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***Title:*** **Advanced Simulations with Creo Simulate 2.0**

***Author:*** Theo Wijers

***Date:*** November 2012

mechanical product  
development and  
consultancy



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## Agenda:

- Introduction
- Why Simulations?
- Theory of Non-Linearity:
  - Geometric: Large Displacements
  - Constraints: Contact
  - Material: Elastoplastic, Hyperelastic
- Combining Non-Linearities with Creo Simulate 2.0
- Examples of combined Non-Linear Analyses
- Examples of Advanced Dynamic Analyses
- Discussion



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## Introduction



Office of CE Masters in Houten, NL

### Contact information:

Sleepboot 11 | 3991 CN Houten | The Netherlands

T +31 (0)30 635 48 50 | F +31 (0)30 635 48 51

[www.cemasters.nl](http://www.cemasters.nl)

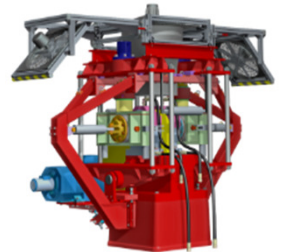
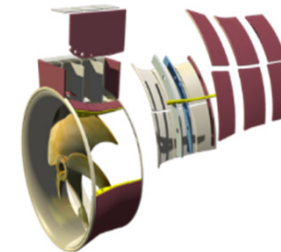


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# Introduction

## Our Customers





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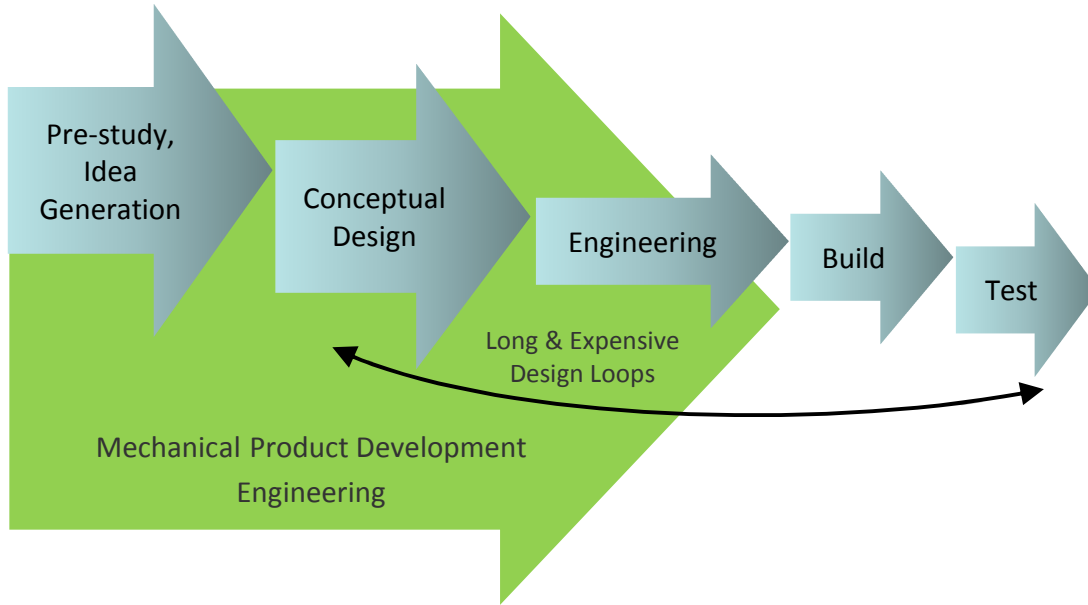
## Why Simulations?

### **CE Masters distinguishes 3 Levels of Engineering:**

1. Engineering without Simulation
2. Engineering with Simulation
3. Integrated Engineering & simulation



# Engineering without Simulation



“Physical Testing”

Characteristics:

- Insufficient insight in product behavior
- Unable to compare design alternatives
- Long and expensive design loops
- Expensive physical prototypes
- Not first time right
- End result is compromise of design issues

Long Time to Market

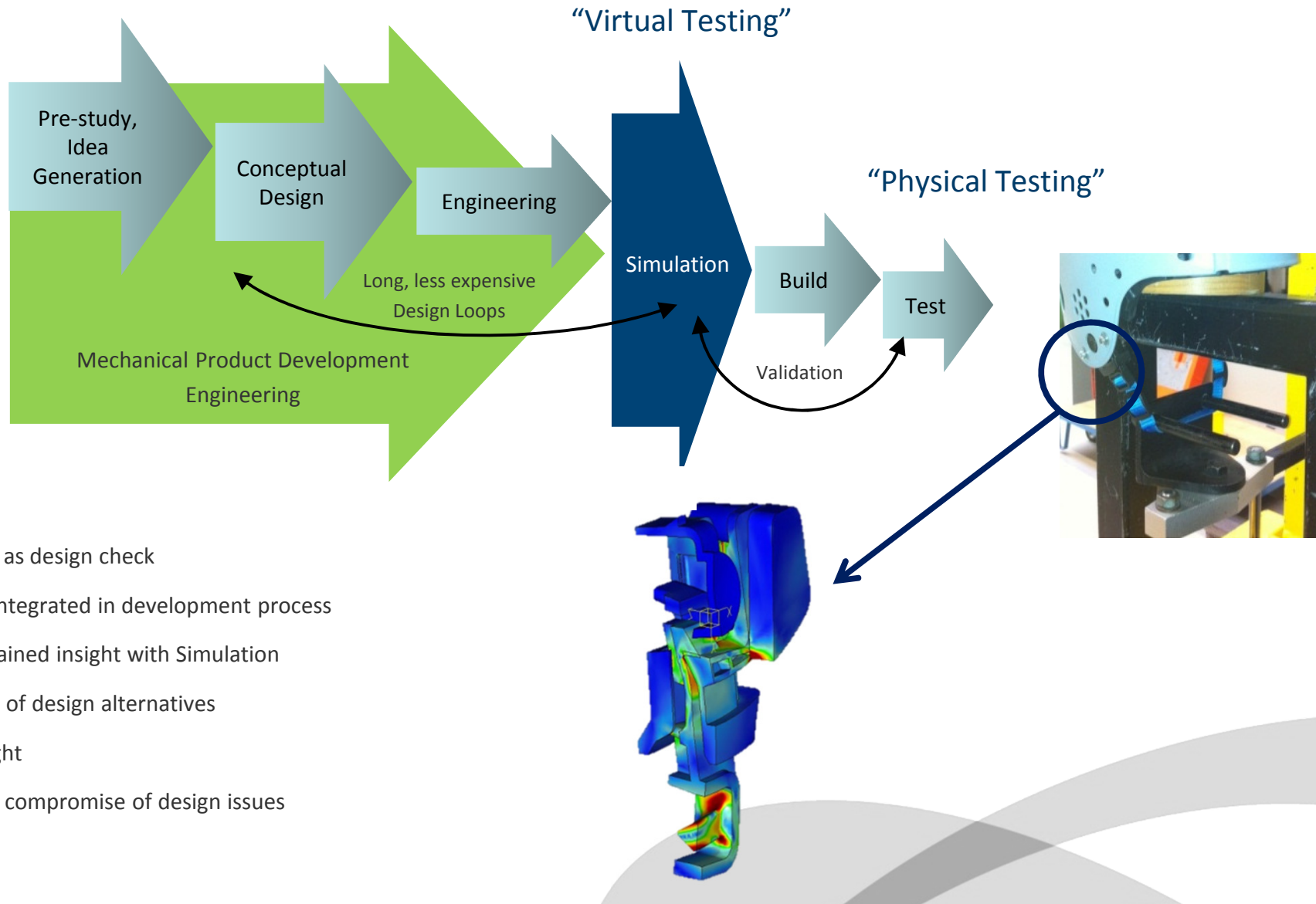
Low Quality

High Costs





# Engineering with Simulation



### Characteristics:

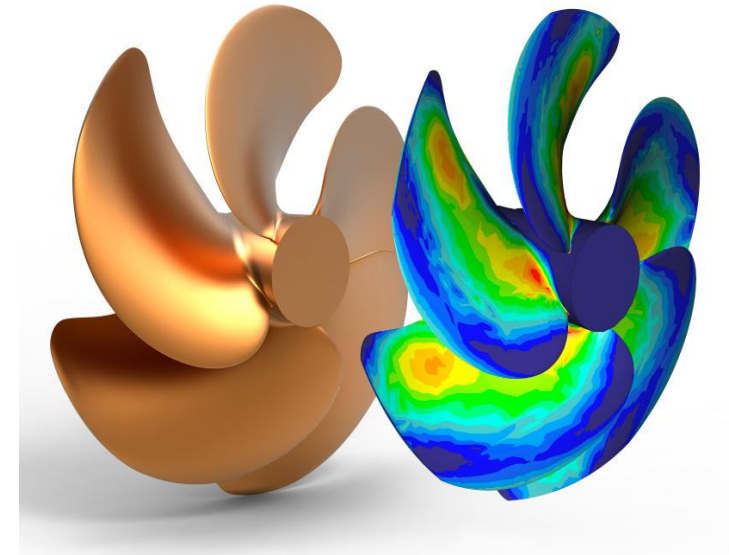
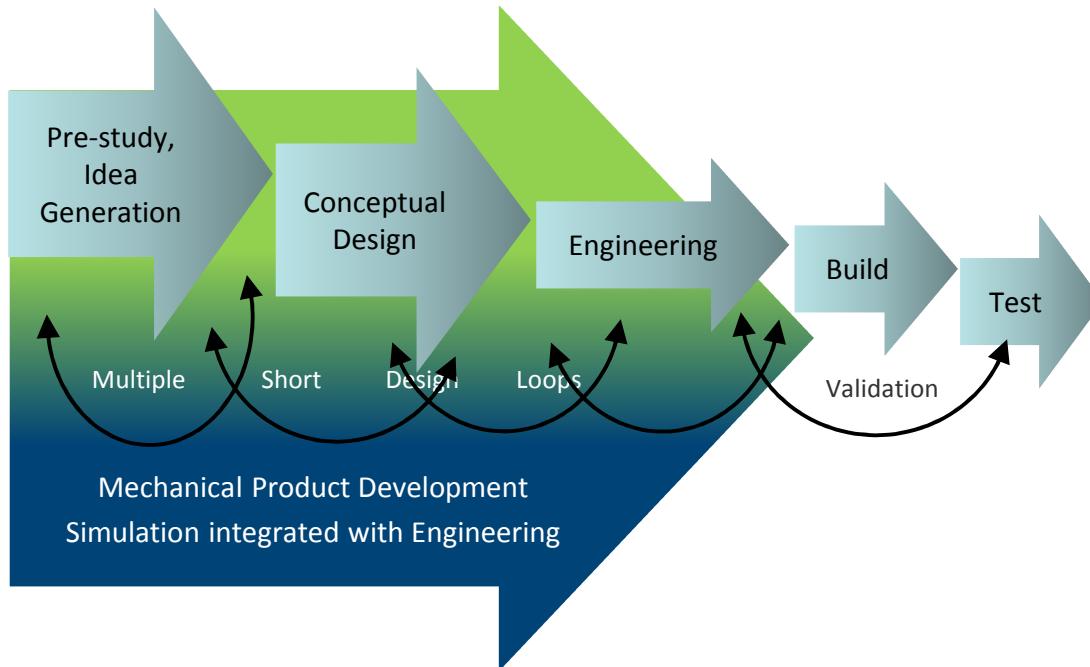
- Simulation used as design check
- Simulation not integrated in development process
- Limited use of gained insight with Simulation
- No investigation of design alternatives
- Not first time right
- End result is still compromise of design issues



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## Integrated Engineering & Simulation



Characteristics:

- Early insight in product behavior
- Ability to compare many design alternatives
- Short and low cost design loops
- Less physical prototypes
- First Time Right approach
- Concept optimized and based on insight

Short Time to Market

High Quality

Low Costs

“Insight driven Engineering”

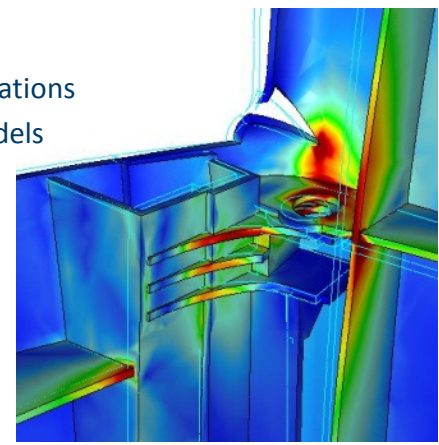
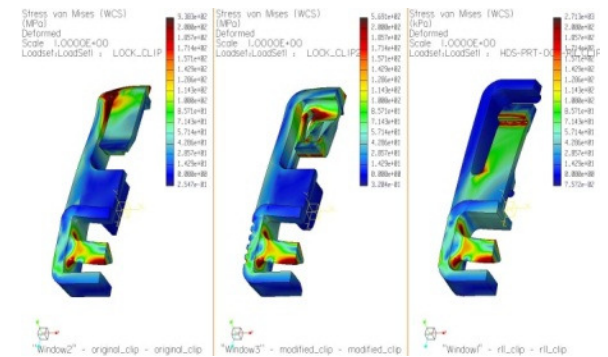
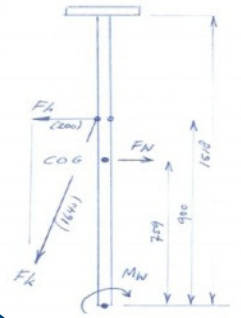
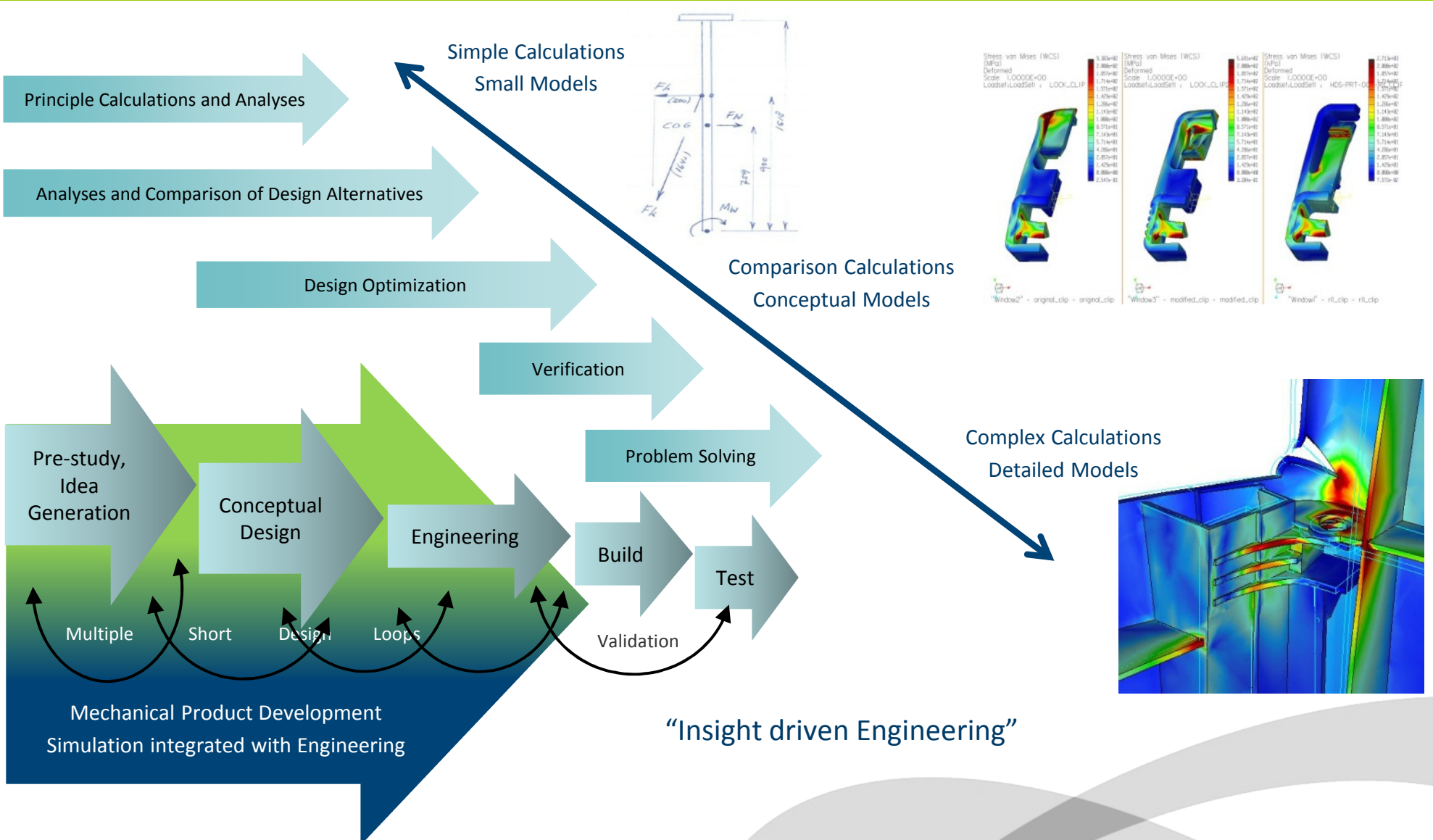




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# Simulation Characteristics





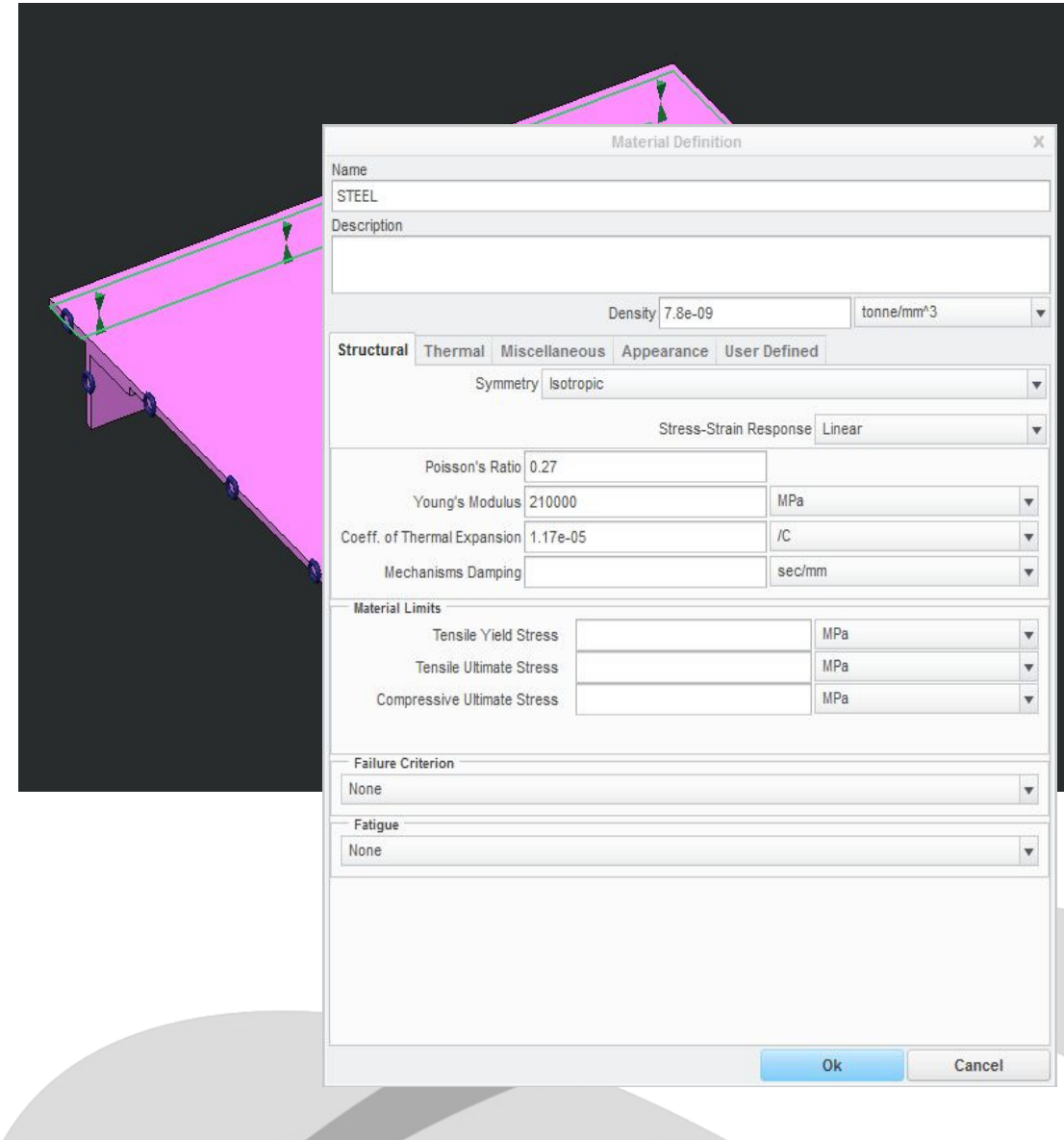
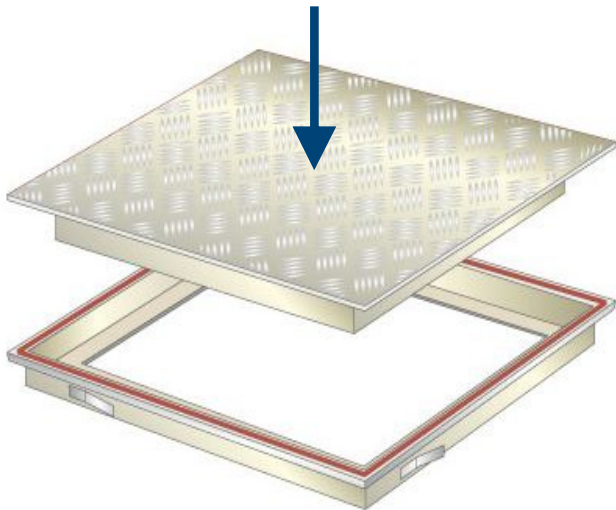
### Comparison of Linear Analysis with:

- Geometric Non-Linearity:            Large Displacements
- Material Non-Linearity:            Elastoplastic Material Property
- Constraint Non-Linearity:            Contact Analyses

## Example: Manhole Cover

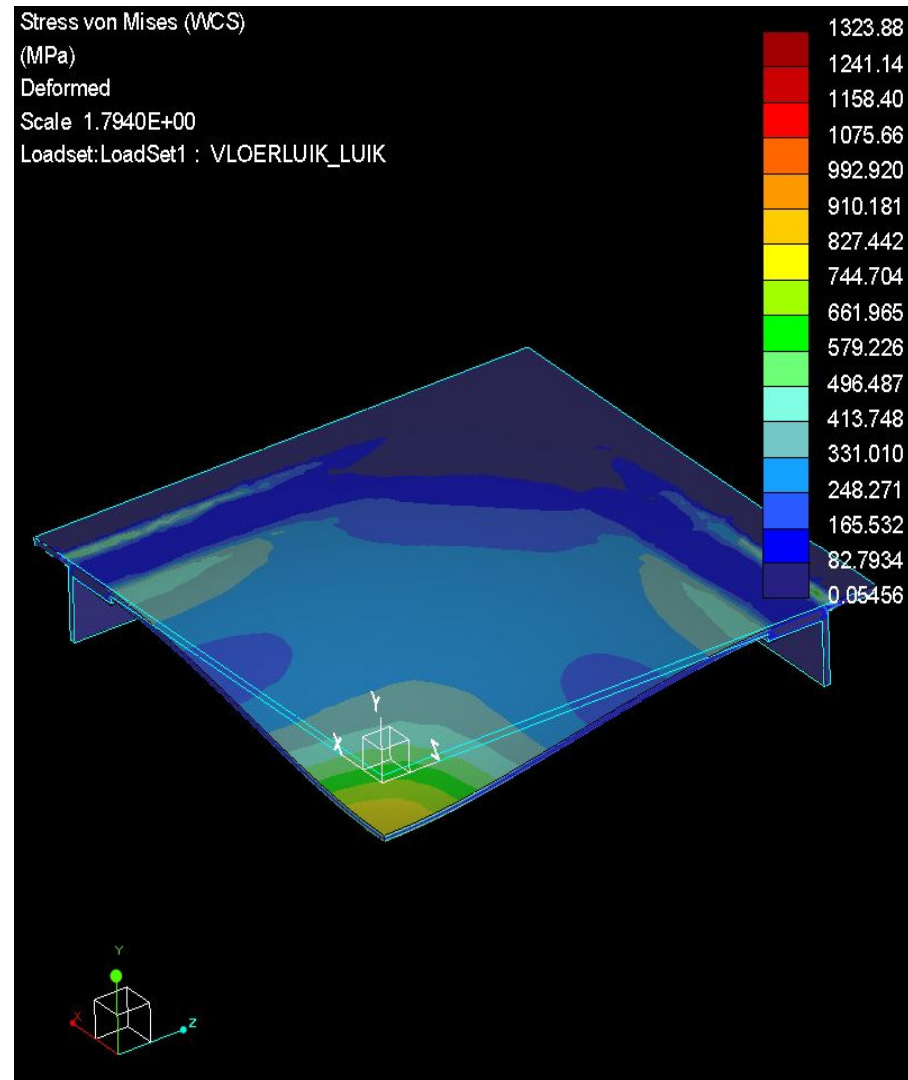
### Linear Analyses:

- ¼ of model due to symmetry
- Material Steel (linear): Emod = 210.000 MPa
- Constraint vertically at contact surface with base
- ¼ of total load:  $F = \frac{1}{4} * 15 = 3,75$  kN

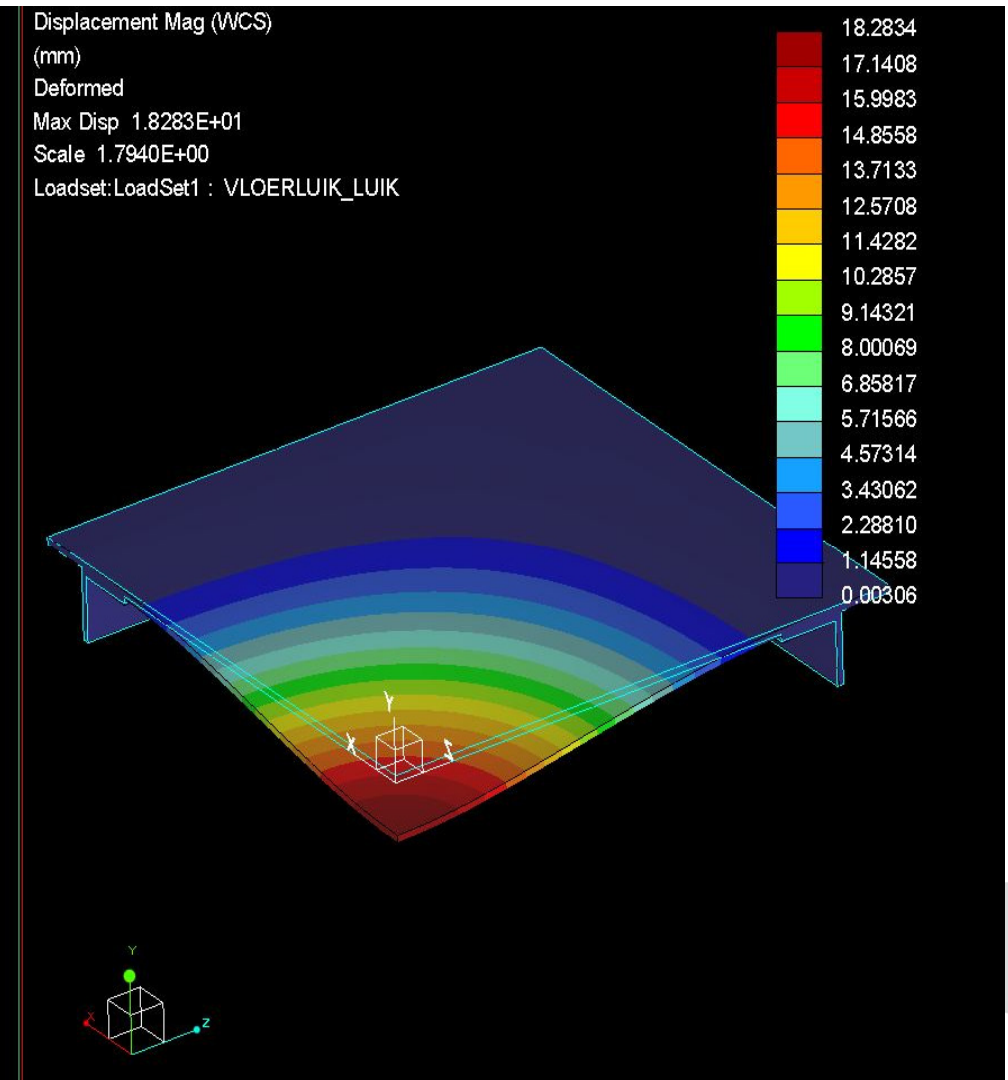


## Results Linear Analysis

Max. VM stress = 1324 MPa



Max. Displacement = 18,3 mm





# Theory of Non-Linearity

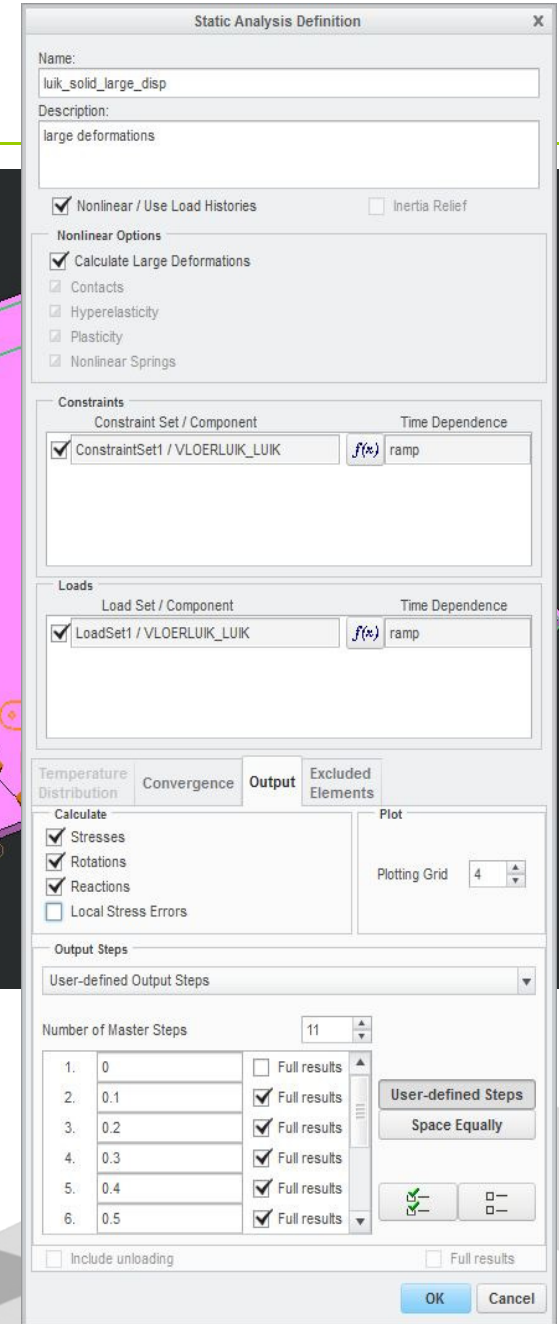
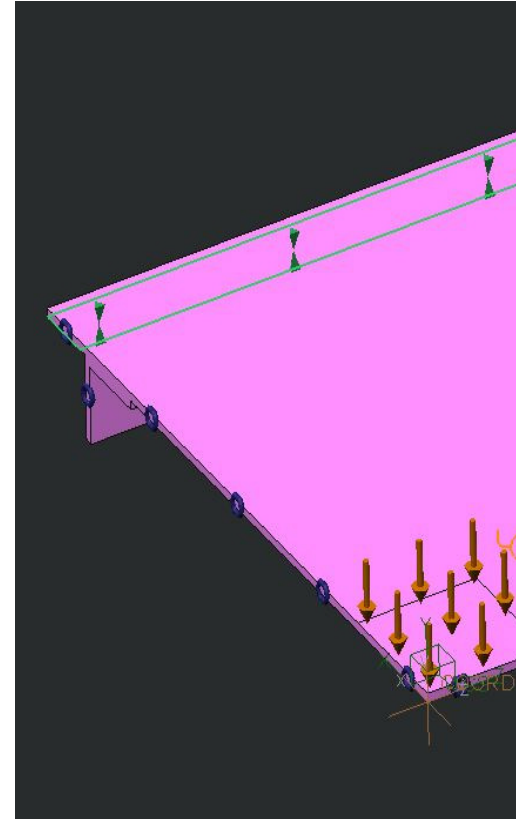
## Geometric Non-Linearity: Large Displacements

### Characteristics:

- The stiffness under loading is Non-Linear (i.e. the stiffness changes due to changed shape)
- The analyses is executed with load steps
- At each load step the stiffness matrix will be recomputed
- (reaction)Load direction can change

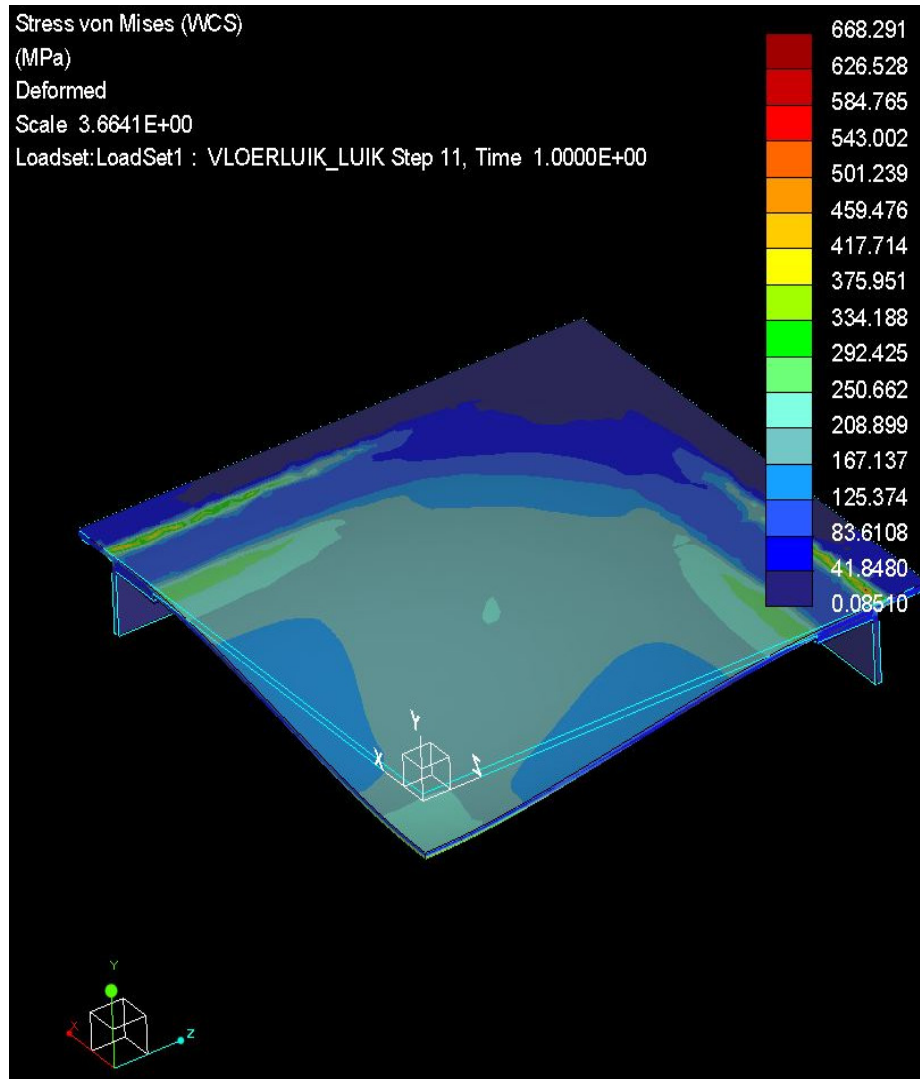
### When to use Large Displacements (rules-of-thumb):

- Deformation larger than the (shell)thickness
- Deformation visible to the naked eye
- Deformation larger than 1/20<sup>th</sup> of part's largest dimension

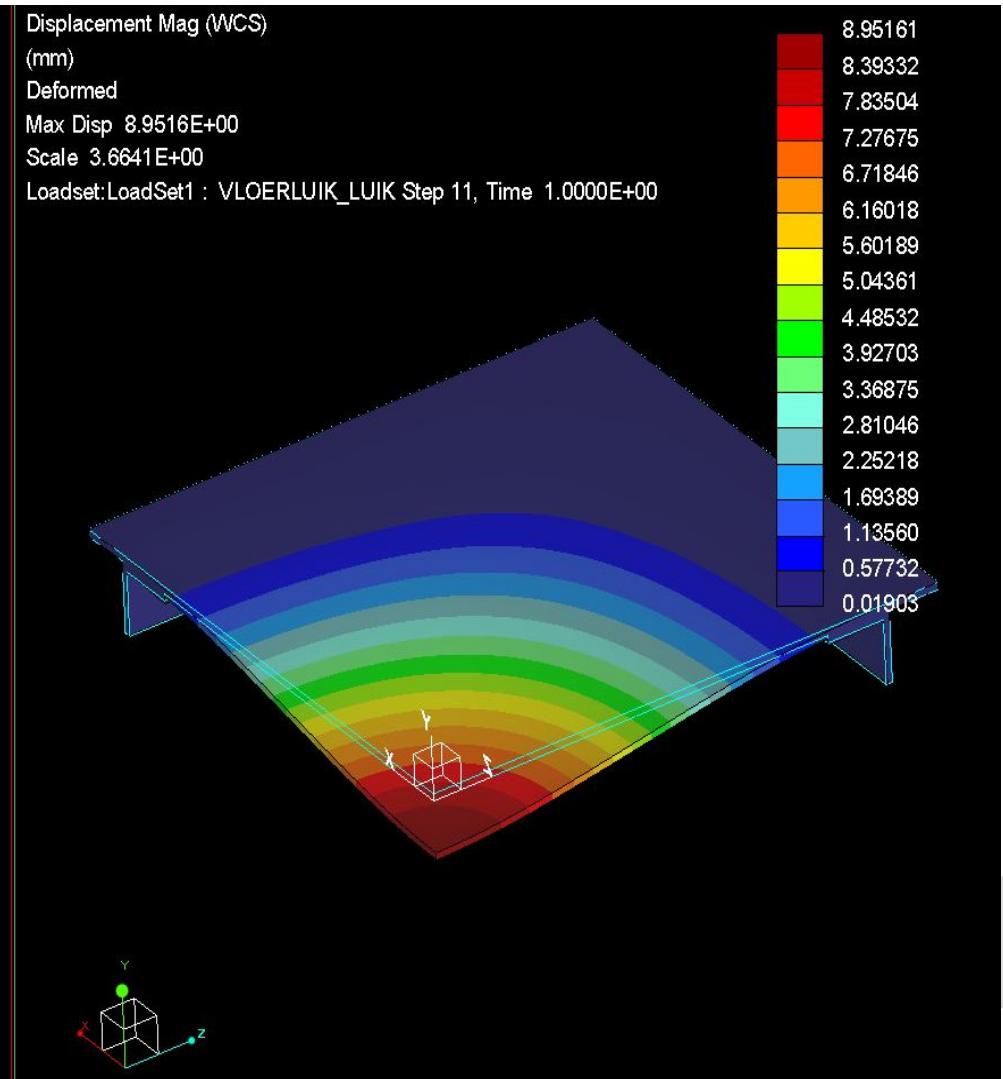


## Results Non-Linear Large Displacement Analysis

Max. VM stress = 668 MPa



Max. Displacement = 8,95 mm

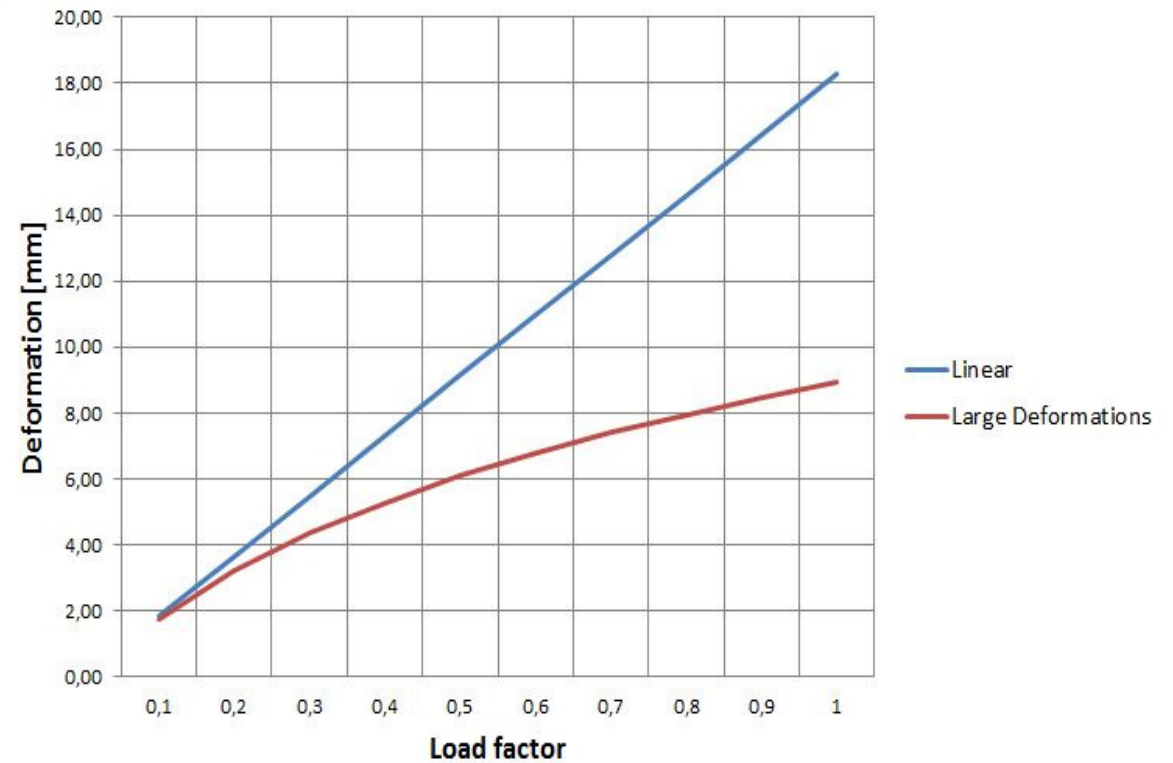
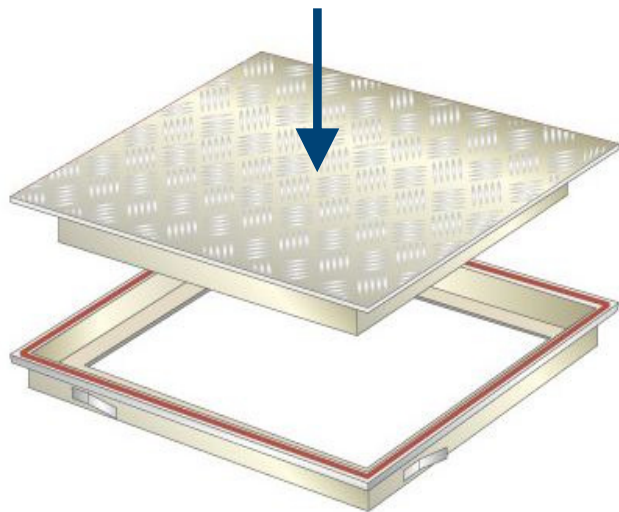




## Theory of Non-Linearity

### Example: Manhole Cover

Comparison Linear Analysis with Large Deformation analyses





## Theory of Non-Linearity

### Material Non-Linearity: Elastoplastic Material

#### Characteristics:

- Until the Yield point the material acts linear
- Above the Yield point the stress-strain curve changes
- Different material laws available

#### When to use Elastoplastic material:

- To calculate realistic deformation (elastic and/or plastic) when the Yield stress is exceeded

### The elasto-plastic stress-strain curve

#### ▪ True elastic limit (1):

- The lowest stress at which dislocations move
- Has no practical importance

#### ▪ Proportionality limit (2):

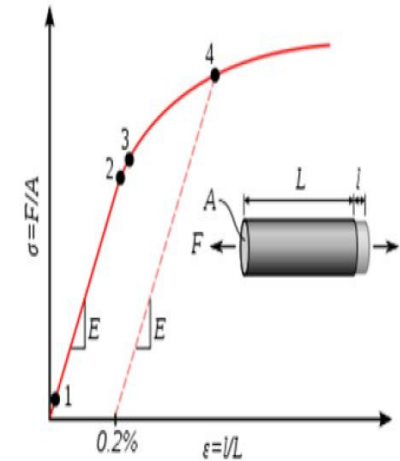
- Limit until which the stress-strain curve is a straight line characterized by Young's modulus,  $E$

#### ▪ Elastic limit, yield strength or yield point (3):

- Is the stress at which a material begins to deform plastically, means non-reversible (this is the lowest stress at which permanent deformation can be measured)
- Before the yield point, the material deforms only elastically and will return to its original shape

#### ▪ Offset yield point or proof stress (4):

- Since the true yield strength often cannot be measured easily, the offset yield point is arbitrarily defined by using the stress value at which we have 0.1 or 0.2 % remaining strain. It is therefore described with an index, e.g.  $R_{p0.2}$  for 0.2 % remaining strain like shown in the image



A typical stress-strain curve for non-ferrous alloys [1]



### Material Non-Linearity: Elastoplastic Material

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#### Implemented Material Laws

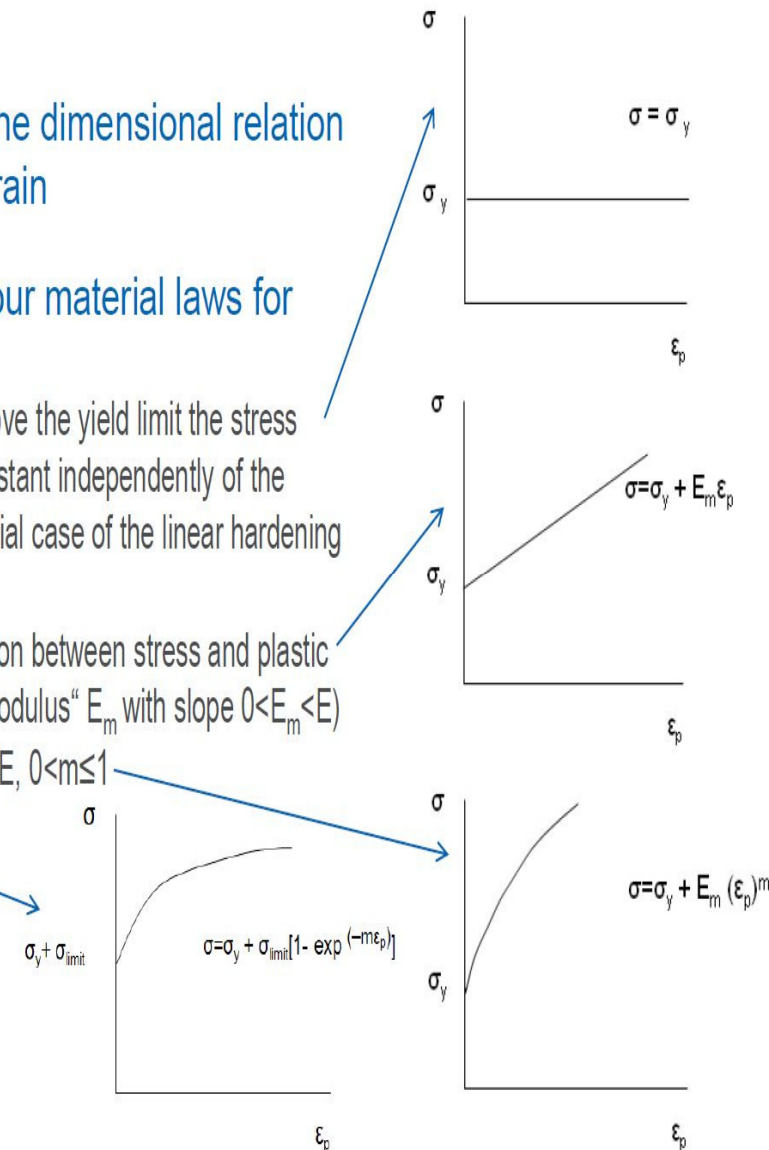
- The material laws are a one dimensional relation of stress versus plastic strain
- Creo Simulate supports four material laws for describing plasticity:

- elastic – perfectly plastic: Above the yield limit the stress ( $\sigma_y = \sigma_{\text{yield}}$  = yield stress) is constant independently of the plastic strain reached (a special case of the linear hardening model with  $E_m = 0$ )

- „Linear hardening“: The relation between stress and plastic strain is constant („tangent modulus“  $E_m$  with slope  $0 < E_m < E$ )

- Power (Potential) law:  $0 < E_m < E$ ,  $0 < m \leq 1$

- Exponential law:  $m > 0$ ,  $\sigma_{\text{limit}} > 0$



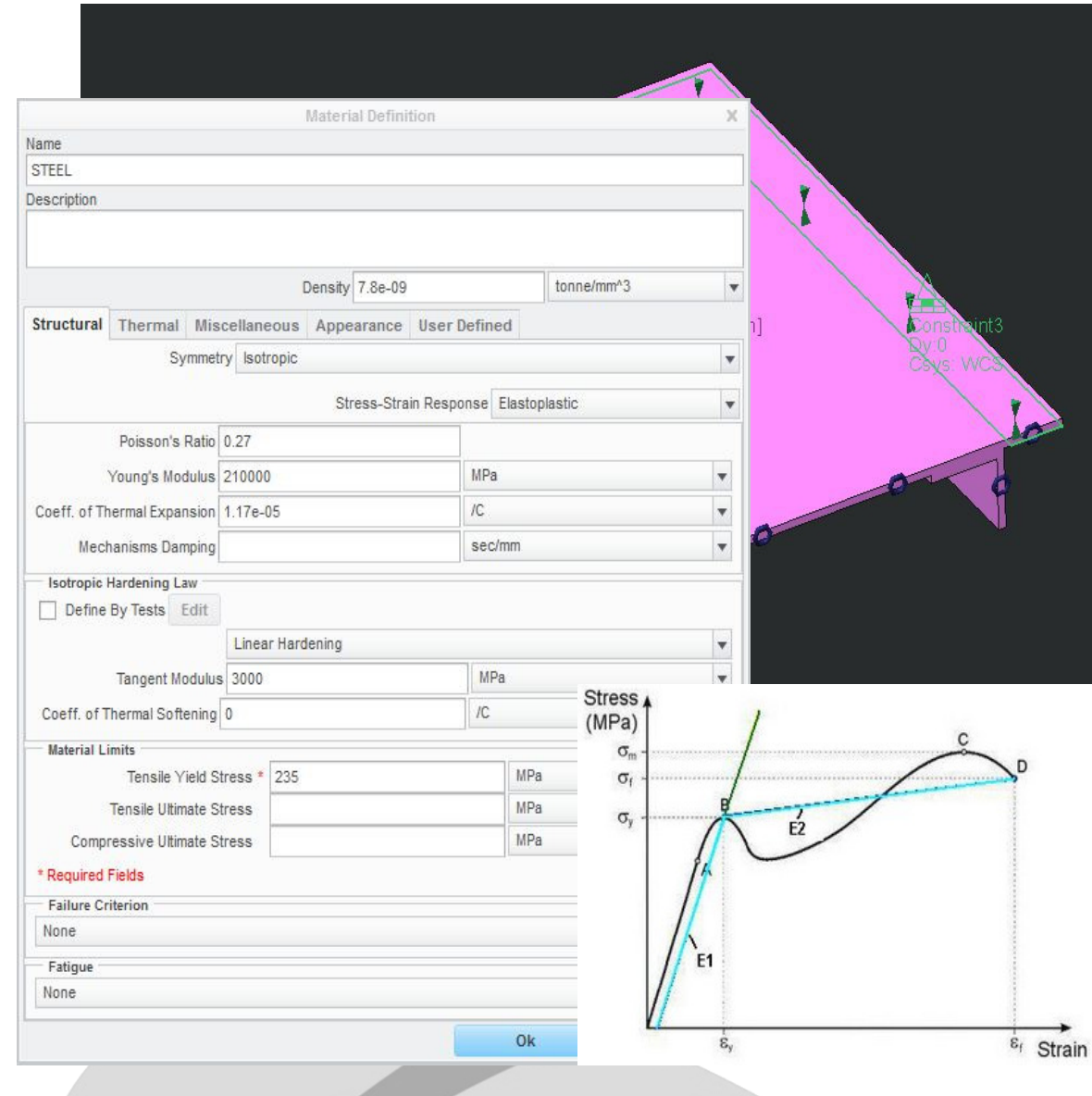
## Material Non-Linearity: Elastoplastic Material

### Characteristics:

- Until the Yield point the material acts linear
- Above the Yield point the stress-strain curve changes
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### When to use Elastoplastic material:

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The image shows a software interface for defining material properties. The main window is titled "Material Definition" and contains the following fields and options:

- Name:** STEEL
- Description:** (empty)
- Density:** 7.8e-09 tonne/mm<sup>3</sup>
- Structural** tab is selected, with **Symmetry** set to **Isotropic**.
- Stress-Strain Response:** Elastoplastic
- Poisson's Ratio:** 0.27
- Young's Modulus:** 210000 MPa
- Coeff. of Thermal Expansion:** 1.17e-05 /C
- Mechanisms Damping:** sec/mm
- Isotropic Hardening Law:** Define By Tests (unchecked), Linear Hardening (selected)
- Tangent Modulus:** 3000 MPa
- Coeff. of Thermal Softening:** 0 /C
- Material Limits:**
  - Tensile Yield Stress: 235 MPa
  - Tensile Ultimate Stress: (empty)
  - Compressive Ultimate Stress: (empty)
- Failure Criterion:** None
- Fatigue:** None

At the bottom right, there is a stress-strain graph with the following features:

- Y-axis:** Stress (MPa)
- X-axis:** Strain
- Points:** A, B, C, D
- Stress values:**  $\sigma_m$ ,  $\sigma_f$ ,  $\sigma_y$
- Strain values:**  $\epsilon_y$ ,  $\epsilon_f$
- Regions:** E1 (initial linear elastic), E2 (post-yield region)
- Curve:** A solid black line showing a yield point (B), a local maximum (C), and a final point (D). A dashed blue line connects points B and D.



# Theory of Non-Linearity

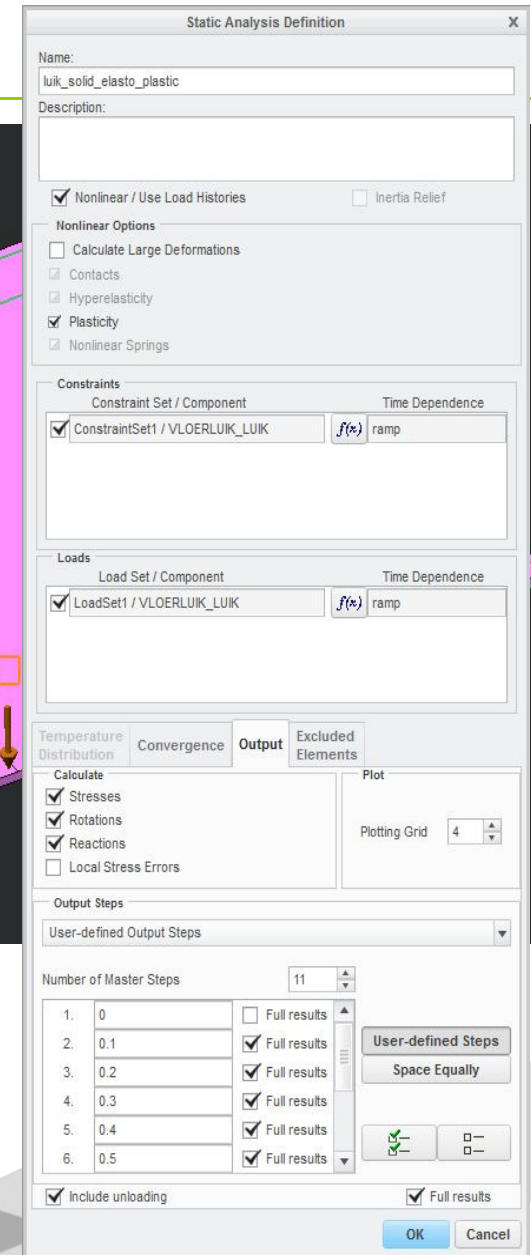
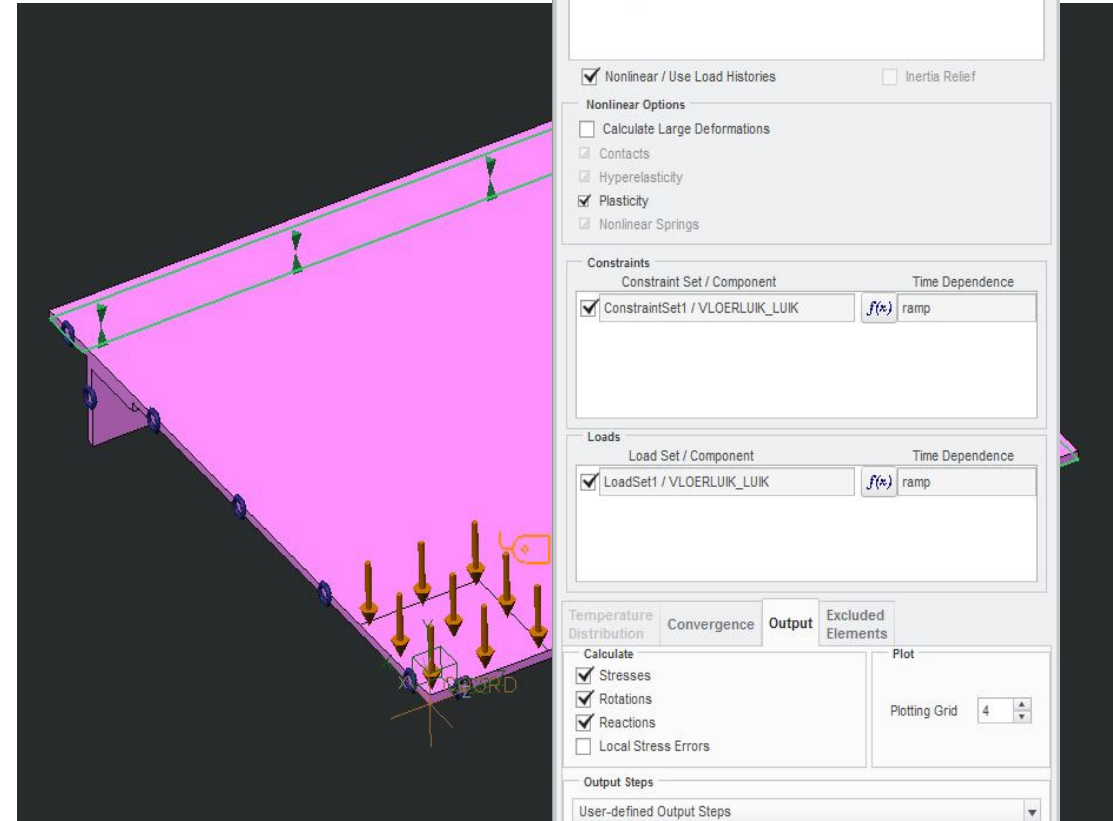
## Material Non-Linearity: Elastoplastic Material

### Characteristics:

- Until the Yield point the material acts linear
- Above the Yield point the stress-strain curve changes
- Different material laws available

### When to use Elastoplastic material:

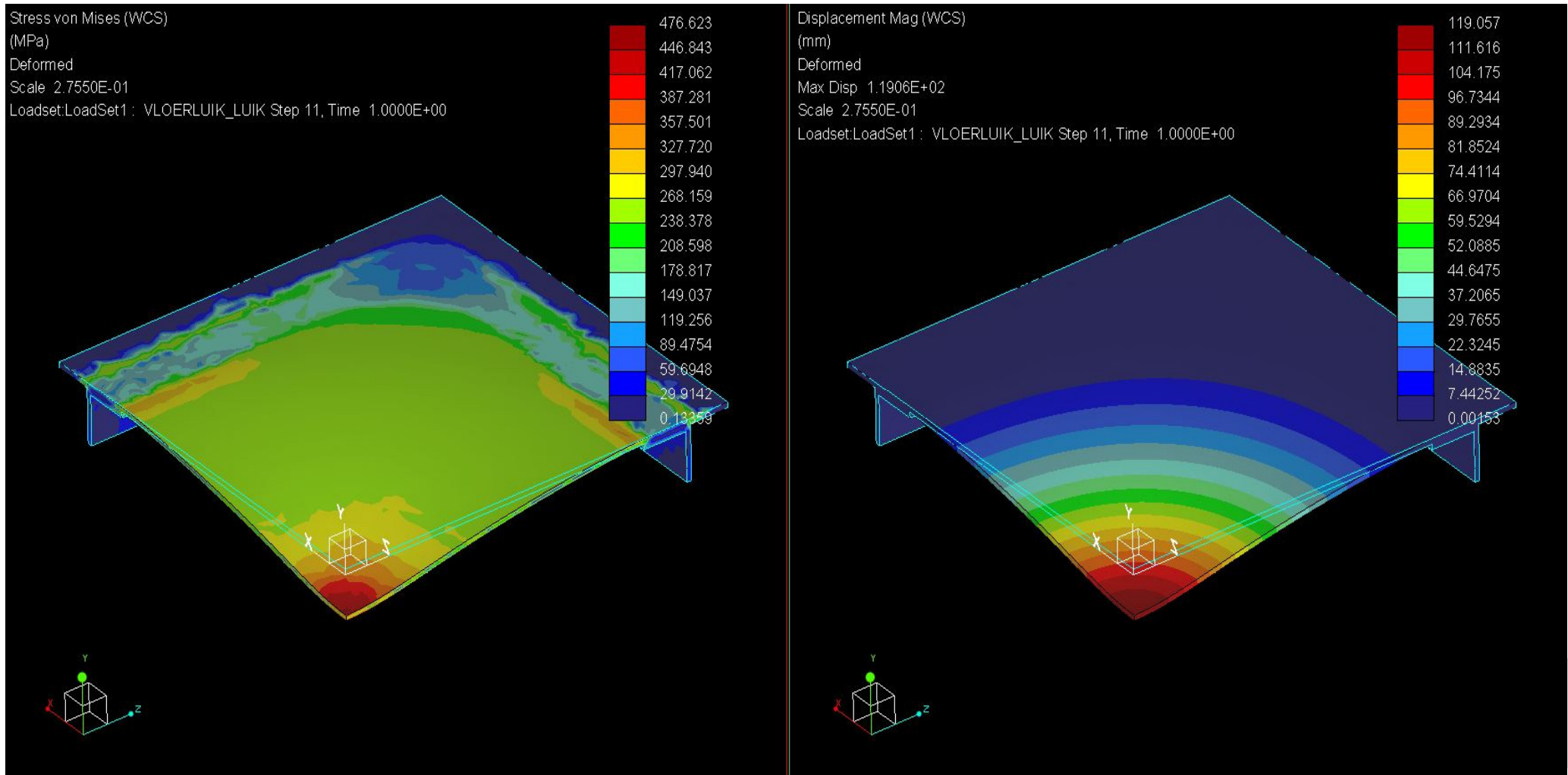
- To calculate realistic deformation (elastic and/or plastic) when the Yield stress is exceeded



## Results Non-Linear Elastoplastic Analysis

Max. VM stress = 477 MPa

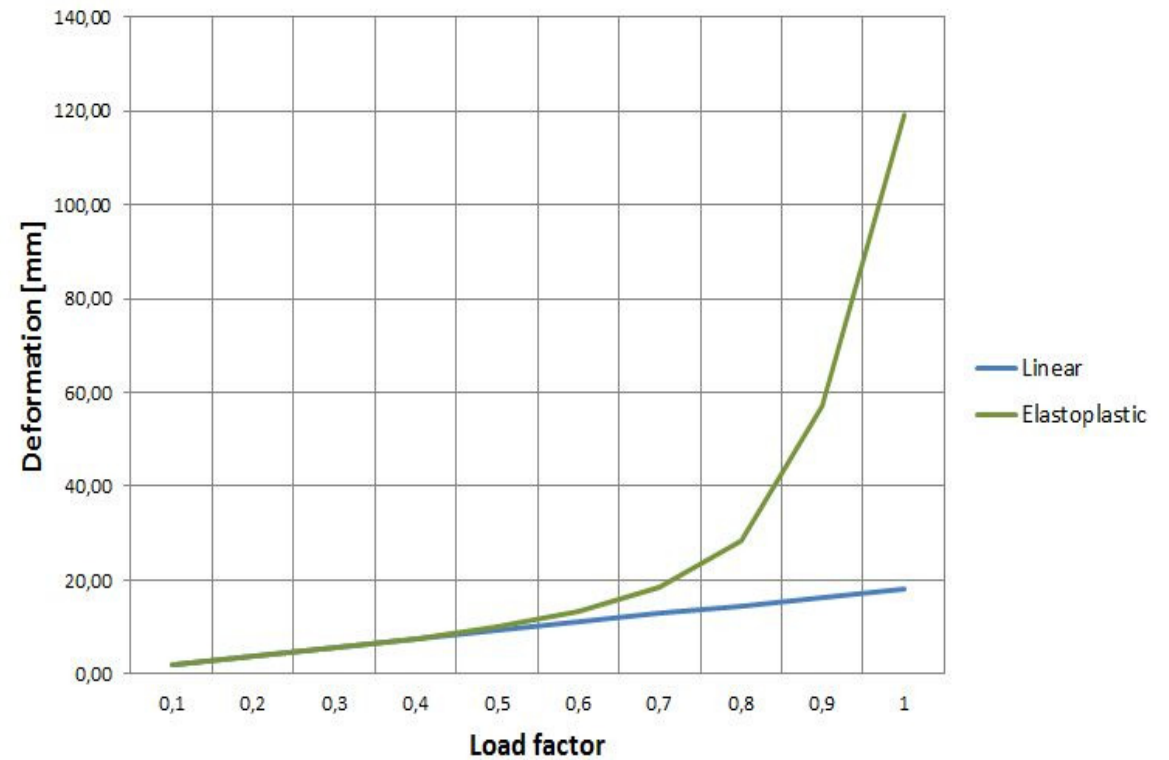
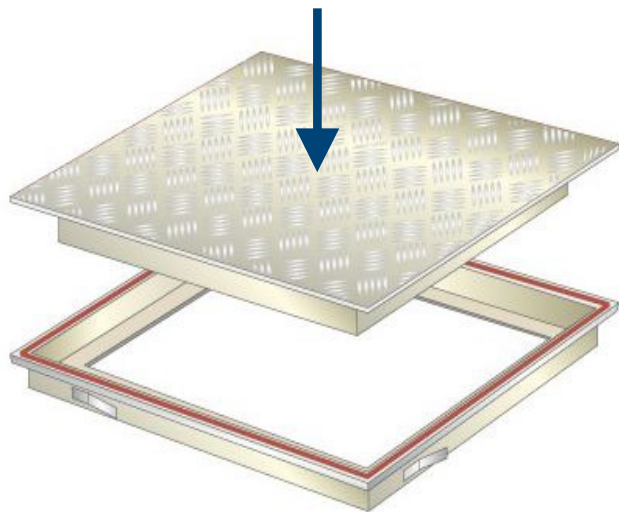
Max. Displacement = 119 mm





## Example: Manhole Cover

Comparison Linear Analysis with Elastoplastic analyses



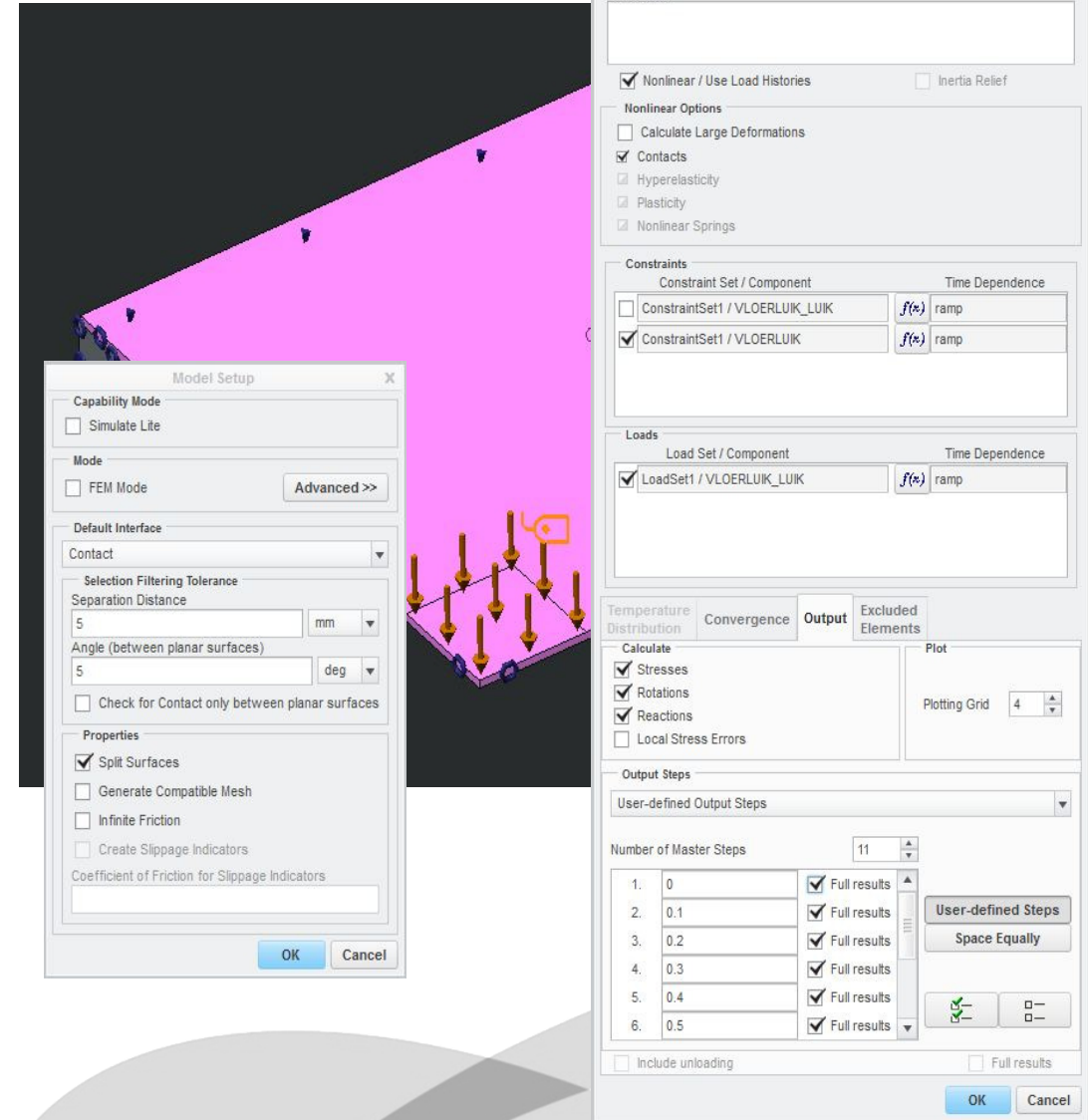
## Constraint Non-Linearity: Contact

### Characteristics:

- Contact acts as a constraint in one direction
- Number of load steps dependent on situation
- At each load step the contact situation will be evaluated

### When to use Contact:

- When contact issues are expected which cannot be captured with constraints
- When contact values are needed (i.e. contact forces, contact area, contact pressure, ...)

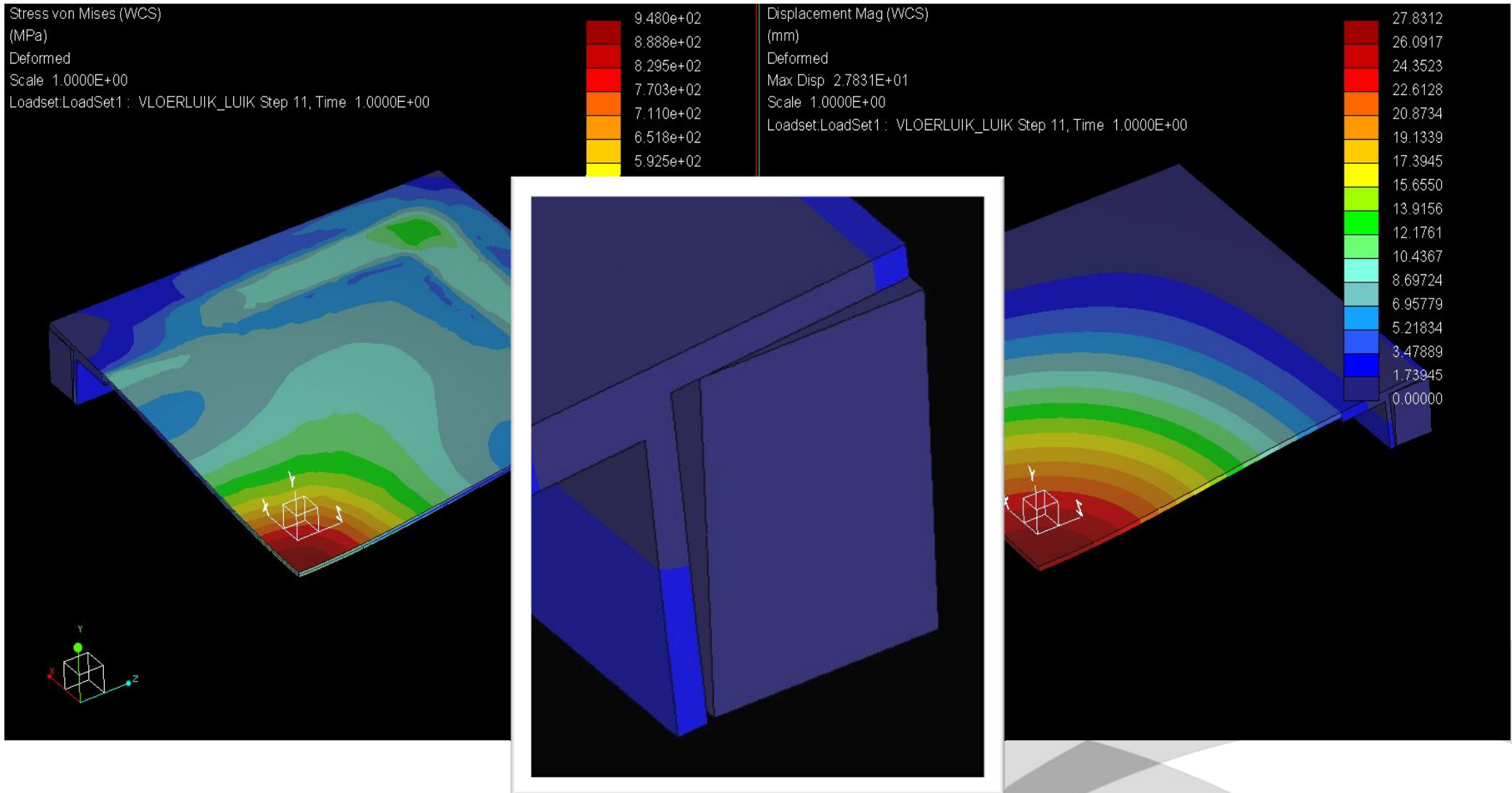




# Results Non-Linear Contact

Max. VM stress = 948 MPa

Max. Displacement = 27,8 mm

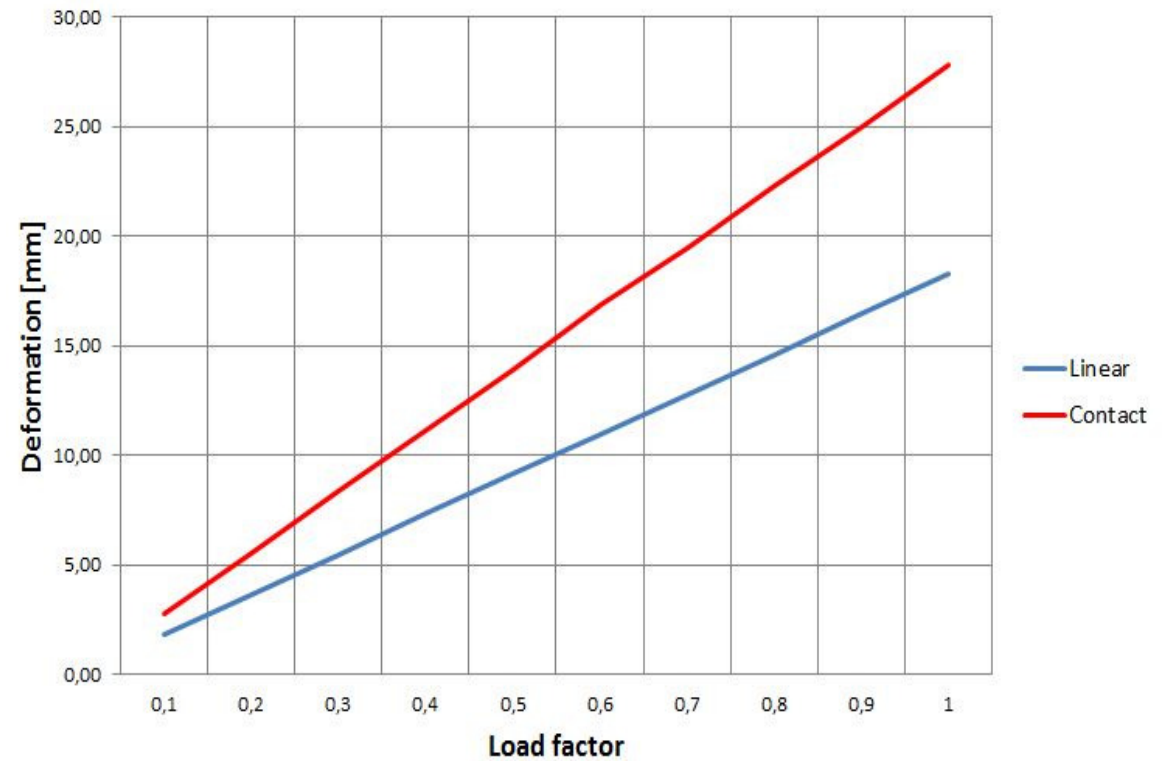
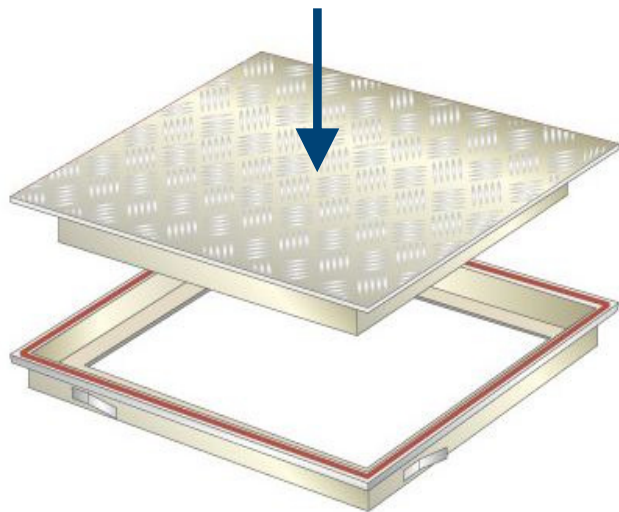




## Theory of Non-Linearity

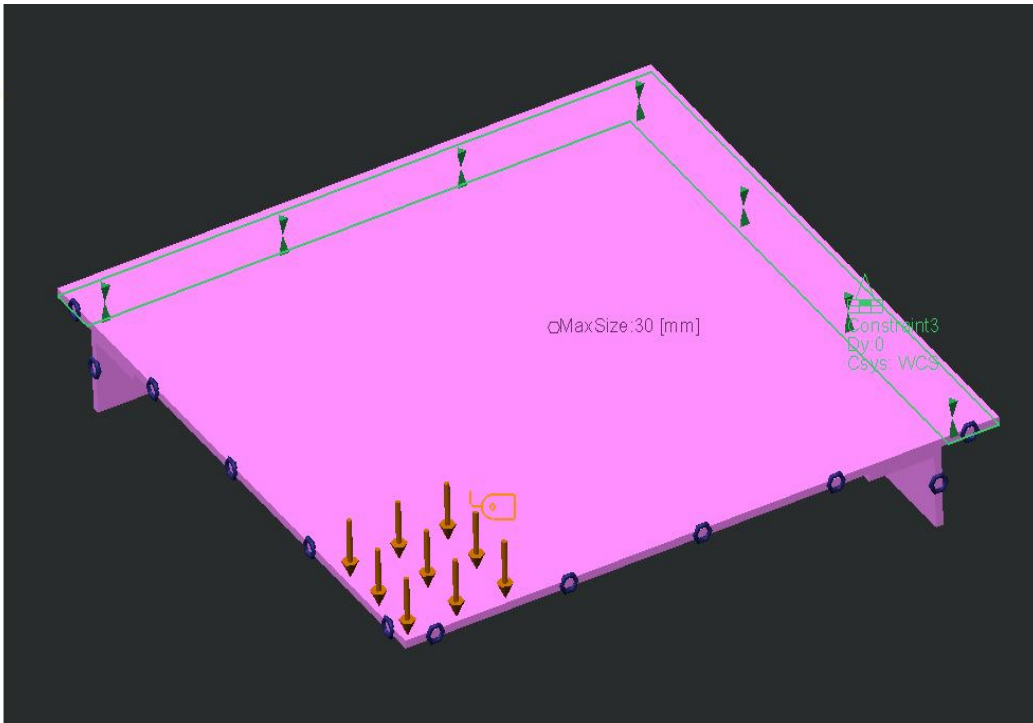
### Example: Manhole Cover

Comparison Linear Analysis with Contact analyses

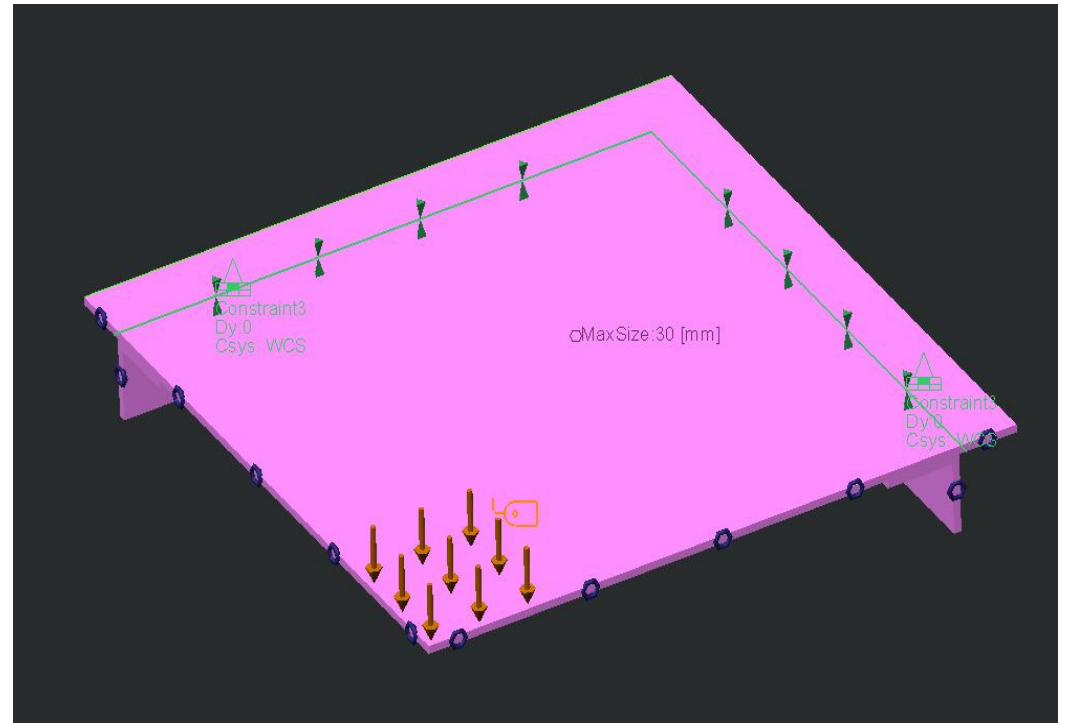




Linear alternative for Non-Linear contact analysis → modified constraint



Surface constraint

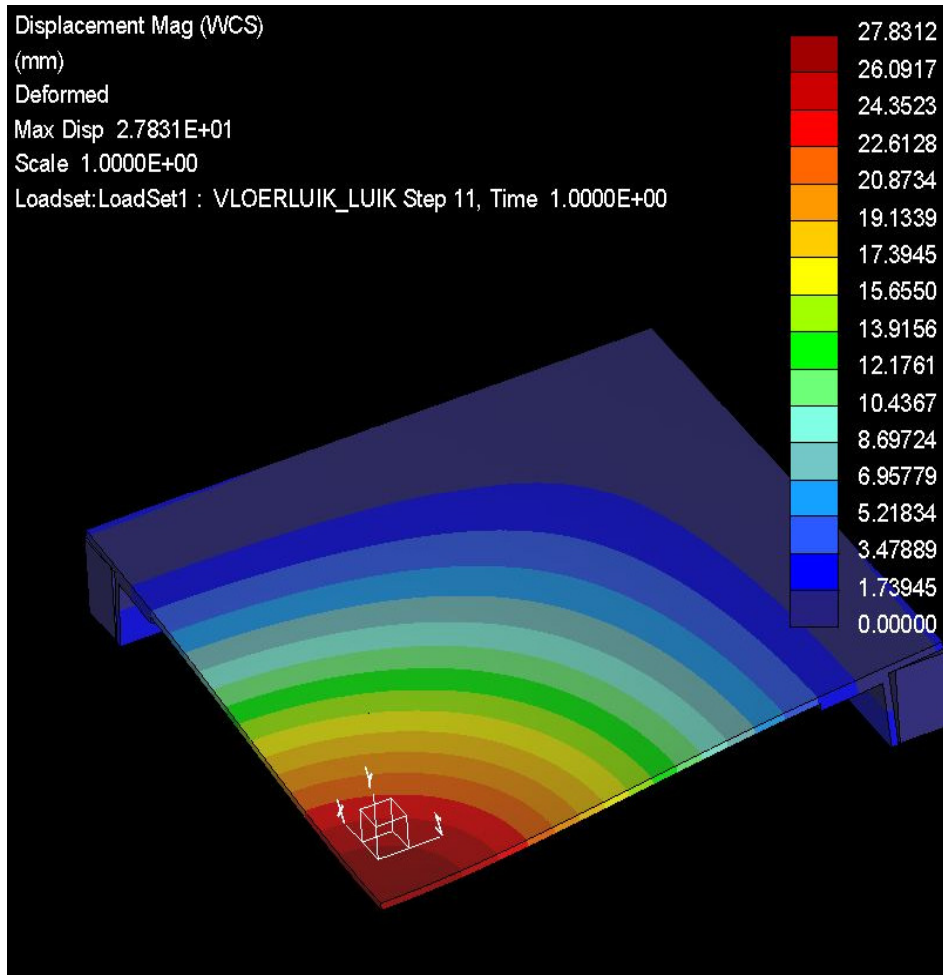


Edge constraint

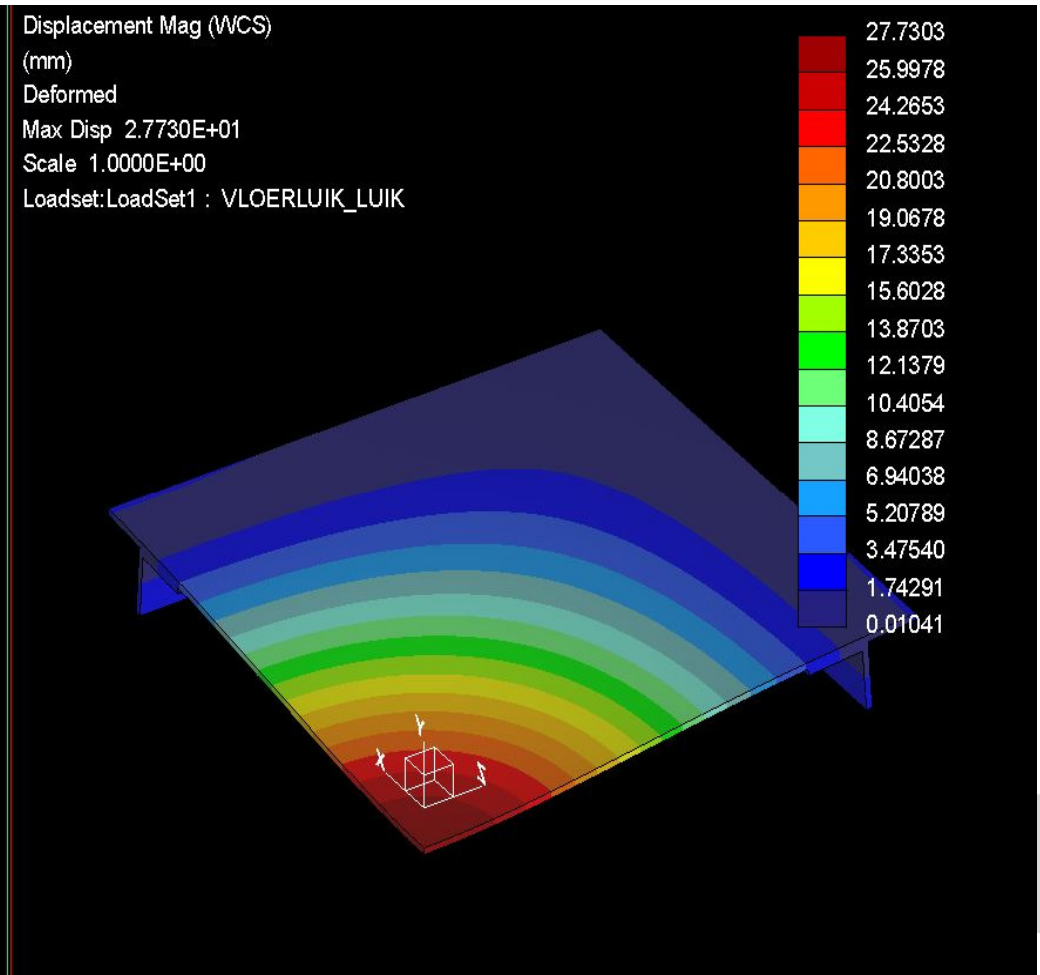




## Non-Linear contact analysis



## Linear analysis with edge constraint

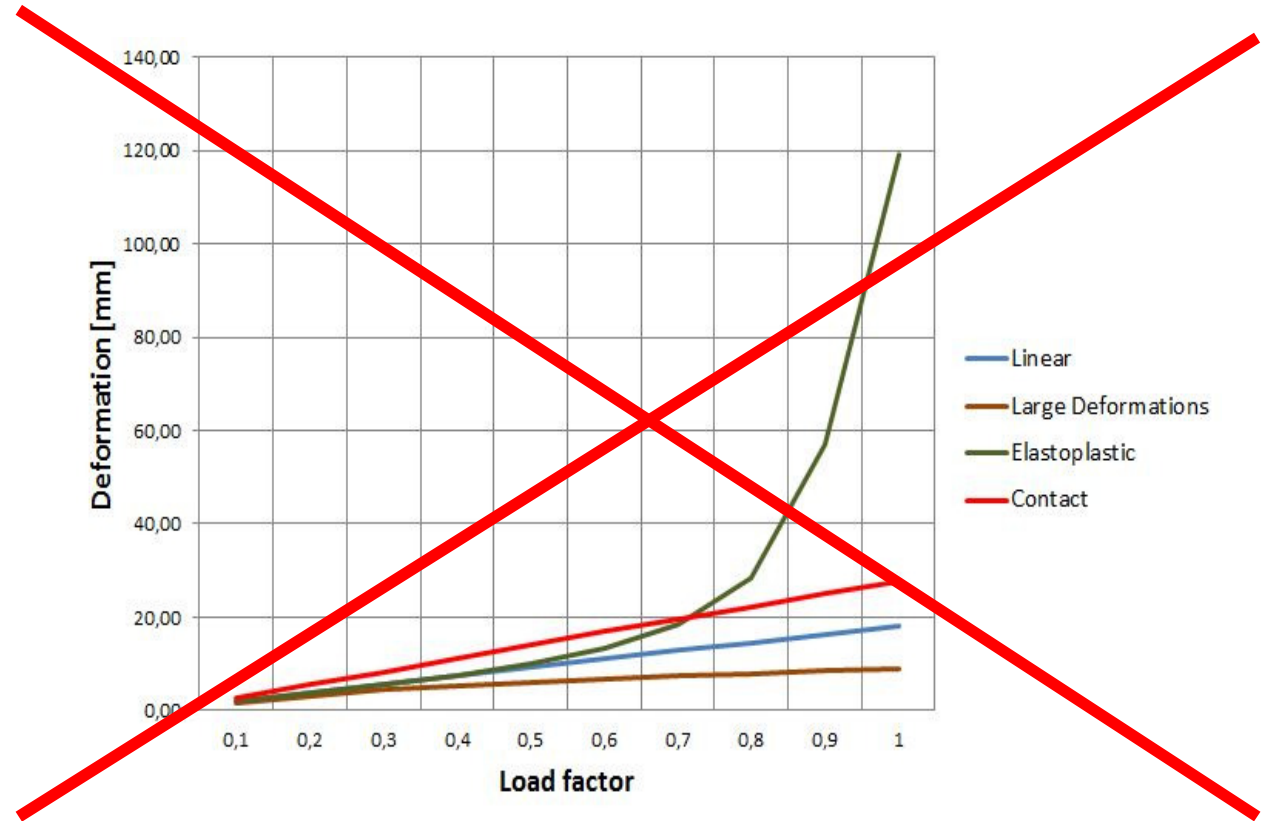
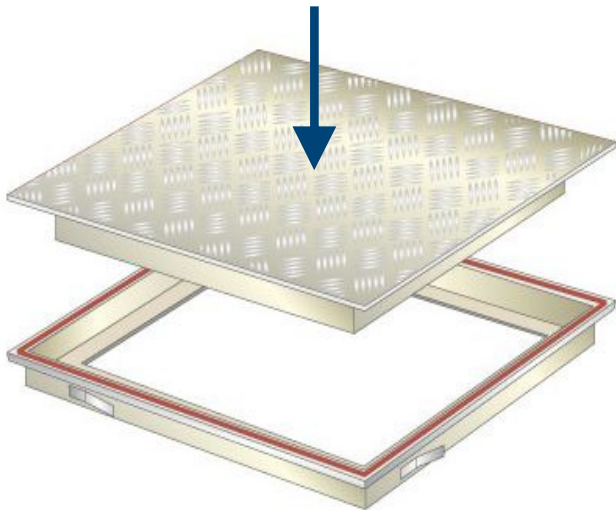




## Theory of Non-Linearity

### Example: Manhole Cover

Comparison Linear Analysis with  
all separated Non-Linear Analyses



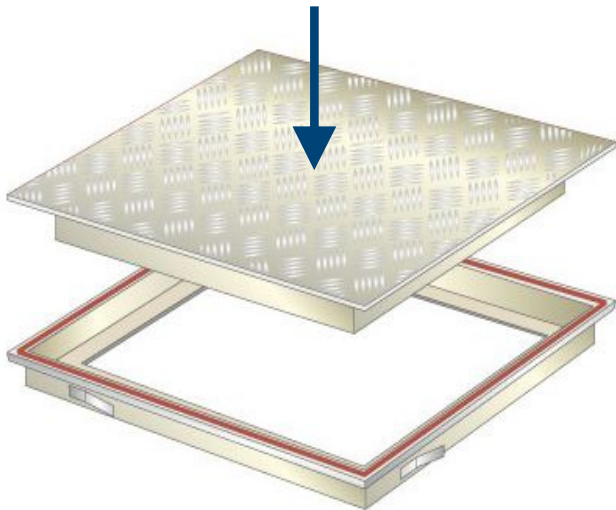
Which one is correct?

None of the above!

## Combining Non-Linearities with Creo Simulate 2.0

Previous analyses show that all  
**Non-Linearities** are occurring at  
the same time:

Large Displacements  
Elastoplastic Material  
Contact



**Static Analysis Definition**

Name: luik\_solid\_LD\_and\_elastop\_edge

Description:

Nonlinear / Use Load Histories  Inertia Relief

**Nonlinear Options**

Calculate Large Deformations

Contacts

Hyperelasticity

Plasticity

Nonlinear Springs

**Constraints**

Constraint Set / Component	Time Dependence
<input checked="" type="checkbox"/> ConstraintSet1 / VLOERLUK_LUIK	f(t) ramp

**Loads**

Load Set / Component	Time Dependence
<input checked="" type="checkbox"/> LoadSet1 / VLOERLUK_LUIK	f(t) ramp

**Temperature Distribution** **Convergence** **Output** **Excluded Elements**

**Calculate**

Stresses

Rotations

Reactions

Local Stress Errors

**Plot**

Plotting Grid: 4

**Output Steps**

User-defined Output Steps

Number of Master Steps: 11

Step	Time	Full results
1.	0	<input checked="" type="checkbox"/> Full results
2.	0.1	<input checked="" type="checkbox"/> Full results
3.	0.2	<input checked="" type="checkbox"/> Full results
4.	0.3	<input checked="" type="checkbox"/> Full results
5.	0.4	<input checked="" type="checkbox"/> Full results
6.	0.5	<input checked="" type="checkbox"/> Full results

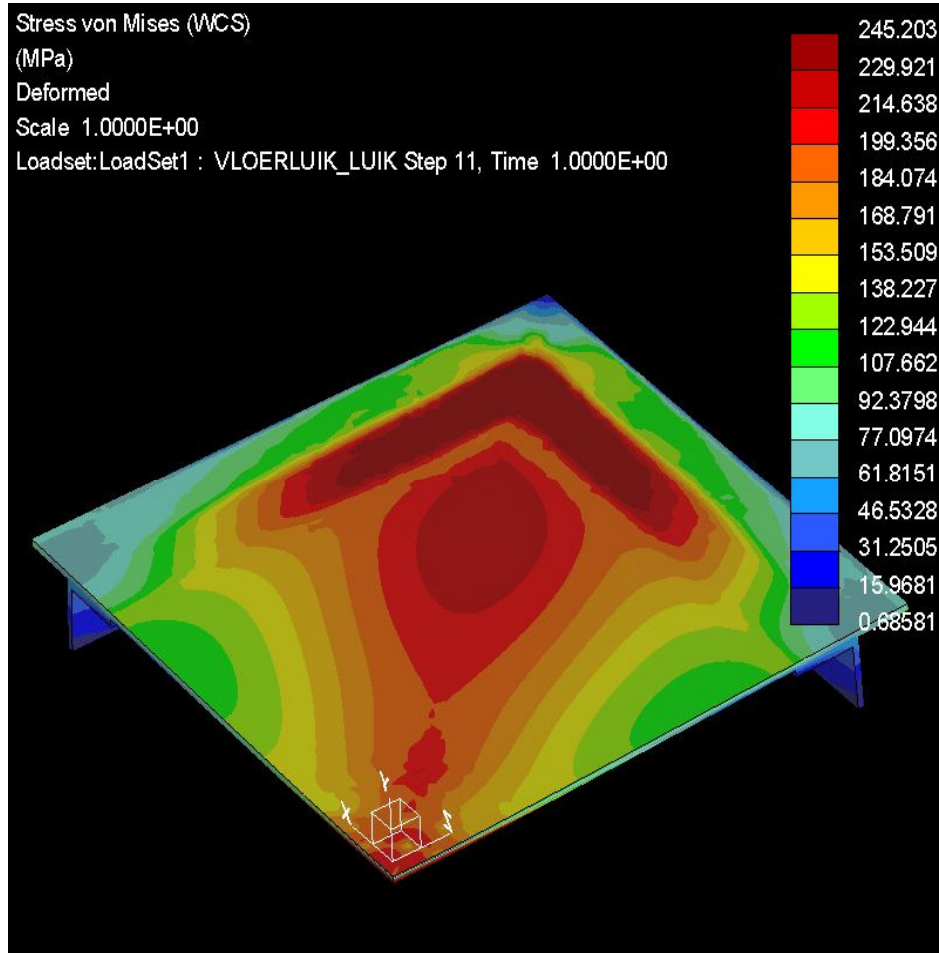
Include unloading  Full results

OK Cancel

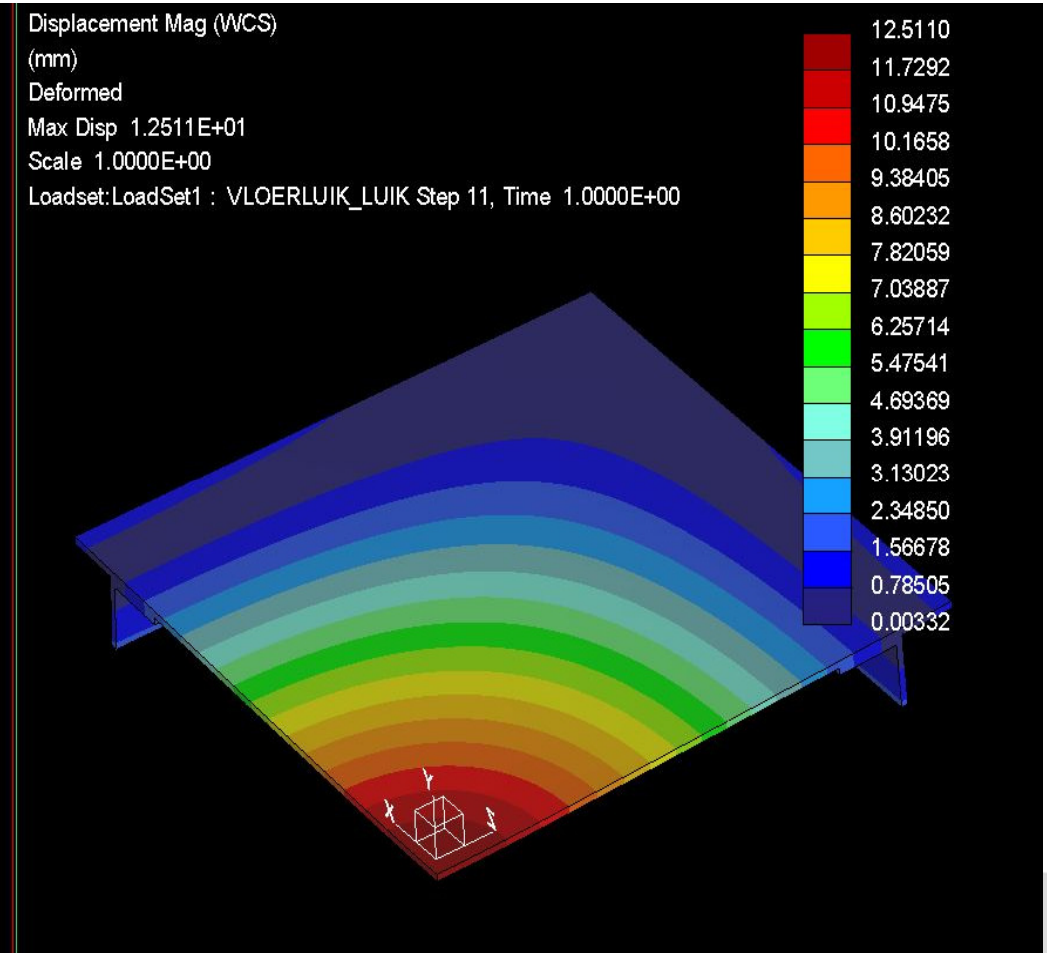


## Results combined Non-Linearities

Max. VM stress = 245,2 MPa



Max. Displacement = 12,5 mm





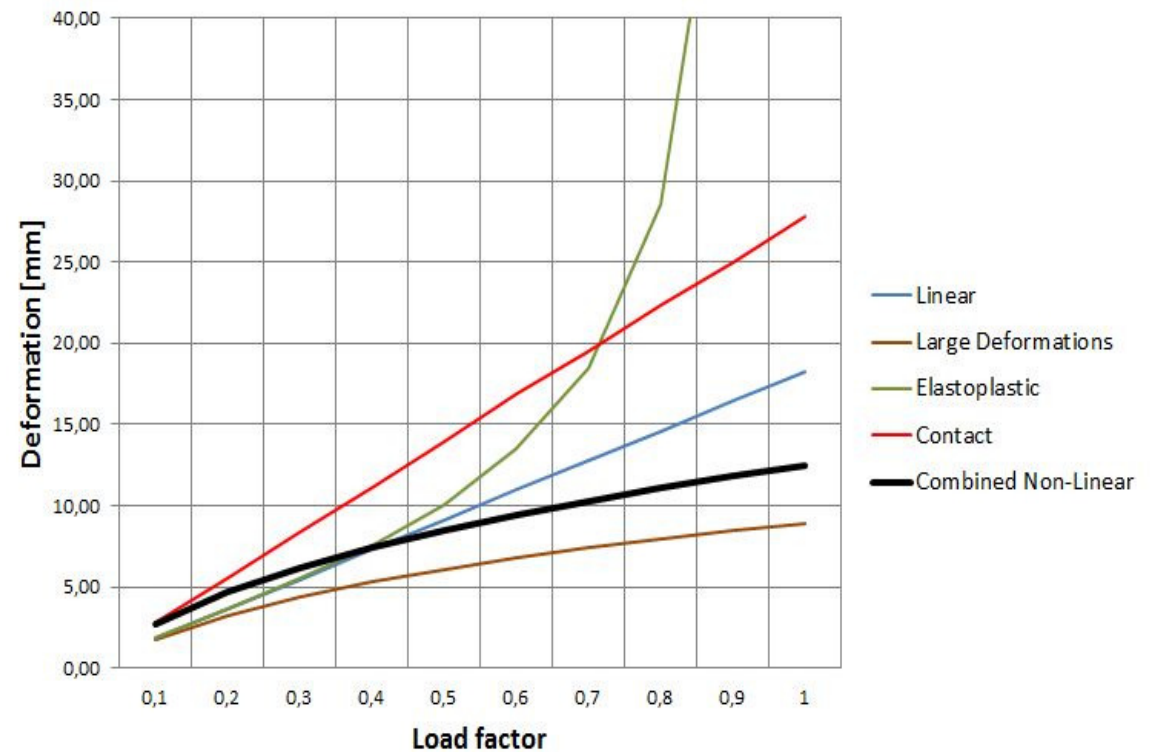
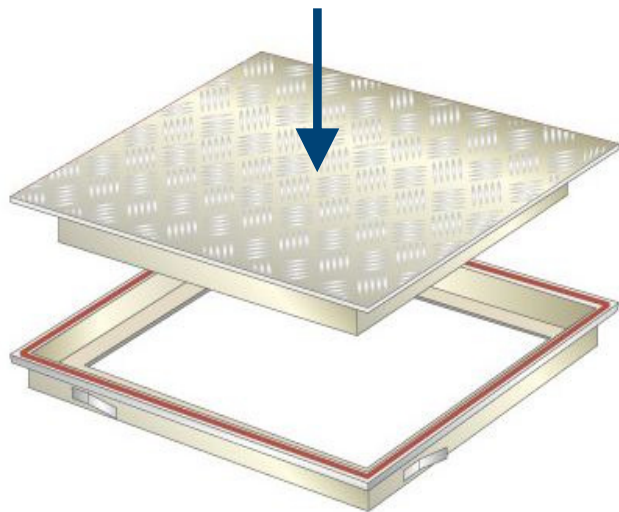
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## Combining Non-Linearities with Creo Simulate 2.0

### Example: Manhole Cover

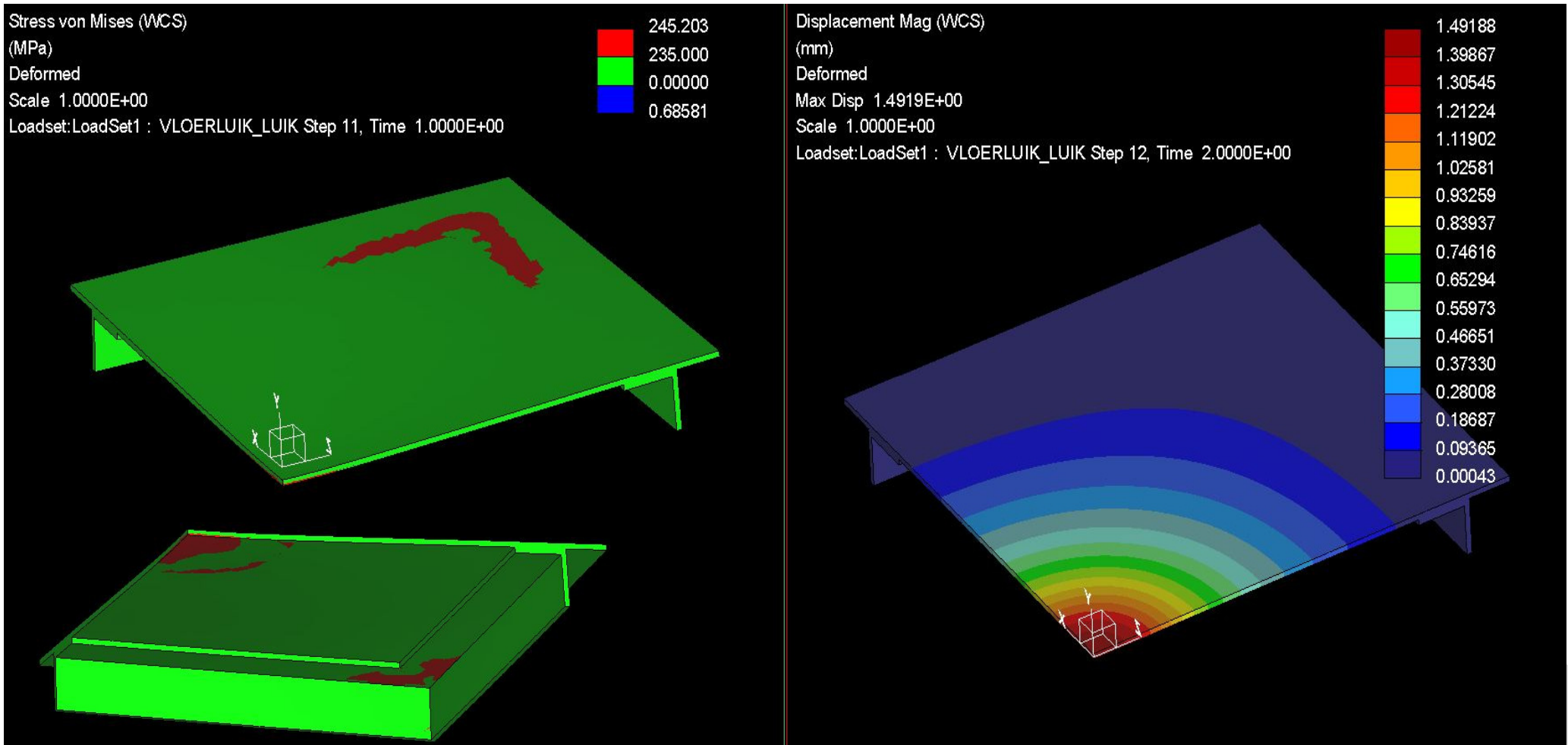
Comparison Linear Analysis with  
all separated Non-Linear Analyses



## Results combined Non-Linearities

Red areas: stresses exceed Yield limit (plasticity)

Permanent Plastic Displacement = 1,5 mm (after un-loading)





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## Examples of Non-Linear Analyses





## Helmet and Clip

[www.egghelmets.com](http://www.egghelmets.com)

Questions:

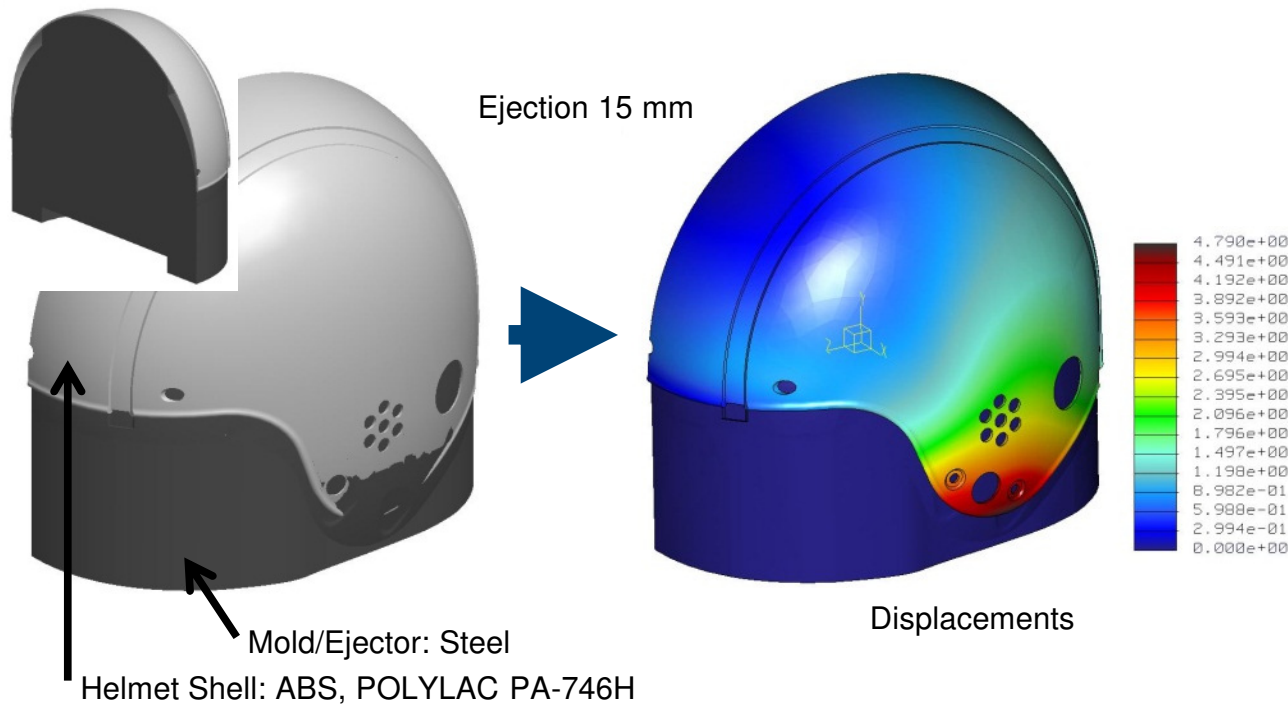
- Can the ABS outer shell be ejected from the mold?
- Does the clip work and survive impact tests?



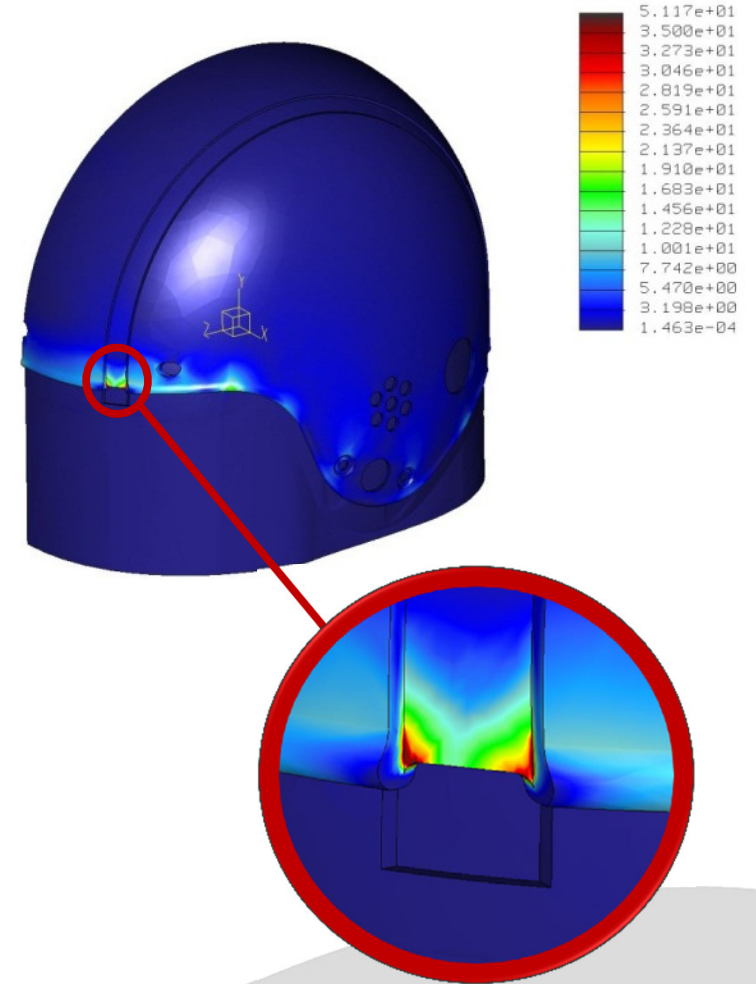


### Ejection of ABS helmet outer shell

- Quasi static approach; incremental ejection steps
- Contact analysis for each ejection step



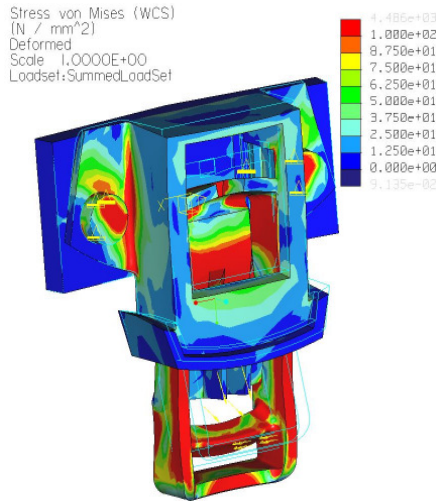
Von Mises stresses





## Contact analyses for different clip concepts

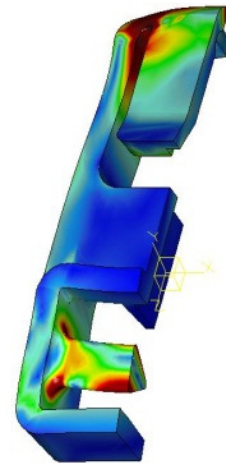
- Initial clip design didn't pass the test
- Comparison of different clip concepts



Initial clip

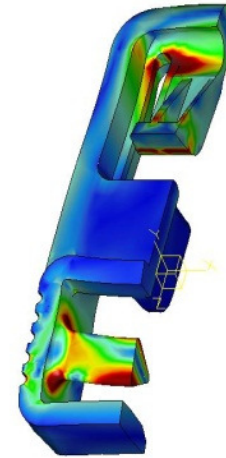
## Different clip concepts

Stress von Mises (WCS)  
(MPa)  
Deformed  
Scale 1.0000E+00  
Loadset:LoadSet1 ; LOCK\_CLIP



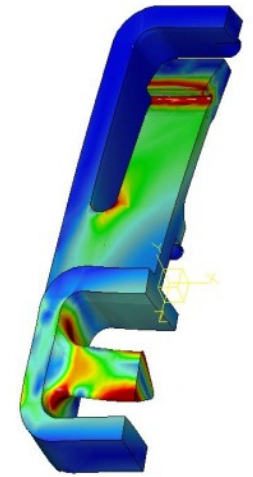
"Window2" - original\_clip - original\_clip

Stress von Mises (WCS)  
(MPa)  
Deformed  
Scale 1.0000E+00  
Loadset:LoadSet1 ; LOCK\_CLIP2



"Window3" - modified\_clip - modified\_clip

Stress von Mises (WCS)  
(kPa)  
Deformed  
Scale 1.0000E+00  
Loadset:LoadSet1 ; HDS-PRT-OC



"Window1" - rll\_clip - rll\_clip



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# Examples Advanced Dynamic Analyses





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## Examples of Advanced Dynamic Analyses

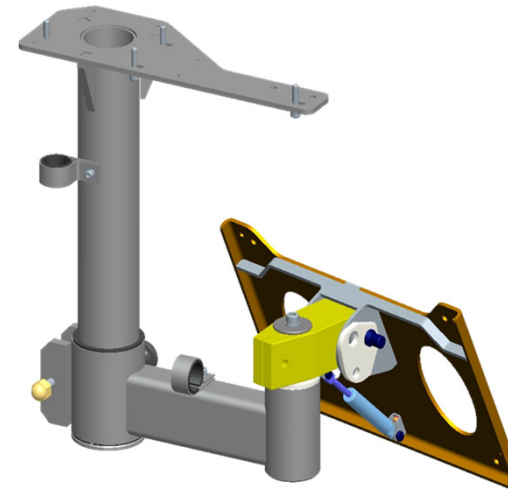
**THALES**

### Mounting Equipment for Communication Devices

[www.thalesgroup.com](http://www.thalesgroup.com)

Questions:

- Does the structure survive vibrations with specific Power Spectral Density diagrams?
- Does the structure survive shock impact?

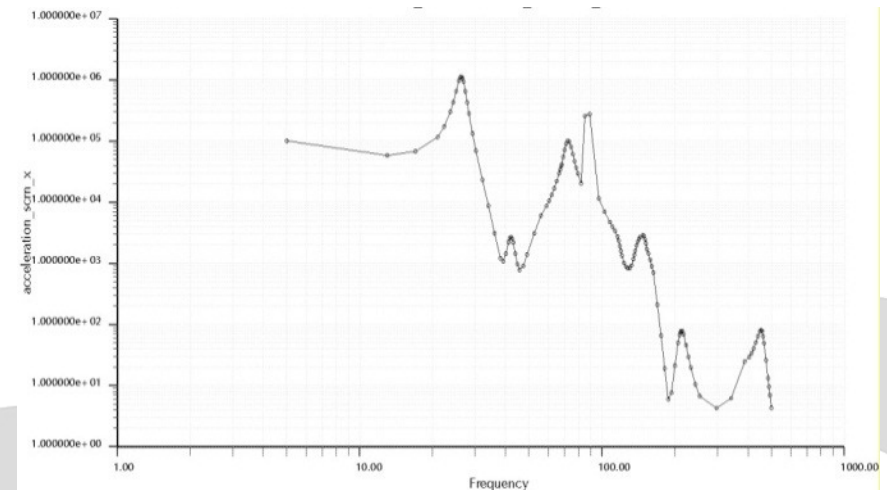
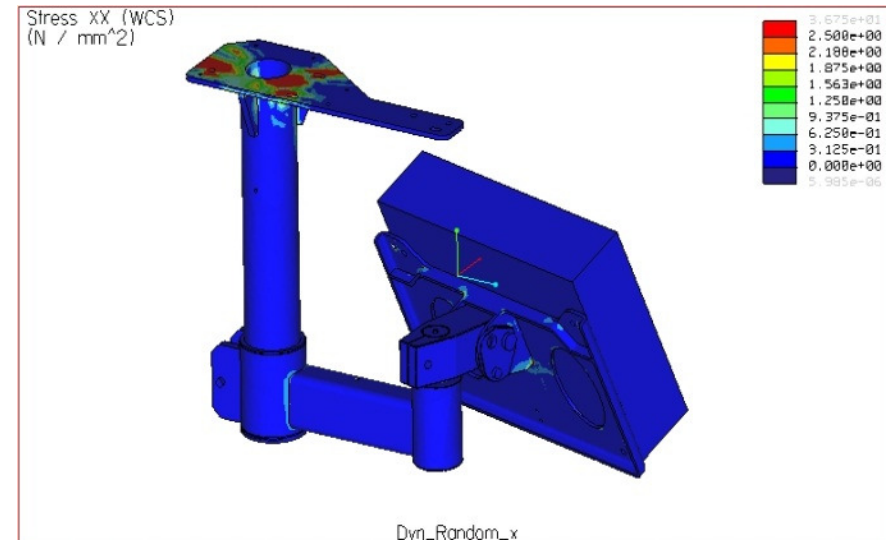
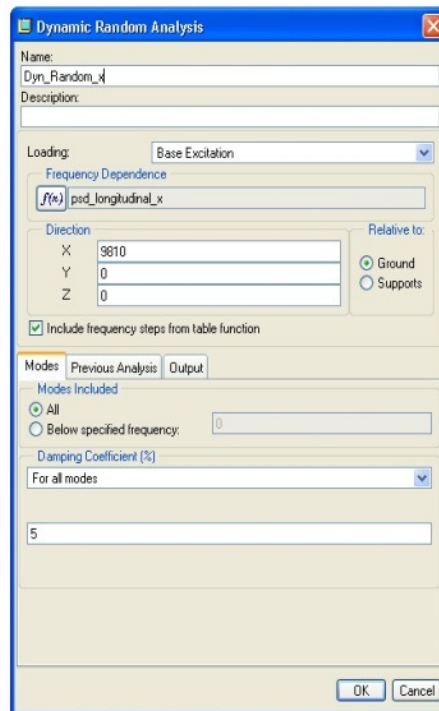
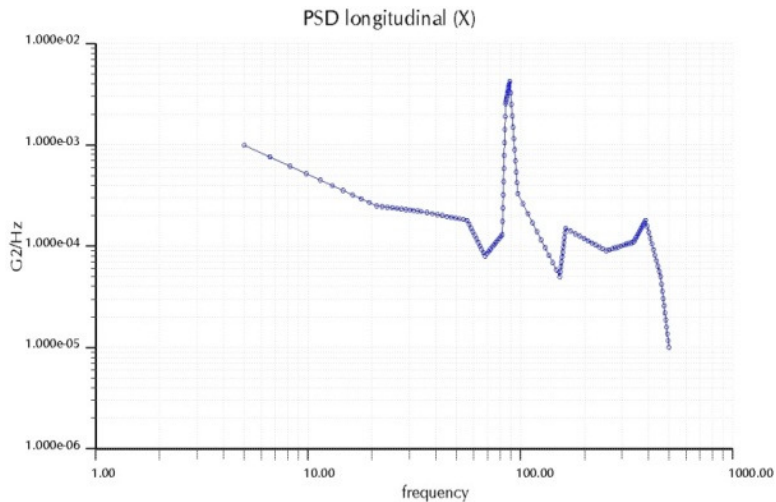




## Dynamic Random Analysis

### Characteristics:

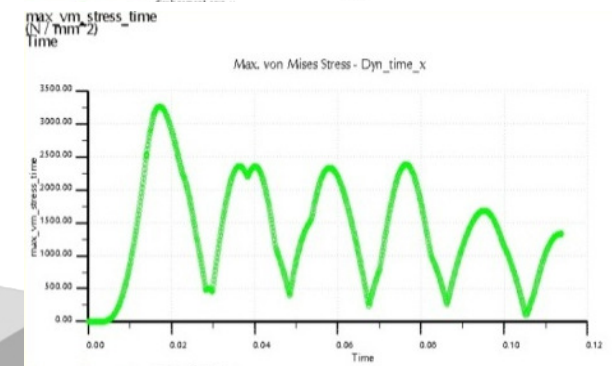
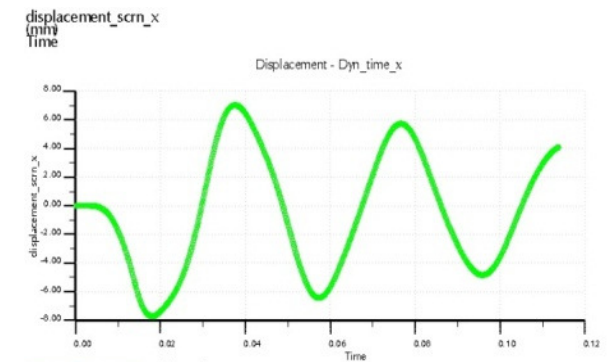
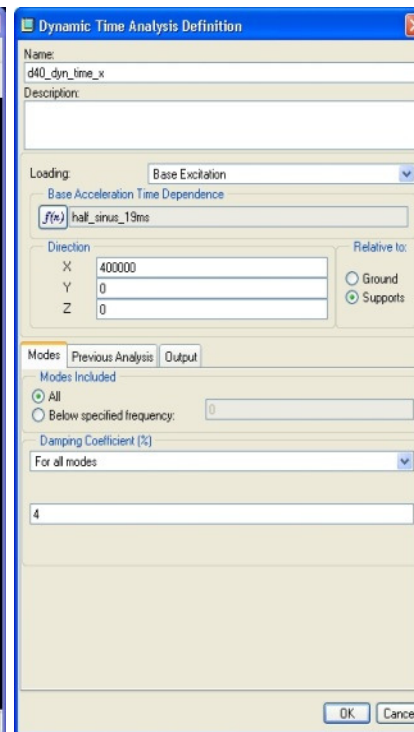
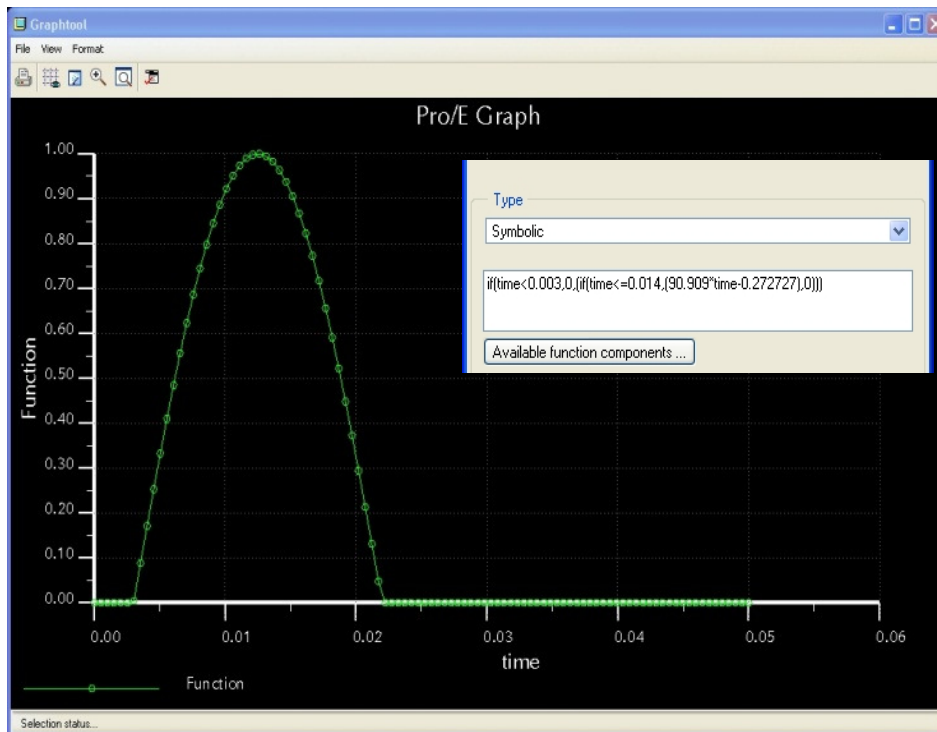
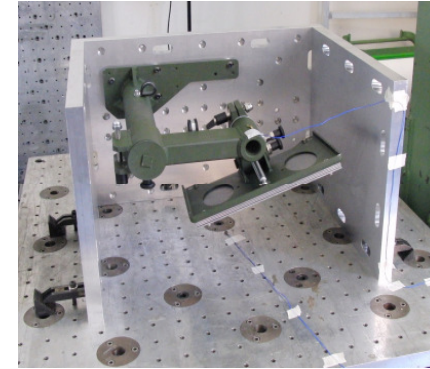
- Calculate Eigen Frequencies
- Dynamic Random Analysis for 3 orthogonal directions



## Dynamic Time Analysis (Shock)

Characteristics:

- Calculate Eigen Frequencies
- Dynamic Time Analysis for 3 orthogonal directions





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**Thank you for your attention!**







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## Modeling & Simulation tiles

*rubbish in  
is  
rubbish out*

*FEA makes a  
good engineer  
better  
but a poor  
engineer  
dangerous*

*a fool with a  
good tool is  
still a fool*