Topology optimization procedure TOPOPTIM

And other various developments made with Cast3M

Guénhaël Le Quilliec

Laboratory of Mechanics and Rheology, EA 2640
Polytechnic School of the University of Tours, France
guenhael.lequilliec@univ-tours.fr

2014 Cast3M Club - November 28th 2014, Paris, France

This document contains animations that are not compatible with this reader.
Please use a compatible PDF reader such as Acrobat 4-and-later.

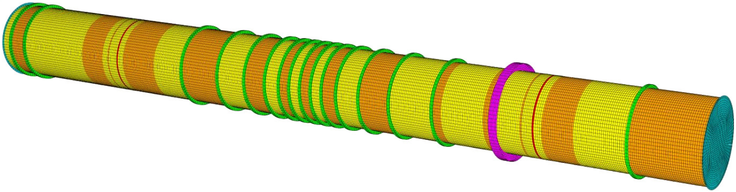
Outline

1. Various developments
2. TOPOPTIM procedure
3. Examples of application
4. TOPOPTIM Links
5. Conclusions and perspectives

Outline

Various developments: ENDOJS procedure

- Fully automatic procedure of fatigue life prediction dedicated to welded structures
- Post-processing of the cyclic loading (RAINFLOW procedure)
- Fatigue life prediction according to Eurocode 3 (ENDOJS procedure)
- Example of application: fatigue life prediction of rotary kiln



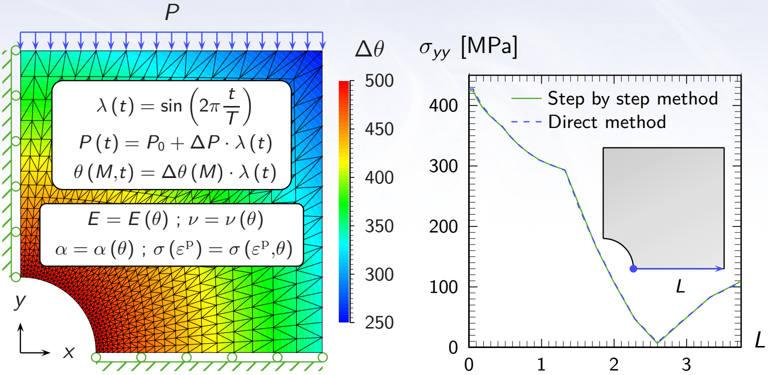
(approx. dimensions 50×5 m; about 20 000 local estimations)

Various developments: PASCYCL procedure

- Non linear direct solver dedicated to cyclic (periodic) loadings
- Inspired of the method of Akel and Nguyen
- The loading can be purely mechanical or thermo-mechanical
- All of the material behavior properties can depend on the temperature
- Local resolution at each integration point can also be direct (to do so, the behavior laws has to be rewritten)
- 3 direct cyclic behavior laws implemented:
  - linear elastic
  - elastic-plastic with non-linear (curve as input) isotropic hardening
  - elastic-plastic with non-linear (curve as input) kinematic hardening
- Use of the Cast3M ACT3 procedure for convergence acceleration
- Asymptotic state reached in one single step, widely faster than usual step by step approaches

Various developments: PASCYCL procedure

- Validation by comparison with the usual step by step method



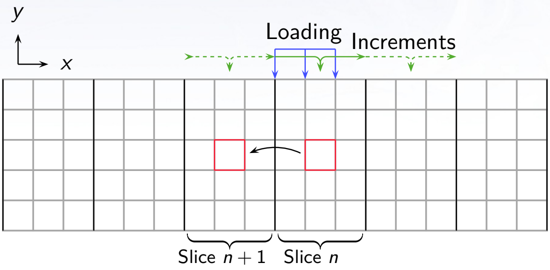
- No difference on the result
- Direct method about 50 times faster in the present example

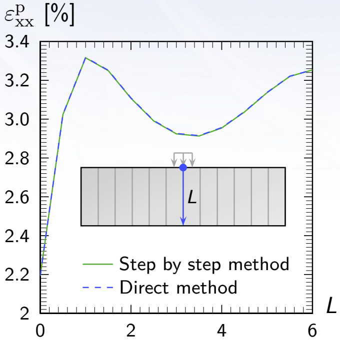
Various developments: PASMOBIL procedure

- Non linear direct solver dedicated to sliding or intermittent (periodic) loadings
- Inspired of the pass-by-pass stationary method of Dang Van and Maitournam
- Extended to intermittent loadings
- Extended to frictional contact loadings (*e.g.* repeated moving impacts)
- Asymptotic state reached in one single step, faster than usual step by step approaches

Various developments: PASMOBIL procedure

- Validation by comparison with the usual step by step method

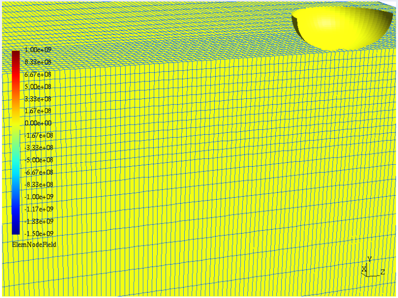




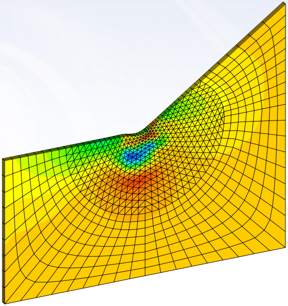
- No difference on the result
- Direct method about 15 times faster in the present example

Various developments: PASMOBIL procedure

- Application example: high frequency hammer peening simulations



Explicit simulation (LSDYNA)



1 slice from an implicit direct simulation (Cast3M+PASMOBIL)

- Direct method about 20 times faster in the present example

Outline

1. Various developments
2. **TOPOPTIM procedure**
3. Examples of application
4. TOPOPTIM Links
5. Conclusions and perspectives

Topologic optimization principle

- Optimal distribution of a material in a specified 2D or 3D design domain Ω
- Considering a given volume V occupied by the material
- Constraints and equilibrium have to be satisfied

$\rightarrow$ Iterative process minimizing/maximizing a physical quantity (*e.g.* compliance/stiffness)

- Often based on the Finite Element Method
- Topology can be parametrized by a scalar element field $\phi(x)$
  - $\phi = 0$ void
  - $\phi = 1$ material

$\rightarrow$ For minimum compliance design with an isotropic material:

$$E(x) = \phi(x) E_0 \; ; \; \int_\Omega \phi(x)\, \mathrm{d}\Omega \leqslant V \; ; \; 0 \leqslant \phi \leqslant 1 \; ; \; x \in \Omega$$

Reference codes and TOPOPTIM

- O. Sigmund's "88 lines code"
  - Penalty factor $p > 1$ to steer the solution to solid-void (or black and white): $E(x) = \phi(x)^p E_0$
  - Lower bound ϕ_{min} instead of 0 to prevent any possible singularity of the equilibrium problem
  - Optional fixed solid region and fixed void regions in sub-area of the reference domain
- W. Hunter's TOPY code
  - Gray Scale Filtering to yield predominantly, or even purely, solid-void designs
- TOPOPTIM
  - Elements reaching the lower bound ϕ_{min} are automatically (and temporarily) removed for better efficiency
  - The mesh is not necessary structured
  - The optimal shape mesh is given as output
  - Fully interpreted code (Gibiane language) easy to modify to combine TOPOPTIM with all other possibilities offered by Cast3M

Outline

1. Various developments
2. TOPOPTIM procedure
3. **Examples of application**
4. TOPOPTIM Links
5. Conclusions and perspectives

Example of code: 2D MBB beam problem

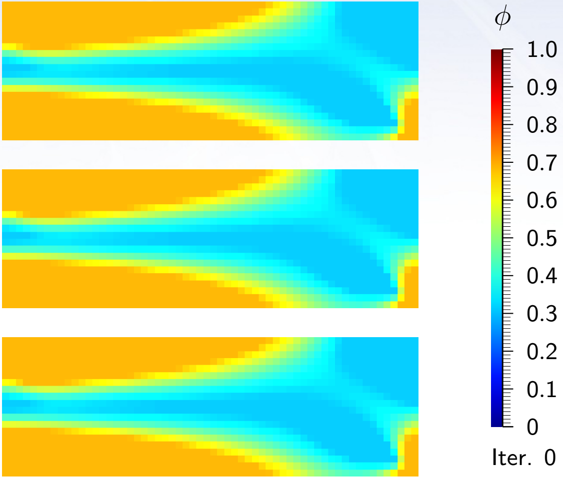
```
* General options
OPTI 'DIME' 2 'MODE' 'PLAN' 'CONT' 'ELEM' QUA4 ;
* Mesh
p0 = 0.0 0.0 ; p1 = 0.0 60.0 ; p2 = 60.0 0.0 ;
lgn0 = DROI 20 p1 p0 ;
msh0 = TRAN lgn0 60 p2 ;
p2 = msh0 POIN 'PROC' p2 ;
* Boundary conditions and loading
bc0 = (BLOQ 'UX' lgn0) ET (BLOQ 'UY' p2) ;
load0 = FORC (0.0 -1.0) p1 ;
* Optimization table
tab0 = TABL ;
tab0.'MAILLAGE' = msh0 ;
tab0.'BLOCAGES_MECANIQUES' = bc0 ;
tab0.'CHARGEMENT' = load0 ;
tab0.'FRACTION_VOLUME' = 0.5 ;
* Optimization
TOPOPTIM tab0 ;
* Plot to screen
TRAC (REDU tab0.'TOPOLOGIE_CH' tab0.'TOPOLOGIE_MAIL')
     (REDU tab0.'MODELE' tab0.'TOPOLOGIE_MAIL')
     (PROG 0.0 'PAS' (1.0 / 56.0) 1.0) ;
```

Comparison with ”88 line code” and TOPY on 2D MBB beam problem

88 Lines
(MATLAB)
Andreassen *et al.*
2011

TOPY
(Python)
W. Hunter 2009

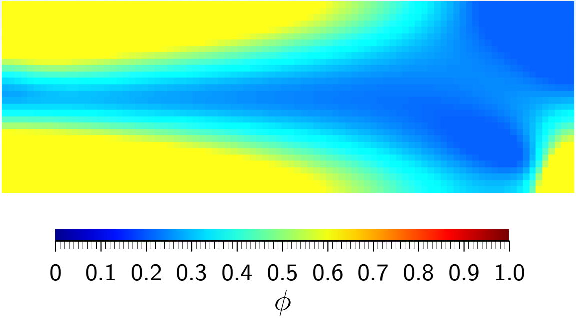
TOPOPTIM
topoptim1.dgibi
(Cast3M)



2D MBB beam problem with penalty factor and GSF

topoptim2.dgibi

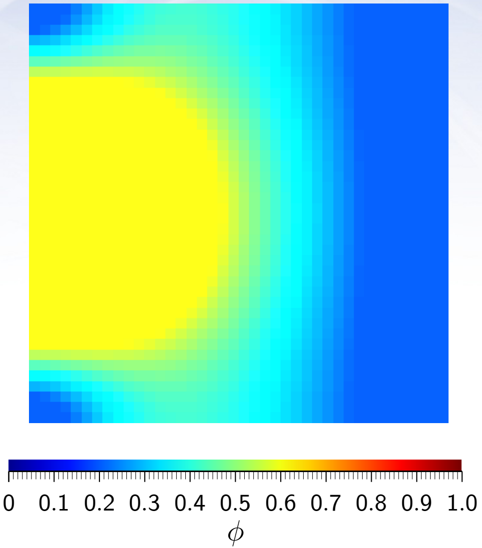
Iter. 0



Heat conduction 2D problem

topoptim3.dgibi

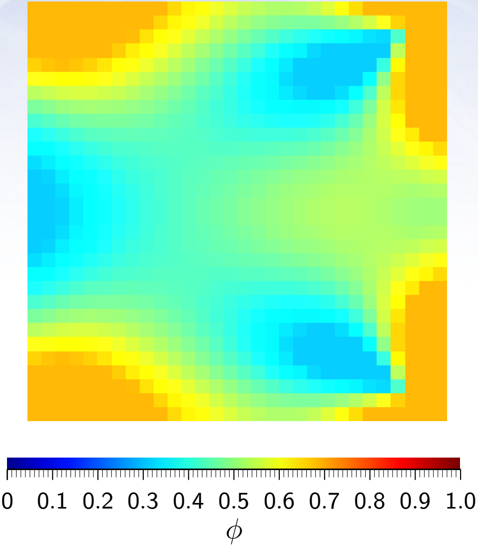
Iter. 0



Multicase mechanical loading

topoptim4.dgibi

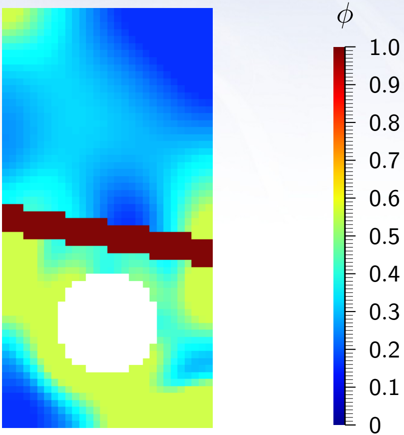
Iter. 0



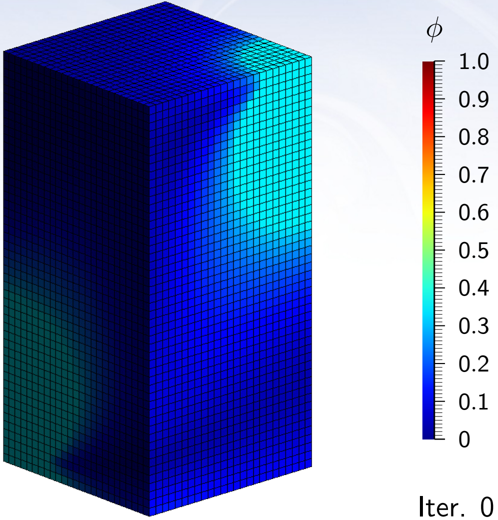
Simple 2D structure with penalty factor, GSF, a hole and an active zone

topoptim5.dgibi

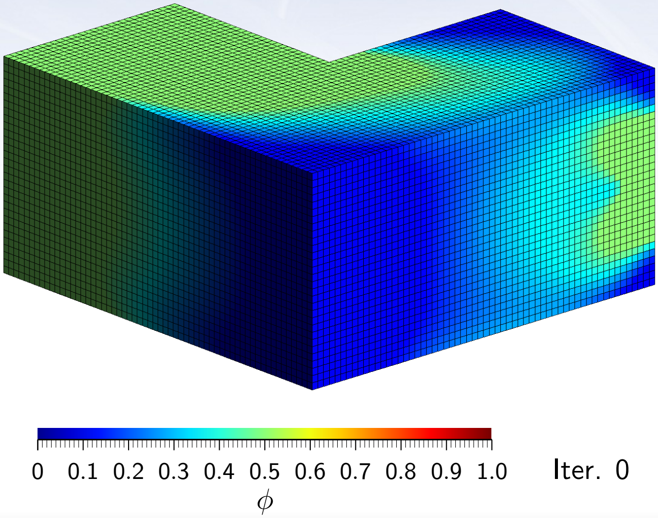
Iter. 0



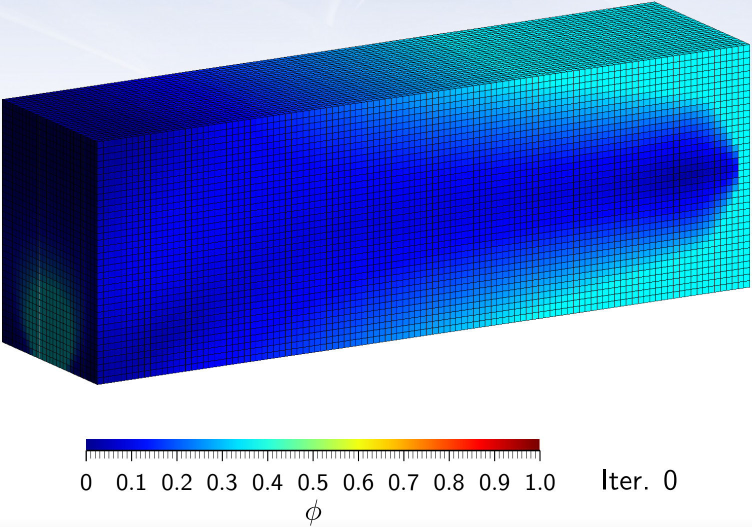
3D trestle problem



3D dogleg problem



3D cantilever problem



Outline

TOPOPTIM Links

- Procedure:

http://www-cast3m.cea.fr/index.php?page=procedures&procedure=topoptim

- Notice:

http://www-cast3m.cea.fr/index.php?page=notices_classees&notice=topoptim

- Simple mechanical and thermal test cases:

http://www-cast3m.cea.fr/index.php?page=exemples&exemple=topoptim1
http://www-cast3m.cea.fr/index.php?page=exemples&exemple=topoptim2
http://www-cast3m.cea.fr/index.php?page=exemples&exemple=topoptim3
http://www-cast3m.cea.fr/index.php?page=exemples&exemple=topoptim4
http://www-cast3m.cea.fr/index.php?page=exemples&exemple=topoptim5

Outline

Conclusions and perspectives

- Currently limited to isotropic materials with linear behavior
- GSF is slightly different than the W. Hunter's version for better efficiency in Gibiane
- Easy to use
- Easy to develop for future improvements
- More efficient due to automatic removing of lower stiffness element
- Output optimum mesh can be saved or directly used in consecutive simulations
- Some perspectives:
    - Optimal shape post-processing and extraction for direct 3D printing
    - Mechanics topologic optimization
    - Convergence acceleration
    - Multi-structure topologic optimization
    - Multi-scale topologic optimization
    - Development of a non-linear version of TOPOPTIM

Thank you for your attention