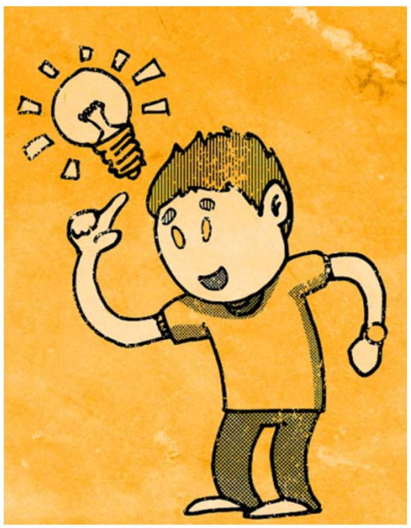
MAE 656 - Advanced Computer Aided Design

01. Introduction – Doc 02

Introduction to the FINITE ELEMENT METHOD

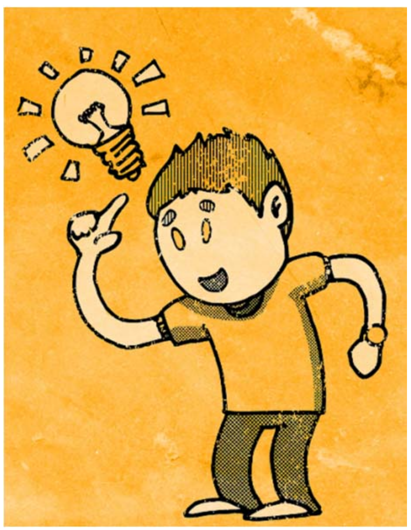
The FEM is… A TOOL

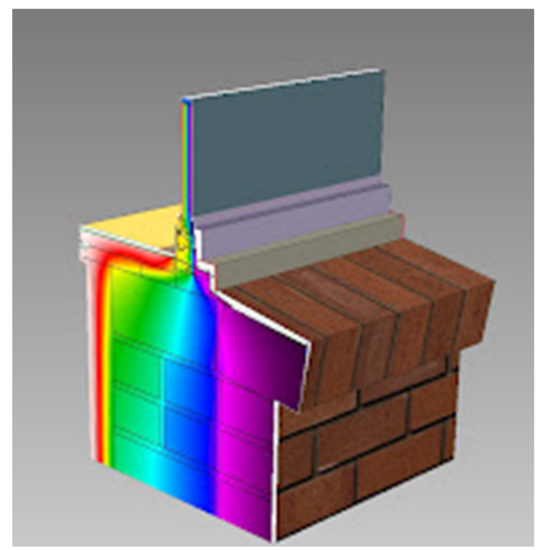
A simulation tool



The FEM is... A TOOL

NOT ONLY STRUCTURAL !





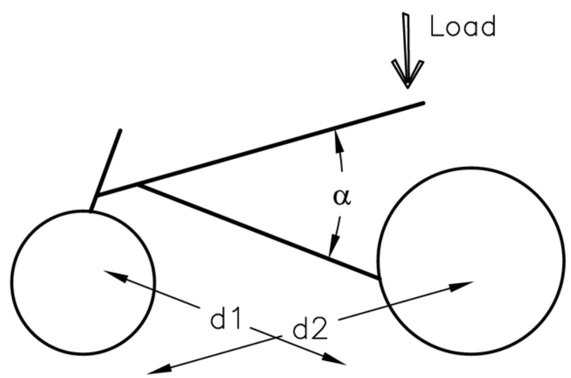
Narrowing the problem

Despite all possible applications,

THIS COURSE will focus on the FEM to perform STRUCTURAL SIMULATONS.

How does it work?

Idealization



We will obtain an approximate solution of the idealized problem!

Problem to Solve

We MUST know the problem to solve:

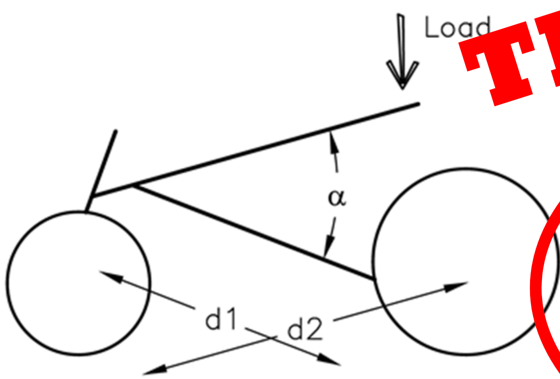
- Loads applied
- Materials
- How the structure is attached to the environment
- Geometry

If one, or a combination, of these elements are unknown: we are DESIGNING the structure.

If all elements are known, we are VERIFYING the structure

Idealization of the problem

We MUST decide how we want to idealize and simulate the problem:



THIS COURSE

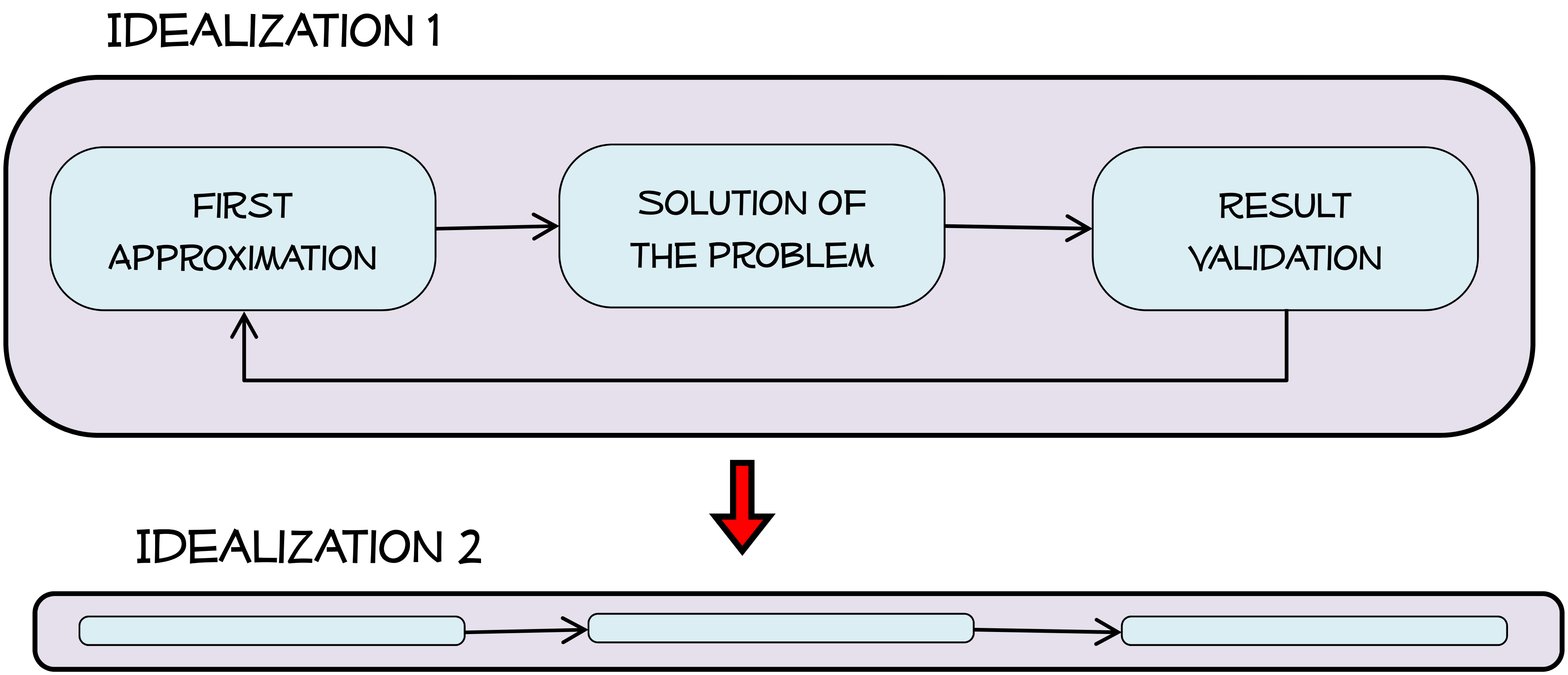
- Analytic Calculation
- Experimental simulation
- Numerical simulation
  - Bar elements
  - FEM
    - Linear elements (beams, trusses)
    - Solid elements (2D, 3D)
    - Shells

Election of the simulation procedure:

COMPROMISE between calculation cost & result accuracy

Solution of the problem - Design

Once having selected the resolution method, we must start an iterative procedure:



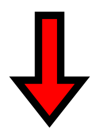
Example (1/4)

We want to design the following bike:

We know:

- Loads applied
- Materials
- Boundary conditions

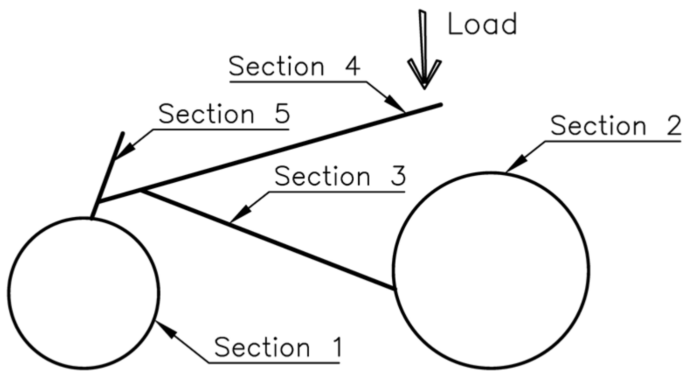
We have to define bar sections



We decide to simulate the bike with a bar model

Example (2/4)

Bar model:



Based on previous experience we predefine sections: #1, #2, #3, #4 & #5

CALCULATE

Verify results:
(according to standards)

- Stresses
- Buckling
- Deformations
- Vibrations
- etc.

YES

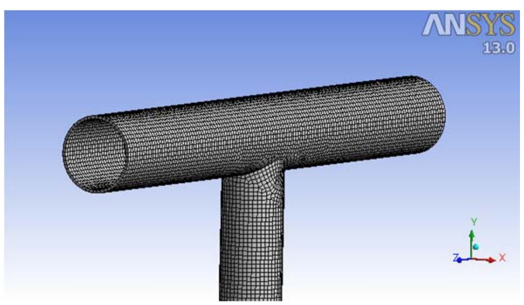
NO

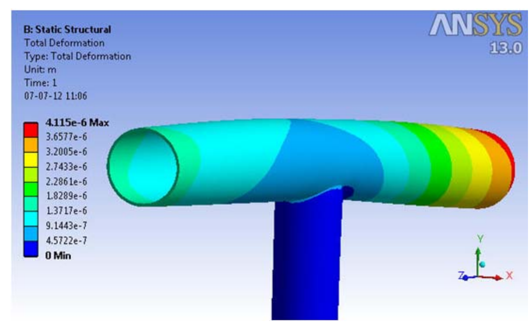
Example (3/4)

Once knowing the exact section of each element, we may want to refine the solution, defining different sections in each bar.

Or we may want to improve the configuration of some joints.

Simulation of specific elements with more accurate models:





Example (4/4)

REMARK:

It does NOT make sense start with a shell model (or, even worst, a solid model) of the bike if we don't have some previous knowledge of bar sections, thickness, etc.

The cost of defining, calculating and analyzing the model is too expensive to perform several iterations!

Element Types

There are several element types:

- Bar Elements
- Solid Elements – 2D
- Solid Elements – 3D
- Surface Elements: Shells and membranes

Along this course we will learn their main characteristics and how we can use them.

In the following let's see a small description of each one

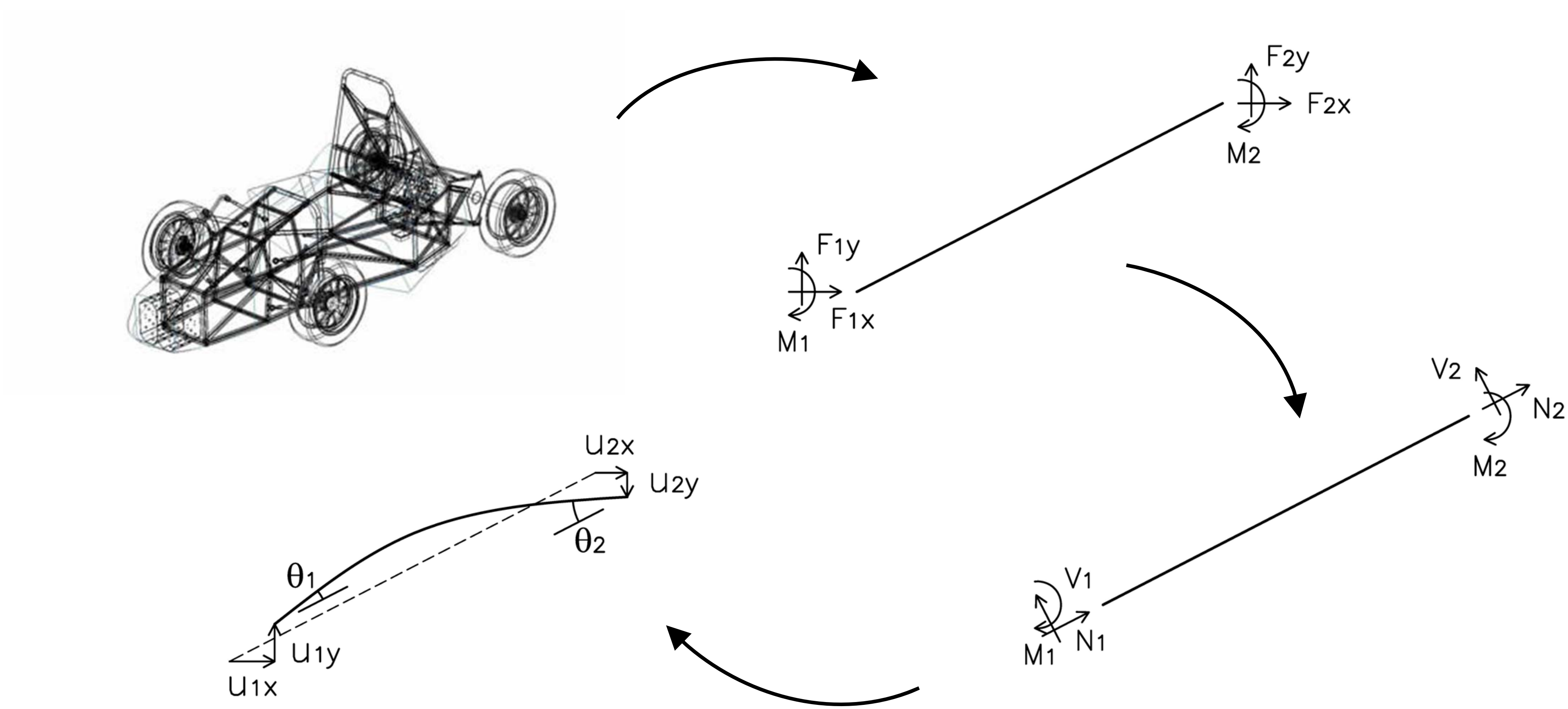
Element Types

Bar elements: TRUSSES and BEAMS

- 1D elements (in a 2D or 3D space)
- One dimension is larger than the other two
- Numerical formulation relates displacements with bar efforts (axial, shear, mending moments and torsion)
- Bars are connected at their ends with the possibility of transferring (or not) movements and efforts
- Trusses: bars work only with axial forces
- Beams: bars can handle shear loads and bending and torsion moments

Element Types

Bar elements: TRUSSES and BEAMS:



Element Types

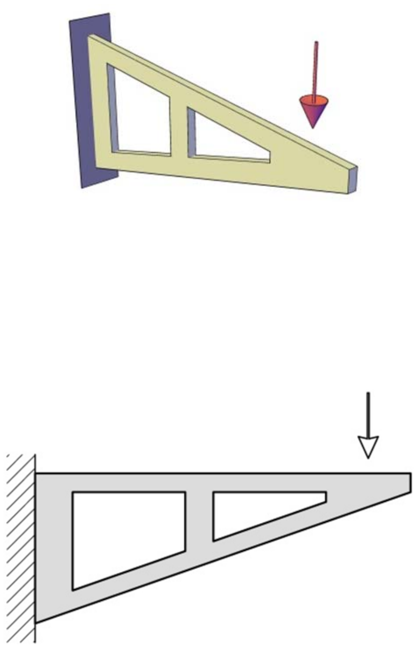
Solid elements: 2D solids

- Plane stress: Solids in which one dimension is smaller than the other two. Loads and boundary conditions are applied in the two proportional directions.
  Stress in the smaller dimension is zero.
- Plane strain: Solids in which one dimension is greater than the other two. Loads and boundary conditions are applied in the two proportional directions.
  Strain in the larger direction is zero.
- Axial symmetry: Solid of revolution. It is solved with the same formulation as plane strain solids

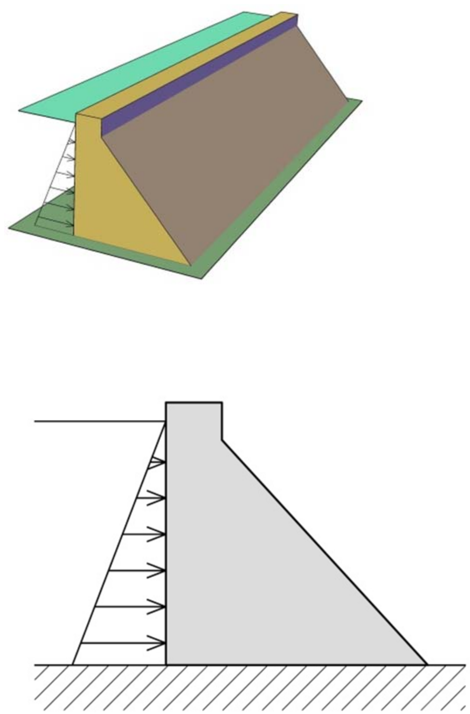
Element Types

Solid elements: 2D solids

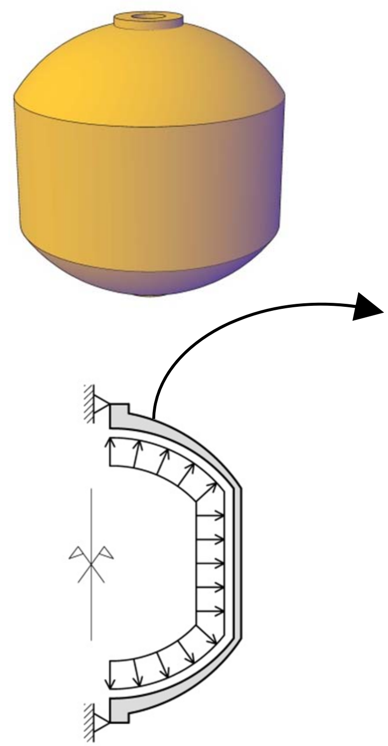
Plane stress



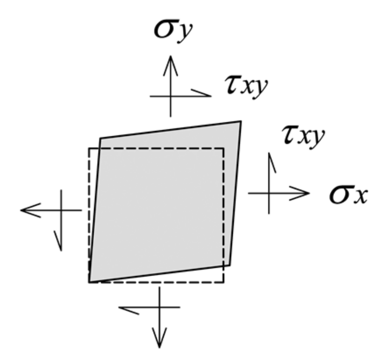
Plane strain



Axial symmetry



In all cases the formulation relates strains with stresses

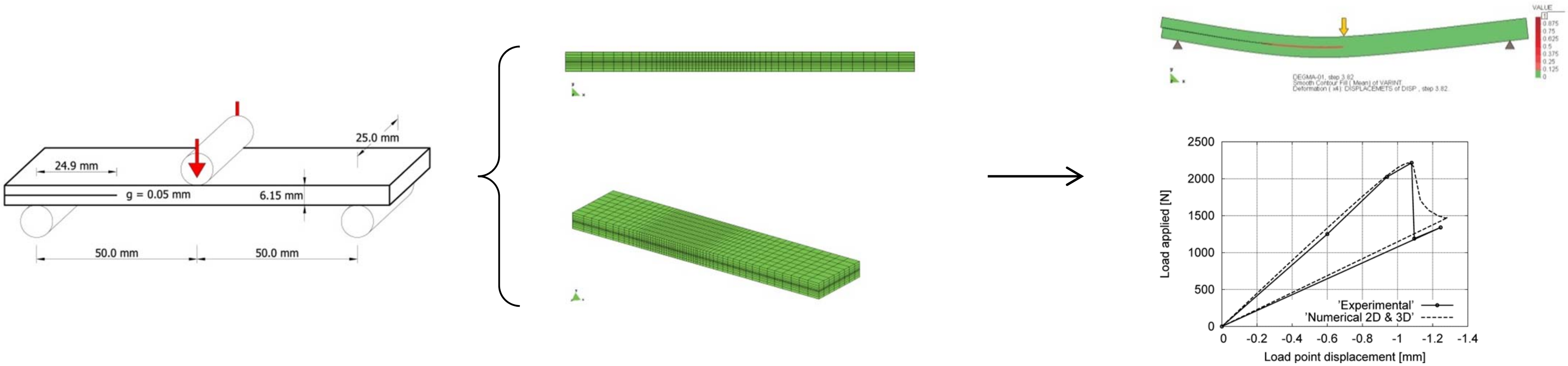


Element Types

Solid elements: 2D solids

In all these cases, the reduction of the computational cost, compared to solve the actual 3D solid, is enormous:

Example: End Notch Flexure Test



2D Simulation	→ 627 elems; 696 nodes	→ s.e. 1392x1392	→ time to solve: 21 min.
3D Simulation	→ 5016 elems; 6264 nodes	→ s.e. 18792x118792 (x13.5)	→ time to solve: 6h 52 min. (x19)

Element Types

Solid elements: 3D solids

- All directions of the element are equivalent, the solid has elements distributed unevenly in it, the loads are not equally distributed, etc.

↓

It is not possible to apply any simplification and the complete solid has to be simulated.

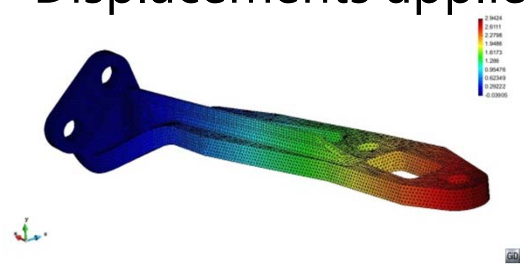
Element Types

Solid elements: 3D solids

As with the solid 2D models, the simulation relates strains and stresses in the different points in which the solid is discretized

Solid

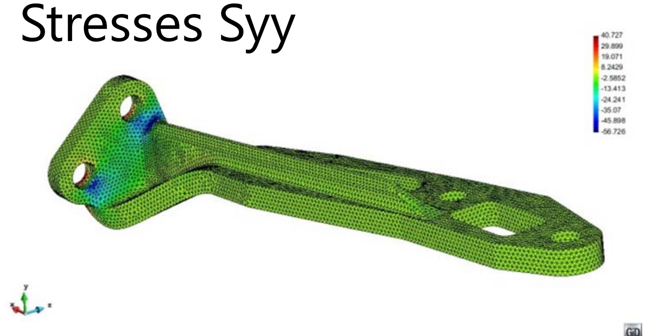
Displacements applied as load



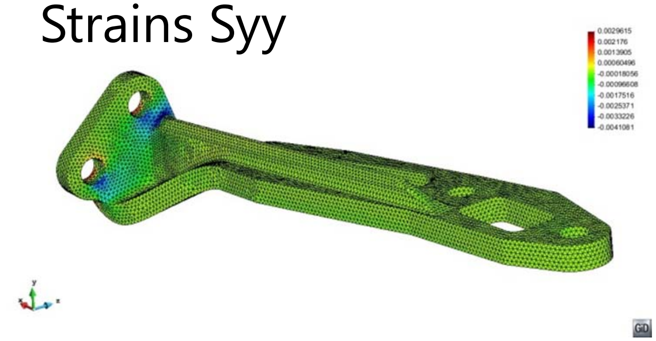
Results

Results

Stresses Syy



Strains Syy



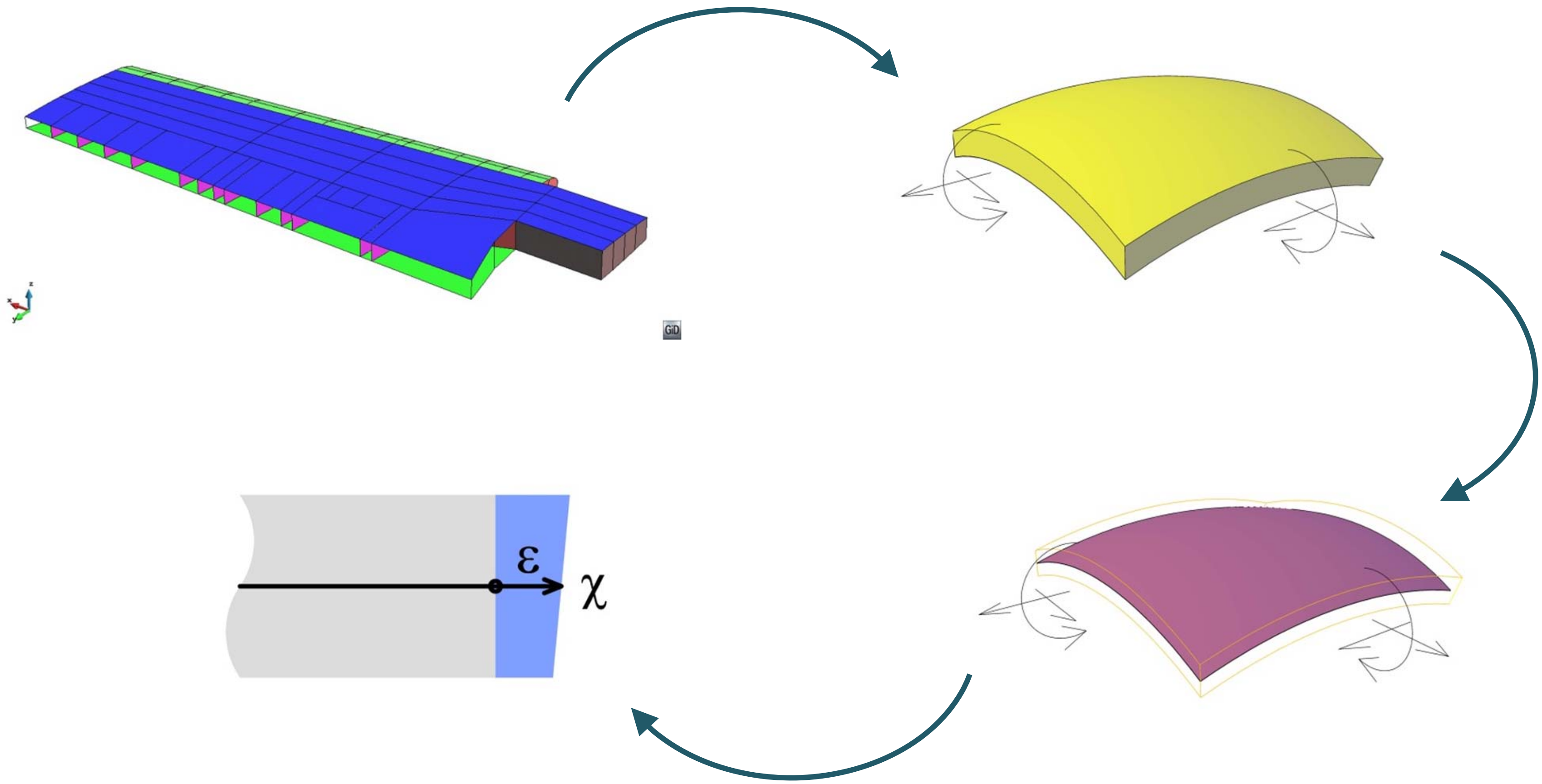
Element Types

Surface elements: SHELLS and MEMBRANES

- 2D elements (in 3D space)
- One dimension, the thickness of the element, is much smaller than the other two
- Numerical formulation relates displacements with membrane forces and bending moments
- Shells: They are capable of handling bending efforts
- Membranes: they are only capable of handling membrane efforts

Element Types

Surface elements: SHELLS and MEMBRANES



Election of element type

The election of the most convenient element to perform a given simulation may be based on:

- Type of structure to be simulated
- Design phase (or how much do we know about the final structure)
- Level of accuracy required from the simulation
- Computational capabilities and computational time available

It is an engineering decision. If it is taken wisely it may save a lot of time (and time is money).

This course will give you some clues. But the best way to learn how to choose wisely is performing simulations.