Numerical Modelling of Hybrid Timber – Structural Glass Systems

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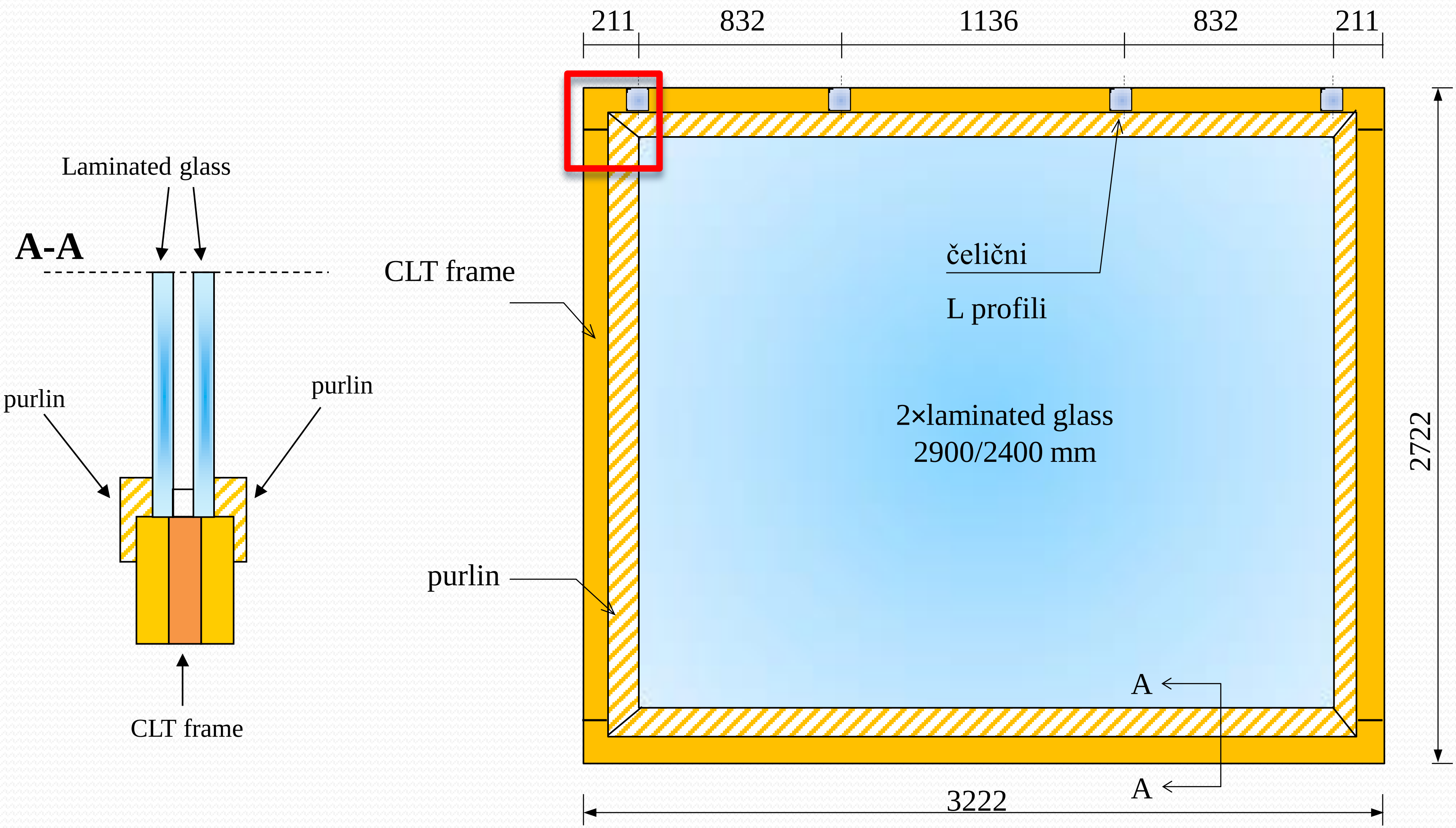
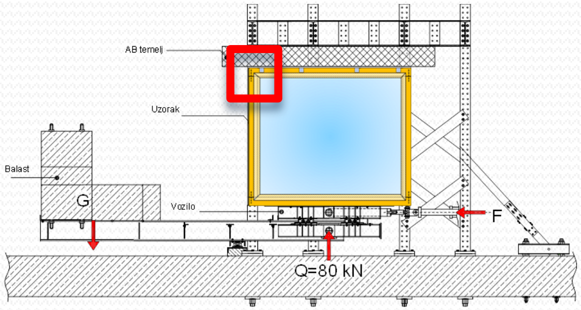
PROJEKT
HRVATSKE ZAKLADE ZA ZNANOST
VETROLIGNUM
Hrvatska zaklada za znanost

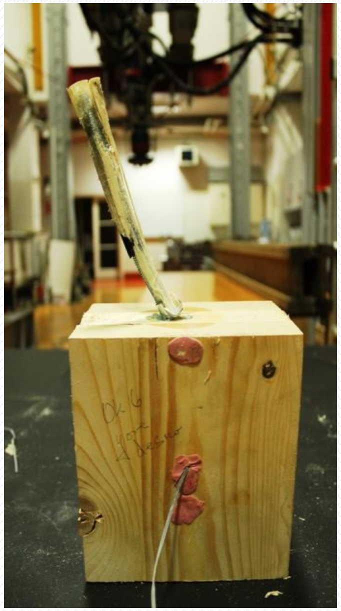
1st WORKSHOP
of the VETROLIGNUM project

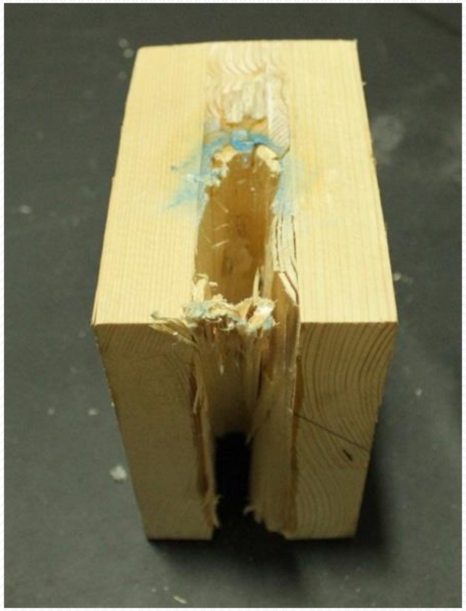
Hybrid Timber – Structural Glass System



Results of Laboratory Test – Failure in the Corner of the Frame







Numerical Analyses (Ansys) - Protocol

1.
- Geometrical model (AutoCad)

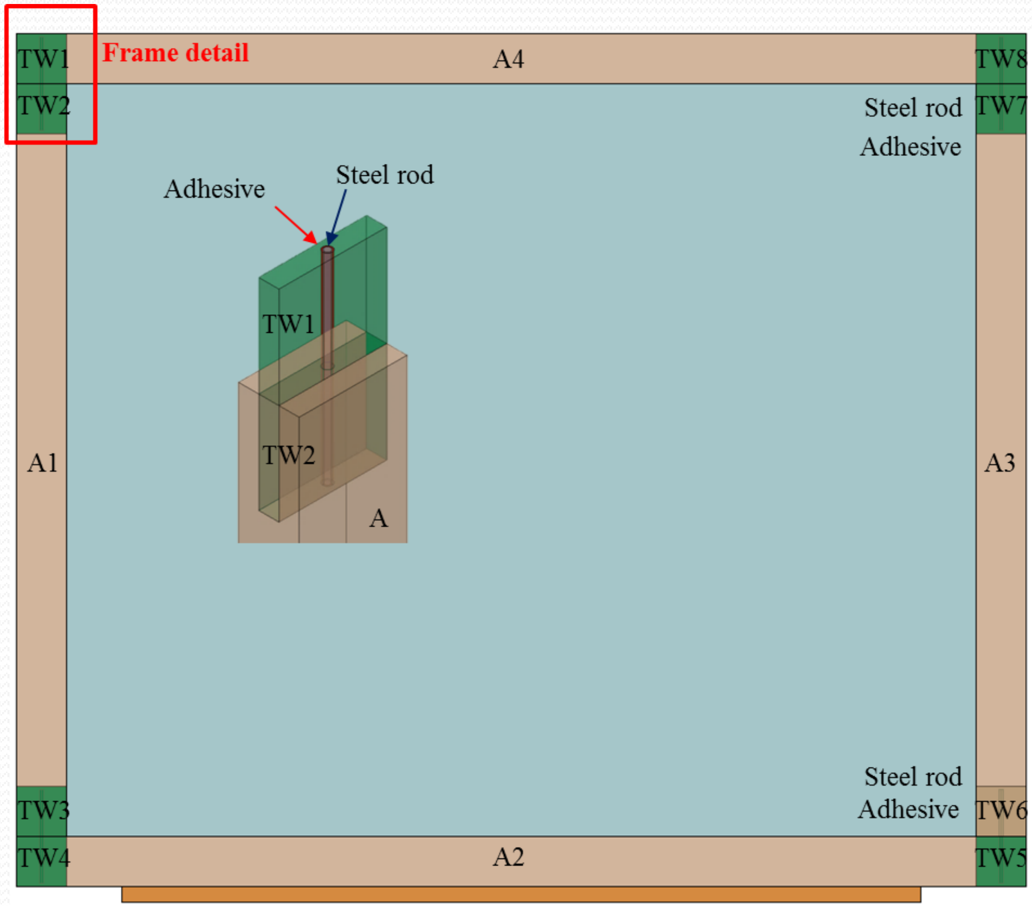
2.
- Material characteristics- Engineering data
- Boundary conditions and loading- Static structural
- Physical characteristics - Connections

3.
- Mesh
- Analysis settings

4.
- Solving the numerical model

5.
- Results

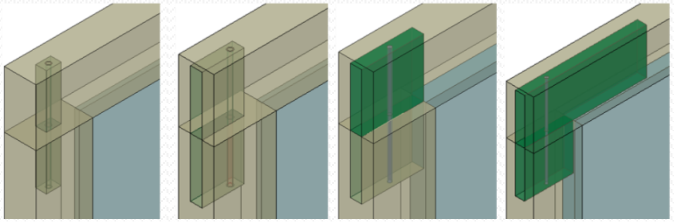
Numerical Analyses (Ansys) - Geometrical Model

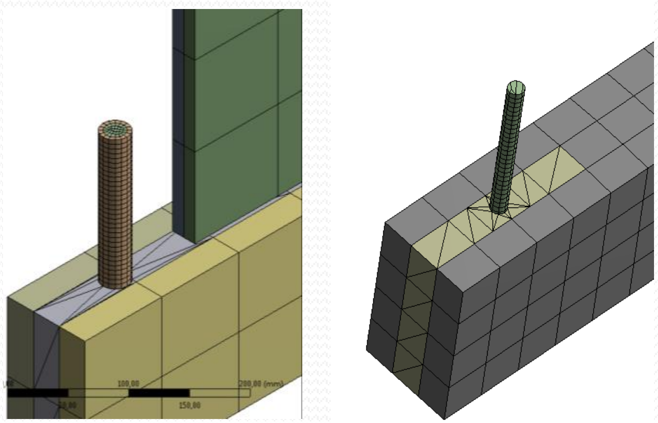


Monotonic load
Steel rod M10
Small nr. of finite elements
Without adhesive
Glass thickness 43,2 mm

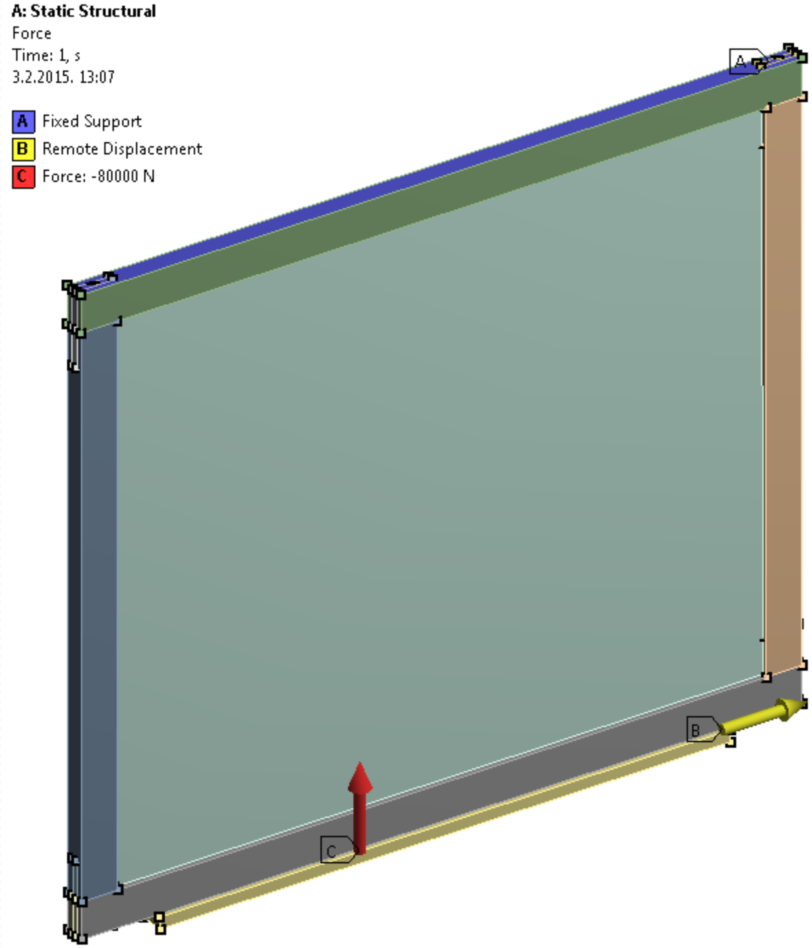
TW 1
TW 2
TW 3
TW 4

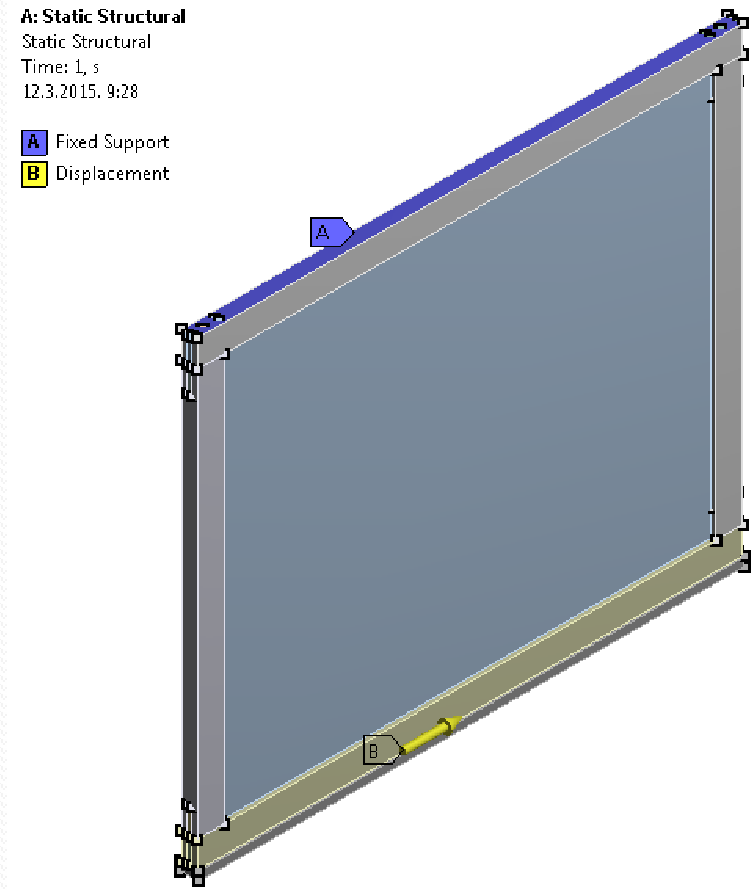
Adhesive
Without adhesive



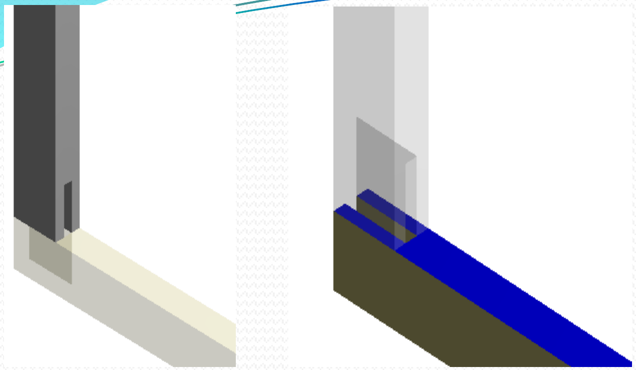


Numerical Analyses (Ansys) - Boundary Conditions and Loading

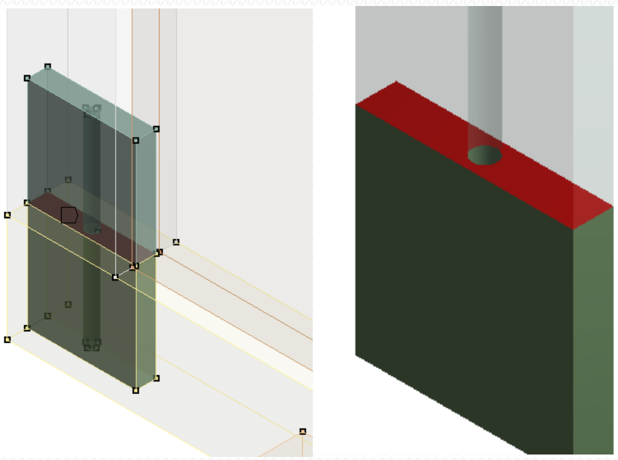




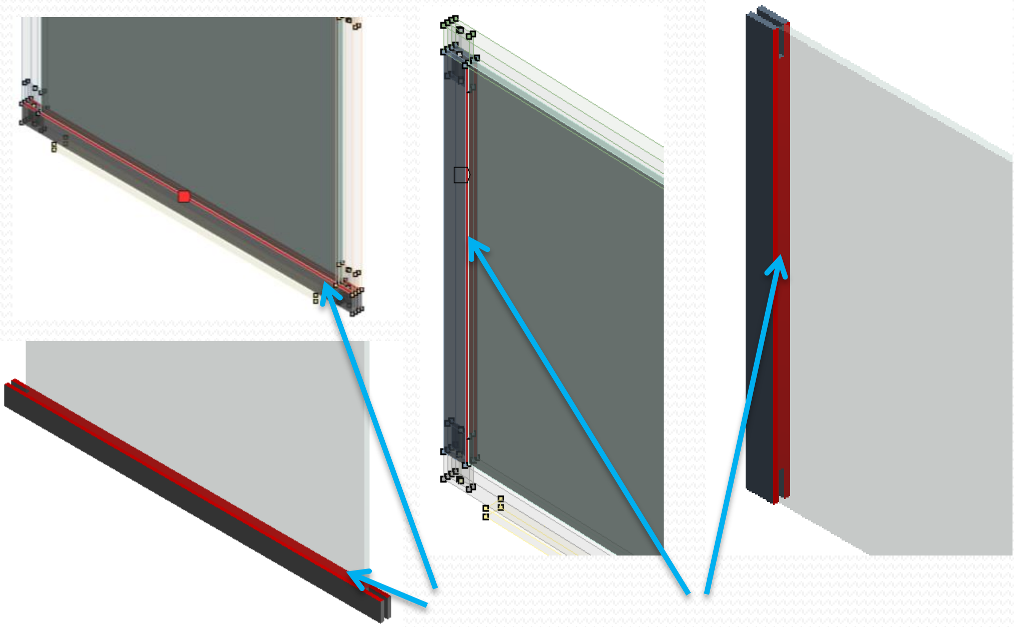
Numerical Analyses (Ansys) - Conections



Frictional 0,3
augmented Lagrange, Gauss point

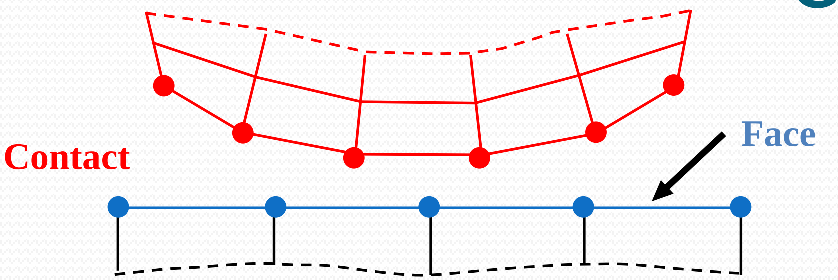


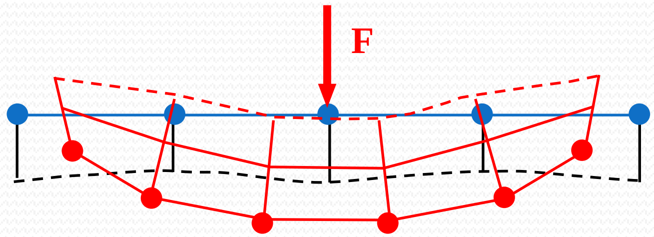
Frictional 0,3
augmented Lagrange, Gauss point



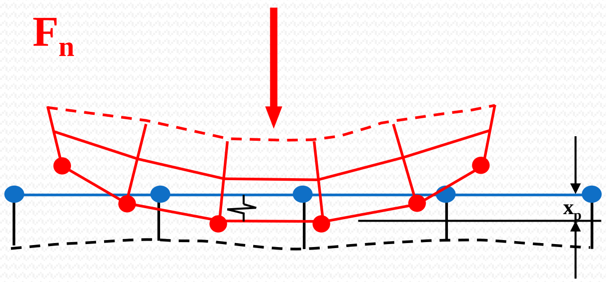
Frictional 0,15
augmented Lagrange, Gauss point

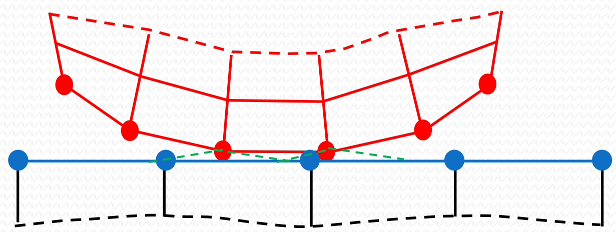
Numerical Analyses (Ansys) - Contact Between Elements

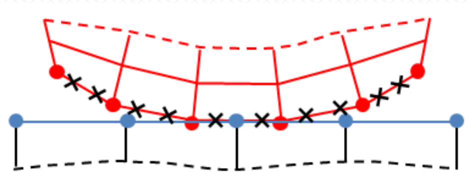




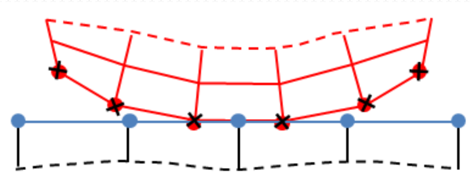
- Pure Penalty
- MPC (Multi-Point Constraint)







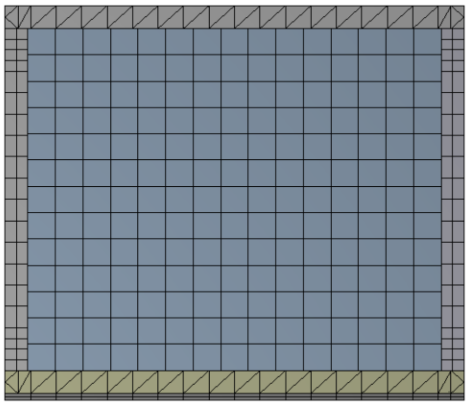
Gauss Point Detection

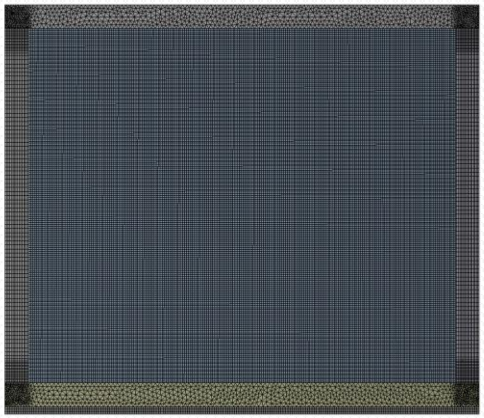


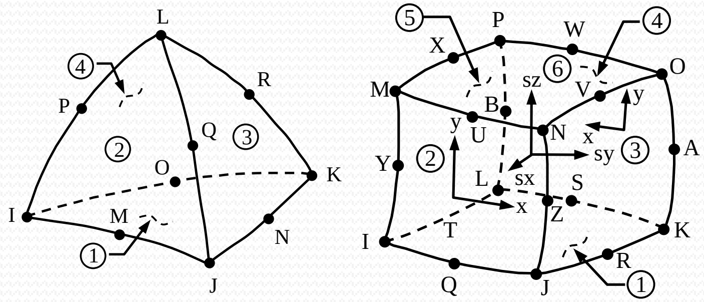
Nodal Detection

Numerical Analyses (Ansys) - Mesh

Finite element	Total No. of elements "weak mesh"	Total No. of elements "dense mesh"
SOLID187 **SOLID186**	5755 (31216 nodes)	288142 (1025768 nodes)







SOLID187 & SOLID186 elements

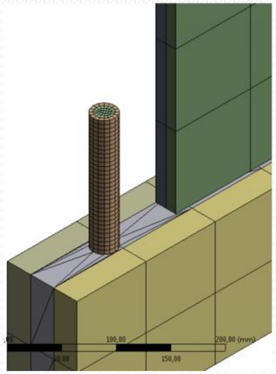
Glass thickness 43,2 mm

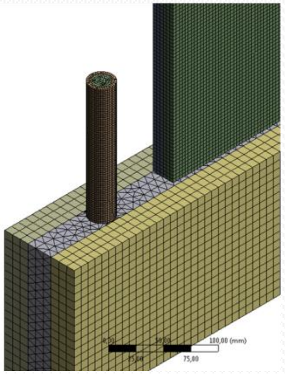
Glass thickness 2×21,6 mm

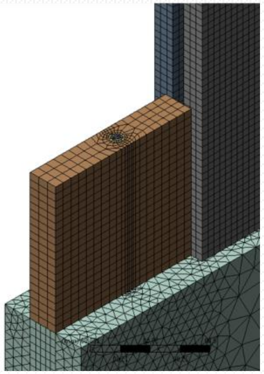
Dense discretization

Weak discretization

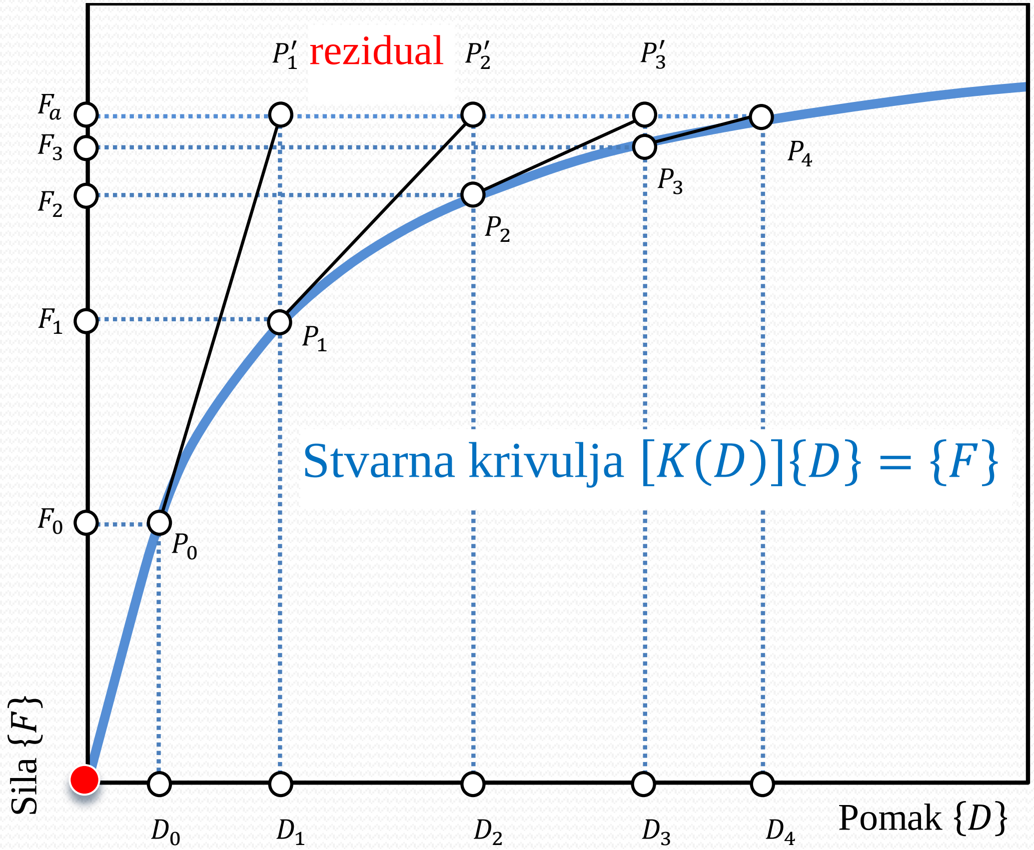
Rod M14







Numerical Analyses (Ansys) - Analysys Settings



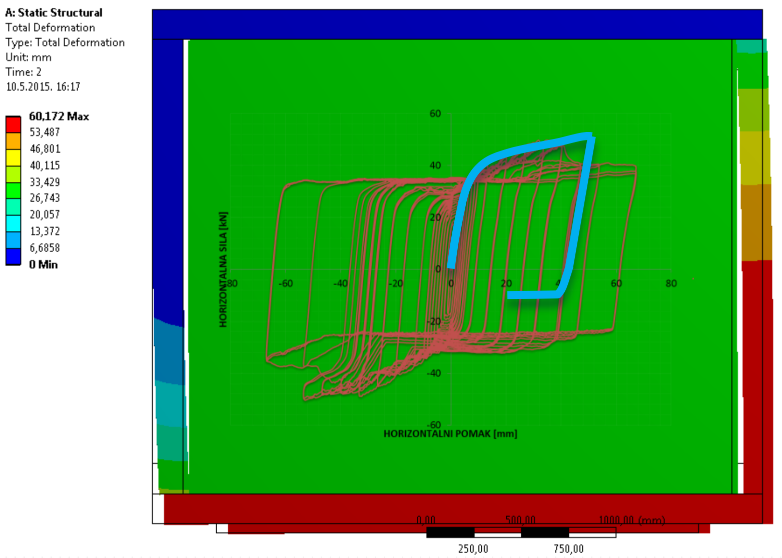
$$[K(D)]\{D\} = \{F\}$$

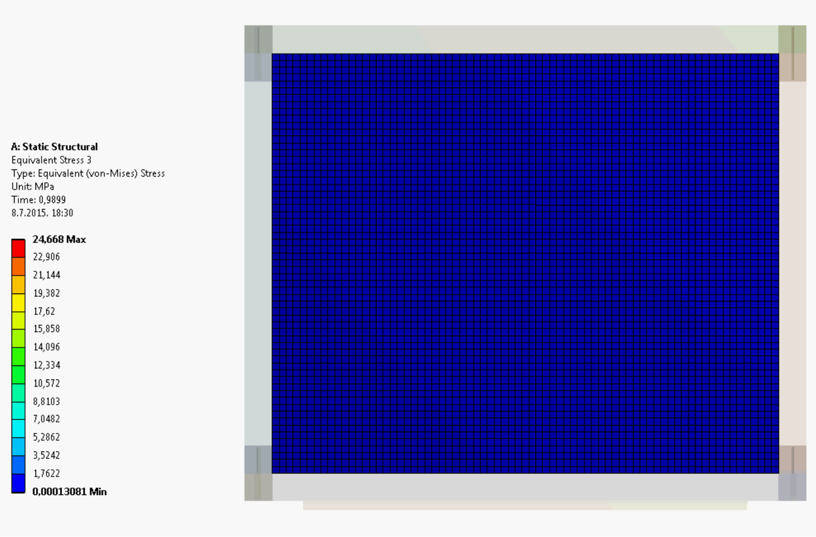
$$[K(D_0)]\{\Delta D\} = \{\Delta F\}$$

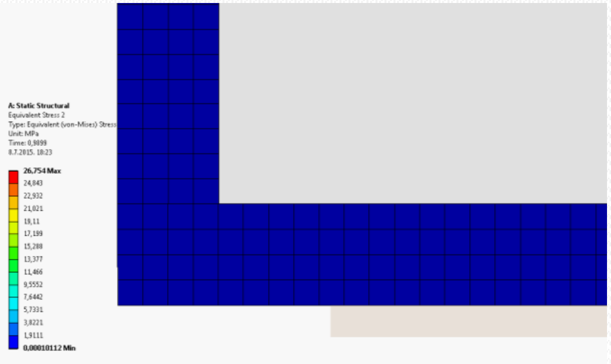
$$[K(D_1)]\{D_1\} = \{F_1\}$$

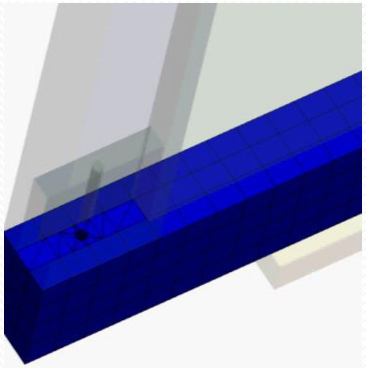
$$F^R = F_a - F_1$$

Numerical Analyses (Ansys) - Results

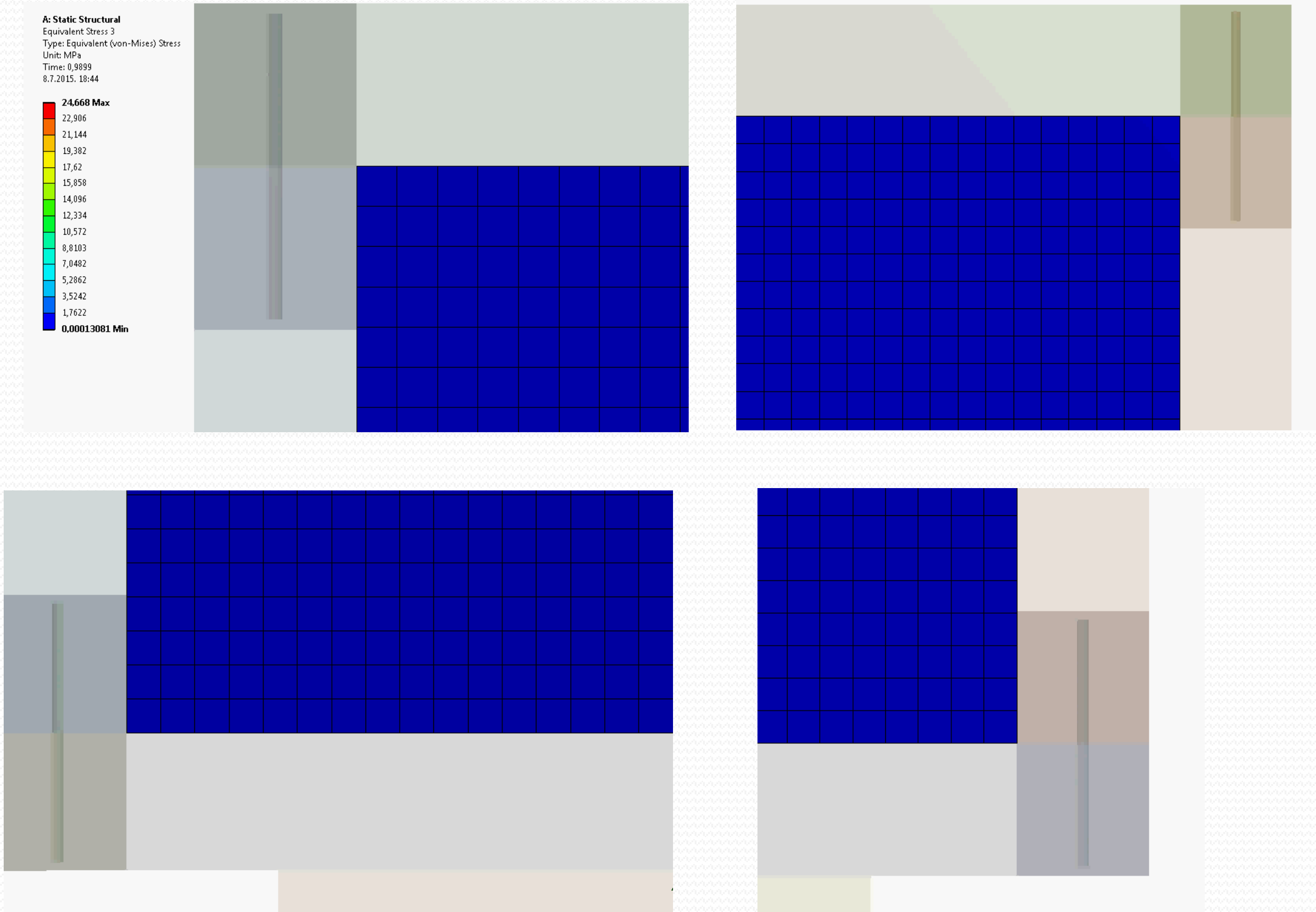




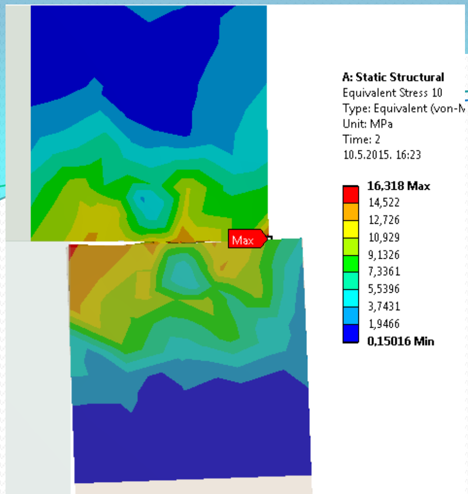


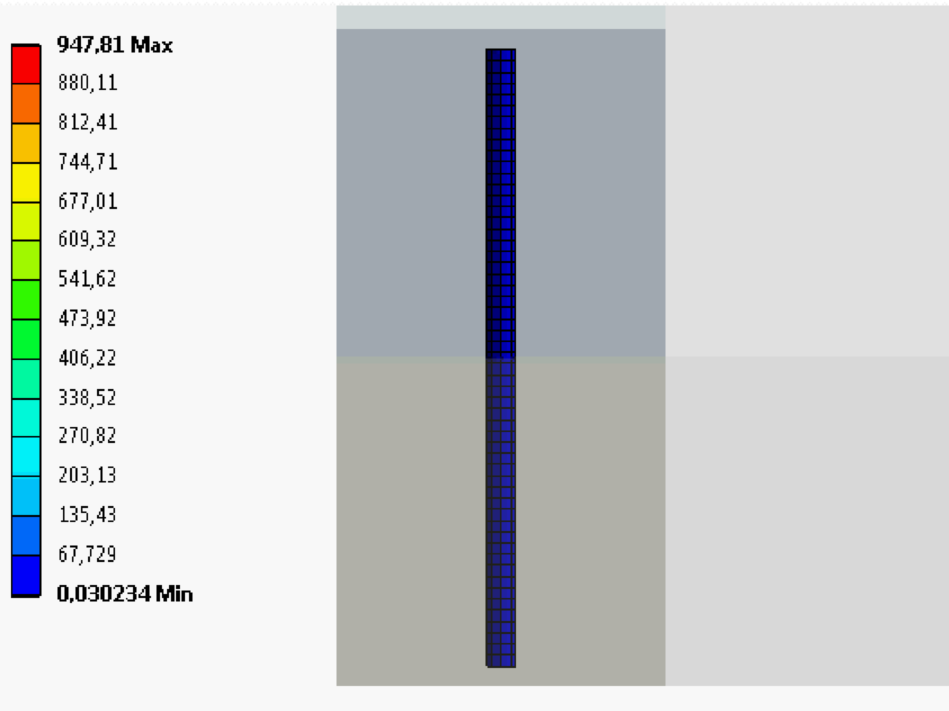


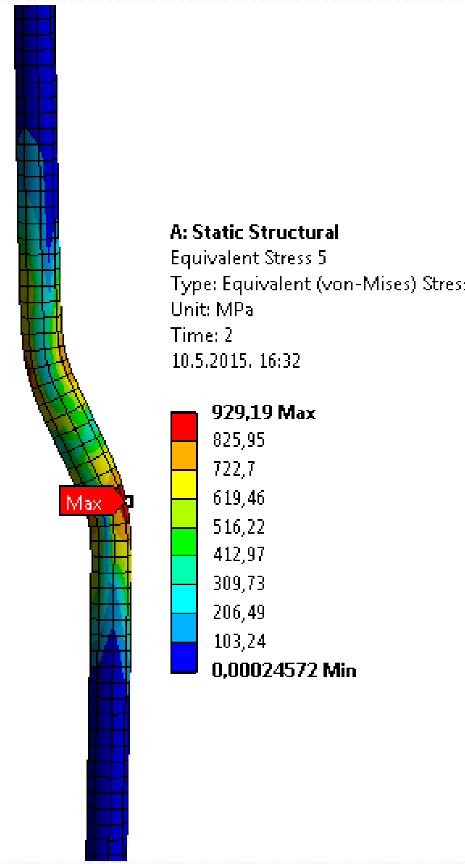
Numerical Analyses (Ansys) - Results

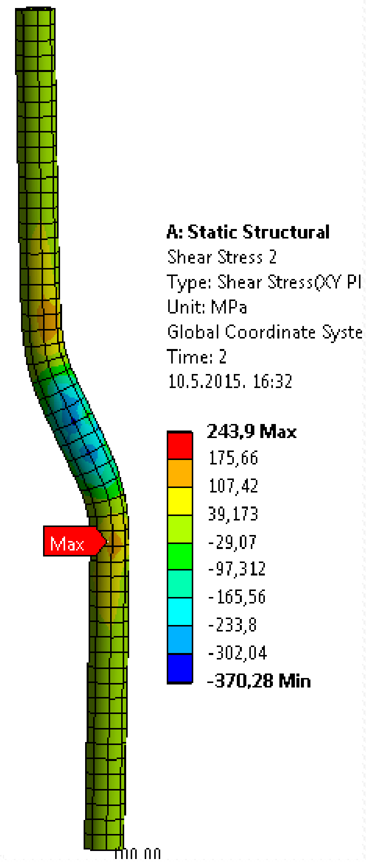


Numerical Analyses (Ansys) - Results

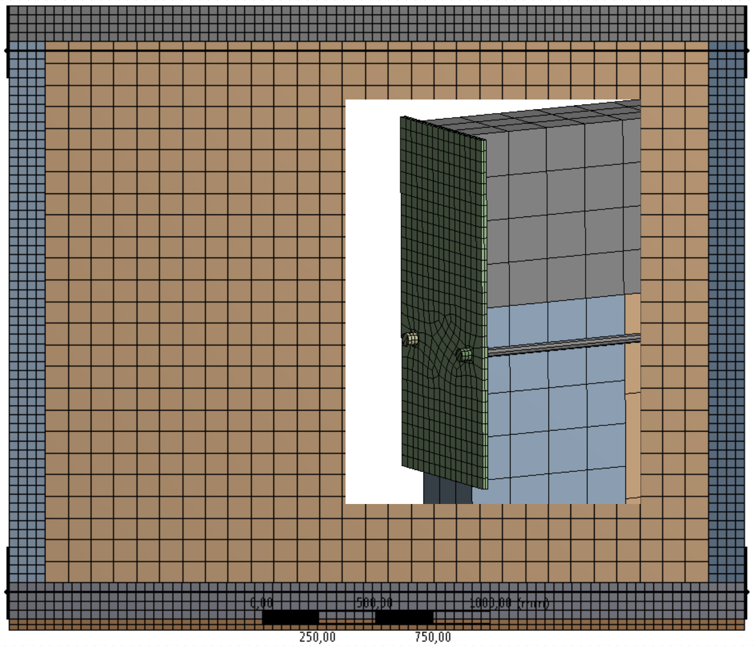


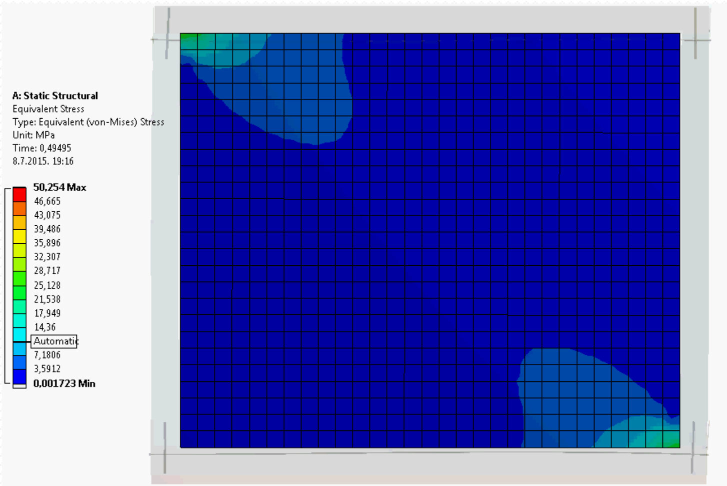


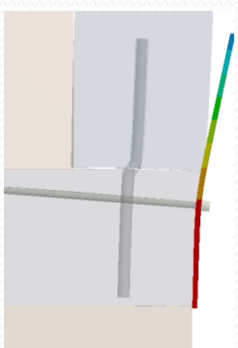


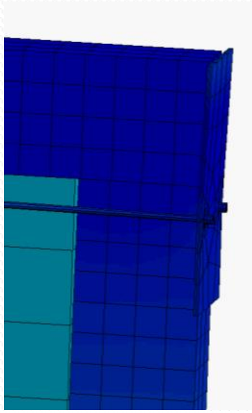


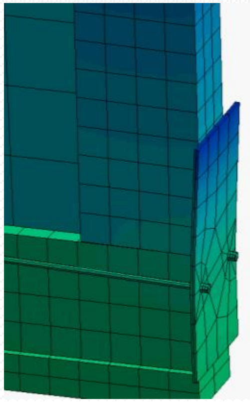
Numerical Analyses (Ansys) Results











Numerical Analyses (Ansys) - Conclusion

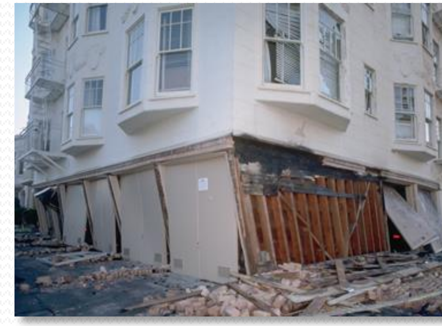
- numerical models showed good corelation with real laboratory experiments
- future work:

- parametrical numerical models (geometry, boundary conditions, types of loading)

- cyclic load and time-history analyses

Seismic Analysis of Hybrid Panel - Basic Principals

- one of the most important parameters when using the modal analysis is the horizontal stiffness of a building

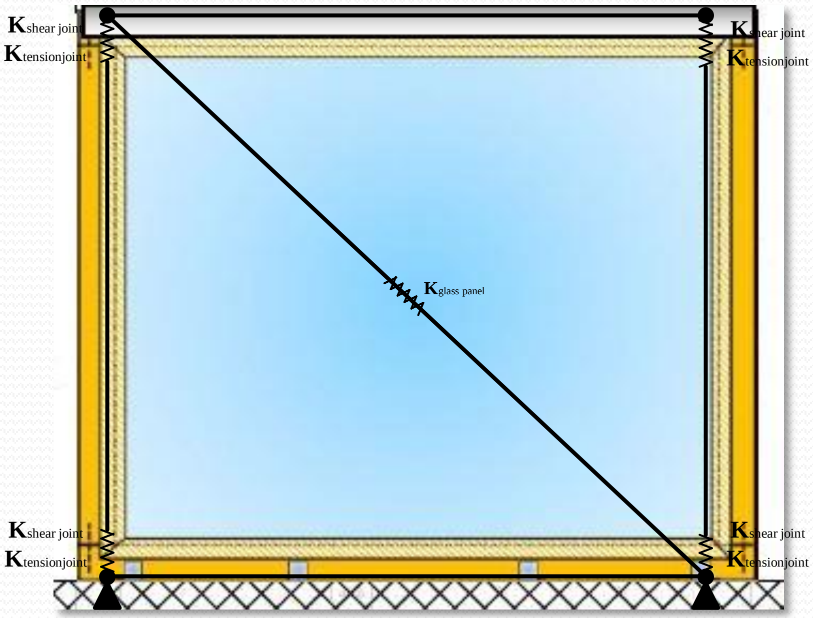


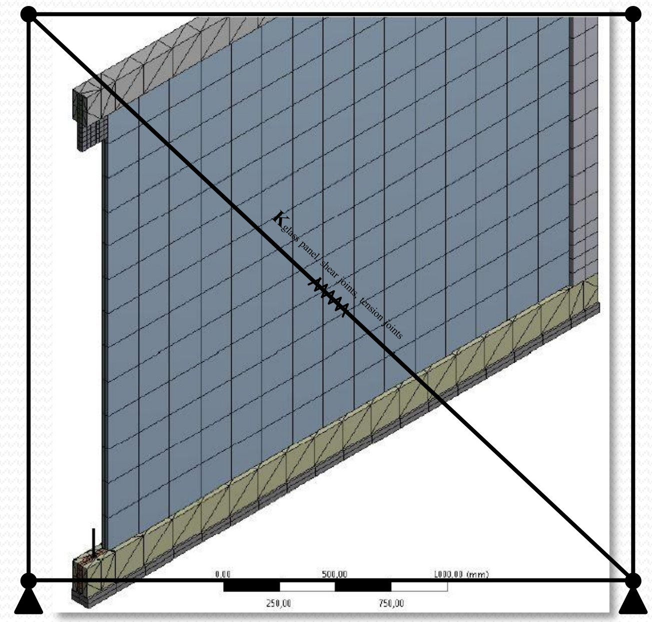
- one of the most important parameters when using the modal analysis is the horizontal stiffness of a building

- in the case of timber-glass panel, the stiffness is predominantly dependent of the shear and hold-down behaviour of joints in frame corners
- glass infill greatly increases panel stiffness, whereby the influence of friction between timber and glass also needs to be taken into account
- for the static calculation of frame building reinforced with timber glass-panel, whole system could be replaced with only one element
- such a truss simplification is mostly suitable for linear elastic design which demands the correct stiffness of system

Seismic Analysis of Hybrid Panel
- Proposal for Calculation of Panell Stifness

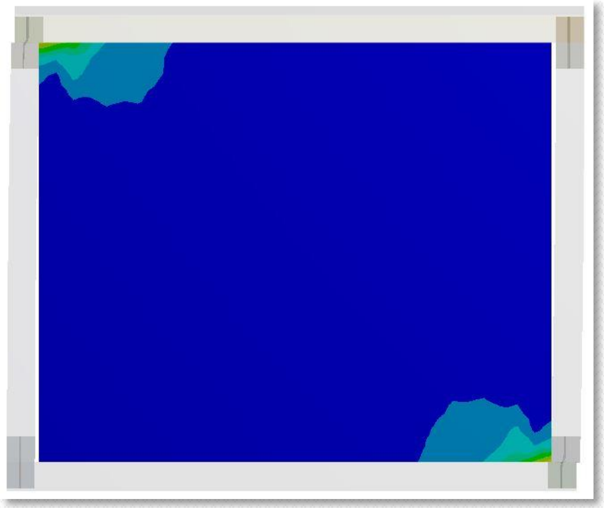
- according to analysis of the different types of frames with infill there isn’t many similarities to describe this system
- on the trail of the studies, certain similarities between the behaviour of CLT panels and timber-frame composite systems were found
- the evolution of the finite element model (if using a substitute diagonal) is proposed

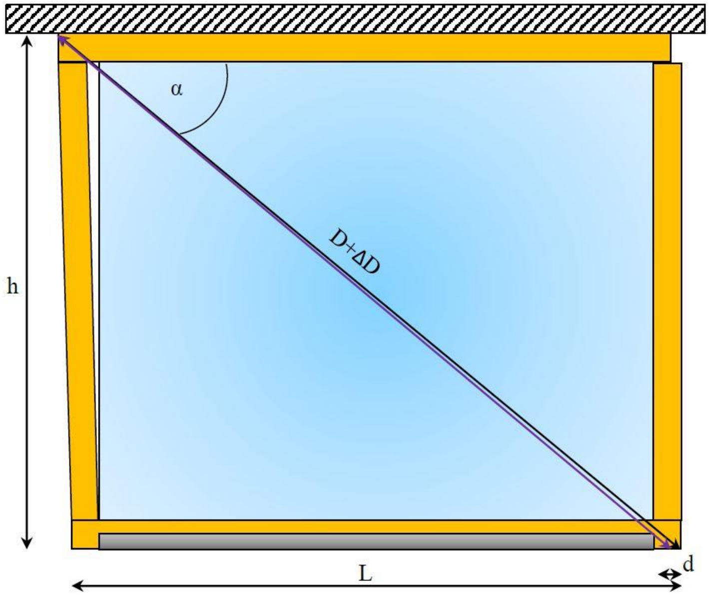




Seismic Analysis of Hybrid Panel
- Proposal for Calculation of Panell Stifness

- fully simplified FE model provides an accurate calculation of the overall panel stiffness, but, it doesn't provide all information necessary for design analysis





- considering the previous research, it was observed that during the horizontal force action, at the time when bearing capacity was reached, a glass infill is activated in form of pressure strut
- regardless to the boundary conditions, width of such stud is equal to 1/12 of the total length of the glass panel diagonal

Seismic Analysis of Hybrid Panel
- Proposal for Calculation of Panell Stifness

- with known element cross-section (mentioned with × total thickness of glass panels) and calculated panel stiffness, it is easy to define an appropriate MOE of panel element

$$E_{eff} = \frac{D \cdot k_{panel}}{A_D} \qquad k_{panel} = \left(\frac{1}{k_{glass}} + \frac{1}{k_{c,bending}} + \frac{1}{k_{c,shear}} \right)^{-1}$$

- where horizontal stiffness of composite panel

is given in equation

- the stiffness of

the glass panel (k_{glass})

$$k_{glass} = \frac{1}{\dfrac{4 \cdot H_{glass}^3}{E_{glass} \cdot L_{glass}^3 \cdot d_{glass}} + \dfrac{H_{glass}}{G_{glass} \cdot L_{glass} \cdot d_{glass}}}$$

- the bending stiffness of

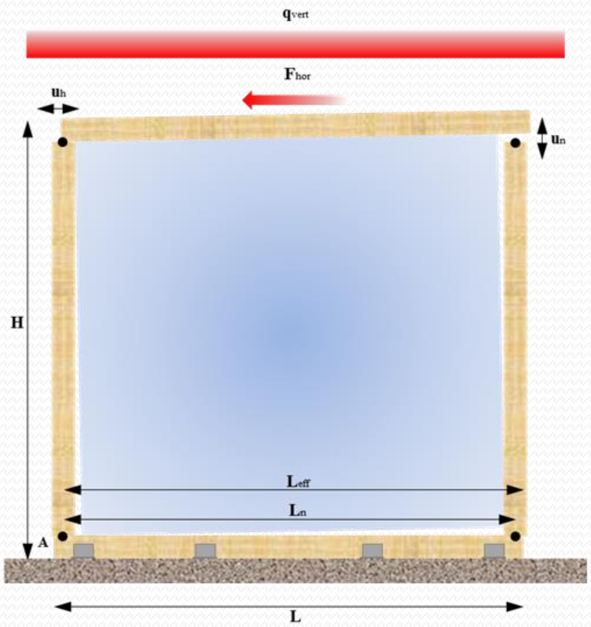
a timber frame connectionsthe ($k_{c,bending}$)

$$k_{c,bending} = \frac{K_n \cdot L_n^2}{H^2} + \frac{q_{vert} \cdot L_{eff}^2 \cdot K_n \cdot L_n}{H^2 \cdot R_{c,n,Rd}}$$

- shear stiffness of

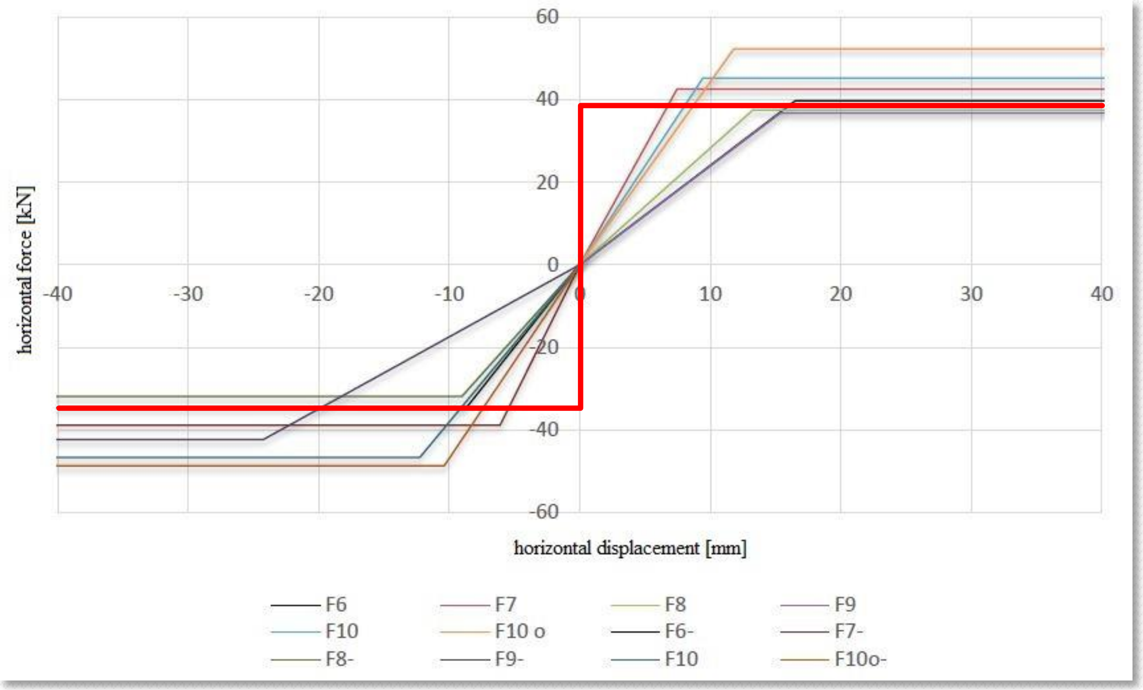
a timber frame connections ($k_{c,shear}$)

$$k_{c,shear} = 4 \cdot K_{c,shear} + \frac{0.6 \cdot q_{vert} \cdot L_{glass}^2 \cdot d_{glass} \cdot c}{u_{slip,Rd}}$$



Seismic Analysis of Hybrid Panel - Proposal for Calculation of Panell Stifness

- because of insufficient data needed to verify this hypothesis, the main objective of further studies is to give parametric analysis of composite panel
- in purpose of this paper, there would be only consider the idealized bilinear behaviour of tested panels with known dimensions and stiffness



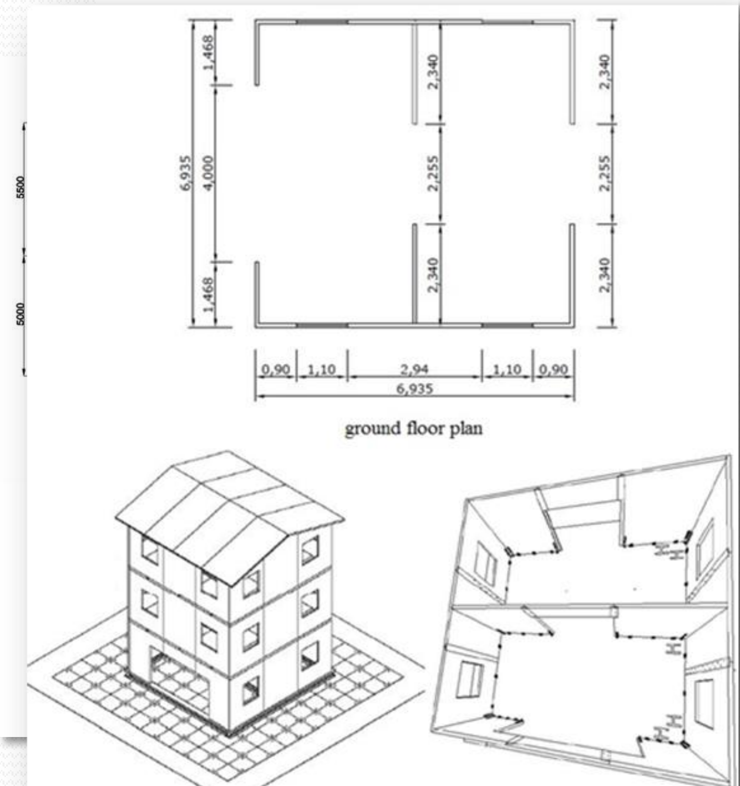
Numerical Evaluation of Hybrid Panel - Case Studies

- purpose of such numerical modelling is to compare storey drift displacements as well as maximum allowable ground acceleration for structures with and without composite panels
- to estimate increase of seismic capacity of frame structures reinforced with panels, three different numerical models are done:

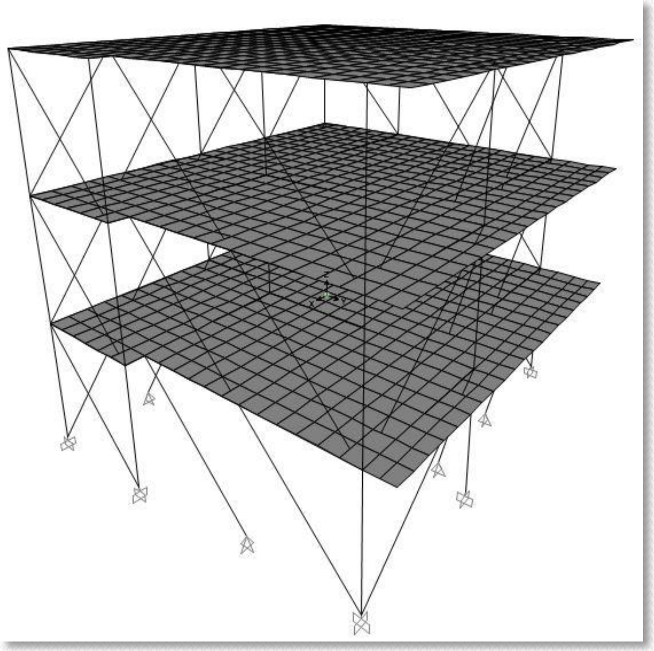
- the first case study - a three-storey plan-asymetric concrete frame structure [European project SPEAR]

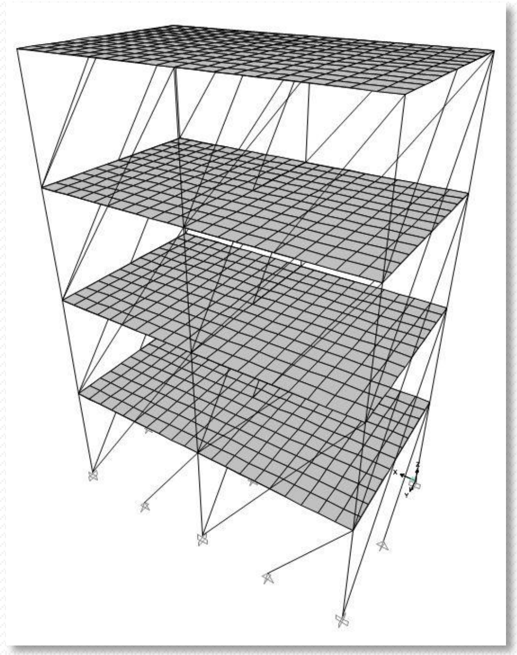
- the second case study - a four-story, two-bay by one-bay steel moment frame building [Japanese project]

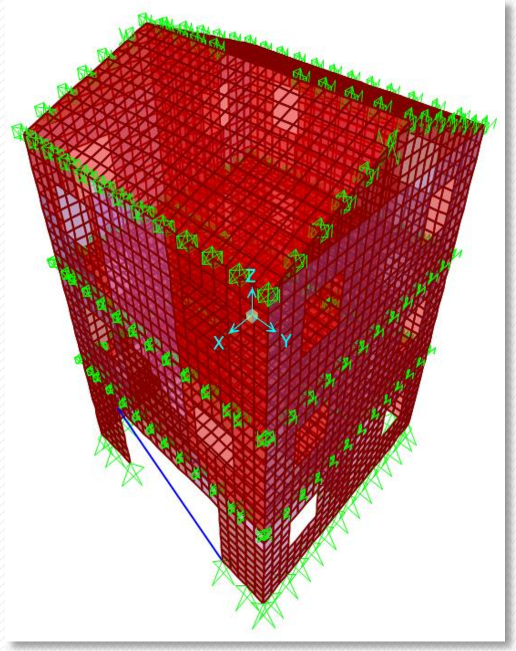
- the third case study - a three-storey CLT house of about square regular plan with a pitched roof [SOFIE Project]



Numerical Evaluation of Hybrid Panel - Numerical Models







- composite panels were fully simplified and introduced in model as substitution diagonal

Parameter	Value
Ground acceleration a_g/g	0.15-1.50
Spectrum type	1
Behaviour factor q	2,5
Correction Factor λ	1
Damping ratio	5%
Ground type	C
Soil factor	1.2
Reduction factor ν for SLS	0.5

- the seismic load was designed according to EN 1998 and two combinations were taken into account

Numerical Evaluation of Hybrid Panel - Numerical Models

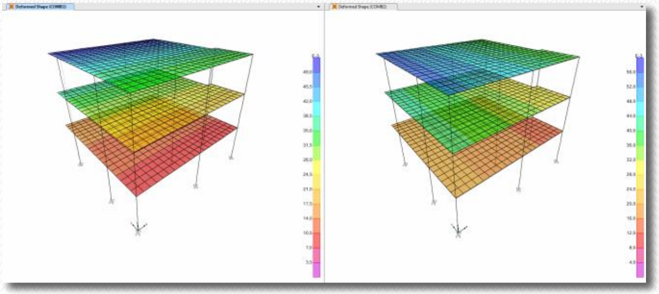
- the construction capacity verification was carried out with respect to the limit values of displacements and storey drifts which was conducted in accordance with European design codes
- the results of numerical analysis indicate the effectiveness of composite timber-glass panel:

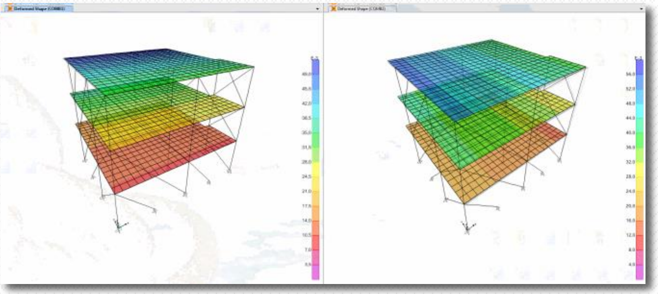
- for the first case study, by installing panels, bearing will be increased - this was expected due to poor seismic capacity of SPECTRA system

- high stiffness of second case study resulted with a negligible effect of panel

- there is a certain improvement in the third case study, but it would be more interesting to check the behaviour of a system if the base floor walls are made of composite panels

Case study structure		Maximum allowable: ground acceleration [g]	storey drift [mm]	displacement on top [mm]
1	Basic	0.27	18	54
	Strengthened	(+69%) 0.47		
2	Basic	0.82	29	116
	Strengthened	(0%) 0.82		
3	Basic	1.4	19	57
	Strengthened	(+7%) 1.5		





Numerical Evaluation of Hybrid Panel - Conclusion

- presented reseach demonstrated the effectiveness of the panel built into the actual frame buildings – it is favorable for structures with lower initial stiffness (like timber frame structures and nonductile concrete frame structures)
- in the context of further research is necessary to:

- examine the other characteristics of the panel element (behaviour without vertical load and with out of the plane load, effect of temperature and humidity changes,…)

- carry out the parametric analysis of panel and find the equation for simplified calculation of panel bearing capacity - significant problem is the lack of research data in the field of joints with glued-in rods

THANK YOU
FOR YOUR ATTENTION!