COST E55 – Eindhoven, October 2007

Shear failure in glulam frames
An actual case

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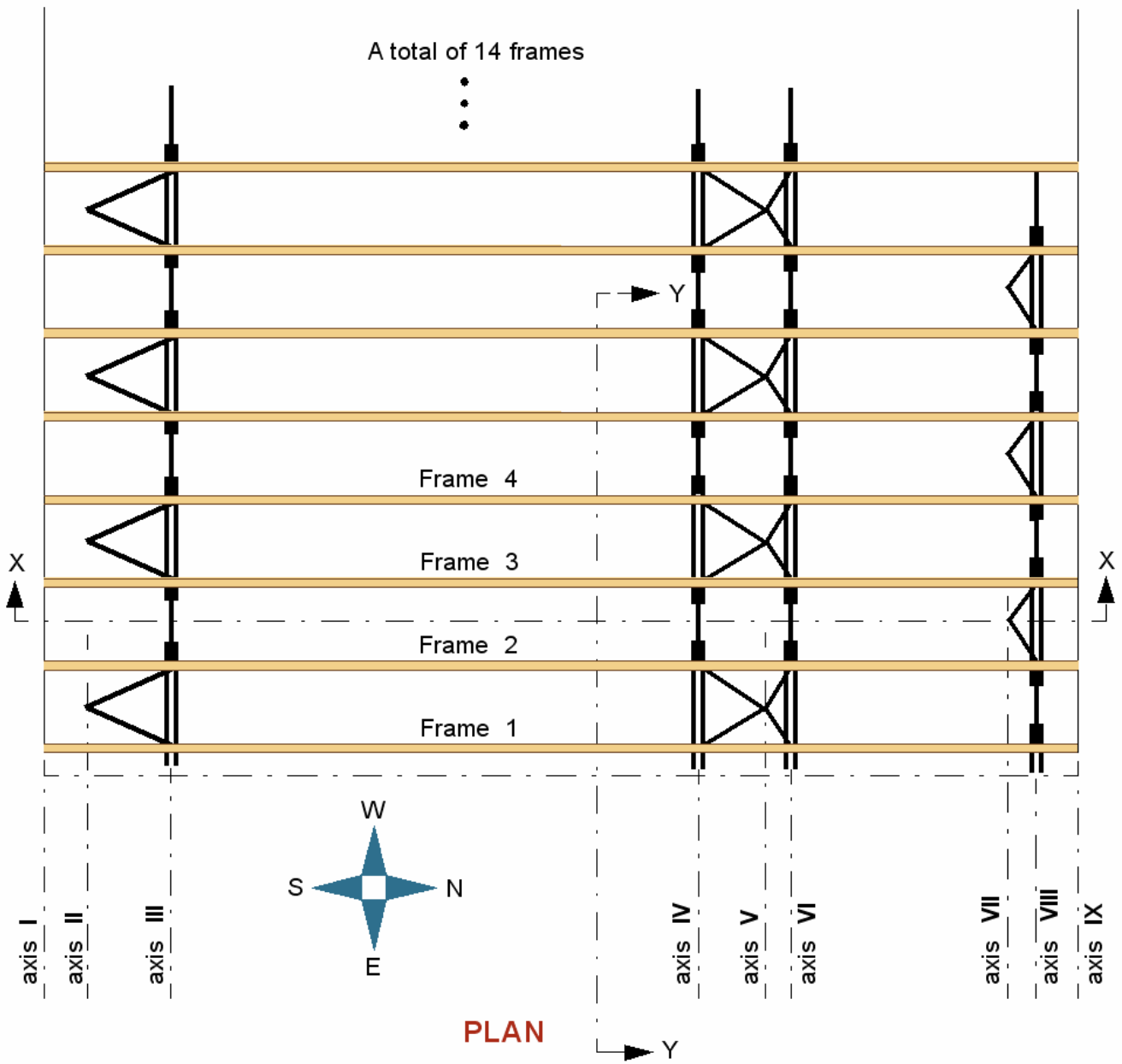
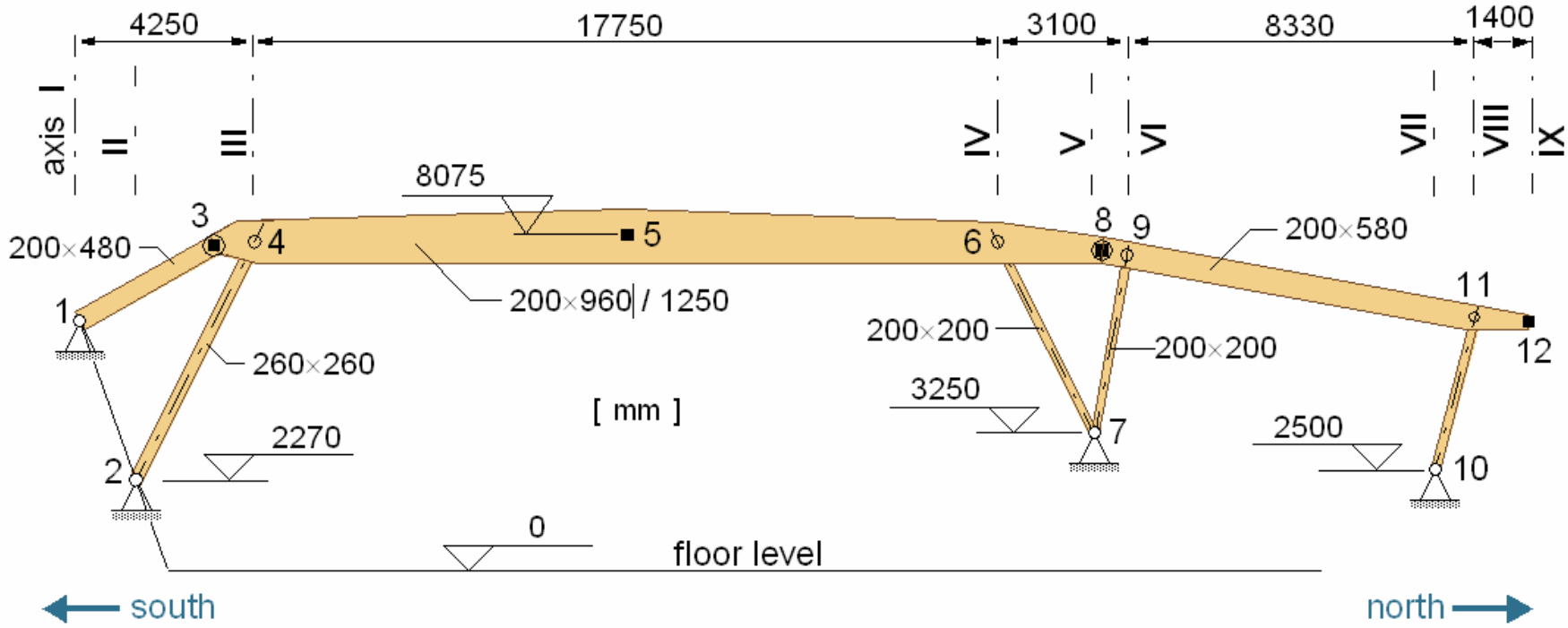
The structure

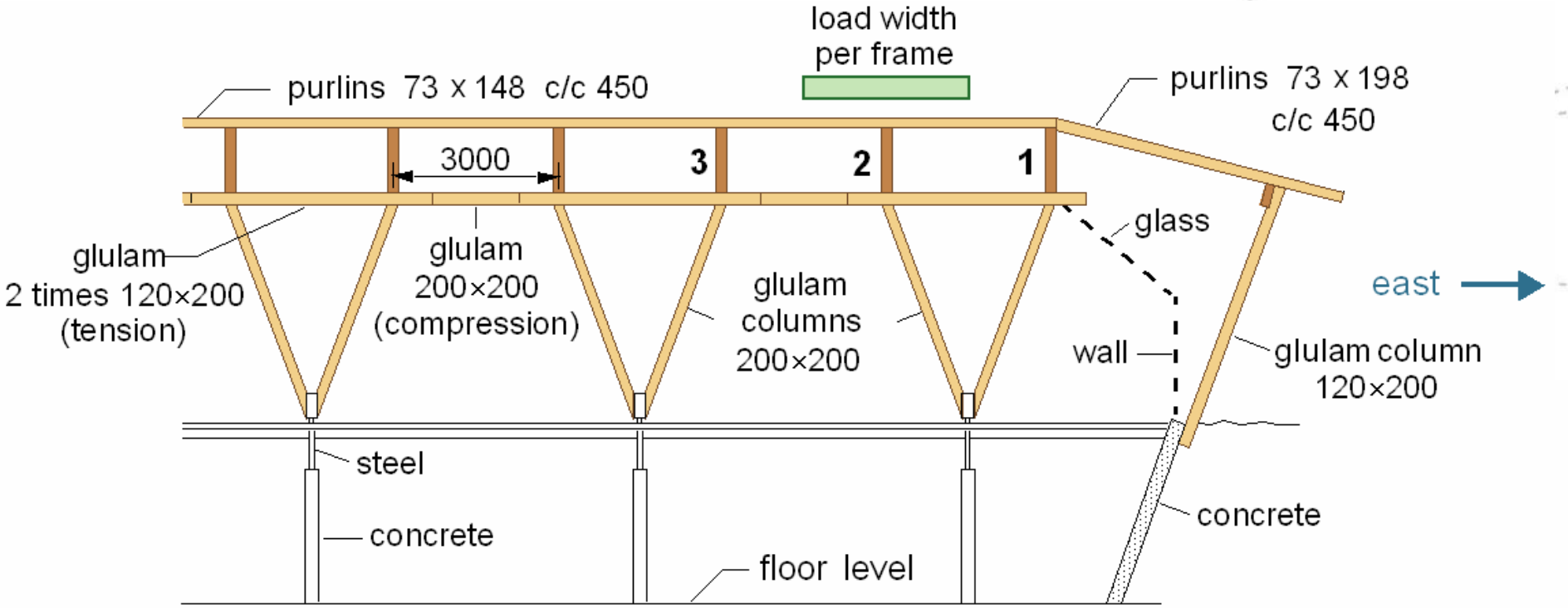
sports centre built in 2001


A total of 14 frames
Y
Frame 4
Frame 3
Frame 2
Frame 1
X
X
W
S
N
E
axis I
axis II
axis III
axis IV
axis V
axis VI
axis VII
axis VIII
axis IX
PLAN
Y

a typical frame



SECTION X - X

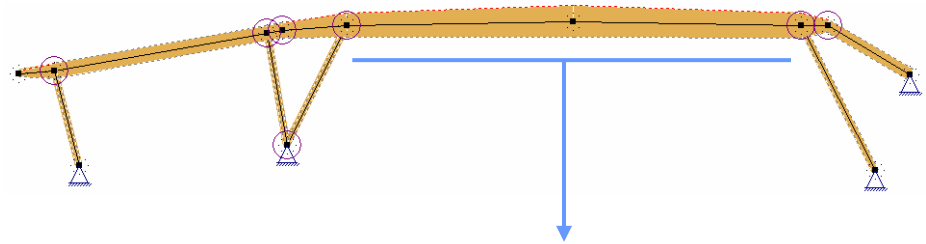

load width
per frame
purlins 73 x 148 c/c 450
purlins 73 x 198
c/c 450
3000
3
2
1
glass
glulam
2 times 120×200
(tension)
glulam
200×200
(compression)
glulam
columns
200×200
east
wall
glulam column
120×200
steel
concrete
concrete
floor level

SECTION Y - Y

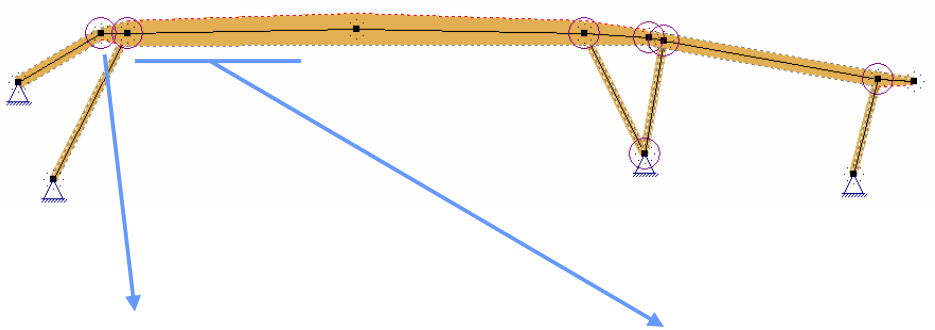
The problem

- At about 8 pm on March 20, 2005, the players of an ongoing indoor bandy training session heard high cracking noise from the ceiling.
- The caretaker was notified and the hall was evacuated.
- In one beam (frame 2) a long crack was visible from the floor.
- On closer inspection severe shear cracks were found in the main beam of 3 frames – number 1, 2 and 10.
- The snow loading was measured the following day; it was found to be from 2,3 to 3,5 kN/m^2, well below the design load of 5,5 kN/m^2

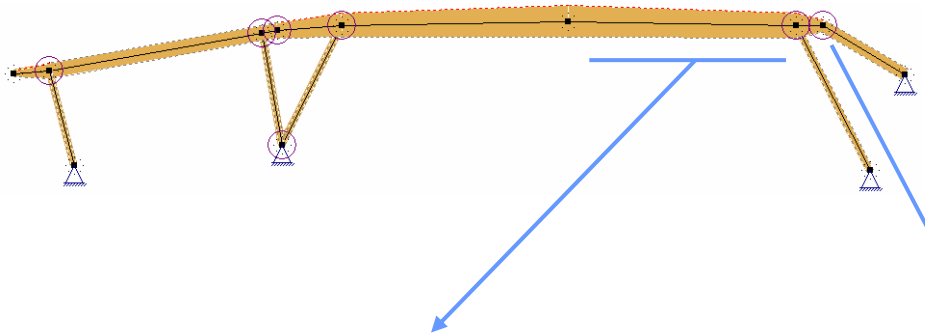
Frame 2

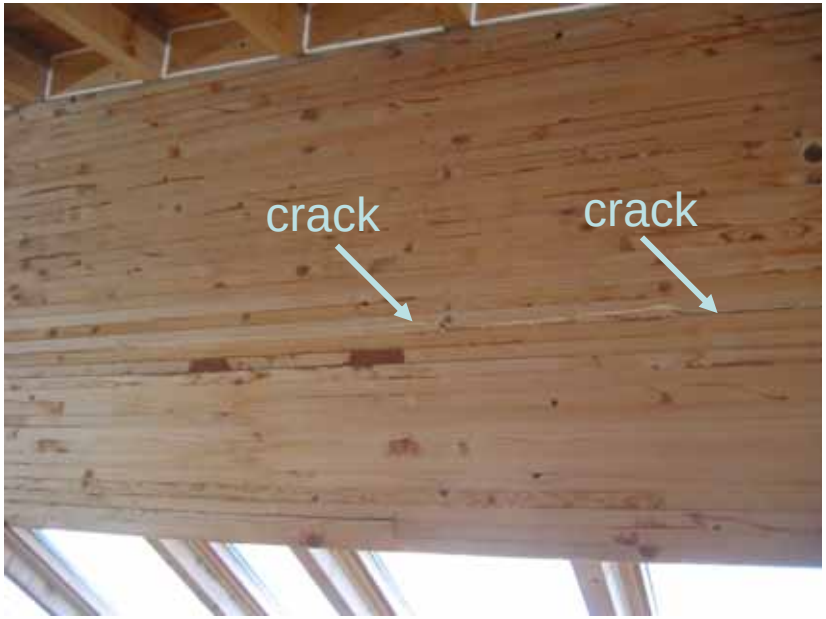


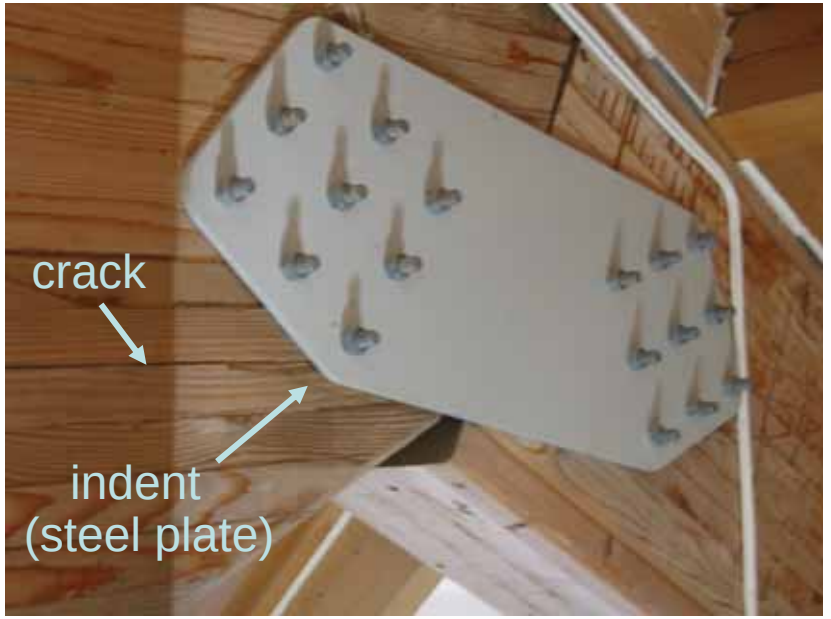
Frame 2



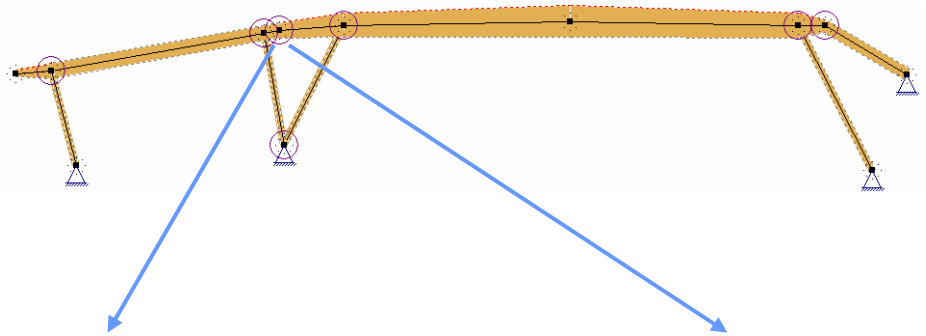
Frame 1



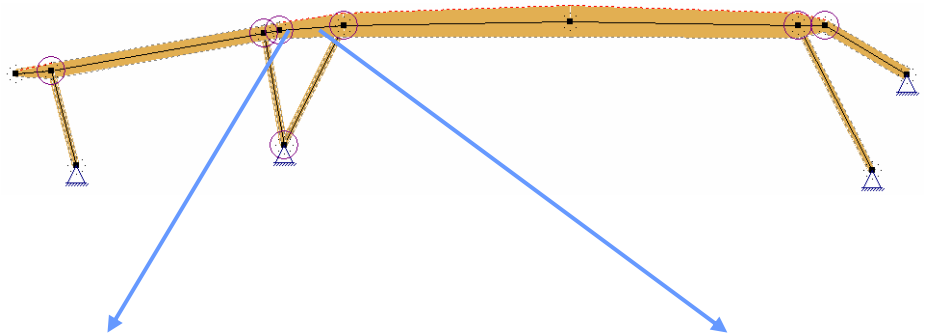




Frame 1



Frame 1



Maximum (measured) vertical displacements [mm]

Frame	03.03.05	16.03.05	08.04.05
1	195	199	190
2	190	188	168
3	106	88	76
10		103	

no snow

The cause ?

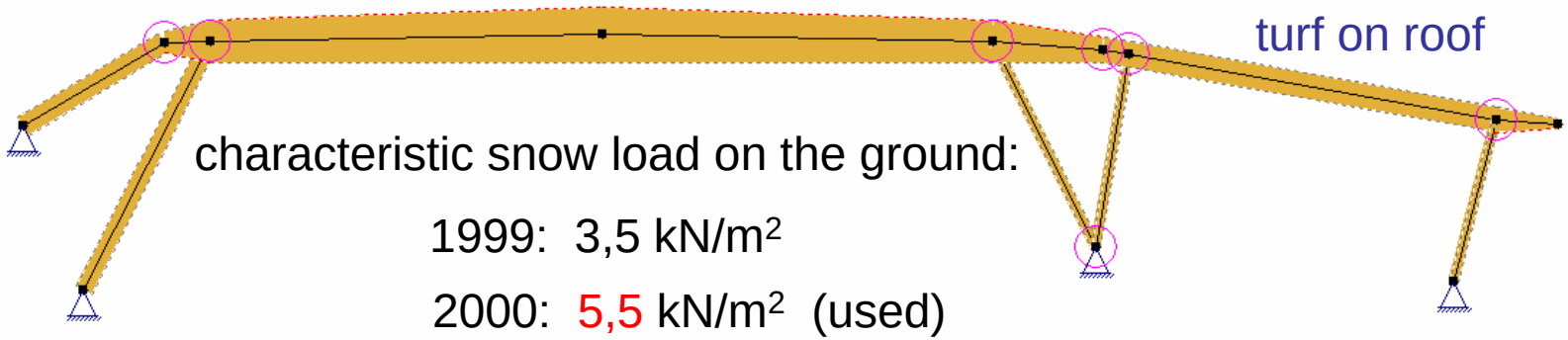
- Possible candidates:
  - excessive loading ? - hardly, but loading uncertain
  - incorrect design ? - not likely, but cannot be ruled out
  - poor detailing ? - ? (joint rotation)
  - moisture (shrinking/swelling) ? - not likely
  - glulam quality ? - variable, so yes, a possible culprit

Loading

Design load, including form and load factors

Actual (measured) load at time of failure

snow s [kN/m]	s_1 = 23,1	s_3 = 19,8	s_1 = 9,15	s_3 = 6,9
	index 1 → frame 1		index 3 → frame 3	
dead load g [kN/m]	g_1 = 10,5	g_3 = 9,0	g_1 = 8,75	g_3 = 7,5



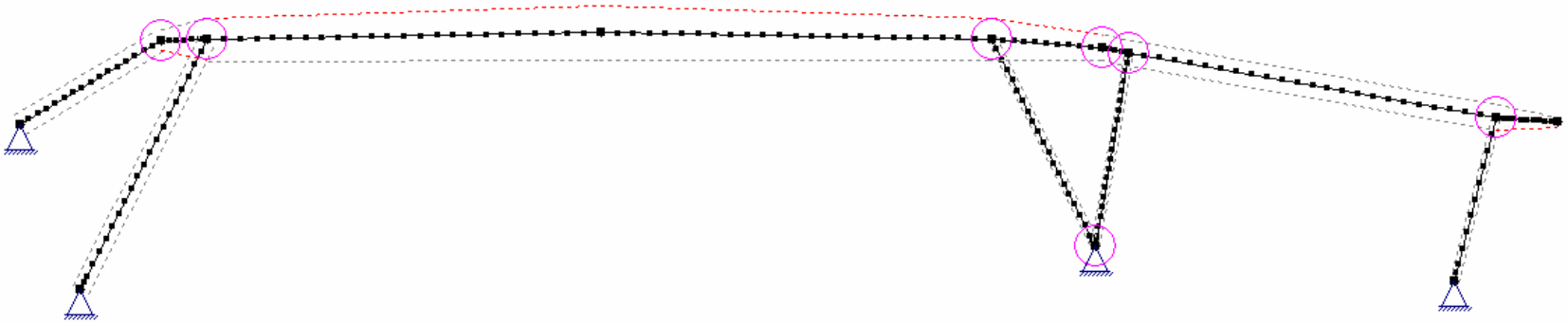
characteristic snow load on the ground:

1999: 3,5 kN/m^2

2000: 5,5 kN/m^2 (used)

2001: 6,5 kN/m^2 (50 years return period)

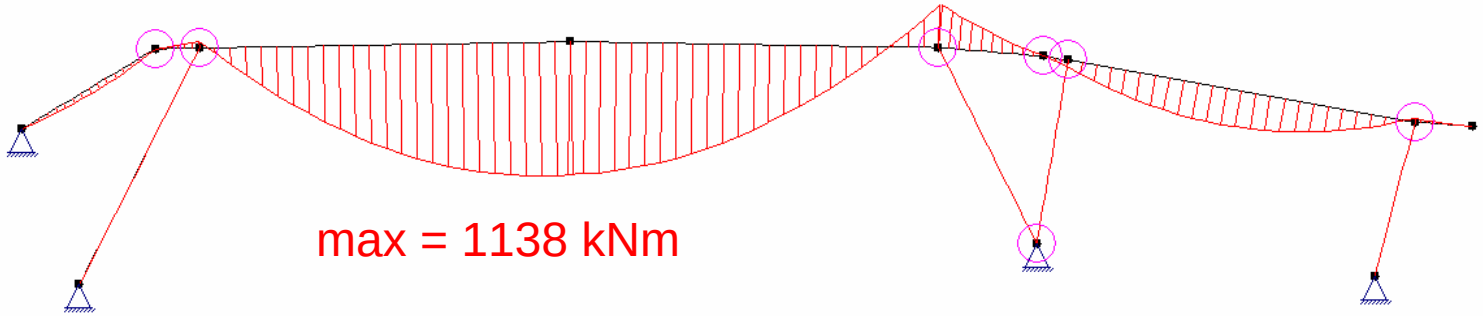
Some calculations



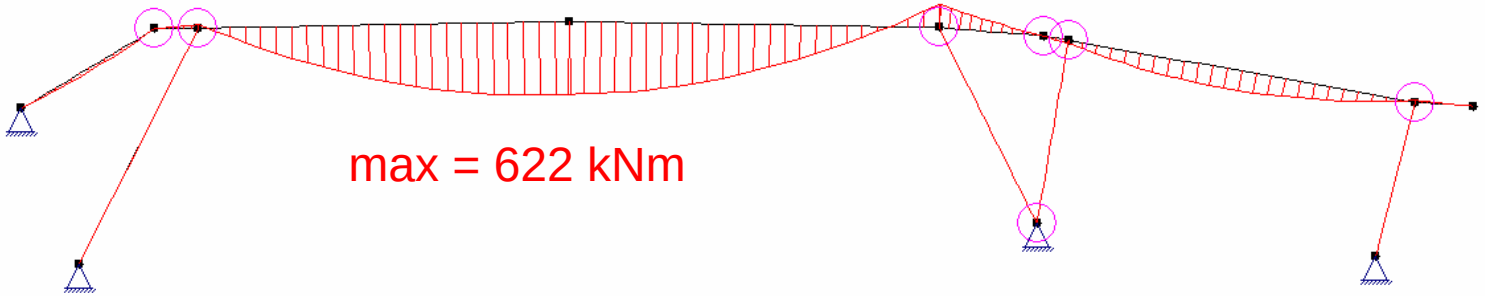
computational model – 2D frame analysis

Bending moment – Frame 1

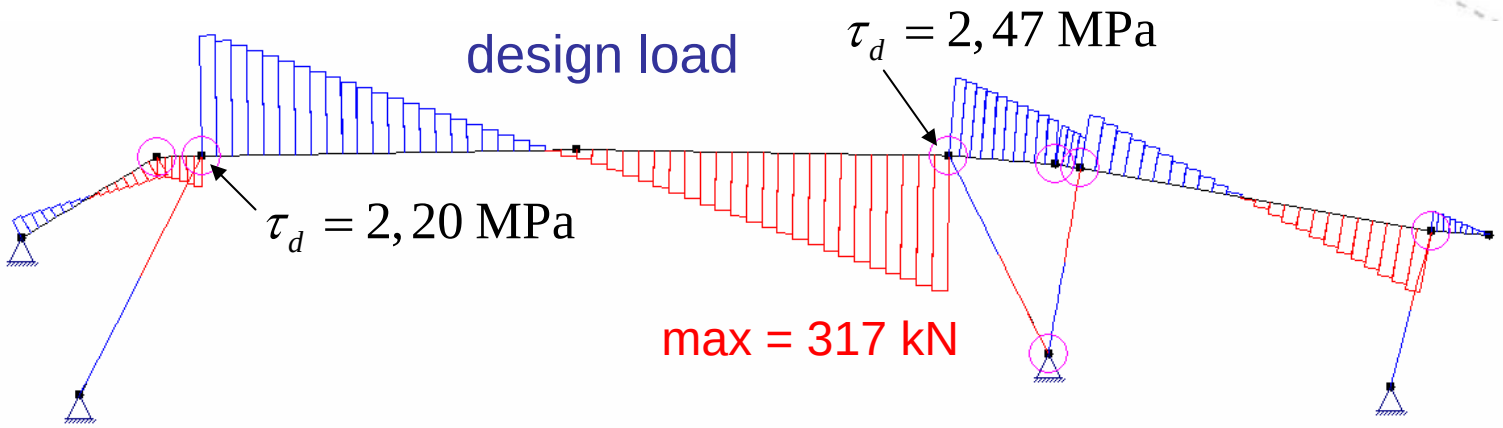
design load

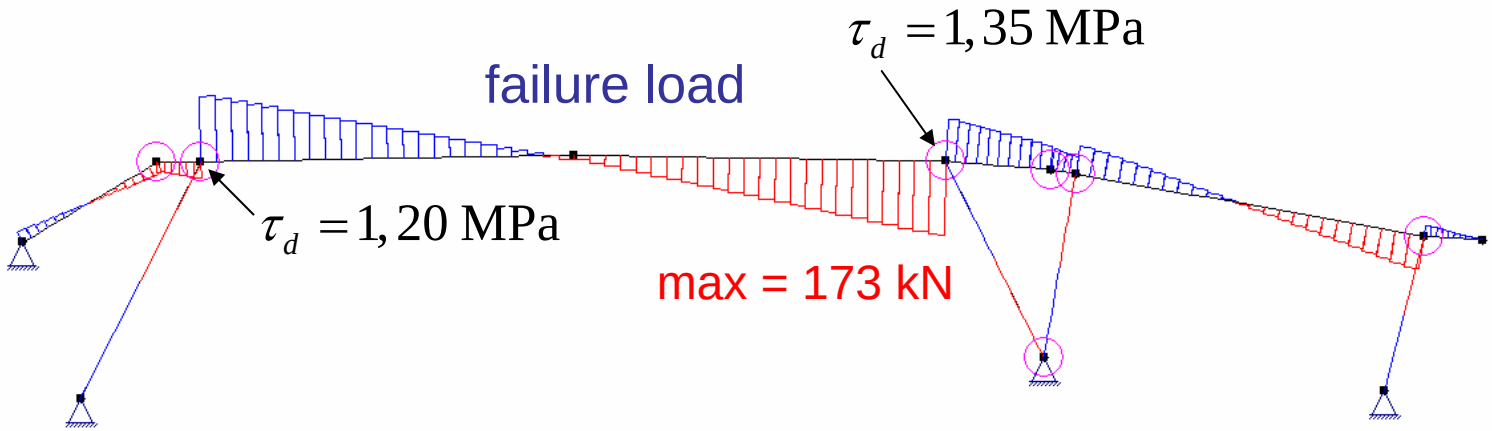


failure load



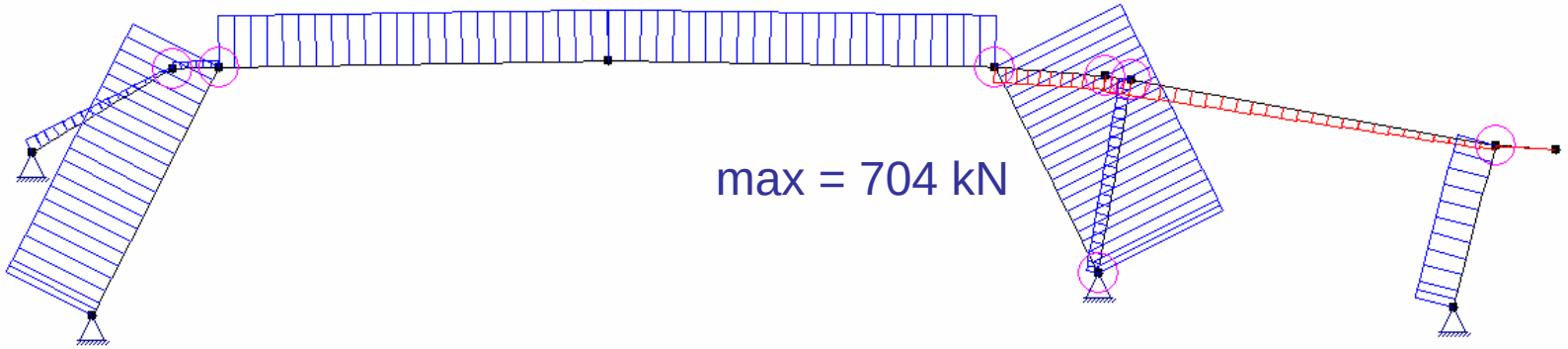
Shear force – Frame 1



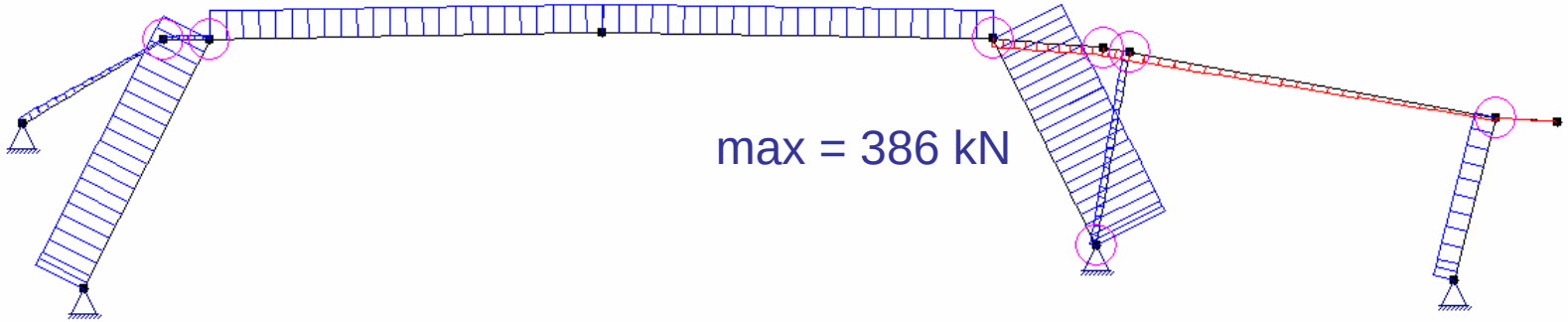


Axial force – Frame 1

design load



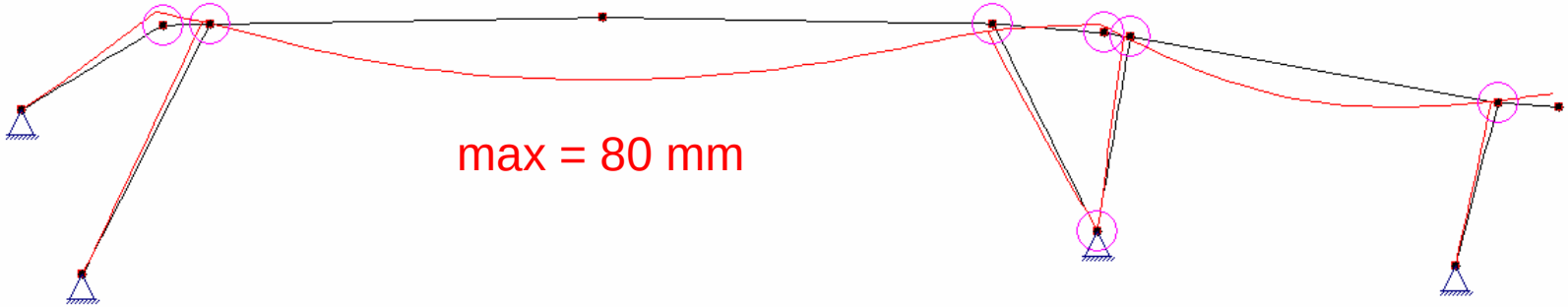
failure load



Displacements – Frame 1

design load

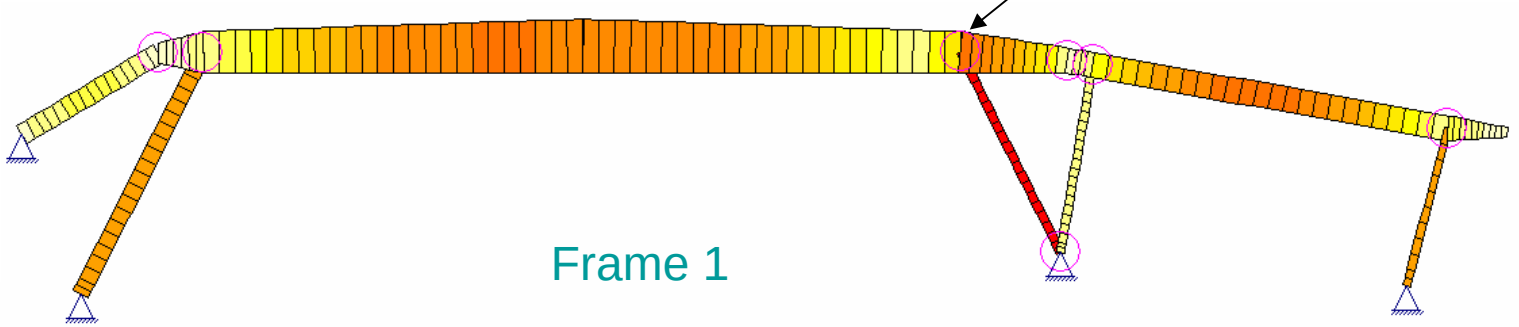
failure load



Capacity – NS 3470
combined bending and axial force

design load

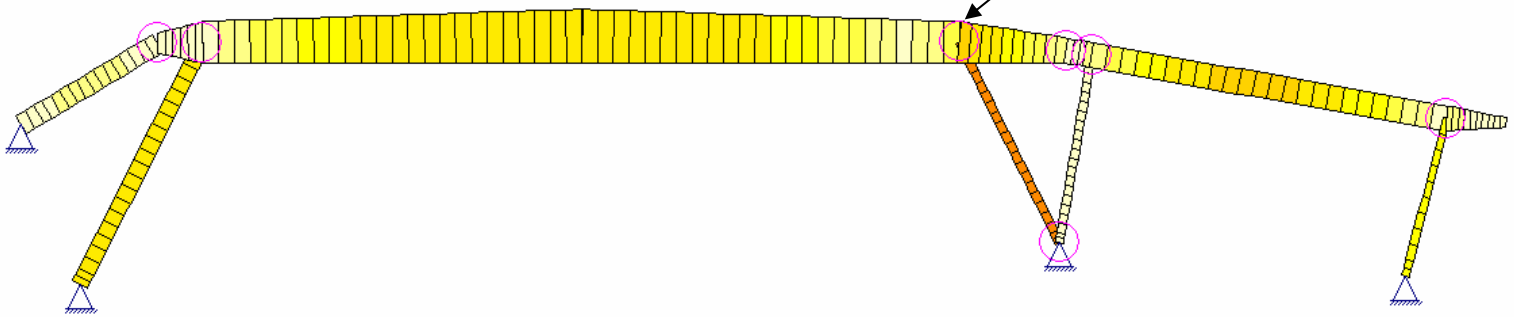
94%

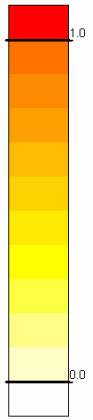


Frame 1

failure load

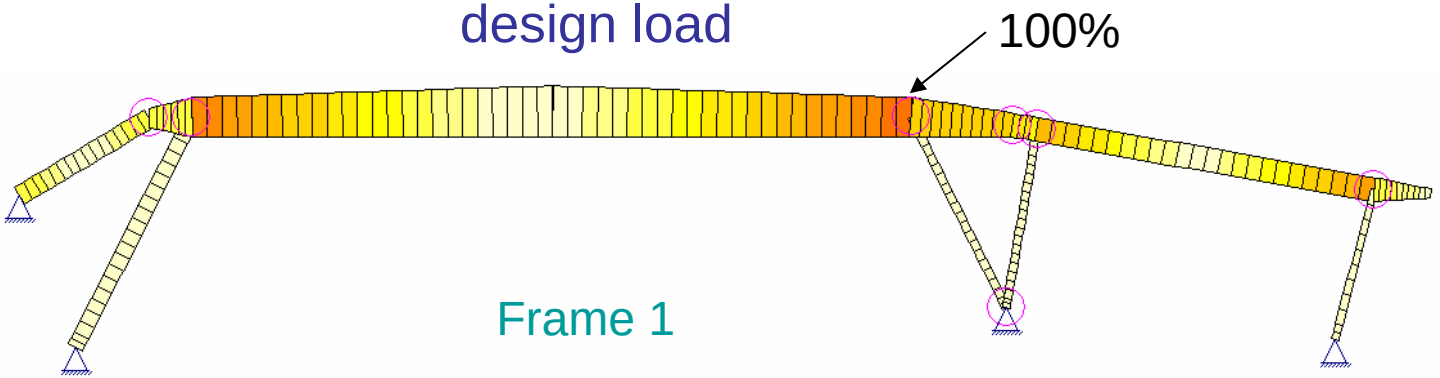
51%





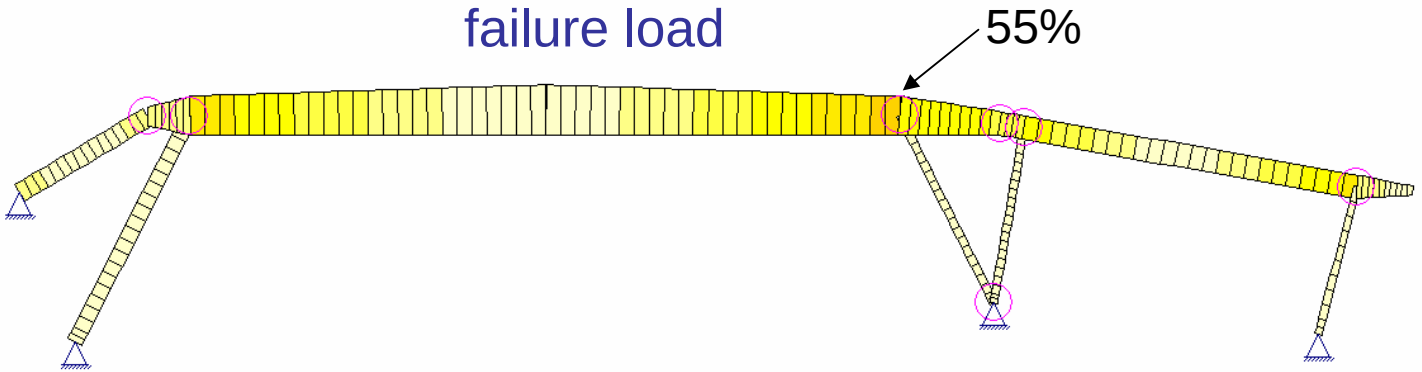
Capacity – NS 3470
shear

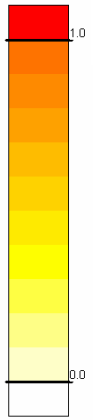
design load



Frame 1

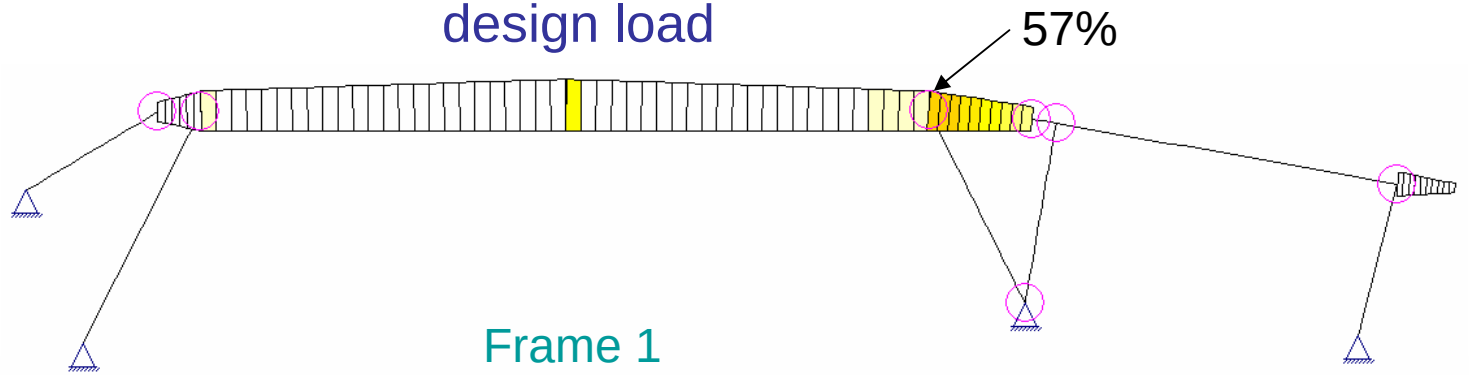
failure load





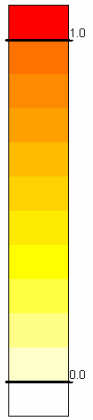
Capacity – NS 3470
tension perpendicular to grain

design load

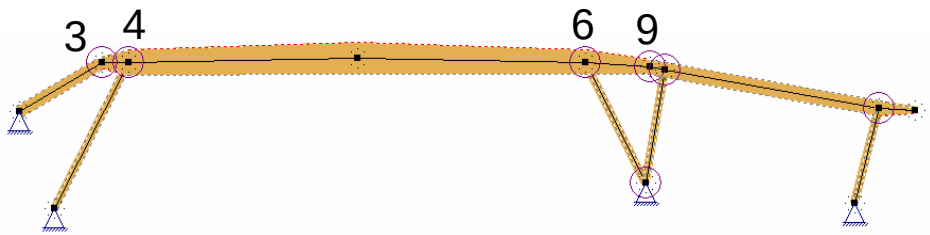


Frame 1

failure load

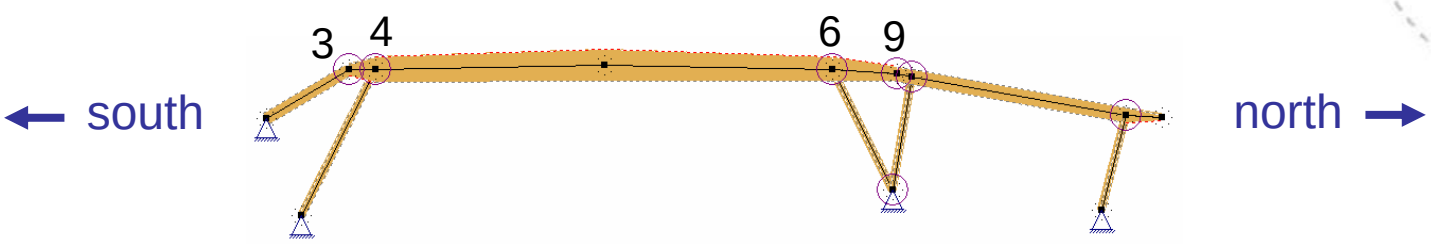


Most likely failure scenario



1. Failure starts in a defect glue line (21) at point 4 of frame 2 and the crack propagates towards the middle of the beam.
2. The shear stresses at the faulty (3rd) glue line of frame 2 increases and causes a complete collapse of this glue line (from 4 to 6).
3. The resulting sagging of frame 2 increases slightly the loading on frame 1 and this causes a shear failure to start in a defect glue line at node 4 – the shear crack propagates towards the middle of the beam.
4. The additional sagging of frame 1 causes a large rotation at joint 9 which in turn causes a crack due to tension perpendicular to grain – this crack propagates towards, but not beyond point 6.

Additional comments

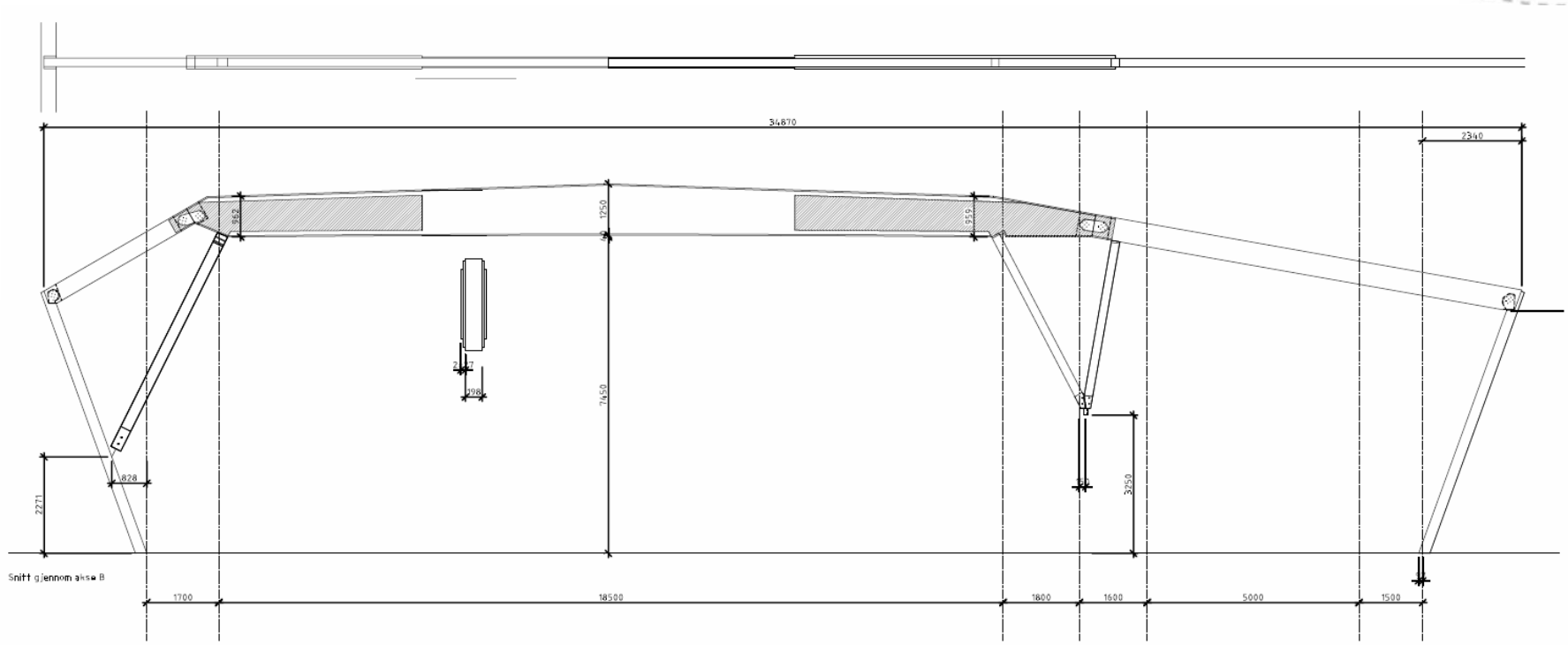


1. The sequence of events can be argued, but we are fairly confident that the failure started in the south end of the main beam.
2. The very noticeable cracking in frame 1, at and near the connection in 9, is a secondary failure (caused by a large rotation of the joint). There is only a minor crack in this region of frame 2 and none at all in frame 10.
3. The (computationally) highest shear stresses are just to the left of point 6, but there are no visible cracks in this part, in any frame .
4. Initially we suspected the connection at point 3 to be part of the problem, but the crack in this area is *below* the connection in frame 1, *above* the connection in frame 2 and in the *middle* of the connection in frame 10.
5. Weight of gravel and turf probably somewhat higher than stipulated.

The repair

- All open cracks filled with glue and closed in correct position (beams jacked up to “normal” displacement)
- Three extra column supports for frame 1
- The three damaged frames reinforced by 27 mm Kerto Q plates glued to both sides of the entire face of the main beam + an additional layer of 45 mm Kerto Q in the most (shear) stressed areas at the ends.
  A two-component epoxy adhesive with long curing time was used.
- All (11) remaining (and not visibly damaged) beams reinforced by one layer of 45 mm Kerto Q glued to each side of the beams in the most (shear) stressed areas at the ends.

Reinforcement by Kerto



Thank you