Research activities overview

Grupo de Mecánica Computacional

Dpto. Mecánica de Medios Continuos

y Teoría de Estructuras

E.T.S. Ingenieros de Caminos, Canales y Puertos

Universidad Politécnica de Madrid

December 20, 2001

Presentation overview

- Universidad Politécnica de Madrid general information
- Basic research
- Teaching
- Engineering applications

Universidad Politécnica de Madrid

- 20 centres
- 10 long-term titles (**5**-6 years). Escuelas Técnicas Superiores.
- 10 short-term titles (2-**3** years). Escuelas Universitarias de Ingeniería Técnica.
- 45155 students (course 99/00).
- 1702 PhD students in 133 PhD programs.
- 130 new doctors (course 99/00).

E.T.S.Ingenieros de Caminos, Canales y Puertos

- 6 full-year courses
- 4 specializations:

  A.- Cimientos y estructuras (structures)

  B.- Transportes (transports)

  C.- Urbanismo y ordenación del territoriio (town planning)

  D.- Hidráulica y energética (hydraulics and energy generation)

- 3125 students
- 203 PhD students
- 16 new doctors (course 99/00)

Departamento de Mecánica de Medios Continuos y Teoría de Estructuras

- PhD program "Diseño avanzado de estructuras: fundamentos y aplicaciones" (Advanced structural design: basics and applications)
- 31 different subjects.
- 54 PhD students

Grupo de Mecánica Computacional

- Grade course: Mechanics (2° year).
- PhD courses:
  - Método de los elementos finitos (The finite element method)
  - Método de los elementos finitos para análisis no lineal (Non-linear finite element method)
  - Análisis sísmico de estructuras (Seismic analysis of structures)

People

- José M. Goicolea
- Felipe Gabaldón
- Ignacio Romero
- Juan Carlos García
- Francisco Martínez
- Juan José Arribas
- Javier Rodríguez
- Juan Antonio Navarro
- Francisco Calvo

Basic research

- Dynamic response of bridges for high speed trains
- Non-linear dynamics
- Mixed finite elements with assumed strains
- Contact/impact
- Finite elastoplasticity
- Strain localization and cracking in concrete
- Biomechanics: modellization of soft tissues.

Dynamic response of bridges for high speed trains

- Motivation: Dynamic nature of railway loads, design speeds of 350 km/h (AVE,TGV,...), new spanish code and international research (UIC, ERRI), resonant effects in real bridges in service.
- Dynamic factor; it does not take into account resonance effects, and applies only for speeds $v \leq 220$ km/h (EC-1 part 3).

Dynamic response of bridges for high speed trains (II)

- Mechanical models:
  - Travelling load models
  - Vehicle-bridge interaction models (detailed or simplified)
  - Track-deck interaction models
  - Other: ballast mast, soil interaction, etc.
- Resonance: for a simple supported beam, travelling load model with no interaction:

$$\frac{v}{f_0} = \frac{d}{i} \qquad i = 1, 2, \ldots$$

Non-linear dynamics

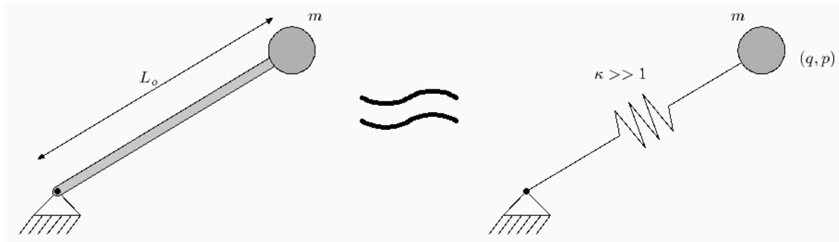
- Conservative and inconditionally dissipative integrators
- Objective formulation of non-linear beams and shells.
- Flexible multibody systems

Conservative and inconditionally dissipative integrators

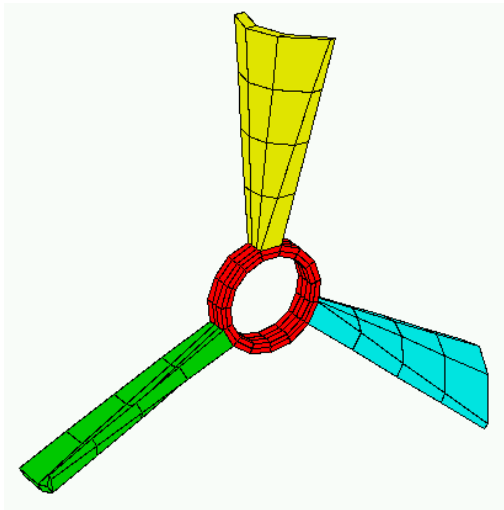
- Motivation: Movement invariants (energy, linear and angular momentum) and symmetry respect to rotations (relative equilibrium)
- Objective: To develop algorithms capable of performing a robust integration the non-linear elastodynamics equations, removing the high frequencies but respecting as much as possible the movement invariants, and avoiding any energy increase.
- Main result: momentum are exactly preserved and energy never increases. Controlled dissipation (particular case: null dissipation, energy-momentum method). Robustness.

Conservative and inconditionally dissipative integrators.
Examples.

- Particle



- Deformable 3D solid.



Objective formulation of non-linear beams and shells

- Motivation: when large rigid rotations are present, standard models introduce strain. Inestabilities usually introduced by abrupt energy increments associated with high frequencies.

- Purpose: exact objective (frame-invariant) formulation of beams ans shell experiencing large rotations and strains, conserving the movement invariants and avoiding any increase of energy.

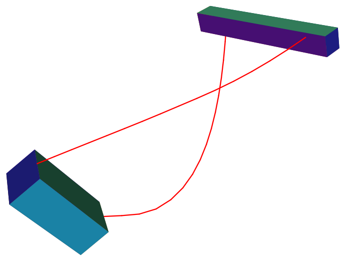
- Main result:objective and robust conserving integration, introducing controlled numerical dissipation.

Flexible multibody systems

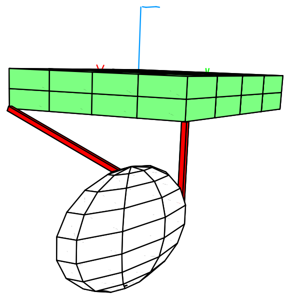
- Composed by rigid and deformable bodies connected by joints.
- Parametrization: inertial cartesian coordinates of selected points (rotation-free)
- Joints (constraints) imposed by penalty
- Deformable bodies subjected to large displacements and strains. Hyperelastic models.
- Energy-momentum method. Specific formulation of internal and constraint forces.

Flexible multibody systems. Examples.

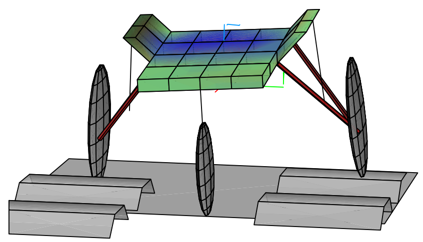
- Swing



- 3D Pendulum



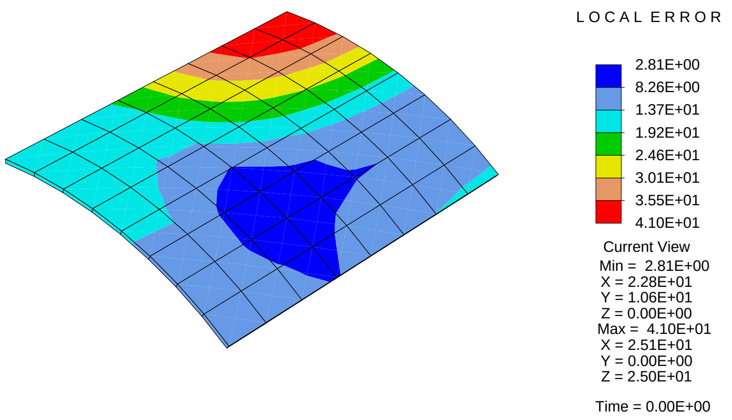
- Vehicle

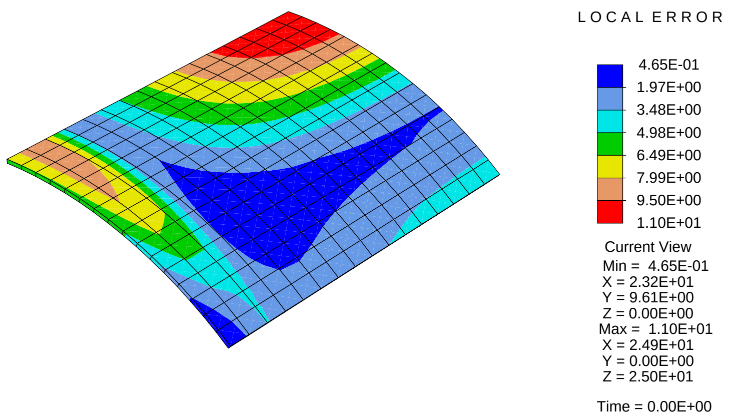


Mixed finite elements with assumed strains

- Applications: plasticity, localization, error estimation and modellization of thin structures.

- New error estimator based on the energy of the incompatible modes.





Modellization of thin structures

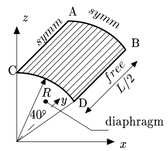


Figure 1. *Scordelis-Lo roof. Definition of the problem.*

Table I. *Results obtained with 3D enhanced elements and thick shell elements for Scordelis-Lo test*

N° of elements	v_B (solid elements)	v_B (shell elements)
$4 \times 4 \times 1$	0.1656	0.3132
$8 \times 8 \times 1$	0.2896	0.3031
$16 \times 16 \times 1$	0.3031	0.3016
$32 \times 32 \times 1$	0.3038	0.3016
$64 \times 64 \times 1$	0.3042	0.3018

shell element S4 from a commercial program element library [1]. The vertical displacement of point B computed with $16 \times 16 \times 1$ enhanced solid elements is $v_B = 0.3031$, very similar to the result $v_{\text{ref}} = 0.3024$ reported in the literature [13].

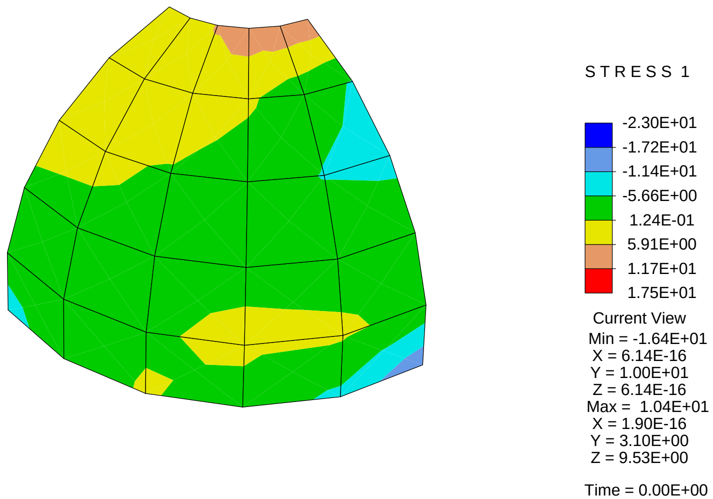
For error estimation the exact solution adopted here is obtained with a 24961 D.O.F. reference mesh, solved with enhanced assumed strain elements. The error estimation is analysed refining over the surface of the roof with only one element along the thickness, as well as refining through the thickness. The meshes considered for the first case are those referenced in table I. The meshes used for refinement along the thickness are $16 \times 16 \times 1$, $16 \times 16 \times 2$, $16 \times 16 \times 3$, $16 \times 16 \times 4$, $16 \times 16 \times 5$ and $16 \times 16 \times 10$.

Figure 2 shows the energy norm $\|\boldsymbol{u}_{\text{ref}}\|_E$ computed with the reference mesh, the energy norm computed with enhanced elements $\|\boldsymbol{u}_{\text{enh}}\|_E$, and the energy norm computed with standard displacement elements $\|\boldsymbol{u}_{\text{h}}\|_E$ versus the number of degrees of freedom, for refinement over the surface. The refinement across the thickness does not show a significant influence on the energy norm [7]. Figures 3 and 4 show the evolution of the global error estimated in terms of the number of degrees of freedom. The theoretical error is evaluated as the difference between the reference energy norm and the energy norm computed with standard elements.

In order to check the assesment of the key hypothesis (20) the rates of convergence m and p employed in the said hypothesis have been computed. The exponent m in $\|\boldsymbol{u} - \boldsymbol{u}_h\|_E = Ch^m$ is approximated via the difference of the reference mesh norm $\|\boldsymbol{u}_{\text{ref}}\|_E$ minus $\|\boldsymbol{u}_h\|_E$ and the exponent p in $\|\boldsymbol{u}_{\text{enh}} - \boldsymbol{u}_h\|_E = Ch^p$ is obtained directly from the finite element computation of the error estimator. Each value of m and p is obtained from the results of two meshes with parameters h_1 and h_2, and the assumption that C and the rate of convergence (m or p)

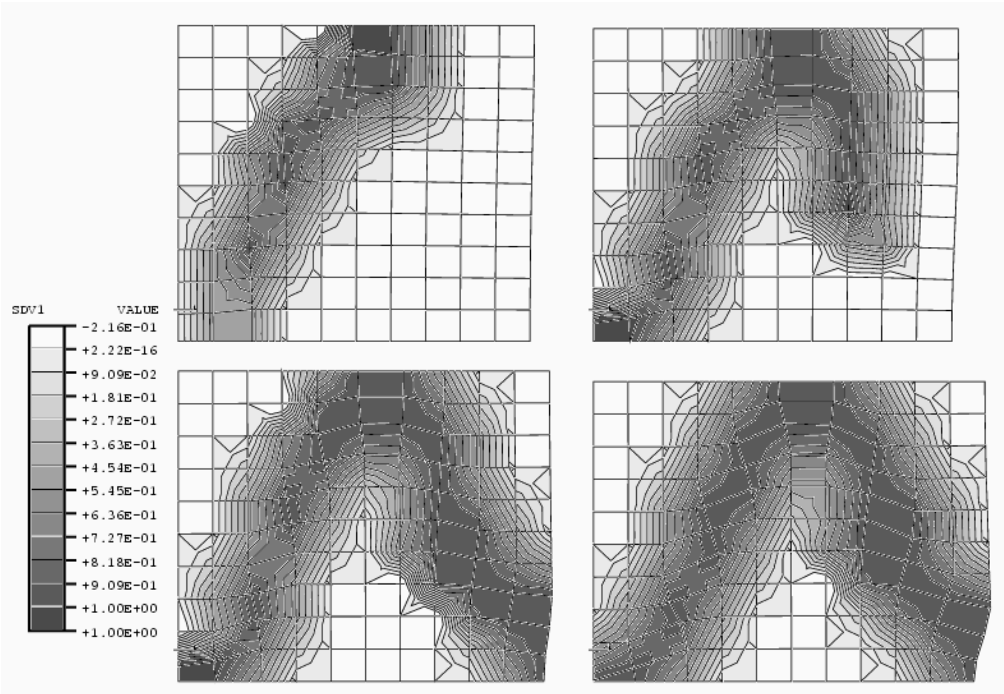
Copyright © 2000 John Wiley & Sons, Ltd.

Prepared using nmeauth.cls



Localization

- Localization: incompatible terms only affects the bending modes, and are energetically excited within the localization band.
- Applications: cracking of concrete (2-phase mixture)



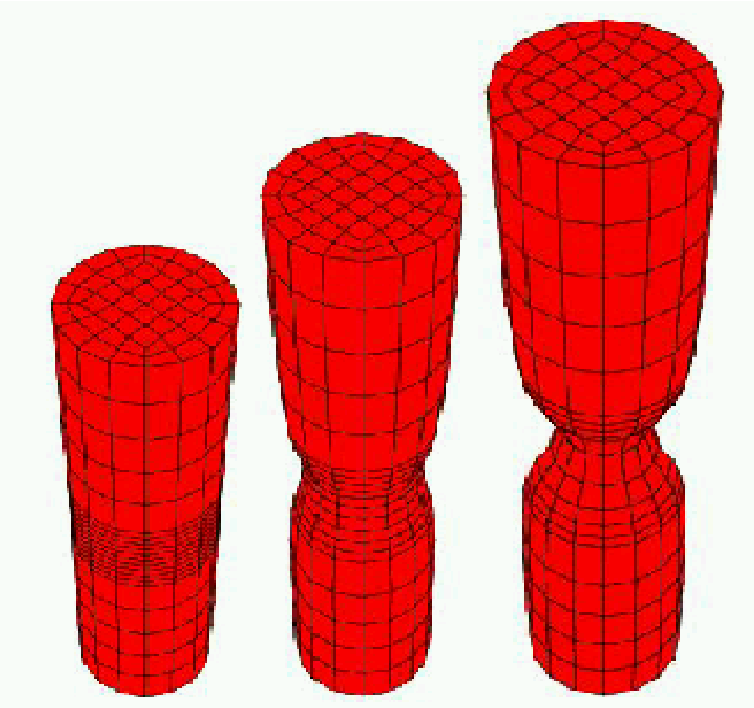
Finite elastoplasticity

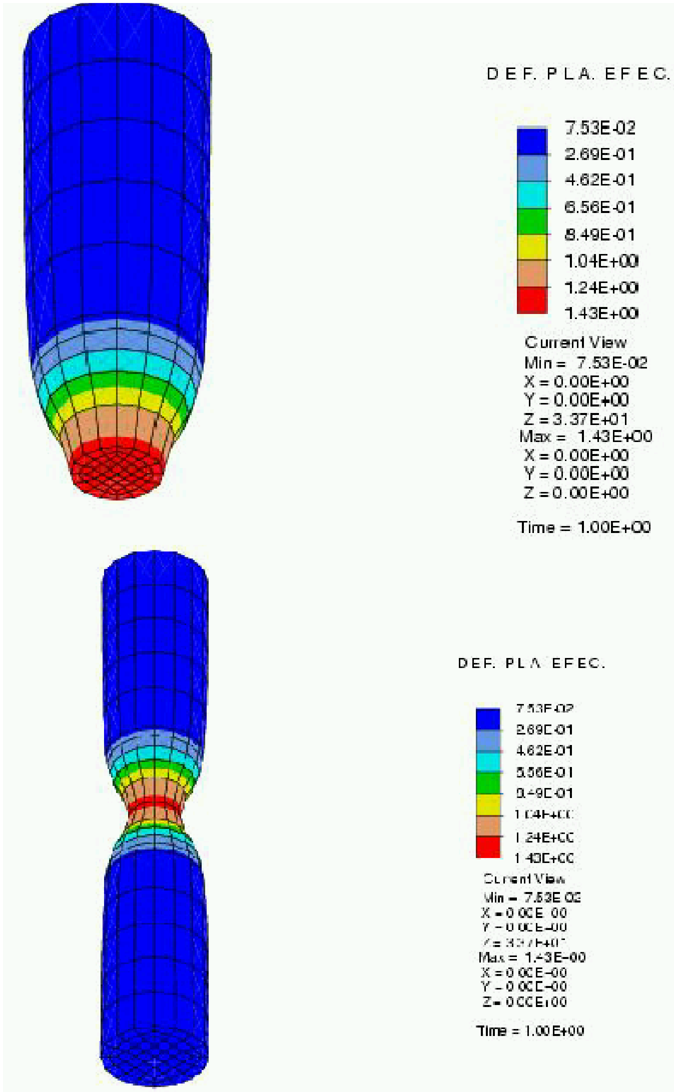
- Requirements:
  - Proper kinematical description of large strains
  - Robust algorithms for the integration of the plasticity equations
- Problems:
  - Blocking, zero-energy modes (hourglass), convergence, element distortion, objectivity (if large rotations).
- Hiperelastic model based on a multiplicative decomposition of the deformation gradient tensor

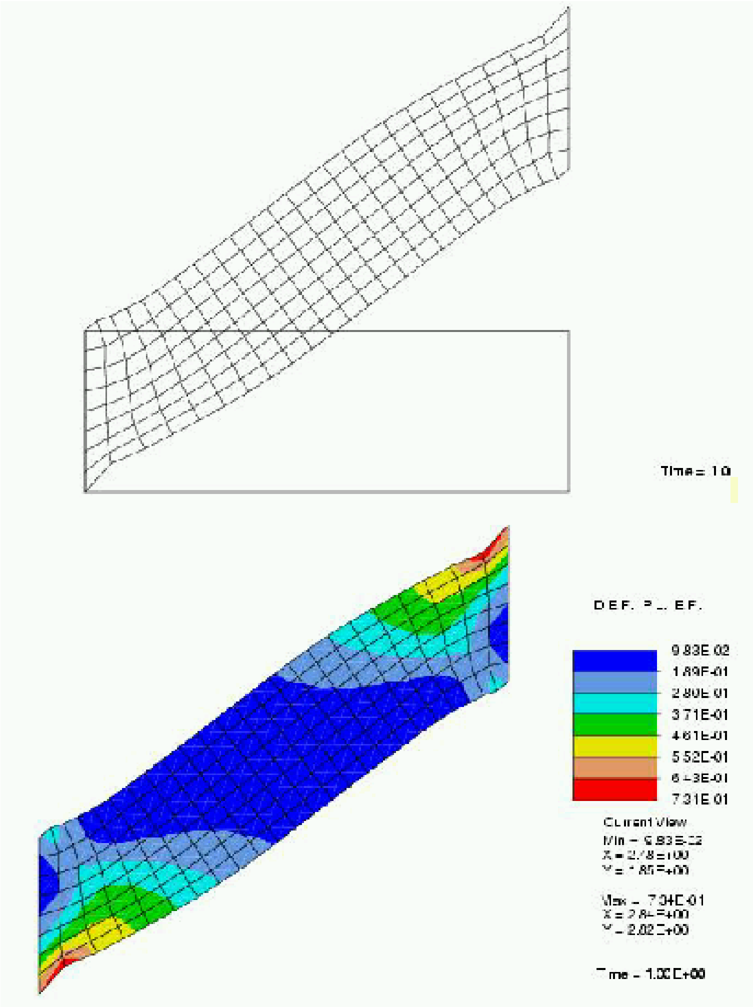
$$\boldsymbol{F} = \boldsymbol{F}^e \boldsymbol{F}^p$$

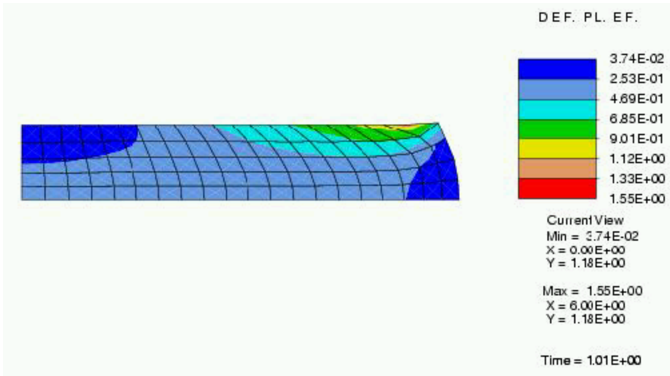
Finite elastoplasticity (II)
Some validations

- Tensile test in a bar
- Double sopported thick beam
- Disc upsetting.




DEF. PLA. EFEC.
7.53E-02
2.69E-01
4.62E-01
6.56E-01
8.49E-01
1.04E+00
1.24E+00
1.43E+00
Current View
Min = 7.53E-02
X = 0.00E+00
Y = 0.00E+00
Z = 3.37E+01
Max = 1.43E+00
X = 0.00E+00
Y = 0.00E+00
Z = 0.00E+00
Time = 1.00E+00
DEF. PLA. EFEC.
2.69E-01
4.62E-01
Time = 1.00E+00

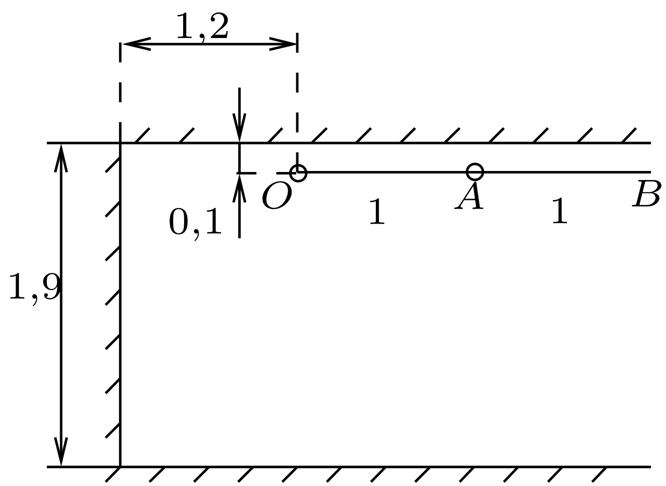

9.83E-02
1.89E-01
2.80E-01
3.71E-01
4.61E-01
5.52E-01
6.43E-01
7.31E-01

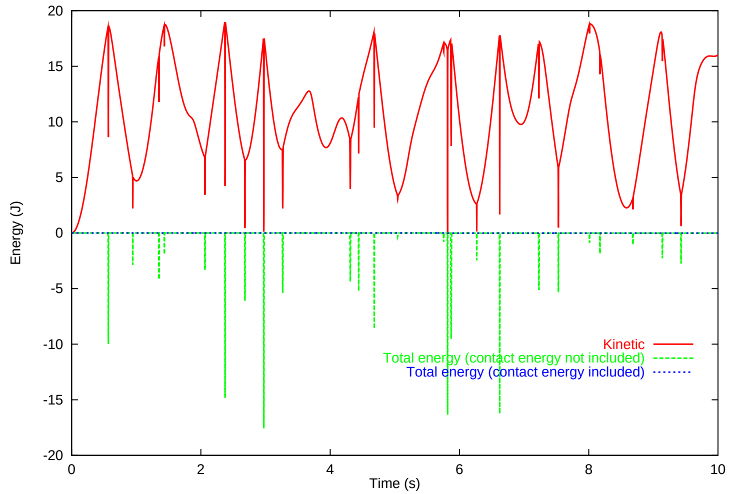

DEF. PL. EF.
3.74E-02
2.53E-01
4.69E-01
6.85E-01
9.01E-01
1.12E+00
1.33E+00
1.55E+00
Current View
Min = 3.74E-02
X = 0.00E+00
Y = 1.18E+00
Max = 1.55E+00
X = 6.00E+00
Y = 1.18E+00
Time = 1.01E+00

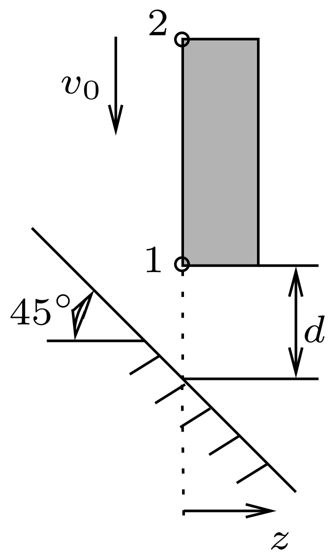
Contact / impact

- Explicit integration
- Implicit integration. In flexible multibody systems, using the penalty method and energy-momentum schemes.
  - Impacts against rigid walls.
  - Joint clearances

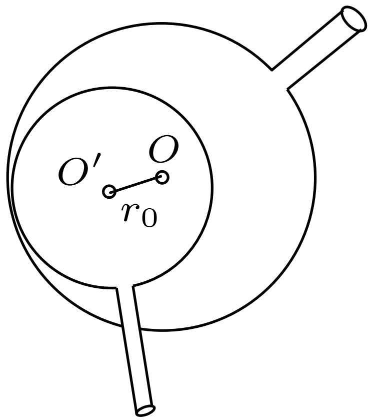
MBS: Impacts with rigid walls



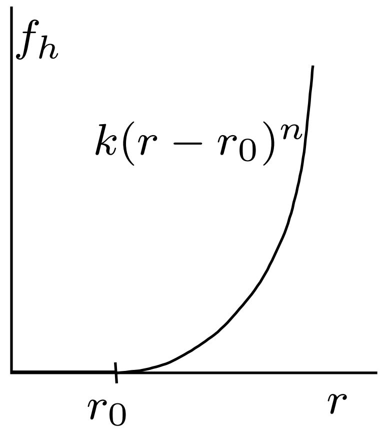




MBS: Joint clearances



(a) Spherical clearance



(b) COntact force (Hertz model)

- Associated constraint:

$$\Phi(r) = \begin{cases} 0 & \text{if } (r - r_0) \leq 0, \\ \left[\frac{2k}{n+1}(r - r_0)^{n+1}\right]^{1/2} & \text{if } (r - r_0) > 0 \end{cases}$$

Application: Fast top with clearance

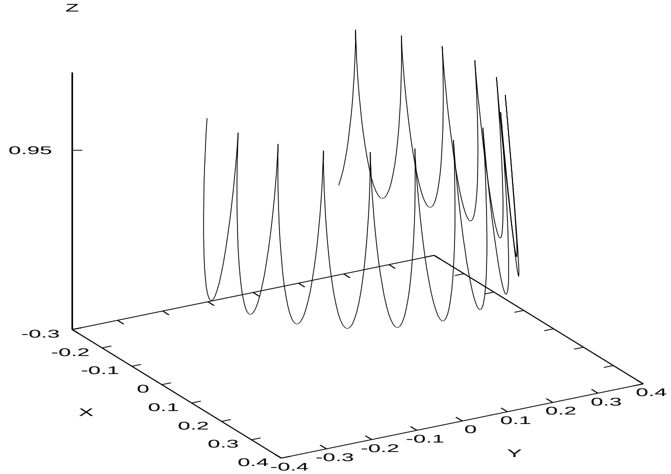
$T_n = 0{,}63\,\text{s};\ T_p = 15{,}7\,\text{s}$

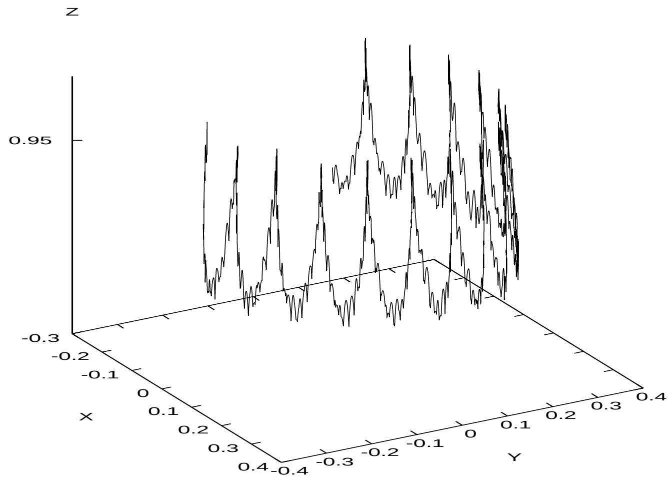
$r_0 = 2$ mm, $n = 1/3$

$E = 100$ MPa, $\nu = 0{,}3$

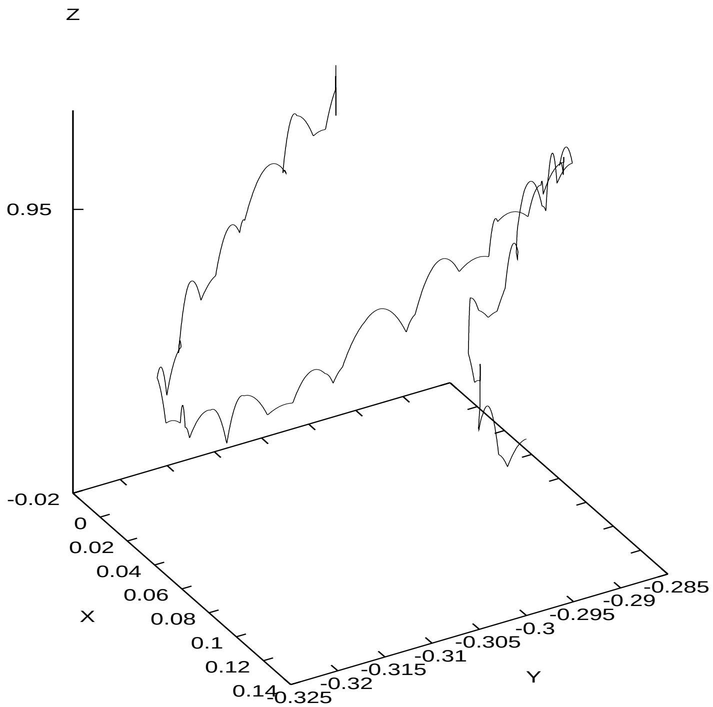
$\Downarrow$

$k = 5{,}15 \cdot 10^6$ N/m

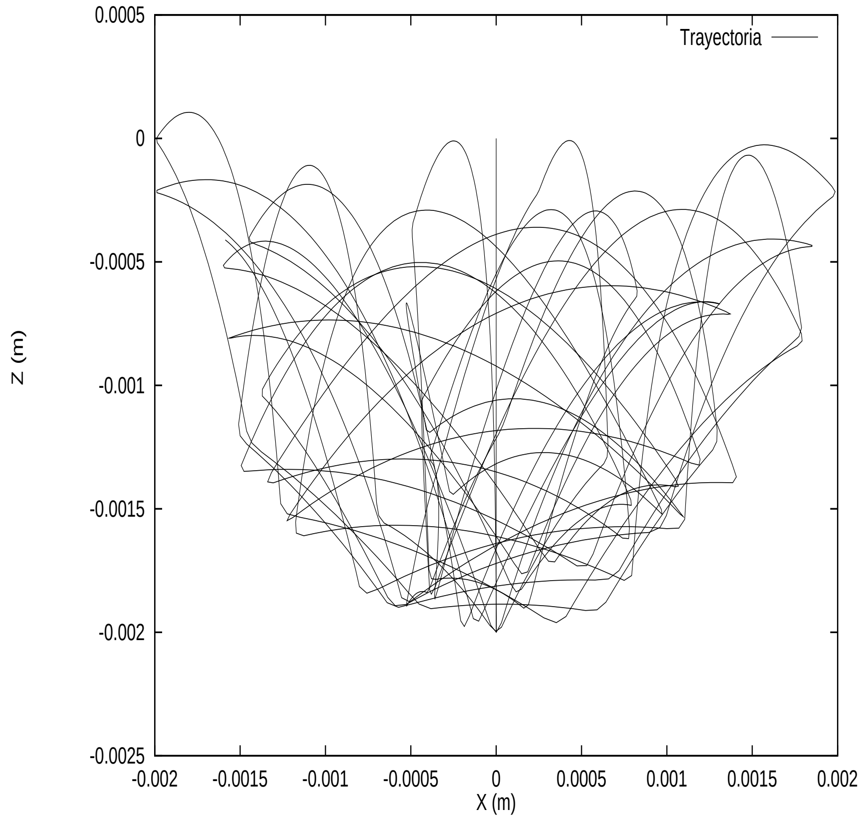




Application: Fast top with clearance (II)

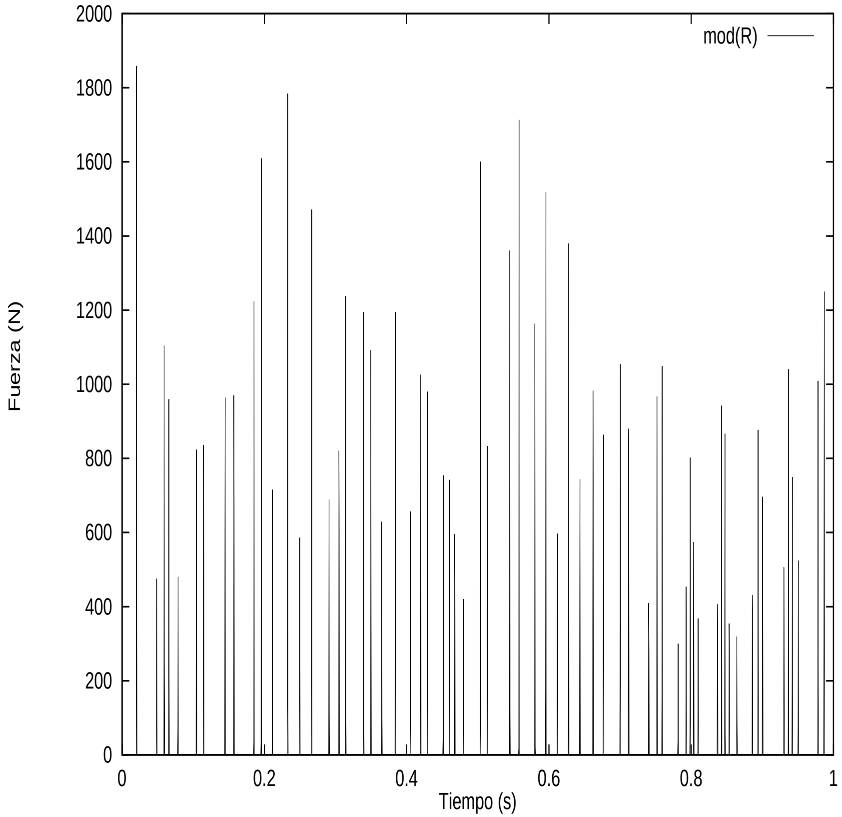


G trajectory (detail)

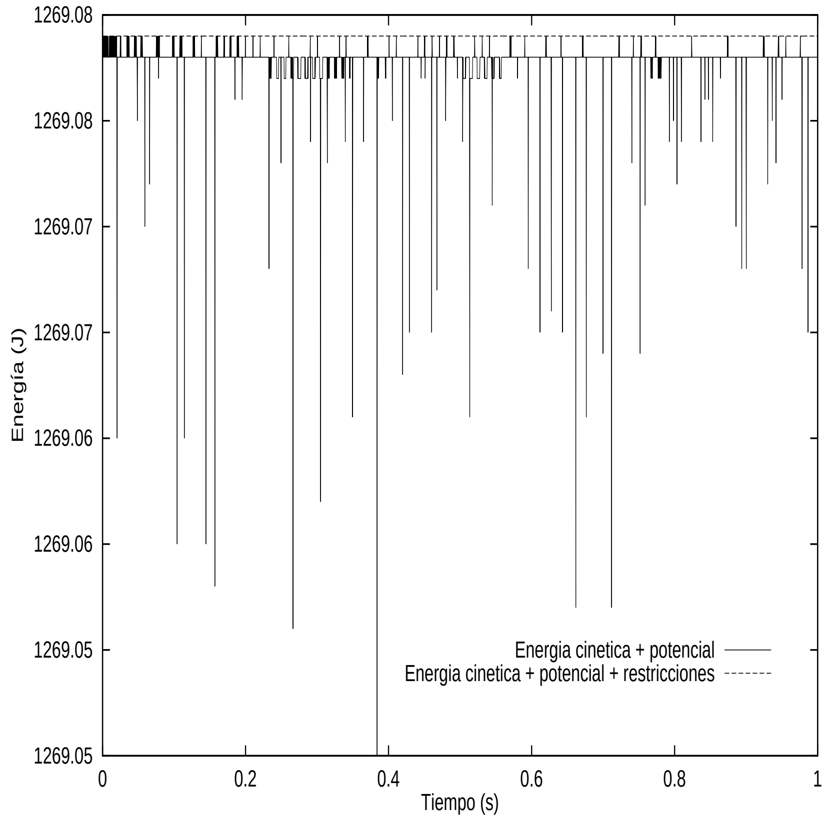


XZ projection of the edge

Application: Fast top with clearance (III)



Modulus of reaction



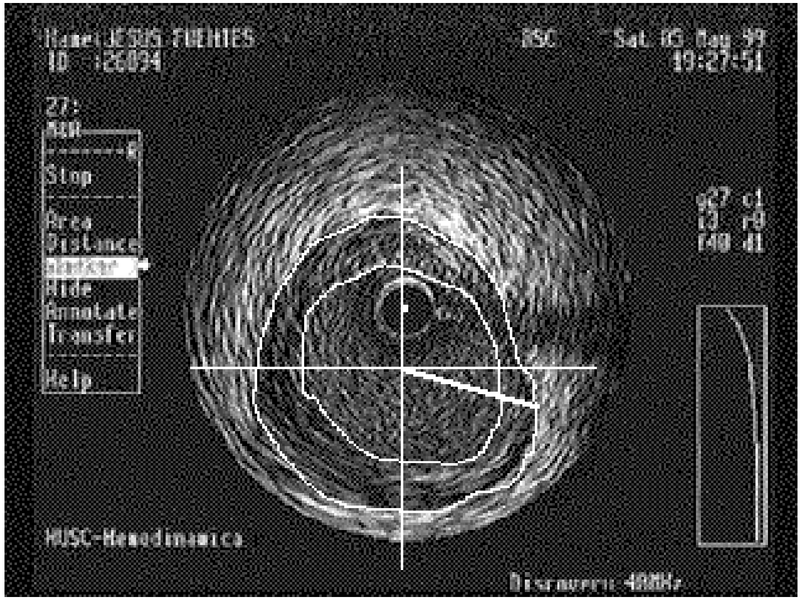
Energy vs. time

Biomechanics: modellization of soft tissue, with application to the coronary arteries

- Objectives:
  - Geometry adquisition and modellization.
  - Identification of material models.
  - Residual stress analysis.
  - Fluid (blood) - structure (arteria wall) interaction.
  - Remodellation and growth.
  - Correlation between atherosclerotic plaque formation and hemodynamical-mechanical variables (mainly shear stress and wall stress)
  - Balloning and stenting mechanics.

Geometry adquisition and modellization

- Angiography for lumen and IntraVascular Ultrasound System (IVUS) for morphology.

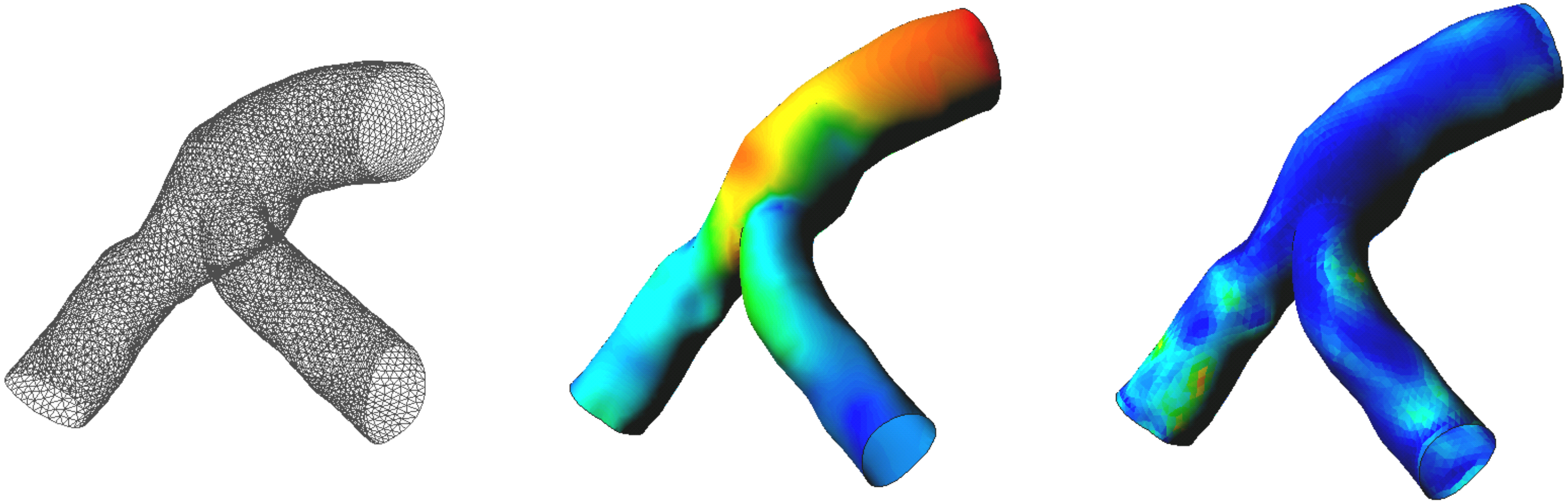


Material models

- Isotropic hyperelasticity.
- Non-isotropic hyperelasticity (fiber reinforced).
- Isotropic and anisotropic viscloelasticity.
- Isotropic and anisotropic damage

Blood-wall interaction

- Preliminary results with "weakly" coupled models (GID, FLUENT, ABAQUS).

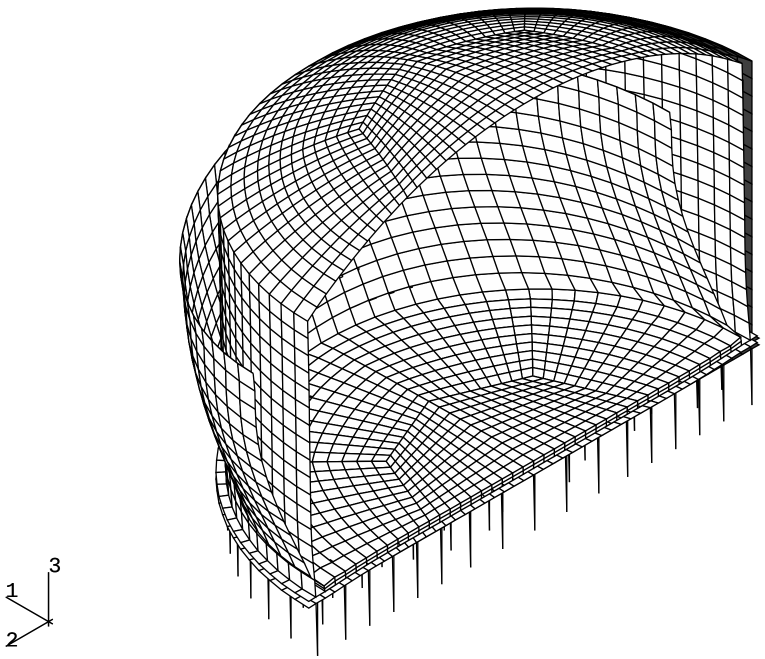


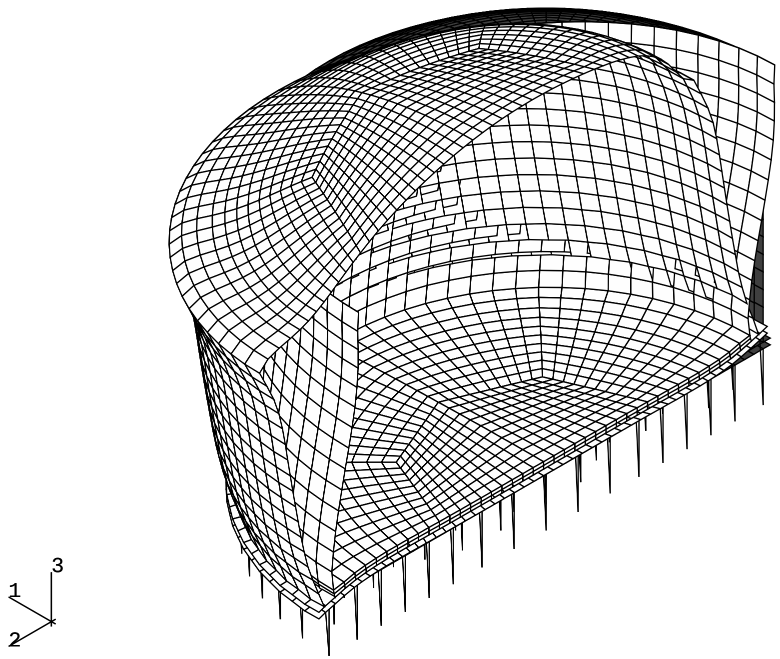
Teaching: Computer tools

- Mechanics (2°) with MAPLE:
  - Analytical manipulation
  - Numerical solution
  - Graphical representation.
- Finite element courses with FEAP
  - Non-linear capabilities
  - Source code availability
  - Graphical capabilities.

Engineering applications

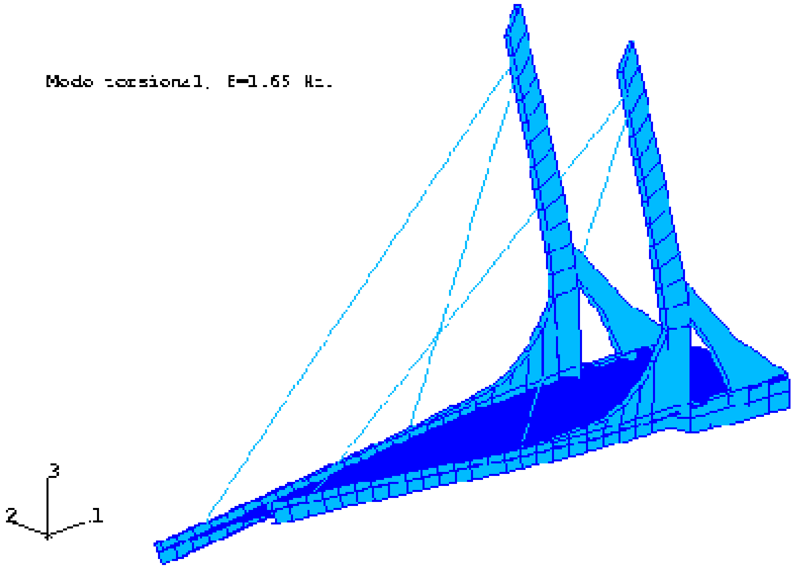
- Liquid Natural Gas tanks. Actions due to earthquake, leakage and external impact.





Engineering applications (II)

- Wind actions over structures.



Engineering applications (III)

- Conceptual design of the Gran Telescopio de Canarias