text{ MPa}^{-1} \]
\[ k_2 = -1.61 \times 10^{-1} \text{ MPa}^{-1} \]
\[ \varepsilon_{\text{am}*} = 1.21 \times 10^6 \text{ MPa d} \]
\[ G_{\text{k}*} = 8.0 \times 10^3 \text{ MPa} \]
\[ E_{\text{k}*} = 1.67 \times 10^4 \text{ MPa d} \]

Creep Hardening: Strain Hardening

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Structural Analysis

Design of casings through salt domes

pipe

cavity

p

a/2

F.E. mesh

Casing detail

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Structural Analysis

Design of casings through salt domes

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Structural Analysis

Jump-out of an API 8R connection

Equivalent plastic strains

Make-up

77.2 tons tensile load

83.6 tons tensile load

87.5 tons tensile load

91.9 tons tensile load

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Structural Analysis

Detail of the threads

Detail of the seal area

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When the dope pressure distribution determined in the full-scale test was included in the finite element model, the numerical results showed a very good agreement with the experimental ones.
Structural Analysis

OCTG Premium Connections

Cone-cone seal

Sphere-cone seal

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Structural Analysis

OCTG Premium Connections

Make Up

disp = 4.10 mm

disp = 5.77 mm

disp = 10.60 mm

disp = 16.60 mm

disp = 20.06 mm

disp = 31.91 mm

disp = 46.72 mm

disp = 52.65 mm

Equivalent Plastic Strain

10.5%
6.72%
4.29%
2.73%
1.74%
1.11%
0.71%
0.45%
Structural Analysis

OCTG Premium Connections

Curve load vs. displacement

disp = 4.6 mm

disp =49.7 mm

disp =64.5 mm

load [kg/rad]

displacement [mm]
Structural Analysis
OCTG Premium Connections

Fatigue analysis: Stress concentration factor

\[
SAF = \max \left[ \frac{\text{DPS}}{|| \text{DTS} ||} \right]
\]  
(for the whole cycle)

Where:
- DPS: Change in the maximum first principal stress
- ||DTS||: Absolute value of change in the average stress applied to the pipe wall

Min. Load = 130 Mpa
Max. Load = 220 Mpa
Structural Analysis

OCTG Premium Connections

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Structural Analysis
Sucker Rod Premium Connection

Detail of the threaded area

Detail of the threaded area

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Structural Analysis
Sucker Rod Premium Connection

Relative principal stresses
\[
\frac{T_{pi}}{T_y}
\]
(Ty = 59.77 kg/mm²)

Detail of the threaded area

Detail of the threaded area

API Design
Principal stress I

New Design
Principal Stress I

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Structural Analysis
Sucker Rod Premium Connection
Fatigue Tests Results

Goodman Diagram HS & D Grade Rods

- Smin (Ksi)
- Smax (Ksi)
- Min YS D Grade (Ksi)
- S allowable D Grade (Ksi)
- Min YS HS Grade (Ksi)
- S allowable HS Grade (Ksi)
- Smin (Ksi)

1" D PC Rods
7/8" D PC Rods
3/4" D PC Rods

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Structural Analysis
UOE pipe manufacturing process

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Structural Analysis

UOE: Process control and Properties assurance

16” OD x 0.5” WT X60
D/t=32

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Structural Analysis
Steam Assisted Gravity Drainage (SAGD)

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Structural Analysis

DrillFem

\[ \mu (\text{pipes/well}) = 0.0 \]

\[ \mu (\text{pipes/well}) = 0.1 \]

Comparison at the central cross section
Structural Analysis

DrillFem

Deviated Well - Data

ID well = 250.825 mm
Pipes MD= 720 mts

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Structural Analysis

DrillFem

Deviated Well - $\mu=0.3$

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Structural Analysis

Waterhammer

Waterhammer experiment. The valve is closed at t=0; the pipe dimensions are L=100m; ID=0.016m and OD=0.018m. Fluid: water (blue)
Structural Analysis

Waterhammer

Normalized pressure at the valve. Comparison of calculated and experimental results

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Non-miscible fluids test. The valve is opened at $t=0.02$; the water pipeline dimensions are $L=100\text{m}$; ID=$0.0893\text{m}$ and OD=$0.01143\text{m}$. Fluid: air (red), water (blue)
Structural Analysis

Waterhammer

Air mesh refinement results for the interface position
Metal Forming
Rolling Processes

Prediction of the evolution of roll temperature during rolling

Elasto-thermal expansion: prediction of thermal crown

Three dimensional rigid-plastic modeling of sheet deformation

Separating force
Roll deformation

Beam-enhanced model to predict bending and flattening of rolls

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On the modeling of industrial processes
Metal Forming

The Mannesmann piercing process
Metal Forming

The Mannesmann piercing process
Localization

(a) $\sigma_y = \sigma_0 \ (\alpha = 1.0)$

(b) $\sigma_y = \sigma_0 (1 + 1.536 \varepsilon) \ (\alpha = 1.0)$

(c) $\sigma_y = \sigma_0 (1 + 3.077 \varepsilon) \ (\alpha = 1.0)$
Localization

External pressure

Compression

Overtorque
Localization
Localization

Finite element modeling and mesh dependency

Equivalent Plastic Strain

External pressure

Compression

Overtorque

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Localization

Finite element modeling and mesh dependency

(a) Uniform extension

(b) Equivalent Plastic Strain

E=200GPa
\nu=0.3
\sigma_y=600MPa
E_t=0

Sym
Localization
Finite element modeling and mesh dependency

The width of the localized zone is forced to be in the elements size scale

Mesh dependent results

Special techniques need to be developed to solve this problem
Localization

Finite element modeling and mesh dependency
Localization
Finite element modeling and mesh dependency
Plasticity + Damage

Load - Displacement QMITC Localized

Load - Displacement QMITC
Heat transfer
Welding

HAZ
Liquid pool zone

Numerical values
Experimental values

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Heat transfer

CCAST System: Thermal model of the continuous casting process

We perform Inverse Analysis to determine the heat transfer coefficients

Slab continuous casting process

Round continuous casting process

CCAST - SIDERAR v3.0
CCAST - SIDOR v1.0

CCAST - SIDERCA v1.1
CCAST - DALMINE v1.0

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CFD

Free Flow Kinetic Hydropower Turbine

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CFD

Free Flow Kinetic Hydropower Turbine
CFD

Free Flow Kinetic Hydropower Turbine

Flow lines
CFD

Free Flow Kinetic Hydropower Turbine

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On the modeling of industrial processes
Dispersed two phase flow: liquid and gas

Photograph of the biphasic plume [ABC-88]

Velocity distribution Coanda effect

\[ z^* = 0.8 \]

[JB-88] Computac, [ABr-90], [MG-85], [SG-82]