Strength of bolt-fixings in laminated strengthened glass

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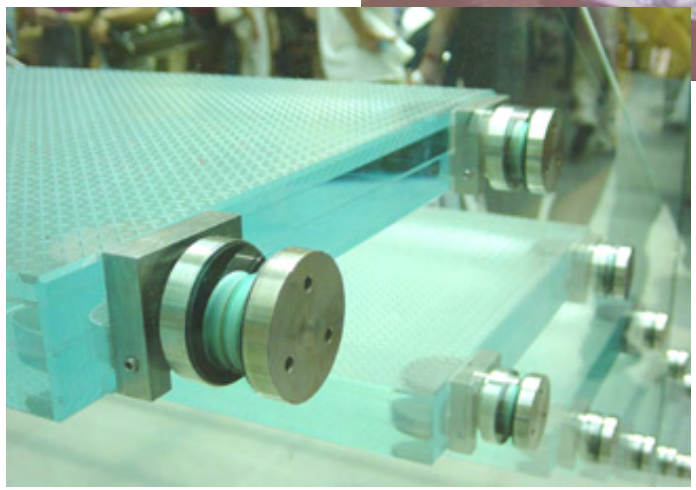
Glass in Building Structures

- **Many advantages from an architect's point-of-view, light, airy constructions**
- **More common to use glass as load bearing parts of the building structure**
- **More advanced structures requires more advanced material knowledge**
- **Lack of design criteria makes it difficult to design safe and secure buildings**



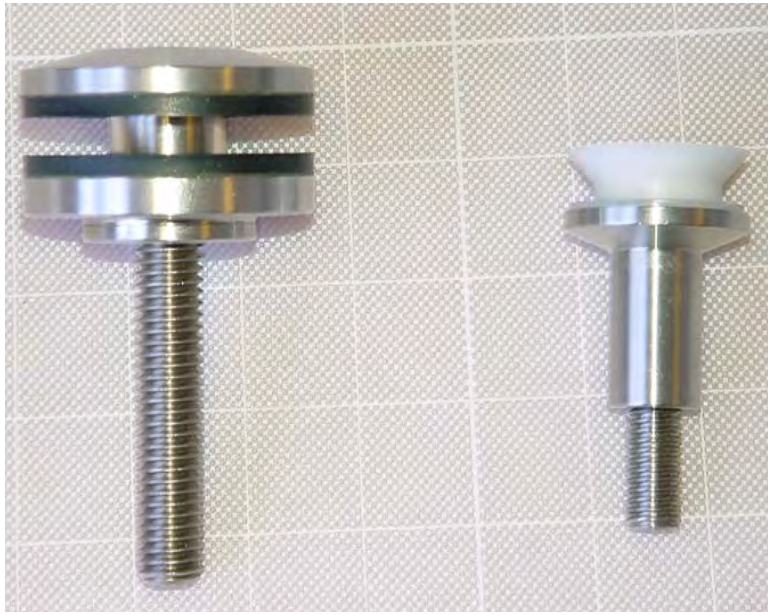
Tensile Strength of Toughened Glass

- **Floatglass**
  - **Ultimate strength bending: ~ 60 MPa**
  - **Design code value: ~ 30 MPa**

- **Toughened glass**
  - **Ultimate strength bending : ~ 200-250 MPa (lower around holes and along edges)**
  - **Design code value: ~ 60 MPa**

Bolted Connections

- **Bolts used as joints to connect glass to glass and to other materials**
- **Methods to predict the mechanical behaviour of glass-bolt joints are required**



Studies of Bolted Connections

- **Establish relationships between loads and strength of the glass-bolt connection**
  - **Experimental tests and numerical analyses**
- **Utilize obtained relationships in design tool for point fixed glass**

Design tool for glass - ClearSight

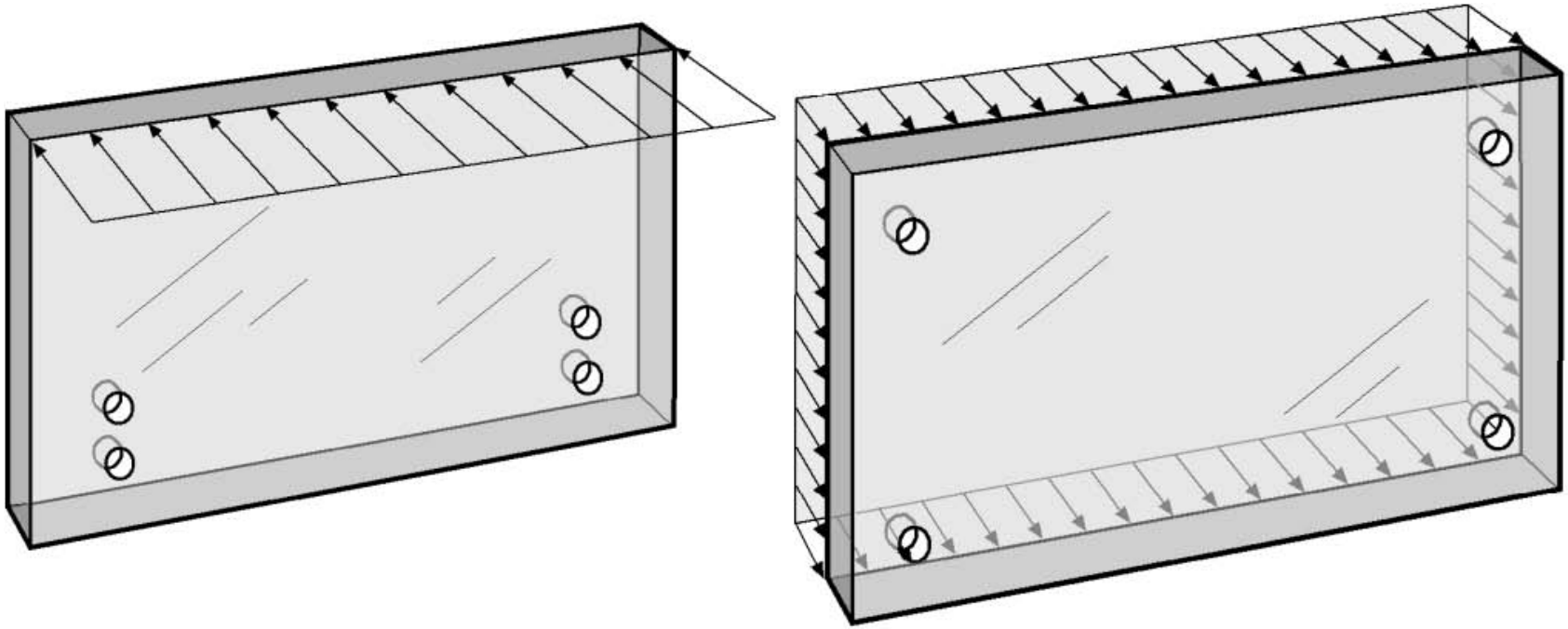
Masters thesis by J. Malmborg

A computer based design tool, for analysing strength of bolt-fixed laminated strengthened glass

Design Tool for Glass contd.

- Easy-to-use computer program – the user must not be acquainted with the numerical method being used
- The result should be easy to interpret
- Program follows building design codes
- Based on the results, the user will be able to determine if the tested configuration holds
- Initially, one type of bolt and a few load cases

Geometry and Load Types



- Two different loads are considered: line load and distributed load
- Arbitrary number of bolts
- Rectangular glass panes

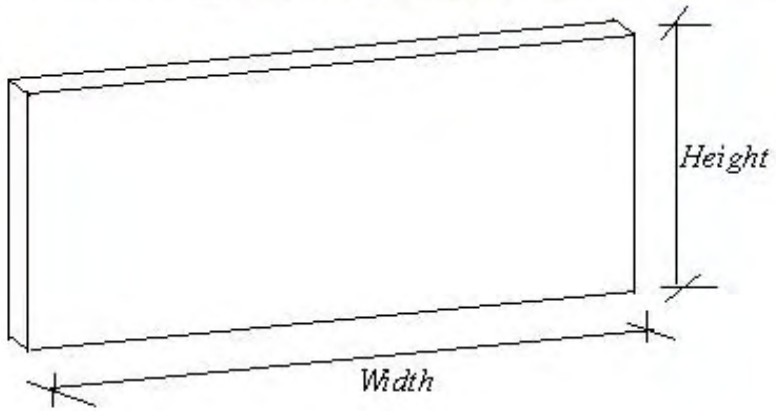
Material Properties

- **Material properties may be given for both glass and the intervening PVB-foil**
- **Stiffness properties, density and the design strength value of glass may given**
- **Default values of the parameters are coded into the program**

ClearSight (D:\feb\Savefiles\demo4\demo4.gfe)

File Run View Advanced About

Structure Geometry | Bolts | Loads | Material properties



Define the structures outer geometry by filling out the form to the right.

If your analysis concerns laminated glass, specify the thickness for each of the three layers.

If the structure is single-layered, check "1 x Glass", then specify the layer thickness.

When you have specified the outer structure, press the tab "Bolts" on the top of this window to continue.

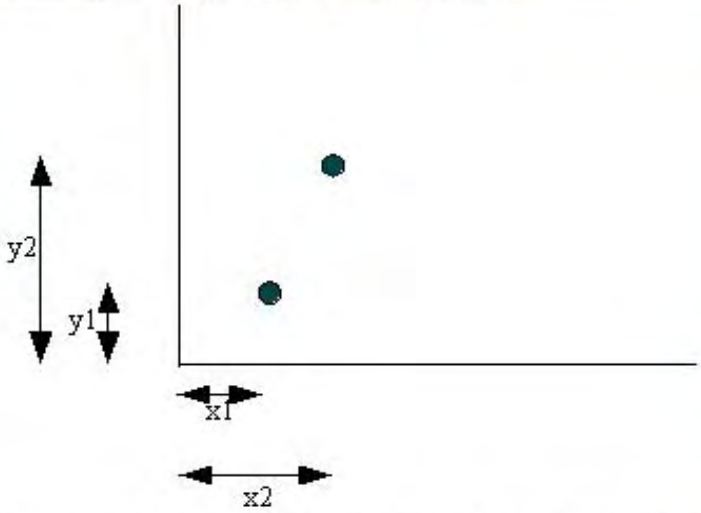
Height	1400	(mm)
Width	1400	(mm)
Number of material layers:	○ 1 x Glass ● 2 x Glass + 1 x PVB	
Thickness of glass layer 1	8.0	(mm)
Thickness of glass layer 2	8.0	(mm)
Thickness of PVB layer	0.76	(mm)

ClearSight | v. 1.0 | Division of Structural Mechanics

ClearSight (D:\feb\Savefiles\demo4\demo4.gfe)

File Run View Advanced About

Structure Geometry | Bolts | Loads | Material properties



Choose your type of bolt in the combination box to the right. (Only the bolt for cylindrical holes has been implemented in this version.) Then, specify the total number of bolts in the structure.

The coordinate table will contain as many rows as the number of bolts you have specified. Enter the coordinates for every bolt in the table. The origin is located at the bottom left corner of the structure. How you enumerate the bolts has no effect on the analysis.

When you have specified the bolts, press the tab "Loads" on the top of this window to continue.

Type of bolt: Cylindrical

Number of bolts: 4

	X	Y
1	50	50
2	1350	50
3	50	1350
4	1350	1350

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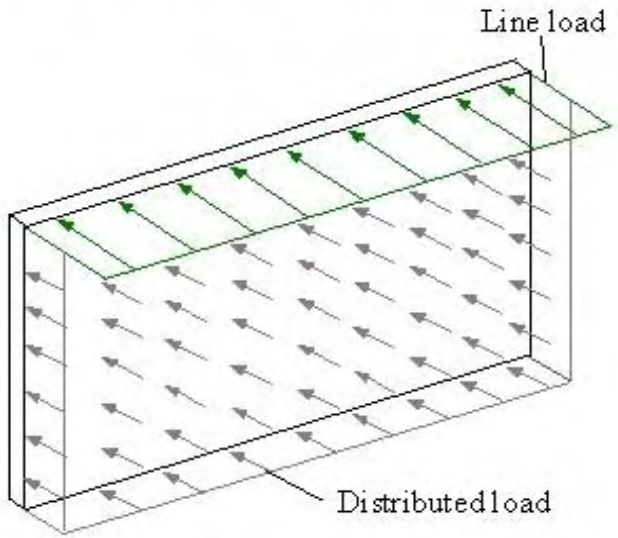
File Run View Advanced About

Structure Geometry | Bolts | Loads | Material properties



Specify the size of the loads acting on the structure.

Balustrades should be designed to carry a line load, acting along the top edge of the balustrade. Facades should be designed to cope with a distributed load acting on the whole structure (i.e. wind loads).

When you have specified the loads, press the tab "Material properties" if you wish to use non-standard values. Otherwise, press "Run" to run the analysis.

Line load [N/m] 0.0

Distributed load [N/m2] 2000.0

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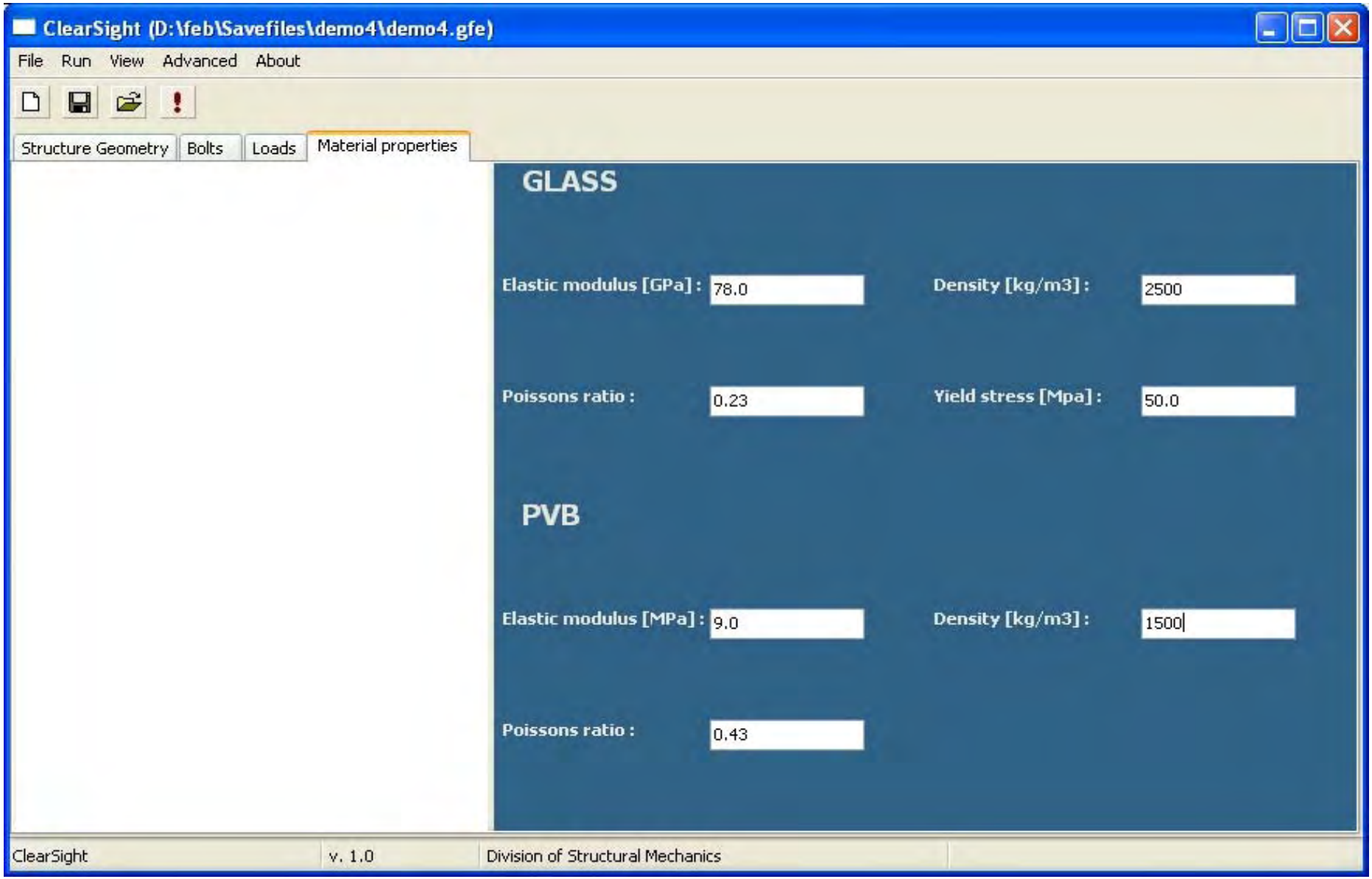
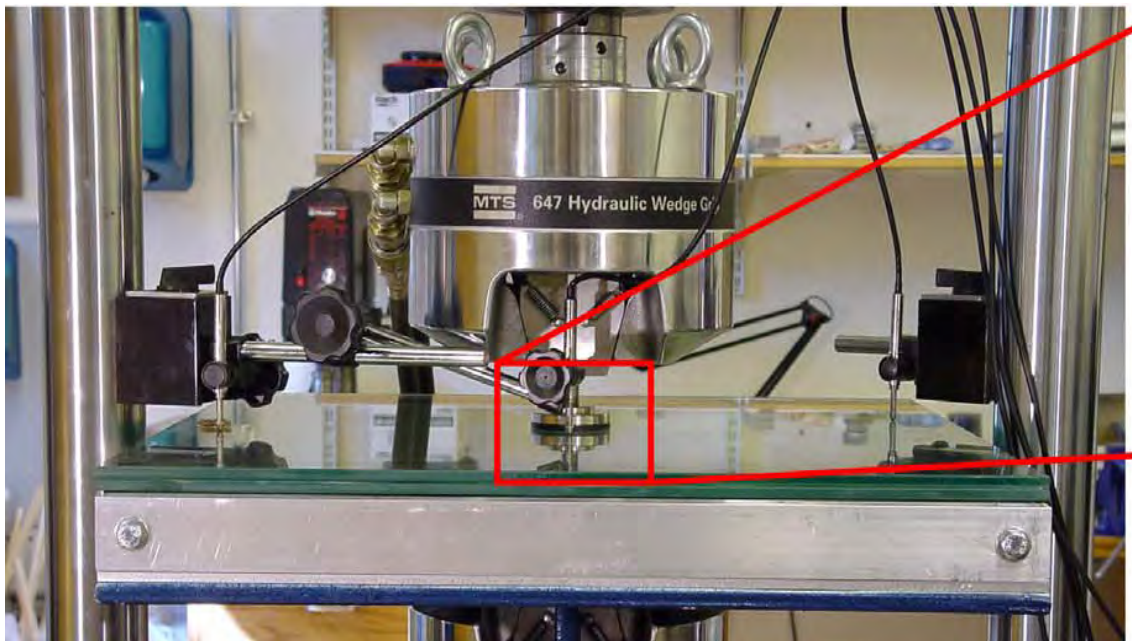

ClearSight (D:\feb\Savefiles\demo4\demo4.gfe)
File
Run
View
Advanced
About
Structure Geometry
Bolts
Loads
Material properties
GLASS
Elastic modulus [GPa] :
78.0
Density [kg/m3] :
2500
Poissons ratio :
0.23
Yield stress [Mpa] :
50.0
PVB
Elastic modulus [MPa] :
9.0
Density [kg/m3] :
1500
Poissons ratio :
0.43
ClearSight
v. 1.0
Division of Structural Mechanics

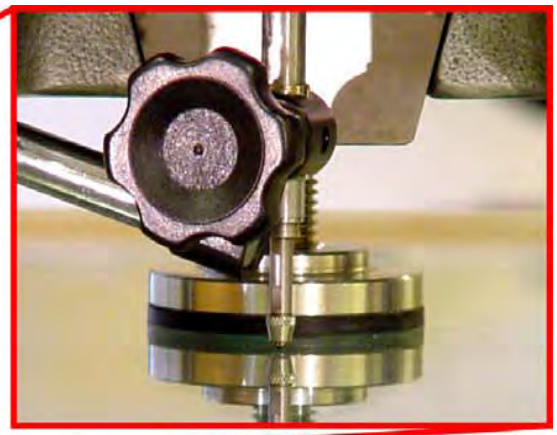
Experimental Studies of Two Types of Bolts

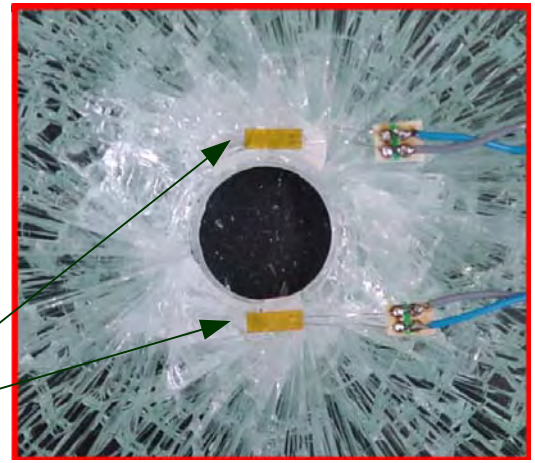
In part from masters thesis by C. Bength

Cylindrical bolt **Countersunk bolt**

Experimental Test Setup

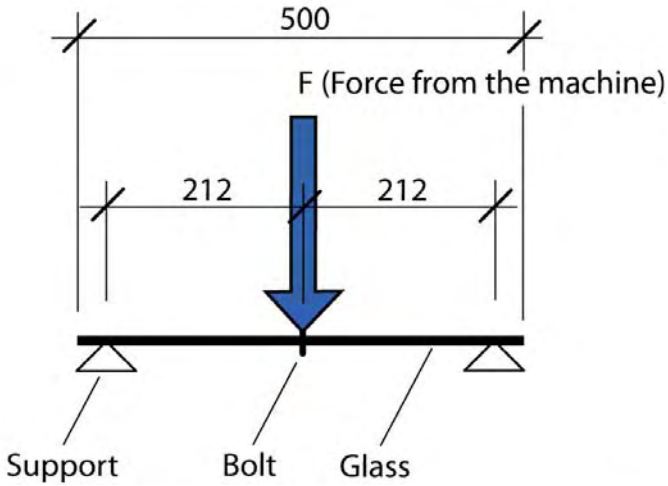


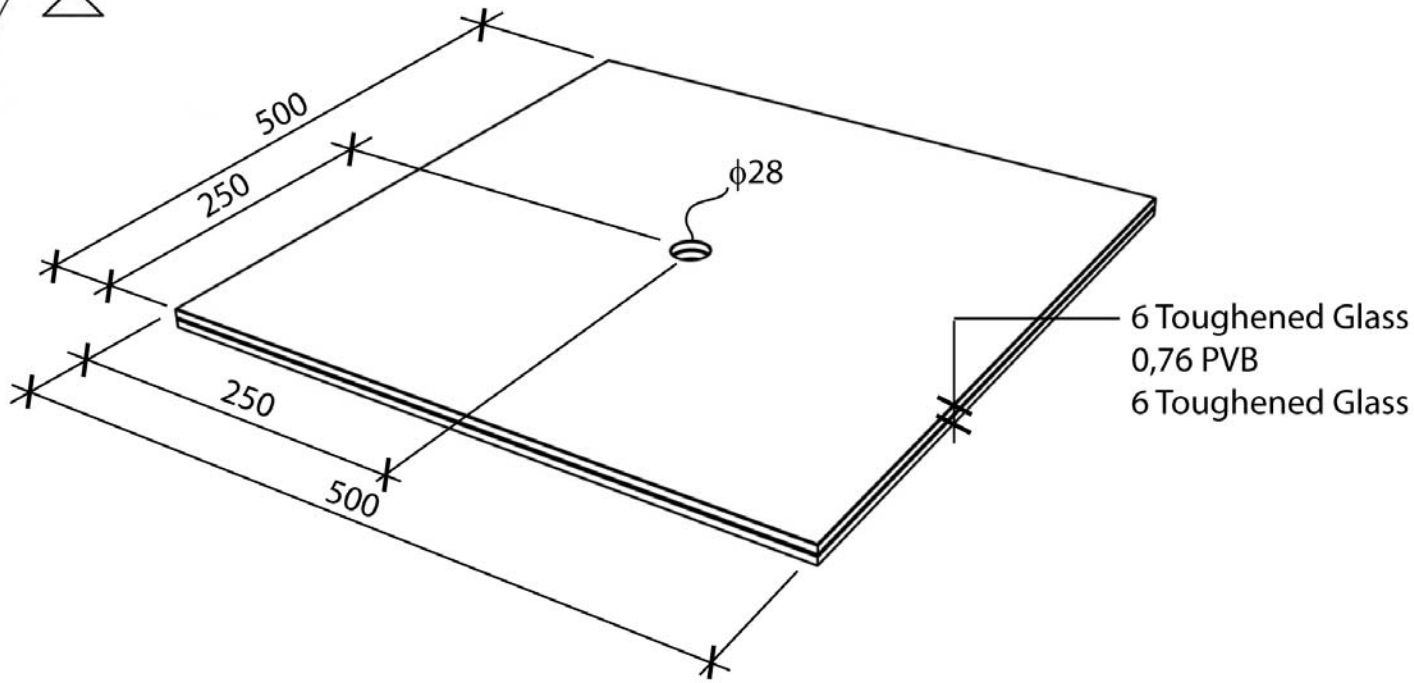




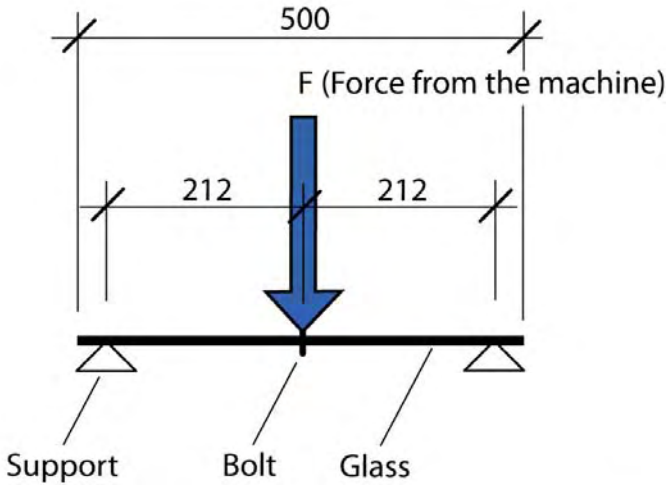
Strain gauges glued on the glass at the tension side, close to the edge of hole

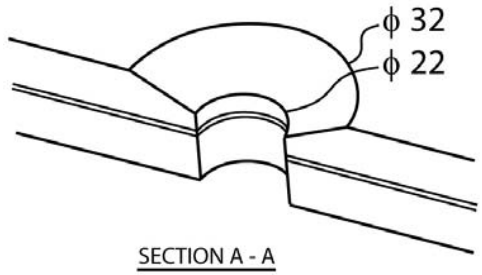
Cylindrical Bolt in Compression Loading

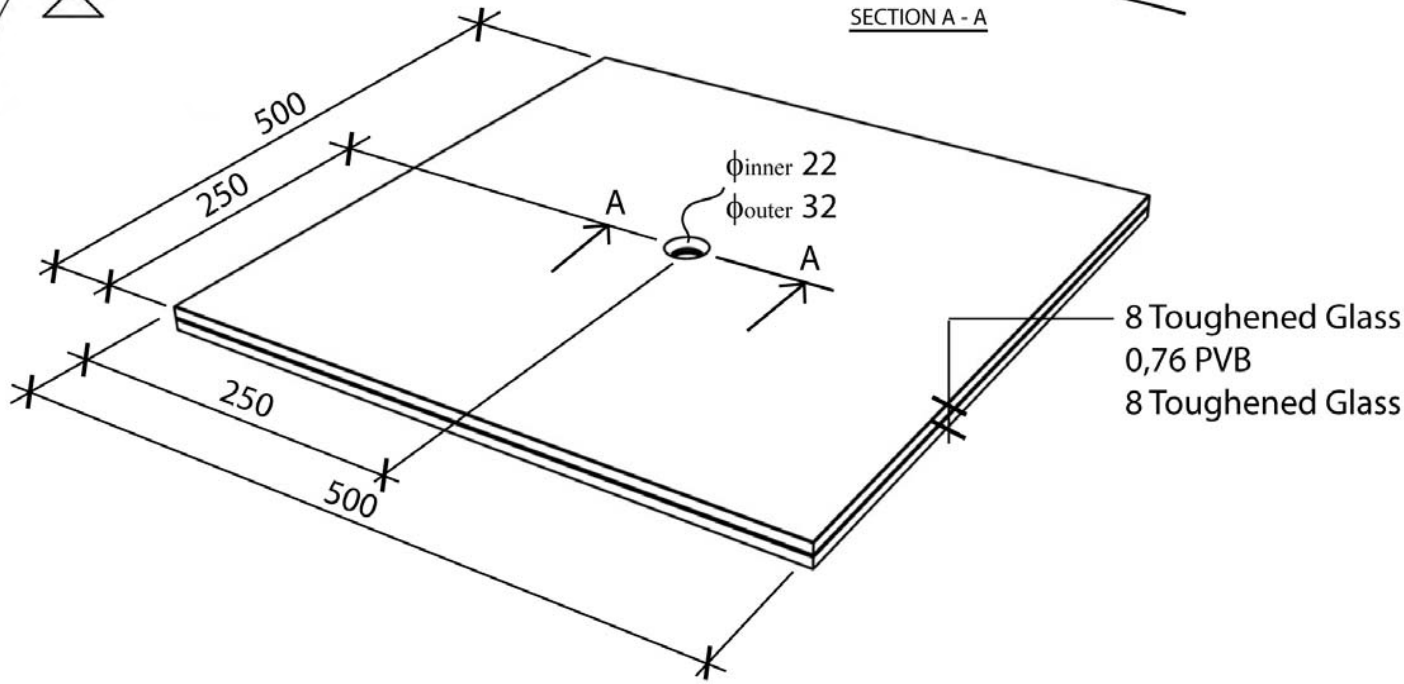




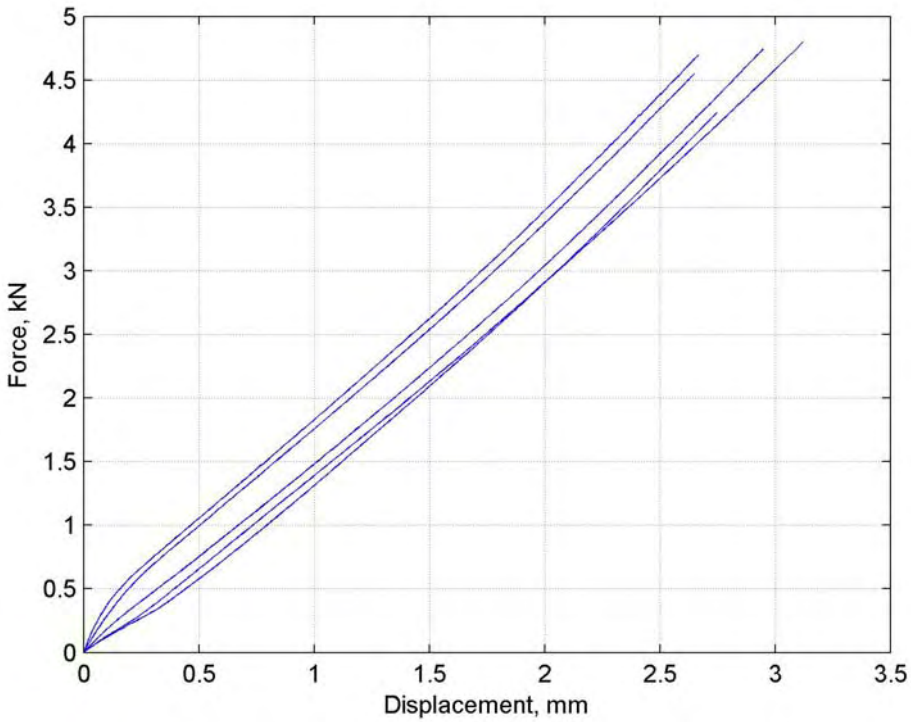
Countersunk Bolt in Compression Loading

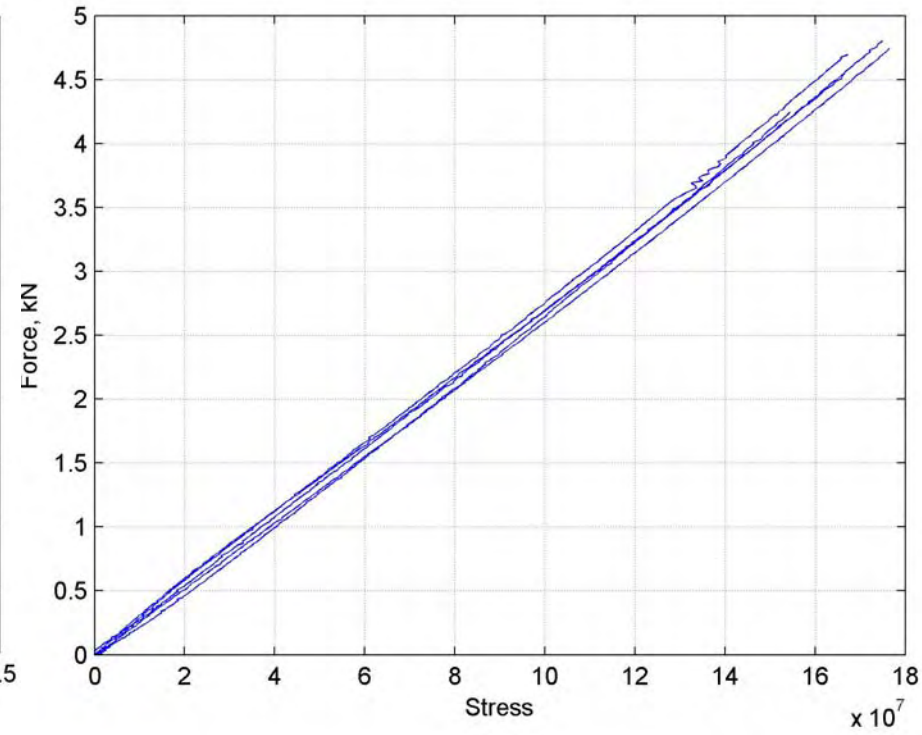




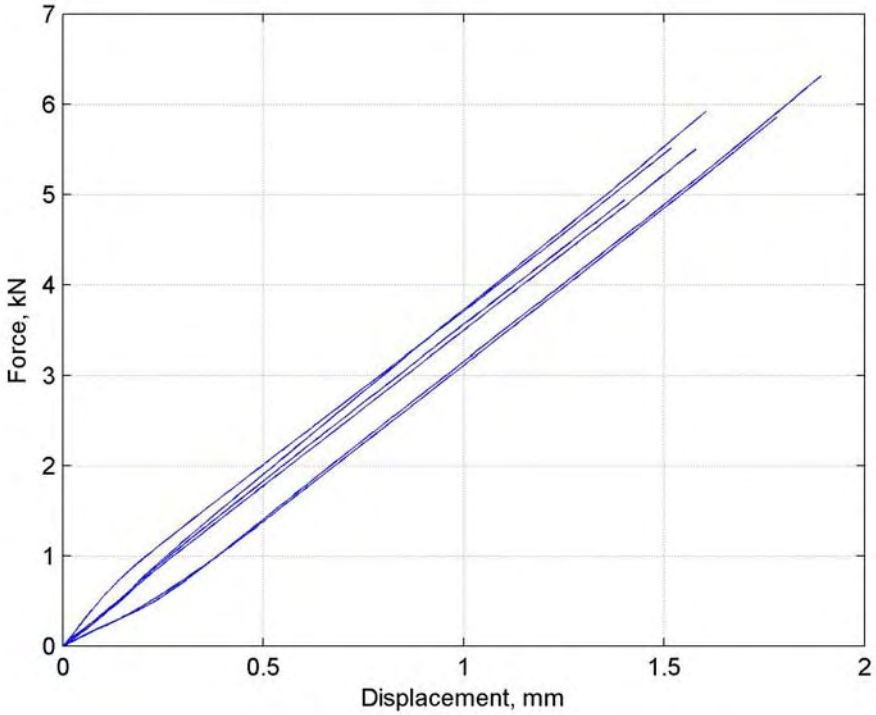


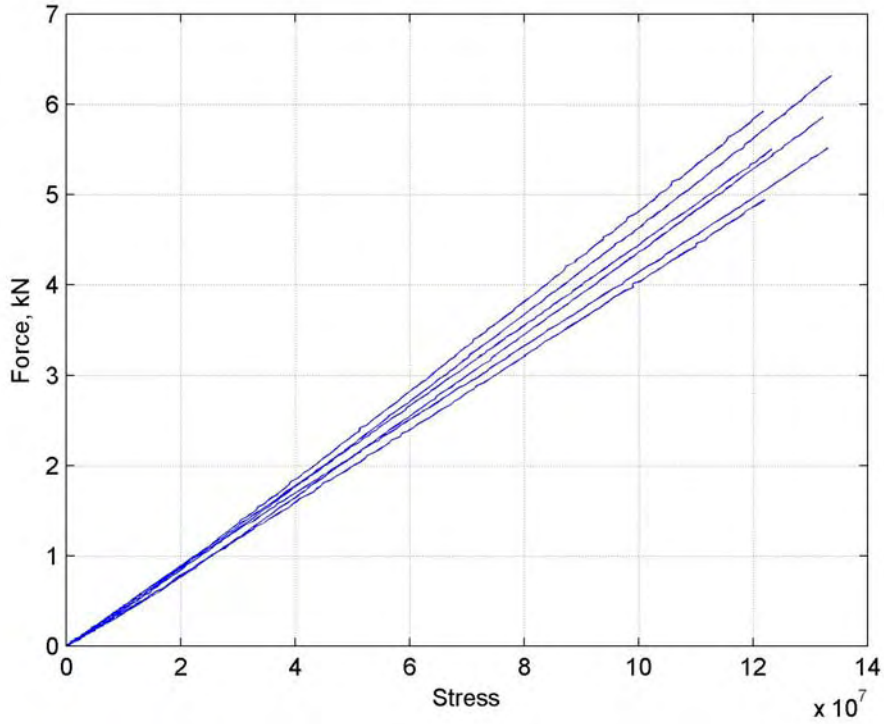
Experimental Results for Cylindrical Bolt





Experimental Results for Countersunk Bolt - load on countersunk end



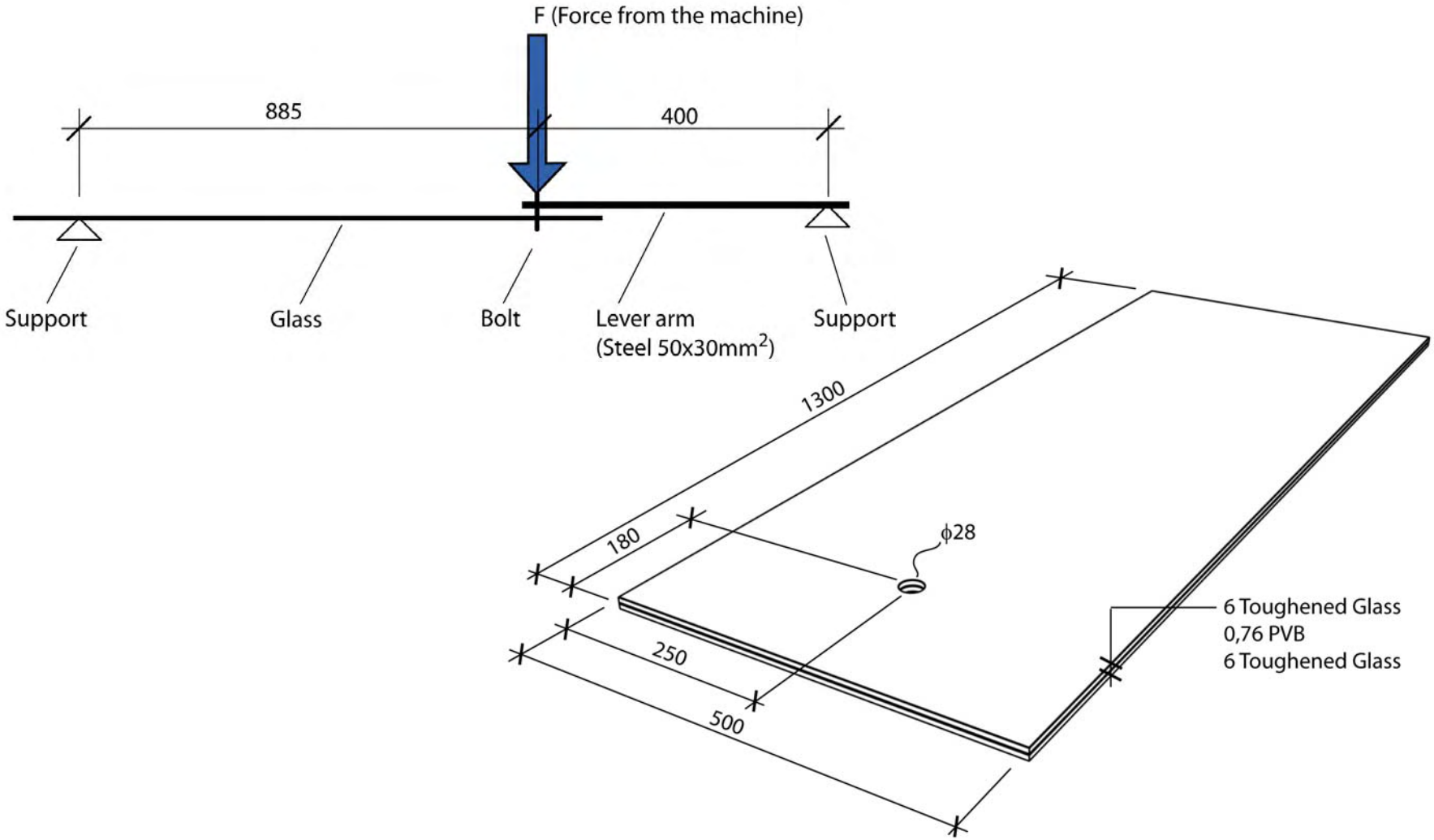


Results of Compression Test

	Force, (N)	Tensile stress at failure, (MPa)
Cylindrical bolt	**4600**	**177**
Countersunk bolt **Load on countersunk end**	**5600**	**127**
Countersunk bolt **Load on flat end**	**7200**	**172**

Experiment - Cylindrical bolt in bending

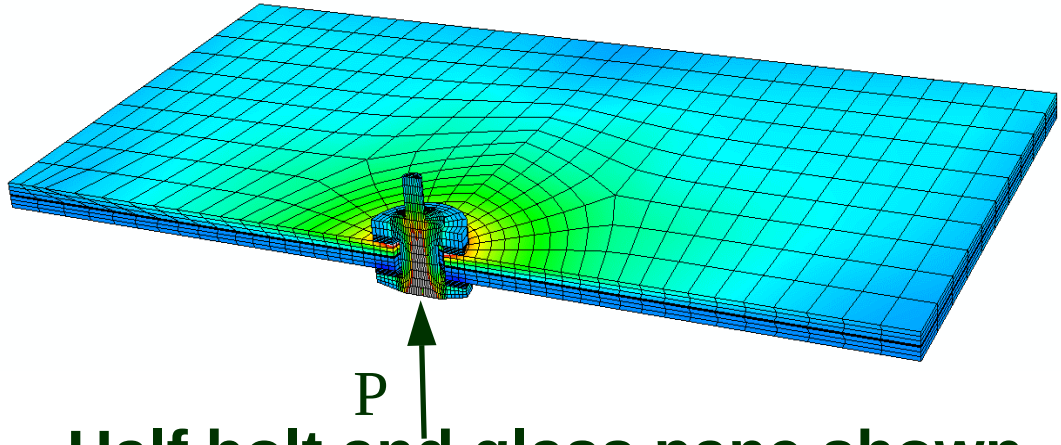
Experiment - Cylindrical bolt in bending



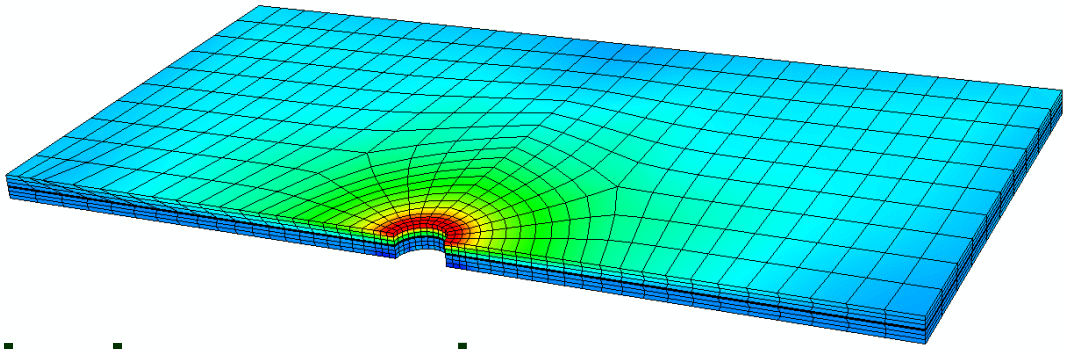
Results of Bending Test

	Bending Moment, (Nm)	Tensile stress at failure, (MPa)
Cylindrical bolt	210	50

Finite Element Analyses of Experimental Tests

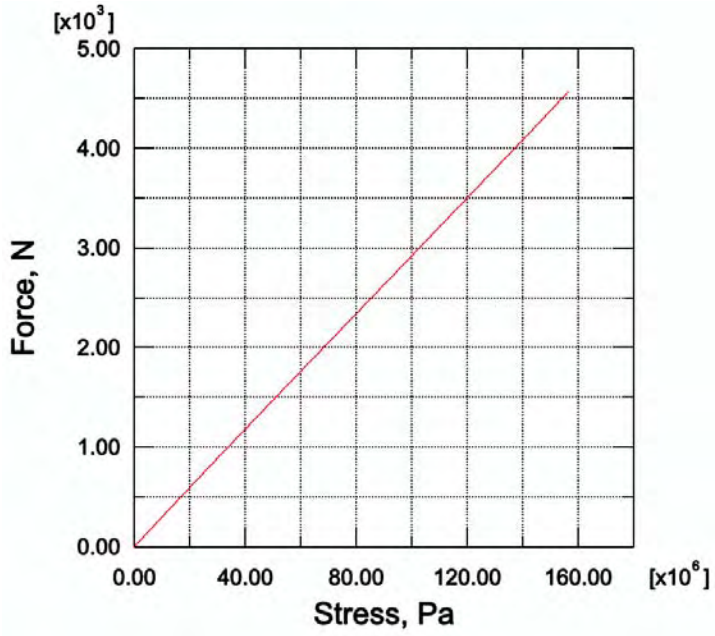


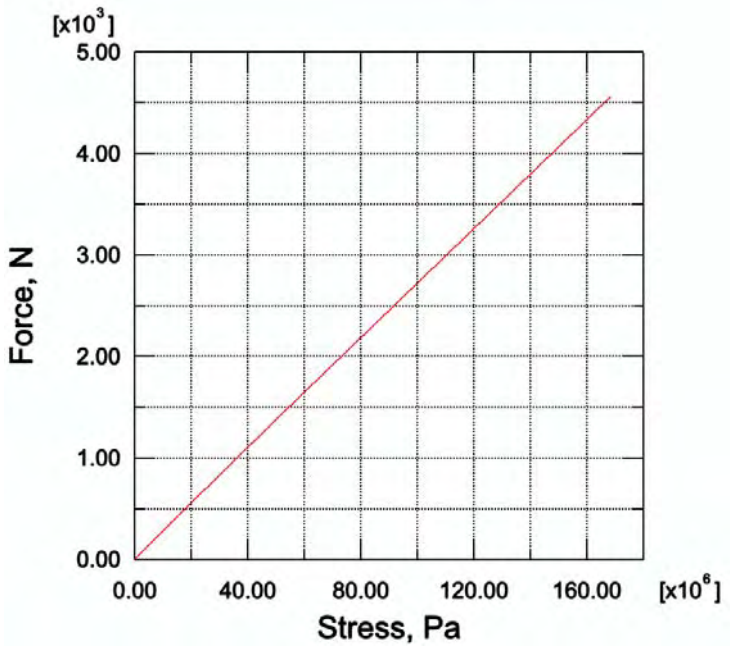
Half bolt and glass pane shown.



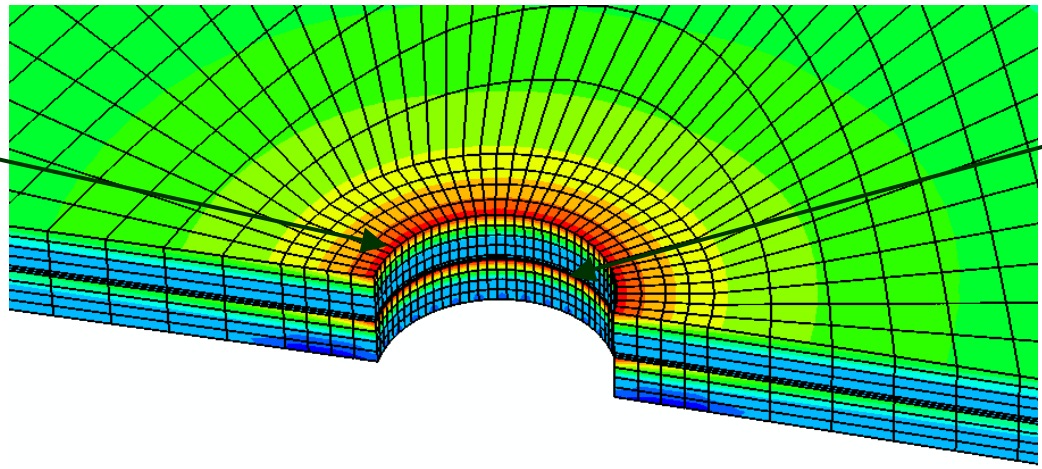
Only glass pane shown.
Stress concentrations around the hole.

FE-analysis for Cylindrical Bolt



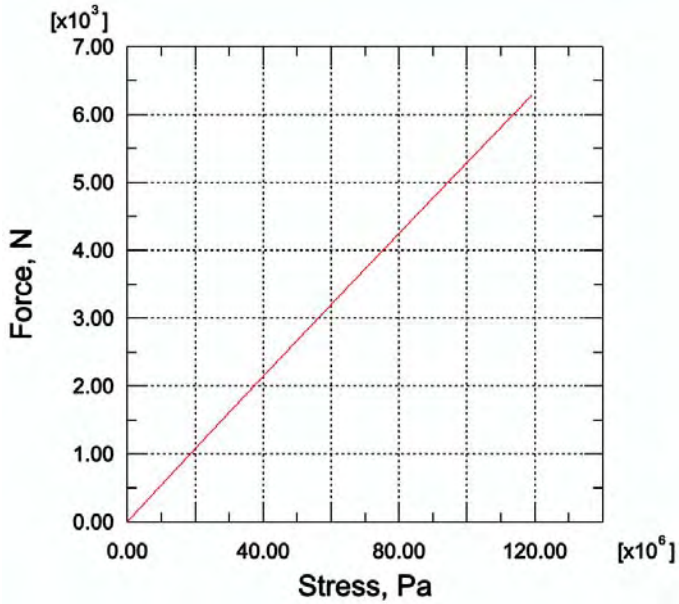


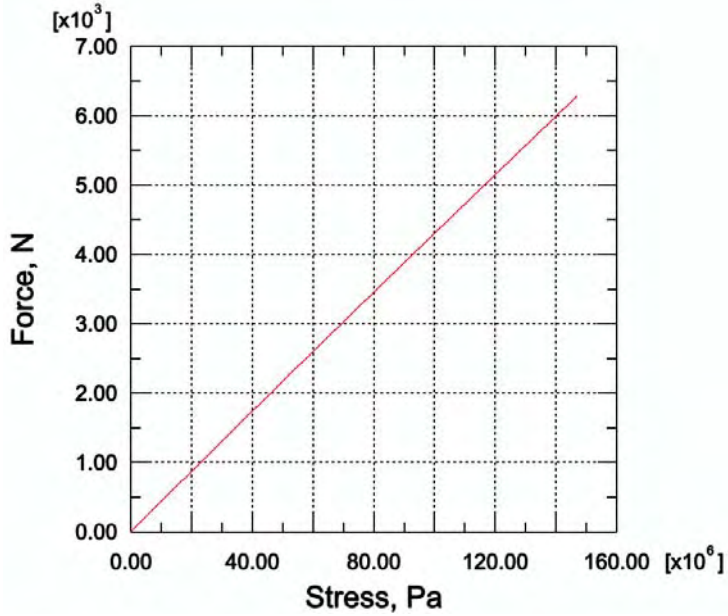
σ_{max}=155MPa



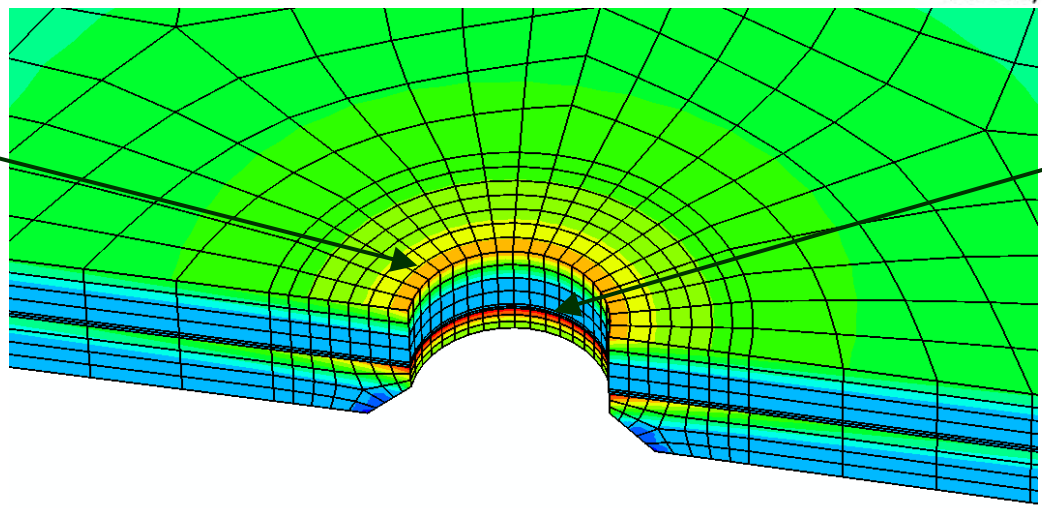
σ_{max}=168MPa

FE-analyses for Countersunk Bolt -load on countersunk end



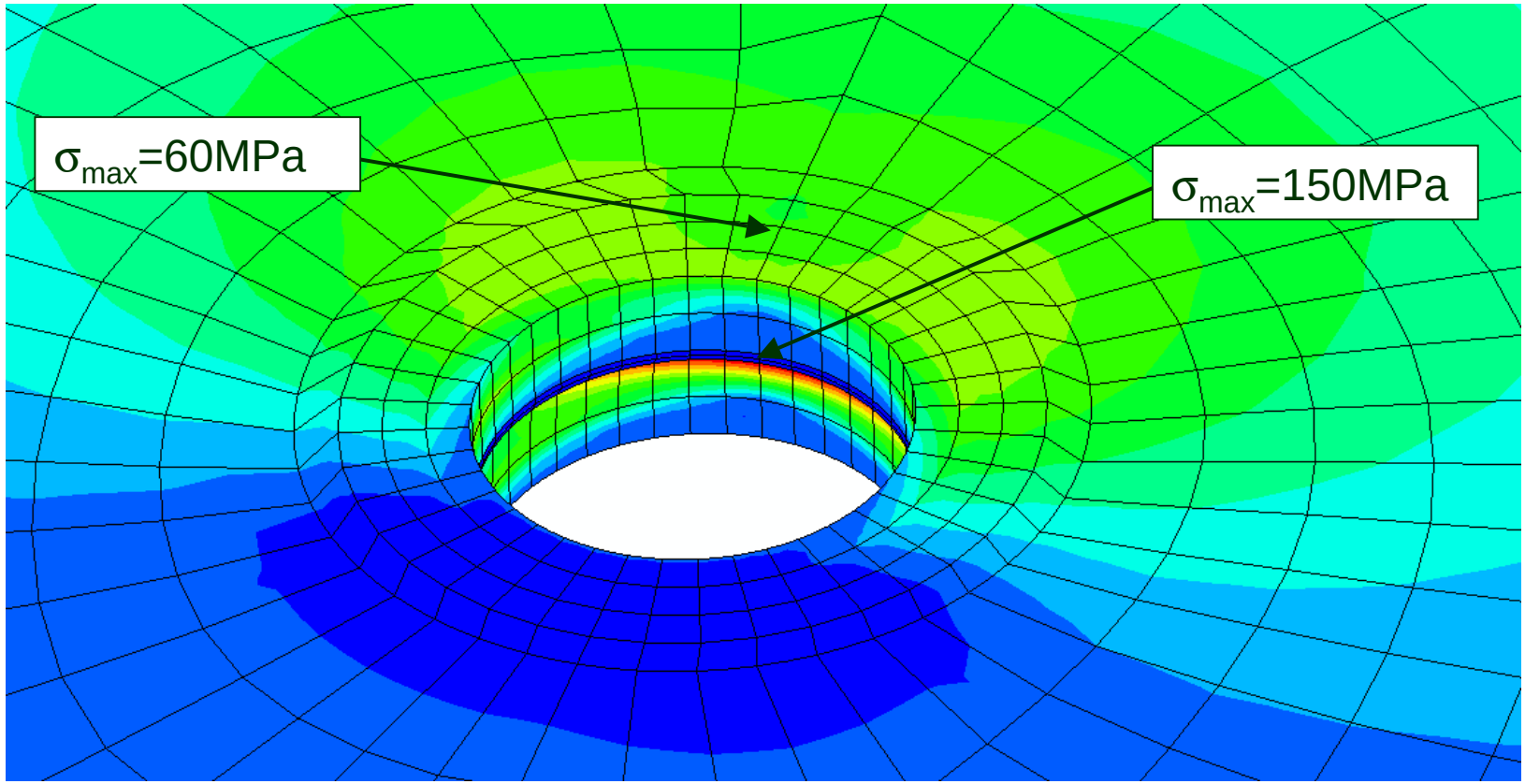


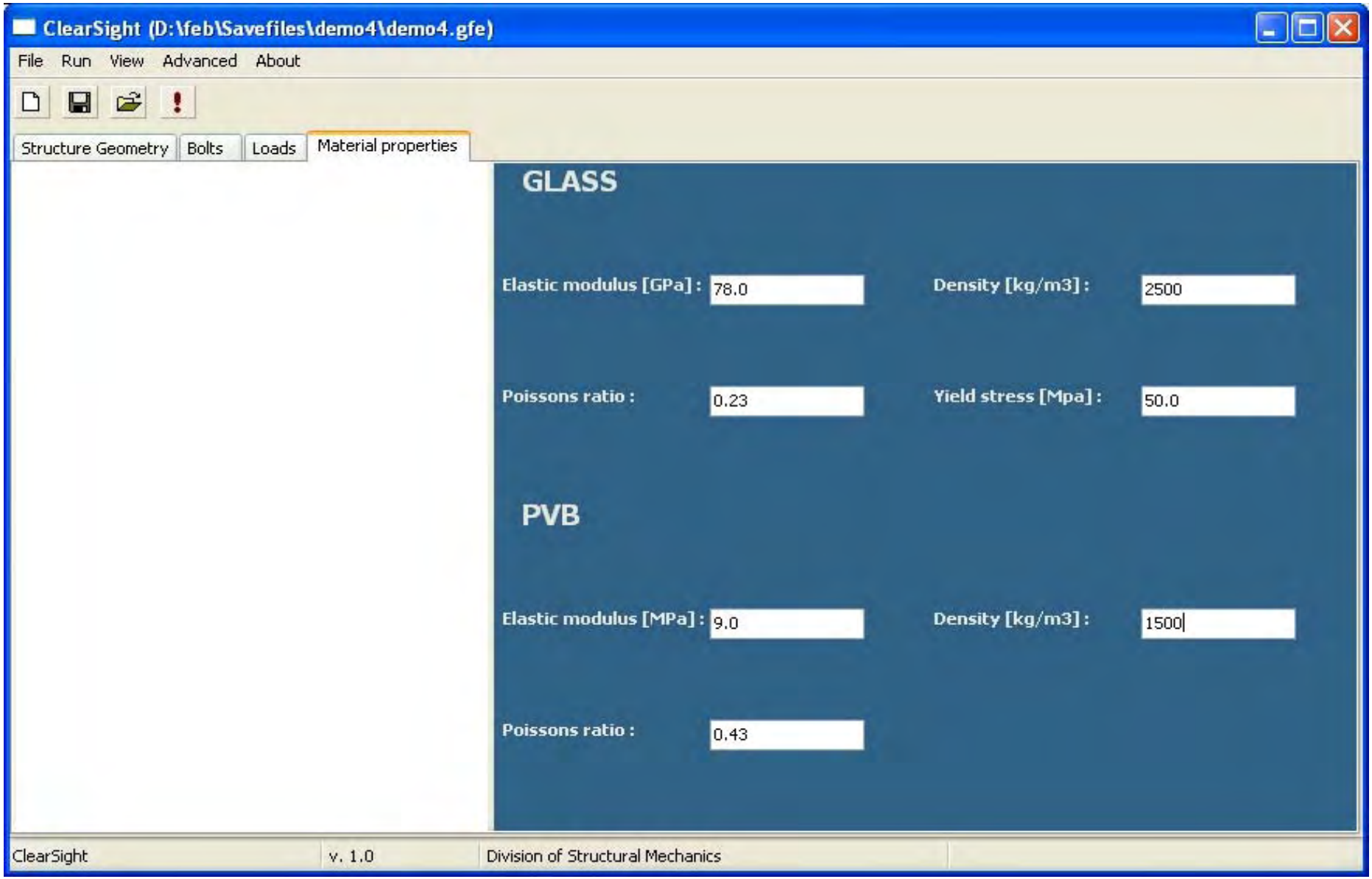
σ_{max}=120MPa



σ_{max}=147MPa

FE-analysis, cylindrical bolt in bending




ClearSight (D:\feb\Savefiles\demo4\demo4.gfe)
File
Run
View
Advanced
About
Structure Geometry
Bolts
Loads
Material properties
GLASS
Elastic modulus [GPa] :
78.0
Density [kg/m3] :
2500
Poissons ratio :
0.23
Yield stress [Mpa] :
50.0
PVB
Elastic modulus [MPa] :
9.0
Density [kg/m3] :
1500
Poissons ratio :
0.43
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v. 1.0
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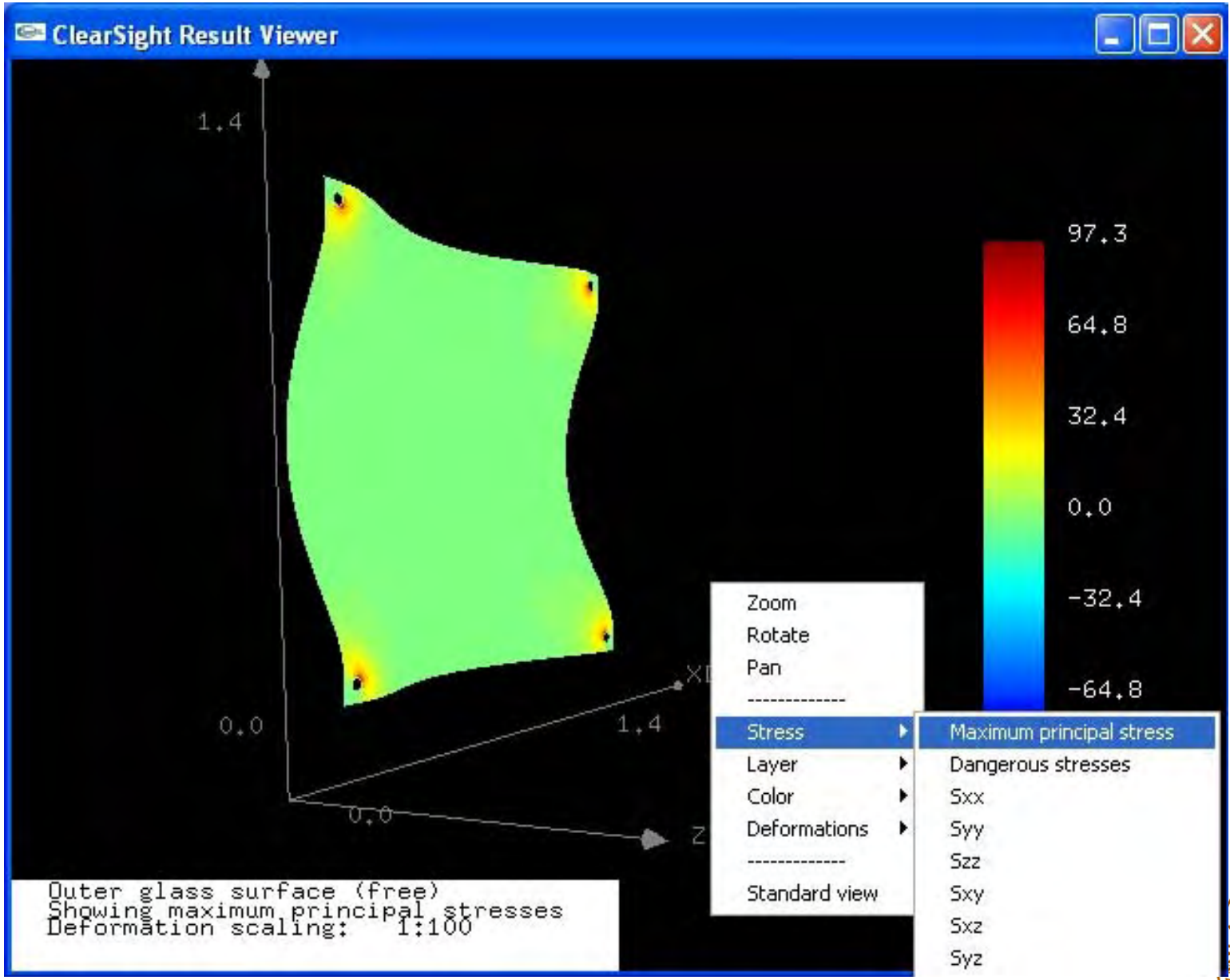
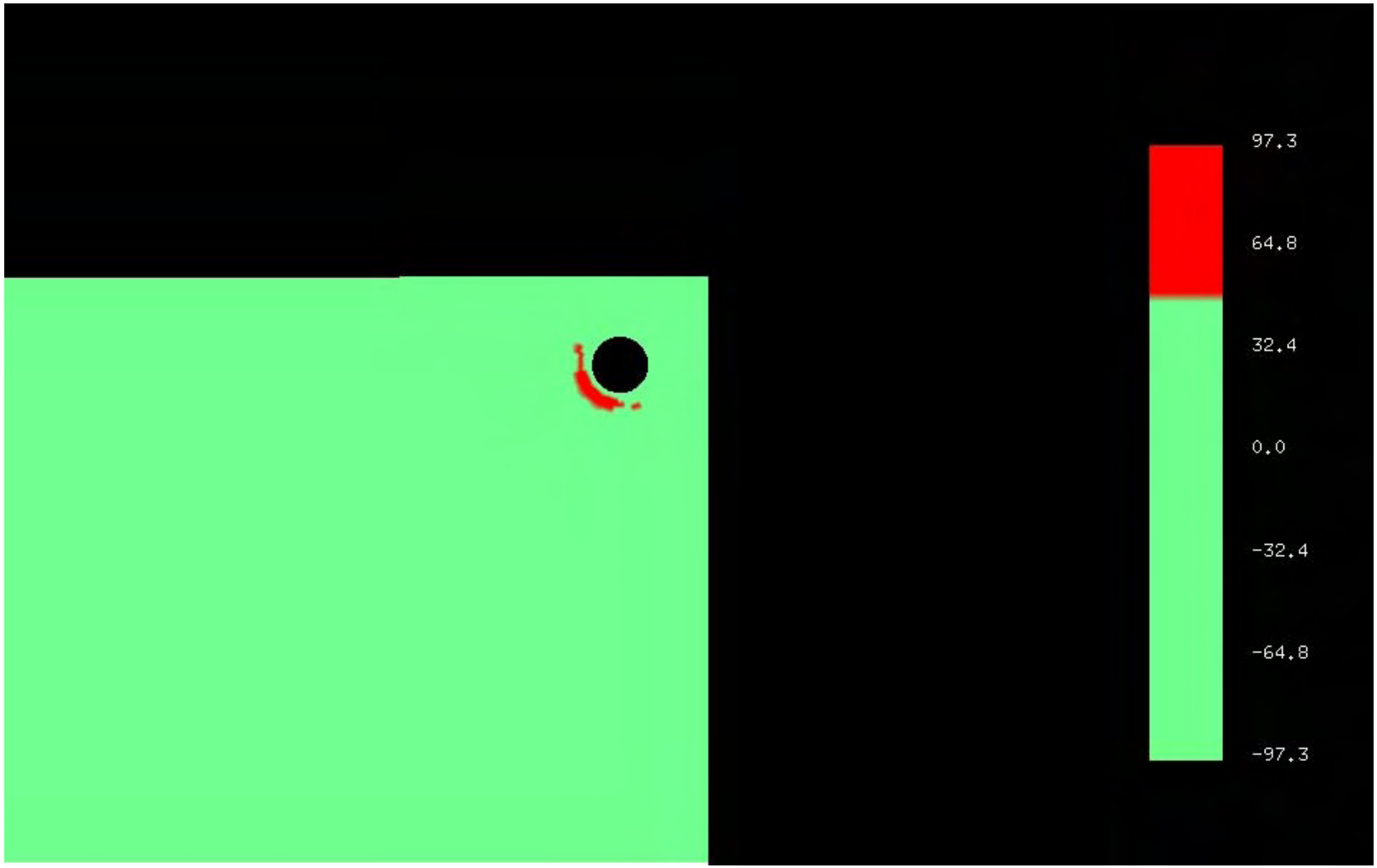
Visualisation of Results

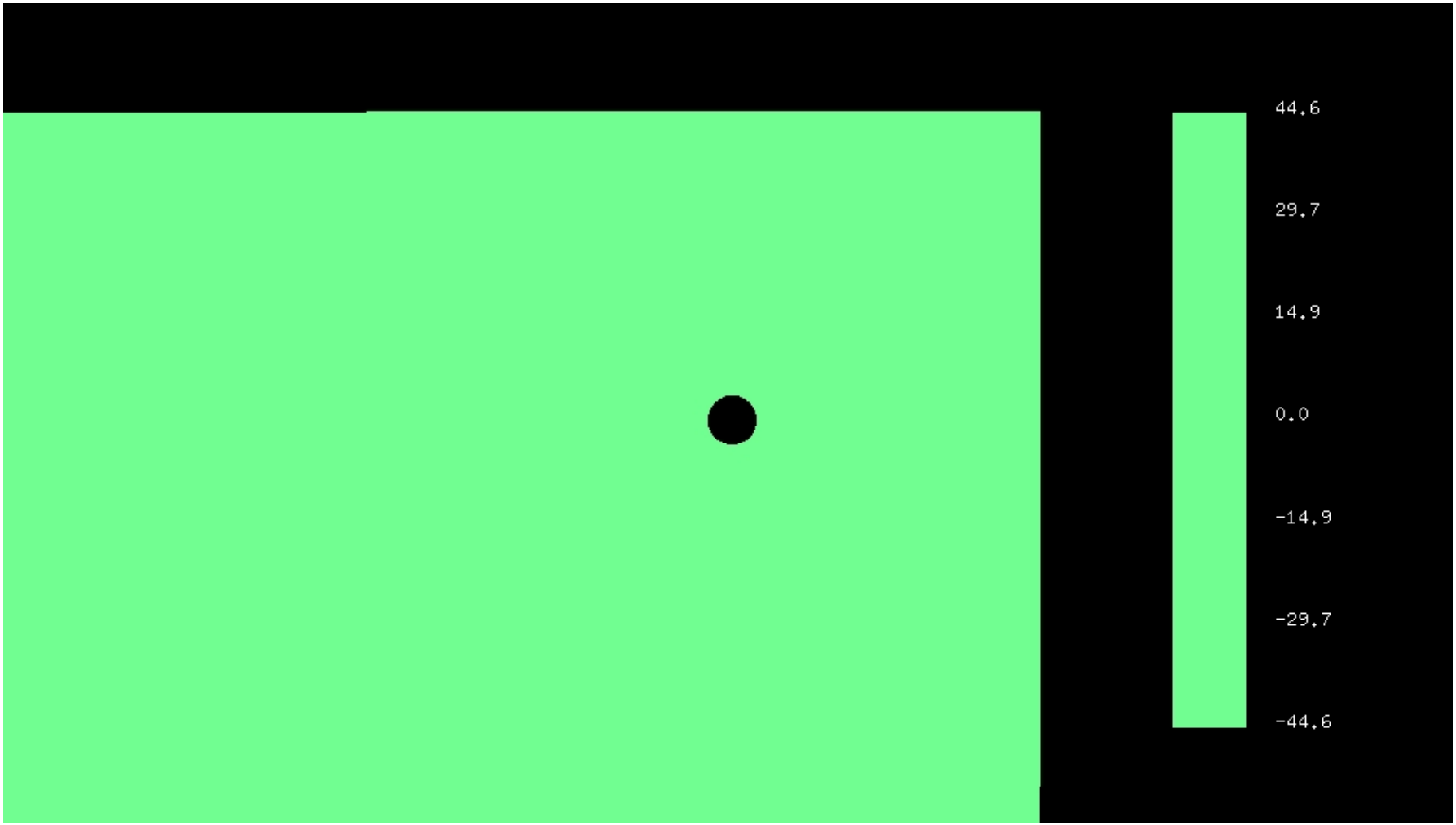


Example 1: Facade Glass



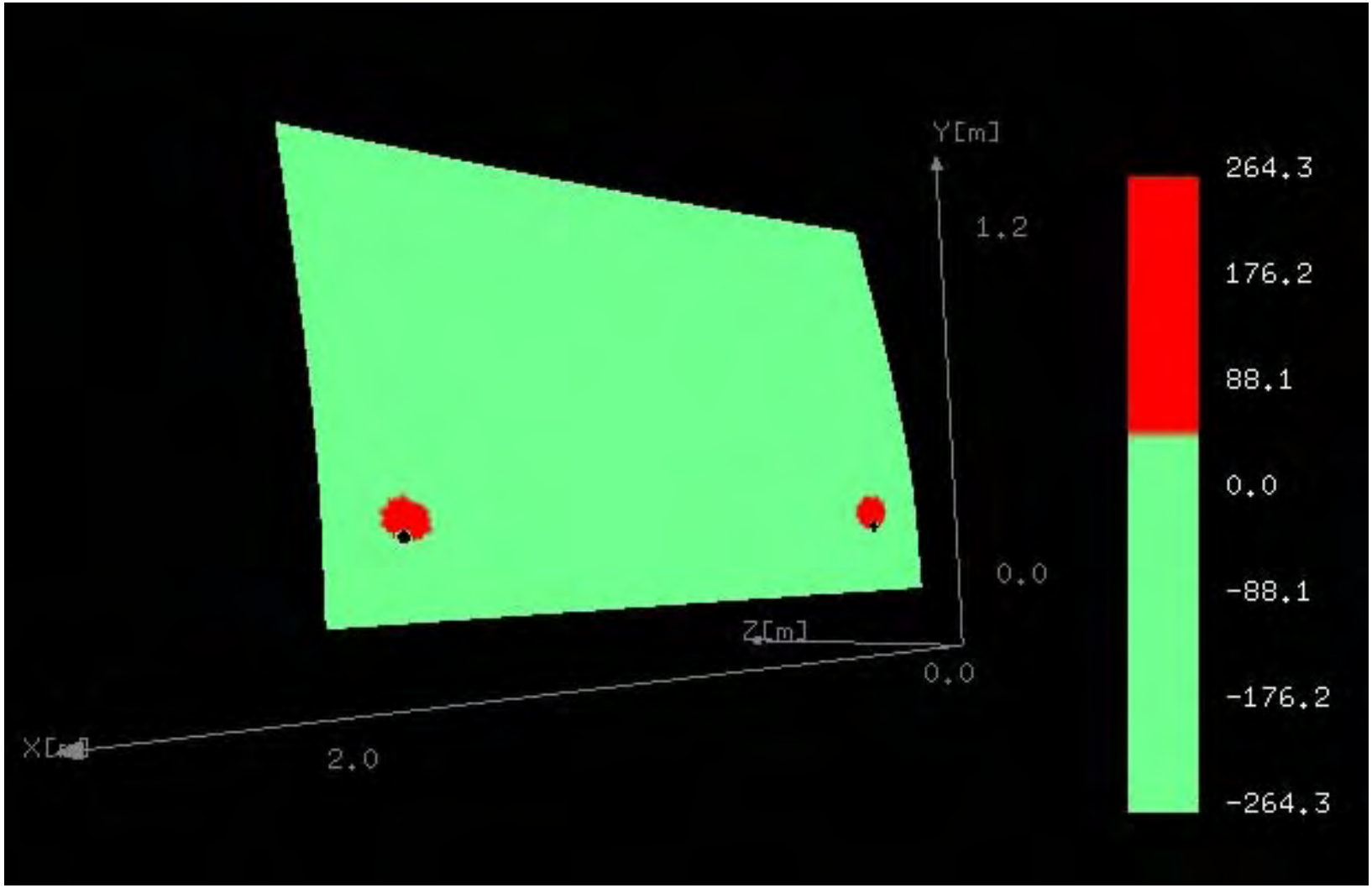
Holes to close to edge!

Example 1: Facade Glass



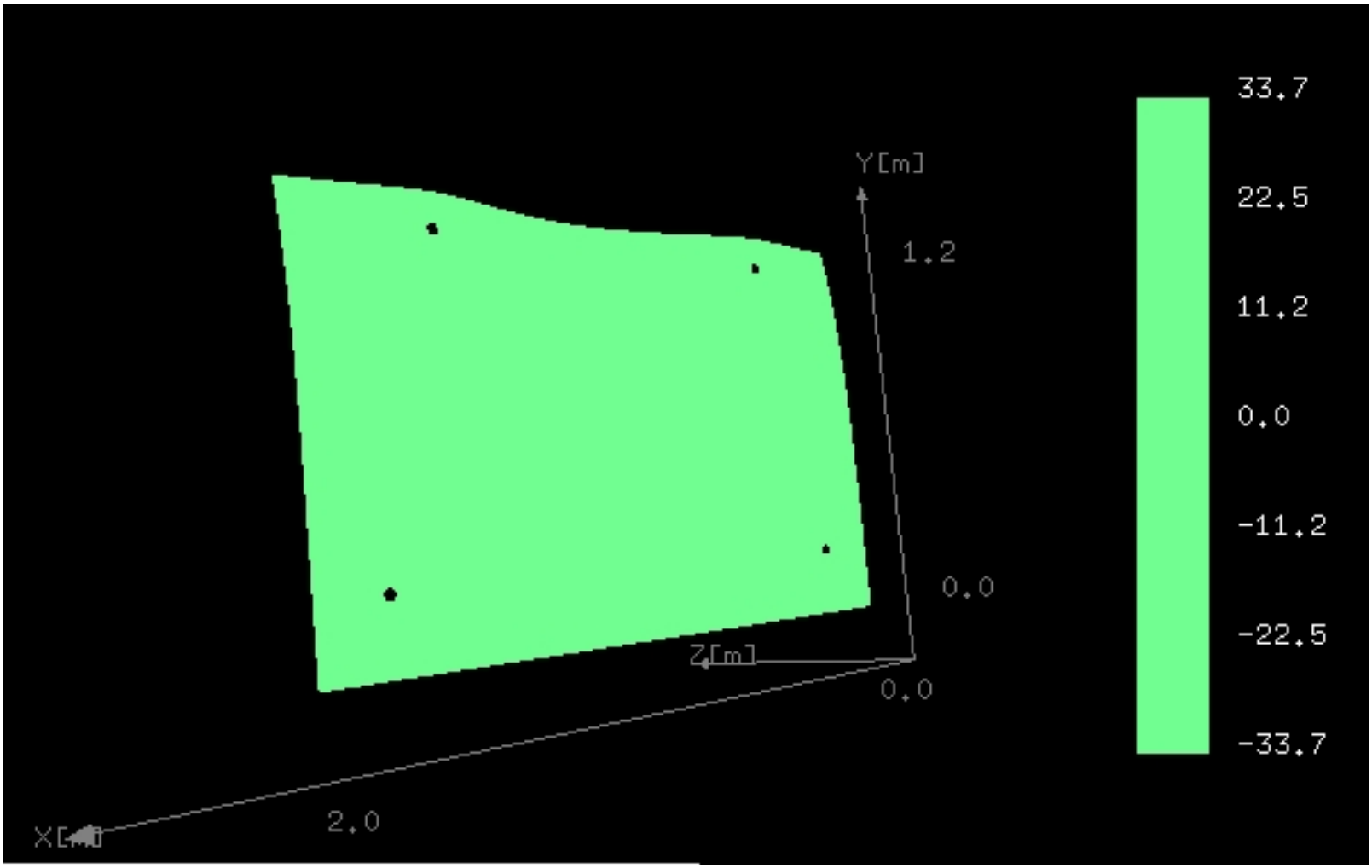
Holes moved, strength not exceeded.

Exempel 2: Balustrade Glass



With two bolt fixings only, the glass will not withstand the loads according to the design code.

Exempel 2: Balustrade Glass



With four bolts, no dangerous stresses develops when subjected to load according to the design code.

Conclusions

- **Svårt att förutse härdningsspänningarnas storlek kring hål och kanter – stor säkerhetsfaktor måste användas.**
- **Komplicerade spänningstillstånd kring hål pga mjukt mellanliggande PVB-skikt.**
- **Numeriska beräkningar överensstämmer bra experimentella data.**
- **Hur fungerar limmade infästningar mekaniskt?**

Thank You