Jean-Pierre Aubry

Beginning with code_aster

A practical introduction to finite element method using code_aster and Gmsh

Framabook
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Version 2.1.2

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ISBN : 979-10-92674-03-3
Prix : 58 euros
Dépôt légal : décembre 2013, Framasoft (impr. lulu.com Raleigh, USA)
5, avenue Stephen Pichon – 75013 Paris
Pingouins : LL de Mars, Licence Art Libre
Couverture : création par Nadège Dauvergne, Licence CC By
Illustration de couverture par Pascal Gallepe
Mise en page avec LaTeX

Preface to the 2013 edition

I am very proud to introduce this book which is a perfect example of the Code_Aster Open-Source community vitality. I will take the opportunity to tell a story, in which I am pleased to have played my part, brilliantly continued by Pascal MIALON, *François* WAECKEL *and Christophe* DURAND.

Founder's goals

The development and release process started more than 25 years ago. Following a report of Yves BAMBERGER to the scientific council, Paul CASEAU, head of EDF R&D, decided in March 1988 to provide EDF needs a global answer.

. . . A unique code for mechanics

During the years 1975-1985, the deployment of the finite element method for mechanical analysis led to multiple software developments. The scattering of EDF R&D teams as well as the need for numerical tools dedicated to typical engineering subjects ended with numerous specific programs rather than one single general software.

Procurement, release and maintenance cost control showed the need, for EDF, for an involvement in a unique software integrating the previous developments. Started as a multidisciplinary project with voluminous specifications and a short timing, it became a great help in know-how management.

. . . A durable code

The need for a long run management of the project cases at EDF plants yielded heavy quality control requirements, regarding nuclear safety requirements. These projects were led by scattered and frequently renewed teams: the software should therefore play an important part regarding experience feedback in the long run.

. . . A code for expertise

The life span analysis of electricity power plants components requires to take into account: the loading history, the manufacturing process, the possible repairs. Thus, the required numerical models should respond to more demanding calculation hypothesis than the one used for classical engineering, systematically including: non-linear approaches, thermal effects, dynamic loading stresses, fluid structure interactions.

These models imply a R&D activity, whose results have to be submitted, as quickly as possible, to an industrial qualification when releasing the software.

Today it is an integrated computation system

. . . A solver

From a functional point of view, *Code_Aster* is a solver for mechanics: from a given geometric representation of the structure, the meshing, it implements the finite element method to produce result fields -deformation, stress, energy, material state-.

. . . For wider needs

But users have wider software needs: from CAD, to mathematical process and graphical result analysis in the end. Obtaining, ever and ever, more realistic input data -loadings, material parameters- requires that *Code_Aster* should be able to interact with other software dealing with the related physical phenomena. If a mechanical engineer may accept to cope with several tools, they certainly expect a “seamless” software offer regarding service, interoperability, version and quality control.

. . . Pre and post integrated processing

The fact that the software integrated from the beginning numerous dedicated tools to the code itself, including mathematical processing, allowed at the time to capitalize a broad panel of engineering technologies as well as regulations and codes approach. This also enabled a “global” certification of the code while avoiding the use of external components with uncontrollable life cycle -commercial spreadsheet. . .-.

. . . From Python supervision to Salome-Meca

The initial architectural design turned out to be relevant and adaptable enough to allow the integration of new methodological input with no need of rebuilding. In 2000, Python was chosen to be the supervisor language and it increased the code modularity in dedicated tools and specific mathematical computation.

The present outcome of this approach is Salome-Meca: an integrated and complete GUI made available on the engineer workstation. With the same quality controlled software, the mechanical engineer can handle the whole simulation, from CAD to coupling with other physical solvers.

Developing the network . . .

. . . A durable process and agile software development

Very early what is now known as “agile software development” was settled down .

Needs are assessed through experience feedback sheets, and do not rely on any global specification. Each request follows its own development cycle, from requirements needs to final delivery, and do not depend on the other development cycles. The continuous update of the development version, available to any user, allows a quick feedback and enables improvement as well as debugging. Finally, developers, code architects and potential users may discuss continuously and more particularly at the stage of integration by the development team.

. . . A network supporting the industry innovation

This network structure, prefiguring the free software style contributes to the computational mechanics research. In twenty years, almost 200 developers and more than twenty doctoral students added their contribution to *Code_Aster* .

A numerical model is considered valid when it can be delivered to the operational teams in a qualified version. It has to fulfill three requirements: reliability, robustness, performance. *Code_Aster* reviewing procedures contribute to this goal through a set of requirements regression test cases, documentation, rules for system architecture. . .- as part of an incremental development process.

. . . Quality first

Documents tracing the code improvements enhance its quality. Apart from these everyday an independent validation occurs: the critical expertise by third parties. This type of reviews, along the versions, enhance the code qualified domain. This qualification, together with Quality Insurance, is essential when studies relating to nuclear safety are undertaken. Ultimately it does benefit to everyone.

Four major audits reinforced *Code_Aster* quality approach as well as its original network development strategy. Thus, thanks to the engineering services requirements and support, collective trust in the software patiently aroused. It is now well established at EDF and beyond.

Assisting internal users . . .

Code_Aster deployment has only possible by keeping a constant relationship between development teams and users.

The first major contribution to quality approach was to provide a user documentation with each new version. But also a theoretical justification of the models used in each verification test cases. This documentation is a great contribution greatly to EDF know-how in the mechanical field. The 20,000 pages current corpus is enhanced or reviewed with every new addition.

. . . Informing and sharing

The users' club, with its local correspondents, is the place where one can share experience and discuss with the development team. The most representative studies, displaying important issue or setting up advanced modeling, are presented at the annual users' day as well as in the free *Code_Aster* information letter.

. . . Training

Hundreds of users follow annual training sessions, basic or more advanced ones, dedicated to dynamics, contact and non-linear analysis . . . The documentation broadness and the pedagogical dimension of more than 3,000 basic test cases allows efficient self-learning. The whole corpus of training documents is now accessible to the entire *Code_Aster* Open-Source Community.

. . . Listening and answering

Exchanges with users benefit of the use of a central main frame coupled with a cooperative system for experience feedback, particularly regarding the cases associated with confidential data.

A powerful simulation tool is nothing without the control and the development of a skill's network. Beyond the hotline, in house users have access to the expertise of R&D mechanical engineers for the implementation of complex studies.

For a wider distribution . . .

"You will not decide for yourself that you are good: others should have to tell you!" (Paul GODIN, *at project inception on January 2 th 1989)*

After a decade of development and three non public versions, releasing *Code_Aster* outside of the in-house user's circle was tempting. The appeal of an external recognition and possible new contributions supported this approach. In addition, valuing the industrial research results was fashionable at the end of the 90's.

. . .. Preparing code portability to prevent isolation

To reach the level of confidence and transparency suited to a tool used in nuclear safety, external distribution imposed itself. Preparing for distribution *Code_Aster*, a tool previously operated only in-house, on secure servers, required a significant number of proof tests to insure portability to other computers.

. . . Trying economic and commercial development

The commercial distribution of the operating and closed source version-was attempted in April, 1998. But this attempt imposed premature investments on the studies environment and above all developments in fields not closely related to our core business. Finally, the ”closed” nature of the code was in contradiction with its expertise goal.

The difficulty was also to find resellers who would accept to get involved in completely new software, particularly if they were already distributing one or more other software. This required from them a capacity that we failed to motivate, in an already very crowded market. This operation was rapidly stopped, in 1999.

. . . Evaluating the free software model

By the end of the twentieth century the free software model was becoming increasingly popular, whether for operating systems -Linux- or for internet development -Apache-. But application software were not yet concerned by this model. One first trigger was the Matra-Datavision choice to initiate, in 1999, the Open Cascade process which led to Salome development. At the same time INRIA [1] started the free distribution of SCILAB/Sicos. Thus we chose to evaluate the full implications of this model to an industrial simulation tool.

For a free diffusion . . .

This exhaustive evaluation of the free software model led to choose, in June 2001, the distribution under the GNU General Public License. The internet web site `www.code-aster.org` was opened on October, 19th 2001.

. . . Remaining close to internal users support

EDF did not intend to evolve to a software publisher. The requirement of maintaining, not increasing, the resources assigned by EDF to outside distribution implied *de facto* to give up the idea of any financial profit. The development team was at the service of the in-house engineering teams and had to remain so. It had also to contribute, as efficiently as possible, to the processing of the company sensitive dossiers.

[1] French national agency for computer science

. . . For a recognition by usage and a supplementary qualification

Beyond the 250 internal users, EDF wished to increase the credibility of its tools through a permanent confrontation with the main commercial tools and the evolution of the best industrial practices.

Open-Source allows a wide confrontation with the state of the art.

With more than the 5,000 annual downloads -20,000 for Salome-Meca- and through the public forum, the independent users community -industrial and academic- is rising . The Open-Source distribution allowed new proof tests and comparisons, a wider reading of the documentation as well as the detection of a few bugs. Several “benchmarks ”reinforced our confidence in the relevance of current models and the performance of the code.

. . . For spreading of competence

Several university teams run tutorial courses in finite elements or in mechanics linked to *Code_Aster*. Some service’s companies have a commercial activity in addition to their contract with EDF. The software talent pool has expended and is now durably established.

. . .For contribution collecting and cooperation building

The modular architecture of the code allows an easy integration of new modules and functionality. While following our quality criteria, significant contributions have already been integrated to the code.

Linus TORVALDS *promotes the free software model through the efficiency of the technical cooperation that it allows.*

Several academic partnerships have been developed. *Code_Aster* co-development agreements enable to develop, trough cost-sharing, common interest models , to guarantee their integration in the source code. They also serve as a foundation to collaborations in geomechanics, crack propagation, sliding contact, X-FEM. . . In 2012, a dozen of thesis had already been added on, and the process is still going on.

***Code_Aster*: a federative role for professional enhancement. . .**

Code_Aster had from the beginning a vocation for general simulation in mechanics.

. . . For all operations related to energy technology

EDF uses it today for modeling the behavior or pathology of its equipment:

- All components of the nuclear steam supply : pressure vessel, steam generators, primary motor-pump, primary and secondary circuits;
- The production equipment: turbo generator set and turbine components, towers and overhead power lines, both wind and hydro turbines;
- The civil engineering applications: pre-stressed concrete containment building, cooling towers, hydroelectric dams, nuclear waste storage sites.

The wealth of the available models -finite elements, behavior laws, analysis methods, post-processing- reflects this by itself.

. . . But also in unplanned areas

Taking advantage of the wide Open-Source deployment, *Code_Aster* has become by now an attractive industrial software. These means of dissemination have been used as an opportunity to show *Code_Aster* relevance in other mechanical simulation areas that were, for some, unexpected: the tectonic of geological layers, biomechanics, forming of steel or porcelain manufactured pieces, vibro-acoustic. . .

. . . For self-sustained development in digital simulation services

The possibilities offered by the GPL license have already allowed the emergence of services companies -training, assistance, development services, simulation deliveries. . .- in several countries. The progressive deployment of parallelism as well as its implementation in *Code_Aster*, particularly with the support of MUMPS Community, both allow these service providers to expand their offer to different organizations -SME, company of intermediate size . . .- with access to supercomputing centers HPC.

One remaining goal to realize would be to allow the emergence of distributors as added value resellers in various parts of the world.

. . . For the users community assistance

One of the latest avatars of the story, but not the last, was founding in July 2011 of *Code_Aster* Professional Network.

Code_Aster ProNet aims to increase *Code_Aster* Open-Source, and Salome-Meca, added values and make them better known. It allows links between the community actors beyond the technical exchanges on the forum.

Five prior modes of action were retained and are now shared by more than fifty members around the world, industrial organizations, research teams, service providers, teachers. . .:

- to create better quality multilateral exchanges -with EDF R&D and between members- by removing the limitations of a public and anonymous forum;
- to increase the members visibility on the various existing applications which have already been carried out and various usages;
- to disseminate insider information related to axes of evolution initiated by the members contributing to development, including EDF R&D ;
- to gather and structure common requests to services providers;
- to improve the collaborative development opportunities.

One to be continued!

The story has not ended yet and will continue to grow with the contributions of the new generations developers and users, after its twenty-fifth birthday in January 2014.

Let me conclude by warmly thanking Jean-Pierre AUBRY who has been using both his engineering and structural designer know-how to offer *Code_Aster* users' community a real learning guide for this specific software.

His high level practice within the forum can now be found here to help anyone discovering the software and also sometimes finite elements. His advices of best practice in the area of structural analysis will be very precious to every reader.

The way in which the numerical approach of structural computations is implanted in the different software is singular enough to require permanent explanations about what lies behind a series of "click".

In the *Code_Aster* command file explicitly writing everything you are doing is required. It will not only help you to remember what you did but it will also help anyone who will need to use the study results: that is traceability!

This guide is there to accompany you to enable you to join this adventure.

Jean-Raymond LÉVESQUE

Former member of *Code_Aster* Team (1989-2002)

Representative of *Code_Aster* ProNet

August 2013

Introduction

Introduction to the second edition

Time went on since the first edition of this book in late 2013.

This time has been used by the **code_aster** team to introduce many improvements with the related syntax changes[1].

This second edition tries to keep up to date with these changes.

Another rather important change has been the recent introduction of **AsterStudy** within **salome_meca**.

AsterStudy is quite a different affair, with a complete GUI it intends to ease up **code_aster** learning curve for beginners.

An important choice for me was: should I write a new book adapted to **AsterStudy**. After a lot of thinking I decided to keep to **code_aster** and strictly **code_aster** with its own cumbersome[2] way of editing the command file among other features.

I decided so because:

[1] Together with a change of logo and written form - **code_aster** - reflected in this second edition!

[2] Cumbersome to the eyes of many beginners, not to my own eyes.

- **AsterStudy** is a work in progress, and in very fast progress indeed, hence a book published today would be very quickly out of date in many respects;
- the GUI monitoring of **AsterStudy** is much more adapted to a dynamic on line video way of learning rather than a static paper book, and there are quite a few number of such videos around.

Despite the word “Beginning” in its title this book presents some rather expert level methods for handling a study and some of these advanced features used in a few of the *.comm* example files are not [yet] available in **AsterStudy** GUI.

In addition I dropped any reference to Salome as a drawing and meshing tool and to Paravis as a tool to view graphical results as I consider that Gmsh does the job just as well[1] for these purposes. Moreover given the evolving nature of SALOME, the chapters of the first edition are mostly outdated on this matter.

In fact this book sticks to my own way of dealing with a **code_aster** study after eleven years of practice.

And these eleven years were a delight!

Jean-Pierre AUBRY

Nantes, December 2013, January 2019.

[1] In fact much better in my own opinion.

Introduction to the first edition

Following is the exact reprint of the introduction to the first edition,

Code_Aster, acronym for Analysis of Structures and Thermomechanics for Studies and Research, is a general Finite Element Analysis software, coming from EDF (Électricité De France) R&D department.

It can handle mechanical, thermal and associated phenomena in all sort of analysis: linear statics, non-linear statics or dynamics, thermics and more.

Its development started in 1989. In 2001 EDF took the rather unusual decision, for a software of this size and scope, to put it under GNU GPL license.

Due to its numerous capabilities, *Code_Aster* is a very complex affair, and its somewhat unfriendly user interface makes the learning curve quite steep at the beginning.

The aim of this book is to ease up this steepness.

In itself *Code_Aster* does not provide any graphical interface for pre or post-processing, this task is left to third party software, and a few of them are also under GNU GPL licenses. This book introduces Gmsh and Salome for this task.

Last but not least, this book is in English, about a software whose native language is French, just as is the native language of the author. I hope the reader will forgive my poor level in Joyce's language.

Finally I have to express my thanks. To "La Machine"[1] for letting me apply, over many years, *Code_Aster* to many peculiar, and peculiar they were, engineering problems.

To Thomas de Soza, now in charge of EDF R&D *Code_Aster* core development team[2] for a helpful, tedious yet uncompromising proof reading and suggestions.

Jean-Pierre AUBRY

Nantes, October 2011, November 2013.

[1] `www.lamachine.fr`, the web site helps to understand why a free software was accepted here!

[2] Who,in 2018 is now sailing in other EDF waters.

Contents

CHAPTER 1

Foreword

1.1 How to read

The first chapters from chapter 3, to chapter 9, are meant to be read by the newbie user in a sequential order; these go from simple to more complicated examples concerning the geometry, the mesh and the model. At the same time we go from simple to more complicated analysis and post-processing tools, starting with a simple analysis and finishing with STANLEY post-processing.

The following chapters are more independent as we dive into non-linear analysis, 3D modeling with contact and friction. Their reading assumes that the fundamentals from the previous chapters have been understood. However the experienced user may find some useful hints, here or there, throughout the chapters.

We refer to the gigantic documentation just as little as necessary. For example we refer to `DEFI_MATERIAU` just enough to define the material used in our examples not wandering into the 157 pages of U4.43.01 document[1].

Going through the examples on the computer one needs to have the programs fully installed. If this is not the case, one needs to go to appendix D to learn how to, and do it!

1.2 What this book is

It is step by step introduction to the finite element analysis using **code_aster** .

In this book we take a few complete examples, from a practical engineer point of view, from the beginning to the solution.

It is limited to mechanical static analysis.

1.3 What this book is not

It is not a text book about mechanical engineering or structural design. Generally speaking, a successful finite element analysis of a structure, i.e. one giving a result without any runtime error or warning, is NO proof of a soundly designed structure!

It is not a text book about finite element theory, and I will not risk myself giving any reference in this matter in the bibliography section, particularly in English.

It is not a **code_aster** description of dynamic analysis like seismic response.

It is not a **code_aster** description of non purely mechanical analysis (hydraulics, thermics, coupling, heat induced stress like in welding).

It is not a collection of benchmarks trying to compare, to the last digit and with various types of meshing or modeling, the results of some problems with some well known analytical solutions.

[1] A large number of them referring to rather exotic cases, at least for the beginner!

1.4 What is **code_aster**

code_aster is a Finite Element Analysis engine, given the appropriate data files it will produce a set of result files. Used in this basic manner, one does not see anything on the screen, except a flow of lines in a terminal, and that's "all". But at the end of a successful run the problem is solved and this is the "all".

Except for the problem manager tool "ASTK", and the post-processing tool "STANLEY"[1], **code_aster** does not provide any GUI.

The whole **code_aster** bundle is about 900 Mb on the hard drive.

1.5 What is Gmsh

"Gmsh: a three-dimensional finite element mesh generator with built-in pre- and post-processing facilities" by Christophe GEUZAINE and Jean-François REMACLE, is a private venture[2].

Gmsh can produce a geometry and convert it to a usable mesh. This is usually done in its own GUI, but could as well be done in a script only manner, with no graphical output.

Gmsh can also read, manipulate and display results in its GUI.

At less than 200 Mb on the hard drive Gmsh is a small boy.

1.6 What are Salome, Salome-Meca and AsterStudy

"SALOME is an open-source software that provides a generic platform for pre- and Post-Processing for numerical simulation. It is based on an open and flexible architecture made of reusable components." It is a joint venture from CEA[3], EDF, and OPEN CASCADE.

[1] All these may well not be used at all.
[2] According to the authors "Gmsh" means nothing.
[3] "Commissariat à l'Énergie Atomique" French agency for nuclear power.

Salome[1] is a very complex piece of software including: a geometry module, a mesh module, some pot-processing modules, and much more.

It is also a very hefty guy filling almost 4 Gb on the hard drive.

Salome-Meca is a bundle which allows to run **code_aster** within Salome in a simple manner which allows to make studies in a single GUI!

AsterStudy is a module within Salome-Meca that, among other useful features, eases up the building of the command file by automating some syntax checking.

How useful this may be for a beginner this book concerns only **code_aster** *in its stand alone version.*

1.7 Typographic

Menus or buttons more generally actions in the GUIs are typeset like this: Menu.

code_aster reserved words, operators, function names, keywords, concepts are typeset like this: `MECA_STATIQUE`.

File, or extension, names are typeset like this: *.comm*.

And windows, or dialog boxes, titles as they appear on the screen are typeset like this: **Gmsh**.

“X” or “YOZ”, in uppercase refer to a global direction or plane, while “x”, in lower case, refers to a local direction i.e. in the local element coordinate system[2].

1.8 Software version

The example meshes and command files have been verified with the following versions:

[1] Apart from being known as the queen of Calchis, Salome is the acronym for “Simulation Numérique par Architecture Logicielle en Open Source et à Méthodologie d’Évolution” which can be crudely translated into “Numerical simulation by means of open source software architecture and with methodological evolution”.

[2] Except in **code_aster** reserved keyword where for example `MFY` is the bending moment in a beam element relative to the local y axis of the beam.

- Gmsh up to 3.07 and 4.0.7[1];
- **code_aster** stable 13.6;
- **code_aster** testing 14.2.

Tests were conducted on different machines, all of them running GNU Linux[2]. In addition tests have been carried as well on openSUSE in a VirtualBox® running in Windows 7® or Windows 10®.

This book deals only with a standalone installation, on a single machine, where the programs are installed in some adequate directories, and the studies are run from a directory with read-write access for the regular user[3].

[1] Some difference between 3.* and 4.* are detailed in 4.7

[2] openSUSE 42.3, Leap 15.0 or Debian 8, the screen caps are from a customized “fvwm” desktop environment.

[3] It is strongly advised NOT to run the programs as *root*, with super user privileges

CHAPTER 2

Beginning with...

If everything seems to be going well, you have obviously overlooked something.

11th Murphy's law.

A study work-flow in **code_aster** is sufficiently different from most "black box" Finite Element Analysis codes to justify this chapter.

A finite element analysis is usually performed to foresee the mechanical[1] behavior of some structure, or part, at the design stage.

For this, we make an idealized model from the plans, sometimes preliminary sketches, of the structure. When we say idealized, we mean that every part is represented by components or elements which are understandable by the finite element program.

Then we apply some loads to the structure and check its behavior under the various loads and compare the behavior with requirements.

For example, for a walking bridge most standards or building codes, for instance Eurocode in Europe, may require:

[1] At least in the limited scope of this book.

- a maximum vertical deflection under the sole action of a given number of people on the bridge, the service load;
- a stress level below the yield stress under the action of 1.35 times the dead load plus 1.5 times the service load;
- the same with the addition of several wind loads with their own coefficients.

In addition:

- the concrete engineer may want to know the reaction forces on the ground for some well specified load cases;
- very often a buckling analysis is required;
- the engineer may want to look at natural frequency and mode shape.

How is this set up in **code_aster** ?

2.1 Preparing the geometry and mesh

The geometry of the problem is prepared from the CAD file of the designer. At the very exception of some solid machine parts, a CAD drawing file always needs to be [deeply] modified to be transformed in a valid mesh.

In this book we draw and mesh the examples from scratch using Gmsh. This means:

- outlining the borders of the structure, or the neutral axis in case of beams, with points and lines;
- building the required surfaces and volumes from these lines;
- creating and naming groups of objects, e.g.:
  - all the lines supporting the same beam section;
  - all the surfaces having the same thickness;

- all the points, lines or surfaces carrying an identical load;
- all the points, bearing some ground fixation.

From this geometry we produce, or rather we instruct the software to produce a mesh, which is a subdivision in elementary objects (point, edge, square, triangle, tetrahedron, etc) changing if necessary the overall or local density or size.

This mesh is exported in a **code_aster** understandable format, for instance the MED format.

2.2 Preparing the command file

The mesh is only a topological entity[1], we need to instruct **code_aster** what to make of it in order to solve a physical problem and output the results.

This is done with a command file, the so called *.comm* file which is essentially a flow of operations. It is written in **code_aster** language[2].

The minimum blocks in this file are roughly:

- reading and modifying the mesh;
- assigning finite elements to it;
- defining the properties of the materials which are used;
- assigning the materials to the model;
- assigning geometric properties to the structural element, (shell thickness, beam section, etc.);
- setting boundary conditions and loads;
- choosing the adequate analysis type and solving;
- calculating the forces, stress, strain or more;
- writing the results in files, in ASCII and binary format.

[1] It consists of nodes, elements and groups.
[2] Which is just a package of specific commands interpreted in Python.

I will allow myself a little digression here: in **code_aster** a command file must be written as an ASCII text while most commercial software hide the creation of this command file behind numerous mouse clicks in no less numerous dialog boxes popping out, here and there, on the screen[a].

code_aster behavior calls for some more forethought from the user compared to the “click factories”[b], and is thus a much better tool for learning what all this business of “finite element calculation” is made of inside.

[a] Although for most of them this file exists and can be edited by hand!
[b] “Usines à clics” to retain the terminology used by C. DURAND former **code_aster** development manager.

2.3 Launching the calculation

Next is the actual execution of the study. This can be done in various ways which are [almost] all[3] described in this book:

- in the GUI of Salome-Meca, easy and simple, which is not the scope of this book;
- in the ASTK interface, less easy, more powerful;
- on the command line with ’as_run’, useful for scripting.

2.4 Viewing the results

Once the calculation is done[4] we are able to read the results in their ASCII format. And, more pleasing, to display colorful views on the screen in Gmsh.

Like...

[3] As far as the basic ones are concerned.
[4] Don’t panic if it does not work on the first go, after many years of practice it hardly ever works on the first run for me!

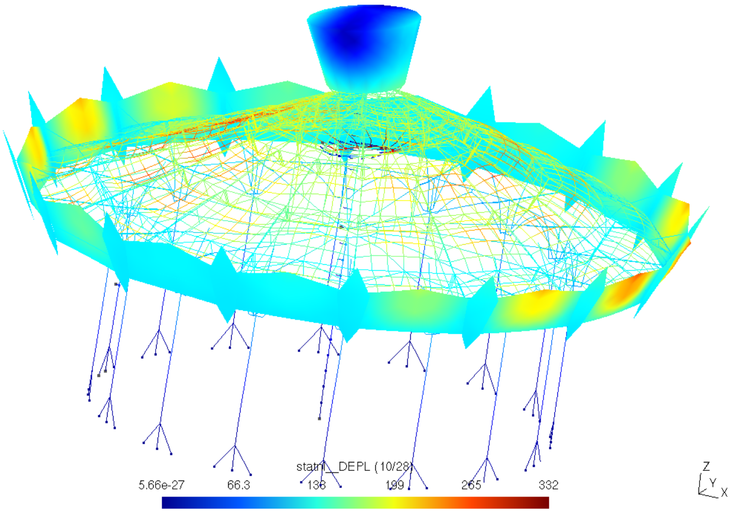


FIGURE 2.1: Post-processing view of ’Ile de Nantes Carousel’ top structure, with beams, plates and cables, built in steel wood glass and canvas, 22 m diameter

CHAPTER 3

Drawing and meshing a simple frame

In this first chapter, we draw a simple structure in Gmsh and make a mesh from the geometry.

3.1 Drawing the frame with Gmsh

As a first example we study an A frame[1], 1 m high, with a 2 m span, with one load under the form of a 10 kg mass at three quarter chord of the span and another load of 100 N, vertical downwards at the quarter chord. This frame is sketched in figure 3.1.

Note: the structure is symmetrical in geometry not in mass.

The first thing to be done is to create a directory for the problem, anywhere we have read-write permissions, we name this directory *frame1*.

Now let's launch Gmsh, we should have something looking like figure 3.2:

[1] It really is an inverted U shape, and could support a swing for the kids in the garden.

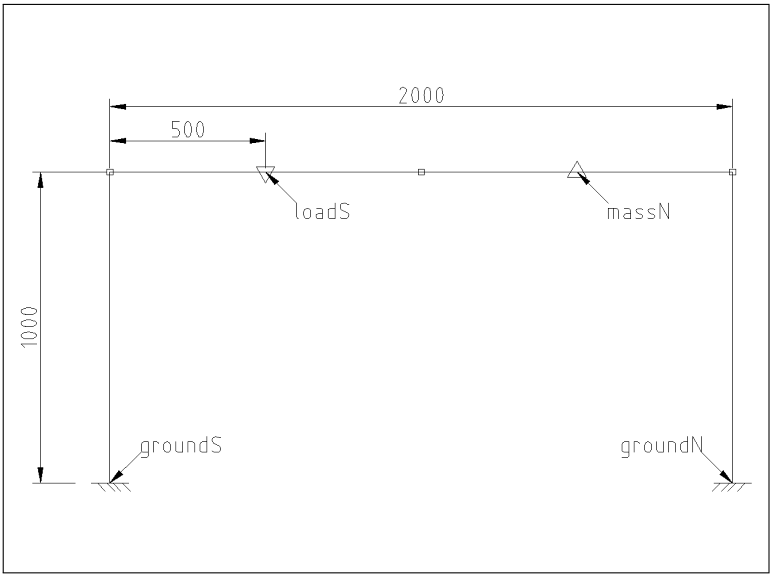


FIGURE 3.1: Sketch of frame1

- one large window, named **untitled.geo**;
- a menu bar on the top;
- a status bar at the bottom;
- a little trihedron at the bottom right;
- a “Modules” tree on the left-hand side.

From the main window choose the menu File > New... and create/save the file in the directory *frame1* recently created, name it *frame1.geo*. In the next dialog box named "Which geometry kernel do you want to use?" push the right most button Built-in .

One important feature of Gmsh is that every change made in the GUI is saved on the fly in the *.geo* file. This behavior may look strange to the beginner used to common spreadsheet and text processor, but once understood, we wonder how we would do without it.

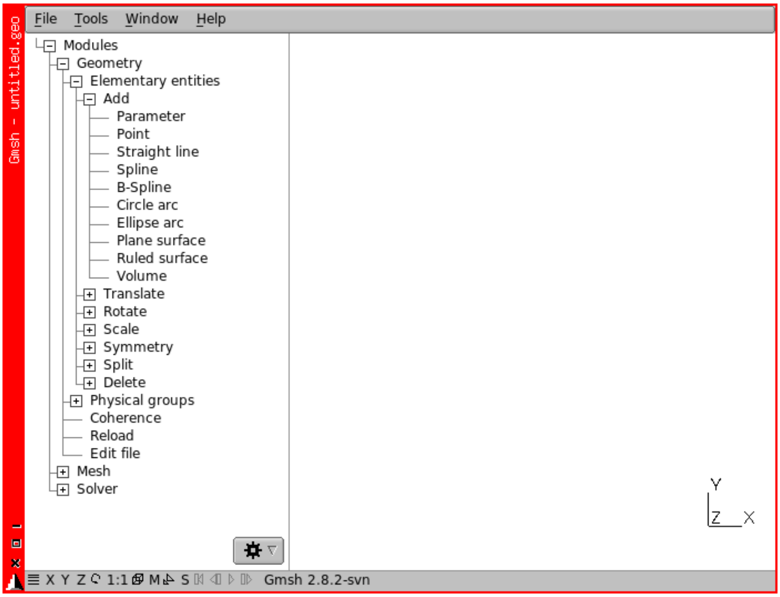


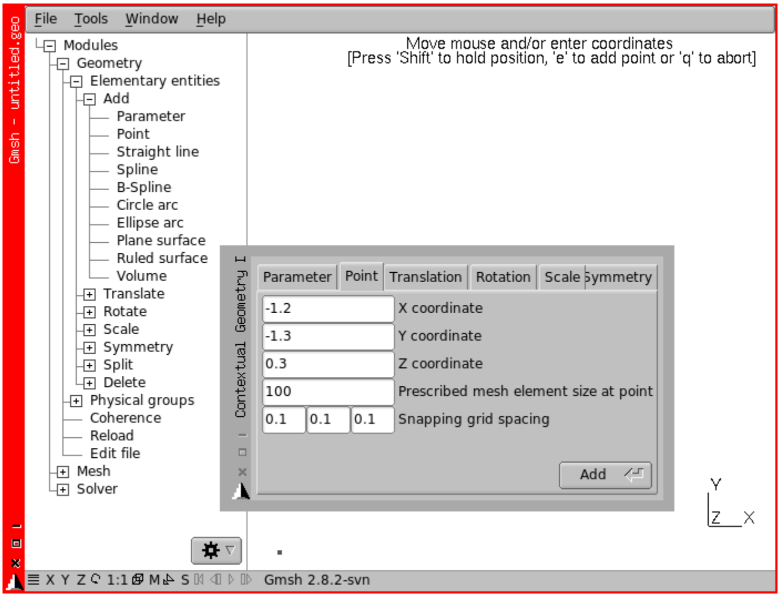
FIGURE 3.2: Gmsh, with some modules expanded

In the tree, under - Modules:

- push on the button Geometry, then Elementary entities;
- then Add › Point, another little windows pops up;
- type in the coordinates x=0, in X coordinate box, y=-1000, z=0;
- in the box Prescribed mesh element size at point enter 100;
- push Add.

We can notice some instructions about what can be done in the context displayed at the top center of the main window. We can also notice at the bottom of the **Gmsh** main window, the status bar reminding us what is the active command. We can see the newly created point as a little square box in Gmsh main window. Now let's open the file *frame1.geo* with our favorite text editor[1]. We can see something like this:

[1] As far as I am concerned, it's jEdit.



Move mouse and/or enter coordinates
[Press 'Shift' to hold position, 'e' to add point or 'q' to abort]

-1.2	X coordinate
-1.3	Y coordinate
0.3	Z coordinate
100	Prescribed mesh element size at point
0.1 0.1 0.1	Snapping grid spacing

FIGURE 3.3: Creating a Point in Gmsh

```
// Gmsh project created on Mon Nov  18 08:32:45 2013
cl1=100;
Point(1) = {0, −1000, 0, cl1};
```

Let's enter a new point, in Gmsh, with x=0, y=-1000, z=1000 then push Add. In the text editor we can see some warning that the source file has been changed, refresh the text window, a new line appears:

```
// Gmsh project created on Mon Nov  18 08:32:45 2013
cl1=100;
Point(1) = {0, −1000, 0, cl1};
Point(2) = {0, −1000, 1000, cl1};
```

In the text editor add a new line like this:

```
Point(3) = {0, −500, 1000, cl1};
```

Save the file, then in Gmsh,in the tree, push on Geometry 〉 Reload script, the new point appears in the main window.

Switching from the text editor to Gmsh GUI is the real way to do things efficiently!

In Tools menu choose Options, then the entry Geometry, by checking or unchecking the Point numbers option we can trigger the display of the numbering of the points. Complete the geometry with a point:

```
  Point(4) = {0, 0, 1000, cl1};
```

Now in the Geometry module we push on the button Elementary entities › Add › New › Straight line, with the mouse we connect the points by choosing the 2 end points of each line, while looking carefully at the request in the top center of the screen.

Then in Geometry › Elementary entities › Symmetry › Line fill the dialog box with A=0, B=1, C=0, D=0 [1], and we pick all the lines with the mouse and type e. The structure has been duplicated by symmetry about the XOZ plane and looks like figure 3.4, depending on the visibility toggles.

Note: new points are automatically created and there is no duplicate point at Point 4. We can have a look in the text editor to see how this is done. And the **Gmsh** window looks like figure 3.4

[1] The symmetry is defined by a vector, A, B, C being the 3 components (in X, Y, Z) of the vector normal to the plane and D the distance in space from the plane to the origin of the global axis, in short the 4 parameters of the plane equation in space!

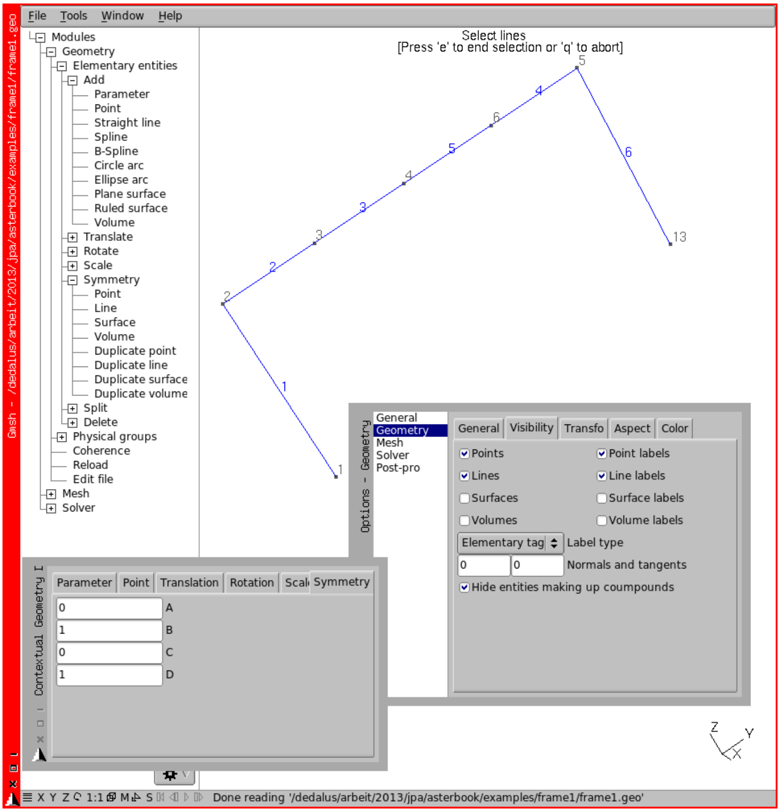


FIGURE 3.4: Geometric entities in Gmsh, with symmetry dialog box

Now we put together in ’Groups’ the geometric entities which share some properties[1], in the tree Geometry » Physical groups » Add » Line, pick with the mouse the four lines being part of the frame top bar, once this is done type e, like in figure 3.5.

We can notice a new line appended in the text editor:

```
Physical Line(7) = {2, 3, 5, 4};
```

[1] In Gmsh groups are called Physical

The actual digits may be different! Edit it so it becomes:

```
Physical Line("topbeam") = {2, 3, 5, 4};
```

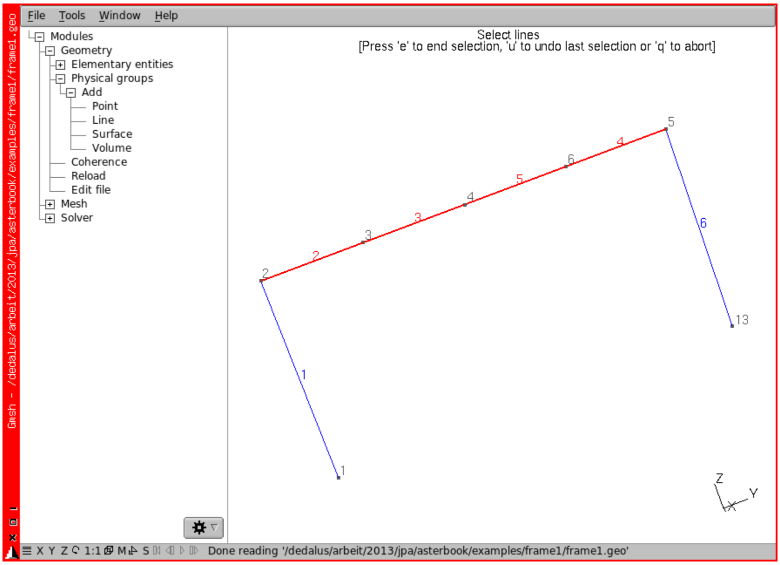

Gmsh - /dedalus/arbeit/2013/jpa/asterbook/examples/frame1/frame1.geo
File
Tools
Window
Help
Modules
Geometry
Elementary entities
Physical groups
Add
Point
Line
Surface
Volume
Coherence
Reload
Edit file
Mesh
Solver
Select lines
[Press 'e' to end selection, 'u' to undo last selection or 'q' to abort]
Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame1/frame1.geo'

FIGURE 3.5: 4 Lines selected to make a Physical

Before we continue a very important warning: within a mesh file which is to be processed later by **code_aster** we must not use group names longer than 24 characters[1] .

This gives the name ’topbeam’ to the group formed by the four lines 2, 3, 5, 4. We keep going on either from the GUI or from the text editor until the groups looks like below, notice we have also groups of points. The final *.geo* file looks like this[2]:

```
// Gmsh project created on Mon Nov  18 08:32:45 2013
cl1=100;
Point(1) = {0, −1000, 0, cl1};
Point(2) = {0, −1000, 1000, cl1};
Point(3) = {0, −500, 1000, cl1};
Point(4) = {0, 0, 1000, cl1};
```

[1] With versions earlier than 11.3.10 it used to be 8 characters, a major improvement!
[2] // at the beginning of a line means this line is a comment in Gmsh, just like in C language.

```
Line(1) = {1, 2};
Line(2) = {2, 3};
Line(3) = {3, 4};
Symmetry {0, 1, 0, 0} {
  Duplicata { Line{2, 3, 1}; }
}
Physical Line("topbeam") = {2, 3, 5, 4};
Physical Line("mast") = {1, 6};
Physical Point("groundS") = {1};
Physical Point("groundN") = {13};
Physical Point("loadS") = {3};
Physical Point("massN") = {6};
```

Some Gmsh hints:

- At the left end of the status bar there are several buttons;
  - X, Y, Z set the view from the selected axis, pushing ⇧ at the same time reverses the axis;
  - S means snapping, sometimes we have to deactivate it, if it was activated by error (if activated it appears in red);
  - a few other buttons whose use is explained in the balloon help.
- To select multiple items at once, we push ctrl and draw a bounding box with the mouse, any entity having a bit of itself within the bounding box is selected.

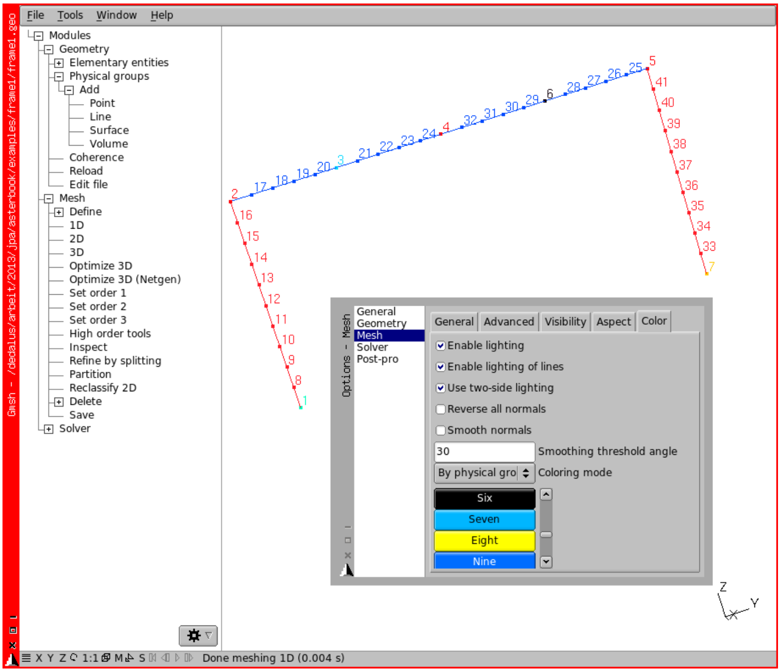
3.2 Meshing with Gmsh

At this stage, we have only geometric entities, we have to transform them into mesh entities.

In the tree push Mesh 〉 1D, the model is meshed like in figure 3.6.

In the **Options** window toggle the boxes in Visibility for Mesh and Geometry to see what has been created.

In the text editor we can see an entry at line 2: ’cl1=100’, this entry ’cl1’ is repeated as the fourth entry at every node. This is the elementary mesh size, named as ’Characteristic length’ in Gmsh which is applied around this given point. Change cl1=500 in this line, save in the text editor, reload in Gmsh and mesh again, we can see quite a coarser mesh.



[✓] Enable lighting
[✓] Enable lighting of lines
[✓] Use two-side lighting
[ ] Reverse all normals
[ ] Smooth normals
30 Smoothing threshold angle
By physical gro Coloring mode

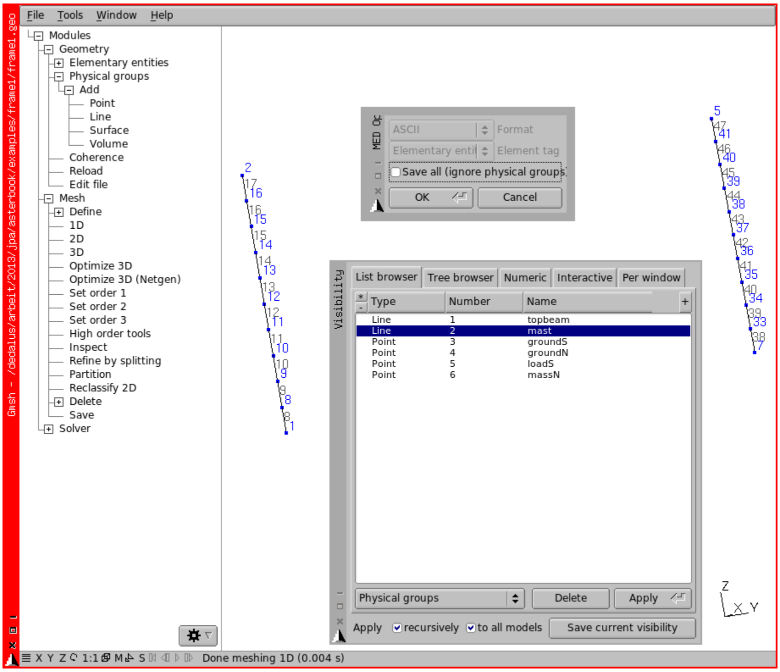
Done meshing 1D (0.004 s)

FIGURE 3.6: This is the mesh, with node numbers and Options > Color > Coloring mode set to By physical group and a bit of tweaking with the colors for the elements

We can just as well push Mesh > Define > Elements size at points in the tree, then fill the Value with any number let's say 10 and pick up one of the point, then do the meshing. The mesh is refined around this point.

Now, to save the mesh we do, menu File > Export... and save the file as *frame1.med*. A small dialog box named **MED Options** pops up, like at the top of figure 3.7:

Leave unchecked the box Save all (ignore physical groups) so as to save the groups created in the mesh.



Type	Number	Name
Line	1	topbeam
Line	2	mast
Point	3	groundS
Point	4	groundN
Point	5	loadS
Point	6	massN

FIGURE 3.7: Only Physical 'mast', 'massN' and 'loadS' are set to visible, with node and line numbers, and coloring by elements

More about that:

- If we leave this box unchecked all the elements belonging to groups are translated to the *.med* file, and *ONLY* these elements, Points elements (or nodes) as well. This means we have to create groups for everything we need later.
- If we check this box all the elements are translated, all of them, but *WITHOUT* any group definition.

This is very important, as when we do the meshing Gmsh meshes all the entities it founds without any distinction, it is only at save time that the real mesh is saved as stated above.

One more hint about using Gmsh, go to the menu Tools ≫ Visibility in the list browser tab at the bottom, pull down to Physicals groups, here we can play with the visibility group by group to see if things look like what we want, like in figure 3.7.

To finish with, pushing ctrl + L or clicking in the status bar, displays the 'Message Console' which is a log, and appears at the bottom of the main window, and can be re-sized.

CHAPTER 4

Creating the command file

Never make anything simple and efficient when a way can be found to make it complex and wonderful.

13th Murphy's law.

In this second chapter, we write a command file to study the behavior of the structure we drew and meshed in chapter 3.

We command to study the behavior under a static linear analysis, with several load cases.

And we command to produce the results files.

- First but important remark: in this first example we start straight away with a multiple load case, solved at once, study.
- Second remark: we describe the file, step by step, regardless of the tools used to produce it.

- Third remark: in this book we show the command files with a small indent scheme rather than in the classical **code_aster** manner with its very large indent[1].
- Fourth remark: all the concepts we create in the command files, in this book, are typeset in lowercase, we leave uppercase to the exclusive use of **code_aster** reserved words[2].

Now let's have a look, bit by bit, at the commented command file for the *frame1* study.

Note: lines beginning with # are comments[3]. Many things are explained directly in the code with commented lines at the right place. A line like, #U4.21.01 means: the following command or operator is described in the U4.21.01 document in **code_aster** documentation available on `http://www.code-aster.org`.

And before going any further a very important warning: within a command file, we must not use concept names[4] longer than 8 characters, which is not much!

4.1 Beginning with `DEBUT()`

Not much to say here, but in more demanding examples the `DEBUT()` procedure may take some arguments, however any *.comm* file must begin with this procedure, whose documentation is U4.11.01.

```
#U4.11.01
DEBUT(
    LANG='EN' ,
);
```

This operator includes he keyword `LANG='EN'` which allows, to some extent, to set the language of the *.mess* file to English, as is explained in chapter 20.11 .

[1] **code_aster** command files do not require any mandatory indent at all as long as we do not use conventional Python inside them, however a command must start at the beginning of a line without any indent.

[2] **code_aster** is case sensitive: 'TRUE', 'true' and 'truE' point to 3 different objects while 'True' is a Python reserved word. And a concept can be named 'modele', while 'MODELE' is a **code_aster** reserved word.

[3] More generally the *.comm* file follows the Python syntax.

[4] The names created on the left hand side on the "=" sign.

4.2 Reading and modifying the mesh

Here, we read the mesh which by default is assigned the Fortran unit LU 20 (Logical Unit 20). The `INFO_MED=2` line provides a more verbose mode of what is read, the output being in the *.mess* file. This feature is quite useful for checking that **code_aster** is actually reading what we expect. And of course we read a file in MED format, the one we saved previously[1].

```
#U4.21.01
mesh=LIRE_MAILLAGE(
    INFO=1,
    #INFO_MED=2,
    UNITE=20,
    FORMAT='MED',
);
```

Now we create some groups within the mesh.

With `CREA_GROUP_MA=_F(NOM='TOUT',TOUT='OUI',)`, we create a group named `'TOUT'` which contains all the elements which are in the mesh[2].

With `CREA_GROUP_NO=_F(TOUT_GROUP_MA='OUI',)`, we create a group of nodes for every group of element, each one of these groups contains all the nodes belonging to the parent element, and bears the same name. This is very useful and sometimes necessary (as here) with MED file imported from Gmsh because nodes are translated as 0D (point) elements.

Thus we can, later on, apply boundary conditions to nodes.

[1] **code_aster** can read other format:

- ASTER (.mail) format, mostly used in the test cases, U4.21.01;
- IDEAS (.unv) format with `PRE_IDEAS`, U7.01.01;
- Gmsh (.msh) format with `PRE_GMSH`, U7.01.31.

[2] This may be useful but we do not use it in this command file.

```
#U4.22.01
mesh=DEFI_GROUP(
    reuse =mesh,
    MAILLAGE=mesh,
    CREA_GROUP_MA=_F(NOM='TOUT' ,TOUT='OUI' ,),
    CREA_GROUP_NO=_F(TOUT_GROUP_MA='OUI' ,),
);
```

With `CREA_GROUP_NO=_F(GROUP_MA='mast',),` we would have done the same only for the 'mast' group. Many other useful things can be done in this command, for example using the boolean `UNION` of groups to simplify their manipulation later on. We can also have a look at the commands: `CREA_MAILLAGE, ASSE_MAILLAGE, MODI_MAILLAGE...` in the generous **code_aster** documentation.

After that is a little trick that saves the modified mesh so it can be checked within Gmsh.

```
#U4.91.01
IMPR_RESU(
    FORMAT='MED' ,
    UNITE=71,
    RESU=_F(MAILLAGE=mesh,),
);
```

4.3 Making a finite element model from the mesh

Here, we transform the mesh in a proper finite element model by assigning some properties to the mesh elements, as explained in U4.41.01[1]. For example:

- we assign, `AFFE=`, to the mesh groups

  `GROUP_MA=('topbeam','mast',);`

- the type of beam, `MODELISATION='POU_D_T';`

- telling as well that we deal with a mechanical behavior, `PHENOMENE='MECANIQUE';`

as explained in U3.11.01.

[1] In **code_aster** the `MAILLAGE` contains only the topology of the mesh and nothing else.

On the next line, we assign to the mesh group 'massN', in fact it is a point, the properties of a discrete element, as explained in U3.11.02 so as to put a mass on it later on.

```
#U4.41.01
model=AFFE_MODELE(
    MAILLAGE=mesh,
    AFFE=(
        _F(
            GROUP_MA=('topbeam','mast',),
            PHENOMENE='MECANIQUE',
            MODELISATION='POU_D_T',
        ),
        _F(
            GROUP_MA=('massN',),
            PHENOMENE='MECANIQUE',
            MODELISATION='DIS_T',
        ),
    ),
);
```

Here the mesh is transformed in a model in the most straightforward manner, the whole mesh at once. We may also not transform some of the mesh elements, thus excluding them from the analysis, just to see what would happen if they were not there, quite useful in preliminary design!

4.4 Defining materials

With this operator, we define a material, with its properties.

```
#U4.43.01
steel=DEFI_MATERIAU(ELAS=_F(E=210000.,NU=0.3,RHO=8e-9),);
```

As we are performing a simple linear elastic analysis only the Young modulus E and the Poisson ratio NU are needed. We also add the mass density RHO as we want to load the frame with its own weight[1].

4.5 Assigning materials to elements

Here we assign to the beam elements groups the material properties 'steel'.

[1] The mass density needs to be given in t/mm^3, as we use mm as length unit and N as force unit, more about unit system in chapter 6.1 .

Note: the discrete element, 'massN', is not assigned a material, this is not necessary, but **code_aster** does not complain if we assign one.

```
#U4.43.03
material=AFFE_MATERIAU(
    MAILLAGE=mesh,
    AFFE=_F(GROUP_MA=('topbeam','mast',), MATER=steel,),
);
```

4.6 Giving properties to elements

With beam, and in general with structural elements, this is a rather tricky part.

Here, we define a set, or concept, named 'elemcar' and assign some physical properties to the model elements, this is described in U4.42.01, and this document is most important and should be read carefully!

We begin with the beam properties, with some alternatives which are commented.

```
#U4.42.01
elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    POUTRE=(
        #the vertical members are rectangular section
        #(40x20 mm) with a thickness of 1.5 mm
        _F(
            GROUP_MA=('mast',),
            SECTION='RECTANGLE',
            CARA=('HY','HZ','EPY','EPZ',),
            VALE=(40, 20, 1.5, 1.5,),
        ),
        #same with the horizontal bar
        _F(
            GROUP_MA=('topbeam',),SECTION='RECTANGLE',
            CARA=('HY','HZ','EPY','EPZ',),VALE=(40, 20, 1.5,1.5,),
        ),
        #next lines would have produced the same section properties
        #_F(
            #GROUP_MA=('topbeam',),SECTION='GENERALE',
            #CARA=(
                #'A','IY','IZ','AY','AZ','EY','EZ',
                #'JX','RY','RZ','RT',
            #),
            #VALE=(
                #171, 11518, 34908, 1.5, 1.5, 0, 0,
                #26700, 20, 10, 12,
              #),
          #),
      ),
```

This next section deals about orientation of the beams, for the moment everything is commented and we review that in detail in chapter 6.3 .

```
      #in the next lines we would give the 'mast' group
      #the same orientation as the top beam
      #leave it commented at first
      #ORIENTATION=_F(
          #GROUP_MA=('mast',),
          #CARA='VECT_Y',
          #VALE=(1.0, 0.0, 0.0,),
      #),
      #and in the next ones we can rotate
      #to the 'topbeam' along its axis,
      #leave it commented at first
      #ORIENTATION=_F(
          #GROUP_MA=('topbeam',),
          #CARA='ANGL_VRIL',
          #VALE=90.0,
      #),
```

In this last section, we set the properties of the mass element.

```
      #in the next line we give to the discrete element
      #the property of a point mass
      #(CARA='M_T_D_N'), and give it
      #the value of 0.01 tonnes e.g. 10 kg
      DISCRET=(
          _F(GROUP_MA='massN' , CARA='M_T_D_N' ,VALE=(.01),),
          #following block set stiffness of point element 'massN'
          #to null stiffness
          #although this is not necessary,
          #commenting this block would raise a warning,
          #unimportant in this case
          _F(
              GROUP_MA=('massN' ,),
              CARA='K_T_D_N' ,
              VALE=(0, 0, 0,),
              REPERE='GLOBAL' ,
          ),
      ),
  );
```

4.7 Setting boundary conditions

Now, we assign the boundary conditions and loads, in several sets as explained in U4.44.01, again, this document is also most important and should be read carefully! In this first set we fix in all 6 DOFs at the bottom of the masts.

```
#U4.44.01
ground=AFFE_CHAR_MECA(
    MODELE=model,
    DDL_IMPO=_F(
        GROUP_NO=('groundS','groundN',),
        DX=0,DY=0,DZ=0,DRX=0,DRY=0,DRZ=0,
    ),
);
```

I strongly advise not to mix fixations and loads in a boundary condition set and to split the loads in as many elementary `AFFE_CHAR_MECA` as is logical.

DDL is the french acronym for DOF.

4.8 Setting loadings

In a second set, we apply the gravity, `PESANTEUR`, to the beam groups and also to the discrete element. `GRAVITE`, the acceleration of gravity is rounded off to 10000 $mm/s^2 = 10\ m/s^2$ so as to produce a 100 N load, symmetrical to the force load, with due allowance to the multiplier used later on.

Despite its name, "pesanteur" meaning "gravity", this keyword may be used to apply any uniform acceleration, in any direction, to any group of a model.

```
selfwght=AFFE_CHAR_MECA(
    MODELE=model,
    PESANTEUR =_F(
        GRAVITE=10000,
        DIRECTION=(0, 0, -1),
        GROUP_MA=('topbeam','mast','massN',),
    ),
);
```

In the third set, we apply a vertical force of 135 N to the node at the first quarter of the top bar.

```
cc=AFFE_CHAR_MECA(
    MODELE=model,
    FORCE_NODALE=_F(GROUP_NO=('loadS',),FZ=-135,),
 );
```

And in the fourth set we apply a distributed vertical force of 0.1 N per unit length (here mm) to the top bar.

```
cr=AFFE_CHAR_MECA(
MODELE=model,
    #FORCE_POUTRE=_F(GROUP_MA=('topbeam',),FZ=-0.1,),
    FORCE_NODALE=_F(GROUP_NO=('topbeam',),FZ=-0.1*2000/17,),
    #17 is the number of nodes in the group 'topbeam'
);
```

In the above lines we have commented the line with FORCE_POUTRE as **code_aster** cannot yet calculate with more than one distributed load on beam elements! However it knows how to in a single AFFE_CHAR_MECA[1].

This is a very annoying limitation. The work around is to replace it with an equivalent nodal force applied to the GROUP_NO=('topbeam',) which we have created earlier with DEFI_GROUP and which contains all the nodes of GROUP_MA=('topbeam',).
This equivalent nodal force is the distributed load multiplied by the length of the beam elements [2].

4.9 Stepping for the load case

Here we define some step functions which are applied to the loads.

For example, for the gravity force 'selfwght', the function 'selfw_m' is applied, 0 at instant 2, 1.35 at instant 3 and for all instant after 3, except at instant 6 where it drops down to 0.

For the nodal force 'cc', the function 'cc_m' is applied , 0 at instant 3, 1 at instant 4 and 5, with 0 at any instant before 3, and again 0 at instant 6.

Finally for the distributed force 'cr', the function 'cr_m' is applied , 0 at instant 4, 1.5 at instant 5, dropping down to 1 at instant 6 where it is acting alone, with 0 at any instant before 4[3].

[1] More about this in chapter 20.1 .

[2] A trick would be to have **code_aster** calculate the exact nodal forces depending on the element length, this is very feasible with some Python coding.

[3] The word instant must be taken here with some restriction, it just only means step, it is not related to time (in time unit, seconds) but the same word, INST, is used by **code_aster** to specify the step in static analysis and a real instant, in seconds (in most unit system), in a dynamic analysis.

```
#U4.31.02
selfw_m=DEFI_FONCTION(
    NOM_PARA='INST',
    VALE=(2,0,  3,1.35,  5,1.35,  6,0),
    PROL_GAUCHE='CONSTANT',PROL_DROITE='CONSTANT',
);
cc_m=DEFI_FONCTION(
    NOM_PARA='INST',
    VALE=(3,0,  4,1,  5,1,  6,0),
    PROL_GAUCHE='CONSTANT',PROL_DROITE='CONSTANT',
);
cr_m=DEFI_FONCTION(
    NOM_PARA='INST',
    VALE=(4,0,  5,1.5,   6,1,),
    PROL_GAUCHE='CONSTANT',PROL_DROITE='CONSTANT',
);
```

4.10 Stepping for the solution

Here we define a step function which is applied to the calculation, we calculate every single instant from 2, `DEBUT=2.0`, to 6, `JUSQU_A=6`, with a step of 1, `PAS=1.0`

```
#U4.34.01
liste=DEFI_LIST_REEL(
    DEBUT=2.0,
    INTERVALLE=_F(JUSQU_A=6,PAS=1.0,),
);
```

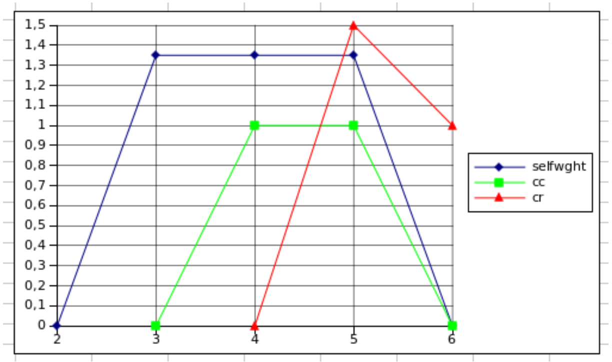


FIGURE 4.1: Load steps

We must understand what is done just above. We perform the calculation at five steps or instants, `INST` in the **code_aster** jargon, from 2 to 6, for every integer:

- at `INST` 2, we have no load at all[1];
- at `INST` 3, 1.35 times the self weight load;
- at `INST` 4, 1.35 times the self weight load, plus 1 times the nodal load 'cc';
- at `INST` 5, 1.35 times the self weight load, plus 1 times the nodal load 'cc', plus 1.5 times the "distributed" load 'cr';
- at `INST` 6, 1 times the "distributed" load 'cr' is acting alone.

This is illustrated in figure 4.1

4.11 Analysing it

After having defined loads and material now is the time for the main calculation. We conduct here a linear static calculation and therefore we use `MECA_STATIQUE`:

- with the previously defined model, `MODELE=model`;
- the defined material set, `CHAM_MATER=material`;
- the properties, `CARA_ELEM=elemcar`;
- the boundary conditions and loads defined under `EXCIT=...`
- at all the instants prescribed in `LIST_INST=liste`;
- and store the results in the concept `stat`.

[1] We start at 2 but we might have started at 0, -5 or 1.342! In linear static the choice is completely arbitrary and left to the user.

```
#U4.51.01
stat=MECA_STATIQUE(
    MODELE=model,
    CHAM_MATER=material,
    CARA_ELEM=elemcar,
    #with the load, or boundary condition defined in EXCIT
    #with the applied step function where needed
    EXCIT=(
        _F(CHARGE=ground,),
        _F(CHARGE=selfwght,FONC_MULT=selfw_m,),
        _F(CHARGE=cc,TYPE_CHARGE='FIXE_CSTE',FONC_MULT=cc_m,),
        _F(CHARGE=cr,TYPE_CHARGE='FIXE_CSTE',FONC_MULT=cr_m,),
    ),
    #the calculation is made for all instant in this list
    LIST_INST=liste,
    #we can give a title to this study
    #TITRE='my_title'
);
```

If `FONC_MULT` had been omitted in `EXCIT` and `LIST_INST` omitted as well we would have run the solution for one load case being the sum of all the `EXCIT` instances.

4.12 Calculating results

For now the concept `stat` contains only the displacement at nodes, as well as the forces at Gauss points, we must enhance it with some useful results on elements.

Enhance! that's why we use the keyword `reuse`, which is curiously written in lower case and in English.

```
#U4.80.01
stat=CALC_CHAMP(
    reuse =stat,RESULTAT=stat,
    CONTRAINTE=(
        'SIEF_ELNO','SIPO_ELNO','SIPM_ELNO',
    ),
    FORCE=('REAC_NODA',),
);
```

4.13 Calculating and printing the mass of the model

The next lines calculate the structural mass of the given groups and put the results in the *.resu* file in a tabular format as explained in U4.81.22.

This should always be done to check the consistency of the model and calculation.

```
#U4.81.22
masse=POST_ELEM(
    RESULTAT =stat,
    MODELE=model,
    MASS_INER=_F(GROUP_MA=('topbeam','mast','massN',),),
    TITRE= 'masse'
);
#U4.91.03
IMPR_TABLE (
    TABLE=masse,
    FORMAT_R='1PE12.3',
)
```

I reckon that checking the calculated mass with the estimates made otherwise is the prime test of the model validity. In structures made of beams this calls for an increased mass density of the materials so as to cope with all the unmodeled bits and pieces which contribute nonetheless to the loading of the structure by their own weight.

`FORMAT_R='1PE12.3'` prints the numbers with twelve characters, 3 digits after the decimal point and one digit to the left of the decimal point, for example $-2.762E+03$ while `FORMAT_R='E12.3'` would print $-0.276E+04$.

4.14 Printing the reactions

Checking the reactions against what is expected is just as well very important, so, in the next lines we calculate the sum of the reactions and put the results in the *.resu* file, in a tabular format, and in the conventional format.

```
#U4.81.21
sum_reac=POST_RELEVE_T(
    ACTION=_F(
        INTITULE='sum reactions',
        GROUP_NO=('groundS','groundN',),
        RESULTAT=stat,
        NOM_CHAM='REAC_NODA',
        TOUT_ORDRE='OUI',
        RESULTANTE=('DX','DY','DZ',),
        MOMENT=('DRX','DRY','DRZ',),
        POINT=(0,0,0,),
        OPERATION='EXTRACTION',
    ),
);
#U4.91.03
IMPR_TABLE (TABLE=sum_reac,FORMAT_R='1PE12.3' ,)
```

This first abstract of code puts the sum of the individual reaction on the groups of node ’groundS’, ’groundN’, in a table named ’sum_reac’ with the `OPERATION='EXTRACTION'` keyword. Then the table is printed with `IMPR_TABLE`.

`MOMENT=('DRX','DRY','DRZ',)`, computes the moment of this sum of reaction about the point whose coordinates are stated in `POINT=(x,y,z,)` coordinates.

Using `RESULTANTE=('DX','DY','DZ','DRX','DRY','DRZ')`, would have printed the sum of the individual reaction force as well as the sum of the individual reaction moment, the sum of the individual moment being not very meaningful!

```
#then in tabular format per group of node
reac1=POST_RELEVE_T(
    ACTION=_F(
        INTITULE='reactionsS' ,
        GROUP_NO=('groundS' ,),
        RESULTAT=stat,
        NOM_CHAM='REAC_NODA' ,
        TOUT_ORDRE='OUI' ,
        RESULTANTE=('DX' ,'DY' ,'DZ' ),
        OPERATION='EXTRACTION' ,
    ),
);
#very simple form
#IMPR_TABLE (TABLE=reac1,)

#or more detailed with field separator
IMPR_TABLE(
    TABLE=reac1,
    FORMAT='TABLEAU' ,
    UNITE=8, #this is also the default value
    #whichever separator that suits the needs
    SEPARATEUR=' * ' ,
    FORMAT_R='1PE12.3' ,
    TITRE='reaction_1' ,
    INFO=2,
);
```

```
reac2=POST_RELEVE_T(
    ACTION=_F(
        INTITULE='reactionsN' ,
        GROUP_NO=('groundN' ,),
            RESULTAT=stat,
            NOM_CHAM='REAC_NODA',
            TOUT_ORDRE='OUI',
            RESULTANTE=('DX','DY','DZ'),
            OPERATION='EXTRACTION',
        ),
);
IMPR_TABLE (TABLE=reac2,FORMAT_R='1PE12.3',)

#now we print the individual reactions
#in the .resu file in RESULTAT format
#U4.91.01
IMPR_RESU(
    MODELE=model,
    FORMAT='RESULTAT',
    RESU=_F(
        NOM_CHAM='REAC_NODA',
        GROUP_NO=('groundS','groundN',),
        RESULTAT=stat,
        FORMAT_R='1PE12.3',
    ),
);
```

4.15 Printing some key values

It is a wise idea to print in the *.resu* file some key values, here we print:

- the minimum and maximum value of the vertical component of the displacement in the 'topbeam' group;
- the minimum and maximum value of the axial force in the 'mast' group of elements;
- the minimum and maximum value of the bending moments in the two beam groups.

This print out gives a quick glance at the overall basic results as a check of what was expected. It can also be used to compare with the values displayed in the post-processor views!

```
IMPR_RESU(
    MODELE=model,
    FORMAT='RESULTAT',
    RESU=(
        _F(
            RESULTAT=stat,
            NOM_CHAM='DEPL',
            NOM_CMP='DZ',
            GROUP_MA=('topbeam',),
            FORMAT_R='1PE12.3',
            VALE_MAX='OUI',VALE_MIN='OUI',
        ),
        _F(
            RESULTAT=stat,
            NOM_CHAM='SIEF_ELNO',
            NOM_CMP='N',
            GROUP_MA=('mast',),
            FORMAT_R='1PE12.3',
            VALE_MAX='OUI',VALE_MIN='OUI',
        ),
        _F(
            RESULTAT=stat,
            NOM_CHAM='SIEF_ELNO',
            NOM_CMP=('MFY','MFZ',),
            GROUP_MA=('topbeam',),
            FORMAT_R='1PE12.3',
            VALE_MAX='OUI',VALE_MIN='OUI',
        ),
    ),
);
```

4.16 Printing some others results in ASCII file *.resu*

Then we put some stress results, all components for every element in the specified groups in the *.resu* file.

```
IMPR_RESU(
    MODELE=model,
    FORMAT='RESULTAT',
    RESU=(
        _F(
            RESULTAT=stat,
            NOM_CHAM='SIPO_ELNO',
            GROUP_MA=('topbeam','mast',),
            FORMAT_R='1PE12.3',
        ),
    ),
);
```

This is a rather restricted set printed to ASCII file, we may want more or different fields according to the study.

4.17 Printing results for graphical viewing, MED file

Finally we put in a *.med* file the results we want to be displayed, in graphical format in the Post-pro module of Gmsh.

```
#U7.05.21
IMPR_RESU(
    FORMAT='MED',
    UNITE=80,
    RESU=_F(
        #following lines print on the named groups,
        GROUP_MA=('topbeam','mast',),
        RESULTAT=stat,
        NOM_CHAM=(
            'DEPL',
            'SIEF_ELNO',
            'SIPO_ELNO',
            'SIPM_ELNO',
            'REAC_NODA',
        ),
    ),
);
```

4.18 Ending the command file with `FIN()`

Well not exactly finally, as the *.comm* file must be ended with the procedure `FIN()`, which like the procedure `DEBUT()` would take some arguments in a more complicated study.

```
#U4.11.02
FIN();
```

CHAPTER 5

Solving in ASTK

It works better if you plug it in.

Sattinger's law.

In this fifth chapter, we assemble the mesh file produced in chapter 3 with the command file produced in chapter 4 in a **code_aster** study using ASTK.

We run this study and look at the results in Gmsh.

5.1 Introducing ASTK for the analysis

Here, we run the study in a tool named ASTK. ASTK, whose name is the contraction of ASTER and TK, is a powerful tool allowing to put together very complex studies in a relatively simple graphical interface.

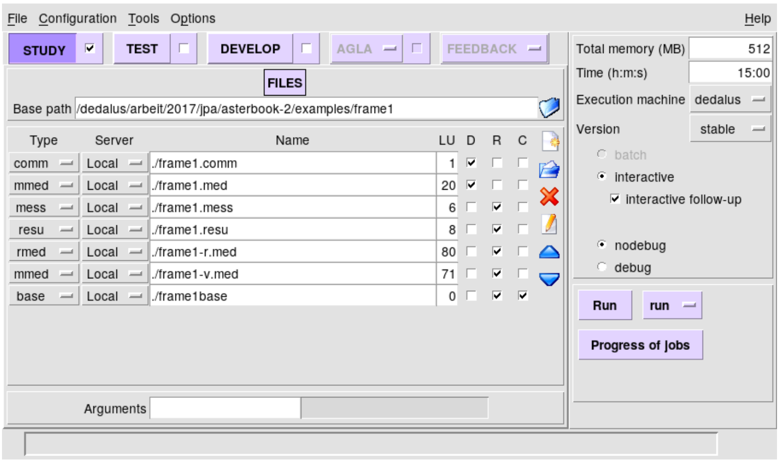
ASTK may be launched from a stand alone **code_aster** installation[1].

The ASTK handling is well described in U1.04.00.

Once launched a window like figure 5.1 appears[2].

[1] Where it stands in *$ASTER_ROOT/bin*.

[2] Here it is filled up, otherwise, at first, it is empty.



[✓ STUDY] TEST DEVELOP

Base path /dedalus/arbeit/2017/jpa/asterbook-2/examples/frame1

Type	Server	Name	LU	D	R	C
comm	Local	./frame1.comm	1	✓		
mmed	Local	./frame1.med	20	✓		
mess	Local	./frame1.mess	6		✓	
resu	Local	./frame1.resu	8		✓	
rmed	Local	./frame1-r.med	80		✓	
mmed	Local	./frame1-v.med	71		✓	
base	Local	./frame1base	0		✓	✓

Total memory (MB) 512
Time (h:m:s) 15:00
Execution machine dedalus
Version stable
batch [✓ interactive]
[✓ interactive follow-up]
[✓ nodebug] debug

FIGURE 5.1: ASTK window

On the top part, right of Base path field, click on the icon looking like a directory, then navigate until reaching the study directory and select it.

In the main part of the window, we can what looks like an empty file lists. And a stack of icon on the right.

Let’s click on the second one from top, looking like a file, one to add some file to the study:

- choose the command file, *frame1.comm*;
- choose the mesh file file, *frame1.med*;

for these two files ASTK chooses by itself the LU number, respectively 1 and 20.

Let’s click on the top icon one to create some new lines of files:

- pull down the name list on the extreme left and choose mess to specify it as a message file, name it *./frame1.mess*, ASTK chooses by itself the LU number 6;

- pull down again the name list on the extreme left and choose resu to specify it as an ASCII result file, name it *./frame1.resu*, ASTK chooses by itself the LU number 8;
- pull down again the name list on the extreme left and choose rmed to specify it as a graphical result file in med format, name it *./frame1-r.med*, ASTK chooses by itself the LU number 80;
- pull down the name list on the extreme left and choose mmed to specify it as a med file, name it *./frame1-v.med*, in the column LU, Logical Unit change 20 to 71, that's what we have specified in the *.comm* file, uncheck the column D, standing for data and check the column R, standing for results as we want to write in this file.
- pull down the name list on the extreme left, this is the last time, and choose base to specify it as a base, name it *./frame1base*, in the column LU, Logical Unit type 0, that's should be done by default, uncheck the column D, standing for data and check the column R, standing for results as we want to write in this file[1].

Tick interactive follow-up and push the button Run. A terminal window should pop up. Once the terminal has disappeared, have a look in the *.mess* file to see if all went well.

ASTK is a powerful tool offering a rather sophisticated handling of jobs, like chaining multiple *.comm* file and multiple output files and much more...
However we have to go back to Gmsh to open the *.med* results file to see what the results looks like.

A few more notes about ASTK:

- on the right side of the **ASTK** window, we can change the Total memory and the Time allocated to the job;
- the file extensions are not mandatory at all and we can use whatever we like, or none at all[2];

[1] We are going to use this date base later on, not in *./frame1* example.
[2] Like any file in the Unix world!

- except for 1, 6 and 8 the LU may be also chosen as one desires;
- Options » ncpus= allows to choose the number of CPU, or cores, dedicated to the job[1][2].

5.2 Viewing the results in Gmsh

We can open the med result file in Gmsh. On the left-hand side in the tree, we can see under Post_processing 5 lines for every one of the 5 fields we saved in the med file. Likewise there are scalar bars in the graphic window.

In the tree untick the values until only stat__DEPL remains ticked and is the only visible field in the graphic window.

Only the ticked views in the tree are visible in the graphic window.

Push the little arrow on the right-hand side to the menu Options which opens a dialog window, this window allows to make change to the display in the graphic window.

First of all it is a good idea to go in Tools » Options » Mesh » Visibility and uncheck everything so the post-processing view is not polluted by some mesh views[3]. Pushing the keys < Alt> + M also hides the mesh, or push the 'M' in the status bar.

Another good idea to go in Tools » Options » Color and uncheck the button Enable lighting in the post processing View[x]. With this the color mapping of results is independent of any light source, otherwise it may become unreadable in areas which are in the shade from the light source.

5.2.1 Handling the steps

To choose the step, we go to the General tab and increase or decrease the list right of Time step, either by typing a value or using the - and + buttons.

[1] This is for standard, non parallel version of **code_aster** .
[2] It is not advised to use more than half the number of cores.
[3] Though sometimes it is useful to see the mesh.

Whatever was the step numbering scheme chosen in **code_aster** Gmsh always starts at 0, likewise the views are also numbered from 0.

And the pull down menu Time display in Tools > Options > Visibility allows to set a sensible display in the title bar, here we are going to choose Time series that fits best the numbering policy chosen in the *.comm* file.

The other options will come handy on other opportunities.

5.2.2 Displaying displacement

To view the deformed shape:

1. in the Visibility tab pull the lower left list to Force vector;
2. in the Aspect tab pull the Vector display list to Displacement;
3. choose a significant value for Displacement factor.

Figure 8.5 shows the deformed shape[1].

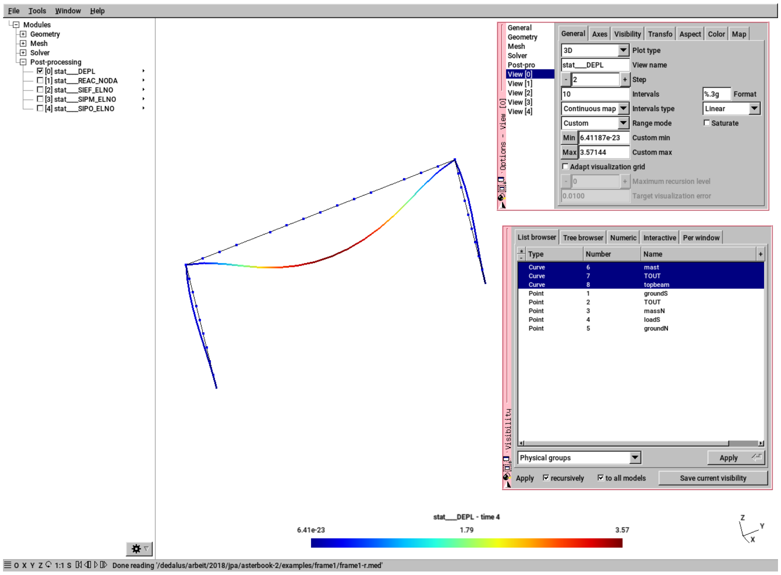
To view individual components:

1. in the Visibility tab pull the lower left list to Force scalar;
2. in the box immediately to the right type in the field Id (Id is 0 for `DX`, 1, is for `DY`, and so on);
3. in the General tab pull the list Range mode to Custom;
4. and push the Min and Max buttons to refresh the display with the proper component values.

To view numerical values:

1. in the General tab pull the list right of Interval types to Numeric values;
2. in the Aspect tab pull the Glyph location list to Vertex to display the values at the nodes.

[1] Note the view restricted to some groups in **Visibility** dialog box, and the mesh has been made visible for lines.



- ☑ [0] stat___DEPL
- ☐ [1] stat___REAC_NODA
- ☐ [2] stat___SIEF_ELNO
- ☐ [3] stat___SIPM_ELNO
- ☐ [4] stat___SIPO_ELNO

3D	Plot type		
stat___DEPL	View name		
2	Step		
10	Intervals	%.3g	Format
Continuous map	Intervals type	Linear	
Custom	Range mode	☐ Saturate	
Min 6.41187e-23	Custom min		
Max 3.57144	Custom max		

☐ Adapt visualization grid

0	Maximum recursion level
0.0100	Target visualization error

Type	Number	Name
Curve	6	mast
Curve	7	TOUT
Curve	8	topbeam
Point	1	groundS
Point	2	TOUT
Point	3	massN
Point	4	loadS
Point	5	groundN

Physical groups

Apply ☑ recursively ☑ to all models

stat___DEPL - time 4

6.41e-23 1.79 3.57

Done reading '/dedalus/arbeit/2018/jpa/asterbook-2/examples/frame1/frame1-r.med'

FIGURE 5.2: Gmsh view of displacement at INST 4, superimposed on the undisplaced mesh

5.2.3 Displaying forces an moment in beam element

Select and make visible the view stat__SIEF_ELNO Here the view of the field as Vector display is meaningless! To view individual components:

1. in the Visibility tab, pull the lower left list to Force scalar;
2. in the box immediately to the right, type in the field Id (Id is 0 for N, 3 is for MT, 4 is for MFY, and so on);
3. in the General tab pull the list Range mode to Custom;
4. and push the Min and Max buttons to refresh the display with the proper component values.

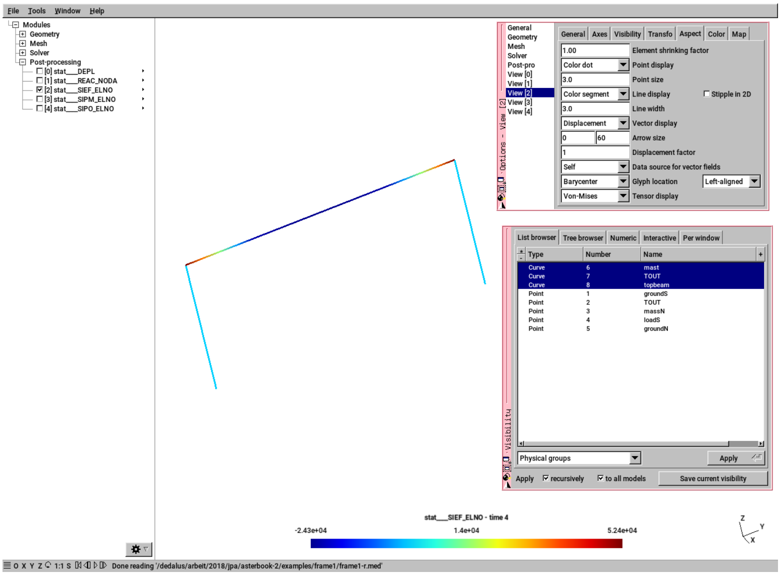
To view numerical values:

1. in the General tab pull the list right of Interval types to Numeric values;
2. in the Aspect tab pull the Glyph location list to Vertex to display the values at the nodes, which sometimes may produce a very cluttered view, or Barycenter to display the values in the middle of the element.

To restrict the view to some groups:

1. in the Gmsh menu Tools choose Visibility;
2. in the Physical groups options restrict the views to whichever groups we want.

Figure 5.3 shows value of the field `SIEF_ELNO` component `MFY`.



☐ [0] stat___DEPL
☐ [1] stat___REAC_NODA
☑ [2] stat___SIEF_ELNO
☐ [3] stat___SIPM_ELNO
☐ [4] stat___SIPO_ELNO

1.00	Element shrinking factor
Color dot	Point display
3.0	Point size
Color segment	Line display ☐ Stipple in 2D
3.0	Line width
Displacement	Vector display
0 60	Arrow size
1	Displacement factor
Self	Data source for vector fields
Barycenter	Glyph location Left-aligned
Von-Mises	Tensor display

Type	Number	Name
Curve	6	mast
Curve	7	TOUT
Curve	8	topbeam
Point	1	groundS
Point	2	TOUT
Point	3	massN
Point	4	loadS
Point	5	groundN

Physical groups
Apply ☑ recursively ☑ to all models

stat___SIEF_ELNO - time 4
-2.43e+04 1.4e+04 5.24e+04

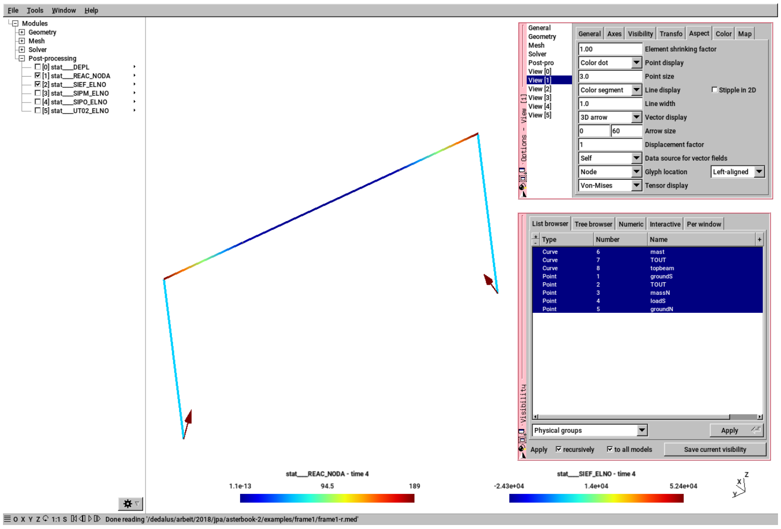
Done reading '/dedalus/arbeit/2018/jpa/asterbook-2/examples/frame1/frame1-r.med'

FIGURE 5.3: Gmsh view of `SIEF_ELNO`, `MFY` at `INST` 4

5.2.4 Adding reaction vectors

1. tick the view REAC_NODA;
2. choose it in the Options window;
3. in the Aspect tab pull the Vector display list to Arrow;
4. in the Aspect tab pull the Glyph location list to Vertex to display the values at the nodes;
5. in the General tab pull the list Range mode to Custom;
6. and push the Min and Max buttons to refresh the display with the proper component values;

so as to produce a view similar to 5.4.



☐ [0] stat___DEPL
☑ [1] stat___REAC_NODA
☑ [2] stat___SIEF_ELNO
☐ [3] stat___SIPM_ELNO
☐ [4] stat___SIPO_ELNO
☐ [5] stat___UT02_ELNO

1.00	Element shrinking factor
Color dot	Point display
3.0	Point size
Color segment	Line display ☐ Stipple in 2D
1.0	Line width
3D arrow	Vector display
0 / 60	Arrow size
1	Displacement factor
Self	Data source for vector fields
Node	Glyph location Left-aligned
Von-Mises	Tensor display

Type	Number	Name
Curve	6	mast
Curve	7	TOUT
Curve	8	topbeam
Point	1	groundS
Point	2	TOUT
Point	3	massN
Point	4	loadS
Point	5	groundN

Physical groups Apply

Apply ☑ recursively ☑ to all models Save current visibility

Done reading '/dedalus/arbeit/2018/jpa/asterbook-2/examples/frame1/frame1-r.med'

FIGURE 5.4: Gmsh view of SIEF_ELNO, MFY plus reactREAC_NODA vectors at INST 4

5.3 Looking at ASCII results

5.3.1 Printing RESULTAT

It is easy to read the *.resu* file with any text editor.

First is the printout of the reaction sum:

```
#
#-------------------------------------------------------------------------------
#
#ASTER 11.03.22 CONCEPT sum_reac CALCULE LE 25/06/2013 A 06:58:46 DE TYPE
#TABLE_SDASTER
 INTITULE         RESU      NOM_CHAM          NUME_ORDRE     INST           RESULT_X
RESULT_Y      RESULT_Z      MOMENT_X      MOMENT_Y      MOMENT_Z
 sum reactions              REAC_NODA                     1      2.000E+00      0.000E+00
0.000E+00      0.000E+00      0.000E+00      0.000E+00      0.000E+00
 sum reactions              REAC_NODA                     2      3.000E+00      8.834E-27
8.811E-12      2.089E+02      6.750E+04     -1.692E-11     -3.061E-24
 sum reactions              REAC_NODA                     3      4.000E+00      1.516E-26
1.137E-13      3.439E+02     -8.731E-11     -2.932E-11     -3.292E-24
 sum reactions              REAC_NODA                     4      5.000E+00      2.913E-26
-2.274E-13      6.439E+02     -1.746E-10     -5.634E-11     -6.151E-24
 sum reactions              REAC_NODA                     5      6.000E+00      9.137E-27
-1.137E-13      2.000E+02     -7.276E-11     -1.801E-11     -1.954E-24
```

Then the printout of the maximum displacement, component DZ, for the ’topbeam’ group:

```
-------------------------------------------------------------------------------
 ASTER 11.03.22 CONCEPT stat CALCULE LE 25/06/2013 A 06:58:46 DE TYPE EVOL_ELAS

                   ENTITES TOPOLOGIQUES SELECTIONNEES
 GROUP_MA : topbeam


 ======>

 ------->
 CHAMP AUX NOEUDS DE NOM SYMBOLIQUE  DEPL
 NUMERO D'ORDRE: 1 INST:      2.000E+00

 LA VALEUR MAXIMALE DE DZ       EST     0.000E+00 EN   17 NOEUD(S) : N2
 LA VALEUR MINIMALE DE DZ       EST     0.000E+00 EN   17 NOEUD(S) : N2

 ======>

 ------->
 CHAMP AUX NOEUDS DE NOM SYMBOLIQUE  DEPL
 NUMERO D'ORDRE: 2 INST:      3.000E+00

 LA VALEUR MAXIMALE DE DZ       EST    -1.534E-03 EN    1 NOEUD(S) : N2
 LA VALEUR MINIMALE DE DZ       EST    -2.116E+00 EN    1 NOEUD(S) : N26

 ======>

 ------->
 CHAMP AUX NOEUDS DE NOM SYMBOLIQUE  DEPL
 NUMERO D'ORDRE: 3 INST:      4.000E+00

 LA VALEUR MAXIMALE DE DZ       EST    -4.531E-03 EN    1 NOEUD(S) : N5
 LA VALEUR MINIMALE DE DZ       EST    -3.571E+00 EN    1 NOEUD(S) : N4

 ======>
 ------>
 CHAMP AUX NOEUDS DE NOM SYMBOLIQUE  DEPL
 NUMERO D'ORDRE: 4 INST:     5.000E+00

 LA VALEUR MAXIMALE DE DZ       EST   -8.708E-03 EN    1 NOEUD(S) : N5
 LA VALEUR MINIMALE DE DZ       EST   -6.772E+00 EN    1 NOEUD(S) : N4

 ======>

 ------>
 CHAMP AUX NOEUDS DE NOM SYMBOLIQUE  DEPL
 NUMERO D'ORDRE: 5 INST:     6.000E+00

 LA VALEUR MAXIMALE DE DZ       EST   -2.785E-03 EN    1 NOEUD(S) : N5
 LA VALEUR MINIMALE DE DZ       EST   -2.133E+00 EN    1 NOEUD(S) : N4
```

5.3.2 Printing results in TABLE

We can print results with IMPR_TABLE or with IMPR_RESU... FORMAT='RESULTAT'. The printed results have, of course, the same value as long as we print the same thing; the appearance may be more pleasing in RESULTAT or in TABLE mode, this a matter of taste.

TABLE makes it easier to export to a spreadsheet. And for this a clever use of the keyword SEPARATEUR allows more exporting flexibility to the output file.

The object TABLE allows many manipulations with some Python code which may be very helpful. Later in this book there are a few examples of tables manipulated with Python.

5.4 Verifying the results

What we have here is not quite a simple problem which could be easily solved by hand, we would need to apply the virtual work theory, leading to a lengthy process of solving a set of 3 equations with 3 unknown variables[1].

However a first critical look at the ASCII results shows:

- at INST=2, reactions are null, as expected there is no load;

[1] This is what **code_aster** does, with a few more equations!

- at `INST=3`, the sum of the vertical reactions is equal to 13.5 times the mass (with due allowance to units and the value of 10 we used for g), the reactions are not symmetrical as expected as a 10 kg mass is sitting at a quarter of the length of the top beam, on 'massN', again as expected;
- at `INST=4`, the sum of the reactions is equal to 13.5 times the mass plus the 135 N force on 'loadS', the reactions are now symmetrical as the 135 N force balances the 10 kg mass, multiplied by the 1.35 factor, again as expected;
- at `INST=5`, the sum of the reactions is increased by 300 N, that's the "distributed load" applied on 'topbeam' with its 1.5 multiplier, again as expected;
- and at `INST=6`, the sum of the reactions is just 200 N, balancing the "distributed load" applied on 'topbeam' with its 1.0 multiplier, all good.

And we should always perform this type of simple checkup, and if it is not "as expected", something is wrong somewhere and should be sorted out. The following tables summarize what are the right[1] results for *frame1* example:

code_aster INST			2	3	4
maximum vertical displacement	DZ	mm	0	-2.116	-3.571
'topbeam' max bending moment	MFY	Nmm	0	3.54E+04	5.24E+04
'topbeam' min bending moment	MFY	Nmm	0	-2.45E+04	-2.43E+04
'groundS' vertical reaction	DZ	N	0	64.33	171.94
'groundN' vertical reaction	DZ	N	0	144.54	171.94
'groundS' moment reaction	DRX	Nmm	0	-2.07E+04	-2.60E+04
'groundN' moment reaction	DRX	Nmm	0	8.04E+03	2.60E+04

code_aster INST			5	6
maximum vertical displacement	DZ	mm	-6.772	-2.133
'topbeam' max bending moment	MFY	Nmm	9.57E+04	2.88E+04
'topbeam' min bending moment	MFY	Nmm	-5.16E+04	-1.82E+04
'groundS' vertical reaction	DZ	N	321.94	100.00
'groundN' vertical reaction	DZ	N	321.94	100.00
'groundS' moment reaction	DRX	Nmm	-4.74E+04	-1.43E+04
'groundN' moment reaction	DRX	Nmm	4.74E+04	1.43E+04

[1] Right? More exactly the one calculated on my computer!

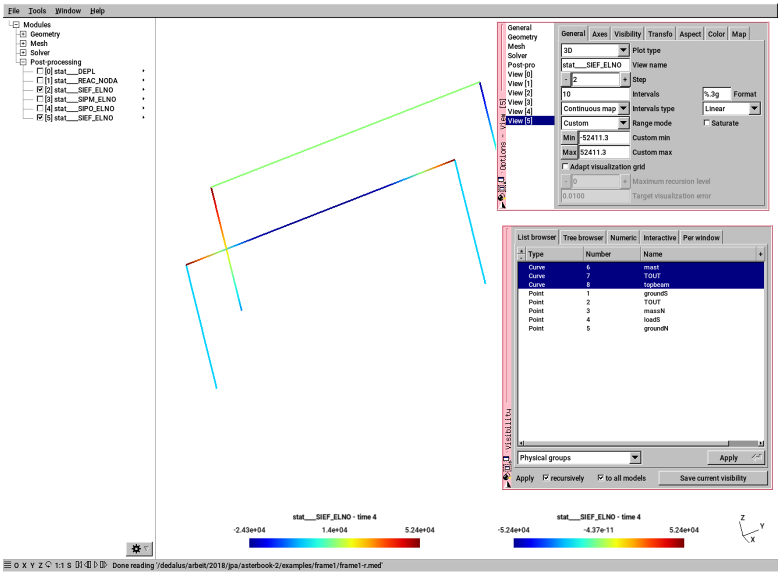
5.5 Spotting a mistake?

Taking a closer look at figure 5.3 we can see a $5.24E4$ value for the bending moment MFY in the ’topbeam’ at the corner where it joins the mast, but the value of the same field MFY seems to be rather different, in fact it is null, in the ’mast’ at the same corner. As the connection is rigid shouldn’t we have the same value in each member?

Have we spotted a mistake in the calculation?

YES but NO!

If we display the value of MFZ we can see the same value of $5.24E4$ for the bending moment MFZ in the ’mast’. Figure 5.5 shows the two result values on the same picture, MFY at the bottom and MFZ at the top.



- ☐ [0] stat___DEPL
- ☐ [1] stat___REAC_NODA
- ☑ [2] stat___SIEF_ELNO
- ☐ [3] stat___SIPM_ELNO
- ☐ [4] stat___SIPO_ELNO
- ☑ [5] stat___SIEF_ELNO

3D	Plot type		
stat___SIEF_ELNO	View name		
2	Step		
10	Intervals	%.3g	Format
Continuous map	Intervals type	Linear	
Custom	Range mode	☐ Saturate	
Min -52411.3	Custom min		
Max 52411.3	Custom max		
☐ Adapt visualization grid			
0	Maximum recursion level		
0.0100	Target visualization error		

Type	Number	Name
Curve	6	mast
Curve	7	TOUT
Curve	8	topbeam
Point	1	groundS
Point	2	TOUT
Point	3	massN
Point	4	loadS
Point	5	groundN

Physical groups — Apply ☑ recursively ☑ to all models

Done reading '/dedalus/arbeit/2018/jpa/asterbook-2/examples/frame1/frame1-r.med'

FIGURE 5.5: MFY in ’topbeam’ equals MFZ in ’mast’ at corner

The answer is that the local axis of the ’topbeam’ and ’mast’ groups are not oriented in the same direction, this is explained in chapter 6.3 .

CHAPTER 6

Understanding some details

Dimensions will always be expressed in the least usable terms. For example, velocity will be expressed in furlongs/fortnight.

Murphy's law.

Before refining the model and the analysis we make a pause to go deeper into some details like:

- units;
- some **code_aster** jargon related to stress results;
- beam elements orientation;
- understanding the various messages of the *.mess* file;
- the "Overwriting" rule.

6.1 Dealing with units

The previous model has its lengths in millimeters, its forces in Newton and its time in seconds. In such a system we need to express the mass in tons and the mass density in t/mm^3. These oddities, though common in the world of engineering are necessary to form an homogeneous system of units.

In *frame1* example: the volume of the element is calculated by **code_aster** in cubic mm which multiplied by the mass density gives us mass in ton, which again multiplied by an acceleration, which is implied in mm per square seconds, gives us kilograms multiplied by meters divided by squared seconds also known as Newton. Then the forces results are in Newton, N, the moments results in $N.mm$ and the stresses in N/mm^2.

All this to say that **code_aster** is not aware of the units we use, given a set of units as entries it produces results in a set of homogeneous units.

The following table summaries the two mostly used mechanical engineering sets of units, “mm.t.s” and “SI”, also known as “ISO”, with a few typical values [1]:

	physical quantity	dimension	mm.t.s	SI
base units	length	L	mm	m
	mass	M	t	kg
	time	T	s	s
	temperature	$\circ$	K	K
derived units	angle	1	rad	rad
	frequency	T^{-1}	Hz	Hz
	force	$M.L.T^{-2}$	N	N
	pressure, stress	$M.L^{-1}.T^{-2}$	N/mm^2	N/m^2
	mass density	$M.L^{-3}$	t/mm^3	kg/m^3
example, steel	mass density	$M.L^{-3}$	7.80E-09	7800
example, gravity	acceleration	$L.T^{-2}$	9810	9.81
example, steel	Young modulus	$M.L^{-1}.T^{-2}$	210000	2.10E11

[1] For temperature the base unit is Kelvin degree, everyday Celsius degree scale uses the same increment, but Farenheit does not.

6.2 Understanding SIEF, SIPO, SIPM...

The fields DEPL and SIEF_ELGA are calculated even if we do not request it in CALC_CHAMP. Calculation and/or printing of any field can be restricted to one or more of its component with NOM_CMP.

Field DEPL means displacement.

The field SIEF_ELGA means SIgma (stress) or EFfort (force or moment), per ELement at GAuss points.

The field SIEF_ELNO means SIgma (stress) or EFfort (force or moment), per ELement at NOde.

With due allowance to stress or effort these two fields are meaningful whatever the element.

For beam[1] elements, the field SIEF_ELNO means EFfort (force or moment), per ELement at NOdes. From a practical point of view it contains the normal force, N, the 2 shear forces, VY and VZ, and the 3 moments, MT, MFY and MFZ in the beam, in its LOCAL axis[2].

The field EFGE_ELNO means EFfort (force or moment), GEneralised, per ELement at NOdes, in the element local axis, it contains the same components as SIEF_ELNO and for any practical purpose shows the same things. The same applies at GAuss points for EFGE_ELGA.

For beams[3], the field SIPO_ELNO means Stress (SIgma POutre), per ELement at end NOdes. This is the stress produced by any of the three forces and moment defined in SIEF_ELNO if they were acting alone on the beam section. For example SMFY is the stress due to the single bending moment MFY, it is computed from MFY above and the beam characteristics, defined in AFFE_CARA_ELEM...POUTRE[4].

SIPM_ELNO[5] (SIgma Poutre Maximum) gives the component of the stress in the direction of the last 2 characters of the component name.

---

[1] Or more generally 1D line elements.

[2] For plates it would be NXX (with the unit of N/mm), NXY, NXY, MXX... in the local element axis. And for 3D elements, pure stresses SIXX, SIYY, SIZZ, SIXY... in the global axis .

[3] And for beams only, this field is restricted to beams.

[4] Here, $\mathtt{SMFY} = \frac{\mathtt{MFY}}{\mathtt{IY}} \times \mathtt{RZ}$.

[5] Same remark as above.

The most important SIXX, can be seen as the extremum, maximum or minimum, normal stress, i.e. the addition of the normal stresses due to the normal force and the two bending moments, beware no shear component here.

As expected the SIPM_ELNO field cannot be calculated on SECTION='GENERALE' beam elements, just as well a SECTION='RECTANGLE', cannot be used if the walls are too thin[1].

For beam elements, another important note is: the stress due to the torsional moment is only true if the "Saint Venant" conditions are achieved, that is to say there is no warping of the section. Which is more and more false as the section differs from a round and closed one to an open one, and/or if the warping is restrained by boundary conditions[2]. The actual stress may then be much higher, by a factor which can be ten or more, the problem then cannot strictly be solved by this type of beam analysis. This is a classical problem of stress analysis described in many text books. Using solid elements connected to beams can be an alternative, this is described in chapter 14.3 .

Another important note: some post processors propose as the first choice of a field the option modulus, which is the "modulus" of the vector formed by the sum of the first three components. For displacement this is the sum of the first three, DX, DY, DZ and is thus a meaningful value[3]. For some other fields like SIEF_ELNO or SIPO_ELNO this modulus has therefore no engineering meaning and should never be looked at as a serious information.

For plates, the fields SIEF_ELGA and SIEF_ELNO give 9 components, the first three being the normal forces, 'N..', the next three the moments, 'M..', and the last three the shear forces, 'V..', in the element LOCAL axis.

Document U2.01.05, named "Stresses, forces and strain", is a useful reference regarding this matter.

[1] Because for thin walls the formula use by **code_aster** to calculate the shear coefficient gives a wrong value.

[2] Some type of beam elements like POU_D_TG take warping restrain into account.

[3] Just as well for reactions.

6.3 Orienting beam elements

As we have seen in chapter 5.5 , not understanding the orientation of beam local axis may lead: at best to improper result interpretation, at worst to completely erroneous results.

In this example the ’topbeam’ group has its local Y axis lying in the XOY global plane. It is the same for the ’mast’ group but since the elements are strictly lying on the global Z axis, the local Y axis is strictly lying in the global Y axis. Figure 6.1 shows the beam orientation as defined in the original *.geo* and *.comm* files.

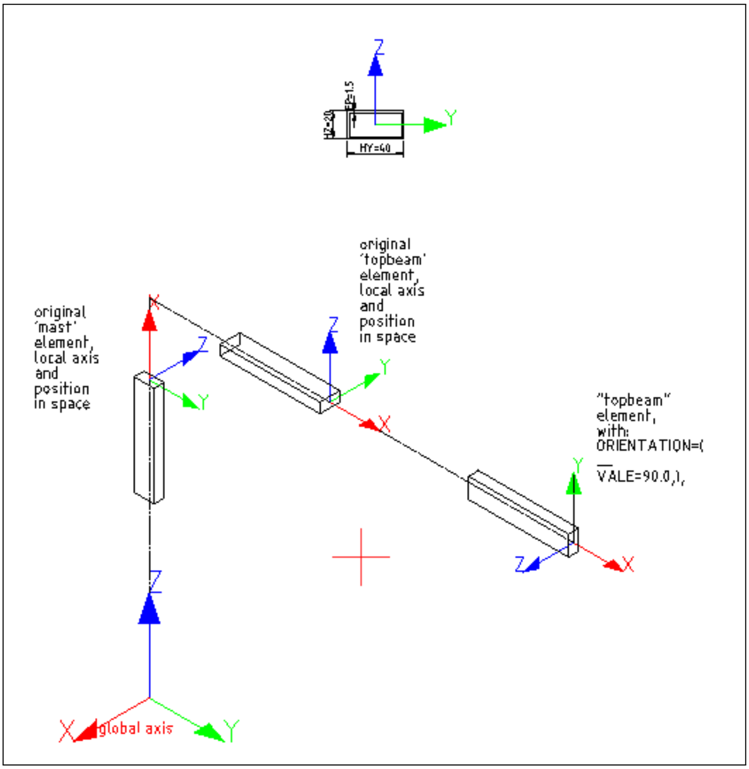

Z
Y
HZ=20
EP=1.5
HY=40
original 'topbeam' element, local axis and position in space
original 'mast' element, local axis and position in space
"topbeam" element, with: ORIENTATION=(VALE=90.0,),
X
Z
Y
X
Z
Y
Y
Z
X
Z
X
global axis
Y

FIGURE 6.1: Original orientation and orienting the ’topbeam’ elements

To modify this, we search for these lines in the *frame1.comm*:

```
      #ORIENTATION=_F(
          #GROUP_MA=('mast',),
          #CARA='VECT_Y',
          #VALE=(1.0, 0.0, 0.0,),
      #),
```

Un-comment them, this puts the local y axis of mast beam pointing in the global X direction and produces a continuous `MFY` in 'mast' and 'topbeam' groups.

Search again for these other lines in the *frame1.comm*:

```
      #ORIENTATION=_F(
          #GROUP_MA=('topbeam',),
          #CARA='ANGL_VRIL',
          #VALE=90.0,
      #),
```

Un-comment them and change `VALE` to 90.0[1], so it becomes:

```
      ORIENTATION=_F(
          GROUP_MA=('topbeam',),
          CARA='ANGL_VRIL',
          VALE=90.0,
      ),
```

If we run the calculation, we can see a reduced maximum displacement. In fact the rectangular section of the top bar (group 'topbeam') was originally lying on its flat side and we have turned it 90 degrees along its own axis so it now lies vertically, just like in the figure 6.1.

The rule for the orientation of the local axis of beams[2] in **code_aster** is very simple:

- the local x axis lies along the beam;
- the local y axis lies by default in the global XOY plane;
- and the local z completes the trihedron.

Here "by default" means: the keyword `ORIENTATION` is not specified in the *.comm* file for the given group.

[1] Here the angles are given in degrees, somewhere else in radians! One has to be careful.
[2] Or any line element.

If the beam is strictly parallel to the global Z axis, the beam y local axis is then exactly coincident with the global Y axis.

If we have a circular array of vertical beams along the Z axis around a circle in the XOY plane and want them to have a rectangular section pointing towards the center of the circle, the trick is to offset them slightly from vertical, just enough so that the tangent of the angle is not null.

In the following figures, we have a few cases depicting beam orientation[1]:

- In figure 6.2, a circular array of three beams of rectangular section, lying "on their flat" at an angle of 30° on the global horizontal plane XOY, without any `ORIENTATION` keyword.

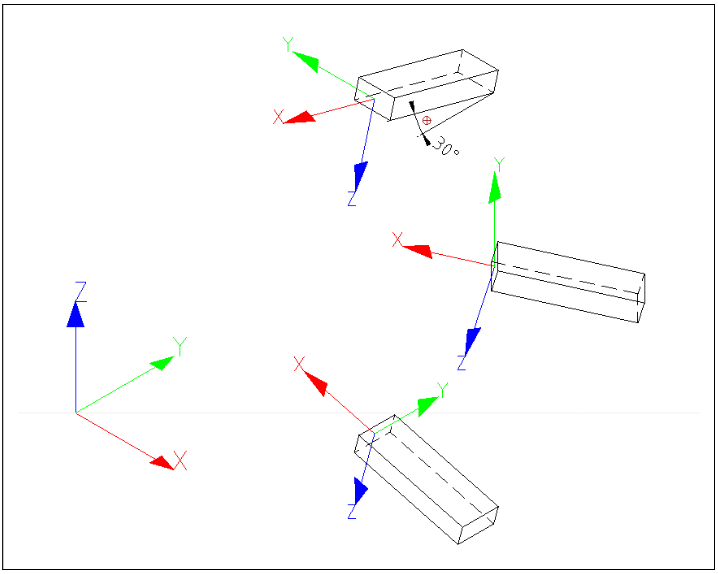


FIGURE 6.2: Circular array of beam, y local axis lying in the global XOY plane

[1] In these figures the global axis Z is vertical

- In figure 6.3, a similar array with the beams lying exactly vertical, *strictly* parallel to Z global axis, without any `ORIENTATION` keyword, note the local y axis pointing in Y global axis.

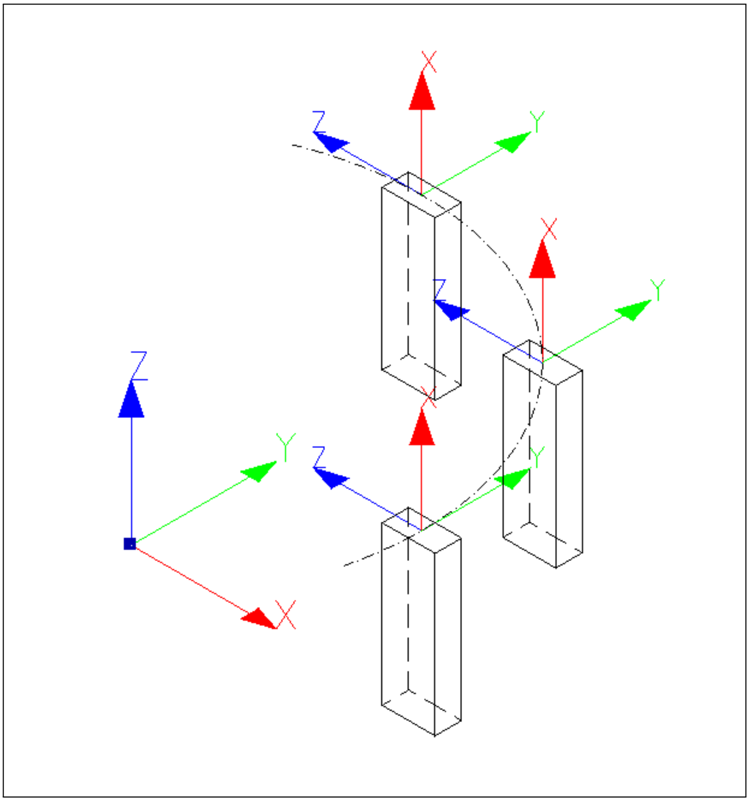


FIGURE 6.3: Circular array of beam, , local x axis strictly vertical, y local axis lying in the global XOY plane and pointing in Y direction

- Figure 6.4, is almost like figure 6.3 but the x local axis is turned a bit so as to be off vertical[1], note the local axis z pointing towards the center of the global coordinate system.

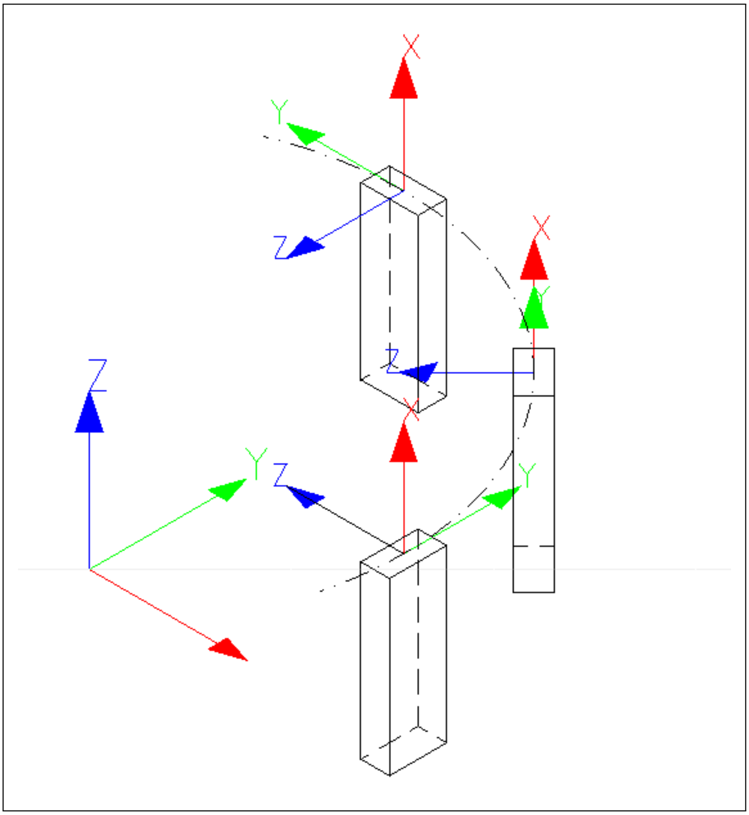


FIGURE 6.4: Circular array of beam, local x axis slightly offset from vertical z local axis lying in the global XOY plane and pointing towards the array's center

[1] The beams are not exactly parallel.

- Figure 6.5 shows almost the same case as n figure 6.2, but the third beam at the top of the figure is rotated by 90° with the keywords `ORIENTATION=_F(....,CARA='ANGL_VRIL', VALE=90.0,),`.

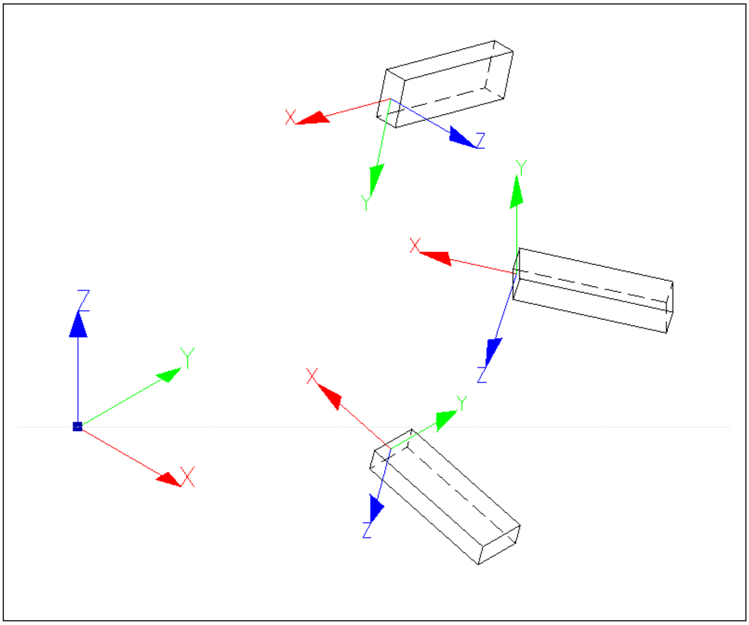


FIGURE 6.5: One beam rotated 90° with `ORIENTATION=_F(.... CARA='ANGL_VRIL', VALE=90.0,)`

- In figure 6.6, the two beams occupy an identical position in 3D space but the order of their nodes is inverted.

As a general rule I advise to build the mesh with:

- global Z is the vertical, earth gravity direction, pointing upward;
- global X is the principal direction of the mesh, the direction of motion for a mobile object (road vehicle, airplane or ship);

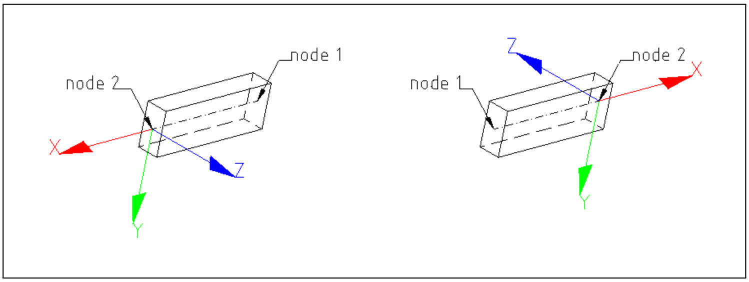


FIGURE 6.6: Node order reversed

- global Y completes the trihedron.

Another way to define the orientation of beam element, or group of beam element, is to use the following syntax:

```
        ORIENTATION=_F(
             GROUP_MA=('topbeam',),
             CARA='VECT_Y',
             VALE=(0.0, 0.0, 1.0),
        ),
```

which orients the local Y axis in the direction of the global Z axis.

Again document U4.42.01 gives all the instructions, and more keywords, on how to change the orientation of the local axis.

When we perform any change of orientation of one beam, we of course change its local axis, this has to be kept in mind to understand the forces and stresses results. This applies also to the forces applied along the beam if defined with the keyword `REPERE='LOCAL'`, and may lead to exactly the reverse of what we expected!

Once we have fully understood the principles of beam orientation in **code_aster** and applied them in the mesh and groups of element we may well find it is hardly ever necessary to use anything but the keyword `ANGL_VRIL` to model any practical model. However when we are in doubt about some orientation it is always a good idea to perform a "dummy" analysis with loads and boundary conditions restricted to the very area raising the doubt and to check the results at various orientations with a quick hand calculation[1].

6.4 Finding it out when things go wrong

In this first example all went well and we got a result at the first try[2]. Let's say this is an exception. We, more than often, have some kinds of errors in the early stages. The only way around is to look at the *.mess* file, the different kinds of errors are quite explicitly described and the *.comm* file can be corrected accordingly.

At the beginning of a project there, most probably, are many syntax errors, and it can make debugging a rather tedious process. Even when the calculation gives a result there may be warnings in the *.mess* file. As is usually stated in the warning itself we must understand what it means before taking the results for granted.

Here is the end of the *.mess* file in case of success:

```
EXECUTION_CODE_ASTER_EXIT_9671=0
```

`=0` means no error, no warning. `9671` is the job ID, in case of problems we find some files with this ID in *$HOME/flasheur* directory.

Here is the end of a *.mess* file with a typical Syntax Error:

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! erreur de syntaxe,
  Erreur de nom:
  name 'DEFI_GROUPE' is not defined ligne 11                !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

We should have typed `DEFI_GROUP` instead of `DEFI_GROUPE`.

If we have `=1` instead of `=0` at the end of the file, we must look higher in the file until we find something like this:

```
!-----------------------------------------------------------!
! <EXCEPTION> <MODELISA7_75>                                !
!                                                           !
! le GROUP_NO couron ne fait pas partie du maillage :       !
! maillage                                                  !
```

[1] In chapter 18.2 we explain how to draw in a Gmsh graphical window vectors showing the local beam axis.

[2] The guy, or girl, who typed all this command file without any error is a lucky one!

```
    !————————————————————————————————————————————————————————————!
```

The error description always begins with a < character. Here some command refers to the group ’couron’ which is not part of the mesh. We do not go any further in the description of errors and warnings as this is well documented in the *.mess* file.

And our ingeniousness in raising errors does not seem to have any limit.

A final note to point out is: if a fatal error is briefly repeated at the end of the *.mess* file, a more complete explanation is situated earlier in the same file, just by the command that generated the fatal error.

6.5 Understanding the “Overwriting” rule

This rule governs how keyword repetitions are handled in the *.comm* file, we give here some practical examples. This topic is explained in U1.03.00[1].

In this first example, we give to the group ’massN’, at first the property of a beam -which is wrong- and in a second sentence the property of a discrete element, only the second one is applied, luckily it is what we wanted. Swapping the two sentences would have raised an error as ’massN’ which is here a point element, cannot be a beam!

```
model=AFFE_MODELE(
    MAILLAGE=mesh,
    AFFE=(
        _F(
            GROUP_MA=('topbeam','mast','massN',),
            PHENOMENE='MECANIQUE',
            MODELISATION='POU_D_E',
        ),
        _F(
            GROUP_MA=('massN',),
            PHENOMENE='MECANIQUE',
            MODELISATION='DIS_T',
        ),
    ),
);
```

In this second example, we specify twice, a load on the same element (here a node).

[1] The translation of the french “Surcharge” by “Overload” in the machine translation of the English version of the documentation does not look satisfactory to me, and I prefer the word “Overwriting”.

```
cc=AFFE_CHAR_MECA(
    MODELE=model,
    FORCE_NODALE=(
        _F(GROUP_NO=('loadS',),FZ=-100,),
        _F(GROUP_NO=('loadS',),FX=2000,FZ=-1000,),
    ),
 );
```

The effective load taken into account in the calculation is `FX=2000, FZ=-1000`:

- the second instance `FZ=-1000` REPLACES the first one `FZ=-100`[1];
- the `FX=2000` of the second sentence is added to the load case[2].

We should always remember clearly this feature when specifying loads within a single `AFFE_CHAR_MECA`.

[1] Some finite element codes would have made the sum resulting in `FZ=-1100`.
[2] As it replaces a non existent item!

CHAPTER 7

Adding end release to the top bar

In this chapter, we slightly modify the first structure, adding end release to the top beam.

We use some parametric scripting capabilities of Gmsh.

It is obvious from the results of the preceding example that the top bar is rigidly linked to the top of the masts. What, if we want a rotation free joint? **code_aster** does not provide any built-in end release option at the end of a beam element. What we do is create a short (10 mm) line element in the mesh at this connection. Then we give it the properties of a discrete element `K_TR_D_L` as specified in U4.42.01. Appendix C 3.1 deals in more details with these elements.

7.1 Using parametric scripting in Gmsh

We take the opportunity to make a new *.geo* file and mesh, using some scripting capabilities of Gmsh to first of all create a new mesh. Here is the file:

```
cl1=100;
max=3;
pas=2;
ly=1000; //half length of frame along y
hz=1000; //height of frame along z
dly=10; //length of hinge along y
Point(1) = {0, 0, 1000, cl1};
//create Point
For i In {0:max:pas}
    Point(10+i) = {0,ly/2*(i−1), hz, cl1};
    Point(20+i) = {0,(ly−dly)*(i−1), hz, cl1};
    Point(30+i) = {0,ly*(i−1), hz, cl1};
    Point(40+i) = {0,ly*(i−1), 0, cl1};
EndFor
//create Line
top[]={}; //initialize list for top
hinge[]={}; //idem for hinge
mast[]={};
For i In {0:max:pas}
    Line(10+i) = {1, 10+i};
    top[]+=10+i; //add element in top list
    Line(20+i) = {10+i, 20+i};
    top[]+=20+i;
    Line(30+i) = {20+i, 30+i};
    hinge[]+=30+i; //add element in hinge list
    Line(40+i) = {30+i, 40+i};
    mast[]+=40+i;
EndFor
//makes  the group 'topbeam' with the list top,
Physical Line("topbeam") = top[];
Physical Line("hinge") =hinge[];
Physical Line("mast") = mast[];
Physical Point("groundS") = {40};
Physical Point("groundN") = {42};
Physical Point("loadS") = {10};
Physical Point("massN") = {12};
```

The first lines set the values of some control variables[1], then some of the frame dimensions which are used in the next loops to create the points. It should be noted that the points are named in a discontinuous order, this is allowed in Gmsh[2]. Next, we initialize some lists which we fill up in the next loop while creating the lines, to finally put these lists in Physical.

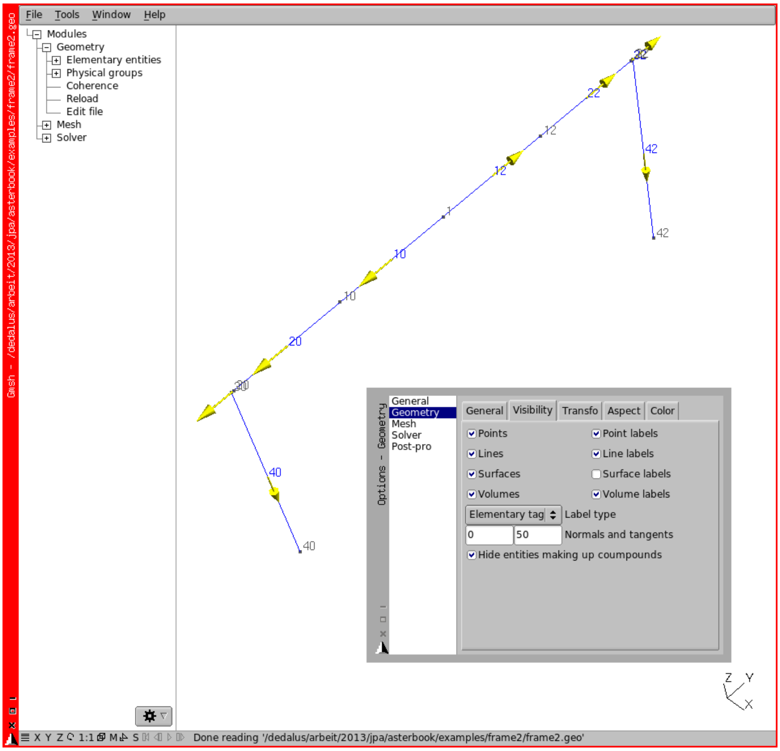
There is a feature in the loop creating the lines, it is the outward orientation of the created geometrical lines. In the **Gmsh** graphical window, if we set the Tangents field at a value of 100, like in figure 7.1, we can

[1] The hinge length is very small and is hardly visible in the graphical window at a normal scale, figure 7.2 is a zoom view on the discrete element n° 30 in black, with mast in red and top beam in green.

[2] This allows us to use some kind of "logical" numbering.

see the lines of the 'topbeam' oriented outwards. If we set a load with `FORCE_POUTRE`, with values related to element orientation like `N`[1] the force pulls outwards from the center, it may be what we want. If not the loop for creating the lines should be written differently[2].

However the **code_aster** `MODI_MAILLAGE ... ORIE_LIGNE` comes in handy to reorient line elements on request.



Gmsh - /dedalus/arbeit/2013/jpa/asterbook/examples/frame2/frame2.geo

- [✓] Points
- [✓] Point labels
- [✓] Lines
- [✓] Line labels
- [✓] Surfaces
- [ ] Surface labels
- [✓] Volumes
- [✓] Volume labels
- Elementary tag — Label type
- 0 | 50 — Normals and tangents
- [✓] Hide entities making up coumpounds

Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame2/frame2.geo'

FIGURE 7.1: 'frame2' with line orientation

[1] In tension along the beam.
[2] We wrote it this way here so as to illustrate the feature.

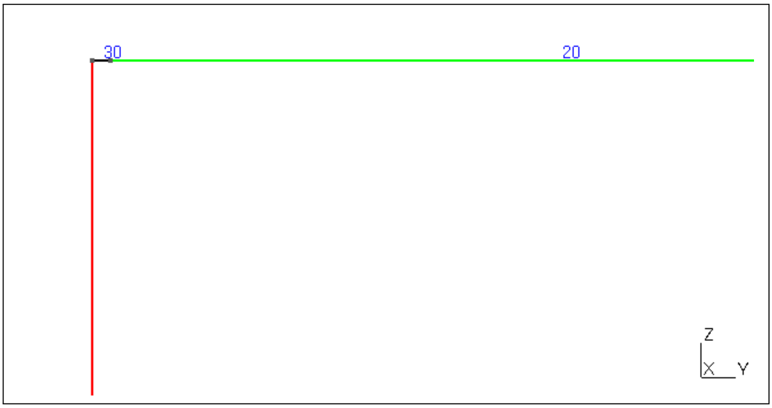


FIGURE 7.2: Zoom on the discrete line, n° 30, in black

7.2 Modifying the *.comm* file

As the line element may not be oriented exactly as we want we first reorient the top beam along the y global axis with a **code_aster** command:

```
#U4.23.04
mesh=MODI_MAILLAGE(
    MAILLAGE=mesh, reuse =mesh,
    ORIE_LIGNE=(
        #next lines reorient all the line element on 'topbeam'
        #along a vector lying along y global axis
        #with origin at node 'masseN
        _F(
            GROUP_MA='topbeam' ,
            VECT_TANG=(0, 1, 0,),
            GROUP_NO='massN' ,
        ),
        #next lines raise an error as the elements in 'mast'
        #are not all connected
        #we would have needed 2 groups 'mastN' and 'mastS'
        #like wise for the 'hinge' group
        #_F(
            #GROUP_MA='mast',
            #VECT_TANG=(0, 0, 1,),
            #GROUP_NO='groundN',
        #),
    ),
);
```

This is inserted juts after the DEFI_GROUP operator and though it is not strictly necessary for this simple example it comes useful with more demanding ones. Note: the elements within a group must be connected so as to apply this operator, if not, we have to split in more groups, which can become a bit tedious.

Secondly we modify AFFE_MODELE.

As said earlier we are going to use a discrete element 'K_TR_D_L' from U4.42.01. in this type of element:

- K stands for stiffness;
- TR for Translation and Rotation;
- D for diagonal only matrix (only 6 terms);
- and L for line (the element being a SEG2 mesh element).

```
model=AFFE_MODELE(
    MAILLAGE=mesh,
    AFFE=(
        ........................
        _F(
            GROUP_MA=('hinge',),PHENOMENE='MECANIQUE',
            MODELISATION='DIS_TR',
        ),
    ),
);
```

Then the ad-hoc lines to add in AFFE_CARA_ELEM are so:

```
    DISCRET=(
        ..........
        #here we define the hinges as an element
        #with very low stiffness 1e1 in rotation around
        #the X axis in GLOBAL coordinates
        _F(
            GROUP_MA=('hinge',),
            CARA='K_TR_D_L',
            VALE=(1e6,1e6,1e6,0,1e9,1e9,),
            REPERE='GLOBAL',
        ),
    ),
    ......................
```

The order of the six value is:

- stiffness in translation along X, Y, Z;

- stiffness in rotation around X, Y, Z;

we give relatively high value to all of them but for the rotation around X which is set to null[1].

X being here in 'GLOBAL' coordinate. In 'LOCAL' it would have been a free rotation around Y with the specified 'ORIENTATION'[2].

Note: the orientation of this discrete line element follows exactly the same rules as the one described earlier for beams.

7.3 Solving

This part is the same as for *frame1* example, see chapter 3.

We should just check, once the calculation is made, that the top bar is really articulated, that is to say no moments are transmitted to the masts. In fact a very small moment is transmitted due to the offset of the vertical load, the length of the hinge, on top of the mast.

7.4 Looking at ASCII results

This example, with the pinned end top beam, provides a very easy way to check up the result, for example the deflection for a simply supported beam subject to a distributed load is known as being:

$$DZ = \frac{5}{384}\frac{pL^4}{EI}$$

which in this case turns out to be:

$$DZ = \frac{5}{384} \times \frac{0.1 \times 1980^4}{210000 \times 11518} = 8.27$$

which compares to the printed results at `INST=6`

[1] Or a very small value.

[2] Appendix C 3.1 provides some formulas to hand calculate the matrix rigidity coefficients of a line member.

```
------------------------------------------------------------------------------
ASTER 11.03.22 CONCEPT stat CALCULE LE 25/06/2013 A 12:12:55 DE TYPE EVOL_ELAS

                  ENTITES TOPOLOGIQUES SELECTIONNEES
GROUP_MA : topbeam


======>

------->
CHAMP AUX NOEUDS DE NOM SYMBOLIQUE  DEPL
NUMERO D'ORDRE: 5 INST:     6.000E+00

LA VALEUR MAXIMALE DE DZ       EST   -2.885E-03 EN    2 NOEUD(S) : N4
LA VALEUR MINIMALE DE DZ       EST   -7.822E+00 EN    1 NOEUD(S) : N1
```

Likewise the maximum bending moment is:

$$MFY = \frac{pL^2}{8}$$

which in this case turns out to be[1]:

$$MFY = \frac{0.1 \times 1980^2}{8} = 49005$$

which compares to the printed results at `INST=6`

```
------------------------------------------------------------------------------
ASTER 11.03.22 CONCEPT stat CALCULE LE 25/06/2013 A 12:12:55 DE TYPE EVOL_ELAS

                  ENTITES TOPOLOGIQUES SELECTIONNEES
GROUP_MA : topbeam


======>

------->
CHAMP PAR ELEMENT AUX NOEUDS DE NOM SYMBOLIQUE  SIEF_ELNO
NUMERO D'ORDRE: 5 INST:     6.000E+00

LA VALEUR MAXIMALE DE MFY           EST     1.164E-10 EN    1 MAILLE(S) : M20
LA VALEUR MAXIMALE DE MFZ           EST     3.073E-13 EN    1 MAILLE(S) : M16
LA VALEUR MINIMALE DE MFY           EST    -4.635E+04 EN    1 MAILLE(S) : M5
LA VALEUR MINIMALE DE MFZ           EST    -3.073E-13 EN    1 MAILLE(S) : M20
```

The [not so] slight discrepancies can be practically put onto the account of the fact that the load is not exactly a distributed load[2].

Generally, this kind of hand calculation is done to provide a rough estimate of a result value to ensure the calculation validity.

If we want to perform a bench mark of **code_aster** , we can:

[1] The question arises whether to use a length of 2000, overall length, or 1980, length excluding the end hinges.

[2] A larger number of nodes on 'topbeam' group would produce a closer result.

- isolate the 'topbeam' as a single span beam pinned in between 2 fixed supports (this can be doe by adding the group oh node 'mast' to the boundary condition 'ground',
- apply in 'cr' a true distributed load with,

  `FORCE_POUTRE=_F(GROUP_MA=('topbeam',),FZ=-0.1,);`
- run the solution with only that load case;

and we will find an exact agreement of the **code_aster** results values with the text book values.

7.5 Using an alternative option with beam elements

Instead of using a `K_TR_D_L` for the 'hinge' group we may use a beam element with a null, or near null, value for the moment of inertia on the right axis. We then should not forget to assign with elements a beam element model and assign them a material as well. Here are the command file abstracts doing that.

Model section:

```
model=AFFE_MODELE(
    MAILLAGE=mesh,
    AFFE=(
        _F(
            GROUP_MA=('topbeam','mast','hinge',),
            PHENOMENE='MECANIQUE',
            MODELISATION='POU_D_T',
        ),
        _F(
            GROUP_MA=('massN',),
            PHENOMENE='MECANIQUE',
            MODELISATION='DIS_T',
        ),
        #next section commented as it is already
        #attributed as a beam just above
        #_F(
            #GROUP_MA=('hinge',),
            #PHENOMENE='MECANIQUE',
            #MODELISATION='DIS_TR',
        #),
    ),
);
```

Material section:

```
material=AFFE_MATERIAU(
    MAILLAGE=mesh,
    AFFE=_F(
        GROUP_MA=('topbeam','mast','hinge',),
        MATER=steel,
    ),
);
```

Element properties section:

```
elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    POUTRE=(
        #the vertical members are rectangular section
        #(40x20 mm) with a thickness of 1.5 mm
        _F(
            GROUP_MA=('mast',),SECTION='RECTANGLE',
            CARA=('HY','HZ','EP',),VALE=(40, 20, 1.5,),
        ),
        #same with the horizontal bar
        _F(
            GROUP_MA=('topbeam',),SECTION='RECTANGLE',
            CARA=('HY','HZ','EP',),VALE=(40, 20, 1.5,),
        ),
        _F(
            GROUP_MA=('hinge',),SECTION='GENERALE',
            CARA=(
                'A','IY','IZ','AY','AZ','EY','EZ',
                'JX','RY','RZ','RT',
            ),
            VALE=(
                171, 0.1, 34908, 1.5, 1.5, 0, 0,
                26700, 20, 10, 12,
            ),
        ),
    ),
    #orientation would be here if necessary
    DISCRET=(
        _F(GROUP_MA='massN', CARA='M_T_D_N',VALE=(.01),),
    ),
);
```

As we use a zero or almost zero for one value of moment of inertia[1] it is of course meaningless to try to calculate the related bending stress in these elements, but the forces and moments are meaningful!

Last but not least using short beam elements or discrete elements is not strictly equivalent, Appendix C provides a deeper insight into discrete stiffness elements.

[1] However the values chosen for IZ or JX are true for the full tubular section and are thus highly questionable.

CHAPTER 8

Making an highway sign

In this chapter, we modify the structure by adding some other beam members and some plating making it much like a highway gantry signal.

After the drawing and meshing of the plates we modify the command file for the plates.

And in the end we look at the graphical results in Gmsh.

For this study, we modify the geometry by adding a second top bar 200 mm below the first one, joining these two bars by 5 vertical members and filling the gaps with a steel plate, leaving the hinged joints in between the masts and the top panel[1]. Thus our frame looks very much like a motorway signal frame. And we modify the last load ’cr’ into ’cv’ representative of the wind blowing onto the top panel.

Figure 8.1 shows the finished structure.

[1] The joints being still modeled with discrete elements.

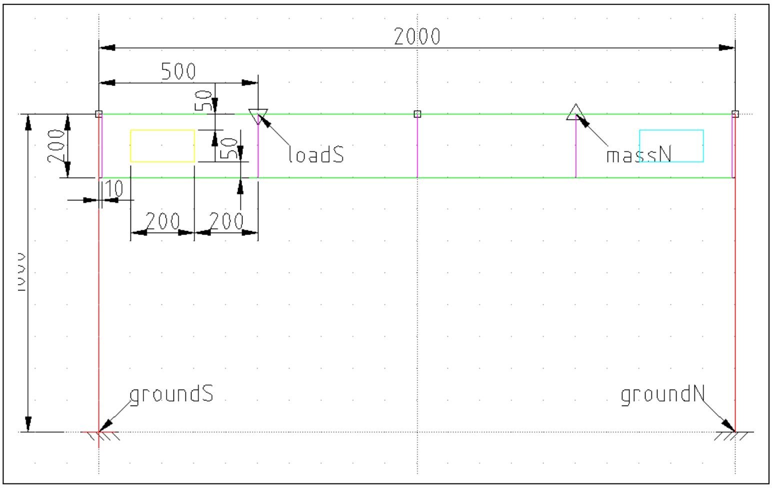


FIGURE 8.1: Sketch of frame3

8.1 Creating geometry and mesh in Gmsh

```
cls=25; //small characteristic length for the surfaces
clb=100; //coarser elsewhere
max=3;
pas=2;
ly=1000; //half length of frame along y
hz=1000; //height of frame along z
hz1=200;
dly=10; //length of hinge along y
Point(1) = {0, 0, hz, cls};
Point(101) = {0, 0, hz-hz1, cls};
//create Point
For i In {0:max:pas}
    Point(10+i) = {0,ly/2*(i-1), hz, cls};
    Point(20+i) = {0,(ly-dly)*(i-1), hz, cls};
    Point(30+i) = {0,ly*(i-1), hz, clb};
    Point(40+i) = {0,ly*(i-1), hz-hz1, clb};
    Point(50+i) = {0,ly*(i-1), 0, clb};
    //next point in middle of inner surfaces
    Point(60+i) = {0,ly/4*(i-1), hz-hz1/2, cls};
    //next points for bottom bar
    Point(110+i) = {0,ly/2*(i-1), hz-hz1, cls};
    Point(120+i) = {0,(ly-dly)*(i-1), hz-hz1, cls};
    //next points for hollows in outside panels
    Point(210+i) = {0,ly/2*(i-1)*1.4, hz-hz1/4, cls};
```

```
        Point(220+i) = {0,ly/2*(i-1)*1.6, hz-hz1/4, cls};
        Point(230+i) = {0,ly/2*(i-1)*1.4, hz-hz1*3/4, cls};
        Point(240+i) = {0,ly/2*(i-1)*1.6, hz-hz1*3/4, cls};
    EndFor
```

```
    //create Line
    top[]={}; //initialize list for top
    hinge[]={}; //idem for hinge
    mast[]={};
    vertb[]={};
    panelN[]={};
    panelS[]={};
    For i In {0:max:pas}
        Line(10+i) = {1, 10+i};
        top[]+=10+i; //add element in top list
        Line(20+i) = {10+i, 20+i};
        top[]+=20+i;
        Line(110+i) = {101, 110+i};
        top[]+=110+i;
        Line(120+i) = {110+i, 120+i};
        top[]+=120+i;
        Line(30+i) = {20+i, 30+i};
        hinge[]+=30+i; //add element in hinge list
        Line(130+i) = {120+i, 40+i};
        hinge[]+=130+i;
        Line(40+i) = {30+i, 40+i};
        mast[]+=40+i;
        Line(50+i) = {40+i, 50+i};
        mast[]+=50+i;
        Line(210+i) = {10+i, 110+i};
        vertb[]+=210+i;
        Line(220+i) = {20+i, 120+i};
        vertb[]+=220+i;
        //next lines for the hollows on outside panels
        Line(250+i) = {210+i, 230+i};
        Line(260+i) = {230+i, 240+i};
        Line(270+i) = {220+i, 240+i};
        Line(280+i) = {210+i, 220+i};
    EndFor
    Line(201) = {1, 101};
    vertb[]+=201;
    //makes sure the hinge line are not split in several elements
    Transfinite Line {hinge[]} = 2 Using Progression 1;
```

Up to here, it is just like the previous example, with more beams, now come the tricky part, creating the surface panels.

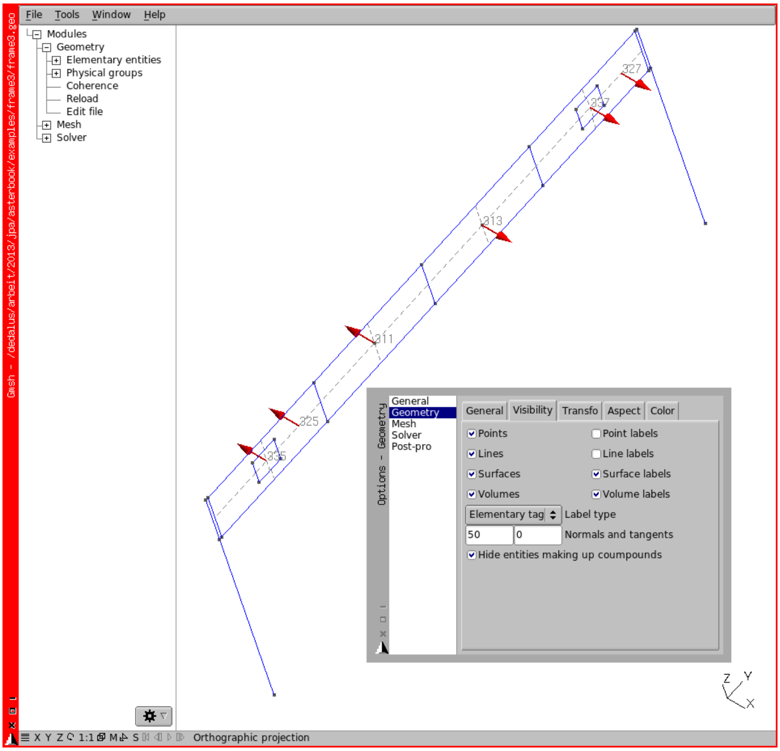
```
    //create surface
    For i In {0:max:pas}
        //Loop and Surface on the interior
        Curve Loop(310+i) = {201, 110+i, -(210+i), -(10+i)};
        Plane Surface(311+i) = {310+i};
        //Loop and Surface on the exterior
        Curve Loop(320+i) = {210+i, 120+i, -(220+i), -(20+i)};
        Curve Loop(320+i+1) = {280+i, 270+i, -(260+i), -(250+i)};
        //hollowed surface with two loops
        Plane Surface(325+i) = {320+i, 320+i+1};
        //inside surface on the inner loop
        //minus sign for coherent normals
        Plane Surface(335+i) = {-(320+i+1)};
    EndFor
    For i In {0:max:pas}
        //forces the surface mesh to pass through the point
        Point{60+i} In Surface{311+i};
    EndFor
    a[]={311, 325, 335};
    panelS[]=a[];
    //changing next line to a[]={-313, -327};
    //would reverse the normal but only in the saved mesh!!
    //not visible in the geam GUI
    a[]={313, 327};
    panelN[]=a[];
    Recombine Surface {panelN[]};
    //Recombine Surface {panelS[]};
```

We create the surfaces within a loop, as we can see in figure 8.2 the normals are oriented differently, changing `a[]={313, 327}` to `a[]={-313, -327}`, with the minus sign would put all the normals in the same direction, however this is not visible in Gmsh GUI until one read a mesh file! For this, in Gmsh File > Save Mesh creates a *.msh* file which can the be opened again and looks like figure 8.3.

We also create a hollow surface with two loops, first the outer one, then the inner one[1].

In the end, we specify `Recombine Surface panelN[];`, for one of the group so as to mesh it with quadrilateral elements while `panelS` is meshed only with triangles.

[1] There may be as many loops as there are hollows.

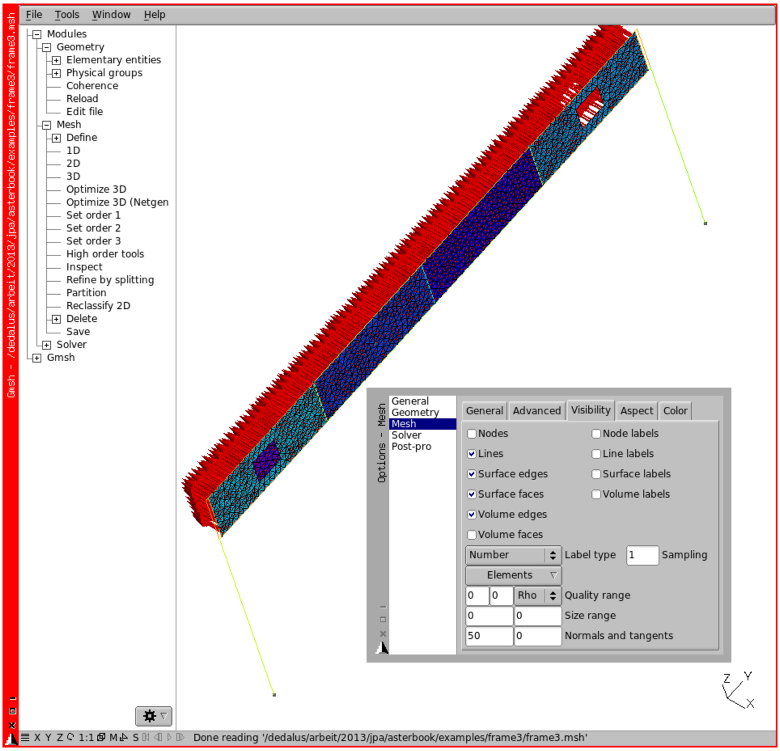


☑ Points ☐ Point labels
☑ Lines ☐ Line labels
☑ Surfaces ☑ Surface labels
☑ Volumes ☑ Volume labels
Elementary tag Label type
50 0 Normals and tangents
☑ Hide entities making up coumpounds

FIGURE 8.2: Orientation of normals from Geometry

Now we create two groups for the surfaces on either side.

```
//makes  the group 'topbeam' with the list top,
Physical Line("topbeam") = top[];
Physical Line("hinge") =hinge[];
Physical Line("mast") = mast[];
Physical Line("vertb") = vertb[];
Physical Surface("panelN") = panelN[];
Physical Surface("panelS") = panelS[];
Physical Point("groundS") = {50};
Physical Point("groundN") = {52};
Physical Point("loadS") = {10};
Physical Point("massN") = {12};
Physical Point("oripanel") = {60};

Color Cyan{ Surface{panelN[]};}
Color Yellow{ Surface{panelS[]};}
Color Green { Line {top[]};}
Color Red { Line {mast[]};}
Color Purple { Line {vertb[]};}
Color Black { Line {hinge[]};}
```



Nodes [ ] Node labels [ ]
Lines [✓] Line labels [ ]
Surface edges [✓] Surface labels [ ]
Surface faces [✓] Volume labels [ ]
Volume edges [✓]
Volume faces [ ]
Number Label type 1 Sampling
Elements
0 0 Rho Quality range
0 0 Size range
50 0 Normals and tangents

Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3.msh'

FIGURE 8.3: Orientation of normals from Mesh saved as *frame3.msh* and re-opened, with a[]=-313, -327

This last part creates the groups and assigns some color to the mesh. To look at the orientations of the Surface in Gmsh, in the menu Tools › Options › Geometry › Visibility, we enter a realistic value in the Normals field. Once meshed, with the extra 2D, the mesh looks like 8.3[1].

The physical point ’oripanel’ is created to be used later as a reference point to set the normal orientation in the command file.

[1] For the color to appear properly on mesh line elements Lines must be unchecked in Tools › Options › Geometry › Visibility.

We used the `Point In Surface` command to force one Point to become a Node belonging to the Surface, the command `Line In Surface` would do the same to force all nodes belonging to a Line to be nodes on the Surface[1].

Creating `Curve Loop` by hand in the text editor must be done carefully as it is easy to create an inverted loop on which Gmsh crashes after an error message.

8.2 Commanding for plate elements

Producing a *.comm* file for plates is quite straightforward for the first part.

```
DEBUT();

mesh=LIRE_MAILLAGE( INFO=1,UNITE=20,FORMAT='MED' ,);

mesh=DEFI_GROUP(
    MAILLAGE=mesh,
    reuse =mesh,
    CREA_GROUP_MA=(
        _F(NOM='panel' ,UNION=('panelN' ,'panelS' ,),),
        _F(NOM='TOUT' ,TOUT='OUI' ,),
    ),
    CREA_GROUP_NO=(_F(TOUT_GROUP_MA='OUI' ,),),
);

mesh=MODI_MAILLAGE(
    MAILLAGE=mesh,
    reuse =mesh,
    #U4.23.04
    ORIE_NORM_COQUE=(
        _F(
            GROUP_MA=('panel' ,),
            VECT_NORM=(1.0, 0, 0),
            GROUP_NO='oripanel' ,
        ),
        #_F(GROUP_MA=('panelN',),),
        #_F(GROUP_MA=('panelS',),),
    ),
);
```

We create a new group which the `UNION` of the two panel groups created in Gmsh.With `ORIE_NORM_COQUE`, we reorient the normals of

[1] If the Point(s) or Line(s) do not lie exactly in the plane of a Plane Surface a distorted mesh is created.

all the elements of this newly created group, in the direction given by VECT_NORM with its origin on the node GROUP_NO='oripanel'.

Then the assignation part.

```
model=AFFE_MODELE(
    MAILLAGE=mesh,
    AFFE=(
        _F(
            GROUP_MA=('topbeam','vertb','mast',),
            PHENOMENE='MECANIQUE',MODELISATION='POU_D_T',
        ),
        _F(
            GROUP_MA=('massN',),PHENOMENE='MECANIQUE',
            MODELISATION='DIS_T',
        ),
        _F(
            GROUP_MA=('hinge',),PHENOMENE='MECANIQUE',
            MODELISATION='DIS_TR',
        ),
        #here is the modeling of plate element
        _F(
            GROUP_MA=('panel',),PHENOMENE='MECANIQUE',
            MODELISATION='DKT',
        ),
    ),
);
steel=DEFI_MATERIAU(ELAS=_F(E=210000.,NU=0.3,RHO=8e-9),);

material=AFFE_MATERIAU(
    MAILLAGE=mesh,
    AFFE=_F(
        GROUP_MA=('topbeam','vertb','mast','panel'),
        MATER=steel,
    ),
);
```

```
elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    POUTRE=(
        _F(
            GROUP_MA=('mast',),
            SECTION='RECTANGLE',CARA=('HY','HZ','EPY', 'EPZ',),
            VALE=(40, 20, 1.65, 1.5,),
        ),
        _F(
            GROUP_MA=('topbeam',),
            SECTION='RECTANGLE',CARA=('HY','HZ','EPY', 'EPZ',),
            VALE=(40, 20, 1.5, 1.5),
        ),
        _F(
            GROUP_MA=('vertb'),
            SECTION='RECTANGLE',CARA=('HY','HZ','EPY', 'EPZ',),
            VALE=(20, 20, 1.5, 1.5,),
        ),
    ),
    DISCRET=(
        _F(GROUP_MA='massN', CARA='M_T_D_N',VALE=(.01),),
        _F(
            GROUP_MA='hinge',
            CARA='K_TR_D_L',VALE=(1e6,1e6,1e6,1e1,1e9,1e9),
            REPERE='GLOBAL'
        ),
    ),
    #the plate is given a thickness of 3 or 1
    #and the orientation of the element is defined
    #by VECTEUR see U4.42.01
    COQUE=(
        _F(GROUP_MA='panelN',EPAIS=3.0,VECTEUR=(0,1,0),),
        _F(GROUP_MA='panelS',EPAIS=1.0,VECTEUR=(0,1,0),),
    ),
);
```

We apply the `panel` properties to the `UNION` group `panel` but we give different thickness to the groups `panelN` and `panelS`[1].

`VECTEUR` is a vector whose projection on the element plane, sets the local x axis of the coordinate system of the element. It is used to compute the principal stresses[2], it should not be normal to **ANY** element in the group[3]! In our case it is a Y (global axis) oriented vector, lying perfectly in the plane of all the elements, it is not always so easy!

We should not make a confusion between the normal vector and the vector defined just above. Just like any structural element, beam or discrete, a plate, or a shell, needs an associated local coordinate system in which:

- local z axis is the normal vector, defined by the mesh topology itself;
- local x axis is the projection of the above defined, `VECTEUR`, vector on the plane tangent to the element at its barycenter, this is unknown by the mesh topology and *has to be defined*;
- local y axis completes the trihedron.

Figure 8.4 illustrates the matter.

[1] And this 1 to 3 different thickness is visible in the flexural stress in the panel.
[2] For anisotropic plates it is also used to define the anisotropic directions.
[3] If this happens **code_aster** raises an error, and the vector needs another definition or the group needs to be split into several others.

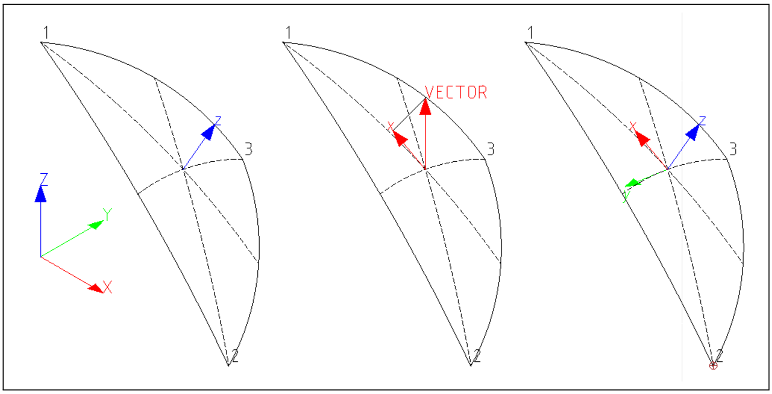


FIGURE 8.4: Shell element local axis

With:

1. triangular shell element (1,2,3), with local z vector, normal, as given from mesher or `ORIE_NORM_COQUE`;
2. VECTOR given as `VECTEUR=(0,0,1)`, projected on element gives local x axis;
3. complete local axis trihedron.

The boundary conditions are as follows.

```
ground=AFFE_CHAR_MECA(
    MODELE=model,
    DDL_IMPO=_F(
        GROUP_NO=('groundS','groundN',),
        DX=0,DY=0,DZ=0,DRX=0,DRY=0,DRZ=0,
    ),
);
```

And the load conditions.

```
selfwght=AFFE_CHAR_MECA(
    MODELE=model,
    PESANTEUR=_F(
        GRAVITE=10000,DIRECTION=(0,0,-1),
        GROUP_MA=('topbeam','vertb','mast','massN','panel',),
    ),
);
```

```
cc=AFFE_CHAR_MECA(
    MODELE=model,
    FORCE_NODALE=_F(GROUP_NO=('loadS',),FZ=−100,),
);

cv=AFFE_CHAR_MECA(
    MODELE=model,
    #here we define a pressure on the plate elements
    FORCE_COQUE=_F(GROUP_MA=('panel'),PRES=0.01,),
    #next line would have meant a distributed force along x
    #equivalent if normals are in the right direction
    #FORCE_COQUE=_F(GROUP_MA=('panel'),FX=-0.01,),
);
```

PRES is a uniform pressure, acting along the normal of the element, but in the opposite direction, this can raise many errors or give unexpected results if the normals are not oriented as we think they are! For this kind of study I would rather use FORCE_COQUE, but for learning from the mistakes let's try with PRES.

Stepping for the load case.

```
selfw_m=DEFI_FONCTION(
    NOM_PARA='INST',
    VALE=(2,0, 3,1.35, 5,1.35, 6,0,),
    PROL_DROITE='CONSTANT',
);
cc_m=DEFI_FONCTION(
    NOM_PARA='INST',
    VALE=(3,0, 4,1, 5,1, 6,0,),
    PROL_GAUCHE='CONSTANT',PROL_DROITE='CONSTANT',
);
cv_m=DEFI_FONCTION(
    NOM_PARA='INST',
    VALE=(4,0, 5,1.5, 6,1),
    PROL_GAUCHE='CONSTANT',PROL_DROITE='CONSTANT',
);

liste=DEFI_LIST_REEL(
    DEBUT=2.0,
    INTERVALLE=_F(JUSQU_A=6,PAS=1.0,),
);
```

And solving.

```
stat=MECA_STATIQUE(
    MODELE=model,
    CHAM_MATER=material,
    CARA_ELEM=elemcar,
    EXCIT=(
        _F(CHARGE=ground,),
        _F(CHARGE=selfwght,FONC_MULT=selfw_m,),
        _F(CHARGE=cc,TYPE_CHARGE='FIXE_CSTE',FONC_MULT=cc_m,),
        _F(CHARGE=cv,TYPE_CHARGE='FIXE_CSTE',FONC_MULT=cv_m,),
    ),
    LIST_INST=liste,
);
```

```
stat=CALC_CHAMP(
    reuse =stat,RESULTAT=stat,
    CONTRAINTE=(
        'SIEF_ELNO',
        'SIPO_ELNO',
        'SIPM_ELNO',
        'SIGM_ELNO',
    ),
    FORCE=('REAC_NODA'),
);
```

In a single call of CALC_CHAMP we calculate forces, stresses and nodal reactions[1].

Keyword SIGM_ELNO is here to calculate the stress in the plate element, but only in the neutral plane.

And the way to post-process the plate elements with the stress and criteria on the top face is as follow:

```
#U4.85.01
stat2=POST_CHAMP(
    RESULTAT=stat,
    GROUP_MA=('panel',),
    EXTR_COQUE=_F(
        NUME_COUCHE=1,
        NIVE_COUCHE='SUP',
        NOM_CHAM=('SIGM_ELNO',),
    ),
);

statsup=CALC_CHAMP(
    RESULTAT=stat2,
    GROUP_MA=('panel',),
    CRITERES=('SIEQ_ELNO','SIEQ_NOEU',),
);
```

At first the concept 'stat' holds the results for all layers. When one needs to compute on a particular layer, it is necessary to extract in a new concept, stat2, the field on the element per node NOM_CHAM=('SIGM_ELNO',), with POST_CHAMP, here on

[1] Though listed under CONTRAINTE, SIEF_ELNO for beams is a force, or moment, and not a stress.

NUME_COUCHE=1[1], as there is only one layer, on the top face NIVE_COUCHE='SUP'. Before using CALC_CHAMP again to compute fields at node CRITERES=('SIEQ_ELNO','SIEQ_NOEU',)) in the final concept statsup.

With this, we have calculated the stresses in the plate elements in the top face NIVE_COUCHE='SUP' together with stresses at nodes, like the well known "von Mises" equivalent stress[2].

```
masse=POST_ELEM(
    RESULTAT =stat,
    MODELE=model,
    MASS_INER=_F(
        GROUP_MA=('topbeam','mast','massN','panelN','panelS'),
    ),
    TITRE= 'masse'
);
```

This, now well known, bit to calculate and print the mass of the model.

8.3 Printing the results

Printing the ASCII results is just like the previous example, however we print the maximum and minimum for SIEQ_NOEU, VMIS on the top face of the plate elements to check the displayed values.

```
IMPR_RESU(
    MODELE=model,
    FORMAT='RESULTAT',
    RESU=(
        _F(
            RESULTAT=statsup,
            NOM_CHAM='SIEQ_NOEU',
            NOM_CMP=('VMIS',),
            GROUP_MA=('panelN',),
            FORMAT_R='1PE12.3',
            VALE_MAX='OUI',VALE_MIN='OUI',
            INST=6.0,
        ),
        _F(
            RESULTAT=statsup,
```

[1] "Couche", in french, means Layer, and "Nive" is an abstract for "Niveau" which means Level.

[2] If the difference in between the neutral plate of the plate and the top face does not jump to the eye, add a bottom face calculation with INF to better show the bending behavior in 'panel'.

```
                NOM_CHAM='SIEQ_NOEU',
                NOM_CMP=('VMIS',),
                GROUP_MA=('panelS',),
                FORMAT_R='1PE12.3',
                VALE_MAX='OUI',VALE_MIN='OUI',
                INST=6.0,
            ),
        ),
    );
```

And now, we are going to prepare a .med result file slightly different from the previous ones, and read this file with Gmsh.

```
    IMPR_RESU(
        FORMAT='MED',
        UNITE=80,
        RESU=(
            _F(
                GROUP_MA=('topbeam','vertb','mast','panel',),
                RESULTAT=stat,NOM_CHAM=('DEPL',),
            ),
            _F(
                GROUP_MA=('topbeam','vertb','mast',),
                RESULTAT=stat,NOM_CHAM=('SIPO_ELNO',),
            ),
            _F(
                GROUP_MA=('topbeam','vertb','mast',),
                RESULTAT=stat,NOM_CHAM=('SIPO_ELNO',),
                NOM_CMP=('SMFY',),NOM_CHAM_MED='smfy',
            ),
            _F(
                GROUP_MA=('topbeam','vertb','mast','panel',),
                RESULTAT=stat,NOM_CHAM=('SIPM_ELNO',),
                NOM_CMP=('SIXXMAX',),NOM_CHAM_MED='sixx',
            ),
            _F(
                GROUP_MA=('panel',),RESULTAT=statsup,
                NOM_CHAM='SIEQ_NOEU',NOM_CMP='VMIS',
                NOM_CHAM_MED='vmis',
            ),
            _F(
                GROUP_MA=('panel',),RESULTAT=statsup,
                NOM_CHAM='SIEQ_NOEU',
            ),
        ),
    );

    FIN();
```

Printing is split in many groups of lines, each one of them performing one and only one specific task.

- First group of lines prints `DEPL`, the standard displacement field.

- Second group of lines prints `SIPO_ELNO` the standard beam stresses field, without specific options, the group 'panel' being excluded of the print out[1].
- Third group of lines prints `SIPO_ELNO` restricted to `NOM_CMP=('SMFY',)` giving it the name, `NOM_CHAM_MED`, 'smfy' in the med file.
- Fourth group of lines prints `SIPM_ELNO` restricted to `NOM_CMP=('SIXX',)` giving it the name, `NOM_CHAM_MED`, 'sixx' in the med file.
- Fifth group of lines prints `SIEQ_NOEU` restricted to `NOM_CMP=('VMIS',)` for the group 'panel' only[2] and for the result concept 'statsup', giving it the name, `NOM_CHAM_MED`, 'vmis' in the med file.
- And finally the sixth group of lines prints `SIEQ_NOEU` as standard, with all the components.

The reason for these restricted outputs is that most of the post-processors do their own averaging or mixture on field from a tensor value calculated by **code_aster** and the results for a selected component within a standard field may be wrong[3].

[1] It is not wise to print results specific to beams on plates.
[2] Likewise it is not wise to print results specific to plates on beams.
[3] By a small amount due to some averaging algorithm, however they are not wrong with a component directly extracted from the **code_aster** calculated results.

8.4 Viewing the results in Gmsh

We can open the med result file in Gmsh. On the left-hand side in the tree, we can see under Post_processing 6 lines for every one of the 6 fields we saved in the med file. Likewise there are 6 scalar bars in the graphic window.

In the tree untick the values until only stat__DEPL remains ticked and is the only visible field in the graphic window.

Only the ticked views in the tree are visible in the graphic window.

Push the little arrow on the right-hand side to the menu Options which opens a dialog window, this window allows to make change to the display in the graphic window.

First of all it is a good idea to go in Tools » Options » Mesh » Visibility and uncheck everything so the post-processing view is not polluted by some mesh view[1]. Pushing the keys < Alt> + M also hides the mesh, or push the 'M' in the status bar.

To choose the step, we go to the General tab and increase or decrease the list right of Time step, either by typing a value or using the - and + buttons. Whatever was the step numbering scheme chosen in **code_aster** Gmsh always starts at 0, likewise the views are also numbered from 0.

8.4.1 Displaying displacement

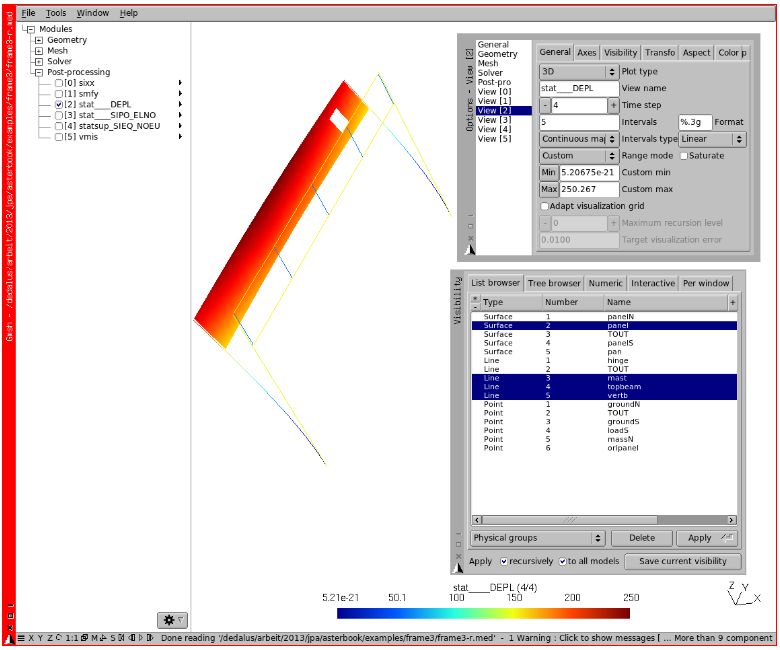
To view the deformed shape:

1. in the Visibility tab pull the lower left list to Force vector;
2. in the Aspect tab pull the Vector display list to Displacement;
3. choose a significant value for Displacement factor.

Figure 8.5 shows the deformed shape[2].

[1] Though sometimes it is useful to see the mesh.

[2] Note the view restricted to some groups in **Visibility** dialog box, and the mesh has been made visible for lines.



3D Plot type
stat___DEPL View name
4 Time step
5 Intervals %.3g Format
Continuous map Intervals type Linear
Custom Range mode ☐ Saturate
Min 5.20675e-21 Custom min
Max 250.267 Custom max
☐ Adapt visualization grid
0 Maximum recursion level
0.0100 Target visualization error

Type	Number	Name
Surface	1	panelN
Surface	2	panel
Surface	3	TOUT
Surface	4	panelS
Surface	5	pan
Line	1	hinge
Line	2	TOUT
Line	3	mast
Line	4	topbeam
Line	5	vertb
Point	1	groundN
Point	2	TOUT
Point	3	groundS
Point	4	loadS
Point	5	massN
Point	6	oripanel

Physical groups Apply
Apply ✓ recursively ✓ to all models

stat___DEPL (4/4)
5.21e-21 50.1 100 150 200 250

Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3-r.med' - 1 Warning : Click to show messages [... More than 9 component

FIGURE 8.5: Gmsh view of displacement at INST 6, superimposed on the undisplaced mesh

To view individual components:

1. in the Visibility tab pull the lower left list to Force scalar;
2. in the box immediately to the right type in the field Id (Id is 0 for DX, 1, is for DY, and so on);
3. in the General tab pull the list Range mode to Custom;
4. and push the Min and Max buttons to refresh the display with the proper component values.

To view numerical values:

1. in the General tab pull the list right of Interval types to Numeric values;

2. in the Aspect tab pull the Glyph location list to Vertex to display the values at the nodes.

8.4.2 Displaying stress in beam element

Select and make visible the view stat__SIPO_ELNO Here the view of the field as Vector display is meaningless! To view individual components:

1. in the Visibility tab, pull the lower left list to Force scalar;
2. in the box immediately to the right, type in the field Id (Id is 0 for `SN`, 3 is for `SMT`, 4 is for `SMFY`, and so on);
3. in the General tab pull the list Range mode to Custom;
4. and push the Min and Max buttons to refresh the display with the proper component values.

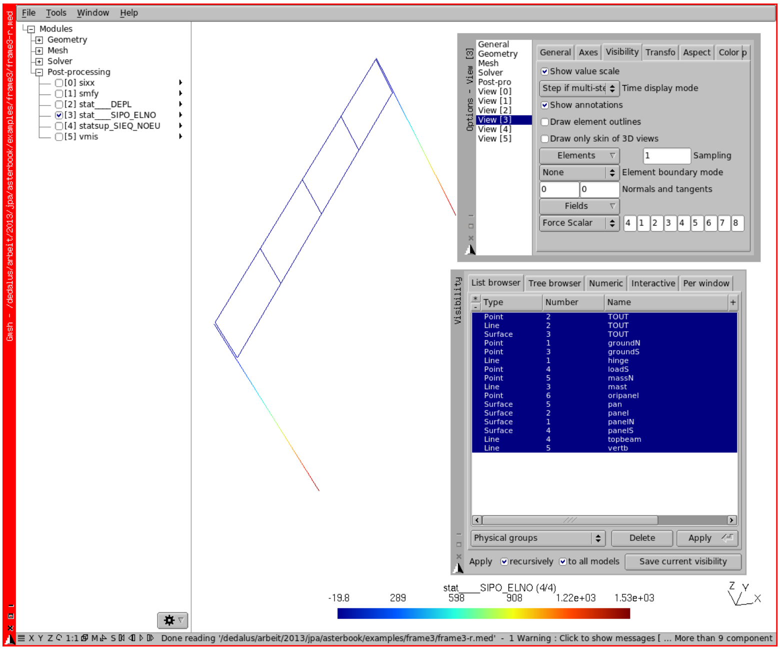
To view numerical values:

1. in the General tab pull the list right of Interval types to Numeric values;
2. in the Aspect tab pull the Glyph location list to Vertex to display the values at the nodes, which sometimes may produce a very cluttered view, or Barycenter to display the values in the middle of the element.

To restrict the view to some groups:

1. in the Gmsh menu Tools choose Visibility;
2. in the Physical groups options restrict the views to whichever groups we want.

Figure 8.6 shows value of the field `SIPO_ELNO` component `SMFY`.



- [✓] Show value scale
- Step if multi-step: Time display mode
- [✓] Show annotations
- [ ] Draw element outlines
- [ ] Draw only skin of 3D views
- Elements — 1 Sampling
- None — Element boundary mode
- 0 0 Normals and tangents
- Fields
- Force Scalar — 4 1 2 3 4 5 6 7 8

Type	Number	Name
Point	2	TOUT
Line	2	TOUT
Surface	3	TOUT
Point	1	groundN
Point	3	groundS
Line	1	hinge
Point	4	loadS
Point	5	massN
Line	3	mast
Point	6	oripanel
Surface	5	pan
Surface	2	panel
Surface	1	panelN
Surface	4	panelS
Line	4	topbeam
Line	5	vertb

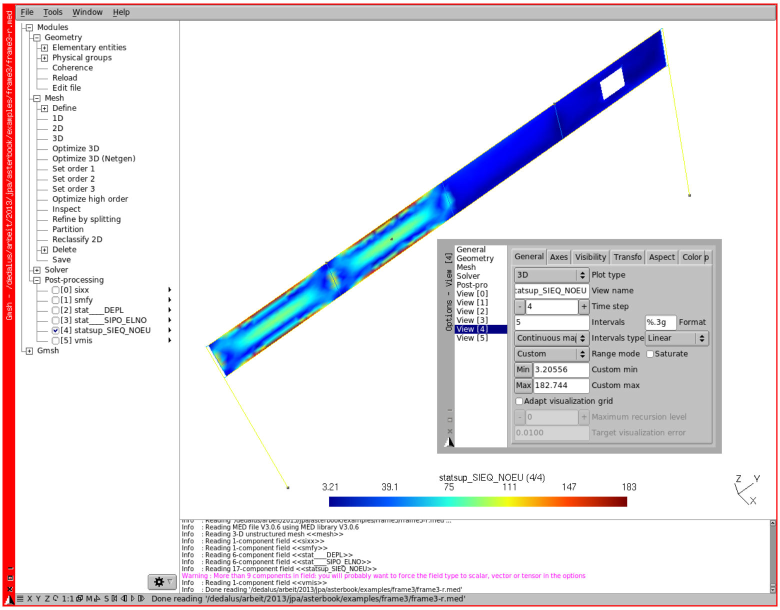
Apply [✓] recursively [✓] to all models — Save current visibility

```
Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3-r.med' - 1 Warning : Click to show messages [ ... More than 9 component
```

FIGURE 8.6: Gmsh view of SIPO_ELNO, SMFY at INST 6

8.4.3 Displaying stress in plate element

Select and make visible the view stat__SIEQ_NOEU, and proceed along just as for the stresses in beam elements.



```
3D                   Plot type
statsup_SIEQ_NOEU    View name
4                    Time step
5                    Intervals         %.3g    Format
Continuous map       Intervals type    Linear
Custom               Range mode        Saturate
Min 3.20556          Custom min
Max 182.744          Custom max
Adapt visualization grid
0                    Maximum recursion level
0.0100               Target visualization error
```

```
Info    : Reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3-r.med' ...
Info    : Reading MED file V3.0.6 using MED library V3.0.6
Info    : Reading 3-D unstructured mesh <<mesh>>
Info    : Reading 1-component field <<sixx>>
Info    : Reading 1-component field <<smfy>>
Info    : Reading 6-component field <<stat___DEPL>>
Info    : Reading 6-component field <<stat___SIPO_ELNO>>
Info    : Reading 17-component field <<statsup_SIEQ_NOEU>>
Warning : More than 9 components in field: you will probably want to force the field type to scalar, vector or tensor in the options
Info    : Reading 1-component field <<vmis>>
Info    : Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3-r.med'
Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3-r.med'
```

FIGURE 8.7: Gmsh view of `SIEQ_NOEU, VMIS component`

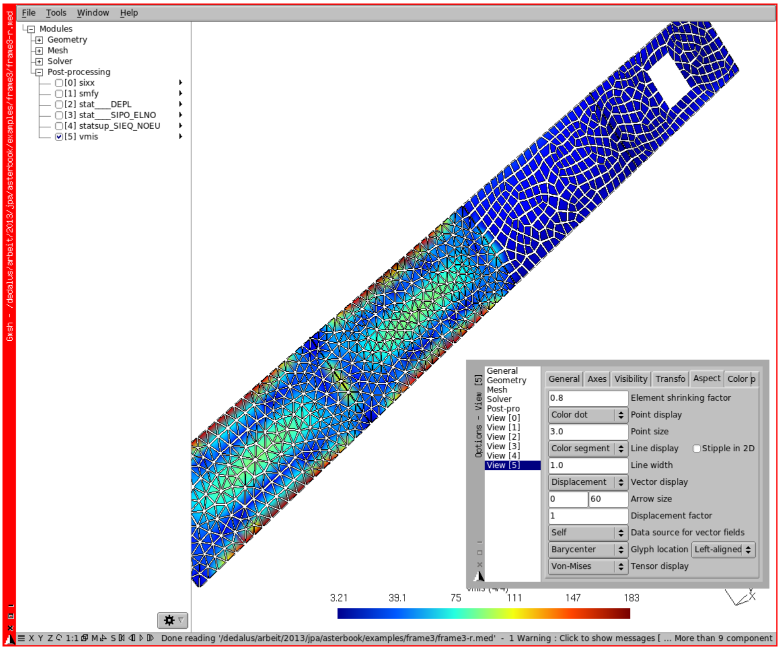
8.4.4 Displaying stress of a named field

In the .comm field we specified some results like this:

```
IMPR_RESU(
    FORMAT='MED',
    UNITE=80,
    RESU=(
        .........................
        _F(
            GROUP_MA=('panel',),RESULTAT=statsup,
            NOM_CHAM='SIEQ_NOEU',NOM_CMP='VMIS',
            NOM_CHAM_MED='vmis',
        ),
    ),
);
```

here the field contains only one component and the view in Gmsh is best made with:

1. in the Visibility tab pull the lower left list to Original Field;



0.8	Element shrinking factor
Color dot	Point display
3.0	Point size
Color segment	Line display ☐ Stipple in 2D
1.0	Line width
Displacement	Vector display
0 60	Arrow size
1	Displacement factor
Self	Data source for vector fields
Barycenter	Glyph location Left-aligned
Von-Mises	Tensor display

Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3-r.med' - 1 Warning : Click to show messages [... More than 9 component

FIGURE 8.8: Gmsh "exploded" view of 'vmis' at INST 6

2. and proceed along as above.

Figure 8.8 shows value of the field 'vmis' MED field with, in dialog box Options:

- tab Visibility with Draw elements outlines ticked on;
- tab Aspect with Element shrinking factor set to 0.8;

to display a well known "exploded" or "shrunk" appearance!

8.4.5 Displaying more...

More tips about the use of Gmsh in post-processing are given in appendix B.

CHAPTER 9

Stiffening it with rods

In this chapter, we add to the structure of chapter 8 a lateral stiffening against lateral load under the shape of rod shrouds.

And we look at the results directly in STANLEY.

Back to engineer problems. We may consider this structure needs stiffening against horizontal loads, so we add four stiffening rods downwards from the top of the masts. These rods are what is called `BARRE` in **code_aster** jargon. These elements transmit axial forces, either tension or compression, but no end moments. Of course the real building must be designed and built according to this feature. To handle correctly these elements, **code_aster** , like any finite element code, requires one single element along the rod length.

Figure 9.1 shows the finished structure with the stiffening rods.

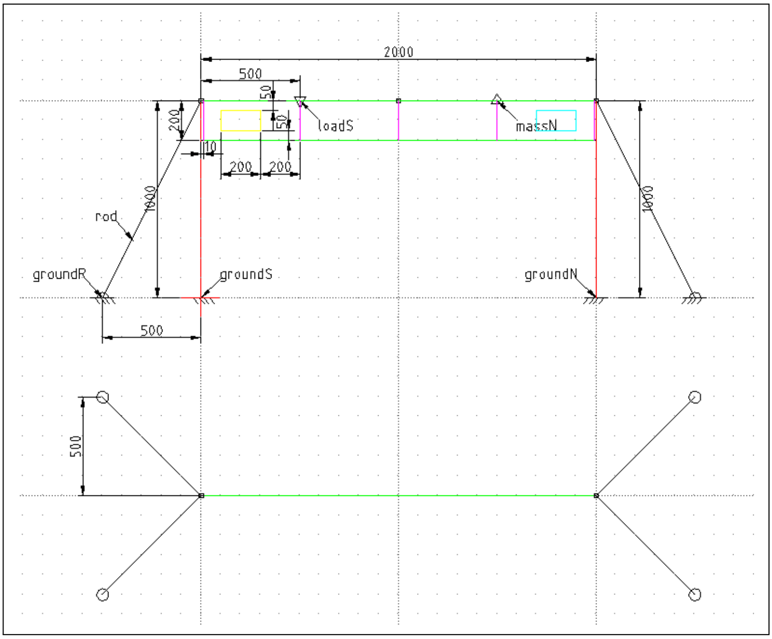


FIGURE 9.1: Sketch of frame4

9.1 Modifying in Gmsh

To create the ground points, the following is added to the points loop.

```
      Point(550+i) = {500,(ly+500)*(i-1), 0, cls};
      Point(560+i) = {-500,(ly+500)*(i-1), 0, cls};
```

In the loop creating the lines, we add[1]:

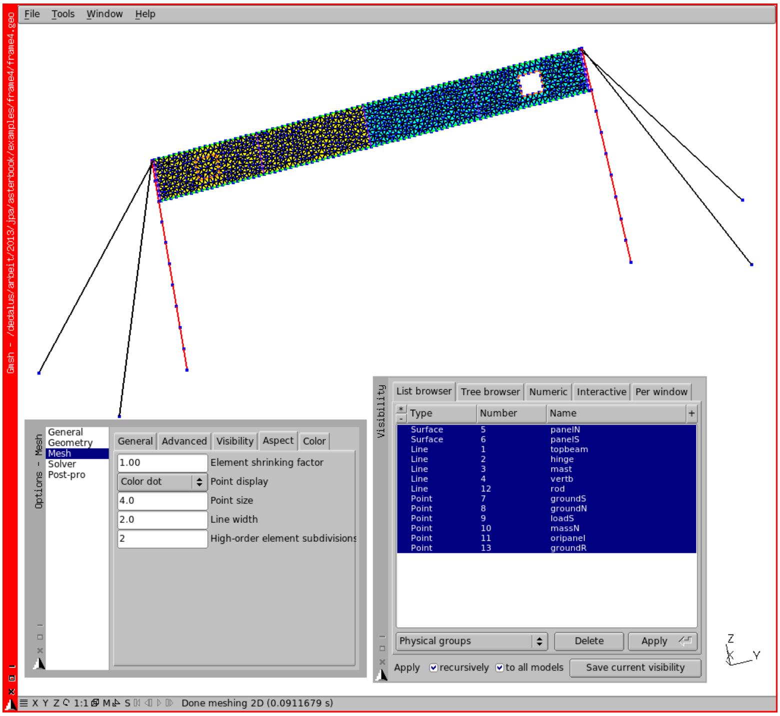
```
      Line(550+i) = {550+i, 20+i};
      rod[]+=550+i;
      Line(560+i) = {560+i, 30+i};
      rod[]+=560+i;
```

And:

[1] And here we can see the advantages of the "logical" numbering scheme we use.

```
Transfinite Line {rod[]} = 2 Using Progression 1;
Physical Line("rod") = rod[];
Physical Point("groundR") = {550, 552, 560, 562};
```

to ensure the rods are meshed as a single element, and finally a group is created for both the rods and the ground points. Once meshed the model looks like figure 9.2, and we save it as *frame4.med*



1.00	Element shrinking factor
Color dot	Point display
4.0	Point size
2.0	Line width
2	High-order element subdivisions

Type	Number	Name
Surface	5	panelN
Surface	6	panelS
Line	1	topbeam
Line	2	hinge
Line	3	mast
Line	4	vertb
Line	12	rod
Point	7	groundS
Point	8	groundN
Point	9	loadS
Point	10	massN
Point	11	oripanel
Point	13	groundR

Done meshing 2D (0.0911679 s)

FIGURE 9.2: Motorway signal frame meshed with rod support, visibility restrained to Physicals.

9.2 Enhancing the command file

We add the following lines[1]:

[1] Not forgetting to add 'rod' in material assignment

```
model=AFFE_MODELE(
    MAILLAGE=meshf,
    AFFE=(
        ..................
        _F(
            GROUP_MA=('rod' ,),
            PHENOMENE='MECANIQUE' ,MODELISATION='BARRE' ,
        ),
        ..................

elemcar=AFFE_CARA_ELEM(
    MODELE=model,
        ......................
        BARRE=_F(
            GROUP_MA=('rod' ,),SECTION='CERCLE' ,
            CARA=('R' ,'EP' ,),VALE=(16,1.5,),
        ),
        ......................

ground=AFFE_CHAR_MECA(
    MODELE=model,
    DDL_IMPO=(
        .....................
        _F( GROUP_NO=('groundR' ,),DX=0,DY=0,DZ=0,),
        .....................
    ),
);
```

A node belonging to a BARRE carries only translational DOFs, that's why the boundary condition misses DRX, DRY and DRZ.

Also the CALC_CHAMP as to be modified as the BARRE element do not know about SIPO_ELNO or SIPM_ELNO

```
stat=CALC_CHAMP(
    reuse =stat,RESULTAT=stat,
    CONTRAINTE=(
        'SIEF_ELNO' ,
        'SIGM_ELNO' ,
    ),
    FORCE=('REAC_NODA'),
);

stat=CALC_CHAMP(
    reuse =stat,RESULTAT=stat,
    GROUP_MA=('topbeam' ,'vertb' ,'mast' ,'panel' ,),
    CONTRAINTE=('SIPO_ELNO' ,'SIPM_ELNO' ,),
);
```

The part for print out may be modified with this addition as it is a good idea to verify the traction or compression force load in the bar[1].

[1] The same type of entry could be put in the .resu file.

```
IMPR_RESU(
    MODELE=model, FORMAT='MED', UNITE=80,
    RESU=(
         ........................
        _F(
            GROUP_MA=('rod',), RESULTAT=stat,
            NOM_CHAM=('SIEF_ELNO',),NOM_CMP='N',
            NOM_CHAM_MED='force_in_rod',
        ),
         ........................
```

Finally, we also save this file as *frame4.comm*

9.3 Using STANLEY, a quick approach to post-processing

Before diving into the use of STANLEY it might be necessary to modify the source of the file *stanley_engine.py*, instructions for this are given in the appendix 4.4 .

Once the calculation is successfully finished we can RMB click on the line of the database and choose Open with... Post-processing using Code_Aster (Stanley) a window like figure 9.3 pops up. Among a few other things a database enables the restart of a calculation where it was left off.

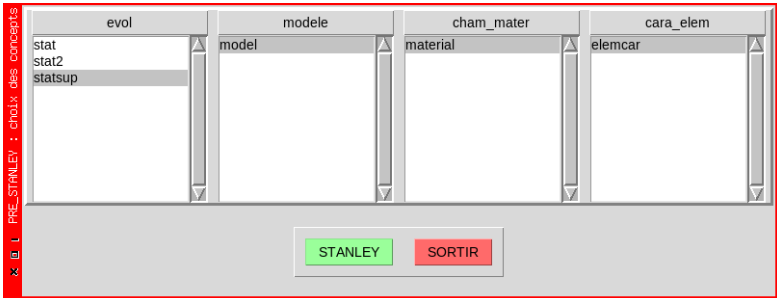
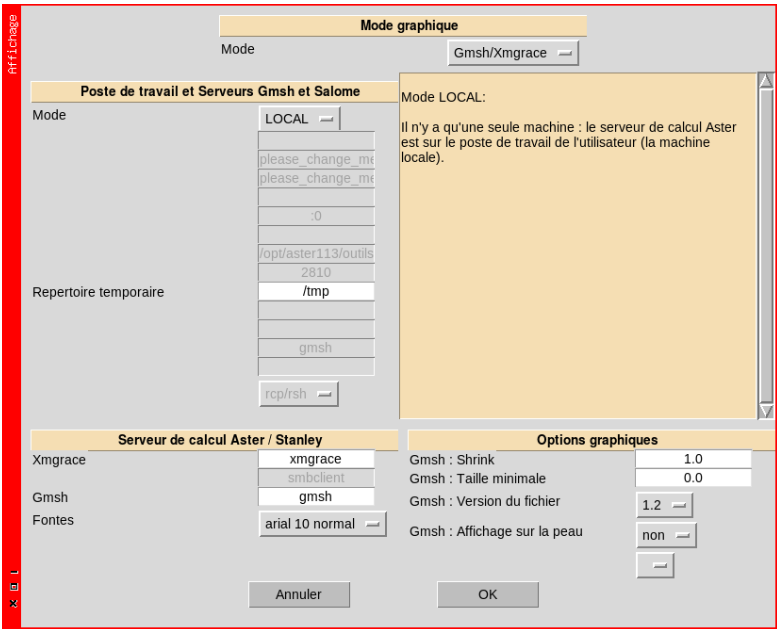


FIGURE 9.3: STANLEY window

STANLEY is a very powerful tool to view results, particularly in the early stages of a study.

The document U4.81.31 explains the use of STANLEY.

At first, we may have to set some parameters in the menu Parametres - Editer, toggle the Mode switch to Gmsh/Xmgrace, push the button OK, figure 9.4.



Affichage

Mode graphique

Mode Gmsh/Xmgrace

Poste de travail et Serveurs Gmsh et Salome

Mode LOCAL

please_change_me

please_change_me

:0

/opt/aster113/outils

2810

Repertoire temporaire /tmp

gmsh

rcp/rsh

Mode LOCAL:

Il n'y a qu'une seule machine : le serveur de calcul Aster est sur le poste de travail de l'utilisateur (la machine locale).

Serveur de calcul Aster / Stanley

Xmgrace xmgrace

smbclient

Gmsh gmsh

Fontes arial 10 normal

Options graphiques

Gmsh : Shrink 1.0

Gmsh : Taille minimale 0.0

Gmsh : Version du fichier 1.2

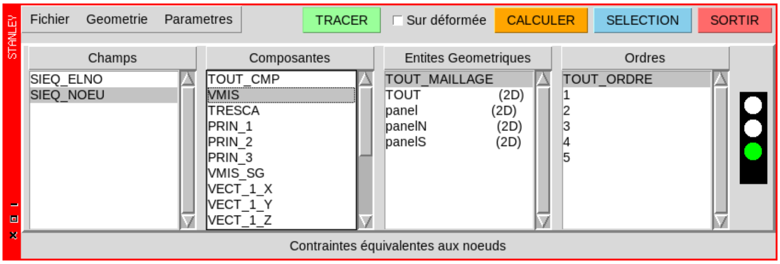
Gmsh : Affichage sur la peau non

Annuler OK

FIGURE 9.4: STANLEY parameters set to Gmsh/Xmgrace” mode

Then select the same item as in figure 9.5, push STANLEY:

- on the left most column named Champs (fields) select SIEQ_NOEU.
- On the next column named Composantes (components) select VMIS;
- on the next column named Entites Geometriques (geometric entities) select panel (2D);



```
Champs         Composantes   Entites Geometriques   Ordres
SIEQ_ELNO      TOUT_CMP      TOUT_MAILLAGE          TOUT_ORDRE
SIEQ_NOEU      VMIS          TOUT        (2D)       1
               TRESCA        panel       (2D)       2
               PRIN_1        panelN      (2D)       3
               PRIN_2        panelS      (2D)       4
               PRIN_3                               5
               VMIS_SG
               VECT_1_X
               VECT_1_Y
               VECT_1_Z
Contraintes équivalentes aux noeuds
```

FIGURE 9.5: STANLEY window, selection made

- on the right most column named Ordres select 5 (this is the load case at the last instant, number 6 in our case)[1].

The window now looks like figure 9.5. On the extreme right the traffic light is green, we can push TRACER.

Had the traffic light been orange we would have had to push CALCULER so as to calculate the field and turn the light to green.

Had the light been red, then the requirements could not be met and the field could not be calculated.

In our case the light is green. Let's go, push TRACER!

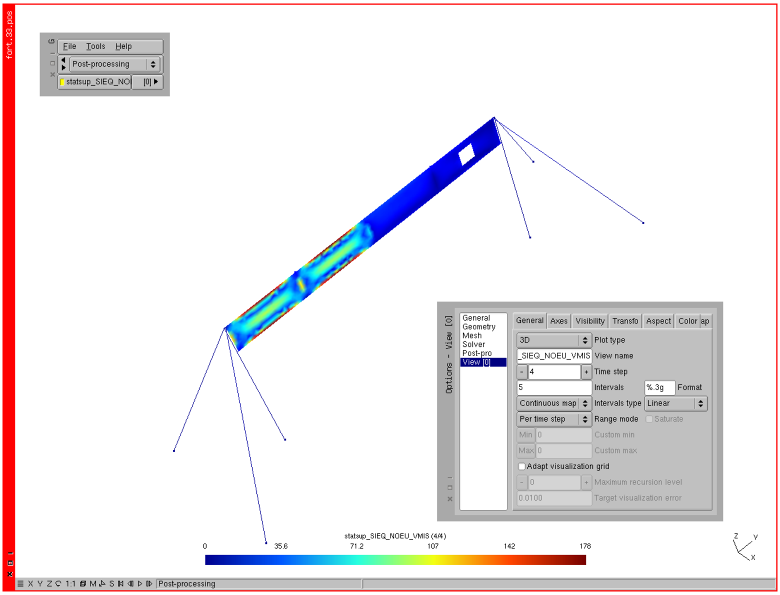
Hum! nothing happens? Then read in appendix D 4.3 . Once corrected or if all go well then a window like figure 9.6 appears.

I am cheating a bit, as at first the selected view is the XOZ plane, and our model has a null y dimension, so we have to turn it a bit, to view something.

A useful hint for Post-processing view in Gmsh is as follows:

- in the **Gmsh** command window, we choose the view we want in the view list;
- push the arrow on the right;
- then Options - Color;

[1] A LMB click on the Ordres opens a large list of options to change to, among which Inst.



3D Plot type
_SIEQ_NOEU_VMIS View name
- 4 + Time step
5 Intervals %.3g Format
Continuous map Intervals type Linear
Per time step Range mode Saturate
Min 0 Custom min
Max 0 Custom max
Adapt visualization grid
- 0 + Maximum recursion level
0.0100 Target visualization error

FIGURE 9.6: Von Mises criteria in 'panel' element in Gmsh Post-pro View

- then uncheck Enable lighting.

With this the color mapping of results is independent of any light source, otherwise it may become unreadable in areas which are in the shade from the light source.

In the **Gmsh** command window, menu File › Save Default Options saves this setting for all further Gmsh work.

One annoying drawback of Gmsh post-processing with STANLEY is that the groups of 1D elements like beams or rods are not present as groups in the file, while the groups of 2D elements are.

There is a lot more to play-with concerning the display appearance in Gmsh, this can be set by pressing the arrow on the right of the View, then Options, a lot of them are available here.

In the Options of Gmsh, if we play with the - + button on the list named Time step we notice that Gmsh has its own stepping, always starting at 0, with steps one by one, whatever the stepping of `INST` stated in the *.comm* file is.

And a final remark, Stanley can be called within a *.comm* file just by writing the line `STANLEY()` just after the calculation, `MECA_STATIQUE` here, as the fields do not need to have been calculated before. And in this case we have to quit STANLEY by pushing SORTIR for the *.mess* and *.resu* and all the results files to be saved on disk.

And last but not least STANLEY may be called by a RMB click on the database even in case of an aborted calculation[1] allowing us to have a look at the results just before the crash, quite useful to guess was went wrong!

[1] As this happens all too often in a non-linear calculation.

CHAPTER 10

Replacing rods, by cables, first step in non-linear

In this chapter, we replace the rods of chapter 9 by cables.

And this implies a non linear analysis which we setup.

10.1 Replacing rod by cables

We can see, in the previous model, some rods being in tension while the others are in compression. These rods when in compression may run away from the load by buckling at a very modest load[1].

This does not mean than the structure will be damaged, the displacements might just be more than calculated and the structure might come back to its original, the one before before load, geometry once the load ends up, or it may not!

[1] More about buckling in chapter 16.1 .

In order to take this kind of failure into account a sound approach is to replace them by wire ropes.

If we want to replace the rod elements by wire rope elements or `CABLE`[1], we need to perform a non-linear analysis. Indeed a cable does not support any compression load: its behavior is therefore non-linear and a dedicated constitutive law has to be used.

Switching to a non-linear simulation is quite easy.

Starting from *frame4.geo*, we create a *frame5.geo* file replacing the group name 'rod' by 'cable', for the sake of clarity. We also change the 'Transfinite' command allowing to mesh the cables with 20 elements, and not a single one, along their length. Then, we update the mesh and export it as *frame5.med*.

Roughly speaking a non-linear analysis is performed in multiple calculation steps in order to diminish the effects of the non-linearities. At each step the geometry may be updated to account for large displacements, the stiffness of each element may change due to non-linear constitutive behavior. This usually makes non-linear calculations more CPU-intensive.

In the case of cables, this stiffness update causes them to be kind of "eliminated" when they are in compression (near-zero stiffness). There are many parameters available in non-linear analysis, here, we just only scratch the surface of what is available.

One last remark before starting: a linear calculation always gives a result, but it may sometimes be irrelevant, for example with displacements exceeding the model dimensions. This is because the calculation is made only once on the un-deformed shape with the assumption of linear elastic behavior. That's why a result should always be questioned and the hypothesis used in the analysis verified. On the contrary non-linear calculations may fail and stop at one step in the middle with a singular matrix or a lack of convergence, in this case we need to tune some parameters and try it again. A close look at the *.mess* file is here of great help. Non-linear analysis may become a rather tedious involvement.

[1] This is how this element is known in the **code_aster** jargon.

10.2 Switching to non-linear analysis

Non-linear calculation requires some changes to the command file, we describe them now.

```
model=AFFE_MODELE(
    MAILLAGE=mesh,
    AFFE=(
        ........
        #here is the modeling of cable element
        _F(
            GROUP_MA=('cable',),
            PHENOMENE='MECANIQUE',MODELISATION='CABLE',
        ),
    ),
);
```

Most structures including cables require some pre-tension being applied in the cable, here, we do it by cooling them[1].

Firstly, we describe a temperature field, set to zero on the whole model.

```
temper1=CREA_CHAMP(
    TYPE_CHAM='NOEU_TEMP_R',
    MODELE=model,
    OPERATION='AFFE',
    AFFE=(
        _F(TOUT='OUI',NOM_CMP='TEMP',VALE=0.,),
    ),
);
```

Secondly, we describe another temperature field, set to -100° C on the cables and to zero on the rest of the model.

```
temper2=CREA_CHAMP(
    MODELE=model,
    TYPE_CHAM='NOEU_TEMP_R',
    OPERATION='AFFE',
    AFFE=(
        _F(TOUT='OUI',NOM_CMP='TEMP',VALE=0.,),
        _F(GROUP_MA=('cable',),NOM_CMP='TEMP',VALE=-100.,),
    ),
);
```

From these two fields we create a thermals results, indexed by the time variable, `INST`:

- from `INST` = -1, which is before the start of the actual calculation, to instant `INST` = 1, the null temperature field is applied;

[1] This is a very common practice with most finite elements codes.

- from INST = 1 to INST = 2, a temperature ramp is created using the second field defined below, this cools the cable creating the pre-tension.
- finally from INST 2 to INST 7, which is beyond the actual calculation range, we apply a constant temperature field in order to maintain the pre-load.

```
ltemp2=DEFI_LIST_REEL(
    DEBUT=2.0,
    INTERVALLE=_F(JUSQU_A=7.0,PAS=1.0,),
);

evtemp=CREA_RESU(
    TYPE_RESU='EVOL_VARC',
    NOM_CHAM='TEMP',
    OPERATION='AFFE',
    AFFE=(
        _F(CHAM_GD=temper1,INST= (-1, 0, 1,),),
        _F(CHAM_GD=temper2,LIST_INST=ltemp2,),
    ),
);
```

Strictly speaking this simple model would have converged without any pre-load in the cable and the real construction itself would not need a significant pre-load considering the load direction and level.

Moreover the time at which the pre-load is introduced in the calculation is not very realistic. In true life we would first erect the structure then tighten the cables and afterward submit it to working loads, so the proper order for applying loads might be:

1. gravity load;
2. thermal load to tighten the cables;
3. service load.

This makes an excellent exercise after having read this book!

The coefficient of thermal expansion for the cable is set to $\alpha = 12 \times 10^{-6}\mathrm{K}^{-1}$.

With a temperature increase $\Delta T = -100°\mathrm{K}$.

This yields a strain $\frac{\Delta L}{L} = \alpha \times \Delta T = -0.0012$.

And, if the cable is constrained, a force:

$$F = \frac{\Delta L}{L} \times E \times SECTION = -1200 \text{ N}.$$

And a normal stress of $\sigma_N = \frac{F}{SECTION} = 120 \text{ N.mm}^{-2}$.

The cable material needs a special treatment as it is supposed to have no stiffness in compression[1], it also needs a proper assignment of temperature behavior.

Also, although in steel, the cable is of wired construction, so we use an “apparent” modulus of elasticity which is somewhat less than solid steel[2].

```
#U4.43.01
steel=DEFI_MATERIAU(
    ELAS=_F(E=210000.,NU=0.3,RHO=8e-9,ALPHA=12e-6,),
);
msteel=DEFI_MATERIAU(
    ELAS=_F(E=100000,NU=0.3,RHO=8e-9,ALPHA=12e-6,),
    CABLE=_F(EC_SUR_E=1.E-4,),
);
```

Then we assign the material to the model.

```
material=AFFE_MATERIAU(
    MAILLAGE=mesh,
    AFFE=(
        _F(
            GROUP_MA=('topbeam','vertb','mast','panel',),
            MATER=steel,
        ),
            #material to cables
            _F(GROUP_MA=('cable',),MATER=msteel,),
    ),
    #here we apply the temperature that makes the pretension
    AFFE_VARC=_F(
        TOUT='OUI',
        NOM_VARC='TEMP',
        EVOL=evtemp,
        VALE_REF=0.0,
    ),
);
```

[1] Since this is not possible and would yield a singular matrix, a cable is assumed to have a fraction of the tension stiffness while in compression, EC_SUR_E stands for E in Compression divided by E.

[2] The value used here, $100000 N.mm^2$ holds true for quite a low quality cable.

Note: the temperature is applied to the whole model in this section, `TOUT='OUI'`, and this is done with `NOM_VARC='TEMP'` in the material assignment.

And finally the cable section, only the section is required, `N_INIT`=10.0 is a numerical pre-tension in the cable so the calculation is possible and has no effects on the results.

```
elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    .................
    CABLE=_F(
        GROUP_MA=('cable',),
        N_INIT=10.0,
        SECTION=(10,),
    ),
    .................
```

The non-linear analysis in **code_aster** allows many options and parameters to be tweaked. Here is an example of the commands which solve our problem.

```
#we may need tweaking with PAS until the problem converges
#here the problem is almost linear so a large PAS is OK
liste=DEFI_LIST_REEL(
    DEBUT=1.0,
    INTERVALLE=_F(JUSQU_A=6,PAS=0.5,),
);
#we may also want a more restricted list
# at which to print results
listresu=DEFI_LIST_REEL(
    DEBUT=1.0,
    INTERVALLE=_F(JUSQU_A=6,PAS=1.0,),
);
```

We start calculation and printing results at `INST` 1 to be able to see the temperature and cable pre-loading in at post-processing

```
#here is the non-linear analysis see
#U4.51.03
#U4.51.11
statnl=STAT_NON_LINE(
    MODELE=model,
    CHAM_MATER=material,
    CARA_ELEM=elemcar,
    EXCIT=(
        _F(CHARGE=ground,),
        _F(CHARGE=selfwght,FONC_MULT=selfw_m,),
        _F(CHARGE=cc,TYPE_CHARGE='FIXE_CSTE',FONC_MULT=cc_m,),
        _F(CHARGE=cv,TYPE_CHARGE='FIXE_CSTE',FONC_MULT=cv_m,),
    ),
    COMPORTEMENT=(
        #the beam and plates parts are allowed to deform in
        # 'PETIT' kinematics, e.g. small perturbations
        _F(
            RELATION='ELAS',
            DEFORMATION='PETIT',
            GROUP_MA=('topbeam','vertb','mast','panel'),
        ),
        #the cables parts are allowed to deform in
        # 'GROT_GDEP' kinematics,
        # e.g. large rotations, large displacements
        _F(
            RELATION='CABLE',
            DEFORMATION='GROT_GDEP',
            GROUP_MA=('cable',),
        ),
    ),
    INCREMENT=_F(LIST_INST=liste,),
    #the resolution method
    NEWTON=_F(
        PREDICTION='TANGENTE',
        MATRICE='TANGENTE',
        REAC_ITER=1,
    ),
    #this numerical trick may speed things up
    RECH_LINEAIRE=_F(),
    #how do we consider the calculation is finished at every step
    #that is a sort of quality criteria as well
    CONVERGENCE=_F(
        RESI_GLOB_RELA=1e-4,
        ITER_GLOB_MAXI=300,
    ),
);
```

With the relevant options for the calculations of results for our study :

```
    statnl=CALC_CHAMP(
        reuse =statnl,
        RESULTAT=statnl,
        CONTRAINTE=(
            'SIEF_ELNO',
            'SIGM_ELNO',
        ),
        FORCE=('REAC_NODA',),
    );

    statnl=CALC_CHAMP(
        reuse =statnl,RESULTAT=statnl,
        GROUP_MA=('topbeam','vertb','mast','panel',),
        CONTRAINTE=('SIPO_ELNO','SIPM_ELNO',),
    );
```

```
#result concept on the face of the panel
stat2=POST_CHAMP(
    RESULTAT=statnl,
    GROUP_MA=('panel',),
    EXTR_COQUE=_F(
        NUME_COUCHE=1,
        NIVE_COUCHE='SUP',
        NOM_CHAM=('SIGM_ELNO',),
    ),
);

statsup=CALC_CHAMP(
    RESULTAT=stat2,
    GROUP_MA=('panel',),
    CRITERES=('SIEQ_ELNO','SIEQ_NOEU',),
);
```

10.3 Printing results

Printing the result is no different of what we have shown previously, keeping in mind that we can print only what's been calculated before.

However we want to see the temperature applied in the different members to check if it really is what we want to apply, so we add this section in the *.resu* printing.

Plus a little bit so have a look at the resulting traction or compression in the cable elements.

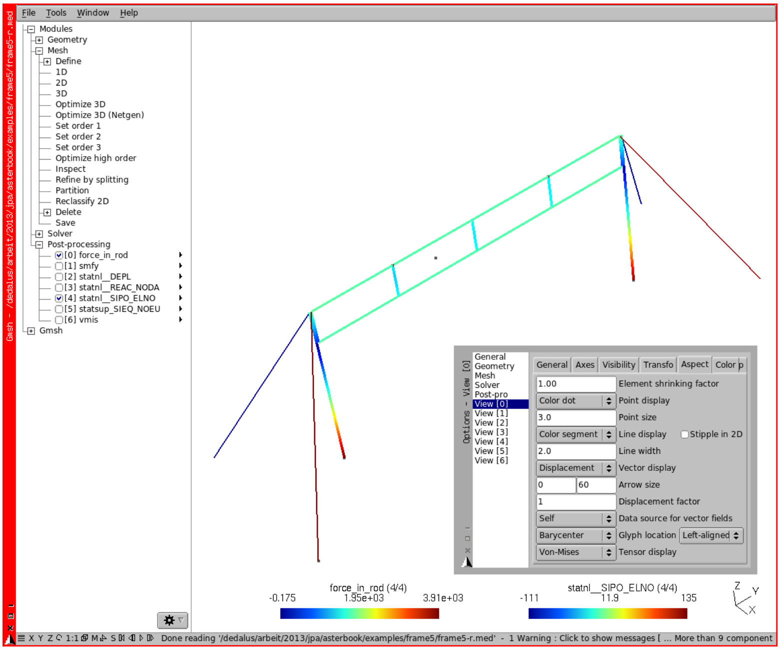
```
IMPR_RESU(
    FORMAT='RESULTAT',
    RESU=(
        _F(
            RESULTAT=evtemp,
            NOM_CHAM='TEMP',
            LIST_INST=listresu,
            VALE_MAX='OUI',VALE_MIN='OUI',
        ),
        _F(
            GROUP_MA=('cable',), RESULTAT=statnl,
            LIST_INST=listresu,
            NOM_CHAM=('SIEF_ELNO',),NOM_CMP='N',
            VALE_MAX='OUI',VALE_MIN='OUI',
        ),
        .................
    ),
);
```

and a more colorful view in the *.med* file.

```
IMPR_RESU(
    FORMAT='MED',
    UNITE=80,
    RESU=(
        _F(
            RESULTAT=evtemp,
            NOM_CHAM='TEMP',
            LIST_INST=listresu,
        ),
        .................
    ),
);
```

And we can use the restricted list of results by introducing this keyword `LIST_INST=listresu,` wherever we want in `POST_RELEVE_T` or `IMPR_RESU`

The results displays as follows, figure 10.1.



1.00 Element shrinking factor
Color dot Point display
3.0 Point size
Color segment Line display ☐ Stipple in 2D
2.0 Line width
Displacement Vector display
0 60 Arrow size
1 Displacement factor
Self Data source for vector fields
Barycenter Glyph location Left-aligned
Von-Mises Tensor display

Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame5/frame5-r.med' - 1 Warning : Click to show messages [... More than 9 component

FIGURE 10.1: Results with cables

A look at the *.mess* file shows us that the calculation is done in hardly more than one iteration at each step which means that the behavior of the structure is almost linear for the given loads. This is what we expected anyway, here the non-linear calculation is made to take into account the cable behavior. And we can actually see that the load carried by the cable, under the wind load, is quite different from the one carried previously by the rods.

Precisely the rods in he previous example carried a tension on the windward side and a compression on the leeward of about the same magnitude, at about 2000 N, for the wind load (at $INST = 6$). When the windward cables carry here a tension of 3900 N, and the leeward ones, at -0.18 N are just slack, the pre-tension being 1140 N. Lowering the pre-tension would produce a no load in the leeward cables.

10.4 A variation in CREA_RESU

Creating the 'evtemp' concept with CREA_RESU can also be written like this:

```
evtemp=CREA_RESU(
    TYPE_RESU='EVOL_VARC' ,
    NOM_CHAM='TEMP' ,
    OPERATION='AFFE' ,
    AFFE=(
        _F(CHAM_GD=temper1,INST=-1.0,),
        _F(CHAM_GD=temper1,INST=1.0,),
        _F(CHAM_GD=temper2,INST=2.0,),
        _F(CHAM_GD=temper2,INST=7.0,),
    ),
);
```

The intermediate values being interpolated at run time in between the given ones[1].

[1] The first alternative gives a more understandable display of 'evtemp', in Gmsh for a *.med* file.

CHAPTER 11

Cycling on a cable

In this chapter, we remove all the top structure to replace it by a cable spanned in between the two masts.

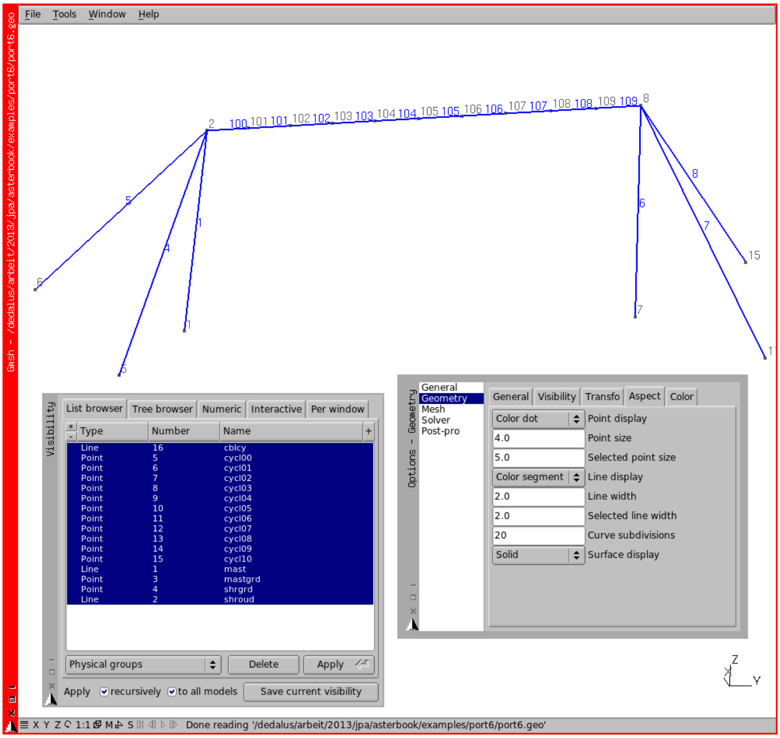
We let a clown cycle along this cable.

Once the analysis is performed we look at the graphical results and animate them on the screen.

And we also produce some time dependent plots with XmGrace, which gives us the opportunity to work with tables.

11.1 Replacing the top bar by a cable

We now model a structure with two vertical masts, each one supported by 2 angled cable shrouds and with an horizontal cable extending in-between the two mast tops. The geometry looks like figure 11.1.



Gmsh - /dedalus/arbeit/2013/jpa/asterbook/examples/port6/port6.geo

Type	Number	Name
Line	16	cblcy
Point	5	cycl00
Point	6	cycl01
Point	7	cycl02
Point	8	cycl03
Point	9	cycl04
Point	10	cycl05
Point	11	cycl06
Point	12	cycl07
Point	13	cycl08
Point	14	cycl09
Point	15	cycl10
Line	1	mast
Point	3	mastgrd
Point	4	shrgrd
Line	2	shroud

Physical groups

Apply [✓ recursively] [✓ to all models]

Color dot	Point display
4.0	Point size
5.0	Selected point size
Color segment	Line display
2.0	Line width
2.0	Selected line width
20	Curve subdivisions
Solid	Surface display

X Y Z 1:1 M S Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/port6/port6.geo'

FIGURE 11.1: Geometry ready for cycling

And the corresponding *.geo* file:

```
cl1=100;
Point(1) = {0, −1000, 0, cl1};
Point(2) = {0, −1000, 1000, cl1};
Point(5) = {−500, −1500, 0, cl1};
Point(6) = {500, −1500, 0, cl1};
Line(1) = {1, 2};
Line(4) = {5, 2};
Line(5) = {6, 2};
Symmetry {0, 1, 0, 0} {
    Duplicata { Line{1, 4, 5}; }
}

Physical Line("mast") = {1, 6};
Physical Line("shroud") = {4, 5, 7, 8};
Physical Point("mastgrd") = {1, 7};
Physical Point("shrgrd") = {5, 6, 11, 15};
```

And its second part building the top cable geometry:

```
//this loop creates the points along the top cable
//notice that Point 100 doubles with Point 2,
// Point 110 with Point 8
For i In {0:10:1}
    Point(i+100)={0,−1000+200*i,1000,cl1};
EndFor
//this loop creates the top cable section
For i In {0:9:1}
    Line(i+100)={i+100, i+100+1};
EndFor
//this loops creates individual Physical Point along the
//cable each one with a "logical" name
For i In {0:10}
    Physical Point (Sprintf("cycl%02g",i)) = {i+100};
EndFor
//this loop creates the Physical Line
//describing the top cable
lg[]={};
For i In {0:9}
    lg[]+=i+100;
EndFor
Physical Line ("cblcy") = lg[];
Transfinite Line {lg[]} = 0 Using Progression 1;
//This line removes the double points at geometry level
Coherence;
//This line removes doubles Nodes, once meshed,
//experiment the difference!!
//Coherence Mesh;
```

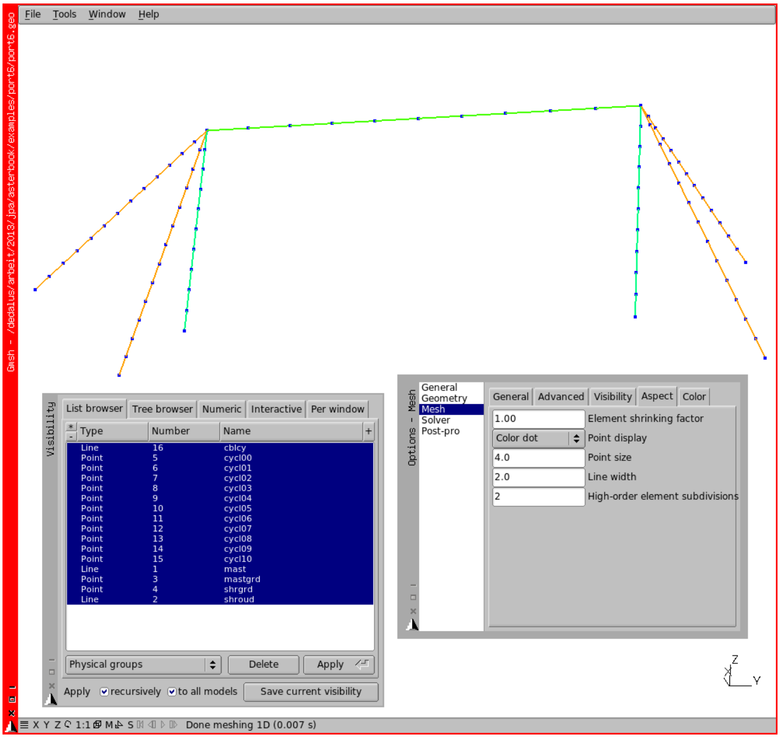
Notice the loop creating the points 100 to 109, along the top cable, together with the lines joining these points. Notice also the loop creating one group of Physical Point with an indexed name, like ’cycl01’, for each one of the above points[1].

And also the ’Coherence’ command removing the double points, as well as its fellow ’Coherence Mesh’ which does not do exactly the same thing.

Experiment with it to grasp the difference !

Once meshed our structure looks like figure 11.2:

[1] Using the C alike command ’Sprintf’.



Type	Number	Name
Line	16	cblcy
Point	5	cycl00
Point	6	cycl01
Point	7	cycl02
Point	8	cycl03
Point	9	cycl04
Point	10	cycl05
Point	11	cycl06
Point	12	cycl07
Point	13	cycl08
Point	14	cycl09
Point	15	cycl10
Line	1	mast
Point	3	mastgrd
Point	4	shrgrd
Line	2	shroud

Apply ✓ recursively ✓ to all models

1.00	Element shrinking factor
Color dot	Point display
4.0	Point size
2.0	Line width
2	High-order element subdivisions

Done meshing 1D (0.007 s)

FIGURE 11.2: Structure meshed, ready for analysis

11.2 Cycling on the cable, like a clown!

Now, we look at the behavior of this model with a clown cycling along the cable. This is done by applying the load in a "sawtooth" manner on the node groups previously created, in relation to time.

Here again the so called "instants" are only steps and not a real time, expressed in seconds. We just take into account the fact that the clown load is changing place, regardless of the speed at which the clown is moving since this would be dynamics, outside the scope of this book[1].

[1] The static analysis carried here is valid for the slow speed implied here.

Note: as we apply the clown load on a single node, we suppose he is using a single wheel vehicle, easier for us, trickier for him !

11.2.1 Commanding for solution

We give the first part of the command file with little commentary as all the concepts used here have been reviewed in the previous chapters.

Firstly, mesh reading, manipulating and model making.

```
DEBUT(
    #next line is only useful for more sophisticated Python call
    #within the .comm file
    #U4.11.1
    #PAR_LOT='NON',
);

mesh=LIRE_MAILLAGE(
    INFO=1,
    #INFO_MED=2,
    UNITE=20,FORMAT='MED',
);

mesh=DEFI_GROUP(
    reuse =mesh,MAILLAGE=mesh,
    CREA_GROUP_MA=_F(NOM='TOUT',TOUT='OUI',),
    CREA_GROUP_NO=(_F(TOUT_GROUP_MA='OUI',),),
);

IMPR_RESU(FORMAT='MED', UNITE=71, RESU=_F(MAILLAGE=mesh,),);

model=AFFE_MODELE(
    MAILLAGE=mesh,
    AFFE=(
        _F(
            GROUP_MA=('mast',),PHENOMENE='MECANIQUE',
            MODELISATION='POU_D_T',
        ),
        _F(
            GROUP_MA=('cblcy','shroud',),
            PHENOMENE='MECANIQUE',
            MODELISATION='CABLE',
        ),
    ),
);
```

Secondly, setting the temperature fields which means increasing the pre-load the cables.

```
#putting pre-load in the vertical cables 'shroud' is enough
#the top cable 'cblcy' is pre-loaded by the shroud
#and the relatively low stiffness of the 'mast'
temper=CREA_CHAMP(
    MODELE=model,
    TYPE_CHAM='NOEU_TEMP_R',
    OPERATION='AFFE',
    AFFE=(
        #here we benefit of the Overwriting rule
        _F(TOUT='OUI',NOM_CMP='TEMP',VALE=0.,),
        _F(GROUP_MA=('shroud',),NOM_CMP='TEMP',VALE=-10.0,),
    ),
);

#from this field we create a thermal result
ltemp=DEFI_LIST_REEL(
    DEBUT=-1.0,
    INTERVALLE=_F(JUSQU_A=11.0,PAS=1.0,),
);

evtemp=CREA_RESU(
    TYPE_RESU='EVOL_VARC',
    NOM_CHAM='TEMP',
    OPERATION='AFFE',
    AFFE=(
        _F(CHAM_GD=temper,LIST_INST=ltemp,),
    ),
);
```

Note how we take advantage of the “Overwriting rule”, described in chapter 6.5 , in superimposing a temperature of -10°C, on ’shroud’ group only, after having set ’TOUT’ at 0°C.

Thirdly, defining the materials.

```
steel=DEFI_MATERIAU(ELAS=_F(
    E=210000.,NU=0.3,RHO=8e-9,ALPHA=12e-6),
);

cablst=DEFI_MATERIAU(
    ELAS=_F(E=100000,NU=0.3,RHO=8e-9,ALPHA=12e-6,),
    CABLE=_F(EC_SUR_E=1.E-4,),
);
```

```
material=AFFE_MATERIAU(
    MAILLAGE=mesh,
    AFFE=(
        _F(GROUP_MA=('mast',), MATER=steel,),
        _F(
            GROUP_MA=('cblcy','shroud',),
            MATER=cablst,
        ),
    ),
    AFFE_VARC=_F(
        TOUT='OUI',
        NOM_VARC='TEMP',
        EVOL=evtemp,
        VALE_REF=0.0,
    ),
);
```

And setting the element's properties.

```
elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    POUTRE=_F(
        GROUP_MA=('mast',),
        SECTION='RECTANGLE',
        CARA=('HY','HZ','EPY', 'EPZ',),
        VALE=(100, 50, 5, 5,),
    ),
    #mast section is increased compared to other examples,
    #it would not withstand the load
    ORIENTATION=_F(
        GROUP_MA=('mast',),CARA='ANGL_VRIL', VALE=90.0,
    ),
    CABLE=_F(
        GROUP_MA=('cblcy','shroud',),
        N_INIT=10.0,
        SECTION=(10,),
    ),
);
```

Fourthly, setting boundary conditions and gravity load.

```
ground=AFFE_CHAR_MECA(
    MODELE=model,
    DDL_IMPO=(
        _F(
            GROUP_NO=('mastgrd',),
            DX=0,DY=0,DZ=0,DRX=0,DRY=0,DRZ=0,
        ),
        _F(GROUP_NO=('shrgrd',),DX=0,DY=0,DZ=0,),
    ),
);

selfwght=AFFE_CHAR_MECA(
    MODELE=model,
    PESANTEUR =_F(
        GRAVITE=10000,DIRECTION=(0,0,-1),
        GROUP_MA=('mast','cblcy','shroud',),
    ),
);
```

And know the part applying the cycling load, as a traveling point load along the 9 nodes previously created on the cable.

```
#in the next line we apply a vertical load of 100 N on each
#of the group of nodes
#(1 node in each group here) on the cable
#with a sawtooth style time stepping on the load
#so as to mimic a rolling load
#this is done in a Python loop, note mandatory indents in the loop
iter=9;
lc=[None]*(iter+1);
lcm=[None]*(iter+1);
for i in range (1,iter+1):
    grpno='cycl%02g' %i;
    lc[i]=AFFE_CHAR_MECA(
        MODELE=model,
        FORCE_NODALE=_F(GROUP_NO=(grpno,),FZ=-100,),
    );
    lcm[i]=DEFI_FONCTION(
        NOM_PARA='INST',
        VALE=(i-1,0, i,1, i+1,0,),
        PROL_GAUCHE='CONSTANT',
        PROL_DROITE='CONSTANT',
    );

selfw_m=DEFI_FONCTION(
    NOM_PARA='INST',
    VALE=(0,1, 10,1,),
    PROL_GAUCHE='CONSTANT',
    PROL_DROITE='CONSTANT',
);
```

Here is a block with some list definition, each one of them serves a special purpose:

- the first one, 'liste' is used as an argument by `INCREMENT`, the calculation[1] is performed at every single step described in this list, it may need to be adapted until the problem converges;
- the second one, 'listresu' is used as an argument by many `IMPR_RESU`, it tells which steps are printed in the results files, it is entirely arbitrary and has no influence on the problem solving, to reduce the size of the files this list should be restricted to useful values;
- the third one, 'listarchiv' is used as an argument by the keyword `ARCHIVAGE`, it tells which steps are saved in the 'database', it has a direct influence on the 'database' size and is entirely to the user's choice.

[1] A linear system solution.

```
liste=DEFI_LIST_REEL(
    #we start at the beginning of the preload
    DEBUT=-1.0,
    INTERVALLE=(
        _F(JUSQU_A=0.0,PAS=0.2,),
        _F(JUSQU_A=10.0,PAS=0.2,),
    ),
);

#we also want a more restricted list
#at which to print results
#only the INST not the NUME_ORDRE
from -1.0 as we want to see the preload
#and only up to 5 as the problem is symmetrical
listresu=DEFI_LIST_REEL(
    DEBUT=-1.0,
    INTERVALLE=_F(JUSQU_A=5,PAS=1.0,),
);

#the following list would restrict the instant
#written in the database hence it's size
listarch=DEFI_LIST_REEL(
    DEBUT=-1.0,
    #to produce the enclosed plot
    INTERVALLE=_F(JUSQU_A=10,PAS=0.2,),
    #maybe this would be enough
    #INTERVALLE=_F(JUSQU_A=10,PAS=1.0,),
);
```

Now, we create the cycling load case:

```
#Python loop to create the argument 'loadr' passed to 'EXCIT'
#loadr is actually a list!
#first the grounded DOF, then the gravity,
#and the various cycling load
loadr=[];
loadr.append(  _F(CHARGE=ground,),  );
loadr.append(  _F(CHARGE=selfwght,FONC_MULT=selfw_m,),  );
for i in range (1,iter+1):
    loadr.append(  _F(
        CHARGE=lc[i],
        TYPE_CHARGE='FIXE_CSTE',FONC_MULT=lcm[i],),
);
```

This is just one of the several available ways to create the argument 'loadr' in Python which is a rich language. A close look at the *.mess* file helps us to understand how **code_aster** translates this bit of Python code.

```
statnl=STAT_NON_LINE(
    MODELE=model,
    CHAM_MATER=material,
    CARA_ELEM=elemcar,
    EXCIT=loadr,
    COMPORTEMENT=(
        _F(
            RELATION='ELAS',
            DEFORMATION='PETIT',
            GROUP_MA=('mast',),
        ),
        _F(
            RELATION='CABLE',
            DEFORMATION='GROT_GDEP',
            GROUP_MA=('cblcy','shroud',),
        ),
    ),
    INCREMENT=_F(LIST_INST=liste,),
    NEWTON=_F(
        PREDICTION='TANGENTE',
        MATRICE='TANGENTE',
        REAC_ITER=1,
    ),
    RECH_LINEAIRE=_F(),
    CONVERGENCE=_F(
        RESI_GLOB_RELA=1e-4,
        ITER_GLOB_MAXI=300,
    ),
    ARCHIVAGE=_F(LIST_INST=listarch,),
);
```

```
    statnl=CALC_CHAMP(
        reuse =statnl,
        RESULTAT=statnl,
        CONTRAINTE='SIEF_ELNO',
        FORCE=('REAC_NODA'),
    );
```

11.2.2 Commanding for results

We are know going to print some results in ASCII format, firstly the usual sum of reactions and individual reactions.

```
    sum_reac=POST_RELEVE_T(
        ACTION=_F(
            INTITULE='sum reactions',
            GROUP_NO=('mastgrd','shrgrd',),
            RESULTAT=statnl,
            NOM_CHAM='REAC_NODA',
            RESULTANTE=('DX','DY','DZ'),
            OPERATION='EXTRACTION',
            LIST_INST=listresu,
            #another way to restrict the useful printing
            #INST=(0, 1, 2, 3, 4, 5, 6, 7,),
            #a good way to produce a lot of
            #maybe useless information
            #TOUT_ORDRE='OUI',
        ),
    );
    IMPR_TABLE (TABLE=sum_reac,)

    IMPR_RESU(
        MODELE=model,
        FORMAT='RESULTAT',
        RESU=_F(
            NOM_CHAM='REAC_NODA',
            GROUP_NO=('mastgrd','shrgrd',),
            RESULTAT=statnl,
            LIST_INST=listresu,
        ),
    );
```

Followed by some key values of forces.

```
  IMPR_RESU(
      MODELE=model,
      FORMAT='RESULTAT',
      RESU=(
          _F(
              NOM_CHAM='SIEF_ELNO',
              GROUP_MA=('mast','shroud','cblcy',),
              RESULTAT=statnl,
              LIST_INST=listresu,
              VALE_MAX='OUI',VALE_MIN='OUI',
          ),
          _F(
              NOM_CHAM='SIEF_ELNO',
              GROUP_MA=('shroud',),
              RESULTAT=statnl,
              LIST_INST=listresu,
              VALE_MAX='OUI',VALE_MIN='OUI',
          ),
          _F(
              NOM_CHAM='SIEF_ELNO',
              GROUP_MA=('cblcy',),
              RESULTAT=statnl,
              LIST_INST=listresu,
              VALE_MAX='OUI',VALE_MIN='OUI',
          ),
      ),
  );
```

And in a *.med* file.

```
  IMPR_RESU(
      FORMAT='MED', UNITE=80,
      RESU=(
          _F(
                GROUP_MA=('mast','shroud','cblcy'),
                RESULTAT=statnl,
                NOM_CHAM=('DEPL','SIEF_ELNO',),
                LIST_INST=listresu,
            ),
            _F(
                GROUP_MA=('mast',),
                RESULTAT=statnl,
                NOM_CHAM=('SIPO_ELNO',),
                LIST_INST=listresu,
            ),
        ),
    );
```

11.2.3 Creating time dependent plots

Up to know, we have only produced numerical or graphical result files with step by step results, in the next section, we produce a graphical plot of some results, displacement or forces, versus “time”[1].

This section must be read carefully and well understood as the production of such a plot is a rather low level code approach in **code_aster** . Yet it reveals a very powerful one!

Firstly, we extract the vertical displacement of the point in the middle of the cable, 'dz5' and at the point at one tenth of the length, 'dz1'.

```
#next lines are how to prepare and save a plot for XmGrace
#here we make a table with the displacement
#in z direction of the point 'cycl05'
#in the middle of the cable in function of the time
dz5=POST_RELEVE_T(
    ACTION=_F(
        OPERATION='EXTRACTION',
        INTITULE='displ_middle',
        RESULTAT=statnl,
        NOM_CHAM='DEPL',
        TOUT_ORDRE='OUI',
        GROUP_NO='cycl05',
        RESULTANTE=('DZ',),
        MOYE_NOEUD='NON',
    ),
    TITRE='displacement middle of cable',
);
#next line line to print it the .resu file, not really useful here,
#just to see what it looks like
IMPR_TABLE (TABLE=dz5,)
```

[1] With the same restriction as above.

```
#the same for point 1
dz1=POST_RELEVE_T(
    ACTION=_F(
        OPERATION='EXTRACTION',
        INTITULE='displ_near_end',
        RESULTAT=statnl,
        NOM_CHAM='DEPL',
        TOUT_ORDRE='OUI',
        GROUP_NO='cycl01',
        RESULTANTE=('DZ',),
        MOYE_NOEUD='NON',
    ),
    TITRE='displacement near end of cable',
);
```

Secondly, we extract the extreme values of the force in the top cable.

```
#here we prepare a table with the EXTREMA
#of the normal force in cable elements
forcec=POST_RELEVE_T(
    ACTION=_F(
        OPERATION='EXTREMA',
        INTITULE='force_in_cable',
        RESULTAT=statnl,
        NOM_CHAM='SIEF_ELNO',
        NOM_CMP='N',
        TOUT_ORDRE='OUI',
        GROUP_MA='cblcy',
    ),
    TITRE='force_in_cable',
);
#first print out
IMPR_TABLE (TABLE=forcec,)
```

Thirdly, we keep only the positive, tension, values.

```
#then we restrict it to the maximum + tension value
forcec=CALC_TABLE(
    TABLE=forcec,reuse=forcec,
    ACTION=_F(
        OPERATION='FILTRE',NOM_PARA='EXTREMA',VALE_K='MAX',
    ),
    TITRE='max_tension_in_cable',
);
#second print out
IMPR_TABLE (TABLE=forcec,)
```

To get a nicer plot we want to scale these values, dividing them by ten.

```
#here we define a function, divide by ten
byten=FORMULE(NOM_PARA='VALE',VALE='VALE/10',),

#then we divide the tension value by ten for a nicer plot
```

```
forcec=CALC_TABLE(
    TABLE=forcec,reuse=forcec,
    ACTION=_F(
        OPERATION='OPER',
        FORMULE=byten,
        NOM_PARA='VALE10',
    ),
    TITRE='max_tension_in_cable/10',
);
#third print out
IMPR_TABLE (TABLE=forcec,)

##the same could be done with a single call to CALC_TABLE
#byten=FORMULE(NOM_PARA='VALE',VALE='VALE/10',),
#forcec=CALC_TABLE(
    #TABLE=forcec,reuse=forcec,
    #ACTION=(
        #_F(OPERATION='FILTRE',NOM_PARA='EXTREMA',VALE_K='MAX',),
        #_F(OPERATION='OPER',FORMULE=byten,NOM_PARA='VALE10',),
    #),
#);
```

And, we create the functions for the plot:

- to have `INST`, against `NUME_ORDRE` as abscissa of the XmGrace plot;

```
#here is a function that loads in a list:
#x = value time step instant, time = value time step instant
time=RECU_FONCTION(
    TABLE=dz5, #could have been dz1
               #as the parameters are the same
    PARA_X='NUME_ORDRE',
    PARA_Y='INST',
);
```

- to have `DZ` for 'dz5', against' `NUME_ORDRE` as one ordinate of the XmGrace plot;

```
#here a function that loads in a list:
#x = value tnum order,
#deltaZ5 = Z displacement in the middle of the cable
deltaZ5=RECU_FONCTION(
    TABLE=dz5,
    PARA_X='NUME_ORDRE',
    PARA_Y='DZ',
);
```

- to have the same for 'dz1;

```
#the same near the end of the cable
deltaZ1=RECU_FONCTION(
    TABLE=dz1,
    PARA_X='NUME_ORDRE' ,
    PARA_Y='DZ' ,
);
```

- to have the tension in the cable as another ordinate of the XmGrace plot.

```
#the same for the tension in the cable
fNc=RECU_FONCTION(
    TABLE=forcec,
    PARA_X='NUME_ORDRE' ,
    PARA_Y='VALE10' ,
);
```

Finally, this next section assembles the whole plot, with some enhancements like titles, legends and scales[1].

```
#here we print these functions in an XmGrace format file
#we need an entry in ASTK for that file with LU=29,
#maybe extension .agr
IMPR_FONCTION(
    FORMAT='XMGRACE' ,
    UNITE=29,
    TITRE='displacement and force ' ,
    BORNE_X=(0,10),
    #restrict to nice ordinates
    BORNE_Y=(-80,100),
    #restrict to useful abscissa
    GRILLE_X=1,
    GRILLE_Y=10,
    LEGENDE_X='time (s)' ,
    LEGENDE_Y='displacement (mm) or force (N*10)' ,
    COURBE=(
        _F(FONC_X=time,FONC_Y=deltaZ5,LEGENDE='dZ5' ,),
        _F(FONC_X=time,FONC_Y=deltaZ1,LEGENDE='dZ1' ,),
        _F(FONC_X=time,FONC_Y=fNc,LEGENDE='tension' ,),
    ),
);

STANLEY()

FIN()
```

[1] There could be many more arguments.

11.2.4 Concluding about this command file

To sum it up what has to be noted in this file is the use of one single Python loop to create the loads , `lc[i]`, of the clown cycling along the cable.

With one line, within the loop, we are able to create 10 load cases!

Another loop appends all the load case in a single Python list `loadr`, used as an argument to `EXCIT` in `STAT_NON_LINE`.

Finally, we use the list `listresu` to limit the printing to the round numbered `INST`.

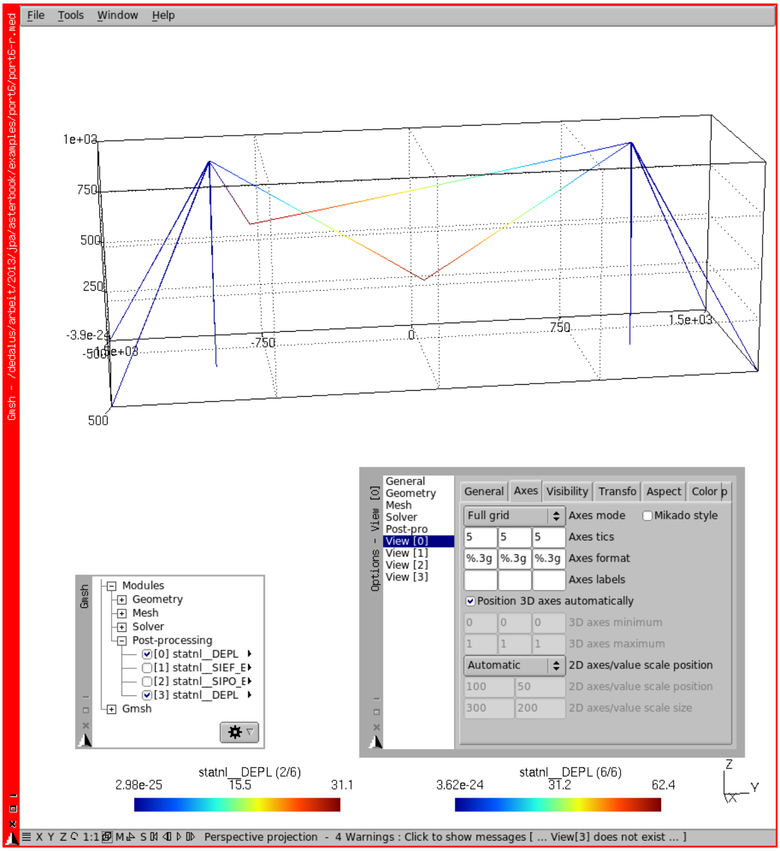
11.3 Viewing results

Figure 11.3 is a view of the displacement at `INST` 2 and 5, in Gmsh. To obtain the 2 superimposed views, we proceed like this:

- we make view[0] the active and only visible, set the proper parameters:
  - OPTIONS » Aspect » Displacement factor to 10;
  - button Min and Max in General tab;
  - Tools » Visibility with only line groups visible;
  - set Time step to 5;
- RMB on the arrow right of view[0], Alias » View with Options, this creates a view[3];
- return in view[0] and set Time step to 2;
- button Min and Max in General tab;
- in the Axes tab set Axes mode to Full grid, just to show a scaled bounding box [1].

We can animate one displacement, the classical 4 buttons (Rewind, Step backward, Play/Pause Step forward) are in the status bar at the bottom of the **Gmsh** window. We can even record this animation: in File » Export... we can choose Format: Movie -MPEG (*.mpg) to record a movie with quite a few options available.

[1] Of course this is not necessary at all.



Modules
- Geometry
- Mesh
- Solver
- Post-processing
  - ✓ [0] statnl__DEPL
  - [1] statnl__SIEF_E
  - [2] statnl__SIPO_E
  - ✓ [3] statnl__DEPL
- Gmsh

General
Geometry
Mesh
Solver
Post-pro
View [0]
View [1]
View [2]
View [3]

General | Axes | Visibility | Transfo | Aspect | Color p

Full grid — Axes mode; Mikado style ☐
5 5 5 — Axes tics
%.3g %.3g %.3g — Axes format
Axes labels
✓ Position 3D axes automatically
0 0 0 — 3D axes minimum
1 1 1 — 3D axes maximum
Automatic — 2D axes/value scale position
100 50 — 2D axes/value scale position
300 200 — 2D axes/value scale size

statnl__DEPL (2/6): 2.98e-25, 15.5, 31.1

statnl__DEPL (6/6): 3.62e-24, 31.2, 62.4

X Y Z 1:1 M S Perspective projection - 4 Warnings : Click to show messages [... View[3] does not exist ...]

FIGURE 11.3: Deformed shape at INST 1 and 5

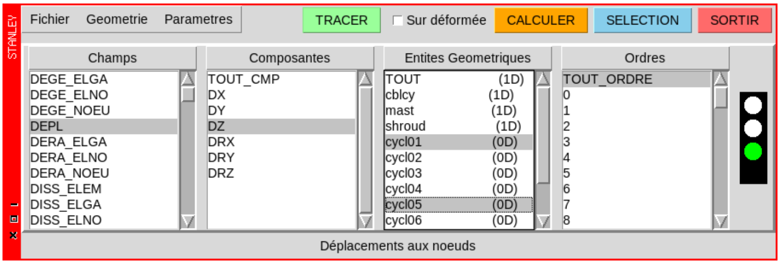
11.4 Plotting results with XmGrace

XmGrace is a GNU plotting program coming within the **code_aster** package[1].

If we run the study in ASTK and let the **STANLEY** window appear:

- in the first column on the left-hand side titled, in French, Champs, we choose DEPL;
- in the second column titled Composantes, we choose DZ;
- in the third column Entites Geometriques, we LMB click the title to toggle it to Courbes and choose cycl01 and cycl05, this is how we previously named the first and the middle nodes on which the clown is cycling.

We leave the last right column Ordres as it is to plot the curve on the whole set of orders, the **STANLEY** window looks like figure 11.4.



```
Champs        Composantes   Entites Geometriques   Ordres
DEGE_ELGA     TOUT_CMP      TOUT       (1D)        TOUT_ORDRE
DEGE_ELNO     DX            cblcy      (1D)        0
DEGE_NOEU     DY            mast       (1D)        1
DEPL          DZ            shroud     (1D)        2
DERA_ELGA     DRX           cycl01     (0D)        3
DERA_ELNO     DRY           cycl02     (0D)        4
DERA_NOEU     DRZ           cycl03     (0D)        5
DISS_ELEM                   cycl04     (0D)        6
DISS_ELGA                   cycl05     (0D)        7
DISS_ELNO                   cycl06     (0D)        8
Déplacements aux noeuds
```

FIGURE 11.4: STANLEY ready for plotting in XmGrace

A gentle push on the TRACER button and the **XmGrace** window like figure 11.5 appears with the plot of the vertical displacement of the two nodes with respect to time or more precisely `NUME ORDRE` as stated along the abscissa axis.

The strange appearance on the left hand side of the plots comes from the fact that the load does start later than `NUME ORDRE`=0. To change

[1] More information is available here `http://plasma-gate.weizmann.ac.il/Grace/`

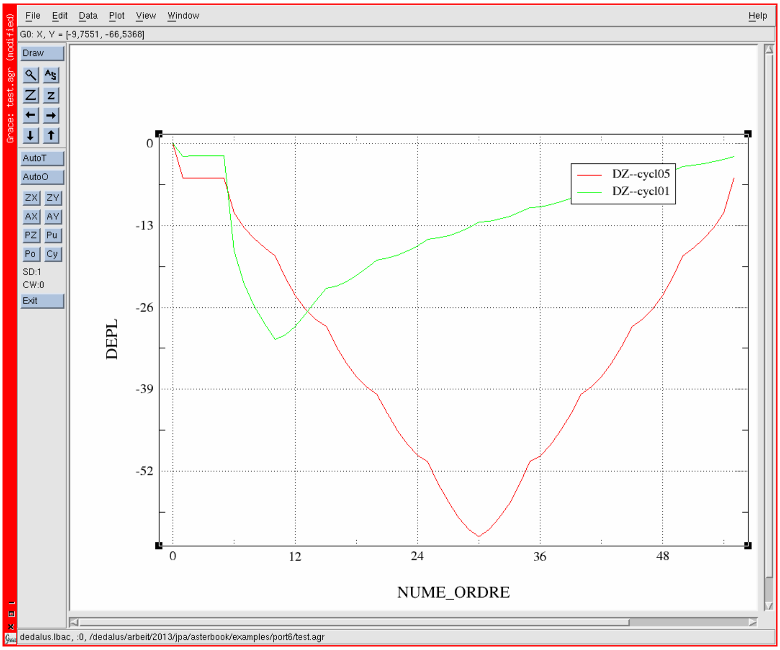

Grace: test.agr (modified)
File Edit Data Plot View Window Help
G0: X, Y = [-9,7551, -66,5368]
Draw
AutoT
AutoO
ZX ZY
AX AY
PZ Pu
Po Cy
SD:1
CW:0
Exit
0
-13
-26
-39
-52
DEPL
0
12
24
36
48
NUME_ORDRE
DZ--cycl05
DZ--cycl01
dedalus.lbac, :0, /dedalus/arbeit/2013/jpa/asterbook/examples/port6/test.agr

FIGURE 11.5: Plot in XmGrace within STANLEY

NUME ORDRE to INST, which is more meaningful in our case, we have to RMB click the last column and select INST[1].

A click on the Stanley menu Geometrie » Ajout Point would have allowed us to plot on another point, created on the fly by giving its coordinates. If these coordinates do not point to a node in the structure the produced plot is meaningless!

[1] The very long list popping up shows us the vast possibilities of STANLEY in post-processing.

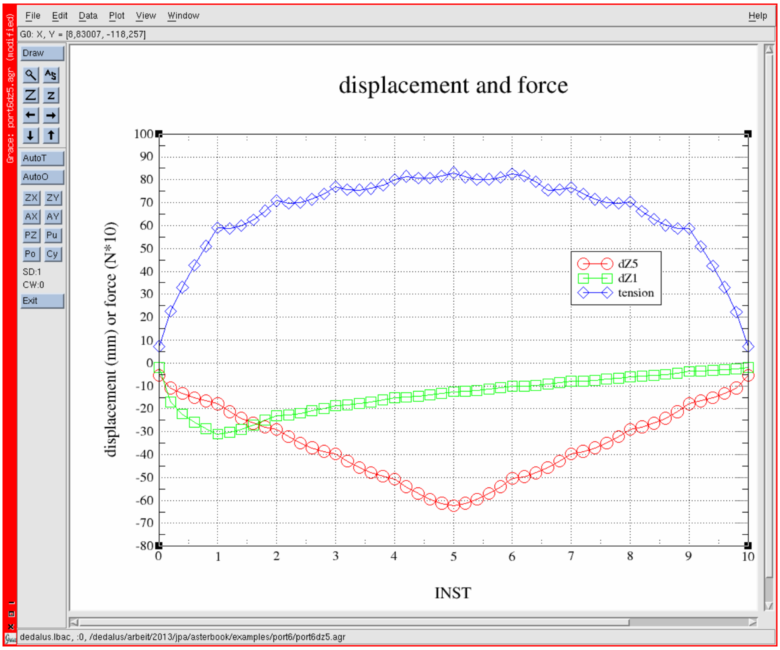


FIGURE 11.6: Combined plot

As we have saved an XmGrace file, in LU 29, with extension *.agr* we can also open it with XmGrace outside of STANLEY. This plot is shown in figure 11.6. The saved plot is somewhat more sophisticated than the one produced from STANLEY and may be customized even more. This is described in the operator `IMPR_FUNCTION` U4.33.01 as well as manual U2.51.01.

This plot shows at its bottom the displacement of the node in the middle of the cable (dZ5), in red, and the displacement of a node at 10% of the length of the cable (dZ1), in green, with respect to time. These displacements have of course a negative value. In blue, the value of the maximum tension in the cable is also displayed. Note: the force scale is multiplied by 10, so as to make a nicer plot.

11.5 Verifying some results

It is quite easy to do a quick check on the results, the formula for a cable with a point load in the middle is well known[1], we have:

$$\tan\theta - \sin\theta = \frac{W}{2EA}, \text{ or if } \theta < 12°, \theta = (\frac{W}{EA})^{\frac{1}{3}}$$

where θ is the slope of the cable at the ends, W the point load, E the cable's Young modulus, A its section and L its length, which gives here:

$$\theta = (\frac{100}{100000 \times 10})^{\frac{1}{3}} = 0.046rad = 2.6°$$

the vertical displacement being:

$$\delta = \frac{L}{2}\tan\theta = 46mm$$

compared to $62mm$ calculated by **code_aster** ; and the tension in the cable:

$$T = \frac{W}{2\sin\theta} = 1078N$$

compared to $496N$ calculated by **code_aster** . The discrepancy is quite large but can be explained by the low pre-load in the 'shroud' cables with which the top of the masts move inward by $1.13mm.$ Setting the temperature from $-10°$ to $-100°$ would give **code_aster** results almost like the formula.

However one of the real design problem in this type of cable vehicle may occur when the vehicle reaches the end of the cable the slope may become steep and the cable should not foul some part of the structure at this stage.

Here, we are self powered and when the clown reaches point 9 the deflection of the cable becomes $31mm$ which for a length to go of $200mm$ gives a slope of around 16%, we must ensure that this guy has got good legs and that the wheel does not slip on the cable!

[1] Again it can be found in [Roark], precisely in TABLE 12.

11.6 Working with tables

To build the entries for the XmGrace plot, we use several operators like POST_RELEVE_T or CALC_TABLE, let's have a closer look of what we actually do.

In the call to POST_RELEVE_T, we ask the code to extract the EXTREMA value of SIEF_ELNO component N, the tension, in the element forming the cycling cable.

As we can see in the following listing (commented as "#first print out" in the command file) we have 2 values, MAX or MIN at each NUME_ORDRE.

```
#force in cable
 INTITULE         RESU     NOM_CHAM         NUME_ORDRE
EXTREMA  MAILLE   NOEUD    CMP      VALE
 force in cable   statnl   SIEF_ELNO
0 MAX      M82      N2       N        0.00000E+00
 force in cable   statnl   SIEF_ELNO
0 MIN      M82      N2       N        0.00000E+00
 force in cable   statnl   SIEF_ELNO
0 MAX_ABS  M82      N2       N        0.00000E+00
 force in cable   statnl   SIEF_ELNO
0 MIN_ABS  M82      N2       N        0.00000E+00
 force in cable   statnl   SIEF_ELNO
1 MAX      M82      N2       N        4.99876E+02
 force in cable   statnl   SIEF_ELNO
1 MIN      M88      N14      N        4.63404E+02
 force in cable   statnl   SIEF_ELNO
1 MAX_ABS  M82      N2       N        4.99876E+02
 force in cable   statnl   SIEF_ELNO
1 MIN_ABS  M88      N14      N        4.63404E+02
 ..............................
```

MIN entry could have been negative, e.g. compressive, if we had not chosen a cable element.

In the first call to CALC_TABLE, we clean the table to keep only the MAX tensile value, resulting in the "#second print out" shown below. Only this MAX is retained under VALE.

```
#force in cable
#FILTRE -> NOM_PARA: EXTREMA          CRIT_COMP: EQ
VALE: ('MAX',)
 INTITULE         RESU     NOM_CHAM         NUME_ORDRE
EXTREMA  MAILLE   NOEUD    CMP      VALE
 force in cable   statnl   SIEF_ELNO
0 MAX      M82      N2       N        0.00000E+00
```

```
  force in cable   statnl   SIEF_ELNO
1 MAX      M82      N2       N          4.99876E+02
 ..............................
```

The value of the tensile force are so large compared to the displacement that the XmGrace plot would not look nice. That's why in the second call to CALC_TABLE, we add another column which contains the value of the tensile force divided by ten, we name this new column 'VALE10', and we use this one in the plot.

```
#force in cable
#FILTRE -> NOM_PARA: EXTREMA          CRIT_COMP: EQ
VALE: ('MAX',)
 INTITULE          RESU     NOM_CHAM         NUME_ORDRE
EXTREMA  MAILLE   NOEUD    CMP      VALE         VALE10
 force in cable   statnl   SIEF_ELNO
0 MAX      M82      N2       N          0.00000E+00  0.00000E+00
 .............................
```

This is just an introduction to the many options in POST_RELEVE_T and CALC_TABLE, they are fully described U4.81.21 and U4.33.03, and we are dealing again with this matter in chapter 19.1 .

CHAPTER 12

Going solid, with contact, a bi-linear spring

In this chapter, with a 2 parts model, we cope with various problems:

- 3D solid meshing and modeling;
- with a quadratic mesh;
- with various options to link the two parts together: glued, glued with free rotation, contact and contact with friction;
- at the same time we run five analysis within a single command file;
- and we run the study without any post processing but saving the results in a base.

12.1 Introducing the study

In this chapter, we study the behavior of what can be seen as a bi-linear leaf spring[1], of rather simple design, shown in figure 12.2. One male part,

[1] The name "leaf" may not be very suitable, as this "leaf" is thicker than it is wide.

which we call 'part1' is a thick plate, in magenta, carrying a pin, in red, at the left-hand end, this 'part1' is solidly fixed at its right-hand end. Two female parts, 'part2' with a hole receiving the pin and solidly fixed at their left-hand end. There is a little radial play, 0.5 mm, of the pin within the hole.

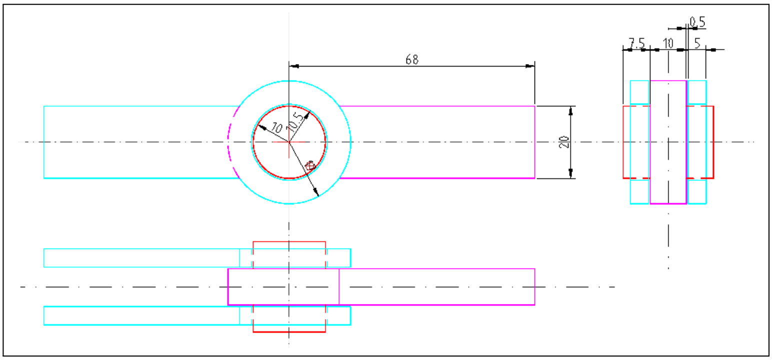


FIGURE 12.1: Dimensional sketch of bi-linear spring

We study the behavior of this model subjected to a vertical load on the pin, under various hypothesis:

1. 'part1' is not linked at all to 'part2' and takes the whole load;
2. both part are solidly 'glued' together around the pin and behave like one single continuous part taking the load;
3. relative rotation is freed around the pin, but not translation;
4. 'part1' moves down until the pin touches the hole face, and then both parts share the load;
5. the same as above, but with friction along the vertical faces, just like there was a nut on the pin, tightened as required, and in this case load sharing starts at the very beginning, before the pin comes in contact of the hole face, which may never happen if the tightening pressure is high enough.

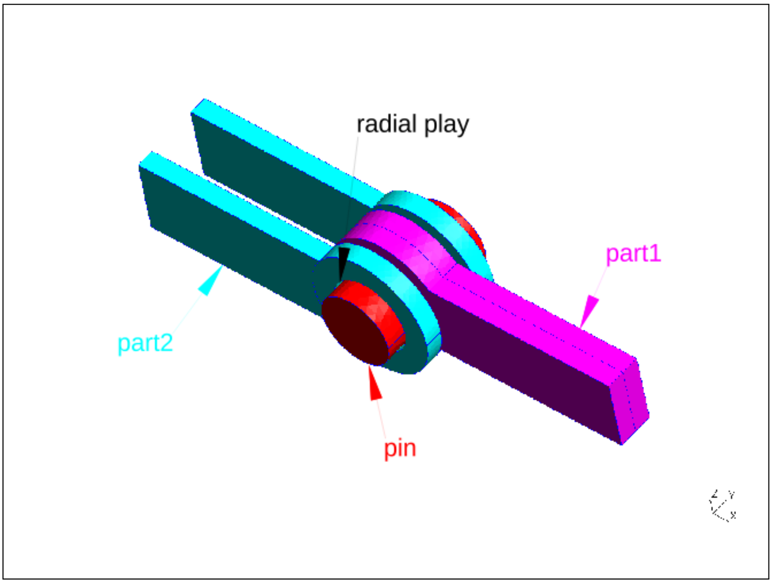


FIGURE 12.2: View of the full model (slightly exploded)

All this is carried at once, within a single run of **code_aster** . However we split the study in two parts:

1. putting the study together and solving;
2. independent post-processing.

For this kind of study the solution may take hours, while post-processing calculations are a matter of minutes. We calculate the solution, store it in a database, and call a post-processing *.comm* file to calculate and print out the results. This post-processing command file can be tailored without having to re-run the solution. This is known as `POURSUITE` in the **code_aster** jargon. We also see how to calculate the solution on a quadratic mesh but projecting the result on a linear[1] simplified mesh.

We also use the symmetry of the model, and the fact that the load acts in the plane of symmetry to mesh only half of the model.

[1] Here linear means non-quadratic as explained in chapter 17.5 .

12.2 Drawing and meshing

12.2.1 Drawing 'part1'

The *.geo* file for Gmsh is as below:

```
//'part1' geometry
cl1=2.5; //characteristic length, for meshing
t1=5; //thickness of half part
r1=10.0; //radius of pin
r2=17.0; //outside radius of eye

Point(1) = {0, −t1, 0, cl1}; //base point
Point(11) = {0, −t1, −r1, cl1};
Point(12) = {r1*Sin(2*Pi/3), −t1, r1+r1*Cos(2*Pi/3), cl1};
Point(13) = {r1*Sin(4*Pi/3), −t1, r1+r1*Cos(4*Pi/3), cl1};
Point(21) = {Sqrt(r2*r2−r1*r1), −t1, r1, cl1};
Point(22) = {−r2, −t1, 0, cl1};
Point(23) = {Sqrt(r2*r2−r1*r1), −t1, −r1, cl1};
Point(24) = {4*r2, −t1, r1, cl1};
Point(25) = {4*r2, −t1, −r1, cl1};
Circle(1) = {11, 1, 12};
Circle(2) = {12, 1, 13};
Circle(3) = {13, 1, 11};
Circle(4) = {21, 1, 22};
Circle(5) = {22, 1, 23};
Line(6) = {21, 24};
Line(7) = {23, 25};
Line(8) = {25, 24};
```

```
//extrusion of lines to create surfaces
//this line would have only extruded the geometry
//fix1s[]  = { Extrude {0, t1, 0} {Line{-8};} };
//this line line extrude the geometry and the associated
//mesh have 3 divisions along the extrusion length
fix1s[]  = { Extrude {0, t1, 0} {Line{−8};Layers {3};} };
edge1s[]  = { Extrude {0, t1, 0} {Line{6, −4, −5, −7};
    Layers {3};} };
pin1s[]  = { Extrude {0, −1.5*t1, 0} {Line{1, 2, 3};
    Layers {5};} };

//creation of plane surface
Curve Loop(41) = {2, 3, 1};
Plane Surface(42) = {41};
Curve Loop(43) = {6, −8, −7, −5, −4};
Plane Surface(44) = {−43, 41};

//extrusion of plane surfaces into volume
//as the bounding surface are layered
//it is not necessary to use layer for extruding the volume
part1v[]  = { Extrude  {0, t1, 0} {Surface{42, 44}; } };
pin1v[]  = { Extrude  {0, −1.5*t1, 0} {Surface{42};} };
```

```
// this point is used to compute and plot displacement
Point{30} In Surface{61};
```

```
//only the items necessary in the calculation are grouped

Physical Point("load1p") = {30};
Physical Surface("bear1s") = {44};
Physical Surface("sym1s") = {103};
Physical Surface("pin1s") = {pin1s[]};
Physical Surface("fix1s") = {fix1s[]};
Physical Surface("load1s") = {61};
Physical Volume("part1v") = {part1v[]};
Physical Volume("pin1v") = {pin1v[]};
```

```
//coloring of mesh
//all surfaces in Cyan
Color Cyan{
    Surface{12, 16, 20, 24, 28, 32, 36, 40, 42, 44, 52, 56,
        60, 61, 103, 120};
}
//then
Color Orange{ Surface{44}; }
Color Black{ Surface{61}; }
Color Green{ Surface{103}; }
Color Red{ Surface{pin1s[]}; }
Color Blue{ Surface{fix1s[]}; }
Color Magenta{ Volume {part1v[], pin1v[] };}
```

It is entirely parametric, with the parameters on the first lines. Once meshed it looks like figure 12.3. Note also how ’Surface’ are created by ’Extrude’ of ’Line’, and ’Volume’ by ’Extrude’ of ’Surface’. The command ’Extrude’ takes the argument ’Layers’ to tell how many elements are created along the length of the extrusion at mesh time.

One remark: we divide the circle in three arcs as Gmsh cannot draw an arc whose angle is equal to or greater than π[1].

At the end of the file is the group building and naming, the last character stands as “v” for volume, “s” for surface and “p” for point.

The last lines are for coloring the mesh, which gives:

- green and black for the plane of symmetry;
- the load is applied onto ’load1s’ which is black;

[1] This not a Gmsh restriction but basic geometry: given the center and 2 points there is an infinite number of arcs in 3D space if the three points are aligned (angle $= \pi$), and 2 arcs in the other case, the one with the angle $< \pi$ is drawn.

- the ground fixation is on 'fix1s' which is blue;
- orange for the plane which receives contact in the 'bolted' joint, 'bear1s';
- while the pin shows in red.

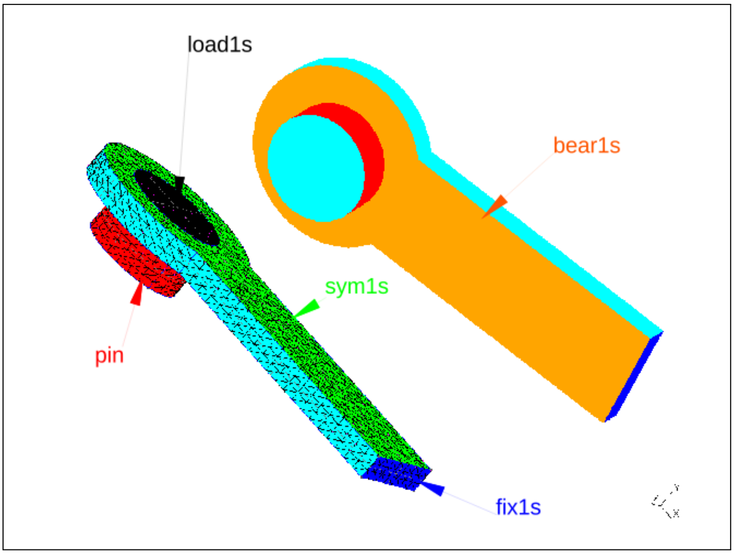


FIGURE 12.3: 'part1' meshed, with and without the element's' outline

12.2.2 Drawing 'part2'

The *.geo* file for Gmsh looks like this:

```
//'part2' geometry
cl1=2.0; //characteristic length, for meshing
off1=5.5; //y offset from part 1
t1=5; //thickness of half part
r1=10.5; //inside radius of eye
r2=17.0; //outside radius of eye

Point(1) = {0, -off1, 0, cl1};
Point(11) = {0, -off1, -r1, cl1};
Point(12) = {-r1*Sin(2*Pi/3), -off1, r1+r1*Cos(2*Pi/3), cl1};
Point(13) = {-r1*Sin(4*Pi/3), -off1, r1+r1*Cos(4*Pi/3), cl1};
Point(21) = {-Sqrt(r2*r2-r1*r1), -off1, r1, cl1};
Point(22) = {r2, -off1, 0, cl1};
Point(23) = {-Sqrt(r2*r2-r1*r1), -off1, -r1, cl1};
Point(24) = {-4*r2, -off1, r1, cl1};
Point(25) = {-4*r2, -off1, -r1, cl1};
Circle(1) = {11, 1, 12};
Circle(2) = {12, 1, 13};
Circle(3) = {13, 1, 11};
Circle(4) = {21, 1, 22};
Circle(5) = {22, 1, 23};
Line(6) = {21, 24};
Line(7) = {23, 25};
Line(8) = {25, 24};
Circle(9) = {21, 1, 23};
```

```
//extrusion of lines to create surfaces
fix2s[]  = { Extrude {0, -t1, 0} {Line{-8};Layers {3};} };
edge2s[]  = { Extrude {0, -t1, 0} {Line{6, -4, -5, -7, 9};
    Layers {3};} };
hole2s[]  = { Extrude {0, -t1, 0} {Line{-1, -2, -3};
    Layers {3};} };

//creation of plane surface
Curve Loop(106) = {4, 5, -9};
Curve Loop(107) = {2, 3, 1};
Plane Surface(108) = {106, 107};
Curve Loop(109) = {6, -8, -7, -9};
Plane Surface(110) = {109};
```

```
//extrusion of plane surface into volume
part2v[]  = { Extrude  {0, -t1, 0} {Surface{-108, 110}; } };
```

```
Physical Point ("move2p") = {11};
Physical Surface("bear2s") = {108};
Physical Surface("hole2s") = {hole2s[]};
Physical Surface("fix2s") = {fix2s[]};
Physical Surface("pres2s") = {142};
Physical Volume("part2v") = {part2v[]};
```

```
//color of mesh
//all surfaces in Cyan
Color Cyan{
   Surface{17, 21, 25, 29, 33, 37, 41, 45, 108, 110,
        142, 164};
}
//then
Color Orange{ Surface{108}; }
Color Purple{ Surface{142}; }
Color Black { Surface{hole2s[]}; }
Color Blue{ Surface{fix2s[]}; }
Color Magenta{ Volume {part2v[]};}
```

The same remarks as for part1 apply:

- the ground fixation is on 'fix2s' which is blue;
- the face of the hole 'hole2s' is black;
- 'bear2s', the plane which applies contact in the "bolted" joint is orange, it is hidden on figure 12.4;
- while the "nut" pressure is applied on 'pres2s' which shows in purple.

12.2.3 Meshing 'part1' and 'part2'

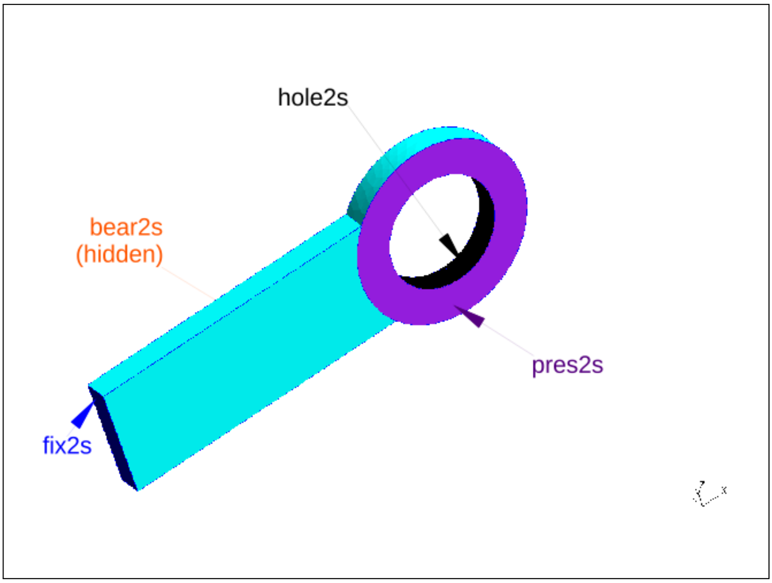


FIGURE 12.4: 'part2' meshed

We create a 3D quadratic mesh on both parts with Mesh 〉 3D and Mesh 〉 Set order 〉 2. We keep these meshes quite coarse to get a solution in a relatively short time. Any serious industrial study, trying to optimize the part, particularly for stress, would, at first, show a more complicated shape, and require much finer a mesh in the strategic areas.

The mesh of 'part2' is shown in figure 12.4 . Note: there is a gap of 0.5 mm in the Y direction in between the two parts.

Finally the appendix about Gmsh tips shows how this part could be drawn and meshed using the Open CASCADE kernel introduced in version 3 of Gmsh.

12.3 Commanding for the solution

We introduce the command file step by step.

12.3.1 Reading and manipulating the meshes

```
DEBUT();
#in group naming
#last char s stands for surface,
#v for volume and p for point
#last but one char stands for the part number

#we read the med file for each part
part1=LIRE_MAILLAGE(UNITE=20,FORMAT='MED',);
part2=LIRE_MAILLAGE(UNITE=21,FORMAT='MED',);

#U4.23.03
#we assemble the two meshes into a new one
mesh12=ASSE_MAILLAGE(
    MAILLAGE_1=part1,
    MAILLAGE_2=part2,
    OPERATION='SUPERPOSE',
);
```

We read the two meshes from to different Logical Units, we assemble them in one single new mesh with `ASSE_MAILLAGE`.

```
#re orient the normal for the face groups,
#with the Gmsh design as seen earlier this should be ok
#but one never knows
mesh12=MODI_MAILLAGE(
    reuse =mesh12,
    MAILLAGE=mesh12,
    ORIE_PEAU_3D=(
        _F(GROUP_MA='sym1s',),
        _F(GROUP_MA='pin1s',),
        _F(GROUP_MA='fix1s',),
        _F(GROUP_MA='hole2s',),
        _F(GROUP_MA='fix2s',),
        _F(GROUP_MA='load1s',),
    ),
);

#define groups of nodes on the new mesh
#should be here, not before,
#to compute and print a correct value for reaction
mesh12=DEFI_GROUP(
    reuse =mesh12,
    MAILLAGE=mesh12,
    #CREA_GROUP_MA=_F(NOM='TOUT',TOUT='OUI',),
    CREA_GROUP_NO=(
        _F(GROUP_MA='fix2s' ,),
        _F(GROUP_MA='fix1s' ,),
        _F(GROUP_MA='sym1s' ,),
        _F(GROUP_MA='load1s' ,),
        _F(GROUP_MA='load1p' ,),
        _F(GROUP_MA='move2p' ,),
    ),
);
```

Then, we reorient the normal to the surface elements to be sure they point in the same outward direction within each group. We create groups of nodes where necessary, for post processing, at the boundary conditions for example.

```
#make a copy of mesh12
qmesh=COPIER(CONCEPT=mesh12);

#convert the quadratic mesh  to linear mesh
#onto which the results will be projected
lmesh=CREA_MAILLAGE(
    MAILLAGE=qmesh,
    QUAD_LINE=_F(TOUT='OUI' ,),
);

#alternatively to run the problem on a linear mesh
#lmesh=COPIER(CONCEPT=qmesh);

#to have a look at the different meshes
IMPR_RESU(FORMAT='MED' , UNITE=71,  RESU=_F(MAILLAGE=qmesh,),);
IMPR_RESU(FORMAT='MED' , UNITE=72,  RESU=_F(MAILLAGE=lmesh,),);

#make a quadratic model
qmod=AFFE_MODELE(
    MAILLAGE=qmesh,
    AFFE=_F(TOUT='OUI' ,PHENOMENE='MECANIQUE' ,MODELISATION='3D' ,),
);

#and a linear model
lmod=AFFE_MODELE(
    MAILLAGE=lmesh,
    AFFE=_F(TOUT='OUI' ,PHENOMENE='MECANIQUE' ,MODELISATION='3D' ,),
);

steel=DEFI_MATERIAU(ELAS=_F(E=2.1e5,NU=0.3,),);

mate=AFFE_MATERIAU(
    MAILLAGE=qmesh,
    AFFE=_F(TOUT='OUI',MATER=steel,),
);
```

Finally, we create the quadratic mesh, named 'qmesh', as a copy[1] of 'mesh12', make a model out of it and assign it a material.

We also create a linear mesh, named 'lmesh' onto which the the graphical results will be projected, with `PROJ_CHAMP`, and make a model out of it.

12.3.2 Setting the boundary conditions

We describe the boundary conditions and loadings which are used throughout the various calculations.

```
#set the boundary fixing for part1
#'encastre' on the right-hand end
#no Y displacement for the symmetrical model
fix1=AFFE_CHAR_MECA(
    MODELE=qmod,
    DDL_IMPO=(
        _F(GROUP_MA=('sym1s','load1s',),DY=0.0,),
        _F(GROUP_MA='fix1s',DX=0.0,DY=0.0,DZ=0.0,),
    ),
);

#set the boundary fixing for part2
#'encastre' on the left-hand end
fix2=AFFE_CHAR_MECA(
    MODELE=qmod,
    DDL_IMPO=_F(GROUP_MA='fix2s',DX=0.0,DY=0.0,DZ=0.0,),
);
```

This is straightforward and does not need any comment, however note that 3D elements do not bear rotational degrees of freedom, thus neither `DRX`, `DRY` nor `DRZ`.

[1] Copying the mesh is not necessary at all and is introduced here to illustrate its use.

12.3.3 Gluing the two parts around the pin

```
#u4.44.01
#we 'glue' volume 'part2' to the face of the pin 'pin1s'
glue=AFFE_CHAR_MECA(
    MODELE=qmod,
    LIAISON_MAIL=_F(
        GROUP_MA_MAIT='part2v' ,
        GROUP_MA_ESCL='pin1s' ,
    ),
);
```

The LIAISON_MAIL, allows to "glue together" two groups of elements. In this case, we ask for the GROUP_MA_ESCL='pin1s', the group of surface elements to be glued in translation and rotation to GROUP_MA_MAIT='part2v', the group of volume of all 'part2'[1]. Which part should be master and which one slave is explained in the documentation.

12.3.4 Relieving rotation around the pin

```
#same thing but only
#the displacement normal to the contact face are glued
#the two part can rotate one in each other
#and slide along the pin axis
#but their respective axis remain identical
#they cannot move one to each other in x and z directions
freerot=AFFE_CHAR_MECA(
    MODELE=qmod,
    #just as above but rotation is allowed
    LIAISON_MAIL=_F(
        GROUP_MA_MAIT='part2v' ,
        GROUP_MA_ESCL='pin1s' ,
        DDL_MAIT='DNOR' ,
        DDL_ESCL='DNOR' ,
    ),
);
```

To relieve the rotation, we use the keywords DDL_MAIT='DNOR' and DDL_ESCL='DNOR' in LIAISON_MAIL, this means: we allowing relative displacement, but the normal distance to the two surfaces remains constant.

[1] MAIT, "maître" in french stands for master and ESCL, "esclave", for slave.

12.3.5 Setting the contact conditions around the pin

```
#define contact in-between the pin and the hole
#as soon as the pin touches the hole surface
#it pushes the hole and part2 with it
contact=DEFI_CONTACT(
    MODELE=qmod,
    FORMULATION='DISCRETE',
    #'hole'overlaps 'pin' so should be 'MAIT'
    #or 'hole' is bigger than 'pin' so should be 'MAIT'
    #U2.04.04
    ZONE=_F(
        GROUP_MA_MAIT='hole2s',
        GROUP_MA_ESCL='pin1s',
    ),
);
```

Here, the master and slave are group of surface elements, with the same remarks about which is which[1]. There are many choices regarding the selection of a contact solver, `FORMULATION`, here again one should read the documentation, and try out!

Concerning contact, U2.04.04 is the first introductory document to be read.

12.3.6 Setting the contact conditions around the pin, with friction

This first part sets the contact with Coulomb friction.

```
contact5=DEFI_CONTACT(
    MODELE=qmod,
    FORMULATION='CONTINUE',
    ALGO_RESO_GEOM='POINT_FIXE',
    REAC_GEOM='CONTROLE',
    NB_ITER_GEOM=2,
    # ALGO_RESO_CONT='NEWTON', #this is the default value
    FROTTEMENT='COULOMB',
    ZONE=(
        _F(
            GROUP_MA_MAIT='bear1s',
            GROUP_MA_ESCL='bear2s',
            ALGO_CONT='PENALISATION',
            ALGO_FROT='PENALISATION',
            COEF_PENA_CONT=40000,
            COEF_PENA_FROT=4000,
            COULOMB=0.1,
        ),
```

[1] Here 'hole2s' which overlaps 'pin2s' should be master.

```
            _F(
                GROUP_MA_MAIT='hole2s',
                GROUP_MA_ESCL='pin1s',
                ALGO_CONT='PENALISATION',
                ALGO_FROT='PENALISATION',
                COEF_PENA_CONT=400000,
                COEF_PENA_FROT=4000,
                COULOMB=0.0,
            ),
        ),
    );
```

The difference between these two contact definitions must be noted:

- as we want to allow friction in-between the two bodies `FORMULATION='CONTINUE'`, `FROTTEMENT='COULOMB'` has to be used;
- although we use two contact `ZONE` they must share these same parameters;
- we set the frictional coefficient, `'COULOMB'`, at 0.1, which is rather a low -slippery- value for steel on steel contact
- we have to use `ALGO_CONT='PENALISATION'` and `ALGO_FROT='PENALISATION'` that specifies we allow some values to the surface stiffness;
- and with `COEF_PENA_CONT=400000` and `COEF_PENA_FROT=4000` we set the values, how these vales are set is explained in the documentation U2.04.04 and U4.44.11.

For friction to take place it is necessary to tighten the bolt, we do this below. We specify this tightening to be done from `INST` -5 to 0, which is before the vertical load is applied[1]. It stricto sensu is a pre-load.

We apply this load using `FORCE_FACE` applying a distributed load on the face of a 3D volume, the unit is force/area.

```
    #pressure load to tighten the joint
    pres=AFFE_CHAR_MECA(
        MODELE=qmod,
        FORCE_FACE=_F(GROUP_MA='pres2s',FY=12,),
    );
```

[1] Just as in true life, the bolt would be tightened before loading the spring.

```
#tightening bolt load steps for non-linear analysis
pres_m=DEFI_FONCTION(
    NOM_PARA='INST',VALE=(-5,0, 0,1),
    PROL_GAUCHE='CONSTANT',PROL_DROITE='CONSTANT',
);
```

This $12N/mm^2$ pressure applied on a $\pi(17.5^2 - 10^2) = 562mm^2$ area gives a total load of $6739N$, which multiplied by the frictional coefficient gives a vertical resisting force of $674N$ which in turn is about 8.6% of the ultimate vertical load $7854N$[1].

12.3.7 Setting the vertical load

```
#vertical load on the pin in part1 on the plane of symmetry
load=AFFE_CHAR_MECA(
    MODELE=qmod,
    FORCE_FACE=_F(GROUP_MA='load1s',FZ=-25.0,),
    #total force is 25*pi*10^2=7854
);

#load steps for non-linear analysis
load_m=DEFI_FONCTION(
    NOM_PARA='INST',VALE=(0,0, 5,1),
    PROL_GAUCHE='CONSTANT',PROL_DROITE='CONSTANT',
);
```

The load is set as a force per unit of area on the group 'load1s', together with a ramp for the non-linear contact solution.

12.3.8 Setting for the five solutions

We solve the study, and later, post-process the results within a Python loop.

- We initialize the loop used in the post-processing and set the 5 solution parameters.

  ```
  #iter is the number of solutions
  iter=5;
  result=[None]*(iter+1);
  ```

- For case 1, 'part1' is free from 'part2' and is loaded alone.

[1] This very modest friction will not restrain displacement very much, except at the beginning of the loading, as we can see at solution time.

```
#case one
#part1 alone with the load
#no 'LIAISON' nor contact with part2
result[1]=MECA_STATIQUE(
    MODELE=qmod,
    CHAM_MATER=mate,
    EXCIT=(
        _F(CHARGE=fix2,),
        _F(CHARGE=fix1,),
        _F(CHARGE=load,),
    ),
);
```

- For case 2, 'part1' and 'part2' are solidly glued together.

```
#case two
#part1 and part2 glued together
result[2]=MECA_STATIQUE(
    MODELE=qmod,
    CHAM_MATER=mate,
    EXCIT=(
        _F(CHARGE=fix2,),
        _F(CHARGE=fix1,),
        _F(CHARGE=glue,),
        _F(CHARGE=load,),
    ),
);
```

- For case 3, rotation is freed around 'part1' and 'part2'.

```
#case three
#part1 and part2 free to rotate at joint
result[3]=MECA_STATIQUE(
    MODELE=qmod,
    CHAM_MATER=mate,
    EXCIT=(
        _F(CHARGE=fix2,),
        _F(CHARGE=fix1,),
        _F(CHARGE=freerot,),
        _F(CHARGE=load,),
    ),
);
```

- For case 4, 'part1' comes in contact with 'part2'.

```
#case four
#part1  coming into contact with part2
linst=DEFI_LIST_REEL(
    DEBUT=0.0,
    INTERVALLE=_F(JUSQU_A=5.0,PAS=1.0,),
);
```

```
result[4]=STAT_NON_LINE(
    MODELE=qmod,
    CHAM_MATER=mate,
    EXCIT=(
        _F(CHARGE=fix2,),
        _F(CHARGE=fix1,),
        _F(
            CHARGE=load,
            TYPE_CHARGE='FIXE_CSTE',FONC_MULT=load_m,
        ),
    ),
    CONTACT=contact,
    COMPORTEMENT=_F(
        RELATION='ELAS',DEFORMATION='PETIT',
        GROUP_MA=('pin1v','part1v','part2v',),
    ),
    INCREMENT=_F(LIST_INST=linst,),
    NEWTON=_F(
        PREDICTION='TANGENTE',
        MATRICE='TANGENTE',
        REAC_ITER=1,
    ),
    CONVERGENCE=_F(RESI_GLOB_RELA=1e-4,ITER_GLOB_MAXI=30,),
);
```

- For case 5, we add some friction along the mating vertical surfaces. For this we need to perform the calculation from the beginning of the pre-load, so we create a new 'listinst'.

```
linst5=DEFI_LIST_REEL(
    DEBUT=-5.0,
    INTERVALLE=(
        _F(JUSQU_A=0.0,PAS=5.0,),
        _F(JUSQU_A=3.75,PAS=1.25,),
        _F(JUSQU_A=5.0,PAS=0.625,),
    ),
);

linst52=DEFI_LIST_INST(
    METHODE='AUTO',
    DEFI_LIST=_F(
        LIST_INST=linst5,
        PAS_MINI=1e-10,
    ),
);
```

This rather sophisticated list of steps does not come from any devilish theory but from trial and error, looking at the convergence table in the *.mess* file:

- it very strongly depends on the pressure load 'pres', values of 10 or 15 require very different stepping schemes;
- it depends also on the mesh, the set given here works for the linear mesh;
- it may also depends also on the **code_aster** solver, the set given here works for the 13.4;
- sometimes the solution is reached with largish steps like `JUSQU_A=0.0,PAS=5.0` in one single step, for the pressure load, in this example[1] here `DEFI_LIST_INST` deals with any further automatic stepping.

```
#case five
#part1  coming in contact with part2
#friction taken into account
result[5]=STAT_NON_LINE(
    MODELE=qmod,
    CHAM_MATER=mate,
    EXCIT=(
        _F(CHARGE=fix1,),
        _F(CHARGE=fix2,),
        _F(
            CHARGE=pres,
            TYPE_CHARGE='FIXE_CSTE',FONC_MULT=pres_m,
        ),
        _F(
            CHARGE=load,
            TYPE_CHARGE='FIXE_CSTE',FONC_MULT=load_m,
        ),
    ),
    CONTACT=contact5,
    COMPORTEMENT=_F(
        RELATION='ELAS',DEFORMATION='PETIT',
        GROUP_MA=('pin1v','part1v','part2v',),
    ),
    INCREMENT=_F(LIST_INST=linst52,),
    NEWTON=_F(
        PREDICTION='TANGENTE',
        MATRICE='TANGENTE',
        REAC_ITER=1,
    ),
    CONVERGENCE=_F(RESI_GLOB_RELA=1e-4,ITER_GLOB_MAXI=50,),
);
```

[1] Which, according to **code_aster** guru Thomas de Soza: “That does not surprise me, tangential contact should be avoided as it raises an indeterminacy. By applying the pre-load in one step one sets a sheer contact”.

```
STANLEY();

FIN();
```

We have created a list holding five 'result[]'. `STANLEY()` call is here so we can have a first look at the results.

With minor alterations, we could have also run the problem from a linear mesh built in Gmsh. Moreover in some more complicated problems some groups can be quadratic while the rest of the mesh is linear.

12.4 Running the study

Now, we can launch the study within ASTK not forgetting to create a 'base', where to save the results[1].

[1] At this stage 'R' (result) should be ticked, not 'D' (data) as we create the base for the first time , 'C' for compressed may be ticked.

CHAPTER 13

Post-processing the spring

In this chapter, we write a command file to post-process the base created in chapter 12.

We project the results of the calculation on a simpler linear mesh.

We look at the results and create some time dependent plots.

All with a significant use of Python.

13.1 Commanding for Post-processing

13.1.1 Preliminaries

We do the post-processing in POURSUITE, that is to say: we read the database previously built and enhance the results it contains. This way we can tailor the post-processing *.comm* file until we get a satisfactory set of information without having to re-run the study.

```
#U4.11.03
POURSUITE(
    #may be required in more complex problems,
    #not here
    #PAR_LOT='NON',
);

#some definition for solution loop
#qres is the list for the quadratic solutions
#sr1 and sr2 are the lists for the sums
#of reaction at the fixing of part1 and part2
#and sr12 the sum of both
qres=[None]*(iter+1);
sr1=[None]*(iter+1);
sr2=[None]*(iter+1);
sr12=[None]*(iter+1);
```

While a normal command file starts with `DEBUT()`, here we start with `POURSUITE()`. Then, we initialize some lists to hold the results.

And we start the post-processing inside the loop over the result[].

```
for i in range (1,iter+1):
    result[i]=CALC_CHAMP(
        reuse =result[i],
        RESULTAT=result[i],
        CONTRAINTE='SIGM_ELNO',
        FORCE='REAC_NODA',
        CRITERES=('SIEQ_ELNO','SIEQ_NOEU',),
    );
```

Printing displacement of typical loaded node, and stresses in elements, at nodes.

```
    IMPR_RESU(
        FORMAT='RESULTAT',
        RESU=(
            _F(
                RESULTAT=result[i],
                GROUP_NO=('load1p',),
                NOM_CHAM='DEPL',NOM_CMP=('DZ',),
                FORMAT_R='1PE12.3',
            ),
            _F(
                RESULTAT=result[i],
                NOM_CHAM='SIEQ_NOEU',NOM_CMP=('VMIS',),
                FORMAT_R='1PE12.3',
                VALE_MAX='OUI',
            ),
            _F(
                RESULTAT=result[i],
                GROUP_NO=('fix1s',),
                NOM_CHAM='SIEQ_NOEU',NOM_CMP=('VMIS',),
                FORMAT_R='1PE12.3',
                VALE_MAX='OUI',
            ),
        ),
    );
```

And reactions at end supports.

```
        #computing and printing the sum of reaction
        #for part1 and part2
        sr1[i]=POST_RELEVE_T(
            ACTION=_F(
                INTITULE='reac1',
                GROUP_NO=('fix1s',),
                RESULTAT=result[i],
                NOM_CHAM='REAC_NODA',TOUT_ORDRE='OUI',
                RESULTANTE=('DX','DY','DZ'),
                OPERATION='EXTRACTION',
            ),
        );
        IMPR_TABLE (TABLE=sr1[i],)
        sr2[i]=POST_RELEVE_T(
            ACTION=_F(
                INTITULE='reac2',
                GROUP_NO=('fix2s',),
                RESULTAT=result[i],
                NOM_CHAM='REAC_NODA',TOUT_ORDRE='OUI',
                RESULTANTE=('DX','DY','DZ'),
                OPERATION='EXTRACTION',
            ),
        );
        IMPR_TABLE (TABLE=sr2[i],)
        sr12[i]=POST_RELEVE_T(
            ACTION=_F(
                INTITULE='reac12',
                GROUP_NO=('fix1s','fix2s',),
                RESULTAT=result[i],
                NOM_CHAM='REAC_NODA',TOUT_ORDRE='OUI',
                RESULTANTE=('DX','DY','DZ'),
                OPERATION='EXTRACTION',
            ),
        );
        IMPR_TABLE (TABLE=sr12[i],)
```

13.1.2 Creating the MED result file

```
        #project the quadratic model qmod result[i]
        #onto the low definition linear model lmod
        #name this result qres[i]
        qres[i]=PROJ_CHAMP(
            RESULTAT=result[i],MODELE_1=qmod,MODELE_2=lmod,
        );
```

```
      IMPR_RESU(
          FORMAT='MED',
          RESU=(
              _F(RESULTAT=qres[i],NOM_CHAM=('DEPL',),),
              _F(RESULTAT=qres[i],NOM_CHAM=('SIEF_ELNO',),),
              _F(
                  RESULTAT=qres[i],
                  NOM_CHAM=('SIEQ_NOEU',),NOM_CMP=('VMIS',),
              ),
              #_F(
                  #RESULTAT=qres[i],
                  #whatever else we want
              #),
          ),
      );
      #here ends the Python loop
```

Projecting the quadratic mesh onto the original mesh and printing results in a med file.

13.1.3 Creating a plot of some results

In his section, we look in details at case 4 and 5 with contact. We want to see what happens to the displacement of the pin, at what time it makes contact with the hole and what are the reactions for each part. This is done in a XmGrace readable graphic created here[1].

This section only holds manipulation of data, this is fast enough to be done on the initial -not projected- results, 'result[i]'[2].

```
  #here we define a function, multiply by 10000
  by10000=FORMULE(NOM_PARA='DZ',VALE='DZ*10000',),

  and initialize some lists
  dz1=[None]*(iter+1);
  dz2=[None]*(iter+1);
  rz1=[None]*(iter+1);
  rz2=[None]*(iter+1);
  rz12=[None]*(iter+1);
  loadt=[None]*(iter+1);
  dtaZ1=[None]*(iter+1);
  dtaZ2=[None]*(iter+1);
  rcZ1=[None]*(iter+1);
```

[1] However we create almost empty plot values for case 1 to 3 in the same time.
[2] Trying to perform the same manipulation on the projected results, 'qres[i]' would calculate the reaction on a wrong number of nodes (about half) and gives completely wrong values and plots!

```
rcZ2=[None]*(iter+1);
```

These lists, if used as an argument in XmGrace, should be no more than 8 characters long, including the trailing "_" plus the index, this is not much!

In this first part, we extract the displacement, in the global Z direction, of node 'load1p' on 'part1'.

```
for i in range (1,iter+1):
    #next lines are how to prepare and save a plot for XmGrace
    #one on each case
    #here we make a table with the displacement
    #in z direction of the point 'load1p'
    #in the centre of the pin on the plane of symmetry
    dz1[i]=POST_RELEVE_T(
        ACTION=_F(
            OPERATION='EXTRACTION',
            INTITULE='displ_part1',
            RESULTAT=result[i],
            NOM_CHAM='DEPL',
            TOUT_ORDRE='OUI',
            GROUP_NO='load1p',
            RESULTANTE=('DZ',),
            MOYE_NOEUD='NON',
        ),
        TITRE='displacement of pin center',
    );
    #print in
    IMPR_TABLE (TABLE=dz1[i],)

    dz1[i]=CALC_TABLE(
        TABLE=dz1[i],reuse=dz1[i],
        ACTION=_F(
            OPERATION='OPER',FORMULE=by10000,NOM_PARA='Z10000',
        ),
    );
    IMPR_TABLE (TABLE=dz1[i],)
```

In this second part, we do the same for node 'move2p' on 'part2'.

```
    #here we make a table with the displacement
    #in z direction of the point 'move2p'
    #on top of part2 above the hole
    dz2[i]=POST_RELEVE_T(
        ACTION=_F(
            OPERATION='EXTRACTION',
            INTITULE='displ_part2',
            RESULTAT=result[i],
            NOM_CHAM='DEPL',
            TOUT_ORDRE='OUI',
            GROUP_NO='move2p',
            RESULTANTE=('DZ',),
            MOYE_NOEUD='NON',
        ),
        TITRE='displacement of part2 above pin',
    );
    #print in
    IMPR_TABLE (TABLE=dz2[i],),

    dz2[i]=CALC_TABLE(
        TABLE=dz2[i],reuse=dz2[i],
        ACTION=_F(
            OPERATION='OPER',FORMULE=by10000,NOM_PARA='Z10000',
        ),
    );
    IMPR_TABLE (TABLE=dz2[i],),
```

And in the third part, we extract the reactions at the ends of ’part1’ and ’part2’ as well as their sums.

```
        rz1[i]=POST_RELEVE_T(
            ACTION=_F(
                OPERATION='EXTRACTION',
                INTITULE='reaction 1',
                RESULTAT=result[i],
                NOM_CHAM='REAC_NODA',
                TOUT_ORDRE='OUI',
                GROUP_NO='fix1s',
                RESULTANTE=('DZ',),
                MOYE_NOEUD='NON',
            ),
            TITRE='reaction 1',
        );


        rz2[i]=POST_RELEVE_T(
            ACTION=_F(
                OPERATION='EXTRACTION',
                INTITULE='reaction 2',
                RESULTAT=result[i],
                NOM_CHAM='REAC_NODA',
                TOUT_ORDRE='OUI',
                GROUP_NO='fix2s',
                RESULTANTE=('DZ',),
                MOYE_NOEUD='NON',
            ),
            TITRE='reaction 2',
        );

        rz12[i]=POST_RELEVE_T(
            ACTION=_F(
                OPERATION='EXTRACTION',
                INTITULE='reaction 12',
                RESULTAT=result[i],
                NOM_CHAM='REAC_NODA',
                TOUT_ORDRE='OUI',
                GROUP_NO=('fix1s','fix2s',),
                RESULTANTE=('DZ',),
                MOYE_NOEUD='NON',
            ),
            TITRE='reaction 1+2',
        );
```

Then, we create some functions of the values we want to plot with respect to INST.

```
        #here a function that loads in a list:
        #x = value time step instant,
        #loadt = applied load, as sum of reactions
        loadt[i]=RECU_FONCTION(
            TABLE=rz12[i],
            PARA_X='INST',
            PARA_Y='DZ',
        );
        #here a function that loads in a list:
        #x = value time step instant,
        #deltaZ1 = Z displacement of part 1
        dtaZ1[i]=RECU_FONCTION(
            TABLE=dz1[i],
            PARA_X='INST',
            PARA_Y='Z10000',
        );
```

```
        dtaZ2[i]=RECU_FONCTION(
            TABLE=dz2[i],
            PARA_X='INST',
            PARA_Y='Z10000',
        );

        rcZ1[i]=RECU_FONCTION(
            TABLE=rz1[i],
            PARA_X='INST',
            PARA_Y='DZ',
        );

        rcZ2[i]=RECU_FONCTION(
            TABLE=rz2[i],
            PARA_X='INST',
            PARA_Y='DZ',
        );
```

To create the plots of displacements and reactions for case 4 and 5 in XmGrace.

```
        #here we print these functions in  XmGrace format files
        #numbering is such than case 4 is in LU 29, case 5 in LU 30
        #we have to have  entry in ASTK for these files
        #type dat in ASTK maybe extension .agr
```

```
      IMPR_FONCTION(
          FORMAT='XMGRACE',
          UNITE=25+i,
          TITRE='displacement and reaction ',
          BORNE_X=(0,8000),
          BORNE_Y=(-10000,8000),
          GRILLE_X=(1000),
          GRILLE_Y=(1000),
          LEGENDE_X='applied load (N)',
          LEGENDE_Y='displacement (mm/10000) or force (N)',
          COURBE=(
              _F(FONC_X=loadt[i],FONC_Y=dtaZ1[i],LEGENDE='dz1',),
              _F(FONC_X=loadt[i],FONC_Y=dtaZ2[i],LEGENDE='dz2',),
              _F(FONC_X=loadt[i],FONC_Y=rcZ1[i],LEGENDE='reacz1',),
              _F(FONC_X=loadt[i],FONC_Y=rcZ2[i],LEGENDE='reacz2',),
          ),
      );
      #end of loop
```

One remark here: `IMPR_FONCTION` is executed for case 1 to 5 but files are created in ASTK only for case 4 and 5 (LU=29 and LU=30), see figure 13.1, so only these last two cases are printed, this is not very optimized!

And the next part makes a plot of the displacement of 'load1p' node for all five cases.

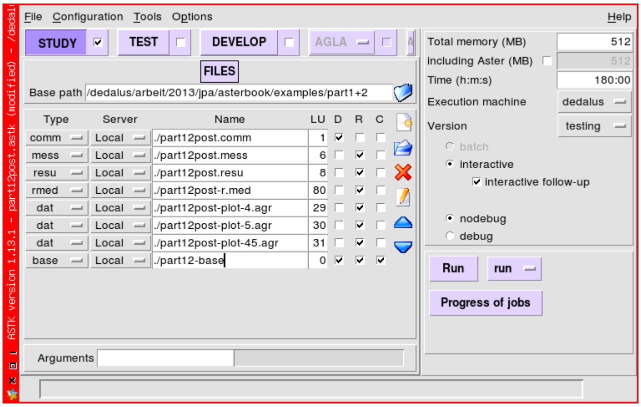
```
  IMPR_FONCTION(
      FORMAT='XMGRACE',
      UNITE=31,
      TITRE='compare displacement',
      BORNE_X=(0,8000),
      BORNE_Y=(0,-10000),
      GRILLE_X=(1000),
      GRILLE_Y=(1000),
      LEGENDE_X='applied load (N)',
      LEGENDE_Y='compared displacement (mm/10000) or force (N)',
      COURBE=(
          _F(FONC_X=loadt[1],FONC_Y=dtaZ1[1],LEGENDE='dz1, case 1',),
          _F(FONC_X=loadt[2],FONC_Y=dtaZ1[2],LEGENDE='dz1, case 2',),
          _F(FONC_X=loadt[3],FONC_Y=dtaZ1[3],LEGENDE='dz1, case 3',),
          _F(FONC_X=loadt[4],FONC_Y=dtaZ1[4],LEGENDE='dz1, case 4',),
          _F(FONC_X=loadt[5],FONC_Y=dtaZ1[5],LEGENDE='dz1, case 5',),
      ),
  );
```

And finally, we need to kill the previously created concepts. If we want to run this command file later on we will have to write them again, as we save the base we have to make allowance for writing them again.

```
#we have to kill the CONCEPT if we want to run this command file
#more than one time
#first the ones lying within a loop
for i in range (1,iter+1):
    DETRUIRE(CONCEPT=_F(NOM=(sr1[i],sr2[i],sr12[i],qres[i],),),);
    DETRUIRE(CONCEPT=_F(NOM=(dz1[i],dz2[i],rz1[i],rz2[i],),),);
    DETRUIRE(CONCEPT=_F(NOM=(rz12[i],loadt[i],),),);
    DETRUIRE(CONCEPT=_F(NOM=(dtaZ1[i],dtaZ2[i],rcZ1[i],rcZ2[i],),),);
#note the Python indent

#then the one outside of a loop
DETRUIRE(CONCEPT=_F(NOM=by10000),);

STANLEY();

FIN();
```

13.2 Running the post processing

Figure 13.1 is a view of the ASTK setup to run the post-processing.



STUDY [✓] TEST [ ] DEVELOP [ ]

Base path /dedalus/arbeit/2013/jpa/asterbook/examples/part1+2

Type	Server	Name	LU	D	R	C
comm	Local	./part12post.comm	1	✓		
mess	Local	./part12post.mess	6		✓	
resu	Local	./part12post.resu	8		✓	
rmed	Local	./part12post-r.med	80		✓	
dat	Local	./part12post-plot-4.agr	29		✓	
dat	Local	./part12post-plot-5.agr	30		✓	
dat	Local	./part12post-plot-45.agr	31		✓	
base	Local	./part12-base	0	✓	✓	✓

Arguments

Total memory (MB) 512
including Aster (MB) [ ] 512
Time (h:m:s) 180:00
Execution machine dedalus
Version testing

batch [✓ interactive]
[✓] interactive follow-up

[✓ nodebug] debug

run

FIGURE 13.1: ASTK windows for Post-processing

We use the same database as previously which this time is set for ’D’ data. and ’R’ results.

13.3 Viewing deformed shape for all cases

Here are the views, in Gmsh, of the deformed shape for all cases, at the last instant for the non linear cases, the first three of them with a displacement factor of 5. The two last ones, with contact, are shown with a a displacement factor of 1. As using a factor different from 1, in these cases, for the displacements will lead to an erroneous picture, e.g. here a displacement of 1 mm of 'part1' induces a displacement of 0.5 mm only on part 2 [1]!

Finally the views are from a quadratic mesh computation except the view for case 5 coming from a linear one.

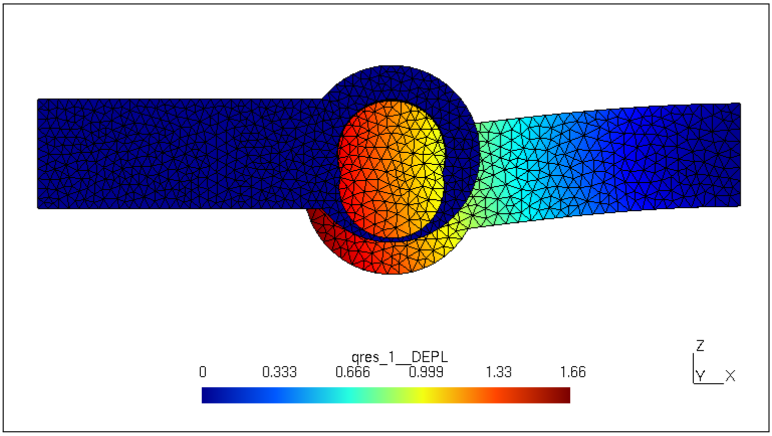


FIGURE 13.2: 'part1' loaded on its own is the only deformed part, it is penetrating inside 'part2'

[1] This is an illustration of the non linear behavior in case of contact (unilateral boundary condition).

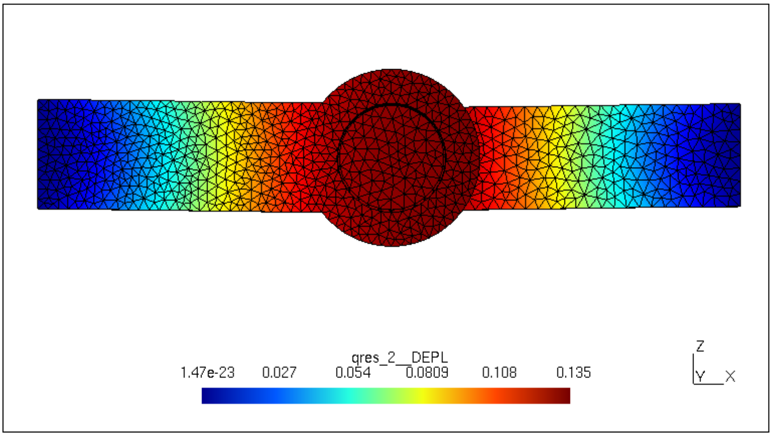


FIGURE 13.3: 'part1' is "glued" 'to part 2'

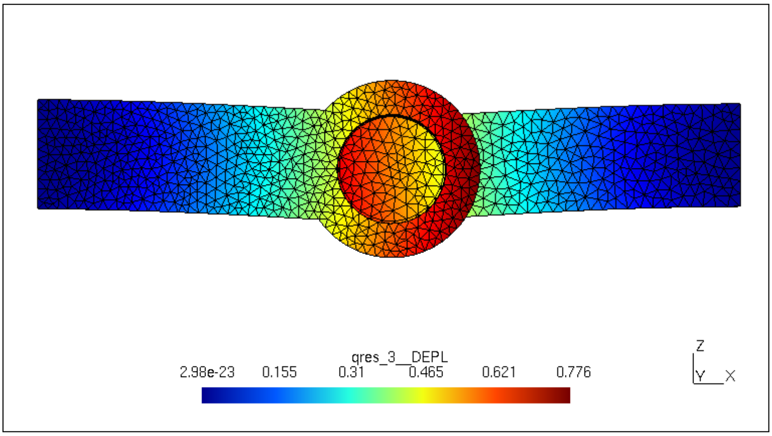


FIGURE 13.4: Rotation is freed around the pin

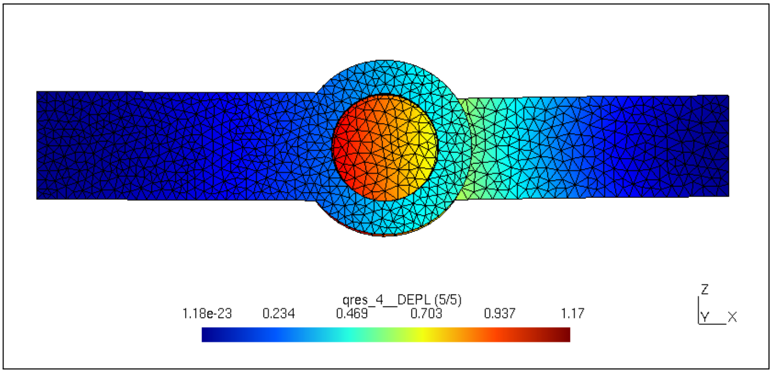


FIGURE 13.5: 'part1' comes in contact with 'part2' (displacement factor = 1)

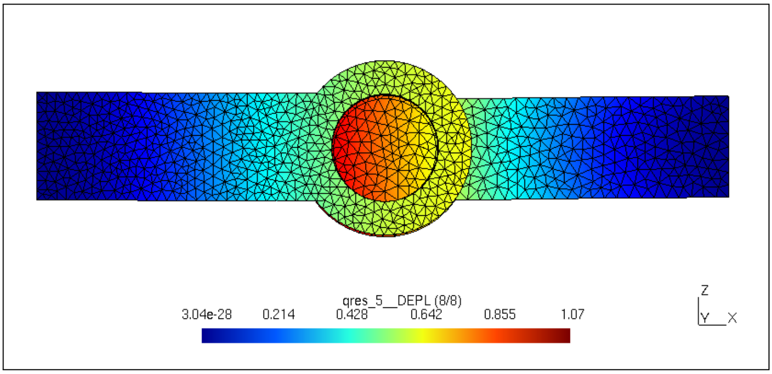


FIGURE 13.6: Here with some friction (displacement factor = 1, calculation from a linear mesh)

13.4 Numerical results

case	sol type	DEPL dZ1	ΣREAC 'part1'	ΣREAC 'part2'	time
1	quadratic	-1.23	7854	0	6
2		-0.13	3802	4052	11
3		-0.57	3663	4191	9
4		-0.87	5536	2318	85
5		-0.85	5436	2418	6630
1	linear	-1.16	7783	0	0.5
2		-0.13	3783	4000	0.6
3		-0.46	3692	4091	0.6
4		-0.82	5515	2268	5
5		-0.77	5522	2261	316

We should note that the displacement given above is the vertical displacement of the node 'load1p' at the center of the loaded area in 'part1' while the previous screen views show the displacement vector, everywhere in the model, this is not exactly the same thing.

As we pointed out in 12.3.6 , the estimated value of the frictional vertical resisting force is about 8.6% of the vertical load, we can see in the above results that the displacement for case 5 is somewhat less, as it shows a decrease of 3.7%, here the estimates is of a softer assembly than the finite element calculation.

The column "time" is the calculation time named USER as it appears at the end of the *.mess* file[1], for the solver, `MECA_STATIQUE` or `STAT_NON_LINE`, only, this is not ELAPSED which would be lower using several cores[2].

It shows a dramatic increase of calculation time for the quadratic mesh[3].

13.5 Checking the results

For all cases we consider the part 1 or 2 as a beam of: $b = 5mm$ width by $h = 20mm$ height, which gives:

[1] On my modest computer.

[2] 2795 instead of 6630 with 4 cores.

[3] In the same time the base goes from $20GB$ to $82GB$.

- a moment of inertia: $I = \frac{b \times h^3}{12} = 3333mm^4$;
- a section modulus $Z = \frac{I}{\frac{h}{2}} = 333mm^3$;
- and an equivalent point load $F = 7854N$.

For the first result the right part, 'part1' is a cantilever beam of $L = 68mm$, hence the displacement comes out at:

$$dz = \frac{FL^3}{3EI} = \frac{7854 \times 68^3}{3 \times 210000 \times 3333} = 1.17mm$$

compared to **code_aster** calculated $1.23mm$ for case one;

and a maximum normal stress of:

$$\sigma = \frac{M}{Z} = \frac{FL}{Z} = \frac{7854 \times 68}{333} = 1584N/mm^2$$

compared to **code_aster** calculated $2031N/mm^2$;

For the second result the assembly of 'part1' and part2' glued together acts a beam fixed at both ends of $L = 136mm$, hence the displacement comes out at:

$$dz = \frac{FL^3}{192EI} = \frac{7854 \times 136^3}{192 \times 210000 \times 3333} = 0.15mm$$

compared to **code_aster** calculated $0.134mm$ for case two;

and a maximum normal stress of:

$$\sigma = \frac{M}{Z} = \frac{FL}{8Z} = \frac{7854 \times 136}{8 \times 333} = 396N/mm^2$$

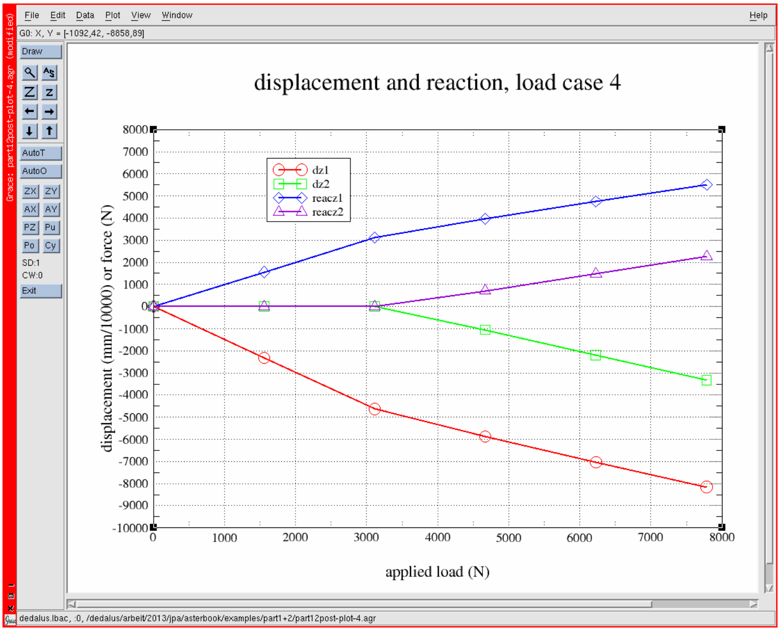
compared to **code_aster** calculated $468N/mm^2$.

The discrepancy is coming from the approximation we are making here. The values for the other results lying obviously in between these two extremes.

This technique, to hand calculate two analytical approximate values for a problem, one, optimistic, the second, pessimistic, is known as "bracketing" and should be used as much as possible to ensure the validity of a finite element result's value!

13.6 Looking at some plots

Creating the plot in the command file is quite a lengthy job, and we are a bit eager to look at it, figure 13.7 shows the plot for case 4, [almost] straight out of the box[1].



G0: X, Y = [-1092,42, -8858,89]

dedalus.lbac, :0, /dedalus/arbeit/2013/jpa/asterbook/examples/part1+2/part12post-plot-4.agr

FIGURE 13.7: XmGrace plot for case 4

The bi-linear behavior of the model is clearly visible here.

[1] I changed one color, thickness of lines and legend position.

And the plot for case 5 in figure 13.8:

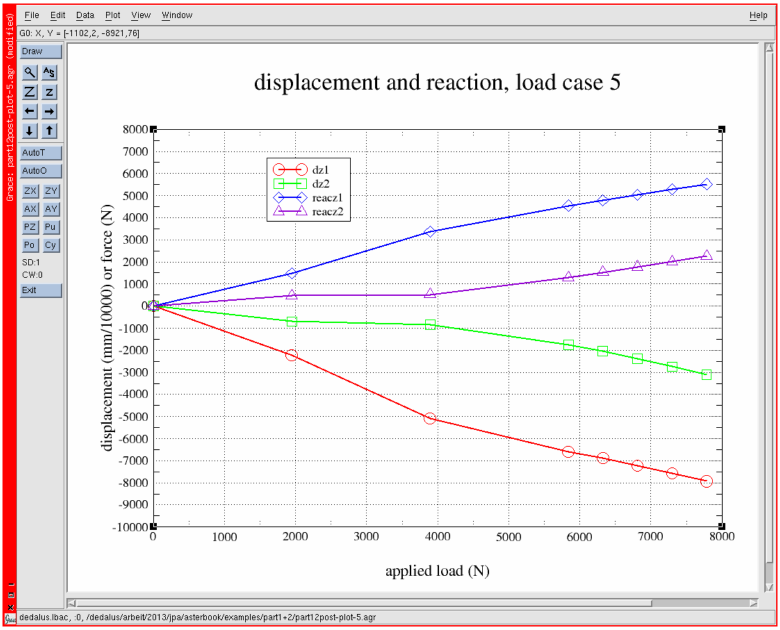


FIGURE 13.8: XmGrace plot for case 5

The friction influence is also clearly visible.

And finally the compared displacements for all five cases is shown in figure 13.9. For case 1 to 3 it is only a single point at the load of $7854N$.

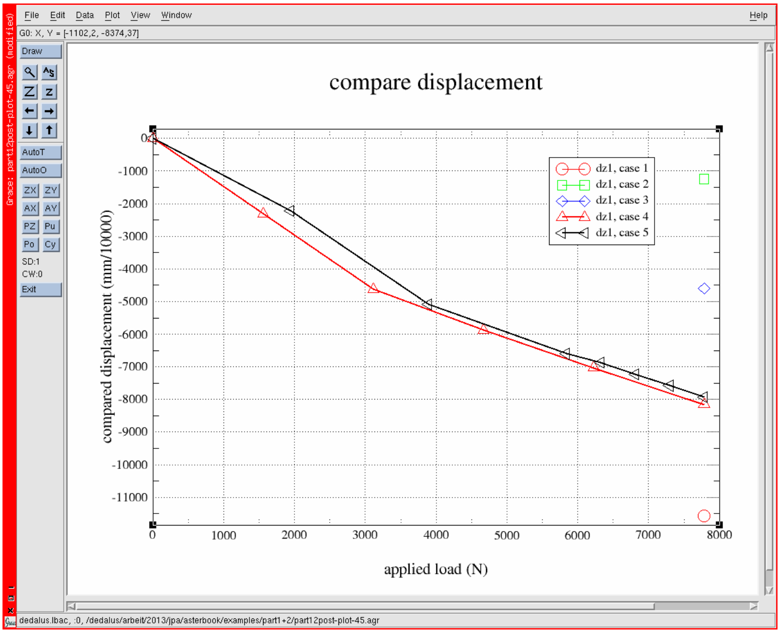

Grace: part12post-plot-45.agr (modified)
File Edit Data Plot View Window Help
G0: X, Y = [-1102,2, -8374,37]
Draw
AutoT
AutoO
ZX ZY
AX AY
PZ Pu
Po Cy
SD:1
CW:0
Exit
compare displacement
compared displacement (mm/10000)
applied load (N)
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-10000
-11000
0
1000
2000
3000
4000
5000
6000
7000
8000
dz1, case 1
dz1, case 2
dz1, case 3
dz1, case 4
dz1, case 5
dedalus.lbac, :0, /dedalus/arbeit/2013/jpa/asterbook/examples/part1+2/part12post-plot-45.agr

FIGURE 13.9: XmGrace plot comparing Z displacement of point 'load1p'

However this analysis is of course only valid in the elastic range. Figure 13.10 shows the von Mises criteria at the last instant for case 4, the maximum value, at around $800 - 900N/mm^2$, is rather above the yield stress[1], which should warn the engineer!

[1] Not to speak of fatigue allowance in a spring design.

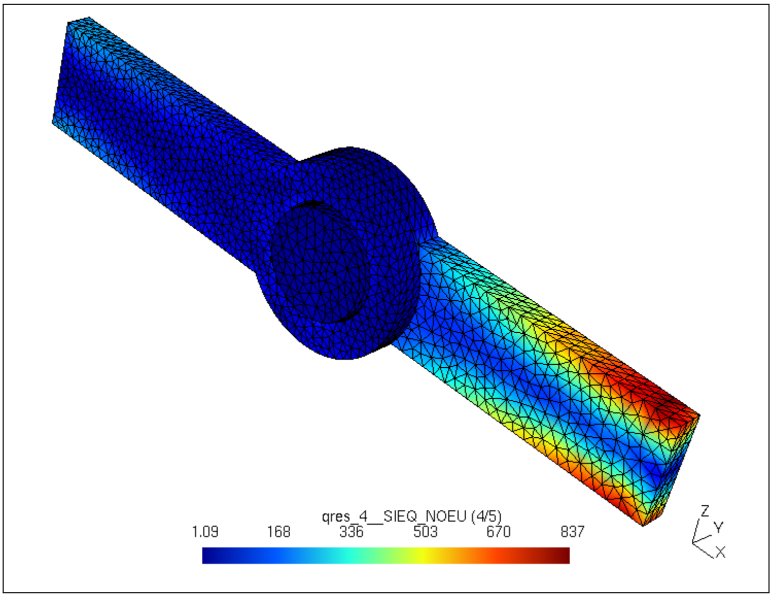


FIGURE 13.10: Von Mises criteria for case4 at last INST.

13.7 Questioning the method, quadratic or not

Looking in the table in 13.4 we can see that the results for a quadratic or linear mesh are very similar this opens the question of the quadratic mesh in this problem.

Adding the much longer computing time.

The answer is fairly simple: the quadratic mesh is here only for a learning purpose, if such a problem was to be run in an industrial project the linear mesh would be the right answer.

CHAPTER 14

Introducing plastic analysis, and more...

In the first part of this chapter, we study the plastic behavior of one of the part of chapter 12.

In the second part, we substitute a length of beam section to one portion of the solid part.

14.1 Running an Elasto-plastic analysis

We have seen in the previous example that the stresses in the components of the model were exceeding the elastic limit, or yield stress, it is of course not the proper behavior for a spring. Nevertheless we describe in this chapter how we can compute and display this behavior for 'part1' alone of the previous example.

As far as the mesh is concerned we just simply use the mesh created for part1 in our previous example.

This calculation is made on a simple linear mesh, it does not really make sense to launch a quadratic mesh refinement until the problem is solved at first with a linear mesh and the result do not show real deficiencies.

14.1.1 Initializing the mesh

Nothing new here.

```
DEBUT();

mesh1=LIRE_MAILLAGE(UNITE=20,FORMAT='MED' ,);

mesh1=MODI_MAILLAGE(
    reuse =mesh1,
    MAILLAGE=mesh1,
    ORIE_PEAU_3D=(
        _F(GROUP_MA='fix1s' ,),
        _F(GROUP_MA='load1s' ,),
    ),
);

mesh1=DEFI_GROUP(
    reuse =mesh1,
    MAILLAGE=mesh1,
    CREA_GROUP_NO=(,
        _F(GROUP_MA='fix1s' ,),
        _F(GROUP_MA='load1s' ,),
    ),
);

IMPR_RESU(FORMAT='MED' , UNITE=71, RESU=_F(MAILLAGE=mesh1,),);

mod1=AFFE_MODELE(
    MAILLAGE=mesh1,
    AFFE=_F(TOUT='OUI' ,PHENOMENE='MECANIQUE' ,MODELISATION='3D' ,),
);
```

14.1.2 Creating the non-linear material

Here, we are dealing with a non linearity related to the material, so we have to describe, within a function, the deformation or strain, of the material versus the stress. Here, we use a rather simple one for a mild steel whose yield limit is $240N/mm^2$, the strain is 20% for a stress of $380N/mm^2$ and 40% for a stress of $420N/mm^2$. Following the curve given in figure 14.1.

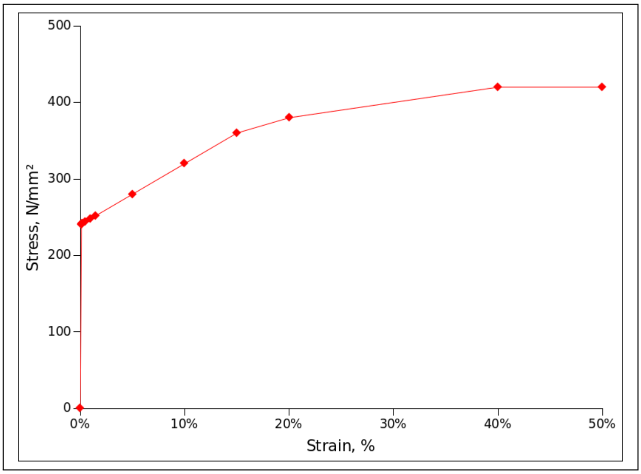


FIGURE 14.1: Steel elastoplastic stress/strain curve

```
s235elpl=DEFI_FONCTION(
        NOM_PARA='EPSI',NOM_RESU='SIGMA',
        VALE=(
                #there should not be a point at 0.0, 0.0
                #0.0000, 0.0
                0.00114, 240.0,
                0.0012, 241.0,
                0.0020, 241.6,
                0.0050, 244.0,
                0.0100, 248.0,
                0.0150, 252.0,
                0.0500, 280.0,
                0.1000, 320.0,
                0.1500, 360.0,
                0.2000, 380.0,
                0.4000, 420.0,
        ),
        INTERPOL='LIN',
        PROL_DROITE='LINEAIRE',
        PROL_GAUCHE='CONSTANT',
);
```

Note that there should not be an explicit point at $(0, 0)$ the first couple of point: `'EPSI'` (ϵ) , `'SIGMA'` (σ) marks the frontier of the elastic domain and should verify $\frac{\sigma}{\epsilon} = E$ where E is the young modulus given in `DEFI_MATERIAU`.

Note also that we may need quite closely spaced points after the sharp bend of the yield limit so the solver does not get lost[1].

Finally, the keyword `PROL_DROITE='CONSTANT',` ensure a constant strain after a stress of $420N/mm^2$.

14.1.3 Setting model and BC

```
steel=DEFI_MATERIAU(
    ELAS=_F(E=210000,NU=0.3,),
    TRACTION=_F(SIGM=s235elpl,),
);

mate=AFFE_MATERIAU(
    MAILLAGE=mesh1,
    AFFE=_F(TOUT='OUI',MATER=steel,),
);

fix1=AFFE_CHAR_MECA(
    MODELE=mod1,
    DDL_IMPO=(
        _F(GROUP_MA=('sym1s','load1s',),DY=0.0,),
        _F(GROUP_MA='fix1s',DX=0.0,DY=0.0,DZ=0.0,),
    ),
);

load=AFFE_CHAR_MECA(
    MODELE=mod1,
    FORCE_FACE=_F(GROUP_MA='load1s',FZ=-25.0,),
);

load_m=DEFI_FONCTION(
    NOM_PARA='INST',VALE=(0,0, 5,1),
    PROL_GAUCHE='CONSTANT',PROL_DROITE='CONSTANT',
);

lreel=DEFI_LIST_REEL(
    DEBUT=0.0,
    INTERVALLE=(
        _F(JUSQU_A=1.2,PAS=0.1,),
        _F(JUSQU_A=1.5,PAS=0.1,),
        _F(JUSQU_A=5.0,PAS=0.1,),
    ),
);

#U4.34.03 for DEFI_LIST_INST
#particularly keyword ECHEC
linst= DEFI_LIST_INST(
```

[1] This may not be absolutely necessary in **code_aster**, but, from previous experiences, I like to do it like that!

```
    DEFI_LIST=_F(LIST_INST=lreel, PAS_MINI=1e-05),
    ECHEC=_F(SUBD_NIVEAU=3),
    METHODE='AUTO'
)
```

14.1.4 Solving

We perform two calculations:

- ’resuq’ is a static linear;
- ’resunl’ is a non linear calculation.

This, just to be able to look at the two results side by side in the post-processor viewer.

```
resuq=MECA_STATIQUE(
    MODELE=mod1,
    CHAM_MATER=mate,
    EXCIT=(
        _F(CHARGE=fix1,),
        _F(CHARGE=load,),
    ),
);

resunl=STAT_NON_LINE(
    MODELE=mod1,
    CHAM_MATER=mate,
    EXCIT=(
        _F(CHARGE=fix1,),
        _F(CHARGE=load,TYPE_CHARGE='FIXE_CSTE',FONC_MULT=load_m,),
    ),
    COMPORTEMENT=_F(
        RELATION='VMIS_ISOT_TRAC', #U4.51.11 para 4.3.1.3
        DEFORMATION='SIMO_MIEHE',  #U4.51.11 para 4.5.3
    ),
    INCREMENT=_F(LIST_INST=linst,),
    NEWTON=_F(
        PREDICTION='TANGENTE',
        MATRICE='TANGENTE',
        REAC_ITER=1,
    ),
    CONVERGENCE=_F(RESI_GLOB_RELA=1e-4,ITER_GLOB_MAXI=300,),
);
```

Here, we specify the non-linear material behavior as well as the geometric non-linear behavior under the key word `COMP_INCR`, `VMIS_ISOT_TRAC` stands for non-linear isotropic von Mises law.

```
resuq=CALC_CHAMP(
    reuse =resuq,
    RESULTAT=resuq,
    CONTRAINTE='SIEF_ELNO' ,
    FORCE='REAC_NODA' ,
    CRITERES=(
        'SIEQ_ELNO' ,
        'SIEQ_NOEU' ,
    ),
);

resunl=CALC_CHAMP(
    reuse =resunl,
    RESULTAT=resunl,
    CONTRAINTE='SIEF_ELNO' ,
    FORCE='REAC_NODA' ,
    CRITERES=(
        'SIEQ_ELNO' ,
        'SIEQ_NOEU' ,
        'EPEQ_NOEU' ,
    ),
);
```

Note that we introduce the criteria `EPEQ_NOEU` which the Equivalent Plastic strain and may be a better design criteria then the stress[1].

Print the key values in *.resu* file.

```
#printing a .resu file to hold some minimum and maximum values
#of some fields and components
IMPR_RESU(
    FORMAT='RESULTAT' ,
    RESU=(
        _F(
            RESULTAT=resuq,NOM_CHAM='DEPL' ,
            NOM_CMP=('DZ' ,),VALE_MAX='OUI' ,VALE_MIN='OUI' ,
        ),
        _F(
            RESULTAT=resunl,NOM_CHAM='DEPL' ,
            NOM_CMP=('DZ' ,),VALE_MAX='OUI' ,VALE_MIN='OUI' ,
        ),
        _F(
            RESULTAT=resuq,
            NOM_CHAM='SIEQ_NOEU' ,
            NOM_CMP=('VMIS' ,),
            VALE_MAX='OUI' ,
        ),
        _F(
            RESULTAT=resunl,
            NOM_CHAM='SIEQ_NOEU' ,
            NOM_CMP=('VMIS' ,),
```

[1] As such it is mandatory in some Construction Codes.

```
                VALE_MAX='OUI',
            ),
            _F(
                RESULTAT=resunl,
                NOM_CHAM='EPEQ_NOEU',
                #and its numerous components
                VALE_MAX='OUI',VALE_MIN='OUI',
            ),
        ),
    );
```

And printing the *.med* file.

```
IMPR_RESU(
    FORMAT='MED',
    RESU=(
        _F(
            RESULTAT=resuq,
            MAILLAGE=mesh1,
            NOM_CHAM=('DEPL','SIEF_ELNO','SIEQ_NOEU',),
        ),
        _F(
            RESULTAT=resuq,
            MAILLAGE=mesh1,
            NOM_CHAM='SIEQ_NOEU',NOM_CMP='VMIS',
            NOM_CHAM_MED='vmislin'
        ),
        _F(
            RESULTAT=resunl,
            MAILLAGE=mesh1,
            NOM_CHAM=('DEPL','SIEF_ELNO','SIEQ_NOEU','EPEQ_NOEU',),
        ),
        _F(
            RESULTAT=resunl,
            MAILLAGE=mesh1,
            NOM_CHAM='SIEQ_NOEU',NOM_CMP='VMIS',
            NOM_CHAM_MED='vmisnl'
        ),
    ),
);

FIN();
```

We print the maximum values and minimum values of some fields and components as a useful check of the values displayed in the post-processing viewers.

We should always do that to ensure that we are displaying the values calculated by **code_aster** .

14.1.5 Looking at the results

After the calculation we can look at the results.

Although the maximum vertical displacement, from $1.6mm$ to $60.5mm$, is multiplied by almost 40; the maximum stress, from 1408 to $416N/mm^2$, is actually divided by around 3.4 and the distribution is rather different!

Just a few Gmsh hints about how reproduce the screen caps in figures 14.3 and 14.2

- the view are moved around with: in the **Options - View[x]** window, Transfo » Coordinate transformation:, the values are in model units, in the model global coordinate system;
- the scalar bars are moved around with: in the **Options - View[x]** window, Axis » 2D axes/value scale position, to manual, fore example with the proper values in the four fields, the values are in pixel, in the screen coordinate system;
- elements outlines are obtained with: in the **Options - View[x]** window, Visibility » Draw element outlines;
- we may also shrink the elements with: in the **Options - View[x]** window, Aspect » Element shrinking factor, for example 0.8 in the top view of figure 14.2.

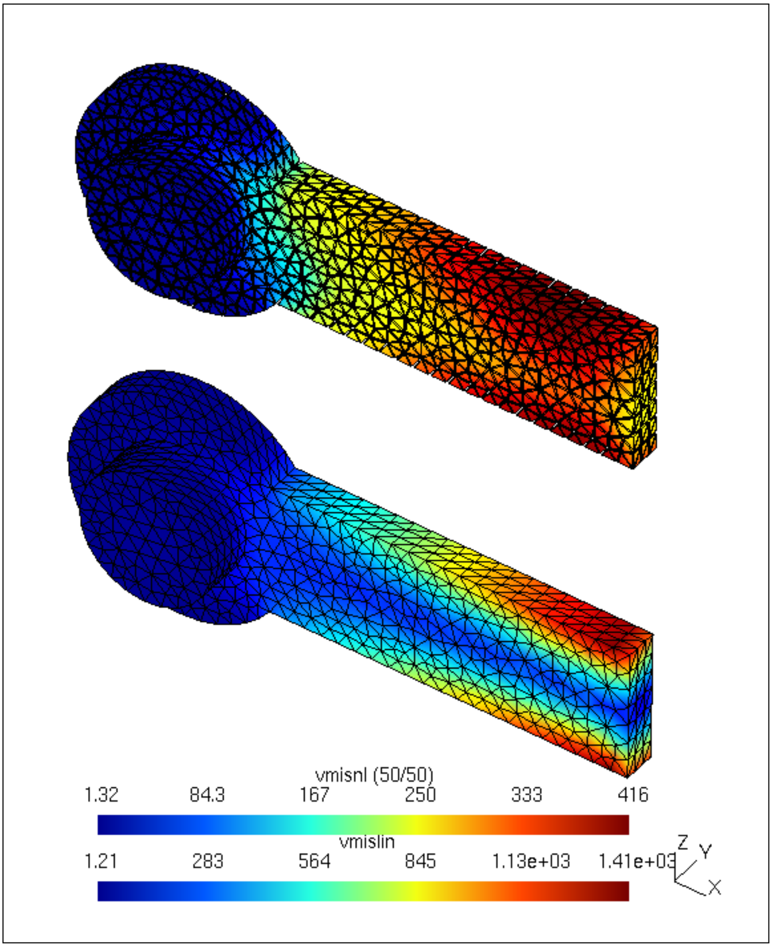


FIGURE 14.2: Compared von Mises stress

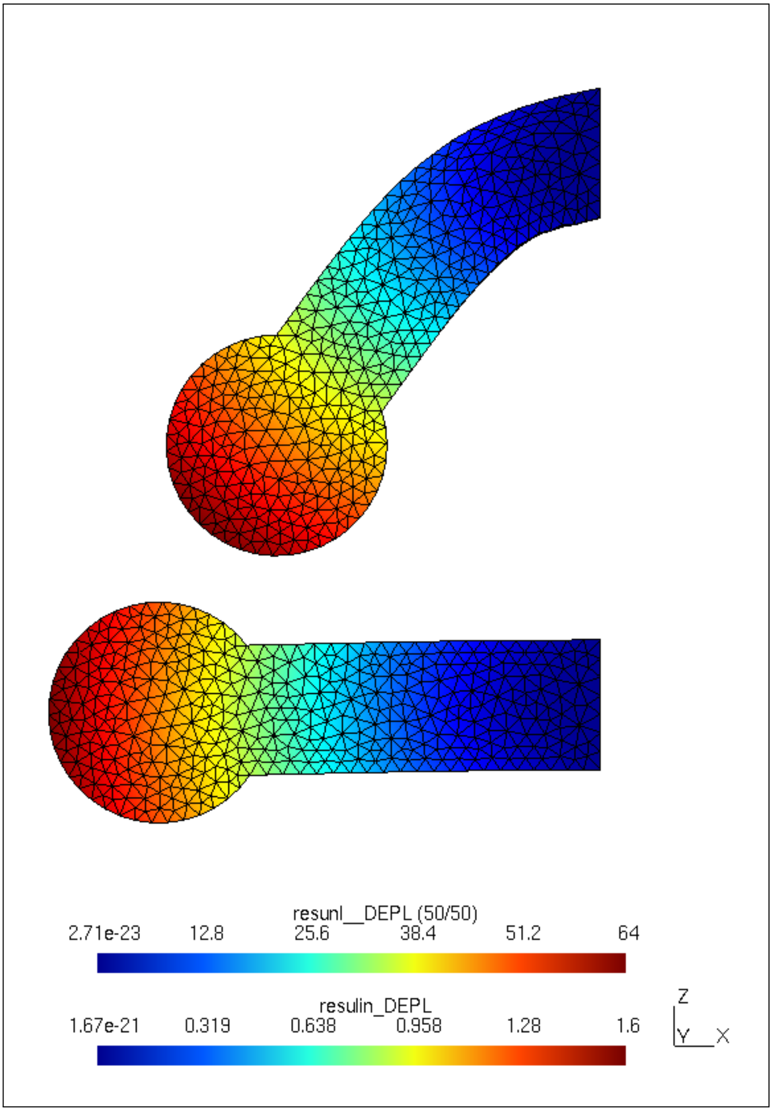


FIGURE 14.3: Compared displacement

14.2 Using a linear hardening material

We may change the material properties to a linear hardening one, i.e. with a constant stress value beyond the elastic limit.

Material will be defined like that :

```
steel=DEFI_MATERIAU(
    ELAS=_F(E=210000,NU=0.3,),
    ECRO_LINE=_F(
        D_SIGM_EPSI=0.0,
        SY=235.0,
        SIGM_LIM=420.0,
    ),
);
```

- elastic properties as before;
- `D_SIGM_EPSI=0.0,` means a null modulus beyond the elastic limit $E_T = 0.0$;
- `SIGM_LIM=420.0,` means an absolute stress limit;
- alternatively an `EPSI_LIM=0.4,`, absolute strain limit could be specified.

And the following change has to be made in `STAT_NON_LINE` operator

```
resunl=STAT_NON_LINE(
    .............
    COMPORTEMENT=_F(
        RELATION='VMIS_ISOT_LINE', #U4.51.11 para 4.3.2.3
        DEFORMATION='SIMO_MIEHE',  #U4.51.11 para 4.5.3
    ),
    .............
);
```

Of course as this is a different plastic strain curve the results are to be different as well!

14.3 Replacing volumes by beams

We may simplify meshing and reduce calculation time by substituting some areas of the 3D mesh by an equivalent beam section. This can be done in the previous example for some length of the part in between the grounding and the eye.

For this, we use the LIAISON_ELEM command described in U4.44.01 in paragraph 4.19, with the first basic points:

- with this we cannot use the trick of the symmetry anymore;
- the cross section of the 3D elements across the joint and the cross section of the beam must be geometrically strictly identical;
- because of the beam we carry an elastic analysis[1].

14.3.1 Meshing

Here is the modified script for creating the geometry and mesh, with the complete model and the beam elements.

```
cl1=2.5; //characteristic length, for meshing
t1=5; //thickness of half part
r1=10.0; //radius of pin
r2=17.0; //outside radius of eye
Point(1) = {0, -t1, 0, cl1}; //base point
Point(11) = {0, -t1, -r1, cl1};
Point(12) = {r1*Sin(2*Pi/3), -t1, r1+r1*Cos(2*Pi/3), cl1};
Point(13) = {r1*Sin(4*Pi/3), -t1, r1+r1*Cos(4*Pi/3), cl1};
Point(21) = {Sqrt(r2*r2-r1*r1), -t1, r1, cl1};
Point(22) = {-r2, -t1, 0, cl1};
Point(23) = {Sqrt(r2*r2-r1*r1), -t1, -r1, cl1};
Point(24) = {(4-2)*r2, -t1, r1, cl1};
Point(25) = {(4-2)*r2, -t1, -r1, cl1};

Circle(1) = {11, 1, 12};
Circle(2) = {12, 1, 13};
Circle(3) = {13, 1, 11};
Circle(4) = {21, 1, 22};
Circle(5) = {22, 1, 23};
Line(6) = {21, 24};
Line(7) = {23, 25};
Line(8) = {25, 24};
fix1s[]  = { Extrude {0, t1, 0} {Line{8};} };
pin1s[]  = { Extrude {0, -1.5*t1, 0} {Line{-1, -2, -3};} };
Curve Loop(33) = {2, 3, 1};
Plane Surface(34) = {33};
Curve Loop(35) = {6, -8, -7, -5, -4};
```

[1] If we switch to a beam model a plastic analysis is still possible but require a more complex input. Moreover the LIAISON_ELEM with OPTION='3D_POU' is not valid in large displacements.

```
Plane Surface(36) = {33, 35};
part1v[]  = { Extrude  {0, t1, 0} {Surface{34, 36}; } };
pin1v[]  = { Extrude  {0, −1.5*t1, 0} {Surface{34}; } };

//line to replace the volume on the right
//beam end point slightly offset from the joining surface
Point(201) = {(4−2)*r2+0.1, 0, 0, cl1};
Point(203) = {4*r2, 0, 0, cl1};
Line(201) = {201,203};
Physical Point("fixp") = {203};
Physical Point("linkp") = {201};
Physical Line("beaml") = {201};

//symmetry of 3D part
//next line helps to understand the structure of fix1s[] list
//element 1 is the surface itself
Printf("fix1s",fix1s[]);
newfix1s[] = {
    Symmetry {0, 1, 0, 0}
    {Duplicata { Surface{fix1s[1]}; } }
};
//same remarks with part1v[] list
//where elemnts 1 and 6 are the volume itself
Printf("part1v",part1v[]);
Printf("pin1v",pin1v[]);
new1v[] = {
    Symmetry {0, 1, 0, 0}
    {Duplicata { Volume{part1v[1],part1v[6],pin1v[1]}; } }
};

Physical Point("load1p") = {33};
Physical Surface("bear1s") = {36};
Physical Surface("sym1s") = {95};
Physical Surface("pin1s") = {pin1s[]};
Physical Surface("fix1s") = {fix1s[], newfix1s[] };
Physical Surface("load1s") = {112,295};
Physical Volume("part1v") = {part1v[], pin1v[], new1v[]};
//all surfaces in Cyan
Color Cyan{
    Surface{12, 16, 20, 24, 34, 36, 44, 48, 52, 53,
    78, 82, 86, 94, 95, 102, 112};
}
//then
Color Orange{ Surface{36}; }
Color Black{ Surface{53, 102}; }
Color Green{ Surface{95}; }
Color Red{ Surface{pin1s[]}; }
Color Blue{ Surface{fix1s[]}; }
Color Magenta{ Volume {part1v[], pin1v[] };}
```

The beam end is slightly offset, in the X direction, from the joining surface, this is not required at all, it just makes the meshing view more explicit. However, we must realize that this short length behaves as a rigid body, so it should not be too long! **code_aster** raises a warning about this at run time. Also the geometry is built in such a way that there is not necessarily a node on the face just facing the end of the beam, it is not necessary.

Note the tricky part with the symmetry of surface and volume and how Gmsh treats that this is explained in the Gmsh doc and the command `Printf` allows to understand what it is about.

We make a quadratic mesh out of this geometry, but this creates `SEG3` on the lines, which is not suitable for the beam elements, this is to be solved in the command file.

14.3.2 Commanding

Here is the command file.

```
DEBUT();

mesh0=LIRE_MAILLAGE(UNITE=20,FORMAT='MED',);

mesh0=DEFI_GROUP(
    reuse =mesh0,
    MAILLAGE=mesh0,
    CREA_GROUP_MA=_F(NOM='TOUT',TOUT='OUI',),
);

mesh0=MODI_MAILLAGE(
    reuse =mesh0,
    MAILLAGE=mesh0,
    ORIE_PEAU_3D=(_F(GROUP_MA='fix1s',),),
);

qmesh=CREA_MAILLAGE(
    MAILLAGE=mesh0,
    QUAD_LINE=_F(GROUP_MA=('beaml',),),
);
```

We revert to a linear mesh on the beam group as beams are only supported by linear elements.

```
qmesh=DEFI_GROUP(
    reuse =qmesh,MAILLAGE=qmesh,
    CREA_GROUP_NO=(
        _F(GROUP_MA='linkp',),
        _F(GROUP_MA='fix1s',),
        _F(GROUP_MA='fixp',),
    ),
);

lmesh=CREA_MAILLAGE(
    MAILLAGE=mesh0,
    LINE_QUAD=_F(GROUP_MA=('TOUT',),),
);

IMPR_RESU(FORMAT='MED', UNITE=71,  RESU=_F(MAILLAGE=lmesh,),);
IMPR_RESU(FORMAT='MED', UNITE=72,  RESU=_F(MAILLAGE=qmesh,),);
```

We create a model ’qmod’ on the quadratic mesh ’qmesh’ and another one ’lmod’ on the linear mesh ’lmesh’.

```
qmod=AFFE_MODELE(
    MAILLAGE=qmesh,
    AFFE=(
        _F(
            GROUP_MA=('part1v','fix1s','load1s',),
            PHENOMENE='MECANIQUE',MODELISATION='3D',
        ),
        _F(
            GROUP_MA='beaml',
            PHENOMENE='MECANIQUE',MODELISATION='POU_D_T',
        ),
    ),
);

lmod=AFFE_MODELE(
    MAILLAGE=lmesh,
    AFFE=(
        _F(
            GROUP_MA=('part1v','fix1s','load1s',),
            PHENOMENE='MECANIQUE',MODELISATION='3D',
        ),
        _F(
            GROUP_MA='beaml',
            PHENOMENE='MECANIQUE',MODELISATION='POU_D_T',
        ),
    ),
);
```

```
steel=DEFI_MATERIAU(
    ELAS=_F(E=210000,NU=0.3,),
);

mate=AFFE_MATERIAU(
    MAILLAGE=qmesh,
    AFFE=_F(TOUT='OUI',MATER=steel,),
);

elemcar=AFFE_CARA_ELEM(
    MODELE=qmod,
    POUTRE=_F(
        GROUP_MA=('beaml',),SECTION='RECTANGLE',
        CARA=('HY','HZ'),VALE=(10, 20,),
    ),
);

#joining the beam to the solid part
#U4.44.01 par 4.19
link=AFFE_CHAR_MECA(
    MODELE=qmod,
    LIAISON_ELEM=_F(
        OPTION='3D_POU',
        GROUP_MA_1='fix1s',
        GROUP_NO_2='linkp',
    ),
);
```

The beam is a rectangle of exactly the same dimension as the solid part.

The `LIAISON_ELEM`:

- uses the `OPTION='3D_POU'`, as we are joining a beam to a solid part;
- with `GROUP_MA_1`, we give the name of the element group of the joint on the 3D side;
- with `GROUP_NO_2`, the name of the group of nodes, in fact only one single node, at the end of the beam on the joint.

```
fix1=AFFE_CHAR_MECA(
    MODELE=qmod,
    DDL_IMPO=(
        #symmetry is not used for this calculation,
        #the beam does not allow it
        #_F(GROUP_MA=('sym1s','load1s',),DY=0.0,),
        _F(
            GROUP_MA='fixp',
            DX=0.0,DY=0.0,DZ=0.0,
            DRX=0.0,DRY=0.0,DRZ=0.0,
        ),
    ),
);

load=AFFE_CHAR_MECA(
    MODELE=qmod,
    FORCE_FACE=_F(GROUP_MA='load1s',FZ=-25.0,),
);
```

Here, we perform the analysis with the linear behavior.

```
#only one single step linear calculation
resuq=MECA_STATIQUE(
    MODELE=qmod,
    CHAM_MATER=mate,
    CARA_ELEM=elemcar,
    EXCIT=(
        _F(CHARGE=fix1,),
        _F(CHARGE=link,),
        _F(CHARGE=load,),
    ),
);

resuq=CALC_CHAMP(
    reuse =resuq,
    RESULTAT=resuq,
    CONTRAINTE=('SIEF_ELNO','SIPM_ELNO',),
    FORCE='REAC_NODA',
    CRITERES=('SIEQ_NOEU',),
);

STANLEY();
```

A call to STANLEY here would process and display results on the quadratic mesh. And we do some post-processing to be printed in the *.resu* file.

```
sr1=POST_RELEVE_T(
    ACTION=_F(
        INTITULE='reac1',
        GROUP_NO=('fixp',),RESULTAT=resuq,
        NOM_CHAM='REAC_NODA',TOUT_ORDRE='OUI',
        RESULTANTE=('DX','DY','DZ'),
        OPERATION='EXTRACTION',
    ),
);
IMPR_TABLE (TABLE=sr1,)
```

```
IMPR_RESU(
    FORMAT='RESULTAT',
    #a print ou in .resu file of Min and Max values
    #so as to check the viewer's displayed values
    #against the calculated ones
    RESU=(
        _F(RESULTAT=resuq,NOM_CHAM='DEPL',
            NOM_CMP=('DZ',),VALE_MAX='OUI',VALE_MIN='OUI',
        ),
        _F(
            RESULTAT=resuq,
            NOM_CHAM='SIEQ_NOEU',
            NOM_CMP=('VMIS_SG',),
            VALE_MAX='OUI',
        ),
        _F(
            RESULTAT=resuq,
            NOM_CHAM='SIPM_ELNO',
            GROUP_MA='beaml',
            NOM_CMP=('SIXX',),
            VALE_MAX='OUI',VALE_MIN='OUI',
        ),
    ),
);
```

To finish by projecting the results on the linear mesh and printing them in the *.med* file.

```
    resuqp=PROJ_CHAMP(
        RESULTAT=resuq,
        MODELE_1=qmod,MODELE_2=lmod,
        PROL_ZERO='OUI'
    );


    IMPR_RESU(
        FORMAT='MED',
        RESU=(
            #the result for 3D is from the-projected results
            _F(
                RESULTAT=resuqp,
                NOM_CHAM=('DEPL','SIEQ_NOEU',),
            ),
            _F(
                RESULTAT=resuqp,
                NOM_CHAM='SIEQ_NOEU',NOM_CMP='VMIS_SG',
                NOM_CHAM_MED='vmislin'
            ),
            #the results for beams are from
            #the non-projected results
            _F(
                RESULTAT=resuq,
                GROUP_MA='beaml',
                NOM_CHAM='SIPM_ELNO',
                NOM_CMP='SIXX',NOM_CHAM_MED='sipmsixx'
            ),
            _F(
                RESULTAT=resuq,
                GROUP_MA='beaml',
                NOM_CHAM='DEPL',
                NOM_CHAM_MED='beamdepl'
            ),
        ),
    );

    FIN();
```

In the med file, the result for the beam are from the non-projected results as the beam has not been converted to quadratic.

14.3.3 Viewing results

After quite a bit of mixing, DEPL from the 'resuqp' and 'resuq' for the beam, and homogenizing the scales, we can display a deformed shape looking like figure 14.4 in Gmsh.

And the same for von Mises criteria in the 3D elements, and maximum normal stress, 'sipmsixx', for beam elements in figure 14.5. In which we use VON_MISES_SG, which the value of the von Mises criteria signed by the trace of the stress tensor, that is the sum of the principal stress to give a better picture of the tension and compression areas[1].

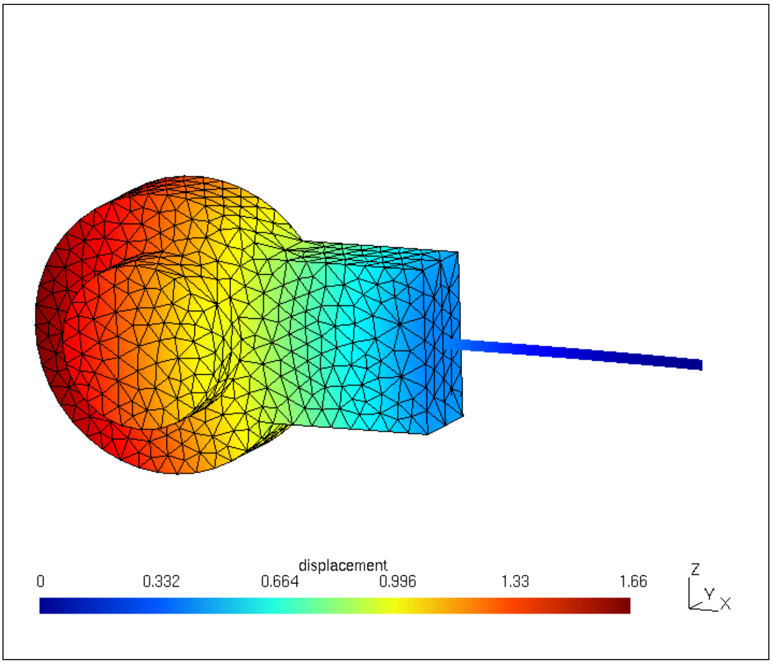


FIGURE 14.4: 3D + beam, displacement

[1] In simpler words: it is positive if there is traction and negative if there is compression.

If we compare these values with the results of the linear analysis of the solid model just above:

- the maximum displacement is $1.66mm$ in the beam+3D model while it is $1.6mm$ in the solid model;
- and the maximum stress, at the ground fixation, `SIPM_ELNO...SIXX` is $1582N/mm^2$ in the beam+3D model which compares favorably with the `SIEQ_ELNO...VMIS` of $1408N/mm^2$ in the solid model;
- also the `SIPM_ELNO...SIXX` is $747N/mm^2$ in the beam at the junction with the solid part which shows a very similar `SIEQ_ELNO...VMIS` of $792N/mm^2$ in the solid part.

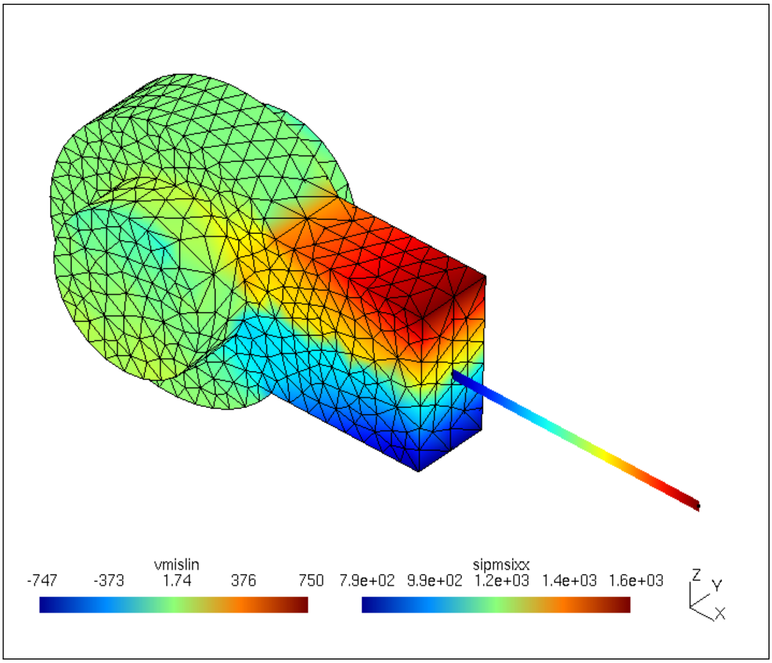


FIGURE 14.5: 3D + beam, stresses

CHAPTER 15

Modal analysis

In the first part of this chapter, we introduce the modal analysis of a very simple structure.

We compare the results with analytical methods and see how some information like generalized mass or effective mass can be extracted

15.1 Analytical modal analysis

In this section, we analyze the modal behavior of a very simple structure, very like an inverted pendulum, 1 meter long with a mass of one kilogram at the free end, the circular object in figure 15.1. The other end is fixed in all three directions, translations and rotations, and carries a mass of one kilogram which cannot move at all, shown as the black rectangle[1]. The section is rectangular, $a \times 2a$, such the mass of the stem is also 1 kg, which gives $a = 7.9mm$, calculated by **code_aster** .

[1] In true life this mass could be the structure holding the stem and resting on the ground.

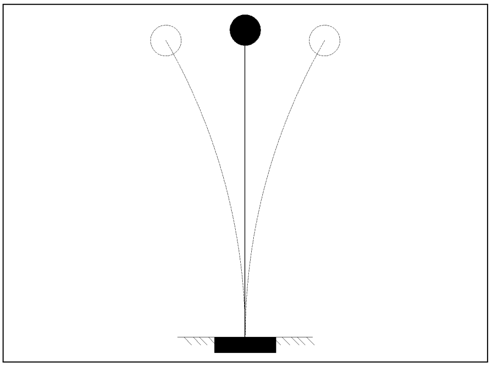


FIGURE 15.1: Inverted pendulum for modal analysis

The first natural frequency can be calculated with the following formula[1]:

$$f = \frac{1}{2\pi}\sqrt{\frac{EI}{L^3(M+0.24Mb)}}$$

Where L is the length of the beam, Mb its mass and M the end mass, all this in a consistent set of unit (kg, m, s). The end mass is supposed to be a point mass with no rotational inertia.

In addition the mode shape is:

$$y(\frac{x}{L}) = (\frac{x}{L})^3 - 3\frac{x}{L} + 2$$

With the above figures the first two frequencies, respectively in the Y and X directions come out at 2.79 and $5.59Hz$.

15.2 Gmsh geometry and mesh

Here is the Gmsh file for geometry.

[1] Which can be found in [Blevins].

```
cl1=100;
Point(1) = {0, 0, 0, cl1};
Point(2) = {0, 0, 1000, cl1};
Line(1) = {2, 1};
Physical Line("stem") = {1};
Physical Point("endmass") = {2};
Physical Point("fix") = {1};
```

One remark here: the mode shape calculation will only be true for a number of antinode lower than the number of element along the length, this governs the chosen meshing density, this remark holds true for the buckling analysis as well.

15.3 Command file, preliminaries

The first part of the command file is straightforward and is given here without any comment.

```
DEBUT(PAR_LOT='OUI',);

mesh=LIRE_MAILLAGE(INFO=1,UNITE=20,FORMAT='MED',);

mesh=DEFI_GROUP(
    reuse =mesh,MAILLAGE=mesh,
    CREA_GROUP_NO=(_F(TOUT_GROUP_MA='OUI',),),
);

model=AFFE_MODELE(
    MAILLAGE=mesh,
    AFFE=(
        _F(
            GROUP_MA=('stem',),
            PHENOMENE='MECANIQUE',MODELISATION='POU_D_T',
        ),
        _F(
            GROUP_MA=('endmass','fix',),
            PHENOMENE='MECANIQUE',MODELISATION='DIS_T',
        ),
    ),
);

steel=DEFI_MATERIAU(ELAS=_F(E=210000.,NU=0.3,RHO=8.0e-9),);

material=AFFE_MATERIAU(
    MAILLAGE=mesh,
    AFFE=_F(GROUP_MA=('stem',),MATER=steel,),
);

#dimension for mass 1 kg
```

```
a=(1.0/8/10/2)**0.5*100;
elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    POUTRE =_F(
        GROUP_MA=('stem',),
        SECTION='RECTANGLE',CARA=('HY','HZ',),VALE=(a, 2*a),
    ),
    DISCRET=_F(
        GROUP_MA=('endmass','fix',),
        CARA='M_T_D_N',VALE=1.0/1000,
    ),
);

ground=AFFE_CHAR_MECA(
    MODELE=model,
    DDL_IMPO=_F(
        GROUP_NO=('fix',),
        DX=0,DY=0,DZ=0,DRX=0,DRY=0,DRZ=0,
    ),
);

massin=POST_ELEM(
    MODELE=model,CHAM_MATER=material,CARA_ELEM=elemcar,
    MASS_INER=_F(TOUT='OUI',),
    TITRE= 'massin',
);
IMPR_TABLE (TABLE=massin,)
```

The line `a=(1.0/8/10/2)**0.5*100;` calculates the dimension of the rectangular section.

One should write 1.0 -a floating number- and not just simply 1 -an integer- as the result 'a' would not then be a floating number but an integer equal to 0 [1].

Note also how we calculate the total mass model without having performed a static analysis beforehand. If we look in the *.resu* file we can see that the computed mass , 'massin', is $3.0E-03$ (metric) tons, including the 1 kilogram mass on the top and the other 1 kilogram mass on the ground.

```
#massin
 LIEU      ENTITE    MASSE
 mesh      TOUT        3.00000E-03
```

[1] In Gmsh any number is handled by default as a floationg point number.

15.4 Command file, analysis

Then follows the modal analysis itself.

```
#modal analysis
ASSEMBLAGE(
    MODELE=model,
    CHAM_MATER=material,
    CARA_ELEM=elemcar,
    CHARGE=ground,
    NUME_DDL=CO('numdof'),
    MATR_ASSE=(
        _F(MATRICE=CO('rigidity'),OPTION='RIGI_MECA',),
        _F(MATRICE=CO('masse'),OPTION='MASS_MECA',),
    ),
);

modes=CALC_MODES(
    TYPE_RESU='DYNAMIQUE', #for a modal analysis
    MATR_MASS=masse,
    MATR_RIGI=rigidity,
    OPTION='PLUS_PETITE',
    CALC_FREQ=_F(NMAX_FREQ=8,),
    #some of the lines in the following VERI_MODE
    #may have to be uncommented
    VERI_MODE=_F(
        #PREC_SHIFT=5.0000000000000001E-3,
        #STOP_ERREUR='NON',
        #STURM='OUI',
        #SEUIL=9.9999999999999995E-07,
    ),
);
```

One remark, for the modal analysis only boundary conditions are taken into account, the analysis is performed with the mass as assigned with RHO for the materials and the masses values assigned to discrete elements, like M_T_D_N[1].

Another remark, once **code_aster** has calculated the modes it performs by default a check of the modes. This check may fail even if the modes are properly calculated. A workaround is to specify in the *.comm* the key word VERI_MODE with some parameters, a choice of which is proposed and commented in the block of code just above[2]. The error messages in

[1] This is not strictly true as a modal analysis can be performed on a pre-loaded structure, for this general instructions are given at chapter 15.9 .

[2] Temporarily uncommenting STOP_ERREUR='NON', it is set by default to STOP_ERREUR='OUI', helped me to identify some problems in a few cases, changing SEUIL value with STURM='OUI' is somewhat more refined.

the *.mess* file gives here some hints about the strategy to follow. Once again one has to be very careful before taking for granted the calculated values.

```
#printing of the mode shapes in a med file
IMPR_RESU(
    FORMAT='MED',UNITE=80,
    RESU=_F(RESULTAT=modes,NOM_CHAM='DEPL',),
);

#printing the values in the .resu file
#for the RESU "modes"
IMPR_RESU(
    MODELE=model,
    FORMAT='RESULTAT',
    RESU=_F(
        RESULTAT=modes,
        #this prints all the info relative to modal analysis
        TOUT_CHAM='NON', #with this we do not print DEPL
        TOUT_PARA='OUI',#prints all the parameter
        #next lines print only the specified parameter
        #NOM_PARA=(
        #'FREQ','MASS_GENE',
        #'MASS_EFFE_DX','MASS_EFFE_DY',
        #),
        #FORM_TABL='OUI', #optional
    ),
);
```

Note: the `CALC_MODES` produces a 'data structure' which holds a collection of `DEPL` fields, these are the Eigen modes and they are indexed by ascending `FREQ` which is the Eigen frequency.

15.5 First results

Here is the print out, of all the parameters, restricted to the first three modes.

```
ASTER 11.04.00 CONCEPT modes
CALCULE LE 05/08/2013 A 07:44:04 DE TYPE MODE_MECA



NUMERO_ORDRE NUME_MODE        FREQ             AMOR_GENE        AMOR_REDUIT
             FACT_PARTICI_DX  FACT_PARTICI_DY  FACT_PARTICI_DZ  MASS_EFFE_DX
             MASS_EFFE_DY     MASS_EFFE_DZ     MASS_GENE        OMEGA2
             RIGI_GENE        CARAELEM         CHAMPMAT         MODELE
             NOEUD_CMP        TYPE_DEFO        TYPE_MODE
             EXCIT                    NORME


          1            1      2.89797D+00      0.00000D+00      0.00000D+00
```

```
               5.72277D-17     1.11285D+00    -1.90428D-25     4.05564D-36
               1.53363D-03     4.49062D-53     1.23836D-03     3.31548D+02
               4.10575D-01    elemcar         material        model
                                               MODE_DYN
                                        SANS_CMP: LAGR
            2            2     5.79544D+00     0.00000D+00     0.00000D+00
               1.11284D+00    -9.82865D-17    -6.81417D-17     1.53364D-03
               1.19631D-35     5.75021D-36     1.23839D-03     1.32596D+03
               1.64206D+00    elemcar         material        model
                                               MODE_DYN
                                        SANS_CMP: LAGR
            3            3     3.02328D+01     0.00000D+00     0.00000D+00
              -6.29580D-17     7.25491D-01     9.25319D-22     1.83407D-36
               2.43544D-04     3.96184D-46     4.62716D-04     3.60841D+04
               1.66967D+01    elemcar         material        model
                                               MODE_DYN
```

We can see the first 2 frequencies, at $2.898Hz$ and $5.795Hz$, in agreement with the analytical calculation. However there is here a very large amount of information and we may restrict even more the printed parameters as it is suggested in the commented code lines, we then get the following output, a bit easier to read.

```
   NUMERO_ORDRE  FREQ              MASS_GENE       MASS_EFFE_DX    MASS_EFFE_DY




            1  2.89797D+00     1.23836D-03     4.05564D-36     1.53363D-03
            2  5.79544D+00     1.23839D-03     1.53364D-03     1.19631D-35
            3  3.02328D+01     4.62716D-04     1.83407D-36     2.43544D-04
            4  6.04188D+01     4.62871D-04     2.43615D-04     4.55821D-33
            5  9.46502D+01     4.48592D-04     3.15069D-32     7.79235D-05
            6  1.88910D+02     4.48749D-04     7.79878D-05     1.81477D-29
            7  1.95518D+02     4.59906D-04     3.58949D-29     3.78823D-05
            8  3.32870D+02     4.67511D-04     1.70046D-30     2.22815D-05
```

The MASS_GENE at $1.238kg$ for the first two modes seems in good agreement with the theory. So are the MASS_EFFE_DX or MASS_EFFE_DY at $1.533kg$[1].

15.6 More results

Here is a bit of code normalizing the modes for the MASS_GENE parameter, extract the MASS_EFFE_UN parameter and print on the fly.

```
#here we normalize the mode for 'MASS_GENE', generalized mass
normode2=NORM_MODE(
    MODE=modes,
    MASSE=masse,
    NORME='MASS_GENE',
);
```

[1] A rule of thumb here would be 1/3 of the stem mass + the end mass.

```
extrnor2=EXTR_MODE(
    FILTRE_MODE=_F(
        MODE=normode2,
        CRIT_EXTR='MASS_EFFE_UN',
        SEUIL=1.E-3,
    ),
    IMPRESSION=_F(
        CUMUL='OUI',
        CRIT_EXTR='MASS_EFFE_UN',
    ),
);
```

Giving the following print out:

```
ASTER 10.06.00 CONCEPT normode2
CALCULE LE 26/02/2012 A 15:11:19 DE TYPE
MODE_MECA



NUMERO_ORDRE FREQ              MASS_GENE        RIGI_GENE



          1  2.89797D+00       1.00000D+00      3.31548D+02
          2  5.79544D+00       1.00000D+00      1.32596D+03
          3  3.02328D+01       1.0:0000D+00     3.60841D+04
          4  6.04188D+01       1.00000D+00      1.44113D+05
          5  9.46502D+01       1.00000D+00      3.53673D+05
          6  1.88910D+02       1.00000D+00      1.40887D+06
          7  1.95518D+02       1.00000D+00      1.50916D+06
          8  3.32870D+02       1.00000D+00      4.37432D+06
```

One remark here: frequencies may happen to be negative, but with a very low value, this is usually due a rigid body mode, it is the same with positive very low values.

Another remark: with a model made of many beam elements, like a large frame, we may find many values corresponding to the local mode of a single element, before finding global modes, whether these local modes should be considered or not is the choice of the engineer[1]!

And one last remark: if the model is showing symmetry or cyclic symmetry there may be several modes with almost the same Eigen frequencies and shapes due to symmetry, and this is normal.

[1] And here looking at the values of MASS_GENE or MASS_EFFE_UN may help.

15.7 Estimating (roughly) the natural frequency

Before starting a modal analysis we should always have a rough idea of the value of the first fundamental, e.g. is it 0.1 Hz, 1 Hz, 10 Hz or 100 Hz!

Here comes quite useful a formula relating the value of the first, natural, frequency and the deflection produced by the action of gravity[1] acting in the same direction:

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{\delta_s}}$$

where

- g is the gravity acceleration, $9.81 m/s^2$;
- δ_s is the deflection of the structure due to the sole action of g^2.

15.8 Viewing mode shapes

Figure 15.2 shows four modes on a single screen, with a scale of 200, from left to right:

- the far left, is the first mode in the YOZ plane at $2.898Hz$;
- the middle left, is the second mode in the XOZ plane at $5.795Hz$;
- the middle right, is the third “quarter wave” in the YOZ plane at $30.23Hz$;
- the far right, is the high order mode number 8 in the YOZ plane at $322.87Hz$;

[1] Real or dummy!

[2] More details about the proof of this formula in [Blevins].

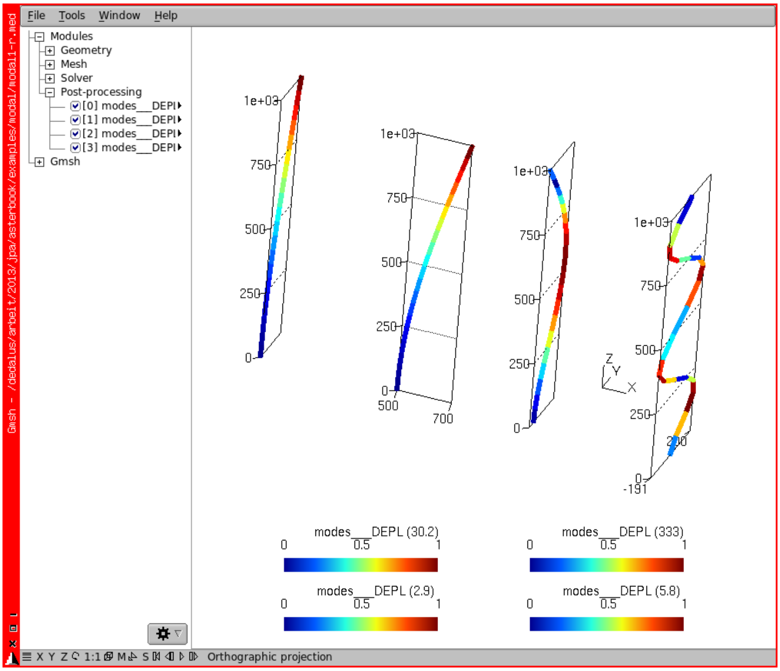


FIGURE 15.2: Four modes in Gmsh

15.9 Modal analysis on an pre-loaded model

The rough guide lines to preform a Modal analysis on an pre-loaded model are as such:

- make a linear elastic analysis with the pre-load, for example here, a tension in the stem;
- extract the geometrical stiffness matrix ’Kg’ associated to this deformed shape;
- add this geometrical stiffness matrix to the mechanical stiffness matrix, ’K + Kg’;
- perform the modal analysis.

In this chapter we perform the modal analysis on the same simple structure preloaded with an axial tension.

15.9.1 Making a static analysis with the preload

We define the load case, here an axial tension of $1000N$.

```
pretens=AFFE_CHAR_MECA(
    MODELE=model,
    FORCE_NODALE=_F(GROUP_NO='endmass',FZ=1.0e3,),
);
```

We make the static analysis with this load.

```
preresu=MECA_STATIQUE(
    MODELE=model,
    CHAM_MATER=material,
    CARA_ELEM=elemcar,
    EXCIT=(
        _F(CHARGE=ground,),
        _F(CHARGE=pretens,),
    ),
);
```

An alternative to the previous block using `MACRO_ELAS_MULT` is
.

```
preresu=MACRO_ELAS_MULT(
    MODELE=model,CHAM_MATER=material,CARA_ELEM=elemcar,
    CHAR_MECA_GLOBAL=ground,
    CAS_CHARGE=_F(NOM_CAS='preload',CHAR_MECA=pretens,),
);
```

We create the result field.

```
si=CREA_CHAMP(
    OPERATION='EXTR',
    TYPE_CHAM='ELGA_SIEF_R',
    RESULTAT=preresu,
    NOM_CHAM='SIEF_ELGA',
);
```

15.9.2 Extracting the geometrical stiffness matrix

Here we extract the geometrical stiffness matrix 'Kg' associated to the deformed shape.

```
meg=CALC_MATR_ELEM(
    OPTION='RIGI_GEOM',
    MODELE=model,CARA_ELEM=elemcar,CHAM_MATER=material,
    SIEF_ELGA=si,
);
```

add this geometrical stiffness matrix to the mechanical stiffness matrix, 'K + Kg';

15.9.3 Adding this geometrical stiffness matrix

We add this geometrical stiffness matrix to the mechanical stiffness matrix, 'K + Kg'.

```
mar=ASSE_MATRICE(MATR_ELEM=meg,NUME_DDL=numdof,);

matassr1=COMB_MATR_ASSE(
    COMB_R=(
        _F(MATR_ASSE=rigidity,COEF_R=1.0,),
        _F(MATR_ASSE=mar,COEF_R=1.0,),
    ),
);
```

15.9.4 Performing the modal analysis

And we performing the modal analysis

```
md=CALC_MODES(
    MATR_RIGI=matassr1,
    MATR_MASS=masse,
    OPTION='PLUS_PETITE',
    CALC_FREQ=_F(NMAX_FREQ=5,),
    SOLVEUR_MODAL=_F(METHODE='TRI_DIAG',),
);
```

15.9.5 Looking at the results

And the results show quite a large increase of the values.

```
 ASTER 13.03.00 CONCEPT md CALCULE LE 28/02/2017 A 08:19:45 DE TYPE MODE_MECA



 NUMERO_ORDRE FREQ                  MASS_GENE          MASS_EFFE_DX       MASS_EFFE_DY
```

```
      1   5.63696D+00     1.26262D-03     1.12149D-27     1.56861D-03
      2   7.59344D+00     1.24567D-03     1.54459D-03     1.23175D-27
      3   3.54363D+01     4.70569D-04     8.17845D-27     2.14219D-04
      4   6.31898D+01     4.65107D-04     2.34191D-04     7.04383D-27
      5   1.00469D+02     4.52733D-04     1.01899D-30     7.40865D-05
```

15.10 What to read in the documentation

U4.52.03 concerns the operator `CALC_MODES`.

U4.52.11 concerns the operator `NORM_MODE`.

U4.52.12 concerns the operator `EXTR_MODE`.

While R5.01.03 gives a good background to the theory and explains the way **code_aster** names the concepts.

15.11 When one should make a modal analysis

Besides finding the eigen value of the frequency and the mode shape a modal analysis is a very efficient way of checking a model for connectivity or odd element properties.

If two nodes, that are believed to be connected, are not (this may a very short distance not appearing at first glance on the mesh) a modal analysis will most probably a singular displacement of this node on the mode shape result viewer.

This kind of trouble occurs all too often with imported CAD files.

A modal analysis also helps in detecting where is lying a bad connectivity that would lead to a failure in a static analysis.

CHAPTER 16

Buckling analysis

In this chapter we perform the Eulerian elastic critical buckling load analysis on a simple column example.

We finally go into some hints to calculate the buckling load of a structure made of beams and plates.

16.1 Checking analytical buckling

Here, we use the same mesh as for the modal analysis to calculate its critical buckling load, precisely its Eulerian linear buckling load. Full description may be found in U2.08.04.

The first critical buckling load can be calculated with the well known Euler's formula

$$P_{cr} = \frac{k\pi^2 EI}{L^2}$$

Where L is the length of the beam, I the quadratic moment in the buckling plane and L the length of the beam all this in a consistent set of unit (kg, m, s).

k is a coefficient whose value is one when both ends are pinned, free to rotate as it is the case here, it would be 4 with both ends clamped.

In the following example the beam section is a rectangle of $7.91mm$ by $2 \times 7.91mm$, the buckling critical values coming out of the preceding formula are:

- $P_{cr} = 1349N$ in the plane of lowest moment of inertia;
- $P_{cr} = 5397N$ in the plane of highest moment of inertia;

This formula gives only the value of the first mode, with a single antinode, higher modes are calculated by **code_aster** .

As far as **code_aster** is concerned what is calculated is a coefficient which is the ratio of the critical load, as seen above, by the applied *variable* load. *Variable* because **code_aster** allows to make the calculation with a fixed load and a variable load and the coefficient is applied to this second variable load. In the following example the fixed load is only the boundary conditions and no forces, except a commented line which can be un-commented in a second run to see what it does.

16.2 Buckling solving

In the *.comm* file we may eliminate what is related to the discrete elements as we do not use them here.

We change the boundary conditions so the bottom is fully pinned and the top fixed along X and Z, but able to move in the Z direction, to avoid instability, we prevent rotation around the beam axis by setting `DRZ=0`.

```
DEBUT();

mesh=LIRE_MAILLAGE(INFO=2,UNITE=20,FORMAT='MED',);

mesh=DEFI_GROUP(
    reuse =mesh,MAILLAGE=mesh,
    CREA_GROUP_NO=(_F(TOUT_GROUP_MA='OUI',),),
);
```

```
model=AFFE_MODELE(
    MAILLAGE=mesh,
    AFFE=_F(
        GROUP_MA=('stem',),
        PHENOMENE='MECANIQUE',MODELISATION='POU_D_T',
    ),
);

steel=DEFI_MATERIAU(ELAS=_F(E=210000.,NU=0.3,RHO=8.0e-9),);

material=AFFE_MATERIAU(
    MAILLAGE=mesh,
    AFFE=_F(GROUP_MA=('stem',),MATER=steel,),
);

a=(1.0/8/10/2)**0.5*100;
elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    POUTRE =_F(
        GROUP_MA=('stem',),
        SECTION='RECTANGLE',CARA=('HY','HZ',),VALE=(a, 2*a),
    ),
);

ground=AFFE_CHAR_MECA(
    MODELE=model,
    DDL_IMPO=(
        _F(GROUP_NO=('fix',),DX=0,DY=0,DZ=0,DRZ=0,),
        _F(GROUP_NO=('endmass',),DX=0,DY=0,DRZ=0,),
    ),
    #uncomment in a second run
    #to see the behavior with a fixed load
    #FORCE_NODALE=_F(GROUP_NO=('endmass',),FZ=-1000,),
);

load=AFFE_CHAR_MECA(
    MODELE=model,
    FORCE_NODALE=_F(GROUP_NO=('endmass',),FZ=-1000,),
);
```

At first, we make a linear static analysis, for the fixed and variable loads.

```
#for variable load
rescl1p1=MECA_STATIQUE(
    MODELE=model,CHAM_MATER=material,CARA_ELEM=elemcar,
    EXCIT=(
        _F(CHARGE=ground,),
        _F(CHARGE=load,),
    ),
    OPTION ='SIEF_ELGA',
);

#for fixed load
```

```
resc12p1=MECA_STATIQUE(
    MODELE=model,
    CHAM_MATER=material,
    CARA_ELEM=elemcar,
    EXCIT=_F(CHARGE=ground,),
    OPTION ='SIEF_ELGA',
);
```

Then, we compute the internal forces related to the two previous calculations, using this field to compute the associated geometrical stiffness matrix.

```
#stress fields for variable load
sigc11p1=CREA_CHAMP(
    TYPE_CHAM = 'ELGA_SIEF_R',
    OPERATION = 'EXTR',
    RESULTAT =resc11p1,
    NOM_CHAM ='SIEF_ELGA',
    TYPE_MAXI = 'MINI',
    TYPE_RESU='VALE',
);

#geometrical stiffness matrix for variable load
regc11p1=CALC_MATR_ELEM(
    OPTION = 'RIGI_GEOM',
    MODELE=model,
    CARA_ELEM=elemcar,
    SIEF_ELGA=sigc11p1,
);

#stress fields for fixed load
sigc12p1=CREA_CHAMP(
    TYPE_CHAM = 'ELGA_SIEF_R',
    OPERATION = 'EXTR',
    RESULTAT =resc12p1,
    NOM_CHAM ='SIEF_ELGA',
    TYPE_MAXI = 'MINI',
    TYPE_RESU='VALE',
);

#geometrical stiffness matrix for fixed load
regc12p1=CALC_MATR_ELEM(
    OPTION = 'RIGI_GEOM',
    MODELE=model,
    CARA_ELEM=elemcar,
    SIEF_ELGA=sigc12p1,
);
```

And, we compute the material stiffness matrix for the total load, and proceed at the assembly of all the matrix.

```
#material stiffness matrix for both loads
remep1=CALC_MATR_ELEM(
    OPTION = 'RIGI_MECA',
    MODELE=model,
    CHAM_MATER=material,
    CARA_ELEM=elemcar,
    CHARGE = (ground, load,),
);

#matrix assemblies
nup1=NUME_DDL(MATR_RIGI=remep1,);

ramc1p1=ASSE_MATRICE(MATR_ELEM=remep1,NUME_DDL=nup1,);

ragep1=ASSE_MATRICE(MATR_ELEM=regc11p1,NUME_DDL=nup1,);

ragc12p1=ASSE_MATRICE(MATR_ELEM=regc12p1,NUME_DDL=nup1,);

#addition
ramep1=COMB_MATR_ASSE(
    COMB_R=(
        _F(MATR_ASSE=ramc1p1,COEF_R=1.0,),
        _F(MATR_ASSE=ragc12p1,COEF_R=1.0,),
    ),
);
```

```
#here we set the mini and maxi value of the modes with STURM
#the calculation fails if there are no modes in this range
#it is then necessary to adjust
#sturm u45201
#then we calculate in the range
mini=-100;
maxi=100;

INFO_MODE(
    MATR_RIGI=ramep1,
    MATR_RIGI_GEOM=ragep1,
    TYPE_MODE='MODE_FLAMB',
    CHAR_CRIT=(mini, maxi,),
);

flamb=CALC_MODES(
    TYPE_RESU='MODE_FLAMB', #for buckling
    OPTION='BANDE',
    STOP_BANDE_VIDE='OUI',
    MATR_RIGI=ramep1,
    MATR_RIGI_GEOM=ragep1,
    CALC_CHAR_CRIT=_F(
        CHAR_CRIT=(-100,100,),
    ),
);

flamb=NORM_MODE(
    reuse=flamb,
    MODE=flamb,
    NORME='TRAN',
);
```

We may have to make several runs changing the values 'mini' for CHAR_CRIT_MIN and 'maxi' for CHAR_CRIT_MAX, until finding values, without forgetting some in the lower range, which really are the critical ones! It may be a better idea to use the alternative option with OPTION='PLUS_PETITE' and NMAX_CHAR_CRIT=12.

```
IMPR_RESU(
    FORMAT='MED',
    UNITE=80,
    RESU=_F(
        RESULTAT=flamb,
        NOM_CHAM='DEPL',
    ),
);

IMPR_RESU(
    MODELE=model,FORMAT='RESULTAT',
    RESU=_F(
        RESULTAT=flamb,
        #INFO_RESU='OUI',
        TOUT_PARA='OUI',
        FORM_TABL='OUI',
    ),
);

FIN();
```

16.3 Looking at results

This buckling analysis can be carried out for only one load case. For the results in ASCII format the quickest place where to look is the *.mess* file, after the summary of the flamb=CALC_MODES command we can find a table looking like that:

```
--------------------------------------------------------------------------


   LES CHARGES CRITIQUES CALCULEES INF. ET SUP. SONT:
      CHARGE_CRITIQUE_INF :  -8.58123E+01
      CHARGE_CRITIQUE_SUP :  -1.34914E+00



--------------------------------------------------------------------------
       CALCUL MODAL:  METHODE D'ITERATION SIMULTANEE
                      METHODE DE SORENSEN
      NUMERO      CHARGE CRITIQUE      NORME D'ERREUR
           1       -8.58123E+01         5.56318E-14
           2       -8.55143E+01         5.14016E-13
           3       -6.57550E+01         6.63348E-14
           4       -4.83596E+01         1.21279E-13
           5       -4.83040E+01         2.09636E-12
           6       -3.36203E+01         3.14336E-13
           7       -2.15401E+01         7.77622E-13
           8       -2.15350E+01         6.39568E-12
           9       -1.21277E+01         1.78573E-12
          10       -5.39407E+00         9.63044E-12
          11       -5.39399E+00         1.82194E-10
          12       -1.34914E+00         1.28157E-10
  NORME D'ERREUR MOYENNE:   0.27676E-10


------------------------------------------------------------------------


             VERIFICATION A POSTERIORI DES MODES

    DANS L'INTERVALLE (-8.62414E+01,-1.34240E+00)
    IL Y A BIEN    12 CHARGE(S) CRITIQUE(S)
------------------------------------------------------------------------
```

Note: the table must be read from the bottom up the most critical load being number 12 in the list, at -1.349, in agreement with the hand calculated value.

The `CHARGE CRITIQUE` is the opposite factor by which the load case has to be multiplied to obtain buckling.

As stated in U2.08.04 we have

$$\mu = -\lambda$$

with λ =Eigen value and μ =multiplying coefficient of the variable load.

- The value of -1.349 means than the structure buckles for 1.394 times the applied variable load, the structure may be considered as safe[1];
- A value of -0.5 would mean than the structure would buckle for half the applied variable load, the structure may be considered as ruined;
- A value of +0.5 would mean than the structure would buckle for half the reversed applied variable load, e.g. changed of sign. The

[1] The value of the safe coefficient is the engineer's, or code of practice choice.

structure may be considered as ruined if the load can change sign, for example a wind action, or safe if the load cannot change sign, for example the gravity;

- A value of 1.349 would mean than the structure would buckle for 1.394 times the reversed applied variable load[1].

Looking at the results with Gmsh we can see in figure 16.1[2]:

- with `NUMERO` 12, we have the lowest mode in the plane YOZ, the plane of lowest moment of inertia with one anti-node for a value of $P_{cr} = 1349N$, it is shown in the figure with the thicker line;
- with `NUMERO` 11, we have the next one in the plane XOZ, the plane of highest moment of inertia with one anti-node for a value of $P_{cr} = 5393.99N$, it is shown in the figure with the intermediate line thickness;
- and with `NUMERO` 10, we have the third one in the plane YOZ, the plane of lowest moment of inertia with two anti-nodes for a value of $P_{cr} = 5394.09N$, it is shown in the figure with the thinner line.

We can see that `NUMERO` 11 and 10 having the same `CHARGE_CRITIQUE` of 5.394 are quite different: 1 antinode, in XOZ plane for `NUMERO` 11; and 2 antinodes, in YOZ plane for `NUMERO` 10. This is exactly what could be expected with 1/2 ratio rectangular section!

[1] We would get this result if we applied `FZ=1000`, a traction load, in `AFFE_CHAR_MECA`.
[2] How to superimpose views is explained in chapter 11.3 .

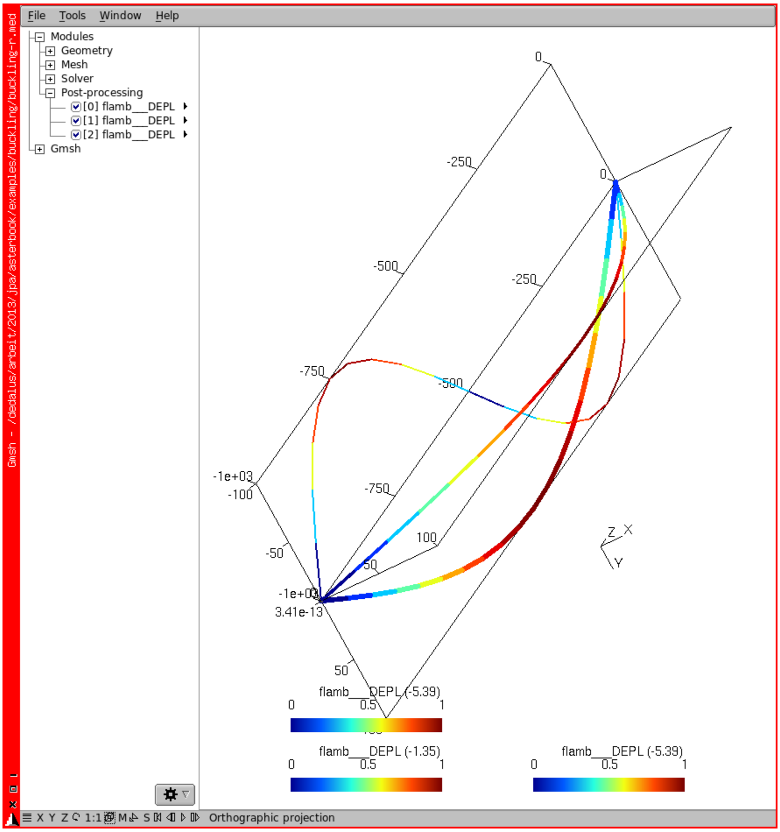


FIGURE 16.1: Three critical loads

16.4 Buckling analysis with plates and beams, or rods

16.4.1 With the actual version

Withe the current version of **code_aster** this kind of analysis does not offer any problem and one can use DKT on a linear mesh for the plate elements.

Howver a model with rod, BARRE, elements has to be modified to analyzed in buckling:

- each rod must be replaced by a fair number of beam elements to allow for the buckling mode shape;
- these beam elements must be given a mechanical properties in agreement with the element section;
- one K_TR_D_L element, with relaxed rotational DOF, must be provided at each end of the rod.

16.4.2 With earlier versions

The analysis given below is no longer required as since version 12.0.12 **code_aster** can handle buckling with DKT elements.

We keep it however as is to describe the way of using COQUE_3D.

Note: for a buckling analysis with plates, like the example *frame3*, elements DKT must be replaced by COQUE_3D not to raise an error.

This can be done in several steps:

1. In Gmsh, we do the meshing in the normal manner then Mesh › Set order › 2.
2. First, in the command file:

```
DEBUT();

meshini=LIRE_MAILLAGE(UNITE=20,FORMAT='MED',);

mesh1=CREA_MAILLAGE(
    MAILLAGE=meshini,
    MODI_MAILLE=_F(
        GROUP_MA=('panelN','panelS',),
        OPTION='TRIA6_7',
        #next line may have to be used
        #PREF_NOEUD='NS',
    ),
);
```

to transform the TRIA6 element into TRIA7[1].

3. Second, in the command file:

```
  mesh=CREA_MAILLAGE(
      MAILLAGE=mesh1,
      QUAD_LINE=_F(
          GROUP_MA=('topbeam','vertb','mast','hinge'),
          #next line may have to be used
          #PREF_NOEUD='m',
      ),
  );
```

   to transform the SEG3 line element back into SEG2 so as to support beam elements, and hinge elements.

4. And finally, in the command file:

```
  model=AFFE_MODELE(
      MAILLAGE=mesh,
      AFFE=(
           ..............
          _F(
              GROUP_MA=('panel',),
              PHENOMENE='MECANIQUE',MODELISATION='COQUE_3D',
          ),
       ..............
  );
```

   to apply MODELISATION='COQUE_3D' to the shell elements.

All this because second order is set to the whole mesh in Gmsh and a modal or buckling analysis in **code_aster** requires COQUE_3D for plates.

We should note also the cascading naming of meshes from the initial meshini to the intermediate mesh1 and to the final mesh. Also the use of PREF_NOEUD may be required, it can take any argument, for its use reading U4.23.02 is required.

Finally, as some post processing viewer seem to be in trouble when displaying quadratic mesh, it is a wise idea to project the med results on a linear mesh, just as we did in 13.1.1 .

[1] Triangle with 6 nodes, to triangle with seven nodes, the seventh one in the center, or QUAD8_9 for quadrangular elements.

16.5 Some remarks about buckling

In true life a structure should not survive the application of the first global critical load. The reason for seeking more values is to detect some local buckling which could endanger the structure well before the first global one.

Just as with modal analysis, if a model with plates is showing symmetry or cyclic symmetry there may be several modes with almost the same buckling loads, for example an hexahedral section tube submitted to a compression end load shows 6 local modes with exactly the same shape repeating on each of the six faces.

An Eulerian buckling analysis in a structure holding beam elements is a rather simple assumption of its behavior[1]. At least too simple for most construction codes calling for more sophisticated check-up needing in turn an extensive use of Python: to extract the desired values and build up some results with the required formulas[2].

code_aster allows also to make non linear buckling analysis which comes particularly useful for space frames, this is described in the test case *ssnl135*.

[1] As it does not take into account: flexural-torsional buckling, web buckling, local flange buckling and a few other oddities.

[2] It may sometimes be easier to justify by hand, with a spreadsheet, the few “dangerous” members.

CHAPTER 17

Pre-processing topics

In this chapter, we introduce some pre-processing topics:

- what are the various beam elements available in **code_aster** ;
- how a call to `MACR_CARA_POUTRE` can calculate the properties of a beam section if we provide a mesh;
- how to make and use a user defined library of beam section;
- what are the various plate and shell elements available in **code_aster** ;
- why, or why not, using a quadratic mesh;
- how to create groups from scratch on a mesh.

17.1 Various type of beams, from Euler-Bernoulli to, multifiber....

code_aster provides various types of elements for beam, it is wise to use the type best suited to a given problem.

In the naming the first three characters POU stand for 'poutre', beam in french. The fifth character determines the support. D stands for 'droite', lying along a straight line, C stands for 'courbe', lying along a circular arc.

POU_D_E is a beam in agreement with Euler-Bernoulli hypothesis, the action of the shear forces on the rotation of cross sections are neglected.

POU_D_T is a beam in agreement with Timoshenko hypothesis, the action of the shear forces may change the cross-section orientation, this is the general type for most cases.

POU_D_TG is the same as POU_D_T. In addition the warping of the section is taken into account, this can be useful in non-linear calculation when an important warping is expected. This is described in U3.11.04. However, if the warping influence is taken into account, i.e. the deformed shape of the structure is correct and the SIEF_* are properly calculated, the calculated SIPO and SIPO do not take into account the warping restrain influence[1]. This has to be hand calculated from the DEPL...GRX and SIPO_ELNO...BX components, more information in R3.08.04 and [Roark], precisely in TABLE 21 & 22.

POU_D_T_GD is a beam element based on Timoshenko theory able to model large displacements and rotations in linear elasticity.

Finally the last character M, in the name of the elements (e.g. POU_D_EM) stands for a Multifiber beam section which is quite complicated an affair, outside the scope of this book, some details can be found in R3.08.08.

For all these types of elements, we have to feed **code_aster** with a large set of properties for the beam section. The built-in presets are limited to circular and rectangular sections, hollowed or not. We have to calculate these properties for any other type of section.

- The first way is to hard code these values in the *.comm* file with SECTION='GENERALE', the values being calculated beforehand with the formulas available in numerous text books[2].

[1] There is just simply not enough information in AFFE_CARA_ELEM to do that!

[2] Not all of them provide the formula to calculate, for example the warping constant of an unusual section, as far as I am concerned I have a few spreadsheets for this task, derived from [Roark].

- Another way is to have the **code_aster** macro command MACR_CARA_POUTRE calculate these properties from a given mesh of the section, this is explained in the next section.

17.2 Using MACR_CARA_POUTRE to calculate section properties

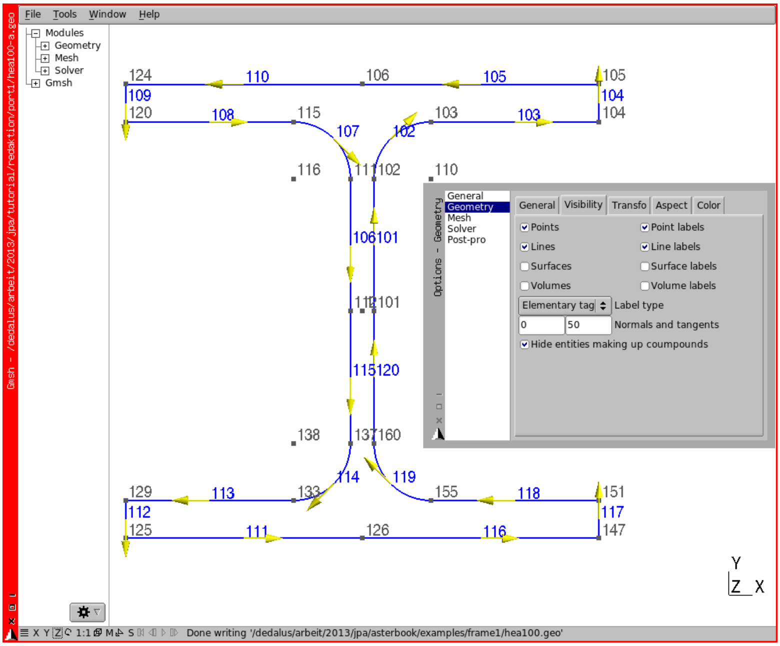
The macro command MACR_CARA_POUTRE[1] allows to calculate within **code_aster** the geometrical and mechanical properties of any section for which a mesh is provided. However this requires some care.

Here is the example of a parametric Gmsh script providing a mesh for any H section.

```
d1 = 3; //element size
h = 96; //overall height
b = 100; //overall width
tw = 5; //web thickness
tf = 8; //flange thickness
r = 12; //web to flange radius

Point(1) = { 0, 0, 0., d1};
Point(101) = {tw/2, 0, 0., d1};
Point(102) = { tw/2, h/2-tf-r, 0., d1};
Point(103) = { tw/2+r, h/2-tf, 0., d1};
Point(110) = { tw/2+r, h/2-tf-r, 0., d1};
Point(104) = { b/2, h/2-tf, 0., d1};
Point(105) = { b/2, h/2, 0., d1};
Point(106) = { 0, h/2, 0., d1};

Line (101) = {101, 102};
Circle(102) = {102, 110, 103};
Line (103) = {103, 104};
Line (104) = {104, 105};
Line (105) = {105, 106};
Symmetry {-1, 0, 0, 0} {
    Duplicata { Line{-101, -102, -103, -104, -105}; }
}
Symmetry {0, -1, 0, 0} {
    Duplicata { Line{
        -110, -109, -108, -107, -106, -105,
        -104, -103, -102, -101};
    }
}
Curve Loop(121) = {
    101, 102, 103, 104, 105, 110, 109, 108, 107, 106,
```

[1] In U4.42.02.

```
    115, 114, 113, 112, 111, 116, 117, 118, 119, 120
};
Plane Surface(122) = {121};

Physical Line("myborder") = {101:120};
//here there should be some close lines bordering
//the inside for an hollow section
//Physical Line("int") = {};
Physical Surface("mysect") = {122};
Physical Point("noderef") = {1};
```



☑ Points ☑ Point labels
☑ Lines ☑ Line labels
☐ Surfaces ☐ Surface labels
☐ Volumes ☐ Volume labels
Elementary tag Label type
0 50 Normals and tangents
☑ Hide entities making up coumpounds

Done writing '/dedalus/arbeit/2013/jpa/asterbook/examples/frame1/hea100.geo'

FIGURE 17.1: Orientation of line elements in yellow

- There should be one group of lines following the outside of the contour, here 'myborder', this contour should be closed and all the lines part of it should be in the same direction: if one walks along the border, one is walking on lines always in the same direction shown by the yellow arrows in figure 17.1. There is a more detailed explanation about how to achieve this in appendix B 2.3 . This group name 'myborder' is at the user's choice, and has to be used again in the *.comm* file.

- Likewise there should be one[1] group of lines following the border of the hollow for an hollowed section.
- There should be a Physical holding one single Point to enable the calculation of shear coefficients, here it is named 'noderef'.
- It is not mandatory to name the surface group.

Once properly meshed and exported in a *.med* file the following bit of code allows to compute and print the section properties.

```
#PAR_LOT='NON' if we use the Python bits
DEBUT(PAR_LOT='NON' ,);
......................
mhea100=LIRE_MAILLAGE(
    UNITE=21,
    FORMAT='MED' ,
    #NOM_MED='hea100',
    #INFO_MED=2,
    #INFO=2,
);

#next command creates the node on 'no'
mhea100=DEFI_GROUP(
    reuse =mhea100,MAILLAGE=mhea100,
    CREA_GROUP_NO=(_F(GROUP_MA='noderef' ,),),
);

#prefix s stands for section
shea100=MACR_CARA_POUTRE(
    MAILLAGE=mhea100,
    GROUP_MA_BORD='MYBORDER' ,
    #GROUP_MA_INTE='int', #if there is an hollow
    GROUP_NO='noderef' ,
    INFO=2,
    ORIG_INER=(0.0 ,0.0),
    TABLE_CARA='OUI' ,
    NOM='hea100' ,
    # 'hea100' is at the user's choice
);

#this prints out the table
IMPR_TABLE(
    TABLE=shea100,
    FORMAT='TABLEAU' ,
```

[1] Or several, for multiple hollows sections.

```
    UNITE=8,
    SEPARATEUR=' * ',
    TITRE='hea100',
    INFO=2,
);

#next section is not mandatory
#and just to look at what we have done
#we extract some values in Python variables
lieu=shea100['LIEU',1]
a=shea100['AIRE_M',1]
#..................
#and print them in a separate file
file=open('our_fullpath_file_name.txt','w')
file.write ('hea100 section properties \n')
file.write ('LIEU   = %s \n' % lieu)
file.write ('AIRE_M   = %s \n' % a)
#..................
file.close()
#we could then build up the AFFE_CARA_ELEM arguments
```

```
#here we extract some values in Python variables
lieu=shea100['LIEU',1] #lieu has to be extracted!
....................
elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    #next line to print the values used for the
    #section properties
    INFO=2,
    POUTRE=(
        ..................
        _F(
            GROUP_MA=('topbeam',),SECTION='GENERALE',
            TABLE_CARA=shea100,
            #next line with the section name defined above
            NOM_SEC='hea100',
        ),
        ................
    ),
..............
);
```

And the properties of the section 'shea100' are used in the calculation.

In real life problems we may have many sections calculated this way as long as they have different NOM_SEC.

17.3 Using beams sections from a library of sections

17.3.1 Defining the library

We begin by defining the beam library at the beginning of the *.comm* file, under the form of a Python dict.

```
sections={
  'ROD10':(10.0/2.0,),
  'RHS35x35x1.5':(35,35,1.5,1.5,),
  'RHS50x50x5':(50,50,5,5,),
  'REC100x150':(100,150,),
  'RHS40x20x1.5':(40,20,1.5,1.5,),
  'GENE001':(171, 11518, 34908, 1.5, 1.5, 0, 0, 26700, 20, 10, 12,),
  'RHS20x20x1.5':(20,20,1.5,1.5,),
};
```

On each line the first entry, like `'ROD10':` defines the **key** of the dict that will be parsed later on, it is a quoted string of any length, followed by a colon.

The second entry defines the **value** to be used in `AFFE_CARA_ELEM`, it takes the form of a list (inside braces) of number whose number depends on the section type.

Here :

- `'ROD*'` will parse the values as for a ROunD solid section like a rod;
- `'RHS*'` will parse the values as for a Rectangular Hollow Section;
- `'REC*'` will parse the values as for a RECtangular solid section;
- `'GENE*'` will parse the values as for a `GENERALE` section.

This can adapted to the needs, and each **key** should be unique within a given dict.

This dict can contain more sections than will be used later one.

17.3.2 Defining a table of assignment

Then we build a table assigning some groups to the section properties.

```
sect2group=(
    'RHS40x20x1.5',('mast',),
    'GENE001','topbeam',
    'RHS20x20x1.5','vertb',
);
```

Or alternatively

```
sect2group=(
    'RHS40x20x1.5',('mast','topbeam',),
    'RHS20x20x1.5','vertb',
);
```

On each line :

- the first entry is a beam section that must exist in the library;
- the second entry is the name of the group to which this section will be assigned;
- this second entry can a list of several groups, then inside brackets.

Commented lines are not allowed within a list like this.

17.3.3 Assigning the values

First we prepare some lists with the group names and the applied sections.

```
nb=len(sect2group);
grpname=[None]*(nb/2);
grpsect=[None]*(nb/2);
for i in range(0,nb,2):
    grpsect[i/2]=sect2group[i]
for i in range(1,nb,2):
    grpname[i/2]=sect2group[i]
```

Second we create the argument for `POUTRE` key word

```
sect=[];
beamtypes=sections.keys();
nbt=len(beamtypes);
nbgrp=len(grpname);
for j in range(nbgrp):
    bsect=grpsect[j];
    bgroup=grpname[j];
    for i in range(nbt):
        if bsect==sections.keys()[i]:
            if 'ROD' in beamtypes[i]:
                sect.append(
                    _F(
                        GROUP_MA=bgroup,
                        SECTION = 'CERCLE',
                        CARA = ('R',),
                        VALE = sections.values()[i],
                    ),
                );
            elif 'REC' in beamtypes[i]:
                sect.append(
                    _F(
                        GROUP_MA=bgroup,
                        SECTION = 'RECTANGLE',
                        CARA = ('HY','HZ',),
                        VALE = sections.values()[i],
                    ),
                );
            elif 'RHS' in beamtypes[i] :
                sect.append(
                    _F(
                        GROUP_MA=bgroup,
                        SECTION = 'RECTANGLE',
                        CARA=('HY','HZ','EPY','EPZ',),
                        VALE = sections.values()[i],
                    ),
                );
            elif 'GENE' in beamtypes[i] :
                sect.append(
                    _F(
                        GROUP_MA=bgroup,
                        SECTION = 'GENERALE',
                        CARA=(
                            'A','IY','IZ','AY','AZ','EY','EZ',
                            'JX','RY','RZ','RT',
                        ),
                        VALE = sections.values()[i],
                    ),
                );
```

Note that some blocks of code like the ones for the ROD or REC are not strictly necessary and not used here!

Third we use this argument in AFFE_CARA_ELEM.

```
elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    POUTRE=tuple(sect),
    ..................
```

The preceding code abstract could be used in *frame3* example.

17.3.4 Using a library from disk

Here we use the **json** module of Python.

From a module that could be a Python script completely independent of the *.comm* file we create a json file.

```
sections={
  'ROD10':(10.0/2.0,),
  'RHS35x35x1.5':(35,35,1.5,1.5,),
  'RHS50x50x5':(50,50,5,5,),
  'REC100x150':(100,150,),
  'RHS40x20x1.5':(40,20,1.5,1.5,),
  'GENE001':(171, 11518, 34908, 1.5, 1.5, 0, 0, 26700, 20, 10, 12,),
  'RHS20x20x1.5':(20,20,1.5,1.5,),
};

import json
with open('libfile.json', 'w') as f:
  json.dump(sections, f)
```

Where *libfile.json* is any full path file name we like [1], this file named could be *'fort.49'* if the specified path is described in ASTK with LU 49.

With a careful look at this example file it is quite easy to create the dict from any word processor or spread sheet and export it as *.csv*.

Reading a library previously saved on disk is as simple as:

```
import json
with open('libfile.json', 'w') as f:
    sections=json.load(f)
```

And this is just only one of the many ways to create and use such a library using Python, neither too verbose nor too abstruse!

17.4 Various types of plates and shells....

Just like the beam elements, plates and shells come in various flavors. It is useful to know the basics about their differences, more details may be found in U2.02.01.

These elements exist either as triangles or quadrangles as we have seen in the *frame3* example. Middle nodes may be created by **code_aster** using commands like `MODI_MAILLAGE / MODI_MAILLE` ...`OPTION='TRIA6_7'`.

[1] As usual with Unix file the extension is not mandatory at all.

17.4.1 Plates

A plate element, “plaque” in french, lies in a plane, there is no curvature in the element, which means that the 4 nodes of a quadrangular element **must** lie in a plane[1]. The plate elements come in various flavors:

- `DKT`[2] , which we use in this book, does not support transverse shear;
- `DST`[3], does support transverse shear;
- `Q4G` also supports transverse shear, but usually requires a more refined mesh than `DKT`, see U2.02.01.

17.4.2 Shells

Unlike plates, shells, “coque” in french, admit a curvature, and have a middle node along the edges. Only them used to be supported for a buckling analysis in *Code _Aster*.

The element here is `COQUE_3D`[4].

17.5 Using quadratic mesh or not

Except when it is a mandatory requirement, as it used to be the case in a buckling analysis for plates, as explained in chapter 16.4 [5], the question arises whether or not to use a quadratic mesh. But first of all what is a quadratic mesh ?

Taking the examples of a 3 node triangular shell element its quadratic extension is a 6 node element where the nodes situated at the middle of the edges sit on the geometrical curve joining the corner nodes.

[1] If this is not the case **code_aster** emits a warning in the .mess file, telling how much the element is distorted and leaving to the engineer the choice of altering the mesh or not.

[2] Strictly speaking a `DKT`, is a triangle, `DKQ` being a quadrangle, but the call of `DKT` is enough in a command file.

[3] Strictly speaking a `DST`, is a triangle, `DSQ` being a quadrangle, but the call of `DST` is enough in a command file.

[4] Elements `COQUE_C_PLAN`, `COQUE_D_PLAN` and `COQUE_AXIS` are outside the scope of this book.

[5] Where we ask **code_aster** to create an extra node at the barycenter of the element.

Now let's take the example of a ring, 100 in diameter, 50 in depth. Figure 17.2 shows the parent geometry and a rather crude linear mesh with 8 faces around the circumference.

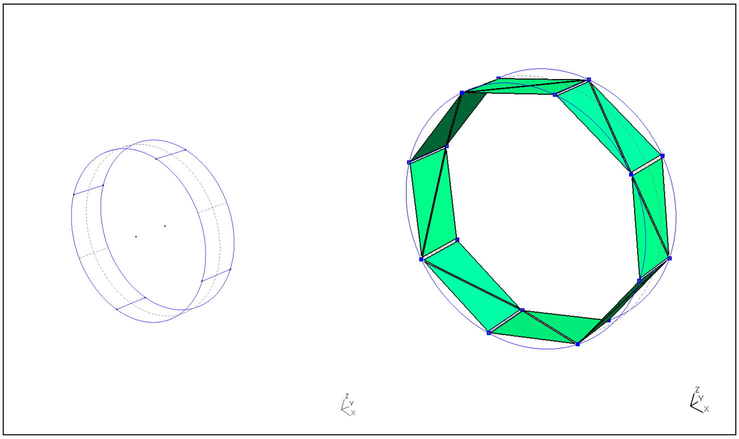


FIGURE 17.2: Parent geometry and 8 faces linear mesh

Figure 17.3 shows the same 8 faces mesh but interpolated, by the mesher, in quadratic and a linear mesh produced when dividing the characteristic length by two (50 instead of 100). The curvature of the ring is better reproduced in both cases.

Figure 17.4 shows the original 8 faces linear mesh and how it is transformed in a quadratic mesh by a simple `CREA_MAILLAGE ... LINE_QUAD` command, the curvature is no better represented[1].

It comes obvious that the `CREA_MAILLAGE ... LINE_QUAD` **code_aster** command cannot produce such as good a quadratic mesh as a mesher, or a higher node density linear mesh, for the simple reason that it does know nothing about the geometrical curvature at the refinement time[2].

However the value of this statement is less and less meaningful if if the original mesh is already quite dense. It also applies less to 3D meshes.

[1] In the pictures the corner nodes, created in the linear command, are depicted in blue, while the intermediate nodes, created either in Gmsh or in **code_aster** show in pink, and the mesh 'Element shrinking factor' is set to 0.95.

[2] The mesh file does not hold any such information!

The calculated results may improve dramatically with a better meshed geometry, from the mesher, versus a command line transformed mesh. Let's think of the behavior of the previous meshes under internal pressure, or buckling under external pressure!

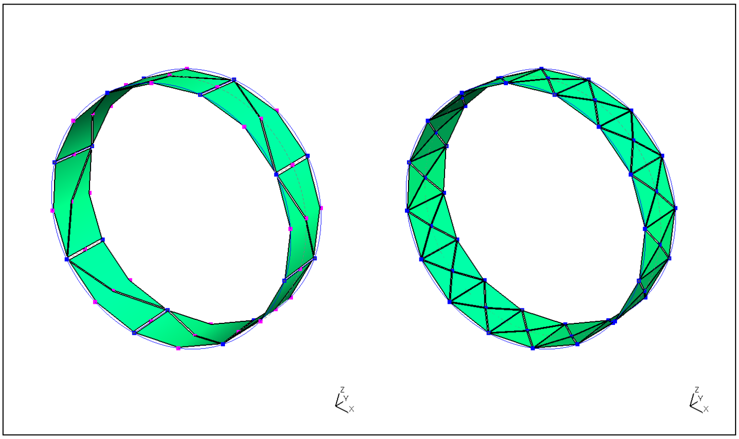


FIGURE 17.3: 8 faces quadratic mesh and 16 faces linear mesh

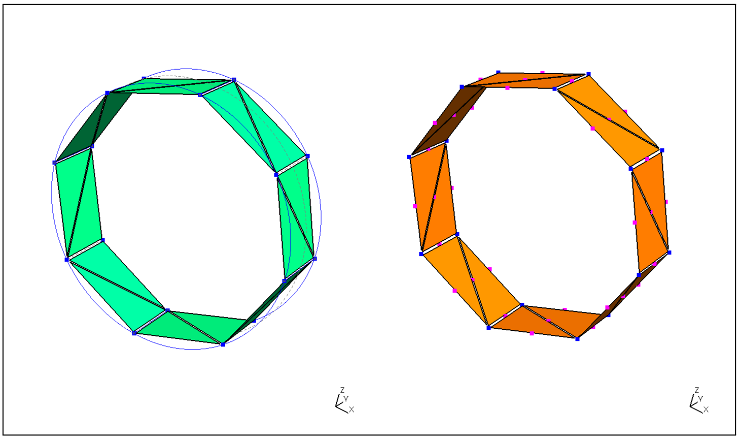


FIGURE 17.4: 8 faces linear mesh and the same transformed by **code_aster**

17.6 Creating groups from scratch

It is possible to create groups in a mesh which does not contain any with the CREA_GROUP command. This is fully documented in U4.22.01.

The following excerpt, inserted in the *.comm*, file creates two of the required groups in the 'part2' mesh of the 3D spring.

```
part2=DEFI_GROUP(
    reuse =part2,
    MAILLAGE=part2,
    CREA_GROUP_MA=(
        #group for fixation
        _F(
            NOM='fx2s',
            TYPE_MAILLE='2D',
            OPTION='BANDE',
            POINT=(-68,-5.5,105,),
            VECT_NORMALE=(1,0,0,),
            DIST=0.5,
        ),
        _F(
            NOM='hole2s-1',
            TYPE_MAILLE='2D',
            OPTION='CYLINDRE',
            POINT=(0,0,0,),
            VECT_NORMALE=(0,1,0,),
            RAYON=10.6,
        ),
        _F(
            NOM='hole2s-2',
            TYPE_MAILLE='2D',
            OPTION='FACE_NORMALE',
            VECT_NORMALE=(0,1,0,),
            VERI_SIGNE='NON',
        ),
        _F(
            NOM='hole2s',
            TYPE_MAILLE='2D',
            DIFFE=('hole2s-1','hole2s-2',),
        ),
    ),
);
```

The first instance creates a group with all the 2D elements:

- lying in a plane, `OPTION='BANDE'`;
- this plane passing through the point situated at one of the corner of 'part2', `POINT=(-68,-5.5,105,)`;

- this plane is normal to the vector `VECT_NORMALE=(1,0,0,);`
- the group retains all the elements at a distance less than 0.5 of the plane, `DIST=0.5`.

The second instance creates a group, 'hole2s-1', of the element lying in a cylinder, as described.

The third creates a group, 'hole2s-2', with all the elements lying in the XOZ plane.

The last one, a boolean difference between the two previous, creates the group 'hole2s' as required.

These powerful tools allow to use a mesh without any predefined groups. This may be an efficient way to proceed with mesh built from CAD drawings, *.iges*, *.step* even *.stl* format.

And more than ever the next line helps to view the groups on the screen and check that everything is as expected.

```
IMPR_RESU(FORMAT='MED', UNITE=71,  RESU=_F(MAILLAGE=part2,),);
```

CHAPTER 18

Gathering more information before processing

In this chapter, we explain how to gather some information from a study without actually solving the problem:

- how to color a mesh according to various properties;
- how to display vectors along the element's local axis;
- how to display the applied load;
- how to calculate length or area of elements, with Python.

18.1 Coloring mesh and model according to properties

We have seen how to color the mesh by groups in Gmsh, however this feature is limited only to the mesh. When a model is made from this mesh in **code_aster** there is many more valuable information we would like to view, like for example material, plate thickness, beam properties, etc. The following lines of code, within the *.comm* file of our *frame3* example, creates a med file in which some concepts are given a color.

```
IMPR_RESU(
    FORMAT='MED',UNITE=82,
    CONCEPT=(
        _F(CHAM_MATER = material,),
        _F(CARA_ELEM= elemcar,REPERE_LOCAL='ELEM', MODELE=model,),
        _F(CHARGE= ground),
        _F(CHARGE= selfwght),
        _F(CHARGE= cc,),
        _F(CHARGE= cv,),
    ),
);
```

If we open the *.med* file we can find a field 'selfwgt#CHME.PESAN'[1] whose details can be seen in figure 18.1:

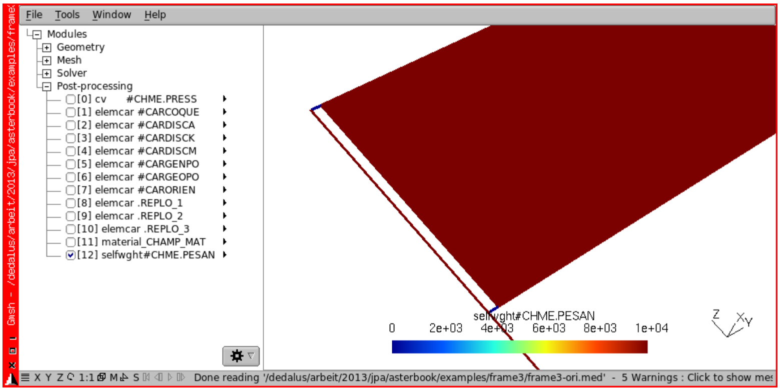
- almost everything is colored in dark red, with a numeric value of 10000, which is the value we specified for gravity acceleration;
- only the tiny discrete elements joining the top structure to the vertical masts are colored in blue, with a numeric value of O, and thus not subject to gravity;

which is exactly what is expected from the load specification in the command file.

The same can be done with concept 'elemcar#CARCOQUE' to display the different thickness like in figure 18.2.

Note: we specified a Logical Unit 82 to save the .med file file used to display the results. This file must be specified in the ASTK setup. Also this `IMPR_RESU` may be done without any call to a solver which allows to ensure the properties are what we expect without launching any lengthy solver step.

[1] Where: selfwgt is the name we gave to the `AFFE_CHAR_MECA`, CHME stands for CHarge-Meca and PESAN is a short cut of PESANteur, the type of load.



Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3-ori.med' - 5 Warnings : Click to show mes

FIGURE 18.1: Coloring concept for gravity load

18.2 Showing element orientation

In addition the line:

```
  _F(CARA_ELEM= elemcar,REPERE_LOCAL='OUI', MODELE=model,),
```

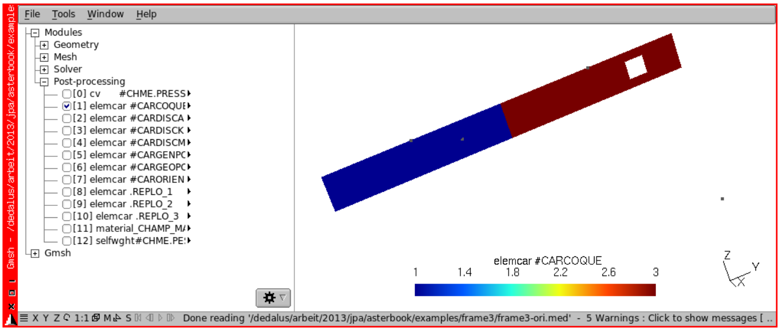
allows to display the local axis of the elements.

Figure 18.3 shows what it looks like for:

- local y axis, view[9] elemcar.REPLO_2, as a green arrow;
- line elements drawn in black;
- nodes drawn in dark blue.

This view shows also some of the Gmsh settings, in the dialog boxes, used to obtain it.

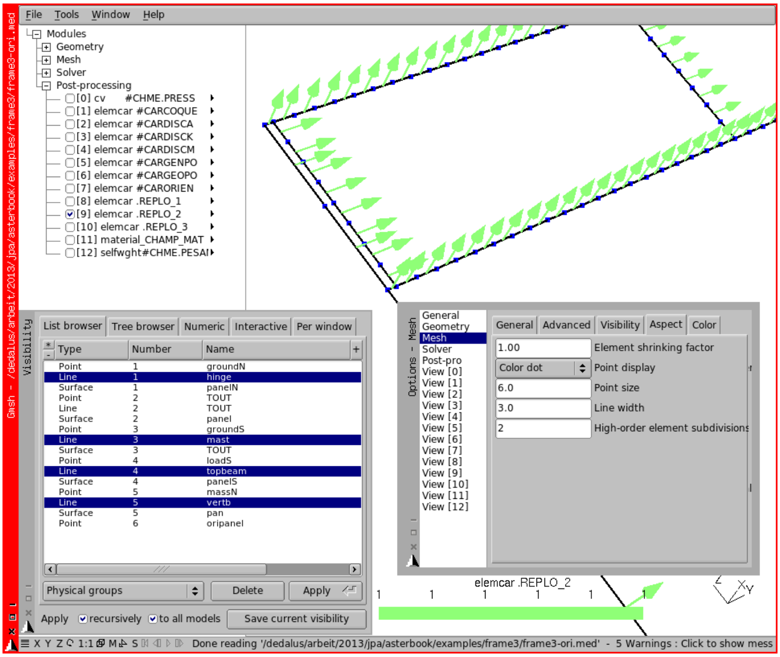
With a bit more tweaking we can get the picture just like 18.4 with the CAD coloring, x local axis in red, y in green and z in blue.



```
Modules
  Geometry
  Mesh
  Solver
  Post-processing
    [0] cv      #CHME.PRESS
    [1] elemcar #CARCOQUE
    [2] elemcar #CARDISCA
    [3] elemcar #CARDISCK
    [4] elemcar #CARDISCM
    [5] elemcar #CARGENPC
    [6] elemcar #CARGEOPC
    [7] elemcar #CARORIEN
    [8] elemcar .REPLO_1
    [9] elemcar .REPLO_2
    [10] elemcar .REPLO_3
    [11] material_CHAMP_MA
    [12] selfwght#CHME.PE
Gmsh
```

```
Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3-ori.med' - 5 Warnings : Click to show messages [ ..
```

FIGURE 18.2: Coloring concept for plate thickness



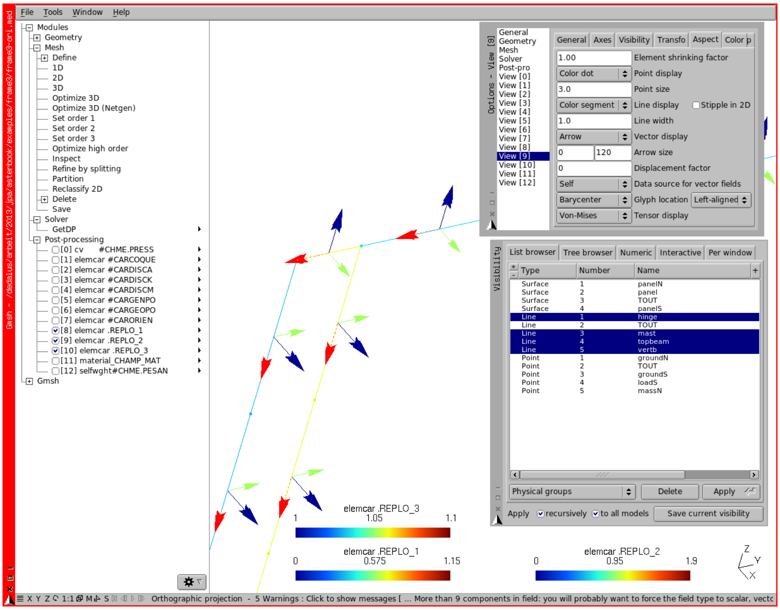
```
Modules
  Geometry
  Mesh
  Solver
  Post-processing
    [0] cv      #CHME.PRESS
    [1] elemcar #CARCOQUE
    [2] elemcar #CARDISCA
    [3] elemcar #CARDISCK
    [4] elemcar #CARDISCM
    [5] elemcar #CARGENPO
    [6] elemcar #CARGEOPO
    [7] elemcar #CARORIEN
    [8] elemcar .REPLO_1
    [9] elemcar .REPLO_2
    [10] elemcar .REPLO_3
    [11] material_CHAMP_MAT
    [12] selfwght#CHME.PESAI
```

Type	Number	Name
Point	1	groundN
Line	1	hinge
Surface	1	panelN
Point	2	TOUT
Line	2	TOUT
Surface	2	panel
Point	3	groundS
Line	3	mast
Surface	3	TOUT
Point	4	loadS
Line	4	topbeam
Surface	4	panelS
Point	5	massN
Line	5	vertb
Surface	5	pan
Point	6	oripanel

1.00	Element shrinking factor
Color dot	Point display
6.0	Point size
3.0	Line width
2	High-order element subdivisions

```
Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3-ori.med' - 5 Warnings : Click to show mess
```

FIGURE 18.3: Local y axis of beams and discret element



Gmsh - /dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3-ori.med

- Modules
  - Geometry
  - Mesh
    - Define
    - 1D
    - 2D
    - 3D
    - Optimize 3D
    - Optimize 3D (Netgen)
    - Set order 1
    - Set order 2
    - Set order 3
    - Optimize high order
    - Inspect
    - Refine by splitting
    - Partition
    - Reclassify 2D
    - Delete
    - Save
  - Solver
    - GetDP
  - Post-processing
    - ☐ [0] cv #CHME.PRESS
    - ☐ [1] elemcar #CARCOQUE
    - ☐ [2] elemcar #CARDISCA
    - ☐ [3] elemcar #CARDISCK
    - ☐ [4] elemcar #CARDISCM
    - ☐ [5] elemcar #CARGENPO
    - ☐ [6] elemcar #CARGEOPO
    - ☐ [7] elemcar #CARORIEN
    - ☑ [8] elemcar .REPLO_1
    - ☑ [9] elemcar .REPLO_2
    - ☑ [10] elemcar .REPLO_3
    - ☐ [11] material_CHAMP_MAT
    - ☐ [12] selfwght#CHME.PESAN
- Gmsh

General, Geometry, Mesh, Solver, Post-pro, View [0], View [1], View [2], View [3], View [4], View [5], View [6], View [7], View [8], View [9], View [10], View [11], View [12]

1.00	Element shrinking factor
Color dot	Point display
3.0	Point size
Color segment	Line display ☐ Stipple in 2D
1.0	Line width
Arrow	Vector display
0 120	Arrow size
0	Displacement factor
Self	Data source for vector fields
Barycenter	Glyph location Left-aligned
Von-Mises	Tensor display

Type	Number	Name
Surface	1	panelN
Surface	2	panel
Surface	3	TOUT
Surface	4	panelS
Line	1	hinge
Line	2	TOUT
Line	3	mast
Line	4	topbeam
Line	5	vertb
Point	1	groundN
Point	2	TOUT
Point	3	groundS
Point	4	loadS
Point	5	massN

Physical groups

Apply ☑ recursively ☑ to all models

Orthographic projection - 5 Warnings : Click to show messages [... More than 9 components in field: you will probably want to force the field type to scalar, vectc

FIGURE 18.4: Local coordinate system of beams and discrete elements

18.3 Showing the applied load

Another way to display the applied load on a model, for a given load case is to run a static calculation under this load case with ALL the nodes of the model fixed in all three directions[1] and to compute and display the reactions, which in this case are exactly the opposite of the applied loads to every node[2]. The following code segment does it for our example *frame3*:

Firstly setting the load multiplier for this particular solving with the prefix “f”. Note the minus one multiplier.

```
#code for printing a vector print out
#of applied forces
#fix all nodes
fixall=AFFE_CHAR_MECA(
    MODELE=model,
    DDL_IMPO=_F(GROUP_NO=('TOUT',),DX=0,DY=0,DZ=0,),
);
#multiplier value is -1 for each load case
fsw_m=DEFI_FONCTION(
    NOM_PARA='INST',VALE=(0,-1, 1,0,),
    PROL_DROITE='CONSTANT',
);
fcc_m=DEFI_FONCTION(
    NOM_PARA='INST',VALE=(0,0, 1,-1, 2,0),
);
fcv_m=DEFI_FONCTION(
    NOM_PARA='INST',VALE=(0,0, 1,0, 2,-1,),
);

listf=DEFI_LIST_REEL(
    DEBUT=0.0,INTERVALLE=_F(JUSQU_A=2,PAS=1.0,),
);
```

Secondly make the static analysis with all the individual load cases, and calculate the reactions.

```
#solving for the individual loads
force=MECA_STATIQUE(
    MODELE=model,CHAM_MATER=material,CARA_ELEM=elemcar,
    EXCIT=(
        _F(CHARGE=fixall,),
        _F(
            CHARGE=selfwght,
```

[1] In some case it may be necessary to fix some rotations as well.
[2] In this case a distributed load is shared between the nodes of the elements.

```
                TYPE_CHARGE='FIXE',FONC_MULT=fsw_m,
            ),
            _F(CHARGE=cc,TYPE_CHARGE='FIXE',FONC_MULT=fcc_m,),
            _F(CHARGE=cv,TYPE_CHARGE='FIXE',FONC_MULT=fcv_m,),
        ),
        LIST_INST=listf,
    );

    force=CALC_CHAMP(
        reuse =force,
        RESULTAT=force,
        CONTRAINTE='SIEF_ELNO',
        FORCE=('REAC_NODA'),
    );
```

Thirdly computes the sum of the reactions of each individual load case an print the tables in the *.resu* file.

```
s_reac=POST_RELEVE_T(
    ACTION=_F(
        INTITULE='sum forces',
        TOUT_ORDRE='OUI',
        GROUP_NO=('TOUT'),
        RESULTAT=force,
        NOM_CHAM='REAC_NODA',
        RESULTANTE=('DX','DY','DZ'),
        OPERATION='EXTRACTION',
    ),
);

IMPR_TABLE (TABLE=s_reac,)
```

Fourthly make a *.med* file.

```
IMPR_RESU(
    FORMAT='MED', UNITE=82,
    RESU=(
        _F(
            GROUP_MA=('TOUT',),
            RESULTAT=force,
            NOM_CHAM='DEPL',
        ),
        _F(
            GROUP_NO=('TOUT',),
            RESULTAT=force,
            NOM_CHAM='REAC_NODA',
            NOM_CHAM_MED='applied force',
        ),
    ),
);
#end of load printout
```

We apply all the individual load cases, actually changed of sign, to view a reaction in the same direction as the force, and in the same time, print out in the *.resu* file the sum of these individual load cases. `NOM_CHAM_MED='applied force'` is used to rename the field in the med file[1].

Opening the file in Gmsh, choosing the dialog box **Options** with:

- 'applied force' as selected, with View[0];
- then in the tab Visibility, Force Vector in the left-hand lower pull down list;
- then in the General tab pull the list Range mode to Custom;
- and push the Min and Max buttons to refresh the display with the proper component values;
- then in the Aspect tab, 3D arrow in the Vector display pull down list;
- and Vertex in the Glyph location one[2].

gives the following view with Lines ticked in the Mesh tab so as to see the background mesh. Which is shown the figure 18.5 for the distributed wind load on the 'panel' group[3].

[1] This method cannot give a print out of externally applied moments, nor can it give a print of `AFFE_CHAR_CINE`.

[2] Choosing Barycenter displays the sum of the distributed load on every element, at the barycenter of the element, instead of the nodal reactions at end nodes.

[3] For such a surface, load the length of the arrow is proportional to the element area, yet not constant!

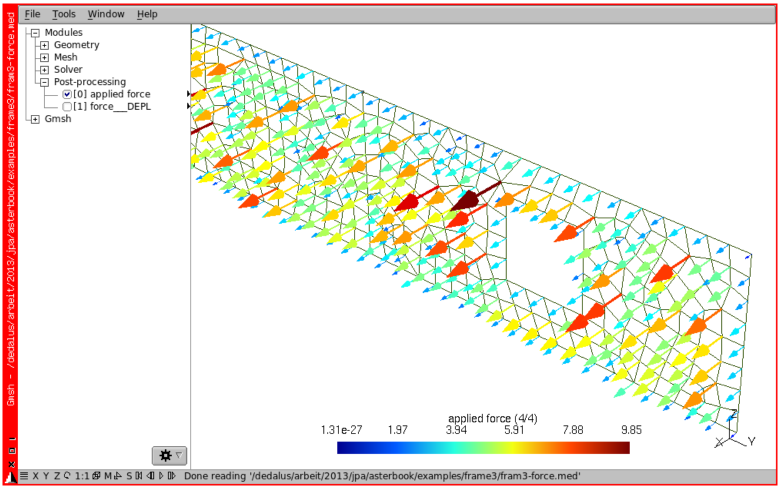

Gmsh - /dedalus/arbeit/2013/jpa/asterbook/examples/frame3/fram3-force.med
File
Tools
Window
Help
Modules
Geometry
Mesh
Solver
Post-processing
[0] applied force
[1] force__DEPL
Gmsh
applied force (4/4)
1.31e-27
1.97
3.94
5.91
7.88
9.85
X Y Z 1:1
Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/fram3-force.med'

FIGURE 18.5: Applied load vector superimposed on a mesh view, limited to group 'panel'

18.4 Calculating length and area of mesh elements

This could also be called "reading and manipulating mesh data".

It may be very helpful to get some statistics about the mesh such as element's length or area by groups[1], the following Python code can do this, and we use it on our *frame3* example. Modify the beginning of the command file as follows:

```
DEBUT(PAR_LOT='NON' ,);

#import the necessary libraries
import sys
from Utilitai import partition
import string
import numpy as N

meshf=LIRE_MAILLAGE(
     ...........
);
```

[1] Maybe just simply to prepare a bill of material in a beam model, or to retrieve the number of nodes along a beam, together with the beam length so as to exactly compute the nodal forces equivalent to a distributed load.

```
meshf=DEFI_GROUP(
    ...............
);

mesh = partition.MAIL_PY()
mesh.FromAster('meshf')

#three methods to define output file

#first,
#hard code path + file name
#file=open('/dedalus/arbeit/2012/jpa/
#tutorial/redaktion/port3/statis.txt','w')

#second, explained in the next chapter
DEFI_FICHIER( UNITE=38, FICHIER='/..../statis.txt')

#third
#an entry in ASTK with LU=38 for example
statis=open('fort.38','w')

listgm1D=['topbeam','vertb','mast',]
listgm2D=['panel',]

#next part to call a comm file that
#calculate length and area of elements
INCLUDE (UNITE=2, INFO=2)
#end of call
```

`DEBUT(PAR_LOT='NON',)` is used since we are going to explore **code_aster** data structures[1]. Then the import lines to import the necessary libraries. The two `mesh = partition.MAIL_PY()` and `mesh.FromAster('meshf')` lines import the mesh object [2].

Afterward, we define a file *statis* where to write the results, of course there should be a matching entry in the **ASTK** window, with LU=38 and 'R' ticked. We define the groups of element on which we want to perform the calculation.

And finally `INCLUDE` another *.comm* file, which also needs an entry in **ASTK**, with LU=2 and 'D' ticked.

This method with `INCLUDE` uses a rather portable *.comm* file for the intended job and makes the main command file shorter and easier to read.

[1] U1.03.02 is a must be read when one wants to manipulate **code_aster** data objects.
[2] Using the same word for 'meshf' and 'mesh' would have raised a runtine error, since here 'mesh' is an instance of the MAIL.PY class.

And now this is the code for this “included” file, doing the job of computing lengths and areas:

```
#length and surface of elements
#intialize the list for coordinates
xcoor=[None]*(4);
ycoor=[None]*(4);
zcoor=[None]*(4);
#first for 1D elements
nbgm =len(listgm1D)
for i in range (0, nbgm):
    beamgm=mesh.gma.get(listgm1D[i])
    totlong=0;
    lgth=len(beamgm)
    for j in range(lgth):
        beamid=beamgm[j]
        for k in range (0, 2):
            nodeid= mesh.co[beamid][k]
            nodecoord= mesh.cn[nodeid]
            xcoor[k]=int(mesh.cn[nodeid,0])
            ycoor[k]=int(mesh.cn[nodeid,1])
            zcoor[k]=int(mesh.cn[nodeid,2])
        lxyz=((xcoor[1]-xcoor[0])**2+(ycoor[1]-ycoor[0])**2
        +(zcoor[1]-zcoor[0])**2)**0.5
        #previous 2 lines one one single line
        #similar layout later in this file
        totlong=totlong+lxyz
    avlong=totlong/lgth
    statis.write('group 1D          : %s\n' % listgm1D[i])
    statis.write('number of element : %d\n' % lgth)
    statis.write('total length      : %d\n' % totlong)
    statis.write('average length    : %d\n' % avlong)
    statis.write('\n')
#be careful with indent in the above code
```

In this code abstract:

- `beamgm[j]` holds the *id* of the *jth* beam in the group beam `gm`;
- `mesh.co[beamid][k]` gives the *id* of the nodes belonging to element *id* `beamid`;
- and `mesh.cn[nodeid,0]` contains the x coordinate of the node, (1 for y and 2 for z)[1].

The same can be done with 2D elements,

[1] In Python a loop like `for k in range (0, 2):` is executed for the value 0 and 1 but not 2! The same rule applies to initialization of lists

```
nbgm =len(listgm2D)
for i in range (0, nbgm):
    plategm=mesh.gma.get(listgm2D[i])
    totsurf=0;
    triacount=0;
    quadcount=0;
    lgth=len(plategm)
    for j in range(lgth):
        plateid=plategm[j]
        tria=len(mesh.co[plateid])
        if tria==3:
            for k in range (0, 3):
                nodeid= mesh.co[plateid][k]
                nodecoord= mesh.cn[nodeid]
                xcoor[k]=int(mesh.cn[nodeid,0])
                ycoor[k]=int(mesh.cn[nodeid,1])
                zcoor[k]=int(mesh.cn[nodeid,2])
            a=((xcoor[1]-xcoor[0])**2+(ycoor[1]-ycoor[0])**2
            +(zcoor[1]-zcoor[0])**2)**0.5
            b=((xcoor[2]-xcoor[1])**2+(ycoor[2]-ycoor[1])**2
            +(zcoor[2]-zcoor[1])**2)**0.5
            c=((xcoor[2]-xcoor[0])**2+(ycoor[2]-ycoor[0])**2
            +(zcoor[2]-zcoor[0])**2)**0.5
            p=(a+b+c)/2
            r=((p-a)*(p-b)*(p-c)/p)**0.5
            surf=p*r
            totsurf=totsurf+surf
            triacount=triacount+1
```

Calculating the area is a matter of straightforward mathematics with triangles, just below we split the quadrangles into two triangles.

```
        elif tria==4:
            for k in range (0, 4):
                nodeid= mesh.co[plateid][k]
                nodecoord= mesh.cn[nodeid]
                xcoor[k]=int(mesh.cn[nodeid,0])
                ycoor[k]=int(mesh.cn[nodeid,1])
                zcoor[k]=int(mesh.cn[nodeid,2])
            a1=((xcoor[1]-xcoor[0])**2+(ycoor[1]-ycoor[0])**2
            +(zcoor[1]-zcoor[0])**2)**0.5
            b1=((xcoor[2]-xcoor[1])**2+(ycoor[2]-ycoor[1])**2
            +(zcoor[2]-zcoor[1])**2)**0.5
            c1=((xcoor[2]-xcoor[0])**2+(ycoor[2]-ycoor[0])**2
            +(zcoor[2]-zcoor[0])**2)**0.5
            p1=(a1+b1+c1)/2
            r1=((p1-a1)*(p1-b1)*(p1-c1)/p1)**0.5
            surf1=p1*r1
            a2=c1
            b2=((xcoor[3]-xcoor[2])**2+(ycoor[3]-ycoor[2])**2
            +(zcoor[3]-zcoor[2])**2)**0.5
            c2=((xcoor[3]-xcoor[0])**2+(ycoor[3]-ycoor[0])**2
            +(zcoor[3]-zcoor[0])**2)**0.5
            p2=(a2+b2+c2)/2
            r2=((p2-a2)*(p2-b2)*(p2-c2)/p2)**0.5
            surf2=p2*r2
            totsurf=totsurf+surf1+surf2
            quadcount=quadcount+1
    avsurf=totsurf/(triacount+quadcount)
    statis.write('group 2D              : %s\n' % listgm2D[i])
    statis.write('number of TRIA3 elem : %d\n' % triacount)
    statis.write('number of QUAD4 elem : %d\n' % quadcount)
    statis.write('total area            : %d\n' % totsurf)
    statis.write('average area          : %d\n' % avsurf)
    statis.write('\n')
#in Python it is not strictly necessary to close a file
#however
statis.close()
```

The print out in the file looks like this:

```
group 1D            : topbeam
number of element : 160
total length        : 3960
average length      : 24

group 1D            : vertb
number of element : 32
total length        : 800
average length      : 25

group 1D            : mast
number of element : 80
total length        : 2000
average length      : 25

group 2D               : panel
number of TRIA3 elem : 689
number of QUAD4 elem : 371
total area             : 386000
average area           : 364
```

This example applies only to line elements with 2 nodes, on a SEG2 or to TRIA3 and QUAD4 elements, however it can easily be adapted to another geometry[1].

[1] Any experienced programmer may find this bit of code not very much optimized, and he will be right, I left it this way so the underlying data structure is more easily understood!

CHAPTER 19

Getting more from post-processing

In this chapter, we give some hints about how to to get more from a result:

- how to manipulate tables to get new result values;
- how to rename components fields;
- how to add node coordinates to a result;
- how to create a mesh from a displacement field;
- how to read a result and enhance it;
- how to use user fields.

19.1 Manipulating results with `TABLE`

Using tables allows to extract some values from a result, order them, combine them and more, to finally print them either as ASCII result or in *.med* format. Here we do some examples with the files of *frame3*.

19.1.1 Printing only a few parameters

In the previous examples we requested the print out of the mass of the model. We printed the default set of data which includes: position of barycenter, quadratic moments and many, more or less useful values. Adding a single line, `NOM_PARA`, in the command file restricts the print out, for example[1]:

```
IMPR_TABLE (
    TABLE=masse,
    NOM_PARA=('LIEU','MASSE',),
    FORMAT_R='1PE12.3',
)
```

gives the following print out, with only the group names and their respective mass:

```
#masse
 LIEU                       MASSE
 topbeam                       2.736E-03
 mast                          2.736E-03
 massN                         1.000E-02
```

19.1.2 Getting the maximum value of a field

In this first example, we extract the minimum value of the force field `SIEF_ELNO` component `N` in all the beam groups (individually for each group). In addition, we print all the other `SIEF_ELNO` components for this element in the *.resu* file:

```
#declare the list which contain the group name
#note index 0 is not used
#nvar number of items in vari
nvar=3;
vari=[None]*(nvar+1);
#specify the group name
vari[1]='topbeam';
vari[2]='vertb';
vari[3]='mast';
#intialize a group name which holds the element
#where the value is minimum
mailncr=[];
```

We first build a table containing the elements where N is extreme, i.e. maximum or minimum.

[1] We get the actual name of the parameters from a full printout.

```
  for i in range (1,nvar+1):
      var=vari[i];
      #build a table containing the elements where N is extreme
      #maximum or minimum
      tabminN=POST_RELEVE_T(
          ACTION=_F(
              INTITULE='extreme_N',
              OPERATION='EXTREMA',
              GROUP_MA=(var,),
              RESULTAT=stat,
              NOM_CHAM='SIEF_ELNO',
              NOM_CMP=('N',),
              LIST_INST=(liste,),
          ),
      );
      #eventually print the table to check
      #IMPR_TABLE (TABLE=tabminN,)
```

Then, we order this table in ascending order.

```
      #order this table in increasing order
      #U.4.33.03
      tabminN=CALC_TABLE(
          TABLE=tabminN,
          reuse=tabminN,
          ACTION=(
              _F(
                  OPERATION='FILTRE',
                  NOM_PARA='EXTREMA',
                  VALE_K='MAX',
              ),
              _F(
                  OPERATION='TRI',
                  NOM_PARA='VALE',
                  ORDRE='CROISSANT',
              ),
          ),

      );
      #eventually print the table to check
      #IMPR_TABLE (TABLE=tabminN,)
```

Now, in this table we select the element in which N is minimum, of course it is the first one after the ordering.

```
      #select the element where N is minimum
      #the first one in the table
      thiselem = tabminN['MAILLE',1];
      #add it the group of element
      mailncr.append (thiselem);
      #thisorder is the order at which this value occurs
      thisorder = tabminN['NUME_ORDRE',1]
      #set the SOUS_TITRE string
```

```
        soustitre=(
            'groupe : ' + str(var)
            + ' -  NUMERO D ORDRE : ' + str(thisorder)
            + ', where N is minimum'
        )
        #print all the values of 'SIEF_ELNO' for the element
        #where N is minimum
        #for beam elements 'EFGE_ELNO'
        #would print a cleaner output
        IMPR_RESU(
            MODELE=model,
            FORMAT='RESULTAT',
            UNITE=8,
            RESU=_F(
                RESULTAT=stat,
                NOM_CHAM='SIEF_ELNO',
                MAILLE=thiselem,
                NUME_ORDRE=thisorder,
                SOUS_TITRE=soustitre,
            ),
        );
        #destroy the concept for the next use of it in the loop
        DETRUIRE(CONCEPT=_F(NOM= tabminN),);
        #end of the Python loop
```

Finally, we create a group in the mesh holding this element and print the result on this group in the *.med* file.

```
    #create the group in the mesh
    mesh=DEFI_GROUP(
        reuse =mesh,
        MAILLAGE=mesh,
        CREA_GROUP_MA=(
            _F(
                NOM='mailncr',
                MAILLE=mailncr,
            ),
        ),
    );

    #print the result in the .med file
    IMPR_RESU(
        FORMAT='MED',
        UNITE=80,
        RESU=_F(
            RESULTAT=stat,
            GROUP_MA='mailncr',
            NOM_CHAM=('SIEF_ELNO',),
            #NOM_CMP=('N',), #commented to plot all the CMP
            NOM_CHAM_MED=('minN',),
        ),
    );
```

It is a wise idea to print the intermediate tables when prototyping the problem, this helps in debugging.

With this code, we get the minimum value of N and the INST when this occurs for *each* group.

Putting the group definition outside a loop produces a result for any element in *all* the groups.

19.1.3 Getting values within a range

Now, we extract values lying within a range, a minimum and a maximum. In the previous examples we created the first table with POST_RELEVE_T. In this example we extract the table directly from the result concept. We extract the component SIXX of the field SIPM_ELNO

```
#create the table from the resu 'stat'
#U4.33.02
tab01=CREA_TABLE(
    RESU=_F(
        RESULTAT=stat,
        GROUP_MA=('vpot2'),
        NOM_CHAM='SIPM_ELNO',
        NOM_CMP='SIXX',
    ),
);

#if we print it we can see that it contains many information
IMPR_TABLE (TABLE=tab01,)
```

And, we can see it contains a lot of information so we reduce its content.

```

#we reduce its content
#U.4.33.03
tab01=CALC_TABLE(
    TABLE=tab01,
    reuse=tab01,
    ACTION=_F(
        OPERATION='EXTR',
        #restricted list of wanted components
        NOM_PARA=('NOM_CHAM','INST','NUME_ORDRE','MAILLE','SIXX',),
    ),
);
```

Finally, we create a new table where the value of SIXX is less than 50 from which we extract the values greater than -50.

```
#create a new table where the value of SIXX is  less than 50
tab02=CALC_TABLE(
    TABLE=tab01,
    ACTION=_F(
        OPERATION='FILTRE',
        NOM_PARA=('SIXX'),
        #LT means Less Than
        CRIT_COMP='LT',
        VALE=50,
    ),
);
#IMPR_TABLE (TABLE=tab02,)

#in this table we extract only the values greater than -50
tab02=CALC_TABLE(
    TABLE=tab02,
    reuse=tab02,
    ACTION=_F(
        OPERATION='FILTRE',
        NOM_PARA=('SIXX'),
        #GT means Greater Than
        CRIT_COMP='GT',
        VALE=-50,
    ),
);
IMPR_TABLE (TABLE=tab02,)
```

19.2 Finding what is in a result

The following line will print in the *.mess* or any other file specified by a LU numberfile a list of all the field and their component present a result concept, this operator is described in U4.91.12.

```
INFO_RESU(RESULTAT=stat);
```

An abstract of a print out looks like this:

```
INFO_RESU(RESULTAT=stat,
          UNITE=6,)

 -------------------------------------------------------
 COMPOSANTES DES CHAMPS PRESENTS DANS LE RESULTAT : stat
    - CHAMP DEPL              :
       * DX
       * DY
       * DZ
       * DRX
       * DRY
       * DRZ
    - CHAMP SIEF_ELGA         :
       * N
    ..................
    - CHAMP SIPM_ELNO         :
       * SIXXMIN
       * SIXXMAX
    — CHAMP REAC_NODA        :
       * DX
       * DY
       * DZ
       * DRX
    ..................
```

19.3 Renaming field’s components in a result

Using NOM_CHAM_MED gives a powerful way to rename the fields so as to get nicer and maybe more explicit names, there is also a feature to rename the components in an ASCII file. For example the following bit of code:

1. puts the reaction in a table, in the standard manner;
2. changes the name of the components in the table, it looks nicer to have R for reactions instead of D which reminds of a displacement!

```
rea_sol=POST_RELEVE_T(
    ACTION=_F(
        INTITULE='reactions sol',
        RESULTAT=stat,
        TOUT_ORDRE='OUI',
        GROUP_NO=('sol',),
        NOM_CHAM='REAC_NODA',
        RESULTANTE=('DX','DY','DZ'),
        OPERATION='EXTRACTION',
    ),
);
IMPR_TABLE (TABLE=rea_sol,) #just to see the difference
rea_sol=CALC_TABLE(
    reuse =rea_sol,
    TABLE=rea_sol,
    ACTION=(
        _F(OPERATION='RENOMME',NOM_PARA=('DX','RX',),),
        _F(OPERATION='RENOMME',NOM_PARA=('DY','RY',),),
        _F(OPERATION='RENOMME',NOM_PARA=('DZ','RZ',),),
    ),
);
IMPR_TABLE (TABLE=rea_sol,)
```

19.4 Adding node coordinates in a result

The following lines add the nodes coordinates to a result of reactions, this may help a third party[1] to better understand the results.

```
IMPR_RESU(
    MODELE=model, FORMAT='RESULTAT',
    RESU=_F(
        NOM_CHAM='REAC_NODA',
        GROUP_NO=('sol',),
        RESULTAT=stat,
        NOM_CMP = ("DX","DY","DZ"),
        IMPR_COOR='OUI',
    ),
);
```

19.5 Creating a mesh on a deformed shape

The following piece of code allows to write in a med file a deformed mesh resulting from a previous calculation. This new mesh can be used as an entry in any subsequent calculation.

Used this way it would, of course, be considered as a stress free mesh!

```
statnl=STAT_NON_LINE(
    ............
);
#extract the displacements from statnl calculation
defshape=CREA_CHAMP(
    RESULTAT=statnl,
    INST=6,
    OPERATION='EXTR',
    NOM_CHAM='DEPL',
    TYPE_CHAM='NOEU_DEPL_R',
);
#make the new mesh
meshdef=MODI_MAILLAGE(
    reuse=mesfdef,
    MAILLAGE=mesh, #the original mesh
    DEFORME=_F(
        OPTION = 'TRAN' ,
        DEPL = DEPL,
    ),
);
#save it
```

[1] For example the concrete engineer in charge of the ground connection for a steel frame building.

```
IMPR_RESU(
    FORMAT='MED',
    UNITE=71,
    RESU=_F(MAILLAGE=meshdef,),
);
```

19.6 Reading (and enhancing) a result

There is an alternative to using `POURSUITE` in order to enhance results. In this section, we see how to read a MED result file created in a previous calculation.

Taking the example of *frame1*, we start by modifying the command file like this: we comment the line containing `SIPM_ELNO` in `CALC_CHAMP` and `IMPR_RESU ... FORMAT='MED'` so the calculated concept 'stat' is saved without this option[1], we can check this by running the calculation and opening the *.med* file.

Then, we create the following command file reading the med result file just created and enhance the results.

```
DEBUT();

#we read the mesh of the study
#this mesh concept is used in the subsequent CALC_CHAMP
mesh=LIRE_MAILLAGE(
    INFO=1,
    UNITE=20,FORMAT='MED',
);

#we need also the MODELE concept
model=AFFE_MODELE(
    MAILLAGE=mesh,
    AFFE=(
        _F(
            GROUP_MA=('topbeam','mast',),PHENOMENE='MECANIQUE',
            MODELISATION='POU_D_T',
        ),
        _F(
            GROUP_MA=('massN',),PHENOMENE='MECANIQUE',
            MODELISATION='DIS_T',
        ),
    ),
);
```

[1] Just like we had forgotten these options at first!

```
#and the field CHAM_MATER  concept
steel=DEFI_MATERIAU(ELAS=_F(E=210000.,NU=0.3,RHO=8e-9),);
material=AFFE_MATERIAU(
    MAILLAGE=mesh,
    AFFE=_F(GROUP_MA=('topbeam','mast',), MATER=steel,),
);

#and the element characteristics
elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    POUTRE=(
        _F(
            GROUP_MA=('mast',),SECTION='RECTANGLE',
            CARA=('HY','HZ','EP',),VALE=(40, 20, 1.5,),
        ),
        _F(
            GROUP_MA=('topbeam',),SECTION='RECTANGLE',
            CARA=('HY','HZ','EP',),VALE=(40, 20, 1.5,),
        ),
    ),
    DISCRET=_F(GROUP_MA='massN', CARA='M_T_D_N',VALE=(.01),),
);
```

And, now the bit of code producing the results.

```
#here we read the EVOL_ELAS result concept
#from the previous calculation
#giving it the name "resur" for result read
resur=LIRE_RESU(
    TYPE_RESU='EVOL_ELAS',
    UNITE=21,
    FORMAT='MED',
    MODELE=model,
    #MAILLAGE=mesh,
    FORMAT_MED=(
        _F(NOM_CHAM='DEPL',NOM_RESU='stat'),
        _F(NOM_CHAM='SIEF_ELNO',NOM_RESU='stat'),
    ),
    TOUT_ORDRE='OUI',
);

#here we create a new result concept name resu
#based on "resur" read above
resu=CALC_CHAMP(
    #with LIRE_RESU next line is not necessary
    #as we create a new resu
    #reuse =resu,
    #with LIRE_RESU next line is mandatory
    MODELE=model,CHAM_MATER=material, CARA_ELEM=elemcar,
    RESULTAT=resur,
    CONTRAINTE=(
        'SIEF_ELNO',
        'SIPO_ELNO',
        'SIPM_ELNO',
        ),
        FORCE=('REAC_NODA'),
);

#print new med resu
IMPR_RESU(
        MODELE=model, FORMAT='MED', UNITE=80,
        RESU=_F(
                GROUP_MA=('topbeam','mast',),
                RESULTAT=resu,
                NOM_CHAM=(
                        'DEPL',
                        'SIEF_ELNO',
                        'SIPO_ELNO',
                        'SIPM_ELNO',
                        'REAC_NODA',
                ),
        ),
);

FIN()
```

In LIRE_RESU, we comment the MAILLAGE=mesh line, as the ELNO type field needs only the MODELE concept, some other results may need a MAILLAGE concept.

We need to carefully study what is done in CALC_CHAMP with the name of the concepts:

- we do not use reuse, as there is no *previously calculated result* and we have to use the lines:

  MODELE=model,CHAM_MATER=material,
  CARA_ELEM=elemcar,.

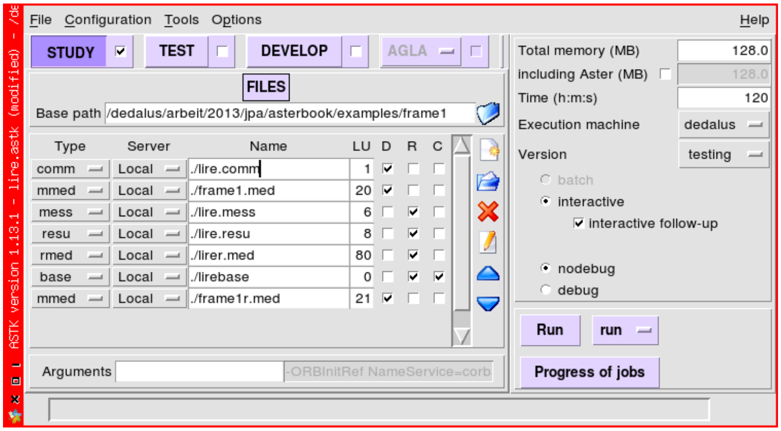
- we add SIPM_ELNO in CALC_CHAMP to calculate this option and in IMPR_RESU ... FORMAT='MED', to print in a med file.

We now create in Astk a study looking like figure 19.1.

Note: the file *frame1r.med* is set as data D as we are using it as an input.

After running the study and opening the *lirer.med* file, we find an entry for SIPM_ELNO.

With this method, we have to reload all the data relevant to the study, mesh, model, material and so on, to be able to perform a calculation,



Base path /dedalus/arbeit/2013/jpa/asterbook/examples/frame1

Type	Server	Name	LU	D	R	C
comm	Local	./lire.comm	1	✓		
mmed	Local	./frame1.med	20	✓		
mess	Local	./lire.mess	6		✓	
resu	Local	./lire.resu	8		✓	
rmed	Local	./lirer.med	80		✓	
base	Local	./lirebase	0		✓	✓
mmed	Local	./frame1r.med	21	✓		

Arguments -ORBInitRef NameService=corb

Total memory (MB)	128.0
including Aster (MB)	128.0
Time (h:m:s)	120
Execution machine	dedalus
Version	testing

batch [✓ interactive]

✓ interactive follow-up

[✓ nodebug] debug

FIGURE 19.1: Astk example for LIRE_RESU study

the only omitted step is the call to the solver, MECA_STATIQUE, or STAT_NON_LINE, or any other.

This is not as easy, or immediate, as a POURSUITE to handle large studies.

On the other hand it allows to read result concepts produced by IDEAS or ENSIGHT for example. All this is described in the U7.02.01 documentation. Finally, we should notice that it is not not possible to read **ALL** the concepts produced by **code_aster** .

19.7 Using user field

Here we are going to create what is called in the U44.81.04 documentation a "user field" known in french as "champ utilisateur" with the keyword CHAM_UTIL.

We are going to do that for calculating the maximum normal stress and the maximum shear stress in a rectangular section beam in example *frame1*.

The maximum normal stress that occurs at the corners of the beam is the sum of the traction/compression stress and of the bending stresses in the two local planes of the beam, while the maximum stress occurs in the middle of one side and the sum of the stress due to torsion and the one due to "vertical' shear stress.

Note that the first one is directly calculated by **code_aster** as the SIPM_ELNO, but the procedure describe here can be applied to almost any situation.

For this purpose we modify the *frame1.comm* as follow.

At the very beginning of the file the following line import the math library of Python

```
import numpy
```

After the CALC_CHAMP operator we add the following:

```
fsig = FORMULE(
    NOM_PARA=('SN','SMFY','SMFZ'),
    VALE="""numpy.sign(SN)*(abs(SN)+abs(SMFY)+abs(SMFZ))""",
);

ftau = FORMULE(
    NOM_PARA=('SMT','SVY','SVZ'),
    VALE="""abs(SMT)+numpy.max(abs(SVY)+abs(SVZ))""",
);
```

which are the formula[1] that will create the values we want, followed by a new instance of CALC_CHAMP

```
stat=CALC_CHAMP(
    reuse =stat,
    RESULTAT=stat,
    CHAM_UTIL=_F(
        NOM_CHAM='SIPO_ELNO',
        FORMULE=(fsig,ftau,),
        NUME_CHAM_RESU=2,
    ),
    INFO=2,
);
```

NUME_CHAM_RESU gives the numbering of the user field that will be used later under the name UT02_ELNO.

```
IMPR_RESU(
    MODELE=model,
    FORMAT='RESULTAT',
    RESU=(
         ..............
```

[1] Note the special syntax of the VALE, with the three doubles quotes to hold a Python formula.

```
        _F(
            RESULTAT=stat,
            NOM_CHAM='UT02_ELNO',
            NOM_CMP=('X1','X2',),
            GROUP_MA=('topbeam',),
            FORMAT_R='1PE12.3',
            VALE_MAX='OUI',VALE_MIN='OUI',
        ),
        ...................
```

Prints typical values in the *frame1.resu* file while:

```
  IMPR_RESU(
     FORMAT='MED',
     UNITE=80,
     RESU=(
         ..............
        _F(
            RESULTAT=stat,
            NOM_CHAM='UT02_ELNO',
            NOM_CHAM_MED=stress_max,
        ),
         ..............
```

Print an entry in the *frame1-r.med* file.

Typical print out in the *frame1.resu* looks like this:

```
  CHAMP PAR ELEMENT AUX NOEUDS DE NOM SYMBOLIQUE  UT02_ELNO
   NUMERO D'ORDRE: 3 INST:      4.000E+00

   LA VALEUR MAXIMALE DE X1                EST    -3.793E+00 EN    1 MAILLE(S) : M17
   LA VALEUR MAXIMALE DE X2                EST     3.233E+00 EN    2 MAILLE(S) : M14
   LA VALEUR MINIMALE DE X1                EST    -4.596E+01 EN    2 MAILLE(S) : M14
   LA VALEUR MINIMALE DE X2                EST     2.967E-14 EN    1 MAILLE(S) : M29
```

Where `X1` is the first component of the field `UT02_ELNO`, `X2` is the second one, there could have been other fields `X3...X30`, including predefined one `VMIS, INVA_2, TRACE`,

More about `CHAM_UTIL` can be found in U4.81.04.

CHAPTER 20

Handling **code_aster**, bits and pieces

In this chapter, we review some hints for a better use of **code_aster**

- how to deal with multiple `FORCE_POUTRE`;
- how to put a load varying as a function;
- how to use `DEFI_FICHIER`
- how to convert a mesh to or from another format;
- how to launch a study from a terminal;
- how to use multiple instances of ASTK;
- how to run ASTK from a salome_meca installation
- why not to alarm when there is an “alarm”;
- how to benefit from the use of the keyword `INFO`;
- how to misuse `GROUP_MA=('TOUT')`!

20.1 Dealing with multiple `FORCE_POUTRE`

As we have discussed earlier the following attempt of using two instances of `FORCE_POUTRE` in two different `AFFE_CHAR_MECA`

```
selfwght=AFFE_CHAR_MECA(
    MODELE=model,
    PESANTEUR =_F(
        GRAVITE=13500,
        DIRECTION=(0,0,-1),
        GROUP_MA=('topbeam','mast','massN',),
    ),
);
...........
cr=AFFE_CHAR_MECA(
    MODELE=model,
    FORCE_POUTRE=_F(GROUP_MA=('topbeam',),FZ=-0.1,),
);
```

raises the following error:

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! <S> Exception utilisateur levee mais pas interceptee.     !
! Les bases sont fermees.                                   !
! Type de l'exception : error                               !
!                                                           !
!  Le chargement contient plus d'une charge repartie.       !
!  Le calcul n'est pas possible pour les modeles de poutre. !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

code_aster fails despite the fact that the displacements are calculated[1].

However the following gives a result with forces and stresses. The load cases are named `inst_x`, where x takes the same value as the `INST` of example *frame1.comm*, in chapter 4.9

```
inst_3=AFFE_CHAR_MECA(
    MODELE=model,
    PESANTEUR =_F(
        GRAVITE=10000*1.35,DIRECTION=(0,0,-1),
        GROUP_MA=('topbeam','mast','massN',),
    ),
);
...........
inst_5=AFFE_CHAR_MECA(
    MODELE=model,
    PESANTEUR =_F(
        GRAVITE=10000*1.35,DIRECTION=(0,0,-1),
```

[1] In fact writing `OPTION='SANS',` in `MECA_STATIQUE` allows to print a result containing only the displacements.

```
          GROUP_MA=('topbeam','mast','massN',),
     ),
     FORCE_NODALE=_F(GROUP_NO=('loadS',),FZ=-135,),
     FORCE_POUTRE=_F(GROUP_MA=('topbeam',),FZ=-0.1*1.5,),
);
............
stat_3=MECA_STATIQUE(
     MODELE=model,
     CHAM_MATER=material,
     CARA_ELEM=elemcar,
     EXCIT=(
          _F(CHARGE=ground,),
          _F(CHARGE=inst_3,),
     ),
);
............
stat_5=MECA_STATIQUE(
     MODELE=model,
     CHAM_MATER=material,
     CARA_ELEM=elemcar,
     EXCIT=(
          _F(CHARGE=ground,),
          _F(CHARGE=inst_5,),
     ),
);
```

This method uses several MECA_STATIQUE[1] with the following drawbacks:

- there are as many solving of the problem as there are MECA_STATIQUE which increases the calculation time;
- FONC_MULT cannot be used at best anymore and the multiplications, if any, must be made within the individual AFFE_CHAR_MECA.

This method is quite cumbersome but may help if CPU time is not critical and a true precise FORCE_POUTRE is required.

20.2 Putting a load varying as a function

In chapter 8 we put on the plates a constant perpendicular pressure load attempting to deal with a wind load, this is only true if the wind is perpendicular to the plates.

[1] Which could easily included in a Python loop, including as well all the post-processing commands.

If the wind is blowing nearer to the X global axis the top panel will behave more like a wing and the load distribution will vary a long Y direction resulting in a center of pressure moving to about a quarter of the chord of the panel [1].

We can mimic such a load in **code_aster** by using the operator AFFE_CHAR_MECA_F which allows to have a load varying along a function of some allowed variables[2] here we are going to use the Y global coordinate[3].

First of all we define the function pres_f to replace the constant value PRES=0.01 used in the example.

```
pres_f=DEFI_FONCTION(
    NOM_PARA='Y',
    VALE=(
        -900, 0.000,
        -800, 0.030,
        -700, 0.030,
        -500, 0.025,
        -300, 0.016,
        -100, 0.008,
         100, 0.005,
         300, 0.003,
         500, 0.002,
         900, 0.000,
    ),
    PROL_GAUCHE='CONSTANT',PROL_DROITE='CONSTANT',
);
```

And we build the load along this function.

```
cv=AFFE_CHAR_MECA_F(
    MODELE=model,
    FORCE_COQUE=_F(GROUP_MA=('panel'),PRES=pres_f,),
);
```

All the rest remains unchanged.

[1] This is also a requirement in the Eurocode.
[2] The _F option does not apply to all the AFFE_CHAR_MECA, this is explained in U4.44.01 document, and of course it applies to relevant variable.
[3] It is possible to build a function of more than one variable as described in U4.31.02 document.

20.3 Using DEFI_FICHIER

In the course of this book, dealing with relatively short examples, we define an output result file[1] with an entry in the **ASTK** window.

The maximum number of file that can be handled this way is 99 which may become not enough, a rather good work around is to use DEFI_FICHIER without any entry in the **ASTK** window, like in the commented following code abstract.

```
#we suppose we include this in the \texttt{frame3} example
#define the output file
DEFI_FICHIER(
    ACTION='ASSOCIER',
    #next should be an ABSOLUTE file path
    FICHIER='/...../frame3/masses.resu',
    UNITE=99,
    TYPE='ASCII',
    ACCES='NEW', #it could be 'APPEND'
    INFO=2,
);

#the file is created and opened, we write in it
IMPR_TABLE (
    TABLE=masse,
    UNITE=99,
    FORMAT_R='1PE12.3',
);

#the file is printed an the \texttt{UNITE} is freed
DEFI_FICHIER(ACTION='LIBERER',UNITE=99,)

#and we can reuse it
DEFI_FICHIER(
    ACTION='ASSOCIER',
    #next shoud be an ABSOLUTE file path
    FICHIER='/...../frame3/depl.med',
    UNITE=99,
    TYPE='LIBRE',
    ACCES='NEW',
    INFO=2,
);

IMPR_RESU(
    FORMAT='MED',
    UNITE=99,
    RESU=(
        _F(
            GROUP_MA=('topbeam','vertb','mast','panel',),
```

[1] Be it ASCII or graphical.

```
                RESULTAT=stat,NOM_CHAM=('DEPL',),
            ),
        ),
    );

    DEFI_FICHIER(ACTION='LIBERER',UNITE=99,)
```

Used inside a Python loop this opens a large number of opportunies for automated post processing.

The documentation file U4.12.03 gives all information about the use of `DEFI_FICHIER`.

20.4 Converting mesh

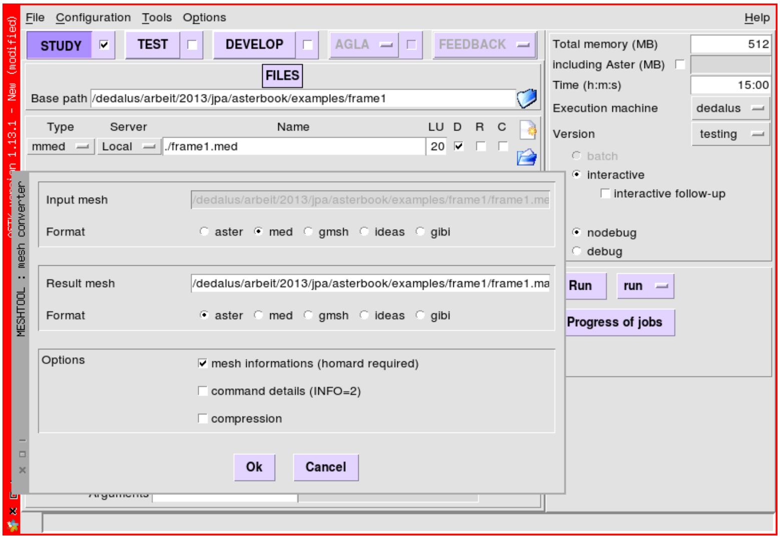
It is very easy to convert a mesh to another format. To do this, in **ASTK**:

- set the Base path to the directory where the mesh to be converted is sitting;
- write a line entry with the mesh file to be converted;
- go to menu item Tools 〉 Mesh converter;
- choose the directory where yo want the new mesh to be created in Result mesh;
- optionally set a name;
- select the Format;
- push Ok;

and after a few more clicks the new mesh is created, figure 20.1 shows the **ASTK** window.

There is no witchcraft in this tool and the next lines in a *.comm* file will do the same:

```
mesh=LIRE_MAILLAGE(UNITE=20, FORMAT='MED',);

IMPR_RESU(
    FORMAT='msh (or UNV or else)',
    UNITE=71,
```



Base path /dedalus/arbeit/2013/jpa/asterbook/examples/frame1

Type	Server	Name	LU	D	R	C
mmed	Local	./frame1.med	20	✓		

Total memory (MB) 512
including Aster (MB)
Time (h:m:s) 15:00
Execution machine dedalus
Version testing
batch [✓ interactive]
interactive follow-up
[✓ nodebug] debug

Input mesh /dedalus/arbeit/2013/jpa/asterbook/examples/frame1/frame1.me
Format aster [✓ med] gmsh ideas gibi

Result mesh /dedalus/arbeit/2013/jpa/asterbook/examples/frame1/frame1.ma
Format [✓ aster] med gmsh ideas gibi

Options
✓ mesh informations (homard required)
command details (INFO=2)
compression

FIGURE 20.1: **ASTK** set to convert a mesh

```
        RESU=_F(MAILLAGE=mesh,),
    );
```

20.5 Getting info about *med* files with xmdump

The *xmdump*[1] which is lying in the `.../public/med-3.3.1/bin` sub directory in the **code_aster** installation directory utility may reveal valuable to get information about a med file.

However it seems unable to print the valuable information of the *med* version.

As discussed elsewhere in this book (in Appendix 4.2 and 4.7) we are facing the fact that there are two different version of *med* files, 3.2 and 3.3, which raises some compatibility troubles with **code_aster** and Gmsh.

[1] Or its command line sibling *mdump*.

20.6 Launching from terminal

It is possible to launch a study just simply from a terminal.

When we launch a study from ASTK a file named *study_name.export* is created. If we open this file in a text editor we can see that it contains, first a series of parameters, some paths and at the end a list of the files of the study with the LU and R, C or RC state of each file.

The following command typed in a terminal launches this study:

```
/opt/aster/bin/as_run /my_directory/frame3.export
```

- assuming */opt/aster* is the **code_aster** installation directory;
- assuming *my_directory* is the study directory name;
- assuming *frame3* is the study name.

Creating a new *.export* file by hand in a text editor with the right parameter for the new study is just enough to run a study. Detailed explanation about this matter can be found in U1.04.00 or more generally in the whole U1.* documentation.

More! Writing a script like this:

```
#!/bin/sh
/opt/aster/bin/as_run /directory_study_1/study_1.export
/opt/aster/bin/as_run /directory_study_2/study_2.export
............
/opt/aster/bin/as_run /directory_study_43/study_43.export
```

saving it somewhere, making it executable and launching it from a terminal would mimic a batch behaviour and solve 43 studies one after the other!

20.7 Multiple ASTK configurations

The following command:

```
/opt/aster/bin/astk --rcdir  $HOME/.astkrc-134
```

launches ASTK with a configuration described in the directory *$HOME/.astkrc-134*.

This allows to have several configurations for each of the ASTK instances in case of multiple **code_aster** installations, for example.

If the *$HOME/.astkrc-134* does not exist it will created, with default options, on the first launch.

The default ASTK configuration file is *$HOME/.astkrc*[1].

20.8 Running ASTK from a salome_meca installation

It is possible to bypass the whole graphical Salome-Meca[2] GUI and access its included ASTK, to run the example just as is described in this book. The command to run ASTK is then:

```
/opt/salome_meca-2018-1/V2018/tools/
Code_aster_frontend-20180/bin/astk
--rcdir $HOME/.astkrc-142
```

Assuming:

- `/opt/salome_meca-2018-1/` is Salome-meca install directory;
- `/$HOME/.astkrc-142` is the ASTK configuration file used here.

20.9 Alarming about 'alarme'?

Very often we can see many items like this one in the *.mess* file:

[1] In the Unix world, he leading "dot" in a file name means a hidden file or directory, it thus may not be visible at fist with the default settings of a graphical window manager.
[2] Or salome_meca, as the naming changed in 2018.

```
<A> <here a name>
...................
Ceci est une alarme. Si vous ne comprenez pas le sens de cette
alarme, vous pouvez obtenir des resultats inattendus !
```

Whose translation is “This is a warning. If you do not understand the meaning of this warning, you may get unexpected results”. This means that we should know what we are doing here.

In fact, in this context, the exact translation of the french word “alarme” is warning, thus the alarm is not so alarming!

Yet we should always tend towards zero warnings by making the necessary changes suggested by these messages.

20.10 Keeping informed with `INFO`

Almost any **code_aster** command supports the keyword `INFO`, it can take three values:

- with `INFO=1`, a standard set of information is printed in the *.mess* file[1];
- with `INFO=2`, a more comprehensive set of information is printed in the *.mess* file;
- `INFO=0`, which may be used only in a few commands, reduces the set of information printed in the *.mess* file.

It is always a wise idea to have a look at what is printed in the *.mess* file for a given command.

For any command, in addition to the keywords stated by the user in the *.comm* file, **code_aster** adds a few other keywords considered as default. Looking at what has been added is useful in two ways:

- at the learning stage (for a given command) is helps to understand what **code_aster** uses as parameter for the command;

[1] `INFO=1` is the default value and it is not possible to print no information!

- with more experience it gives a good hint of what could be altered to produce the expected, or a better, result.

For example setting `INFO=2` within a `LIAISON_*` command allows to see the equations and the eliminated DOF actually used!

Another example is with the commands `LIRE_MAILLAGE`, `MODI_MAILLAGE`, `CREA_MAILLAGE`, `DEFI_GROUP...` With `INFO=1` a decent set of information is printed in the *.mess* file which help to check that:

- the read mesh is what we expect;
- the expected groups do exist, with their expected number of elements and their right name;
- and much more information.

With `INFO=2` the level of information goes more into the details:

- for every node, its coordinates;
- for every element its connectivity;
- and so on.

Here is a example of the `LIRE_MAILLAGE` with `INFO=1` for *frame3* example:

```
  # Commande No :  0002
Concept de type : maillage_sdaster
  # --------------------------------------------------------------
  mesh = LIRE_MAILLAGE(INFO=1,
                       FORMAT='MED',
                       UNITE=20,
                       INFO_MED=1,
                       VERI_MAIL=_F(APLAT=1.E-3,
                                    VERIF='OUI',),
                       )
====== VERIFICATION DU MAILLAGE ======

  MAILLE POI1 M1      INCLUSE DANS UNE AUTRE
  MAILLE POI1 M2      INCLUSE DANS UNE AUTRE
  MAILLE POI1 M3      INCLUSE DANS UNE AUTRE
  MAILLE POI1 M4      INCLUSE DANS UNE AUTRE
  MAILLE POI1 M5      INCLUSE DANS UNE AUTRE
```

```
 ———————————— MAILLAGE mesh — IMPRESSIONS NIVEAU  1 ———————————

 MED file generated by Gmsh

 NOMBRE DE NOEUDS                        907

 NOMBRE DE MAILLES                      1439
                              POI1                   5
                              SEG2                 224
                              TRIA3                842
                              QUAD4                368

 NOMBRE DE GROUPES DE MAILLES             12
                          loadS                              1
                          massN                              1
                          groundS                            1
                          groundN                            1
                          oripanel                           1
                          topbeam                          160
                          hinge                              4
                          vertb                             40
                          mast                              20
                          panelS                           842
                          panelN                           368
                          pan                               40

 ——————————————————————————————————————————————————————————————————


   # Fin commande No : 0002   user+syst:
 0.03s (syst:        0.00s, elaps:       0.03s)
   # ---------------------------------------------------------------
```

This valuable information should be read at first if something goes wrong.

In the same manner one may use `DEBUT (IMPR_MACRO='OUI')` to print in details what is happening inside each macro command.

Unfortunately there is no way to print less `INFO` (or no `INFO` at all) than the default value!

20.11 Changing language

The following addition to the `DEBUT` operator will set the language of the *.mess* file to English, unfortunately only some parts of it!

```
#U4.11.01
DEBUT(
    LANG='EN',
);
```

There is more about it in the the doc "U4.11.01.pdf" with some of the subtleties of encoding.

20.12 Using GROUP_MA=('TOUT') and its danger

The following sequence of operators:

```
mesh=DEFI_GROUP(
    reuse =mesh,
    MAILLAGE=mesh,
    CREA_GROUP_MA=(
        ..........
        _F(NOM='TOUT',TOUT='OUI',),
        ..........
    ),
);

...............

elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    .................
    some keyword (like POUTRE)=(
        _F(
            GROUP_MA=('TOUT'),
        ..................
        ),
```

may lead to anything from a run time warning or error message to a totally erroneous result.

For example the GROUP_MA=('TOUT') may contain elements that are not POUTRE.

The use of GROUP_MA=('TOUT') should be avoided as much as possible unless we really know what we are doing!

In the operator like AFFE_CARA_ELEM, AFFE_CHAR_MECA and a few others it is wiser to use, named, clearly identified, group names like GROUP_MA=('mast').

APPENDIX A

Living with good practice

When all else fails, read the directions.

Allen's axiom.

Before moving to some technical appendixes we review now a few advices of good practice:

1. Put all the files related to a given study in a single directory [a].
2. In this directory, do NOT allow file names with special character, like space or blank, which may prevent reading other files in the directory.
3. In the source files, command or Gmsh script, write more comment than we think necessary, as we will probably have forgotten why we did "this like that" when we re-open the file in a few months. And even more if somebody else has to use them.
4. When working with Gmsh, keep an eye on the 'Message Console', some strange behaviors are probably traced in it.

[a] In which we have read, write, execute permissions.

5. Check the geometry overall dimensions, with CAD imported file there maybe a confusion between meter and millimeter.
6. Check the mesh for double nodes or double elements.
7. Use a coherent system of units throughout the study.
8. As much as possible do some hand calculation to guess [and check] some of the result's key values.
9. Check the **code_aster** output results for mass, of the whole model, or group by group, with the expected values.
10. Check the coherence of the sum of the reactions with the supposed applied external loads for the various load cases.
11. Always read carefully the *.mess* file output:
    - if things went wrong, hints for the solution are lying in it;
    - if we got a result, the explanation why it may be meaningless often lies in it;
    - more generally, check all the warning messages lines, they begin with <A>.
12. Do not take for granted the colorful pictures and the associated scalar bars produced by the post-processing tool, always print in the *.resu* file the `VALE_MAX` and `VALE_MIN` for the same field and component, as we expect the post-processing tool to show the **code_aster** calculated values. If it does not[a], at first try to find out how and why the post-processor is misused.
13. Make sure that the *.mess*, *.resu* files we are reading in a text editor, and the *.med* file we are viewing in the Post-pro module really belongs to the same analysis of the same problem.
14. Before blaming the software, try to find out where and why things went wrong.
15. And if a bug is suspected[b] report it on the **code_aster** forums.
16. Be patient and obstinate.

[a] And experience shows it is not always the case!
[b] Yes it happens! A bug is commonly described as a "feature" by many developers.

APPENDIX B

Using Gmsh, tips and tricks

This appendix reviews some hints for a better use of Gmsh:

- how to really view what we want;
- how to use powerful Gmsh Plugins, to create a view of a composite result or to animate a mode shape;
- how to properly create and orient surfaces;
- a quick introduction to the legacy *.pos* Post-pro file;
- and a few more tips...
- to finish with the OpenCASCADE kernel introduced in version 3.*, allowing more 3D CAD like geometry operations.

2.1 Viewing the right results

We may get puzzled by the many mouse clicks necessary to view what we want in Gmsh Post-processing module, here are some hints.

First of all it is a good idea to go in Tools › Options › Mesh › Visibility and un-check everything so the post-processing view is not be polluted by some mesh views[1]. Pushing Alt + M is also useful to hide the mesh (or click the M in the status bar).

Another good idea is to disabled the lighting of the view which may make the post processing colors quite unreadable, for this Tools › Options › Color › Unable lighting in the post processing view.

In the **Gmsh** window only the checked views, numbered from [0] up are visible, for example in figure B.1 only view [2], named 'stat___DEPL' is checked and visible in the main window.

In the window Tools › Options all the options chosen in the right tab apply to the View[x] highlighted in the left-hand list.

2.1.1 Viewing `ELNO` type fields

To view one specific component in an `ELNO` type field (like forces or stresses) the following sequence must be followed:

1. in the Visibility tab pull the lower left list to Force scalar;
2. in the box immediately to the right type in the field Id (for a `SIPO_ELNO` field Id is 0 for `SN`, 4 is for `SMFY` for example);
3. in the General tab pull the list Range mode to Custom;
4. and push the Min and Max buttons to refresh the display with the proper component values.

We should not forget the Min and Max buttons to be sure that the displayed field and the scalar bar are matched.

Sometimes it is interesting to view on the graphical screen some numeric values and then the values on all the elements connected to a given node pile one on each other, the trick is then to slightly shrink the elements :

In View[x] go to the tab Aspect and adjust the field Element shrinking factor to a suitable value.

[1] Though sometimes it is useful to see the mesh or some groups in it.

2.1.2 Viewing vector type fields

To view the deformed shape:

1. in the Visibility tab pull the lower left list to Force vector[1];
2. in the Aspect tab pull the Vector display list to Displacement;
3. choose a significant value for Displacement factor.

And to view reactions as vector arrows:

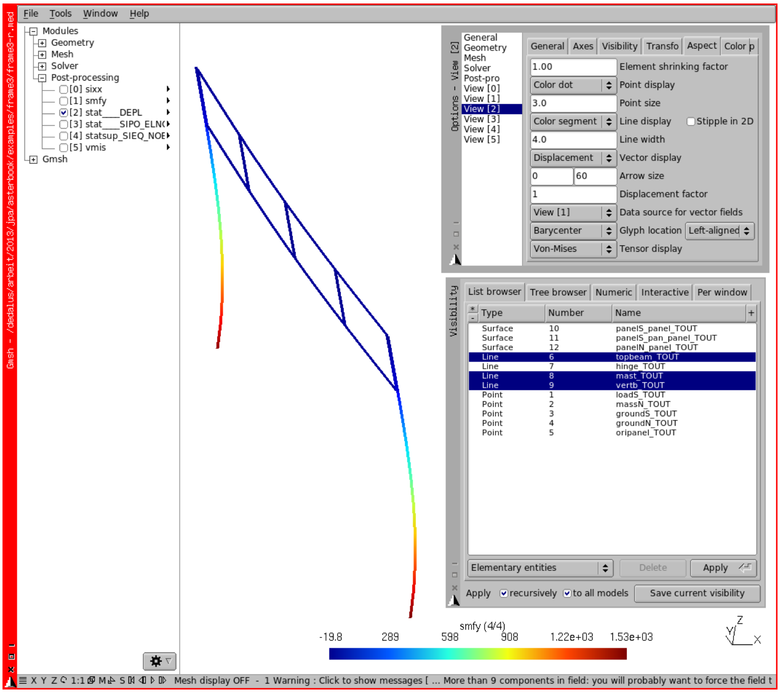
1. in the Visibility tab pull the lower left list to Force vector;
2. in the Aspect tab pull the Vector display list to Arrow;
3. pull the Glyph location list to Vertex to display the arrow on the nodes.

2.1.3 Viewing scalar fields on deformed shapes

The use of Data source list to View[x] allows to draw on the specified selected view a field coming from the Data source view, for example a stress field on a deformed shape.

For example view B.1 shows as active view View[2] which contains a field of `DEPL` type with a large displacement factor, to show the deformed shape, Data source is View[3] which is `smfy` bending stress. The Show scalar value is checked for View[2] and in addition in Tools » Visibility the view is restricted to some groups of elements.

[1] The word Force is quite misleading here as the field can be a displacement, or any field whose first three components makes a sensible vector.



1.00	Element shrinking factor
Color dot	Point display
3.0	Point size
Color segment	Line display ☐ Stipple in 2D
4.0	Line width
Displacement	Vector display
0 / 60	Arrow size
1	Displacement factor
View [1]	Data source for vector fields
Barycenter	Glyph location Left-aligned
Von-Mises	Tensor display

Type	Number	Name
Surface	10	panelS_panel_TOUT
Surface	11	panelS_pan_panel_TOUT
Surface	12	panelN_panel_TOUT
Line	6	topbeam_TOUT
Line	7	hinge_TOUT
Line	8	mast_TOUT
Line	9	vertb_TOUT
Point	1	loadS_TOUT
Point	2	massN_TOUT
Point	3	groundS_TOUT
Point	4	groundN_TOUT
Point	5	oripanel_TOUT

Mesh display OFF - 1 Warning : Click to show messages [... More than 9 components in field: you will probably want to force the field t

FIGURE B.1: Bending stress on deformed shape

2.2 Using Plugins

2.2.1 For creating and viewing a composite result

In this section, we see how Gmsh plugins can be used to view new results calculated from the existing ones. We create a result which is the vector of the displacement in the horizontal plane only, for our example *frame4*.

First of all, we add this in the command file so as to create a view for displacement component DX and another one for DY.

```
IMPR_RESU(
    MODELE=model, FORMAT='MED', UNITE=80,
    RESU=(
        _F(
            GROUP_MA=('topbeam','vertb','mast','panel',),
            RESULTAT=stat,NOM_CHAM=('DEPL',),
        ),
        _F(
            NOM_CHAM='DEPL',NOM_CMP=('DX',),NOM_CHAM_MED='dx',
            RESULTAT=stat,
        ),
        _F(
            NOM_CHAM='DEPL',NOM_CMP=('DY',),NOM_CHAM_MED='dy',
            RESULTAT=stat,
        ),
...........................
```

Once the calculation is made, we open the med result file in Gmsh

In the tree of the **Gmsh** window, we RMB click on the view named dx > Plugins,

- then in the pull down list, select MathEval,
- on the right-hand side frame, go down to the View field, we type 0, which is the number of the view where the component DX is displayed[1],
- and for OtherView field we choose 1, where the component DZ is displayed
- in the top field write the following equation `Sqrt(v0^2+w0^2)` which stands for $\sqrt{DX^2 + DY^2}$ where DX in the 'View' v0=View[1], DY in the 'OtherView' w0=View[2].

then Run[2].

A new View, number [10], is created at the end of the list, it contains a field with the value we have specified, we can change its name in Options > View general > View name.

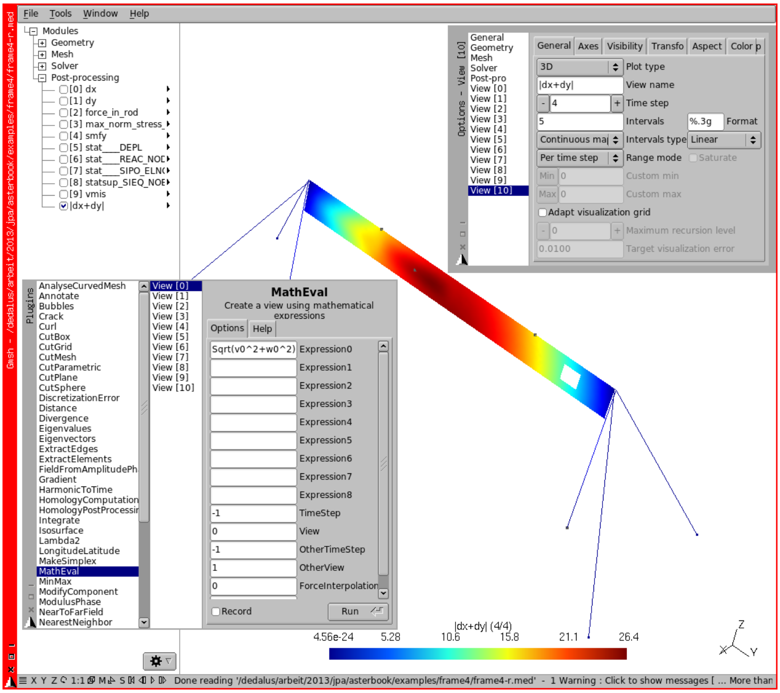
The same result could be obtained by typing View[0], using DEPL as data source and the formula `Sqrt(v0^2+v1^2)`.

Figure B.2 sums all this up with the result displayed.

If we tick the check box Record in the **Plugins** window a new file is created in the study directory named like the *.med* file with the extra

[1] It could well be a different number.

[2] We left the other fields by default, -1 means all, -1 for TimeStep means making the evaluation for all the existing values of TimeStep.



Plot type: 3D
View name: |dx+dy|
Time step: 4
Intervals: 5
Format: %.3g
Intervals type: Continuous ma| / Linear
Range mode: Per time step
Saturate
Custom min: Min 0
Custom max: Max 0
Adapt visualization grid
Maximum recursion level: 0
Target visualization error: 0.0100

Expression0: Sqrt(v0^2+w0^2)
Expression1:
Expression2:
Expression3:
Expression4:
Expression5:
Expression6:
Expression7:
Expression8:
TimeStep: -1
View: 0
OtherTimeStep: -1
OtherView: 1
ForceInterpolation: 0

Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame4/frame4-r.med' - 1 Warning : Click to show messages [... More than

FIGURE B.2: MathEval Gmsh plugin in action

extension *.opt*. Every time we open the med file in Gmsh the Plugin is run so as to enhance the result. This *.opt* file may be edited if we want to get rid of some results, or create new ones[1].

This was just a simple example of Gmsh Plugins the list and the possibilities are large[2].

Maybe just one note: this kind of *.opt* file may be appended to a *.geo* file to pass any valid Gmsh set of instruction to the main file, they will be executed on the fly when the file is read.

[1] If we open this file we can see that it contains the instructions we have just entered in the Gmsh GUI windows, which mean we can tailor the Plugins or create new ones juts by editing this *.opt* file.

[2] There is an Help tab in the Gmsh **Plugins** window briefly describing the Plugin functions and the syntax.

And a final note the same result can be achevied by usinf a user field CHAM_UTIL as described in section 19.7 .

2.2.2 For animating a mode shape

A modal analysis result is a displacement result related to time, it would be good to view the deformed shape as an animated view, this is possible in Gmsh. We do it now, for mode 7, at 196 Hz, of the pendulum example of chapter 15.1 .

In Gmsh all the mode shape are saved in a single view, we first extract the right view, due to Gmsh numbering it happens to be at 'Time step 6'. We extract this 'Time step' in a new view using Plugin 'Extract Elements':

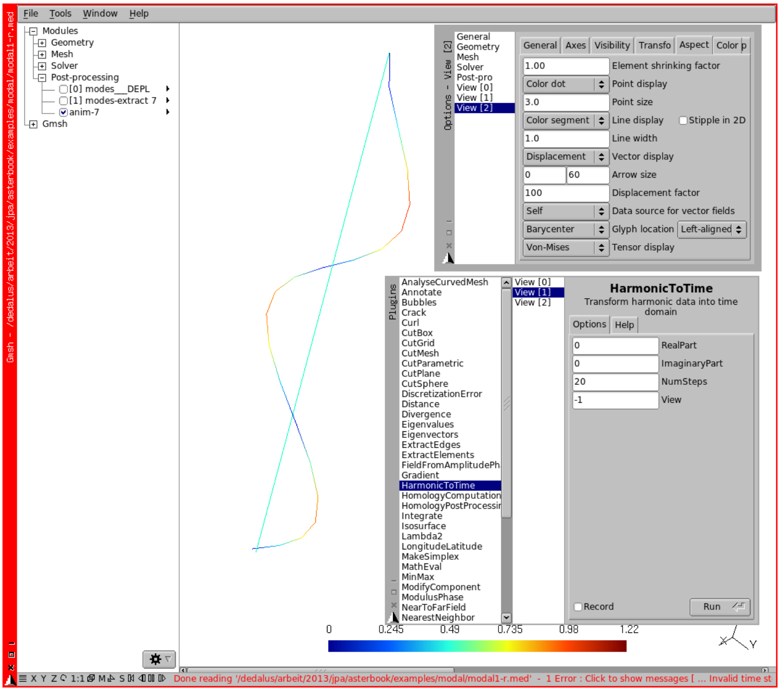
- setting TimeStep to 6;
- setting Visible to 1;
- setting Dimension to -1;
- setting View to 0, as we extract from view [0],

and we rename this newly created view [1] 'modes-extract 7'.

And now, we RMB click on the view named [1] modes-extract 7 > Plugins,

- then in the pull down list, select HarmonicToTime;
- on the right-hand side frame, set the values as below:
  - RealPart=0;
  - ImaginaryPart=0[1];
  - NumSteps=20 to set the number of views of the animation;
  - View=-1 to run the plugin on the current view;
- pushing Run creates a new view[2].

[1] We are taking the real part of view 0 and the imaginary part of view 0 as well, mixing up the view numbers would lead to meaningless result display.
[2] We may explore the Help tag to fully understand the meaning of the parameters.



1.00 Element shrinking factor
Color dot Point display
3.0 Point size
Color segment Line display ☐ Stipple in 2D
1.0 Line width
Displacement Vector display
0 60 Arrow size
100 Displacement factor
Self Data source for vector fields
Barycenter Glyph location Left-aligned
Von-Mises Tensor display

HarmonicToTime
Transform harmonic data into time domain
0 RealPart
0 ImaginaryPart
20 NumSteps
-1 View

Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/modal/modal1-r.med' - 1 Error : Click to show messages [... Invalid time st

FIGURE B.3: HarmonicToTime setup with a snapshot of animation

Making this view active and pushing the little Play button at the bottom of the window runs the animation as long as Force Vector is selected in Visibility and a large enough Displacement value[1] is set in the Aspect tab.

Figure B.3 shows the plugin's dialog box setup together with a snap shot of the animation.

2.3 Orienting Surfaces

We have stressed earlier the fact that a proper orientation of surface elements is needed, otherwise the loads may not be what expected and/or the stress results may be meaningless. Let's take the example of the

[1] In this very example a value of 100 provides a sensible view.

frame3.geo of example *frame3* to illustrate the way surfaces are oriented in Gmsh as shown on figure B.4[1].

Surface 311 is defined this way:

```
Curve Loop(310) = {201, 110, −210, −10};
Plane Surface(311) = {310};
```

The `Curve Loop` describes the surface's borders in a sequential way[2] just like we were walking along the border:

- 201 is the first Line;
- 110 is the second one, this couple sets the surface Normals, shown here in red;
- 210 and 10 are the next lines, they are changed of sign because they are walked on the reverse way when describing the border, the orientation of the lines, the Tangents are here shown in yellow.

The next Line `Plane Surface` creates the plane from the loop.

A loop made with RMB on the lines in the GUI produces a valid surface. On the contrary when we do so in a script, directly in the text editor, it is very easy to create an inverted loop, upon reading by Gmsh this causes an annoying crash!

Hollowed Surface 325 and the little inside surface 335 are created like this:

```
Curve Loop(320) = {210, 120, −220, −20};
Curve Loop(321) = {280, 270, −260, −250};
Plane Surface(325) = {320, 321};
Plane Surface(335) = {−321};
```

The first loop is just as before, it sets the normal to the surface, the loop 321 sets an inner border for the hollow, and `Plane Surface` sets the surface[3].

The surface 335 is created from the second loop, reverting the loop number, with the minus sign to keep a consistent normal with surface 325, this because the loop 321 is walked along in the direction opposite to loop 320.

[1] On the figure the **Gmsh** tree is teared off to a proper box with Window 〉 Attach/Detach Menu.

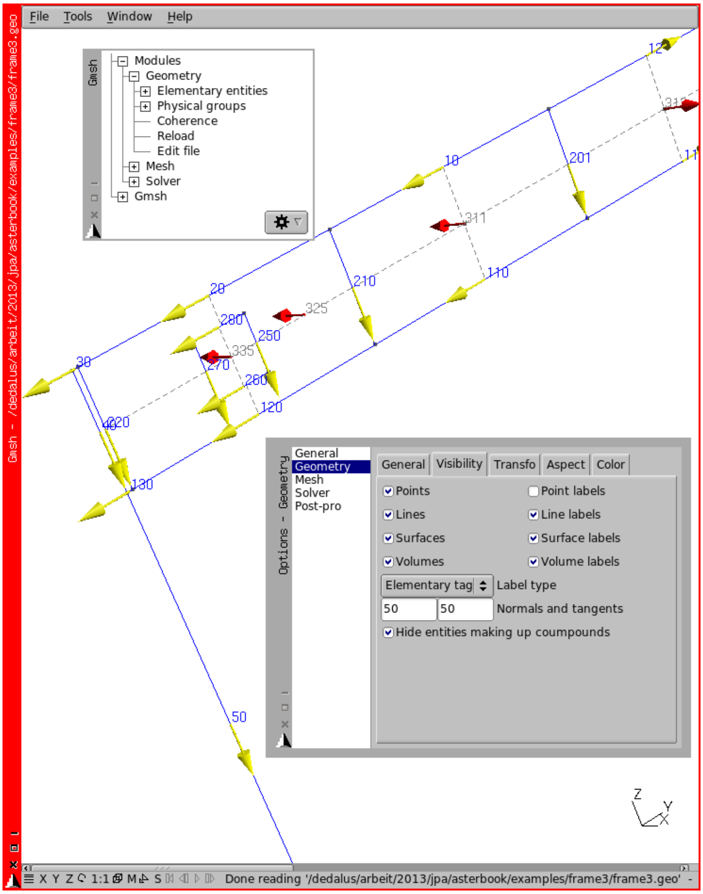
[2] It may not be the order in which we clicked on the Lines in the GUI.

[3] There may be more inner loops than a single one

We must point here that an extreme care must be taken in orienting the normals to the surfaces, we must choose one policy consistent with the problem and the way the *.comm* file is written.

In fact it is somewhat easier to do in practice than to explain!

And, as we stated in chapter 8 it is a good practice to reorient the surfaces within the MODI_MAILLAGE operator.



☑ Points ☐ Point labels
☑ Lines ☑ Line labels
☑ Surfaces ☑ Surface labels
☑ Volumes ☑ Volume labels
Elementary tag Label type
50 50 Normals and tangents
☑ Hide entities making up coumpounds

Done reading '/dedalus/arbeit/2013/jpa/asterbook/examples/frame3/frame3.geo'

FIGURE B.4: Surface orientation

2.4 Using the legacy Gmsh Post-pro files

When using STANLEY we have seen result windows popping out named **fort33.pos**, this is the legacy Gmsh graphical Post-pro format. The next code abstract would print such a file in LU 37 if appended to the command file of example *frame3*.

The main advantage of this file format is, it can be scripted at will, “à la Gmsh”.

Another nice advantage is that the component, `CMP`, together with the field, `CHAM` is printed in the title, which sadly missing in the *.med* format.

Its disadvantage: no group selection for viewing can be done within the GUI, it has to be specified in the command file, or scripted.

```
IMPR_RESU(
    FORMAT='GMSH',
    UNITE=37,
    RESU=(
        _F(
            GROUP_MA=('topbeam','vertb','mast','panel',),
            RESULTAT=stat,NOM_CHAM=('DEPL',),
            #next 2 lines to be able to view the deformed shape
            #and or arrow vectors
            #this maybe applied to REAC_NODA,
            #and all vector fields as well
            NOM_CMP=('DX','DY','DZ',),
            TYPE_CHAM='VECT_3D',
        ),
        _F(
            GROUP_MA=('topbeam','vertb','mast','panel',),
            RESULTAT=stat,NOM_CHAM=('DEPL',),
            #to print all individual components
        ),
        _F(
            GROUP_MA=('topbeam','vertb','mast',),
            #if no CMP are specified they are all printed
            #and this can lead to very large files
            RESULTAT=stat,NOM_CHAM=('SIPO_ELNO',),
        ),
        _F(
            GROUP_MA=('topbeam','vertb','mast',),
            RESULTAT=stat,NOM_CHAM=('SIPO_ELNO',),
            NOM_CMP=('SMFY',),
        ),
        _F(
            GROUP_MA=('topbeam','vertb','mast','panel',),
            RESULTAT=stat,NOM_CHAM=('SIPM_ELNO',),
            NOM_CMP=('SIXX',),
        ),
        _F(
            GROUP_MA=('panel',),RESULTAT=statsup,
            NOM_CHAM='SIEQ_NOEU',NOM_CMP='VMIS',
        ),
        _F(
            GROUP_MA=('panel',),RESULTAT=statsup,
            NOM_CHAM='SIEQ_NOEU',
        ),
    ),
);
```

More details are described in U7.05.32.

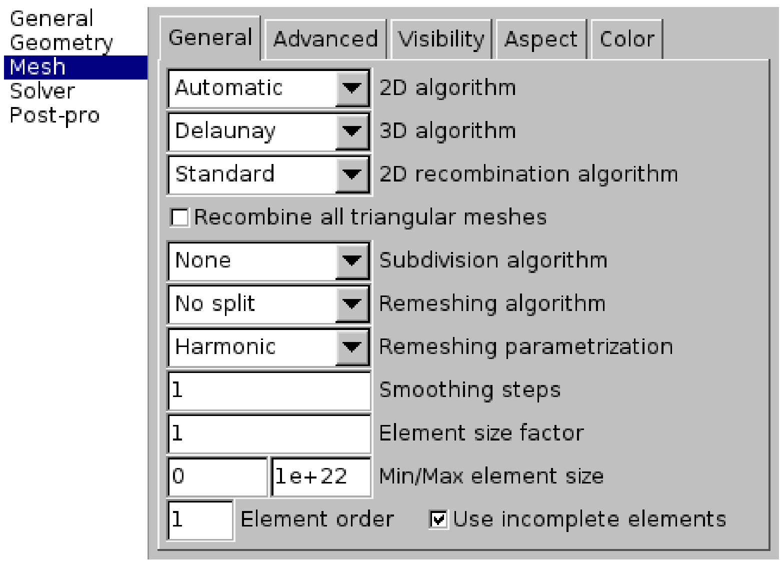
2.5 Meshing algorithms

Gmsh handles quite a few algorithms for meshing in 2D or 3D, they are available in Mesh > General > 2D algorithm pull down list or Mesh > General > 3D algorithm pull down list. Most of the time some tweaking around is necessary until one gets a satisfactory mesh.

Mesh > General > 2D recombination algorithm allows some flexibility on how the triangular elements are recombined in quadrangular elements if the check box Mesh > General > Recombine all triangular meshes is checked.

The equivalent can be put at the beginning of the *geo* script with lines like :

```
Mesh.Algorithm 1
//2D mesh algorithm
//(1=MeshAdapt, 2=Automatic, 5=Delaunay,
//6=Frontal, 7=BAMG, 8=DelQuad)
//Default value: 2

Mesh.Algorithm3D 1
//3D mesh algorithm
//(1=Delaunay, 2=New Delaunay, 4=Frontal, 5=Frontal Delaunay,
//6=Frontal Hex, 7=MMG3D, 9=R-tree)
//Default value: 1
```


General
Geometry
Mesh
Solver
Post-pro

General | Advanced | Visibility | Aspect | Color

Automatic — 2D algorithm
Delaunay — 3D algorithm
Standard — 2D recombination algorithm
☐ Recombine all triangular meshes
None — Subdivision algorithm
No split — Remeshing algorithm
Harmonic — Remeshing parametrization
1 — Smoothing steps
1 — Element size factor
0 | 1e+22 — Min/Max element size
1 — Element order ☑ Use incomplete elements

FIGURE B.5: Gmsh mesh algorithms

2.6 Importing geometry files

It is not a good idea to import directly a *step* or *iges* file in the Gmsh GUI and to make the necessary changes from there, a far better idea is to create a *geo* along this template[1].

```
//import the step file
Merge "imported_step_file.stp";

//optionally create some new points
//be careful not to overwrite existing points
Point(1037) = {-650, -420, 188, 40.0};

//set some tolerance, values have to be adapted
Geometry.AutoCoherence=1;
Geometry.Tolerance=1e-6;
Mesh.ToleranceEdgeLength=0;

//set the mesh element size
Characteristic Length {1:1065} = 15;
```

[1] The Id used in this abstract are of course just an example.

```
Characteristic Length { 476, 477, 478, 479,} = 2;

//build the groups
Physical Volume("body") = {1};
Physical Surface("couron") = {192, 413};
Physical Point("centerp") = {1041};

//do not forget Coherence
Coherence;
```

If a 3D volume *step* file contains only one part building different groups may become a nightmare.

If it contains several parts a few commands in the GUI may reveal useful :

- Geometry › General › Cut and merge faces helps in ensuring mesh continuity along the shared edges ;
- Geometry › General › Sew faces is less obvious ;
- Geometry › General › Remove degenerated edges and faces ;
- Geometry › General › Remove small edges ;
- and Geometry › General › Remove small faces do what it is meant to do.

A few remarks about step format and Gmsh:

- The only line type known, in the *.step* file is BSpline or NURBS, and the controls points are shown as points in Gmsh, thus a straight line shows many control points along its length. Once meshed nodes do not necessarily sit on these control points!
- One BSpline may describe one circle arc equal to or larger than π, then very strange things may happen at mesh time. Ideally the source CAD file should use only circle arc smaller than π[1].

[1] A full circle needs at least three arcs

2.7 Importing Nastran® and other alien mesh files

If we import a Nastran® created data file, *.bdf* or *.dat*, we may find that the groups created do not seem to exist any more. In fact all the properties related to groups are described as “Elementary Entity”.

The code given below allows to restore the groups. If we open it in Gmsh we can see at the end of the translation a *.msh* file appearing on the screen as well as being saved, with all the groups restored.

```
Merge "/my_problem.bdf";

vols[] = Volume "*";
For i In {0 : #vols[] - 1}
  Physical Volume(vols[i]) = vols[i];
EndFor

surfs[] = Surface "*";
For i In {0 : #surfs[] - 1}
  Physical Surface(surfs[i]) = surfs[i];
EndFor

lines[] = Line "*";
For i In {0 : #lines[] - 1}
  Physical Line(lines[i]) = lines[i];
EndFor

Save "/my_problem.msh";
```

Restored groups, but without names, only Ids! Next bit of code added at the beginning of the *.msh* file will name the groups. Then it is just a matter of saving it as a *.med* file

```
\$MeshFormat
2.2 0 8
\$EndMeshFormat
\$PhysicalNames //example for 'frame3'
11              //number of groups
0 7 "groundS"   //0 for point group, 7 is the Id, "group_name"
0 8 "groundN"
0 9 "loadS"
0 10 "massN"
0 11 "oripanel"
1 1 "topbeam"   //1 for line group
1 2 "hinge"
1 3 "mast"
1 4 "vertb"
2 5 "panelN"    //2 for surface group
2 6 "panelS"
\$EndPhysicalNames
```

```
\$Nodes
...................
```

`http://laurent.champaney.free.fr/perso/outils.html` provides a few perl scripts converting fea files. I found the utility *dxf2geo*, converting *.dxf* to *.geo* quite handy. There also are scripts for NASTRAN®, CAST3M®, SAMCEF®, UNV®, ABAQUS®.

2.8 Customizing Gmsh

Menu File ≫ Save Model Options saves a file with the current file name plus the extensions *.opt* containing all the options of the current file. Opening again *current_file_name* loads the options with it.

Menu File ≫ Save Options A default saves the current options as default Gmsh options in *$HOME/.gmsh-options*.

The file *$HOME/.gmshrc* holds the options specific to a session when *$HOME/.gmsh-options* holds wider scope options, in these files, with the help of the manual we can configure Gmsh just as we want.

2.9 Using the Open CASCADE kernel

2.9.1 Introducing Open CASCADE

CAS.CADE (abbreviated from Computer Aided Software for Computer Aided Design and Engineering) was originally developed in the early 1990s by Matra Datavision, developer of Euclid CAD software as the underlying infrastructure for its future version Euclid Quantum. In 1998 the company abandoned software development to concentrate on services, and most of the software development facilities were sold to Dassault Systèmes, developer of competing CATIA.

In 1999 Matra Datavision decided to publish its CAS.CADE infrastructure under an open-source model under the Open CASCADE Technology Public License and renamed it Open Cascade.[1]

Open Cascade is at the root of Salome development and of a few other open source CAD software like FreeCAD.

[1] The above sentences coming from `https://en.wikipedia.org/wiki/Open_Cascade_Technology`.

2.9.2 Using Open CASCADE in Gmsh

In the conventional use, the one we used in all the previous examples of this book:

“Gmsh uses a boundary representation (“BRep”) to describe geometries. Models are created in a bottom-up flow by successively defining points, oriented lines (line segments, circles, ellipses, splines, . . .), oriented surfaces (plane surfaces, surfaces, triangulated surfaces, . . .) and volumes.”

“Starting with Gmsh 3.0, models can also be built using constructive solid geometry. Instead of the built-in geometry kernel, you need to use the OpenCASCADE kernel:

SetFactory("OpenCASCADE");

In addition to the "bottom-up" geometry commands, you can now use "top-down" commands[1].

2.9.3 Drawing examples with OpenCASCADE kernel in Gmsh

The following code draws the ’part2’ of the example in chapter 12.

```
//'part2' geometry
//using OpenCASCADE kernel
cl1=2.0; //characteristic length, for meshing
off1=5.5; //y offset from part 1
t1=5; //thickness of half part
r1=10.5; //inside radius of eye
r2=17.0; //outside radius of eye

//to use OpenCASCADE kernel
SetFactory("OpenCASCADE");

//outer cylinder of the round end
Cylinder(1) = {0,-off1,0, 0,-t1,0, r2};
//inner cylinder of the round end
Cylinder(2) = {0,-off1,0, 0,-t1,0, r1};
//rectangular shaft
Box(3) = {0,-off1,-r1, -4*r2,-t1,2*r1};

//union of outer cylinder and shaft
v0() = BooleanUnion{ Volume{3}; Delete; }{ Volume{1}; Delete; };
//differece for the final part
v1() = BooleanDifference{
```

[1] The above sentences coming from Gmsh documentation.

```
    Volume{v0}; Delete; }{ Volume{2}; Delete;
};

//to create unique surfaces, lines and points
//at the boundary of the volume
s1() = Unique(Abs(Boundary{ Volume{v1()}; }));
l1() = Unique(Abs(Boundary{ Surface{s1()}; }));
p1() = Unique(Abs(Boundary{ Line{l1()}; }));

Characteristic Length{p1()} = cl1;

//create Physical
Physical Point ("move2p") = {11};
Physical Surface("bear2s") = {2,6,10};
Physical Surface("hole2s") = {11};
Physical Surface("fix2s") = {1};
Physical Surface("pres2s") = {8,12};
Physical Volume("part2v") = {v1};

//coloring
//all surfaces in Cyan
Color Cyan{
   Surface{s1};
}
//then
Color Orange{ Surface{2,6,10}; }
Color Purple{ Surface{8,12}; }
Color Black { Surface{11}; }
Color Blue{ Surface{1}; }
Color Magenta{ Volume {v1};}
```

The code creating the part is quite compact, just a few lines.

But it is not so obvious to logically extract the Ids of the required surfaces that are at the boundary of the volume to create Physicals.

APPENDIX C

Using discrete elements

This appendix reviews how to use and set the proper values of the discrete stiffness and mass elements, point and line.

3.1 Stiffness matrix

When using discrete element to mimic end release at the end of a beam it is best to use the right[1] values for the stiffness matrix coefficients. This is particularly true if one wants to retrieve the lateral shear force on a lug and pin assembly, for example.

[1] Or as right as possible!

3.1.1 `K_TR_D_L` element

Here are some formulae to calculate the coefficients for a `K_TR_D_L` element.

$$K_x = K1_n = \frac{EA_x}{s}$$

$$K_y = K1_z = \frac{12}{\beta s^3} EI_z$$

$$K_z = K1_y = \frac{12}{\alpha s^3} EI_y$$

$$KR_x = K1_x = \frac{GI_x}{s}$$

$$KR_y = K3_y = \frac{3+\alpha}{\alpha s} EI_y$$

$$KR_z = K3_z = \frac{3+\beta}{\beta s} EI_z$$

where

$K_x, K_y, ...KR_x, ...$ are the notations used in U4.42.01.

$$\alpha = 1 + \frac{12EI_y}{GA_z s^2} \qquad \beta = 1 + \frac{12EI_z}{GA_y s^2}$$

s being the length of the element, E the Young modulus and G the Coulomb modulus[1].

This, applied to a solid rectangular section, $HY = 10$, $HZ = 100$, yields the following value:

$$A_x = HY.HZ = 1000$$

$$A_y = A_z \simeq \frac{2A_x}{3} = 667$$

$$I_x = \frac{HY^3.HZ}{3} = 33333^{2}$$

[1] The above formulae and the notation are extracted from [Tuma].

[2] HY^3 as $HY << HZ$, this value is more and more false as HY gets closer to HZ to become $2.25 \times H^4$ when $H = HY = HZ$.

$$I_y = \frac{HY.HZ^3}{12} = 833333$$

$$I_z = \frac{HY^3.HZ}{12} = 8333$$

When one wants to relax a rotation around an axis the KR* should be set to zero or a very small value.

We can print the `SIEF_ELNO` or `EFGE_ELNO` for these elements and make the proper dimensioning of lugs and pins by hand.

We should be careful for the choice of the length "s" in calculating the stiffness matrix values, as too high a value may give wrong results, not only in the discrete elements but in the surrounding ones.

This is due to the fact that the stiffness matrix is diagonal as reflected in the `D` of its name. This means that a shear force (or a lateral displacement) at the left end of the element is transmitted as a shear force at the right end but does not produce a bending moment at the right end, neither does it produce a rotation of the left end.

To solve this issue we have to use `K_TR_L` elements.

3.1.2 `K_TR_L` element

With this element we mimic exactly the behavior of of beam element. The drawback is: we have to fill the full matrix with 78 terms!

First of all, we need to compute the terms linking left shear force to right bending moment:

$$K2_y = \frac{6}{\alpha s^2} EI_y$$

$$K2_z = \frac{6}{\beta s^2} EI_y$$

$$K4_y = \frac{3-\alpha}{\alpha s} EI_z$$

$$K4_z = \frac{3-\beta}{\beta s} EI_z$$

Then fill the matrix like this:

```
#numerical value for a rod section, diam 10 mm, length 100 mm
k1n=1.65e5;
k1z=1.23e3;
k1y=1.23e3;
k1x=7.93e5;
k3y=4.06e6;
#k3y=0; #release rotation about local y
k3z=4.06e6;
k2z=6.05e4;
k2y=6.05e4;
#k2y=0; #release rotation about local y
k4y=2.00e6;
#k4y=0; #release rotation about local y
k4z=2.00e6;
elemcar=AFFE_CARA_ELEM(
MODELE=model,
  DISCRET=(
    _F(
      GROUP_MA=('kt',),
      CARA='K_TR_L',
      VALE=(
        k1n,
        0.0, k1z,
        0.0, 0.0, k1y,
        0.0, 0.0, 0.0, k1x,
        0.0, 0.0,-k2y, 0.0, k3y,
        0.0, k2z, 0.0, 0.0, 0.0, k3z,
       -k1n, 0.0, 0.0, 0.0, 0.0, 0.0, k1n,
        0.0,-k1z, 0.0, 0.0, 0.0,-k2z, 0.0, k1z,
        0.0, 0.0,-k1y, 0.0, k2y, 0.0, 0.0, 0.0, k1y,
        0.0, 0.0, 0.0,-k1x, 0.0, 0.0, 0.0, 0.0, 0.0, k1x,
        0.0, 0.0,-k2y, 0.0, k4y, 0.0, 0.0, 0.0, k2y, 0.0, k3y,
        0.0, k2z, 0.0, 0.0, 0.0, k4z, 0.0,-k2z, 0.0, 0.0, 0.0, k3z,
      ),
      SYME='OUI',
      REPERE='LOCAL',
    ),
    #here for a 'K_TR_D_L' element
    #_F(
      #GROUP_MA=('ktd',),
      #CARA='K_TR_D_L',
      #VALE=(k1n, k1z, k1y, k1x, k3y, k3z,),
      #REPERE='LOCAL',
    #),
  ),
);
```

With this quite lengthy input, the element can be any length and behaves just like a short beam, except on the relaxed DOF, or DOFs. The fancy layout just above tries to display the lower half of the symmetrical matrix in a clean manner. We could even input an unsymmetrical matrix if needed, more about this in U4.21.01[1].

3.2 Mass matrix

In the simpler case we use discrete element, M_T_D_N, to model a point mass, this is quite straightforward and is explained in chapter 4.6 . Furthermore the mass may be given an offset, which is useful in some dynamic calculation, this is fully explained in #U4.42.01.

3.3 Combining both

If one single discrete line element carries at the same time a mass and a stiffness it needs two entries in AFFE_CARA_ELEM. Here is an abstract of code allowing to give a mass to the stiffness line element of *frame2* example:

```
elemcar=AFFE_CARA_ELEM(
    MODELE=model,
    ......................
    DISCRET=(
        _F(
            GROUP_MA=('hinge',),
            CARA='K_TR_D_L',
            #the values used in the previous calculation
            #VALE=(1.00e6,1.00e6,1.00e6,1.00e9,0,1.00e9,),
            #the values calculated with this chapter's formula
            VALE= (3.59e6,6.32e5,3,22e5,2.16e8,0,2.58e8,),
            REPERE='LOCAL',
        ),
        _F(
            GROUP_MA=('hinge',),
            CARA='M_TR_D_L',
            VALE=(M1,M2,M3,M4),
            REPERE='LOCAL',),
        ),
    ),
    ......................
);
```

Where:

[1] The slightest error in the indexing of the matrix components produces, of course, wrong results.

- $M1$ is half the mass of the element[1];
- $M2$ is the rotational moment of inertia of the element about its own axis;
- $M3$ and $M4$ are the rotational moments of inertia of the element about the perpendicular axis.

Which gives for a prismatic element:

$$M1 = \frac{m}{2}$$

$$M2 = \frac{m.r^3}{3}$$

$$M3 = M4 = \frac{m.s^2}{12}$$

m being the mass of the element, s its length and r the radius of gyration of the element cross section[2].

In most practical static problems, with a short element length, giving the value of $M1$ is enough.

3.4 Using 0 length line element

In the example in chapter 7 we used `K_TR_D_L` elements with a length of $10mm$, the problem could have been solved using a length of 0 mm i.e. the two nodes of the elements would be sitting at exactly the same place.

We do not recommend doing so for the following reasons :

- at mesh times the two nodes may be merged into a single one and the line element will be discarded raising a run time error, this will happen in Gmsh if we use `Coherence` at some place in the *.geo* file ;

[1] Yes, half the mass here, don't ask me why!
[2] For more complete computing of the mass matrix we, again refer to [Tuma].

- as the length of the line is 0 its orientation is somewhat difficult to know unless it is forced with the keyword `ORIENTATION` with `CARA=VECT_Y`;
- in true life the joint between two elements is having a physical length, better use it!

In the same manner, using a single node, `POI1` element with `K_TR_D_N` properties to model a joint is really calling for trouble!

The problem seems sane and should be solved without any warning or error but the results will not be the expected one.

With this we do not have an element with one or more relaxed DOF at one end but a fixed joint between two elements with a node carrying some stiffness at the same place, which is not the same thing!

APPENDIX D

Installing and maintaining, tips

A web page is only a page until its printed. Then it can be any number of pages.

Kent's Law.

How to install, update, maintain **code_aster** and Gmsh.

In the next sections we, quite often, find the sequence: download an archive, unpack it... It is a wise idea to perform, before anything else, a "md5sum"[1] checkup to ensure the archive integrity, any archive failing this checkup should be immediately discarded!

4.1 **code_aster** installation

For a stand alone version of **code_aster** go to this link:

`http://www.code-aster.org`

[1] If this package is not installed by default in our distribution, we have to install it (in openSUSE it is in coreutils package).

Look for the download area, once it is found, download the archive that suits.

For the installation, *strictly* follow the instructions given on the page.

I make the installation in */opt/asterxxx*, where xxx is the aster version number[1]. Of course I change the ownership of this directory so that I own (and not root) this directory with read and write access.

This is how this can be done from a generic command line, open a terminal and type the following commands[2] supposing that "myself" is our user name:

```
#we suppose myself is the user name
#in most Linux distribution it (myself) belongs to users group
#change to directory /opt
cd /opt
#become root
su
#at prompt give password
#create sub directory /asterxxx
mkdir asterxxx
#change the owner of /asterxxx
chown myself:users ./asterxxx
```

The line `ASTER_ROOT='/opt/asterxxx'` has also to be changed in the *setup.cfg* file, sitting in the unpacked archive directory.

This installation is somewhat long, about 30 minutes, as it is a true compilation, not installation of binaries.

In the grand old days there was, somewhere in the installation directory a sub-directory with a substantial set of documentation. This is no longer the case and the documentation must be read online, thankfully it is *.pdf* files which can be downloaded for a more comfortable local reading.

The full set can also be downloaded, it's an archive of over 300 Mb.

And finally the English version is an excellent demonstration of what machine translation can do, in good, and in bad[3]. But it is much better than nothing.

In addition **code_aster** comes with a bundle of test cases, lying in *$ASTER_ROOT/13.6/share/aster/tests* these tests maybe studied and run to understand usual or unusual commands.

[1] With this method i keep a working installation of previous versions, just in case.

[2] A line beginning with # is a comment.

[3] Not to say “worst”!

Finally the first installation may take quite a long time as some pre-requisites will probably be missing! They are not all checked on the first 'configure' part of the compilation.

Also as **code_aster** is compiled we have to install the 'dev' version of the packages.

This will ease up on further installations though, nevertheless it is a good idea to have a look at this page:

`https://www.code-aster.org/V2/spip.php?article91`

At the time of this writing Python 3.x is not yet supported by **code_aster** and some Linux distribution have decided that Python 2.7 was deprecated and do not install it, in this case we will have to install its package[1].

4.2 **code_aster** versions

On the **code_aster** download page one can see several versions available. Here are some hints about their naming, helping to choose the one that suits[2]:

- ***stable***

  This release is the version of exploitation validated by EDF on the basis a complete documentation and tests of validation put on line. This version is the object independently of a qualification by EDF for its internal needs. During two years, it is put up to date every six months, by integrating only bug fixes, without modification of the user interface or documentation.

- ***unstable***

  This version is weekly updated with the new features and bug fixes. That refers to the updates numbered 11.x.y.

[1] This is for the installation only as once installed **code_aster** uses its own embedded Python 2.7.

[2] This description is abstracted from Pronet website

- ***testing***

  That version is a frozen state, each six months, of the “unstable” version. It is updated every six months.

At the time of this writing, October 2013, we have:

- stable, 13.6.
- testing, 14.2.

Since version 13.6 and 14 **code_aster** will only print graphical results in 3.3 *med* format, hence needing Gmsh version 4 to read them.

However **code_aster** version 13.6 and 14 are able to read *med* 3.2 as mesh input.

code_aster version 13.4 and earlier only handle 3.2 *med* format.

4.3 **code_aster** setup

The following is a summary of how I solved some issues, with quite a bit of trial and error, but, there may be other ways, or my advice may not work.

Once we get working with **code_aster** graphical tools, like STANLEY, the tool may not launch at all with nasty messages in the *.mess* file. Here is the usual workaround:

In the **ASTK** window, menu Configuration > Preferences > Network:

- the Client machine name field should be the machine name, which can be obtained by typing the command ’hostname’ in a terminal;
- the Domain name can be left empty;
- Forced DISPLAY variable can be set to :0.0;
- and button ssh and scp pushed on.

And STANLEY should then launch itself on request.

Some other issues may need to apply the following recipes:

In the **ASTK** window, menu Configuration ≫ Servers... the Server name maybe changed from localhost to the machine name as above.

If nothing happens when we push TRACER in **STANLEY** window, despite a green light, lets try the following:

In the **STANLEY** window, menu Parametres ≫ Editer, in the pull down list right off Mode choose Gmsh/Xmgrace, push OK it should then work in this mode.

When the setup is right the interactive follow-up box in **ASTK** may be checked and when pushing Run a terminal window opens telling us all what's going on, in fact it is almost a copy of what is written in the *.mess* file, quite useful in case of longish problems, we know where we are.

Some of these advice are worth only for a single machine setup, the same machine acting as client and calculation server.

4.4 Modify STANLEY source code

Unfortunately STANLEY does not work properly on the recent version of **code_aster** [1].

However this can easily be corrected, this is how to proceed[2]:

- Locate the file *stanley_engine.py*[3].
- Locate this line:

  ```
  if self.selection.contexte.resultat.__class__
  == mode_meca and self.selection.nom_cham ==
  'DEPL':
  ```

  this should be something line 1766.
- Replace it by

  ```
  if self.selection.nom_cham == 'DEPL':.
  ```

[1] At least until the developers modify the code accordingly.
[2] This come from this forum post
`https://www.code-aster.org/forum2/viewtopic.php?id=23103`
[3] For a 14.2 version it is lying at $ASTERROOT/14.2/lib64/Stanley/.

4.5 **code_aster** directories maintenance

Every time a study is launched:

- a directory is created in */tmp*, its name maybe something like *user-machine-xxxx-user*[1] where:
  - `user` is user's name;
  - `machine` is machine name;
  - `xxxx` is the job unique ID and is a randomly created number.

  this directory is created with user permissions, after the study is successfully finished it contains almost only *xxxx-user.export*;
- a few files are created in *$HOME/flasheur*, they are named, for example *frame3-oxxxx-user*[2]. File *frame3-oxxxx-user* contains full information about the calculation run, a bit more than the *.mess* file.

These directories and files are never automatically deleted [3] [4], we have to delete them at times otherwise **code_aster** may run out of disk space, in which case the study may stop abruptly without any clear error message.

4.6 Gmsh installation

To get Gmsh go to this link:

`http://geuz.org/gmsh/`

Download the "Current stable release", which is a *.tgz* archive. Unpack it somewhere, I do that in */opt*, again as regular user.

The executable is then */opt/gmsh/bin/gmsh*. Run it any way, command line, launching script or window manager menu entry[5].

[1] This naming convention changed from time to time.
[2] There are also files with preceding letter o, i, u ,e ,p.
[3] At least on my openSuSE distribution as a standard setup.
[4] However a study */tmp* directory and the files in *$HOME/flasheur* can be deleted in the **ASJOB** window.
[5] It is always a good idea to try launching any software from a terminal for the first time as there is then a clear warning of what is missing or what is going wrong.

There is no real need to compile anything from source for an everyday use, I have never done it[1] !

On the same link under *Documentation* the *Reference manual* is also a very useful mine of information.

4.7 Gmsh versions, 3.0.* and 4.0.*

Up to version 3.0.7 Gmsh could only make and read *med* files in version 3.2.

Since version 13.6 and 14 **code_aster** will only print graphical results in 3.3 *med* format, hence needing Gmsh version 4 to read them.

4.8 Linux distribution packages

Some Linux distribution[2] offers a package for Gmsh.

This is the best way to install a outdated version of Gmsh and I do not advise to install this!

In the same way some distribution proposes a package (or several packages) to build **code_aster** , I tried it out and was far from being convinced of the advantage of this over the standard way of installing **code_aster** .

And the version was just as well pretty much outdated, I do not advise to install this!

4.9 Windows® installation

If you really want to use a Windows operating system.

The windows version of Gmsh is no different from the Linux one[3].

There is around a Windows version of **code_aster** , I have no experience with it but it looks like working properly.

[1] Except for fun!
[2] Here I have experience with Debian.
[3] There is also a MacOs® version.

However it seems to me that using **code_aster** gives a chance to have a try at Linux and once being used to it it will probably difficult to go back.

Installing on Windows a virtual machine running a Linux distribution is the best way to begin with, and VMware® or VirtualBox® are pretty good at that.

As far as virtualization is concerned another recent opportunity is docker®[1]. A quick search in **code_aster** forum with the keyword "docker" will give more information about a **code_aster** container by user "tianyikillua" the code being hosted at `https://quay.io/user/tianyikillua`.

4.10 Uninstallation

As both, **code_aster** and Gmsh are full stand alone installation there is only one thing to do to uninstall them: remove the directory they have been installed in, that's all.

If we have created some launching scripts, desktop menu entries and/or desktop icons they will of course point to no existing objects after that!

4.11 A word about CAELinux

There is a very easy way to try out all these programs, it comes under the shape of a live CD containing all of them, plus much more. This is called CAELinux.

It can be downloaded from: `http://caelinux.com`

I have started this way!

The site contains also a wiki, a forum and many useful information.

In the Wiki among may useful sections I must quote the ones by:

- Claws Andersen: `http://www.caelinux.org/wiki/index.php/Contrib:Claws`;

[1] More information about it at `https://en.wikipedia.org/wiki/Docker_(software)`.

- Kees Wouters: `http://www.caelinux.org/wiki/index.php/Contrib:KeesWouters`;

which contain many information, hints and examples.

4.12 About the forums

code_aster web site hosts some forums which are very helpful in solving many issues. It's like a potluck. What's available is what people have brought. And the forums must not be confused with a commercial software hot line help.

The same applies to Gmsh mailing list.

4.13 Distribution, window manager and more

Since 1998 I have used the openSUSE distribution[1], having started a few years before with a Slackware, I found life to be easy with it. The web site is:

`http://software.opensuse.org`

To make things a little bit more difficult I use "FVWM" as a window manager, it can be heavily customized through hand written configuration files, the look and behavior can be almost anything one likes[2]. The web site is:

`http://www.fvwm.org`

And, of course, this book is made with LaTeX, what else?

[1] At the time it was named S.u.S.E Linux, and that was version 5.2.
[2] Like the left-hand side tittle bar in some screen shots of this book.

Bibliography

[Roark] ROARK, Raymond J. and YOUNG, Warren C. (1976). *Formulas for Stress and Strain*. New York: McGraw-Hill Book Company.

First published in 1938, many times updated, has been, and still is, the reference handbook for a few generations of engineers all over the world!

[Blevins] BLEVINS, Robert D. (2001). *Formulas for Natural Frequency and Mode Shape*. Malabar: Krieger Publishing Company.

A comprehensive set about anything that can vibrate.

[Tuma] TUMA, Jean J. (1988). *Handbook of Structural and Mechanical Matrices*. New York: McGraw-Hill Book Company.

[Donaldson] DONALDSON, Toby (2009).*Visual Quickstart Guide Python*. Berkeley: Peachpit Press.

Very short, 185 pages, yet comprehensive introduction to Python.

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