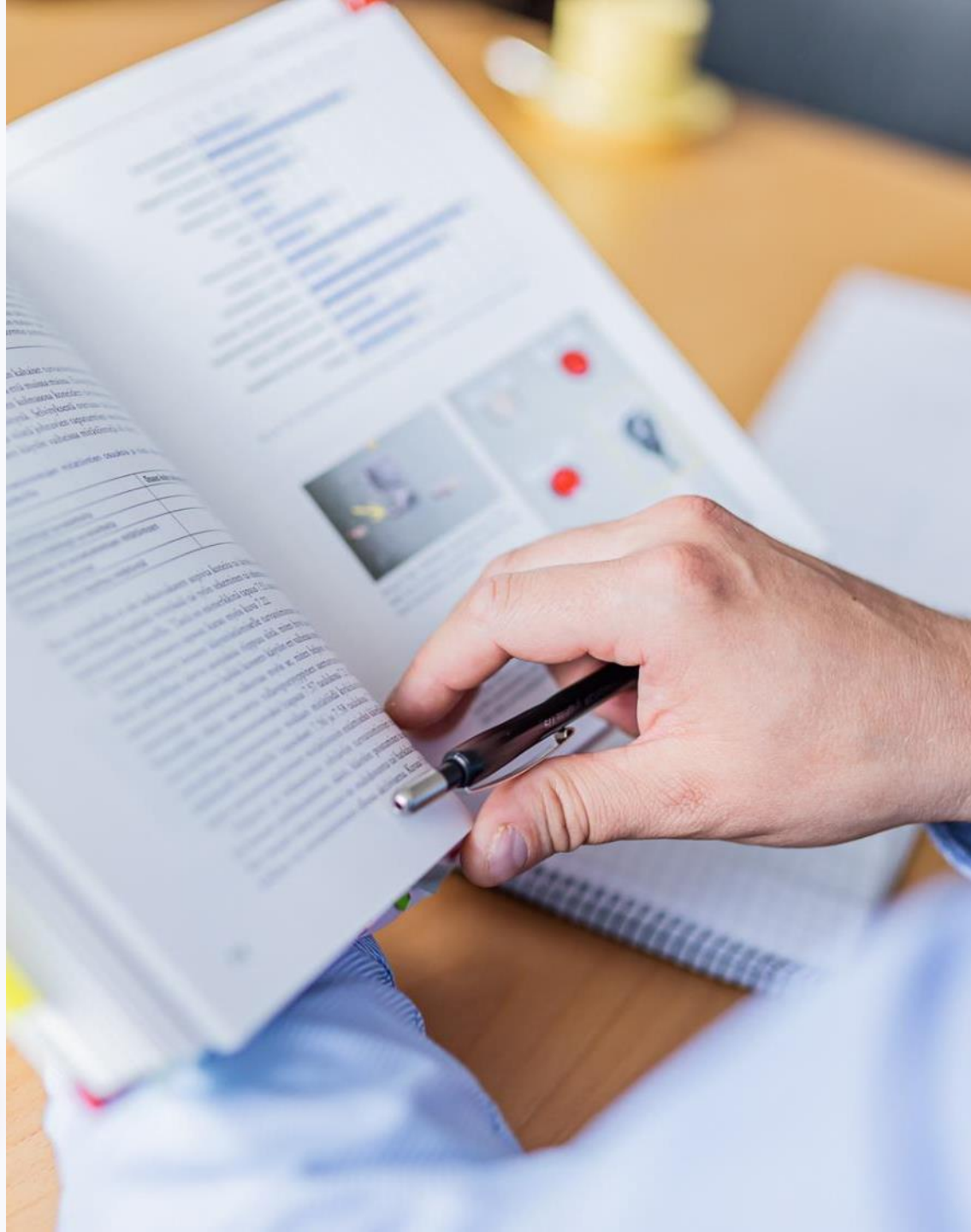
eNTOP

engineering company

SUOMALAISTA
KONE- JA LAITESUUNNITTELUA

ENTOP



ENTOP AS NUMBERS

FOUNDED

1988

EXPERTS

35+

TURNOVER

3.0M€

PROJECTS

100/a

DESIGN WITH QUALITY

QUALITY

We are proud of our design quality

Continuous improvement for our knowledge and tools.

CUSTOMERS

We care about our customers.

We have a long experience from various fields of industry.

TOOLS

We use the best tool for each job.

PEOPLE

We have a good feeling around our people. The company culture is strong and supporting.

We have more than 35 experts.

WIDE RANGE OF SERVICES

MECHANICAL DESIGN

TECHNICAL CALCULATIONS

PRODUCT DEVEOPMENT

MACHINE SAFETY

TEAM

KIMMO MÄÄTTÄNEN

CEO

+358 50 336 9852

kimmo.maattanen@entop.fi

HELI PORVALI

Assistant

+358 44 770 0841

heli.porvali@entop.fi

KIMMO PYYKKÖ

Technical director, Tampere

+358 44 369 7071

kimmo.pyykko@entop.fi

AKU ARASOLA

Design manager

+358 44 770 0839

aku.arasola@entop.fi

TUOMO KUUSI

Development director, Helsinki

+358 50 409 3704

tuomo.kuusi@entop.fi

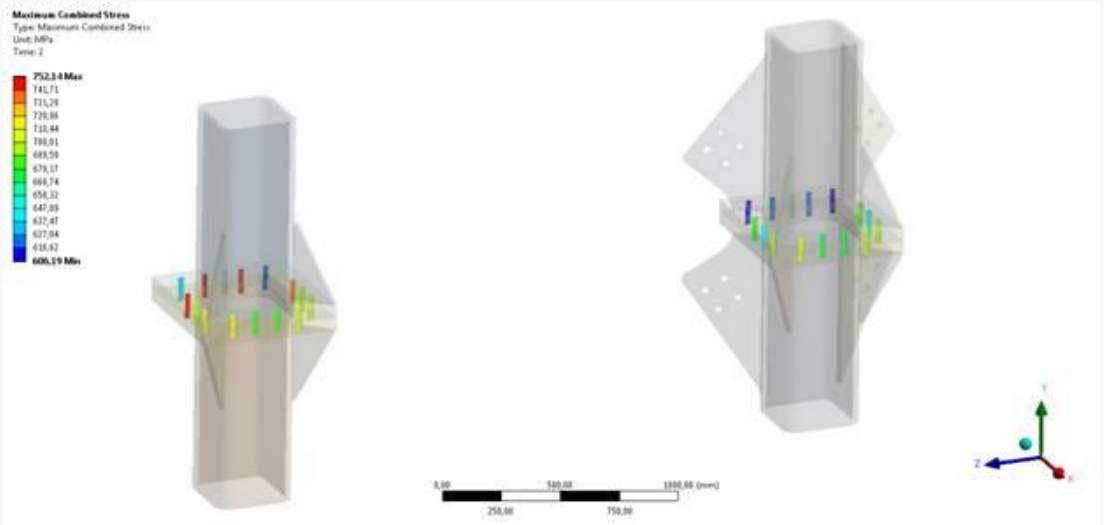
FEA

25.9.2023

eNTOP

AGENDA

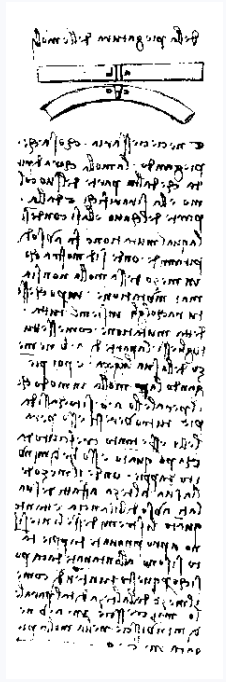
- History
- Theory
- How?
- Where?
- Cases



FINITE ELEMENT METHOD

INTRODUCTION

- Mathematical representation of nature
- Leads to differential/integral equations
- Usually hard to solve analytically
- Achieve ”Good enough” answer



FUNDAMENTAL CONCEPTS

- Elastic problems
- Thermal problems
- Fluid flow
- Electrostatics
- Etc

- Governing equation

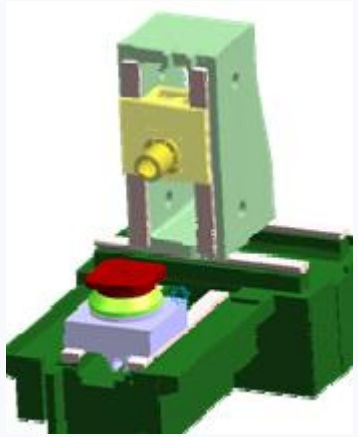
$$L(\phi) + f = 0$$

- Boundary conditions

$$B(\phi) + g = 0$$

IN MECHANICAL ENGINEERING

Machining center:
Mechanical/ thermal loads



Set of simultaneous equations

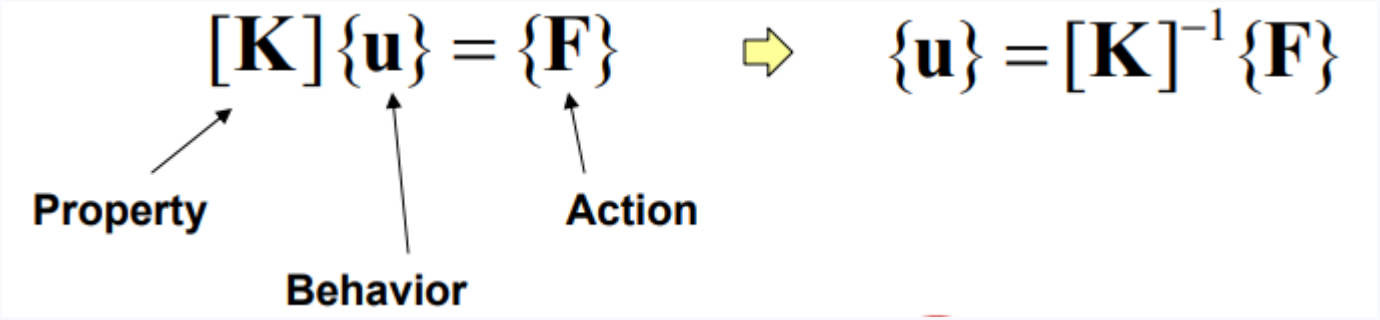
Governing Equation: $L(\phi) + f = 0$

Boundary Conditions: $B(\phi) + g = 0$

FEM

$$[\mathbf{K}]\{\mathbf{u}\} = \{\mathbf{F}\}$$

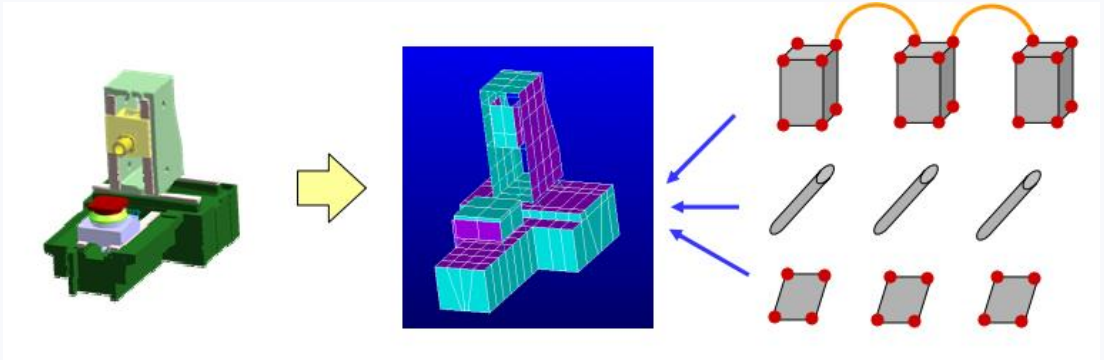
FEM “FORMULA”



	Property, K	Behaviour, u	Action, F
Elastic	Stiffness	Displacement	Force
Thermal	Conductivity	Temperature	Heat source
Fluid	Viscosity	Velocity	Body force
Electrostatic	Diaelectric permittivity	Electric potential	Charge

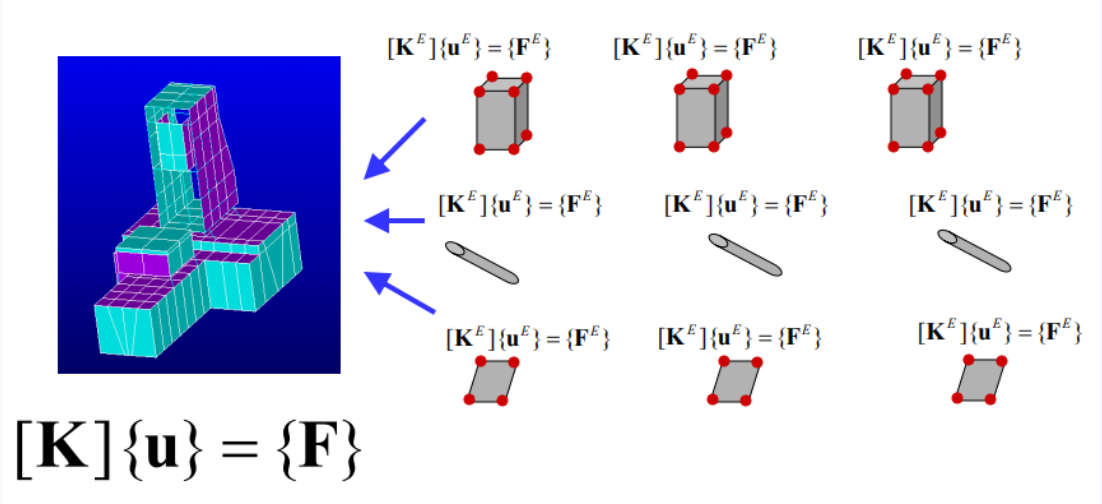
FINITE ELEMENT

- Cannot make algebraic equations over the domain
- Split the domain to finite pieces
- Polynomial equations along element
- Connect adjacent elements by nodes

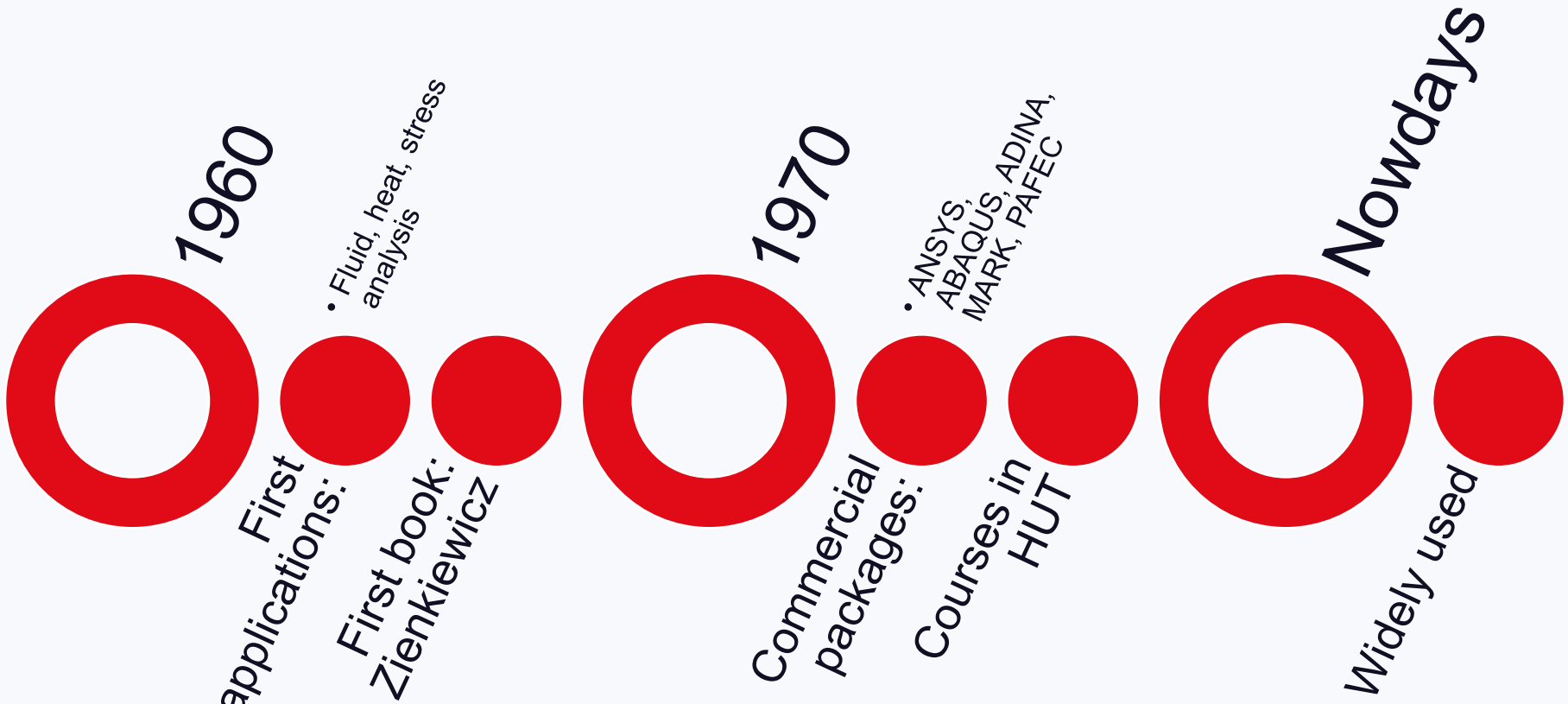


MORE FINITE ELEMENTS

- Form equations for each element (easy!)
- Assemble
- Solve



HISTORIC MILESTONES



NUMBERS

- In 1960: 100 beam elements (=300 dof)
- In 2000: ~10 000 shell elements (=60 000 dof)
- In 2010: ~400 000 solid elements (=1,6M dof)
- In 2020: ~3M solid elements (=12M dof)

$$
\begin{bmatrix}
\frac{A_z \cdot E_z}{L_z} & 0 & 0 & 0 & 0 & 0 & -\frac{A_z \cdot E_z}{L_z} & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{E_z \cdot Iz_z \cdot \phi 1z_z}{(L_z)^3} & 0 & 0 & 0 & \frac{E_z \cdot Iz_z \cdot \phi 2z_z}{(L_z)^2} & 0 & -\frac{E_z \cdot Iz_z \cdot \phi 1z_z}{(L_z)^3} & 0 & 0 & 0 & \frac{E_z \cdot Iz_z \cdot \phi 2z_z}{(L_z)^2} \\
0 & 0 & \frac{E_z \cdot Iy_z \cdot \phi 1y_z}{(L_z)^3} & 0 & -\frac{E_z \cdot Iy_z \cdot \phi 2y_z}{(L_z)^2} & 0 & 0 & 0 & -\frac{E_z \cdot Iy_z \cdot \phi 1y_z}{(L_z)^3} & 0 & -\frac{E_z \cdot Iy_z \cdot \phi 2y_z}{(L_z)^2} & 0 \\
0 & 0 & 0 & \frac{E_z \cdot J_z}{2 \cdot (v_z + 1) \cdot L_z} & 0 & 0 & 0 & 0 & 0 & -\frac{E_z \cdot J_z}{2 \cdot (v_z + 1) \cdot L_z} & 0 & 0 \\
0 & 0 & -\frac{E_z \cdot Iy_z \cdot \phi 2y_z}{(L_z)^2} & 0 & \frac{E_z \cdot Iy_z \cdot \phi 4y_z}{L_z} & 0 & 0 & 0 & \frac{E_z \cdot Iy_z \cdot \phi 2y_z}{(L_z)^2} & 0 & \frac{E_z \cdot Iy_z \cdot \phi 3y_z}{L_z} & 0 \\
0 & \frac{E_z \cdot Iz_z \cdot \phi 2z_z}{(L_z)^2} & 0 & 0 & 0 & \frac{E_z \cdot Iz_z \cdot \phi 4z_z}{L_z} & 0 & -\frac{E_z \cdot Iz_z \cdot \phi 2z_z}{(L_z)^2} & 0 & 0 & 0 & \frac{E_z \cdot Iz_z \cdot \phi 3z_z}{L_z}
\end{bmatrix}
$$

$$
\begin{bmatrix}
-\frac{A_z \cdot E_z}{L_z} & 0 & 0 & 0 & 0 & 0 & \frac{A_z \cdot E_z}{L_z} & 0 & 0 & 0 & 0 & 0 \\
0 & -\frac{E_z \cdot Iz_z \cdot \phi 1z_z}{(L_z)^3} & 0 & 0 & 0 & -\frac{E_z \cdot Iz_z \cdot \phi 2z_z}{(L_z)^2} & 0 & \frac{E_z \cdot Iz_z \cdot \phi 1z_z}{(L_z)^3} & 0 & 0 & 0 & -\frac{E_z \cdot Iz_z \cdot \phi 2z_z}{(L_z)^2} \\
0 & 0 & -\frac{E_z \cdot Iy_z \cdot \phi 1y_z}{(L_z)^3} & 0 & \frac{E_z \cdot Iy_z \cdot \phi 2y_z}{(L_z)^2} & 0 & 0 & 0 & \frac{E_z \cdot Iy_z \cdot \phi 1y_z}{(L_z)^3} & 0 & \frac{E_z \cdot Iy_z \cdot \phi 2y_z}{(L_z)^2} & 0 \\
0 & 0 & 0 & -\frac{E_z \cdot J_z}{2 \cdot (v_z + 1) \cdot L_z} & 0 & 0 & 0 & 0 & 0 & \frac{E_z \cdot J_z}{2 \cdot (v_z + 1) \cdot L_z} & 0 & 0 \\
0 & 0 & -\frac{E_z \cdot Iy_z \cdot \phi 2y_z}{(L_z)^2} & 0 & \frac{E_z \cdot Iy_z \cdot \phi 3y_z}{L_z} & 0 & 0 & 0 & \frac{E_z \cdot Iy_z \cdot \phi 2y_z}{(L_z)^2} & 0 & \frac{E_z \cdot Iy_z \cdot \phi 4y_z}{L_z} & 0 \\
0 & \frac{E_z \cdot Iz_z \cdot \phi 2z_z}{(L_z)^2} & 0 & 0 & 0 & \frac{E_z \cdot Iz_z \cdot \phi 3z_z}{L_z} & 0 & -\frac{E_z \cdot Iz_z \cdot \phi 2z_z}{(L_z)^2} & 0 & 0 & 0 & \frac{E_z \cdot Iz_z \cdot \phi 4z_z}{L_z}
\end{bmatrix}
$$

SHORT THEORY

STIFFNESS MATRIX

- System:

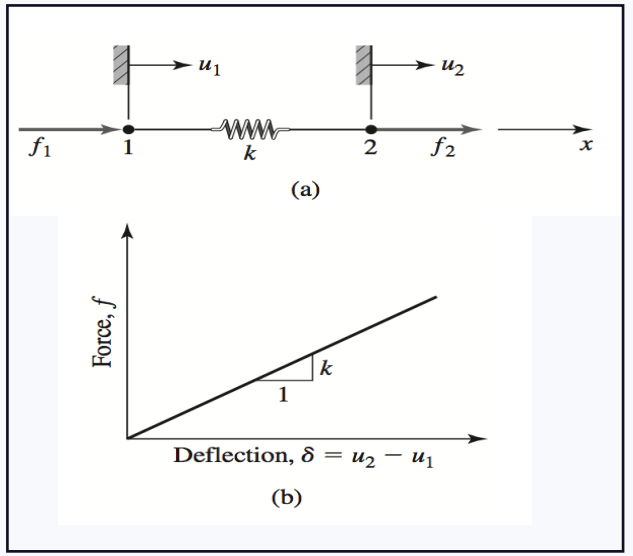
$$\begin{bmatrix} k & -k \\ -k & k \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = \begin{Bmatrix} f_1 \\ f_2 \end{Bmatrix}$$

- Single element

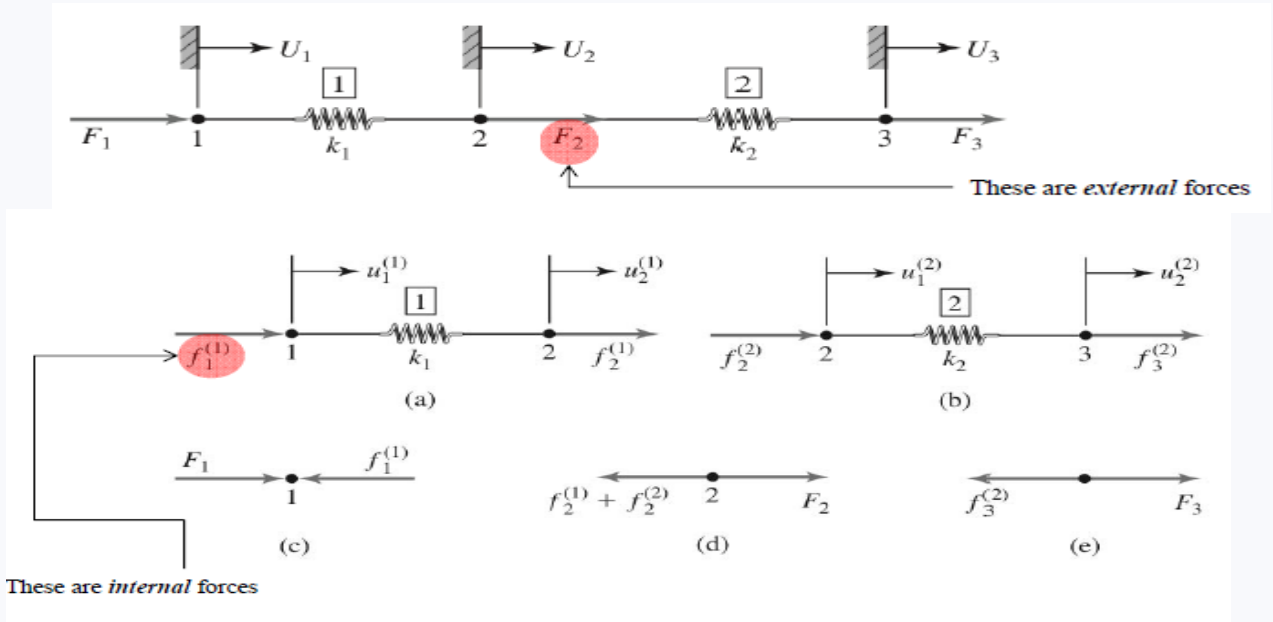
$$[k_e] = \begin{bmatrix} k & -k \\ -k & k \end{bmatrix}$$

- Formula

$$\{F\} = [K]\ \{X\}$$



SYSTEM OF TWO ELEMENTS



SYSTEM OF TWO ELEMENTS

Superscript refers to element

$$\begin{bmatrix} k_1 & -k_1 \\ -k_1 & k_1 \end{bmatrix} \begin{Bmatrix} u_1^{(1)} \\ u_2^{(1)} \end{Bmatrix} = \begin{Bmatrix} f_1^{(1)} \\ f_2^{(1)} \end{Bmatrix}$$

$$\begin{bmatrix} k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \begin{Bmatrix} u_1^{(2)} \\ u_2^{(2)} \end{Bmatrix} = \begin{Bmatrix} f_2^{(2)} \\ f_3^{(2)} \end{Bmatrix}$$

Boundary conditions

$$u_1^{(1)} = U_1 \qquad u_2^{(1)} = U_2 \qquad u_1^{(2)} = U_2 \qquad u_2^{(2)} = U_3$$

SYSTEM OF TWO ELEMENTS

Element matrices:

$$\begin{bmatrix} k_1 & -k_1 \\ -k_1 & k_1 \end{bmatrix} \begin{Bmatrix} U_1 \\ U_2 \end{Bmatrix} = \begin{Bmatrix} f_1^{(1)} \\ f_2^{(1)} \end{Bmatrix}$$

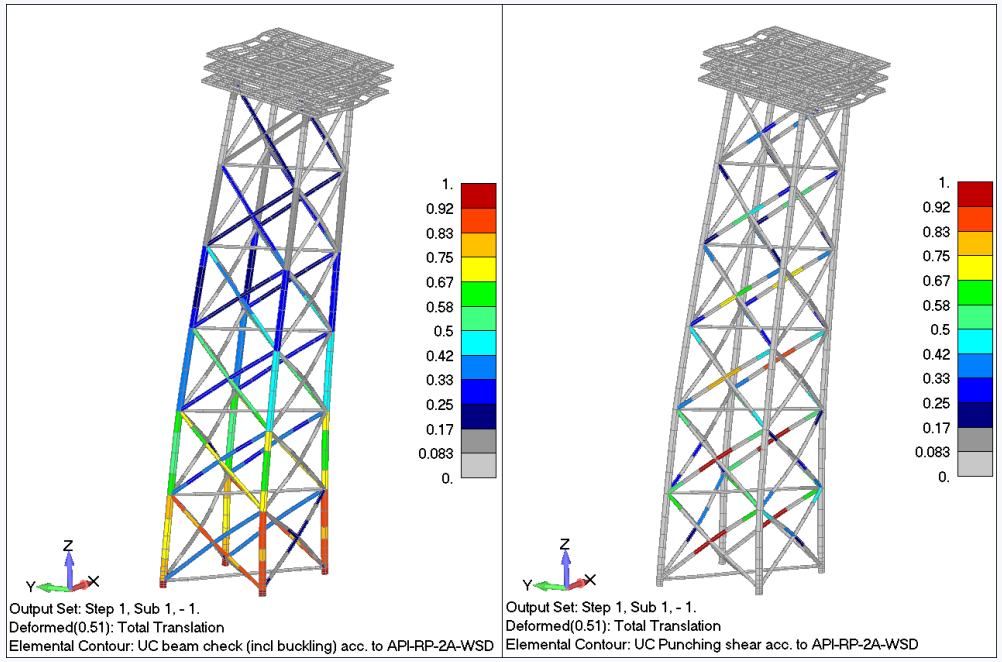
$$\begin{bmatrix} k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \begin{Bmatrix} U_2 \\ U_3 \end{Bmatrix} = \begin{Bmatrix} f_2^{(2)} \\ f_3^{(2)} \end{Bmatrix}$$

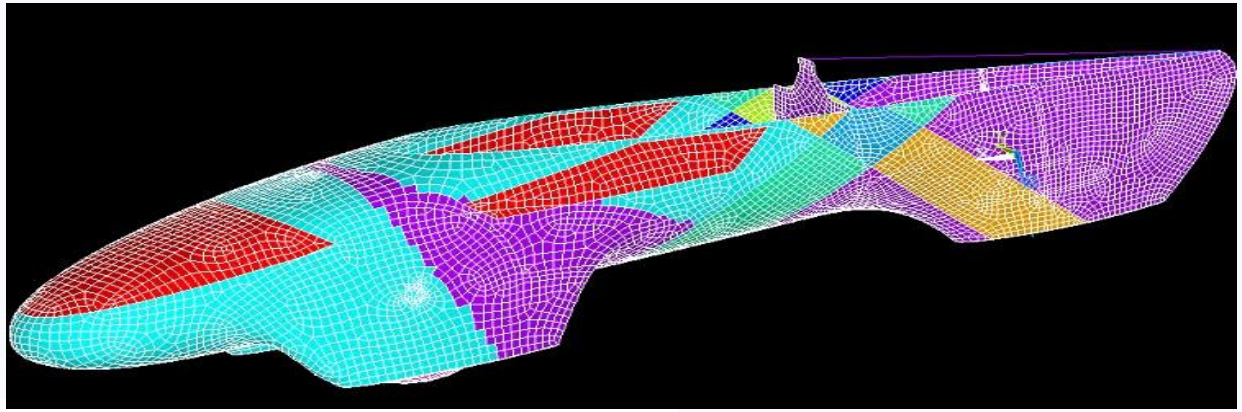
System matrix:

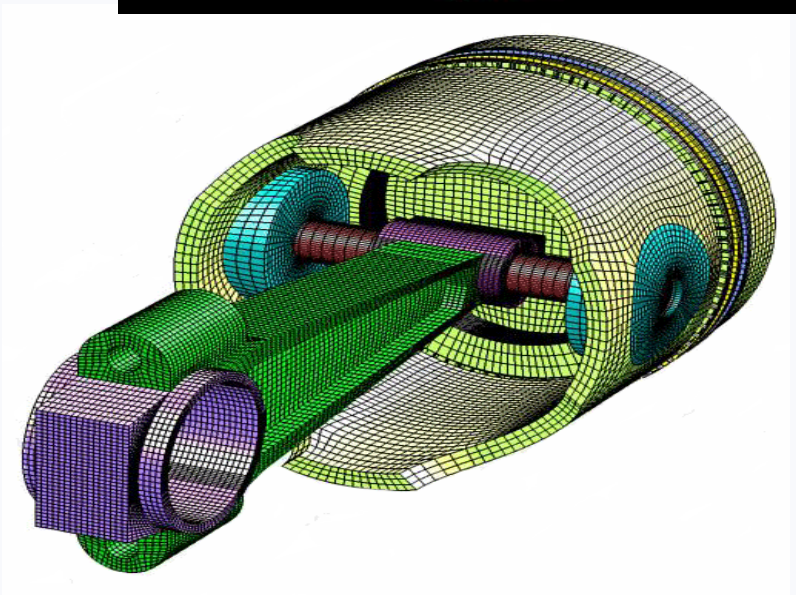
$$\begin{bmatrix} k_1 & -k_1 & 0 \\ -k_1 & k_1 + k_2 & -k_2 \\ 0 & -k_2 & k_2 \end{bmatrix} \begin{Bmatrix} U_1 \\ U_2 \\ U_3 \end{Bmatrix} = \begin{Bmatrix} f_1^{(1)} \\ f_2^{(1)} + f_2^{(2)} \\ f_3^{(2)} \end{Bmatrix}$$

$$\{F\} = [K]\ \{X\}$$

ELEMENT TYPES

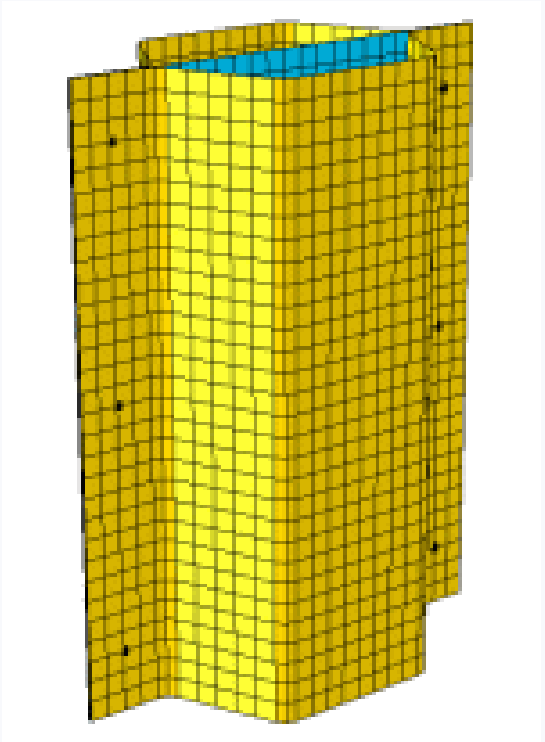






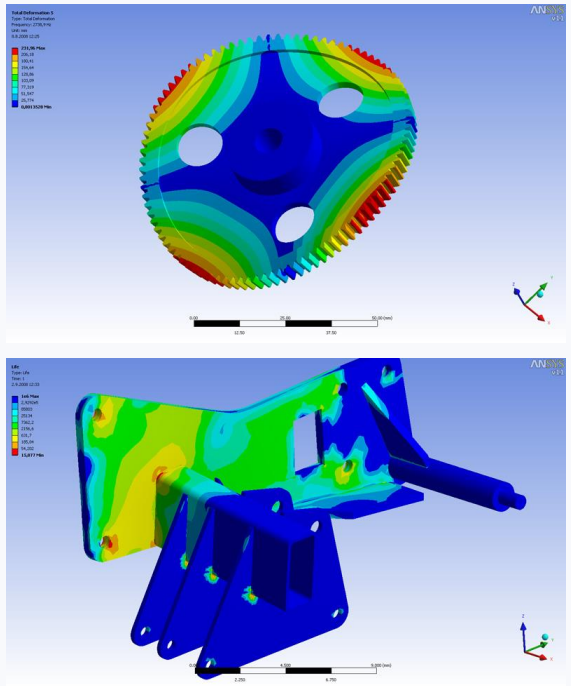
USAGE SCENARIOS

- Structures
- Heat
- Fluids
- Magnetics
- Sound/noise
- Coupled physics

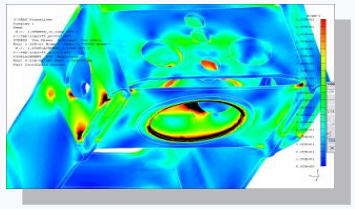


FEM IN PRACTCE

- Predict product’s behaviour in real life using mathematical models.
- Achieve engineering results (stresses, displacements etc)
- Numerical approximation

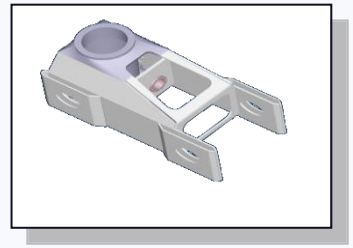


PROCESS

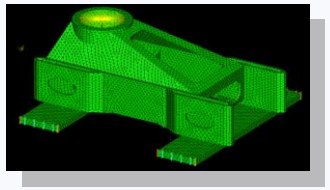


Results

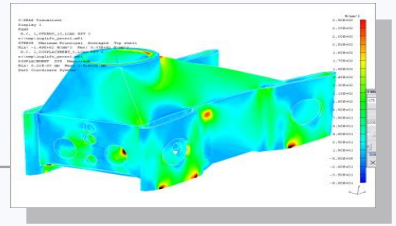
Geometry



FE model



Solver



TOOLS

Abaqus

ANSYS

LS-dyna

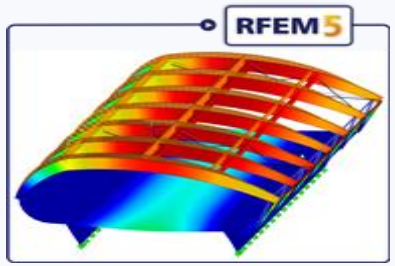
COMSOL

MSC Nastran

ADINA

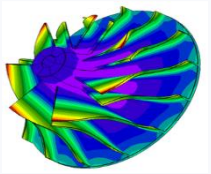
NX for Simulation

Nastran



Elmer

Calculix



FreeFem++

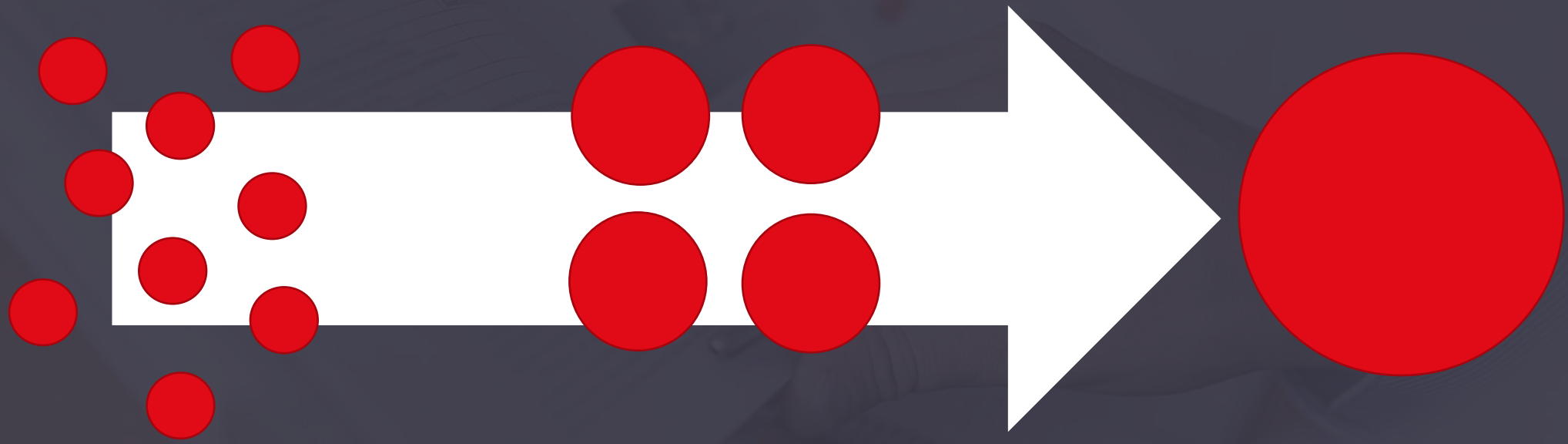
ROLES IN R&D

CONCEPT DESIGN

IDEAS

CONCEPTS

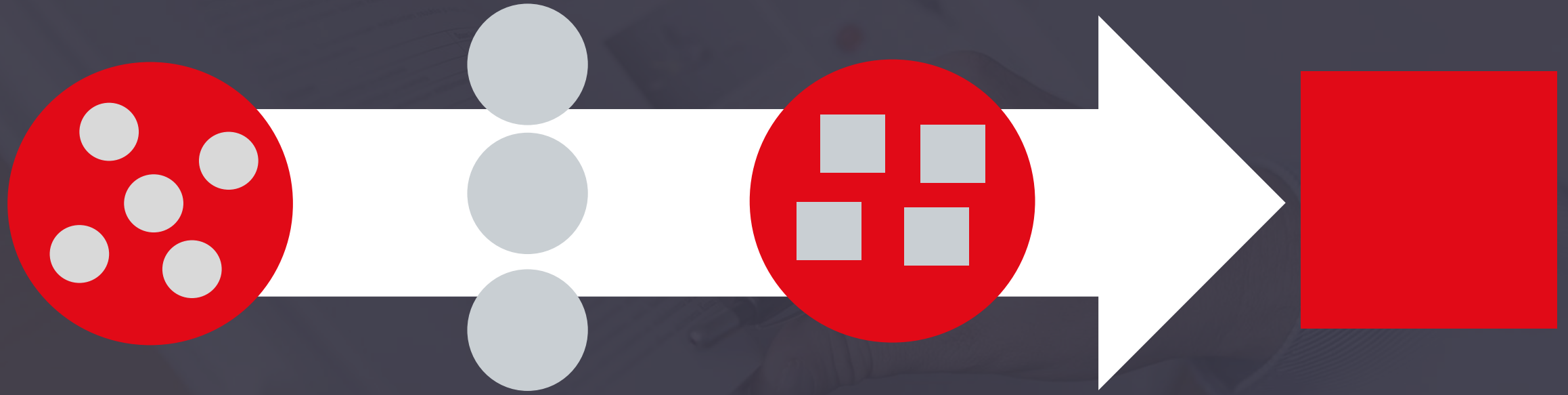
FREEZE POINT



"BRING HARD FACTS TO CONCEPT EVALUATION"

PRODUCT DEVELOPMENT

SIMULATE OPTIMIZE EVALUATE VERITY



"VIRTUAL PROTOTYPES, VIBRATIONS."

PRODUCT LAUNCH

SIMULATION FOR MANUFACTURING

VERIFICATION DOCUMENTS

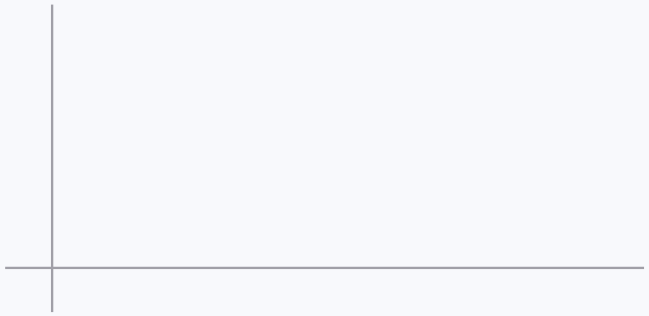
PRODUCT SUPPORT

STANDARDS, VERIFICATION

SPECIAL SERVICES

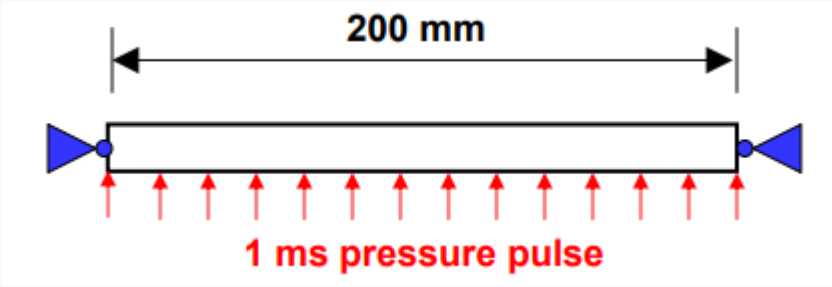
- Study of the failed structures.
- Vibration analysis.
- Mechanical testing.
- Thermal analysis and testing.
- Electronics analysis and testing.

ERRORS AND PITFALLS

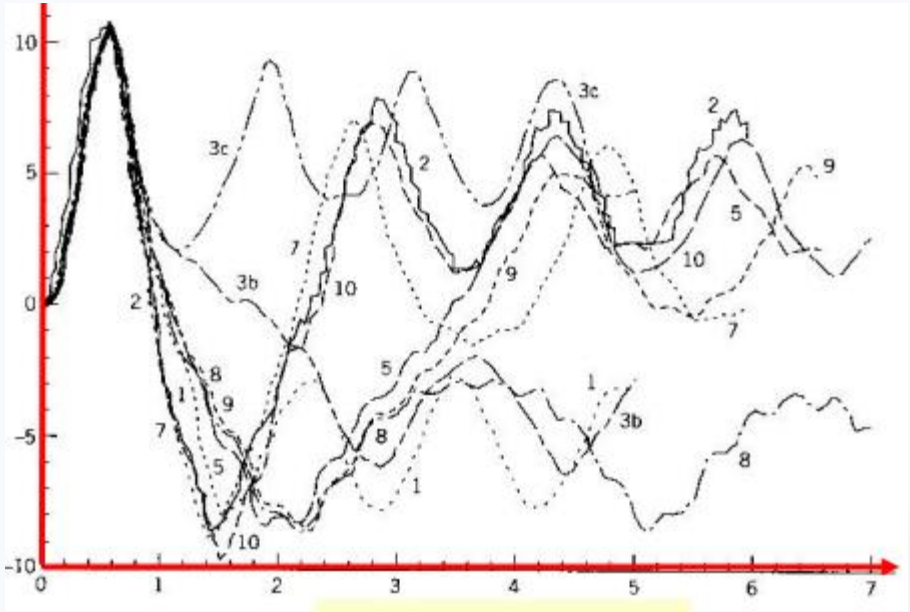


THE USER

- Hinged supports
- Pulsed pressure loading



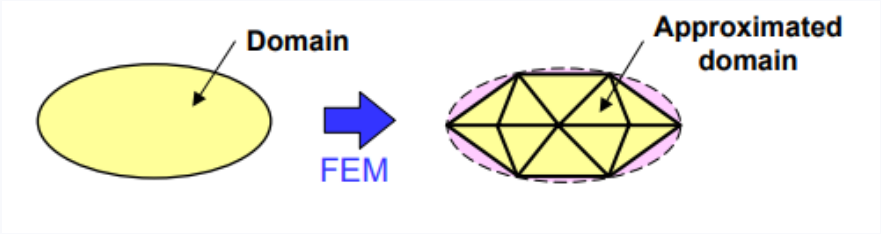
- Unknown: midpoint displacement
- over time



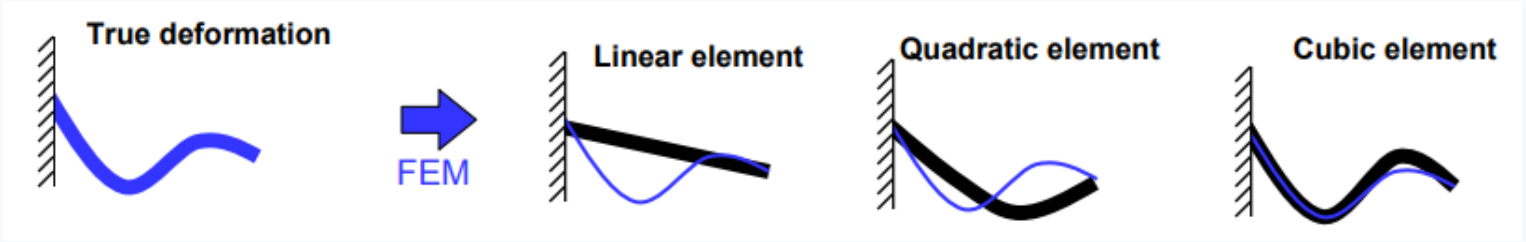
- Analysis done by 10 experts with different FEM programs

MATHS BEHIND THE HOOD

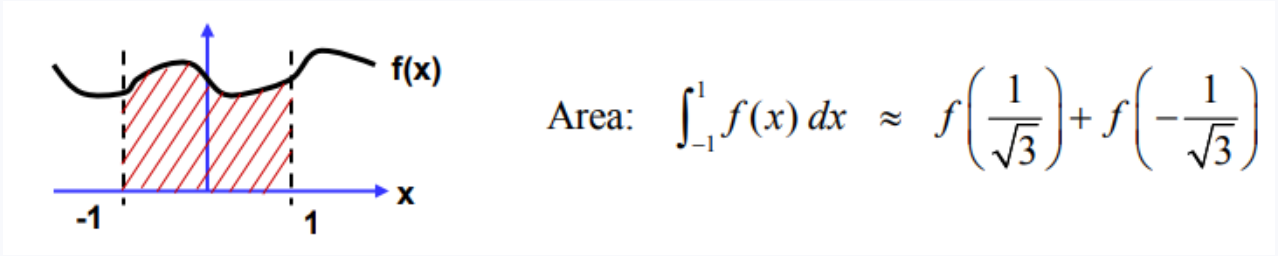
- Geometry is simplified



- Variables are assumed to be polynomial over element



- Generally very simple integration techniques

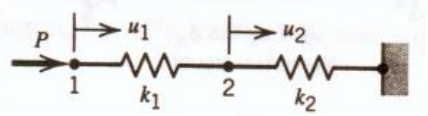


COMPUTING

- Computers can handle only finite number of digits
- Numerical difficulties

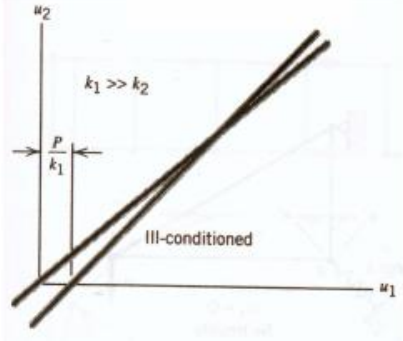
$$\sqrt{2} = 1.41421356, \quad \pi = 3.14159265$$

- Very large and very small numbers



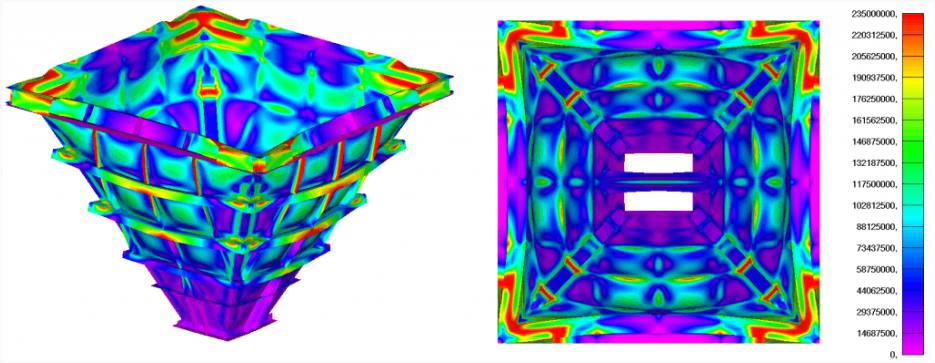
$$k_1 \gg k_2 \ , \quad k_2 \approx 0$$

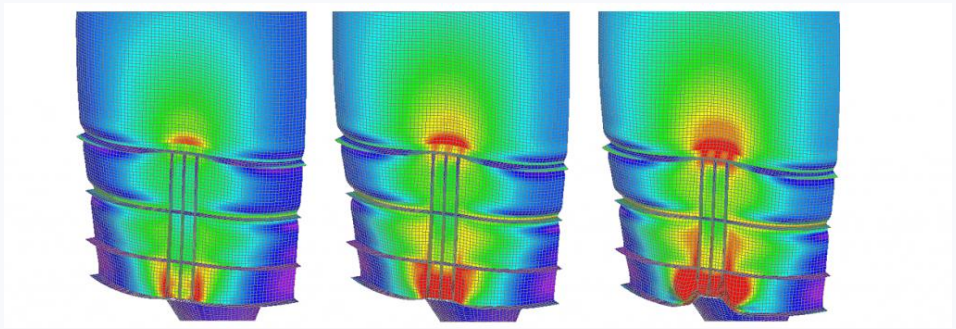
$$[(k_1 + k_2) - k_2]u_2 = P \Rightarrow u_2 = \frac{P}{k_2} \approx \frac{P}{0}$$



READING THE RESULTS

- What is acceptable limit?
- What was asked?
- Singularities
- Verification
- Hand
- Another analysis
- Second opinion



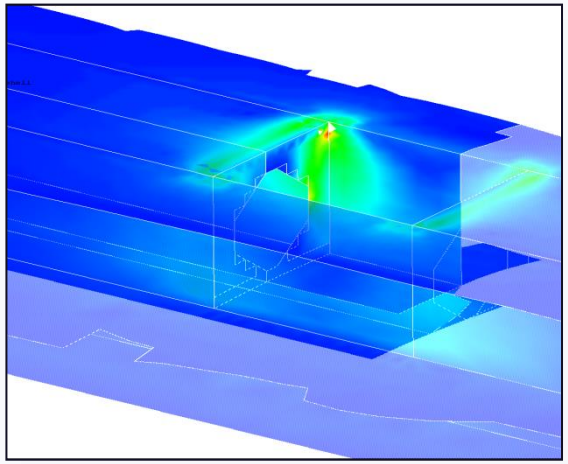


MISUSE OF TOOLS

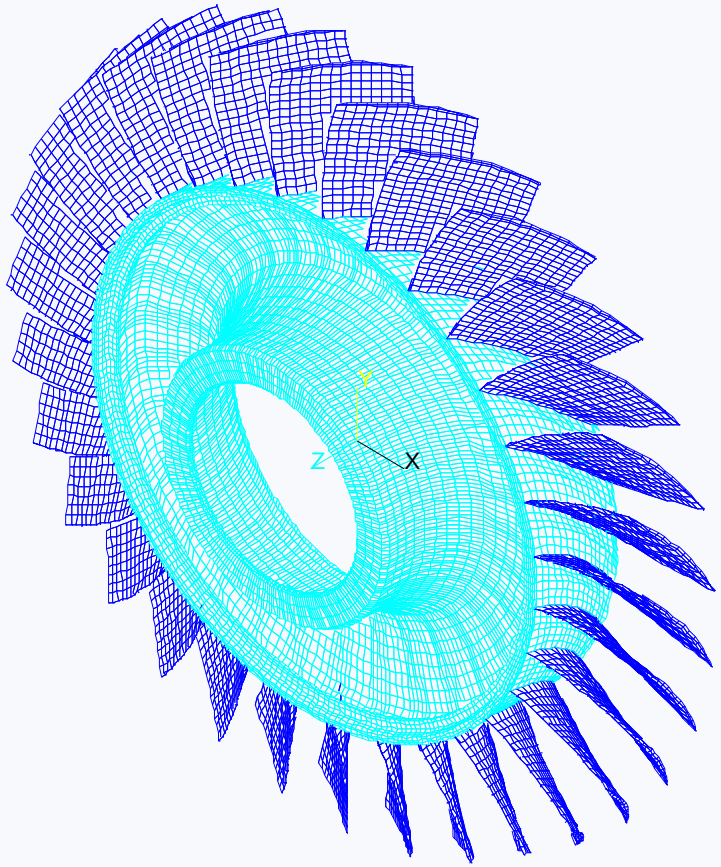
- Wrong elements used. I.e. Solids used instead of shells
- Distorted elements
- Insufficient supports
- Inconsistent units
- Too large numerical differences
- Misplaced forces

MISC

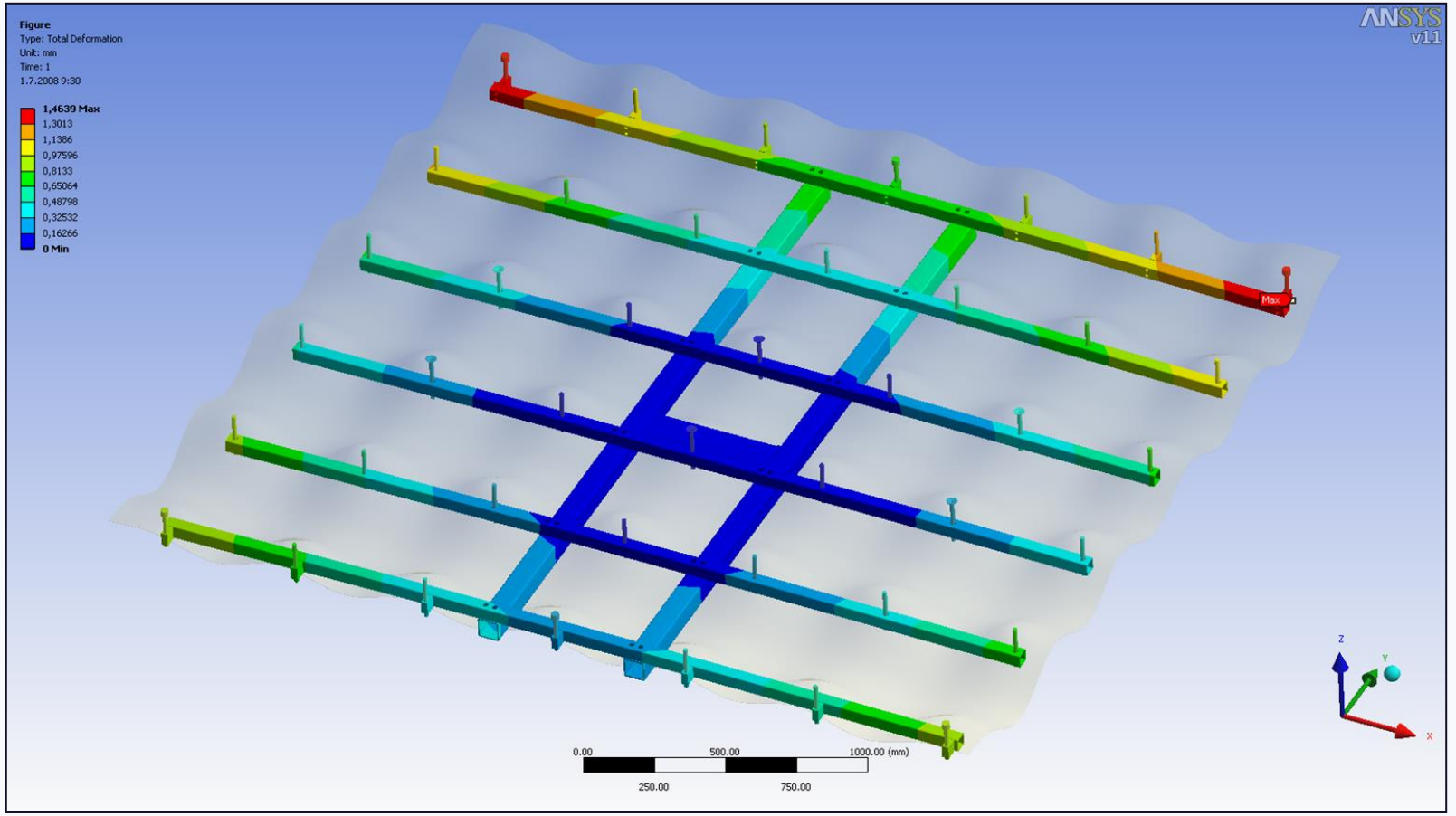
- Sometimes hard to find correct loads and boundary conditions
- Model is always idealised version of reality
- Material models
- Specialist required
- Might lead to ”shoot with shotgun”



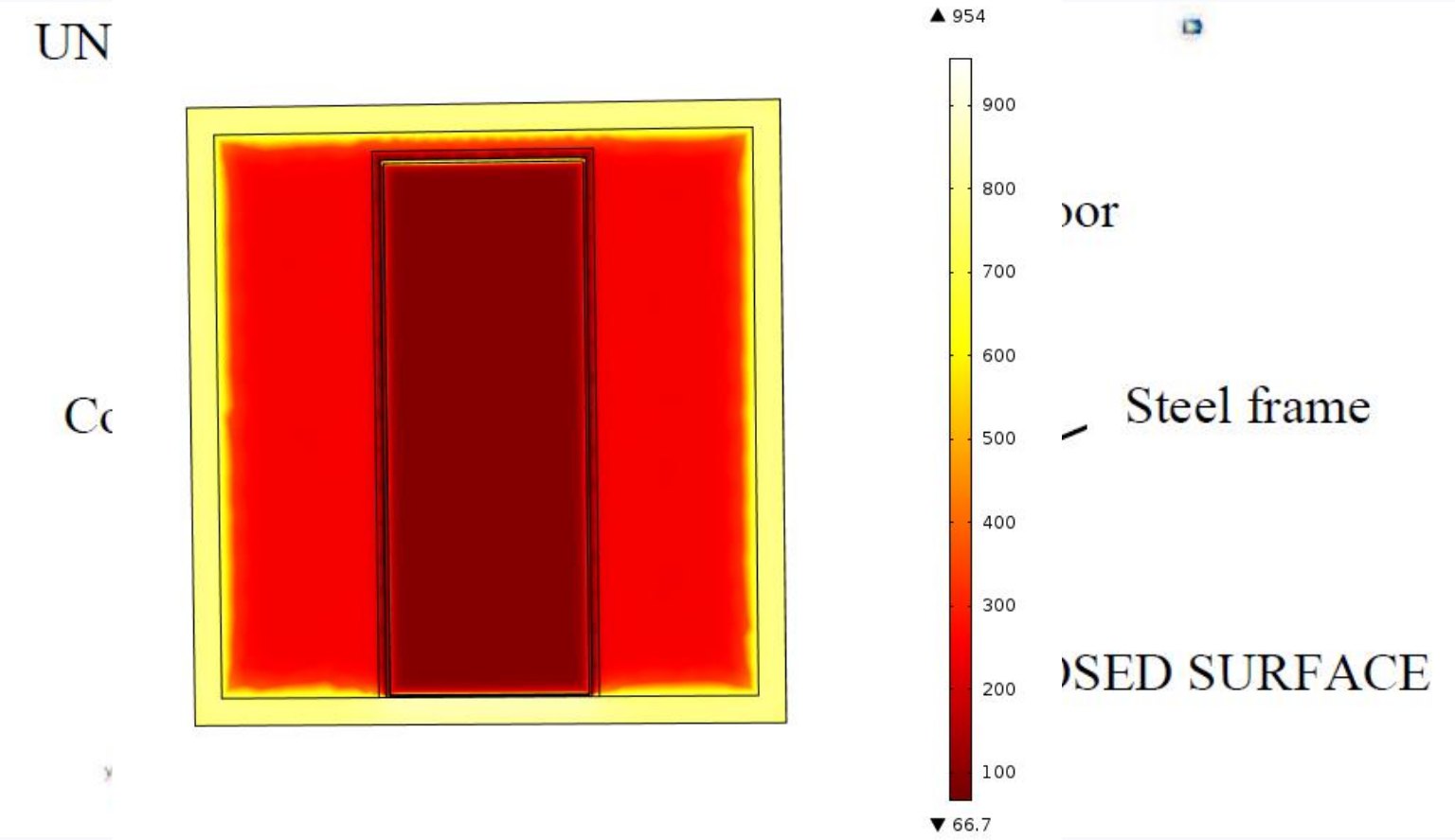
CASES



ALUMINIUM FRAME

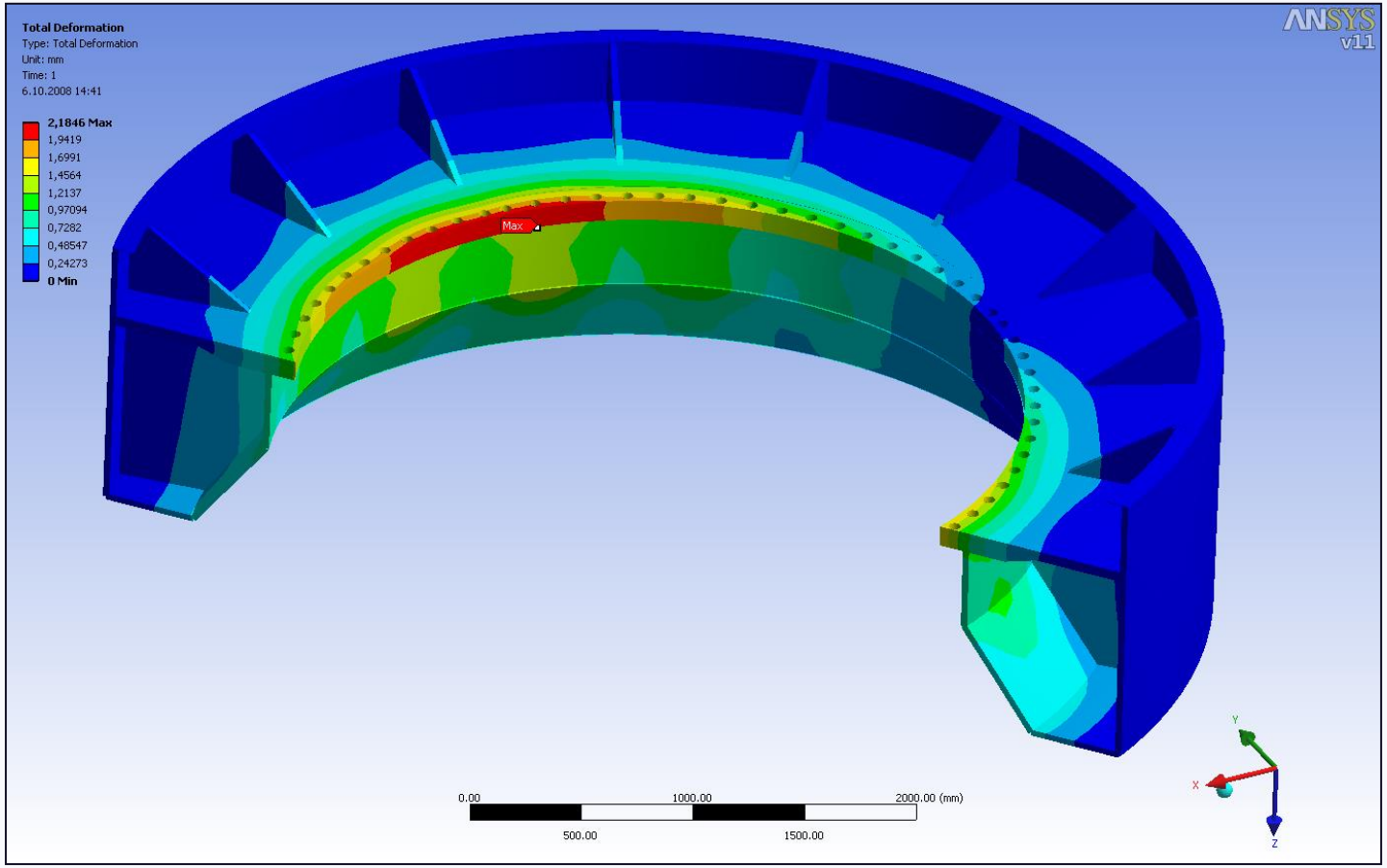


FIRE SIMULATION

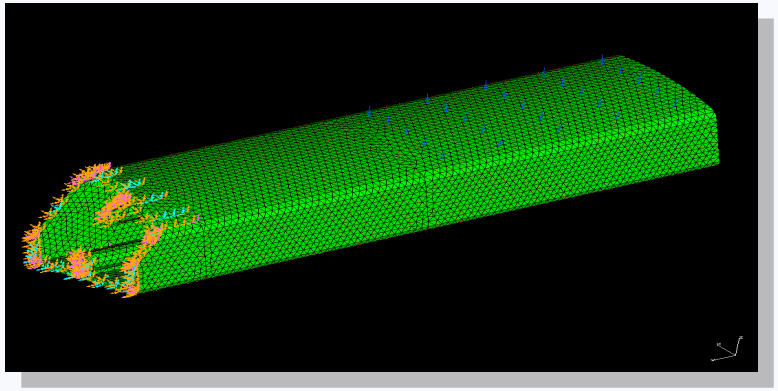


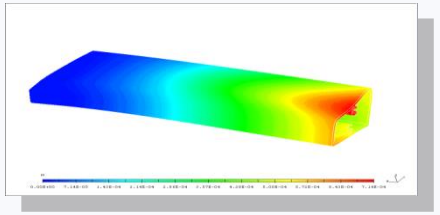
BOLT CONNECTION

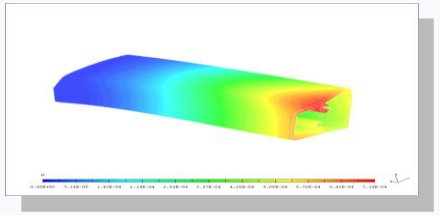
FRAME

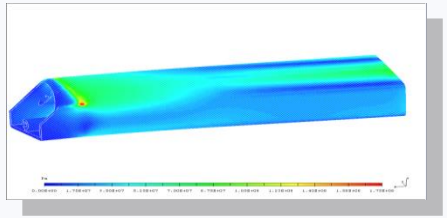

Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
6.10.2008 14:41
2,1846 Max
1,9419
1,6991
1,4564
1,2137
0,97094
0,7282
0,48547
0,24273
0 Min
Max
ANSYS
v11
0.00
1000.00
2000.00 (mm)
500.00
1500.00
Y
X
Z

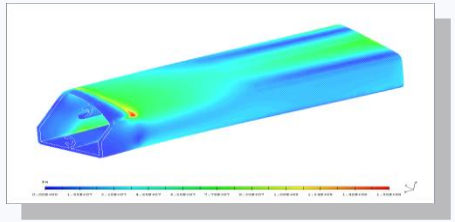
OPTIMIZATION

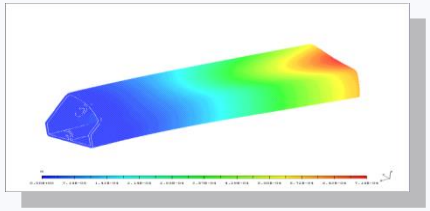




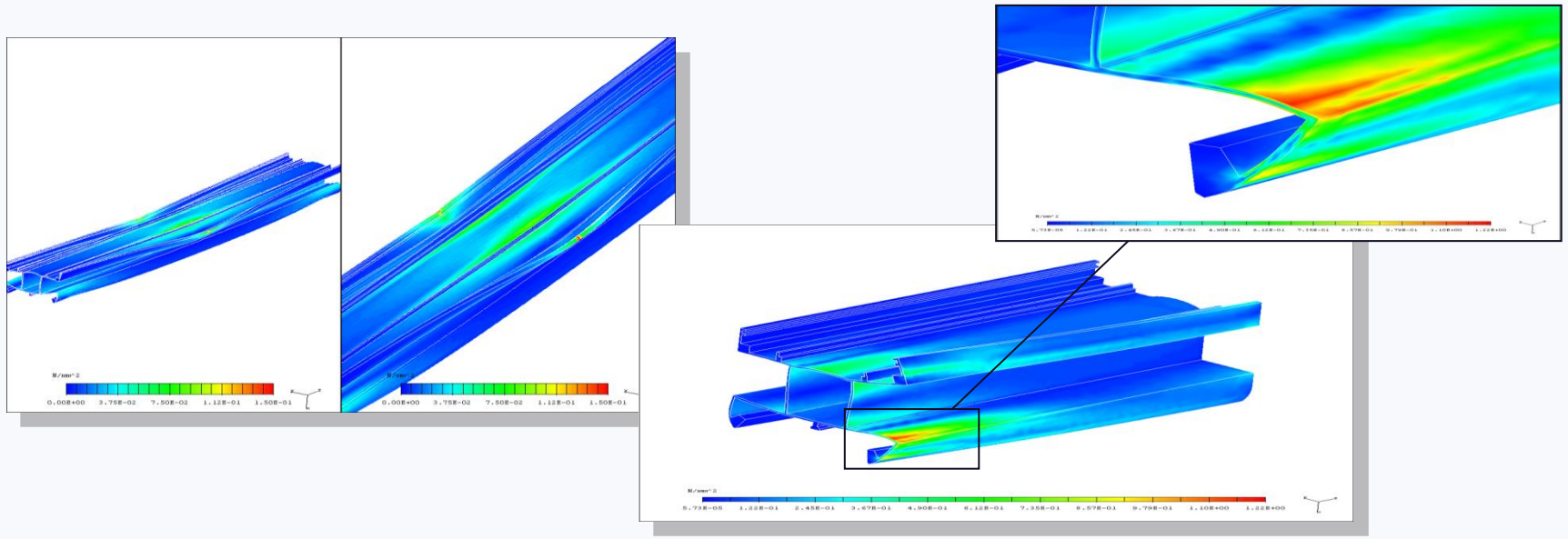




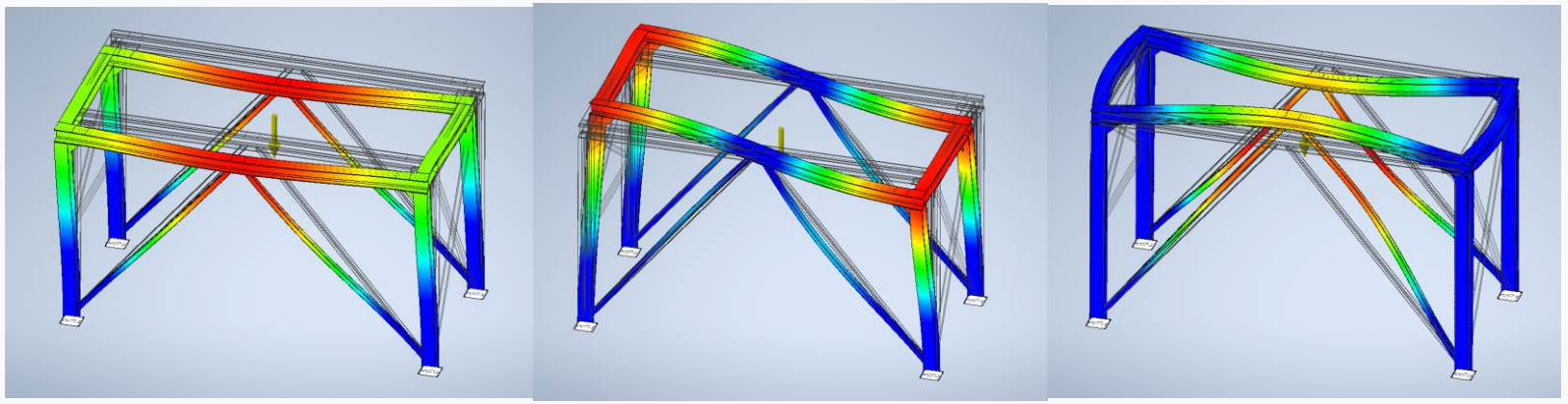


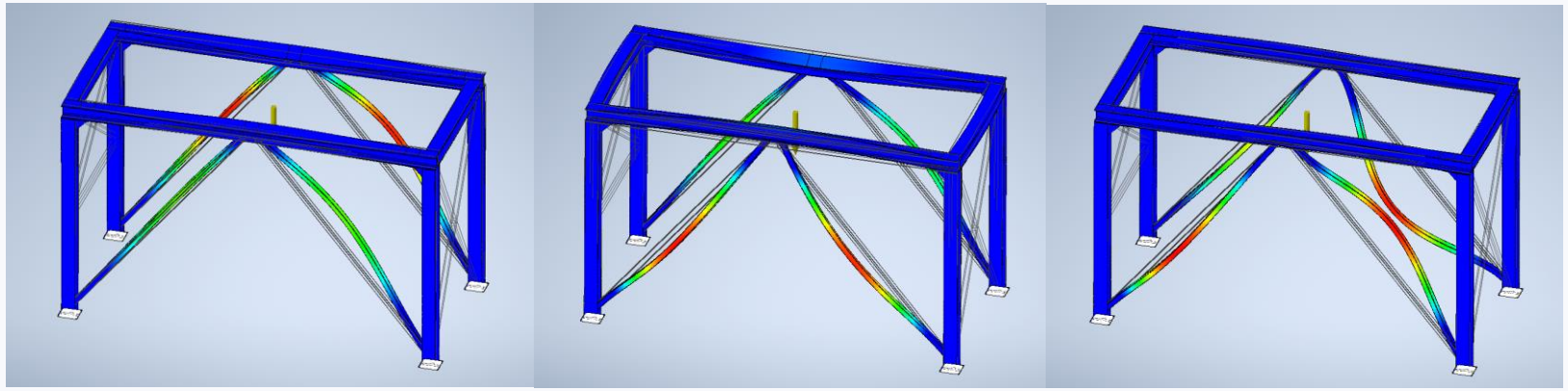


BUCKLING

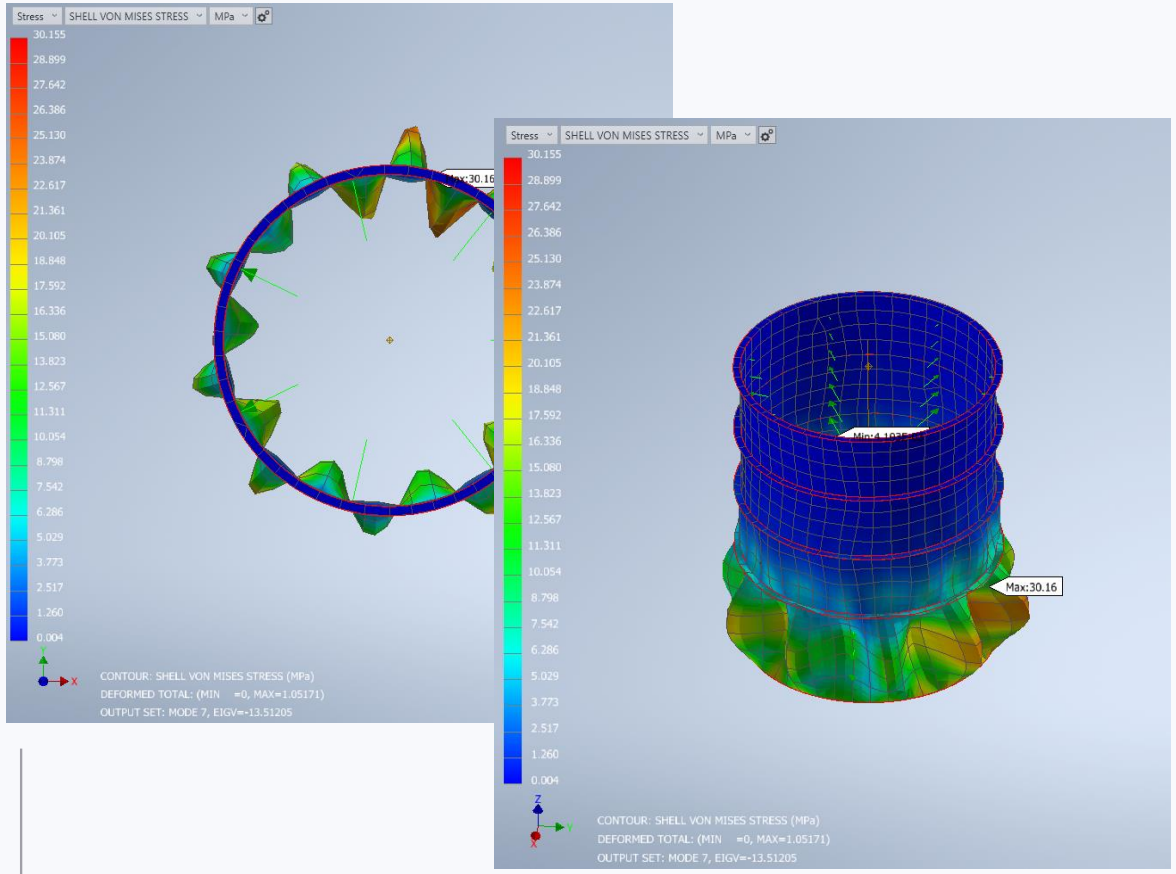


NATURAL FREQUENCIES

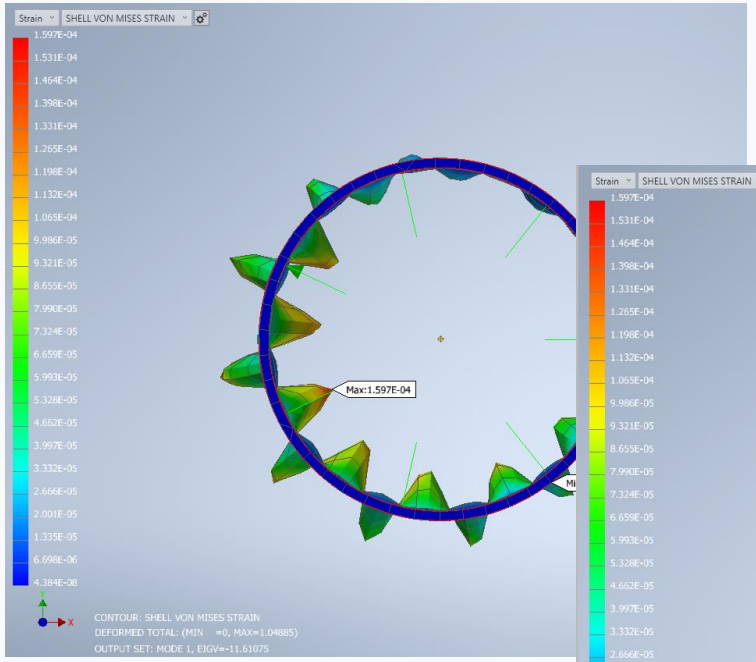


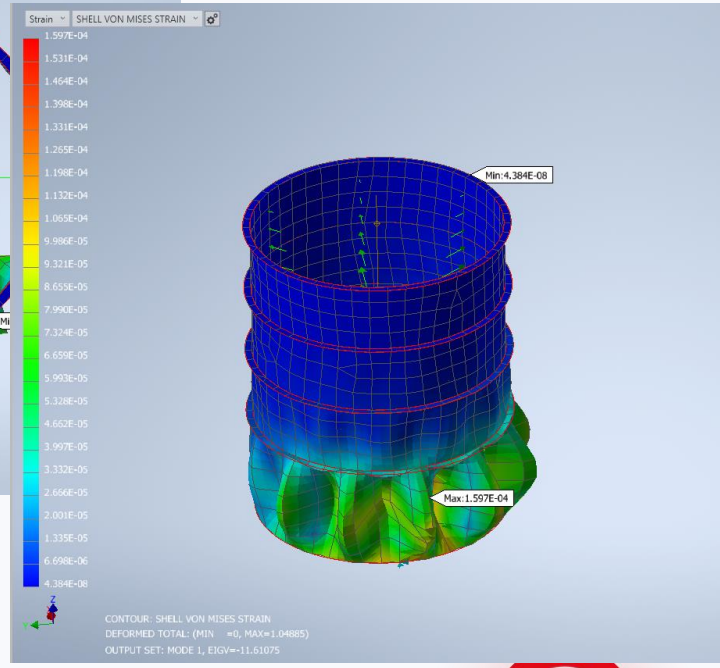


BUCKLING

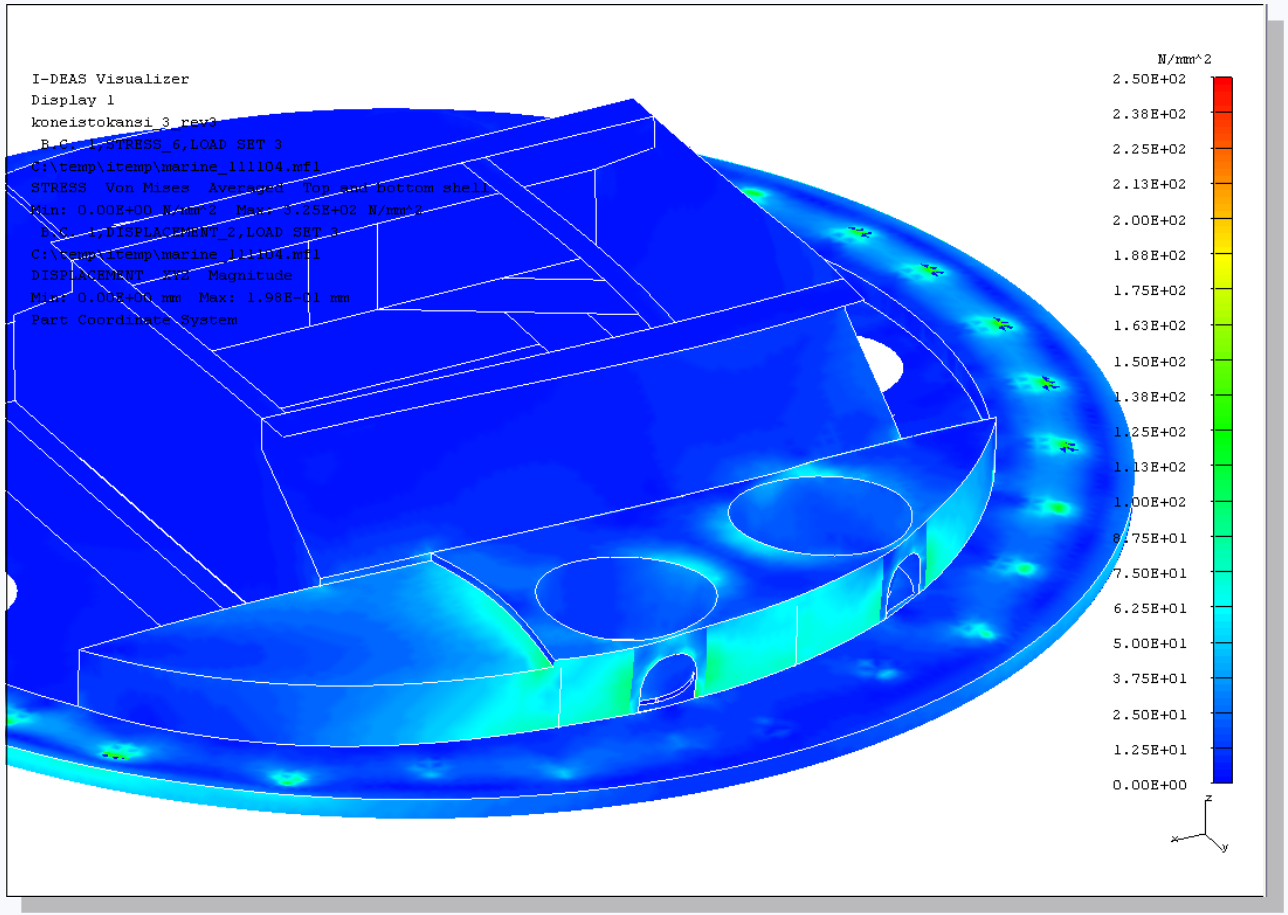

Stress
SHELL VON MISES STRESS
MPa
30.155
28.899
27.642
26.386
25.130
23.874
22.617
21.361
20.105
18.848
17.592
16.336
15.080
13.823
12.567
11.311
10.054
8.798
7.542
6.286
5.029
3.773
2.517
1.260
0.004
CONTOUR: SHELL VON MISES STRESS (MPa)
DEFORMED TOTAL: (MIN =0, MAX=1.05171)
OUTPUT SET: MODE 7, EIGV=-13.51205

Stress
SHELL VON MISES STRESS
MPa
30.155
28.899
27.642
26.386
25.130
23.874
22.617
21.361
20.105
18.848
17.592
16.336
15.080
13.823
12.567
11.311
10.054
8.798
7.542
6.286
5.029
3.773
2.517
1.260
0.004
Max:30.16
CONTOUR: SHELL VON MISES STRESS (MPa)
DEFORMED TOTAL: (MIN =0, MAX=1.05171)
OUTPUT SET: MODE 7, EIGV=-13.51205

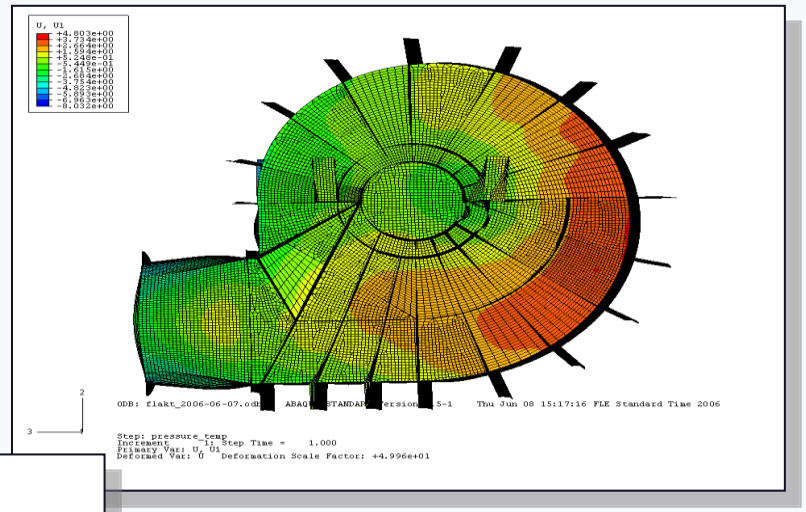

Strain
SHELL VON MISES STRAIN
1.597E-04
1.531E-04
1.464E-04
1.398E-04
1.331E-04
1.265E-04
1.198E-04
1.132E-04
1.065E-04
9.986E-05
9.321E-05
8.655E-05
7.990E-05
7.324E-05
6.659E-05
5.993E-05
5.328E-05
4.662E-05
3.997E-05
3.332E-05
2.666E-05
2.001E-05
1.335E-05
6.698E-06
4.384E-08
Max:1.597E-04
CONTOUR: SHELL VON MISES STRAIN
DEFORMED TOTAL: (MIN =0, MAX=1.04885)
OUTPUT SET: MODE 1, EIGV=-11.61075

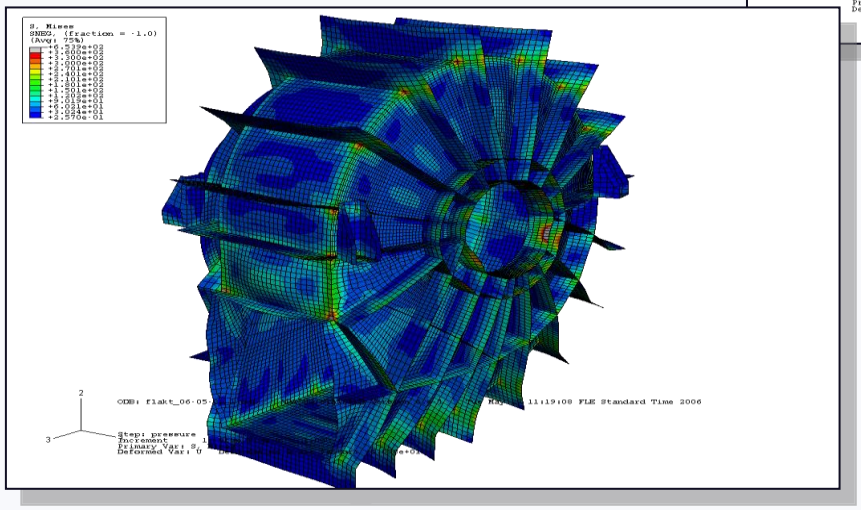

Strain
SHELL VON MISES STRAIN
1.597E-04
1.531E-04
1.464E-04
1.398E-04
1.331E-04
1.265E-04
1.198E-04
1.132E-04
1.065E-04
9.986E-05
9.321E-05
8.655E-05
7.990E-05
7.324E-05
6.659E-05
5.993E-05
5.328E-05
4.662E-05
3.997E-05
3.332E-05
2.666E-05
2.001E-05
1.335E-05
6.698E-06
4.384E-08
Min:4.384E-08
Max:1.597E-04
CONTOUR: SHELL VON MISES STRAIN
DEFORMED TOTAL: (MIN =0, MAX=1.04885)
OUTPUT SET: MODE 1, EIGV=-11.61075

STIFFENER PLATE

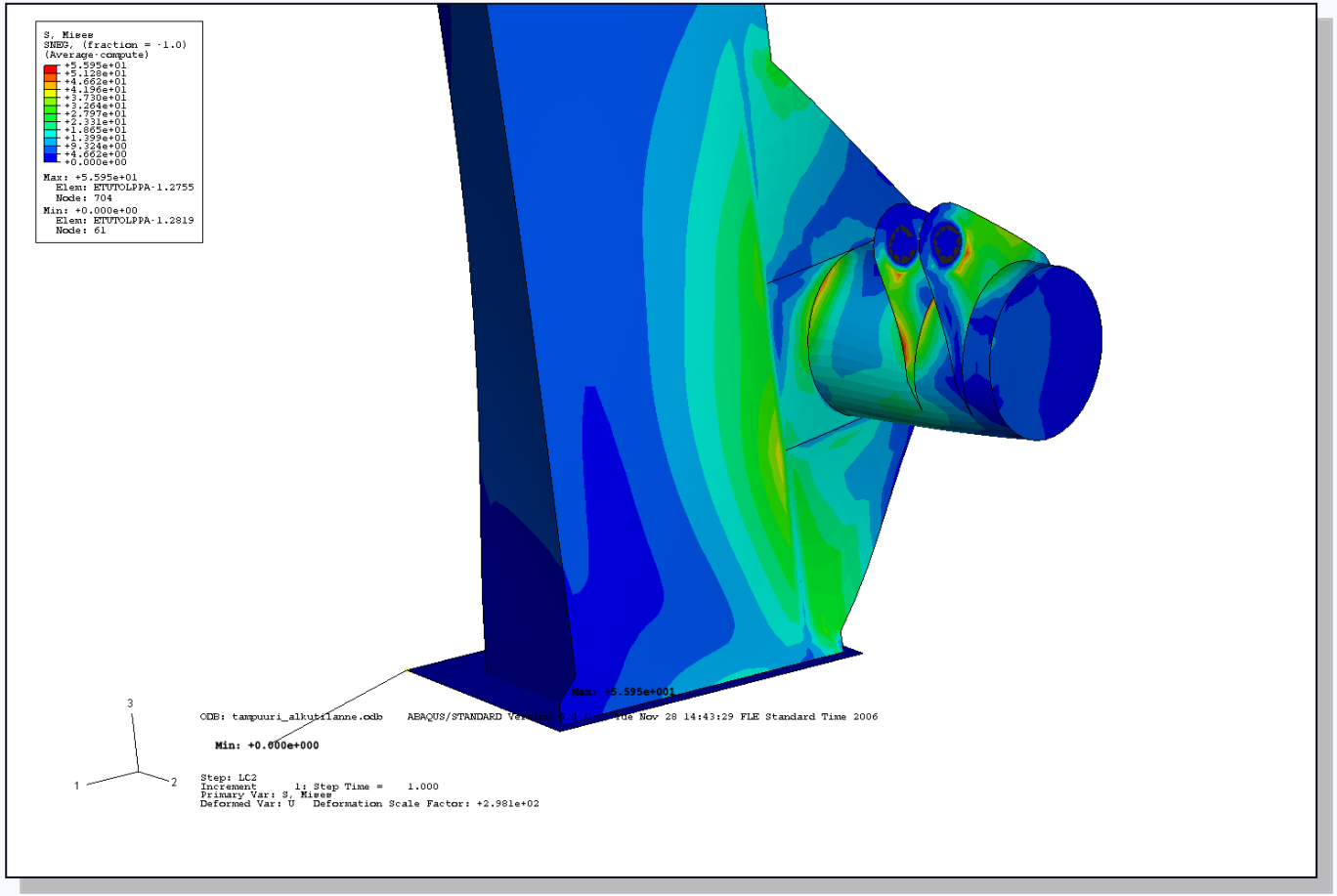


PED COMPONENTS

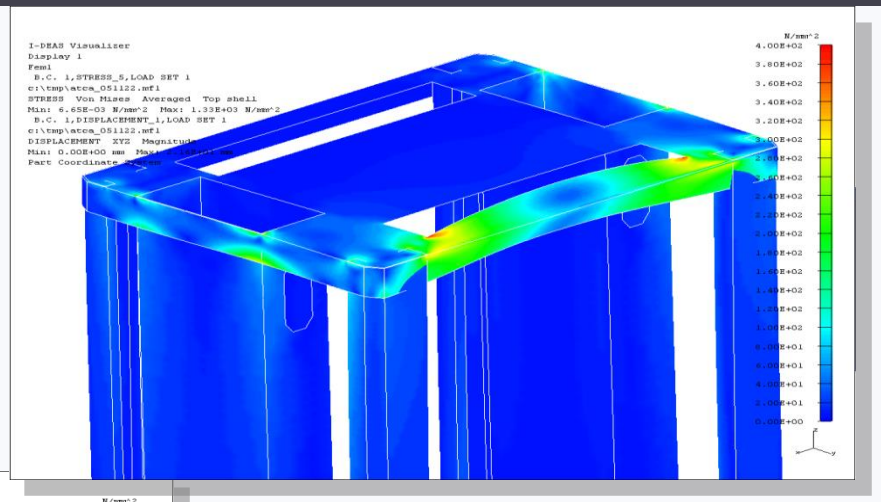


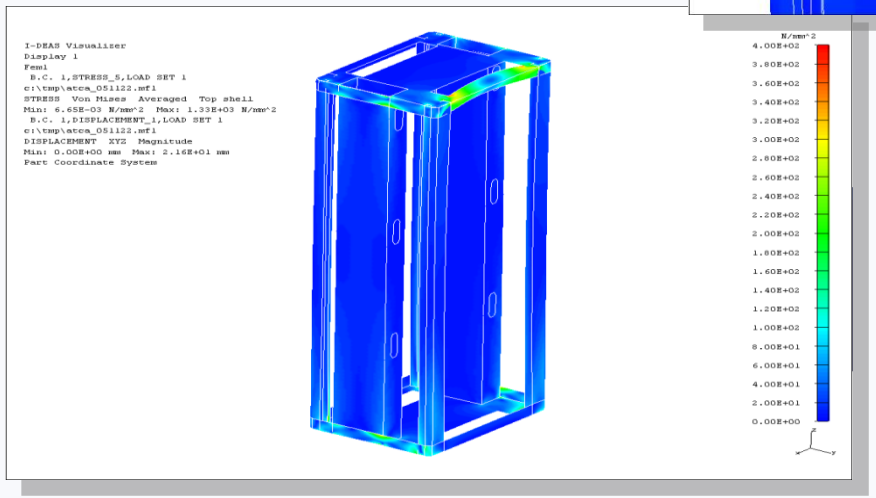


WELD LIFETIME ANALYSIS

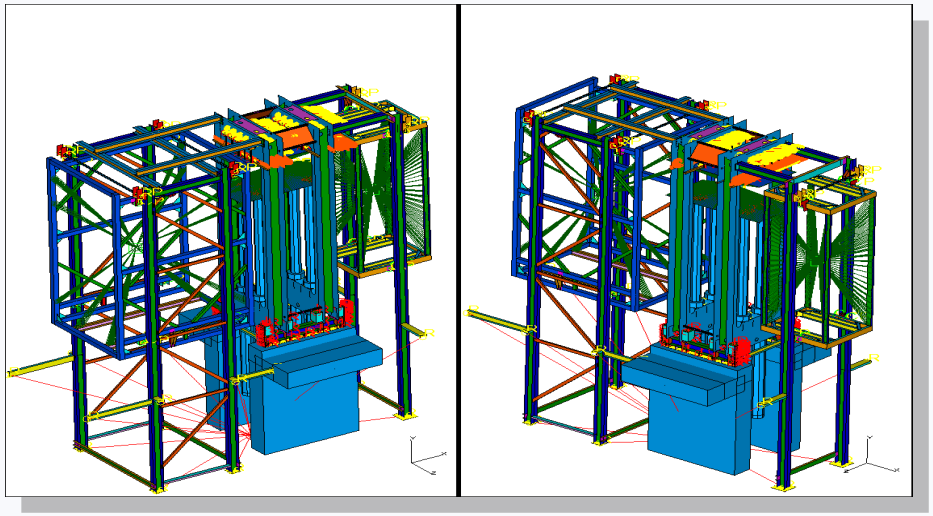


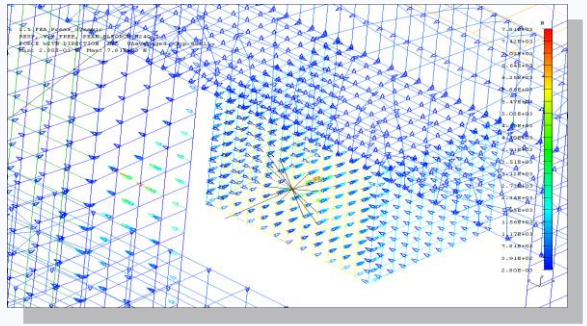
SHEET METAL STRUCTURES

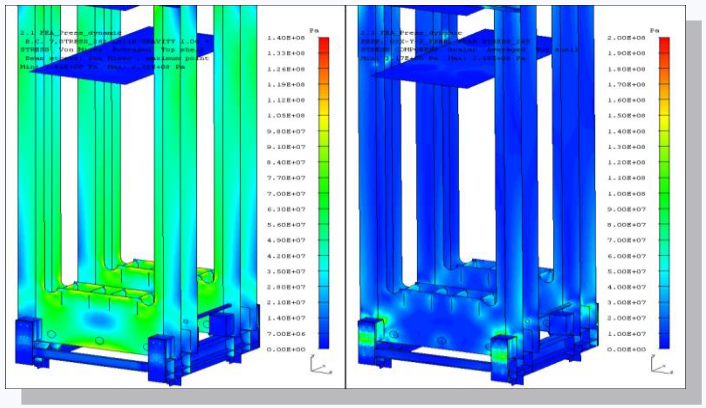




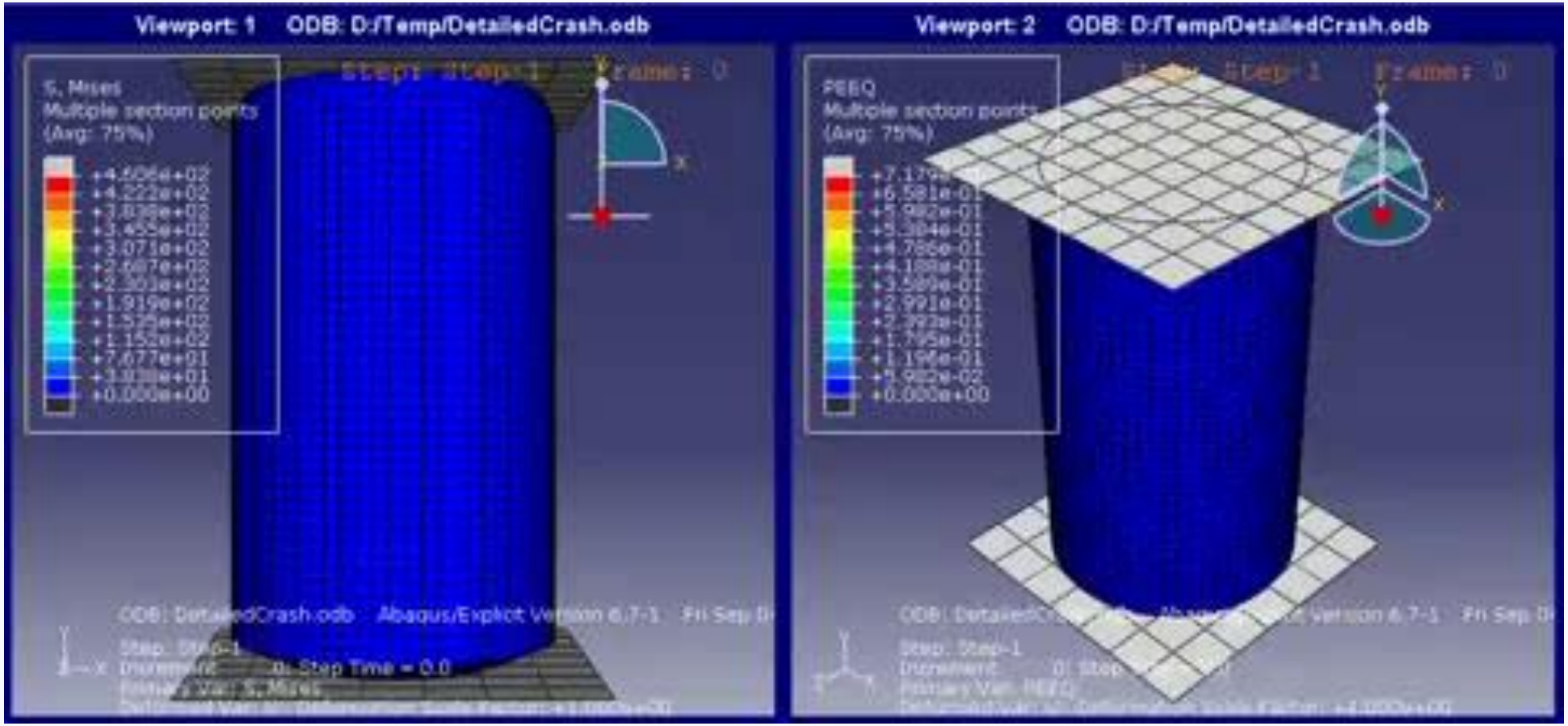
FRAMES



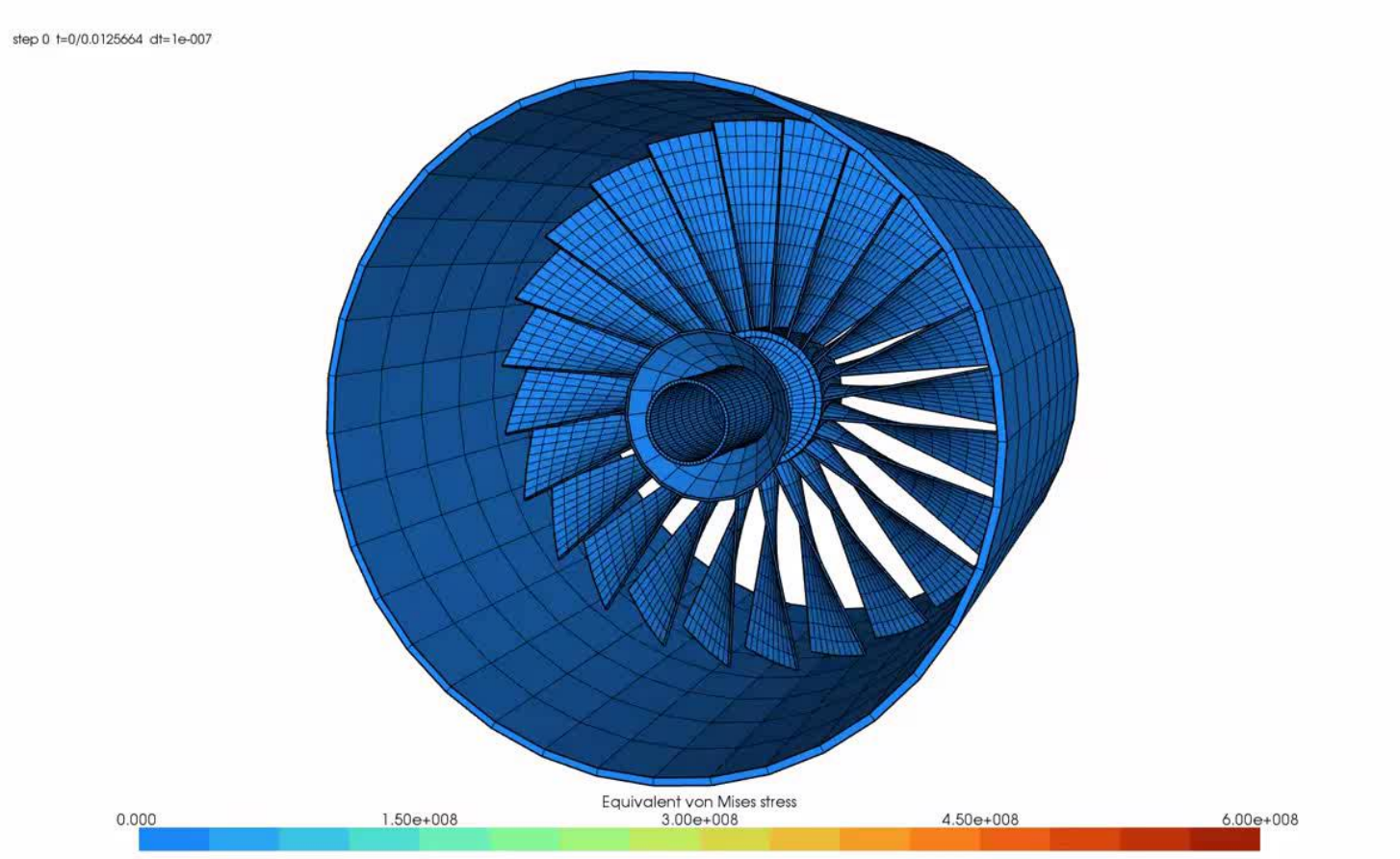




NONLINEAR CRUSHING

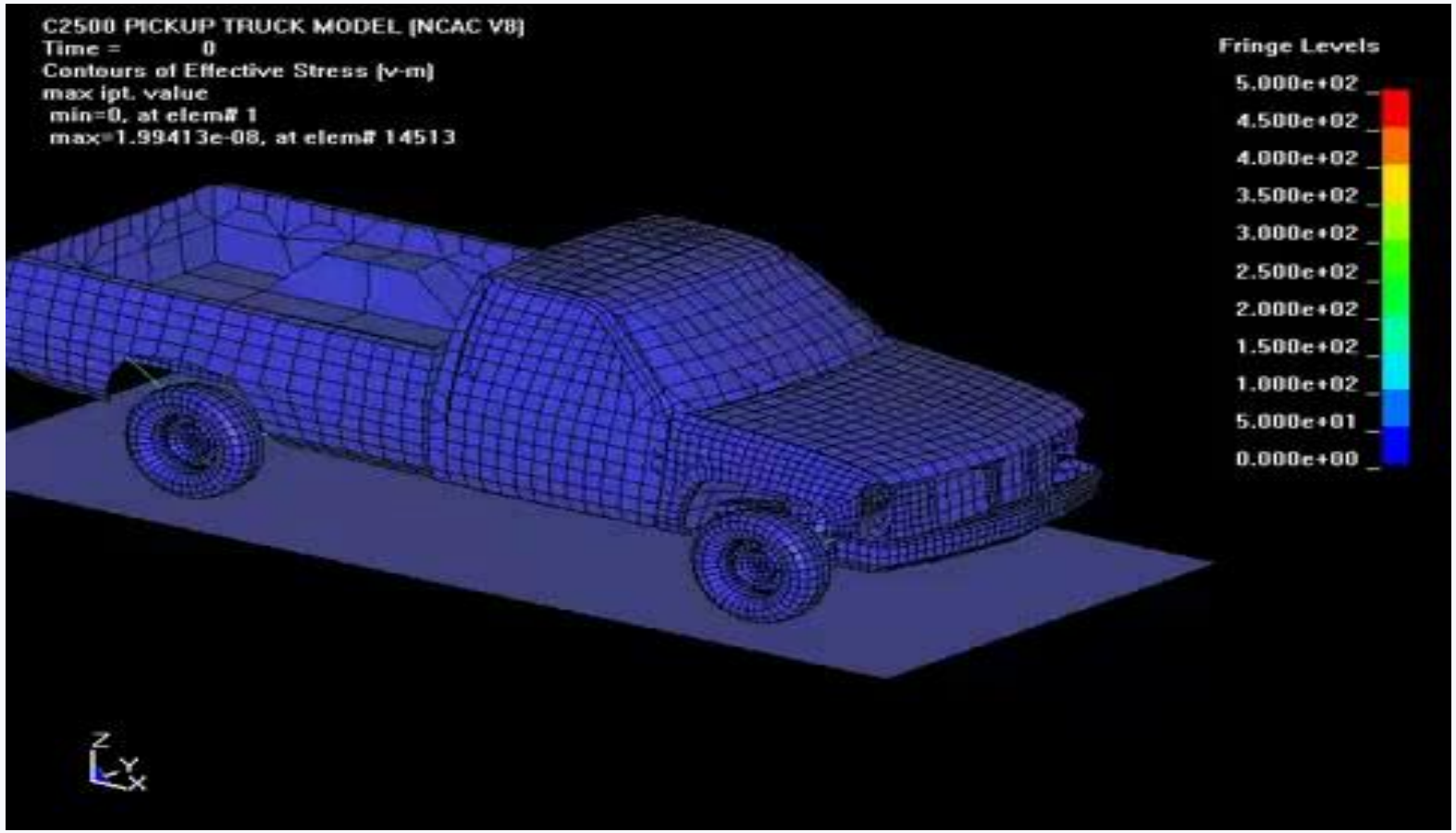


BLADE LOSS

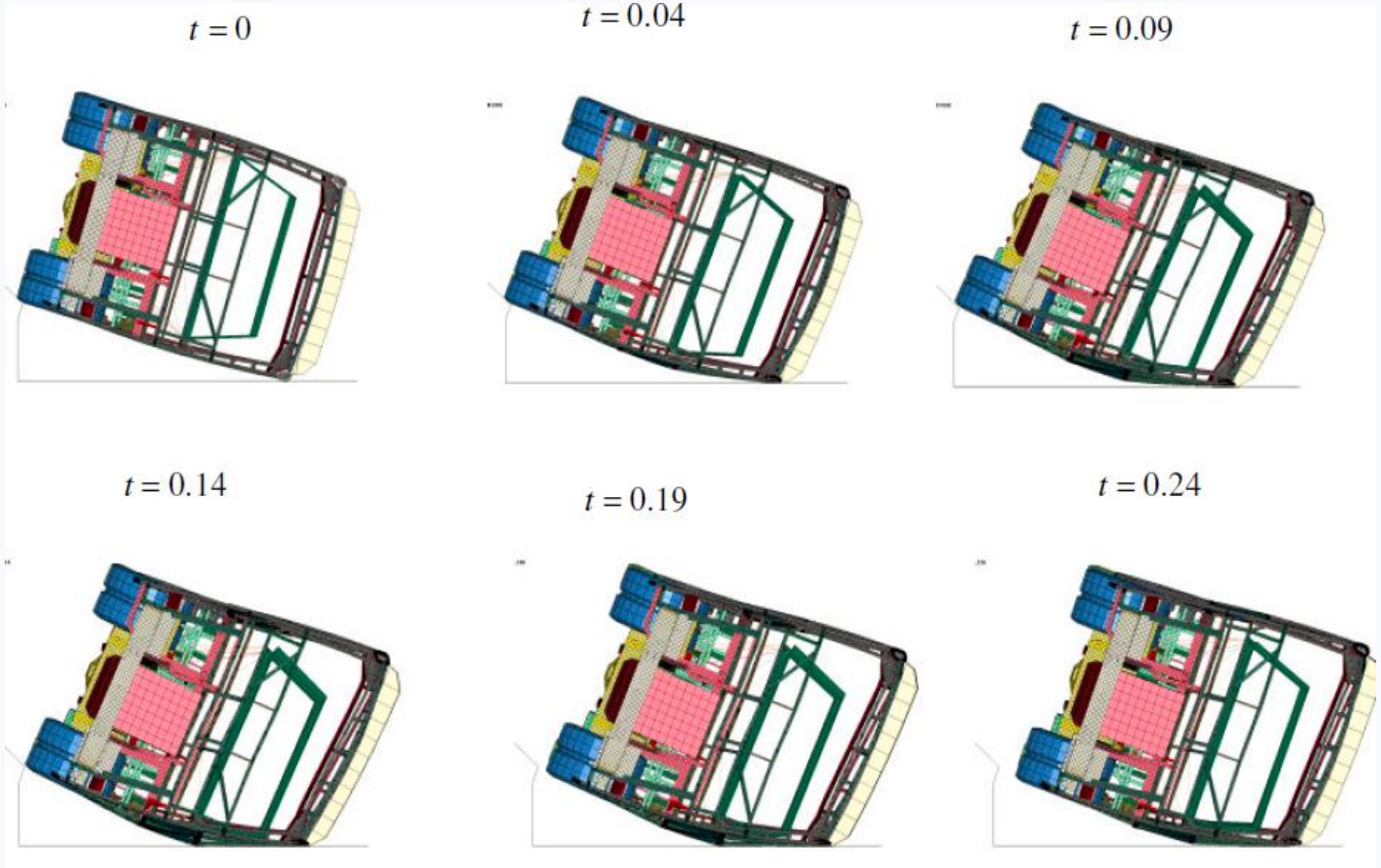

step 0 t=0/0.0125664 dt=1e-007
Equivalent von Mises stress
0.000
1.50e+008
3.00e+008
4.50e+008
6.00e+008

HYDRODYNAMICS

CRASH SIMULATION



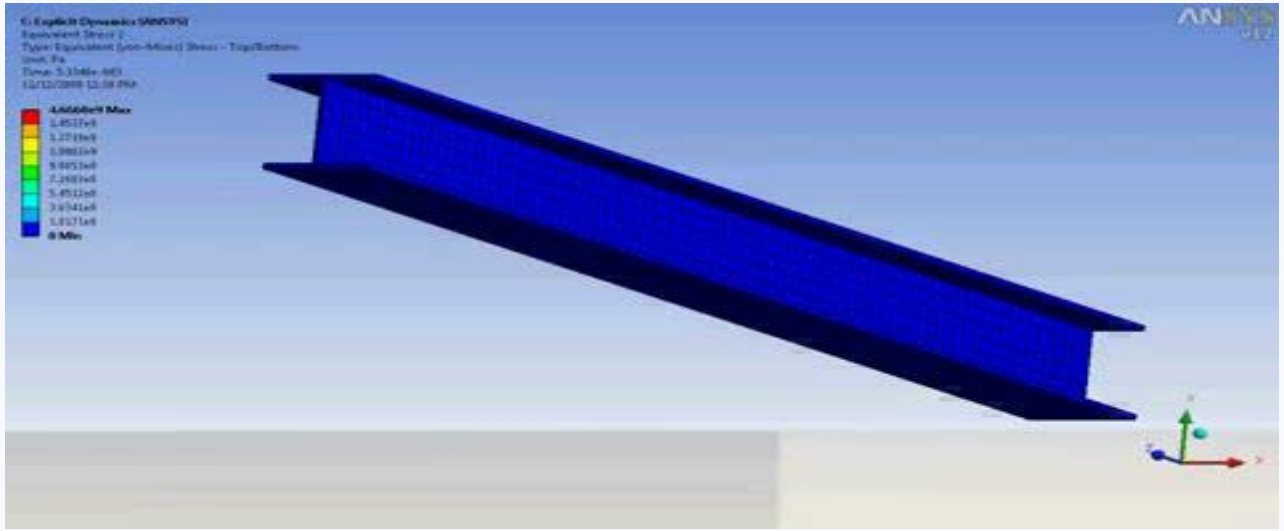
ROPS/FOPS SIMULATION



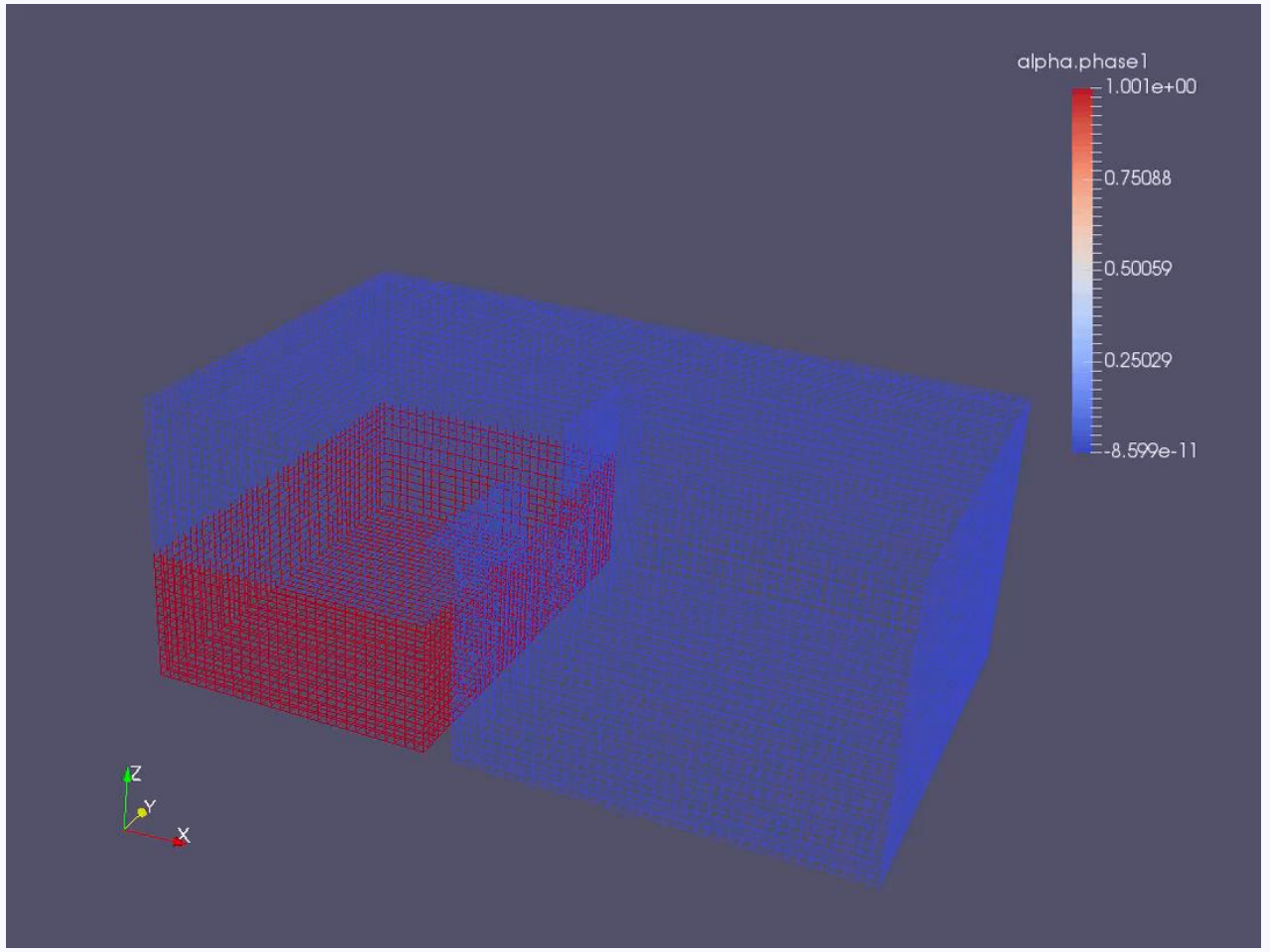
ROPS/FOPS

CFD

IMPACT SIMULATION



FLOW ANALYSIS




THANKS!
ENTOP