

# Ductility of wooden connections with slotted steel gusset plates and 12 mm steel dowels

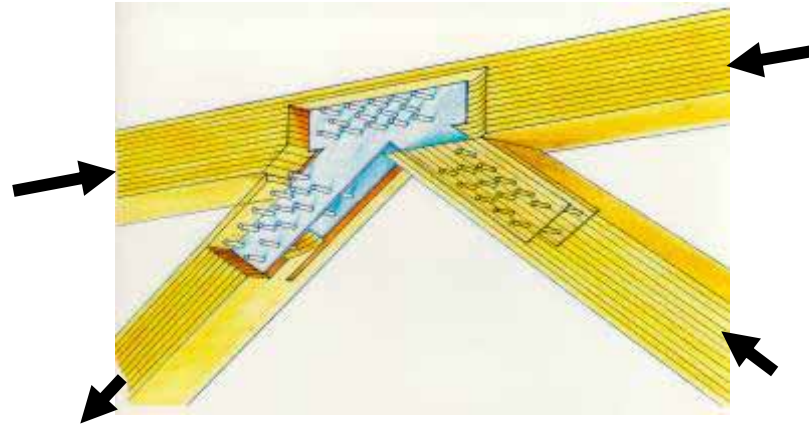
Jan Siem, NTNU

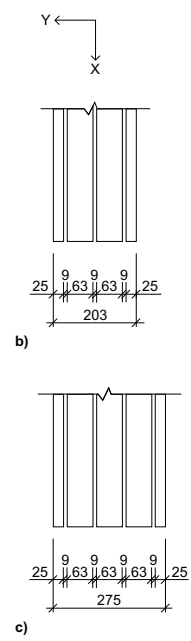
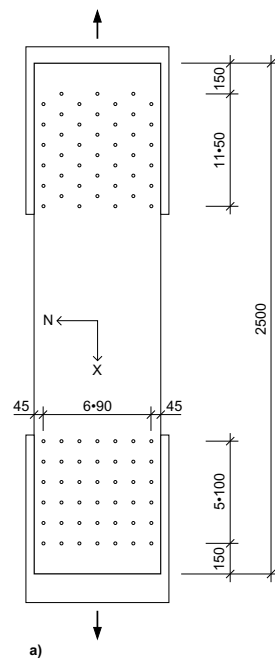
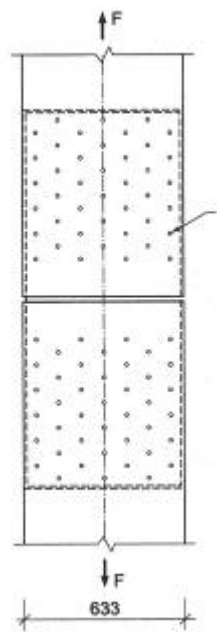
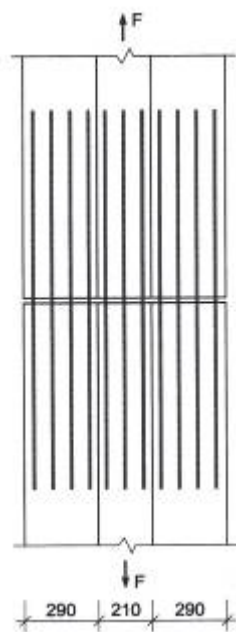
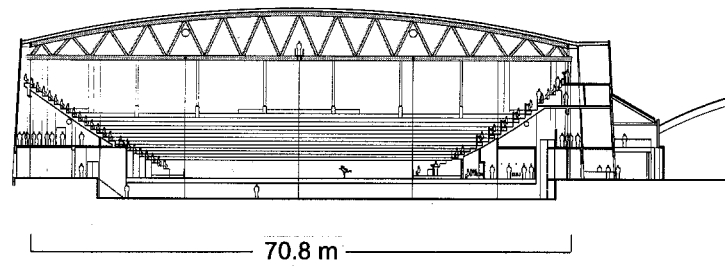




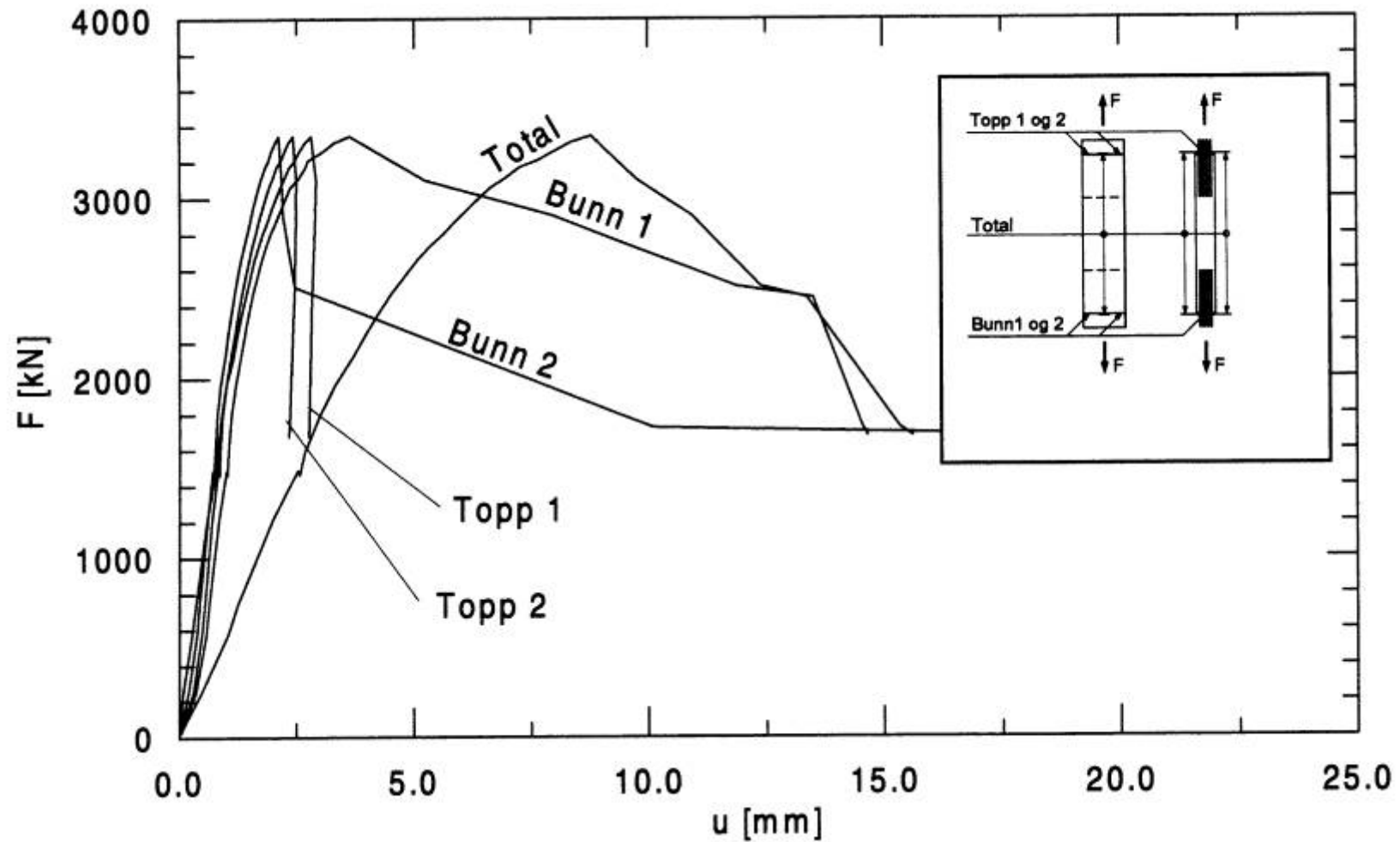




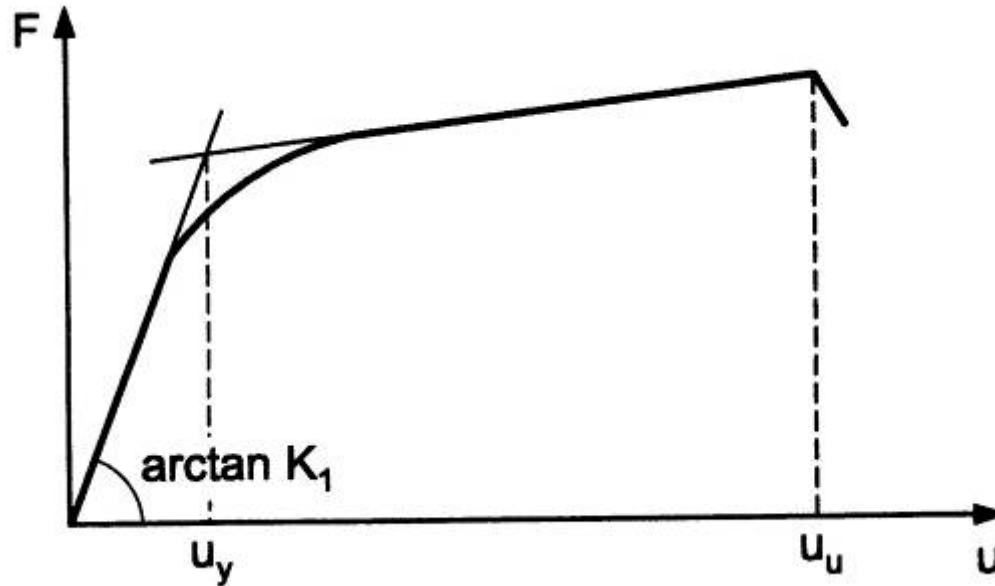




# Full scale test



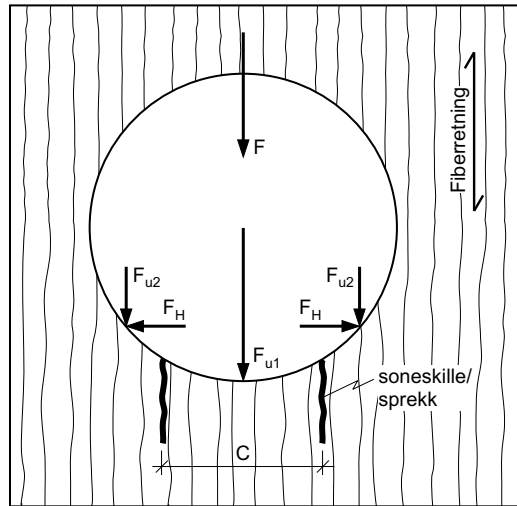
# Racher



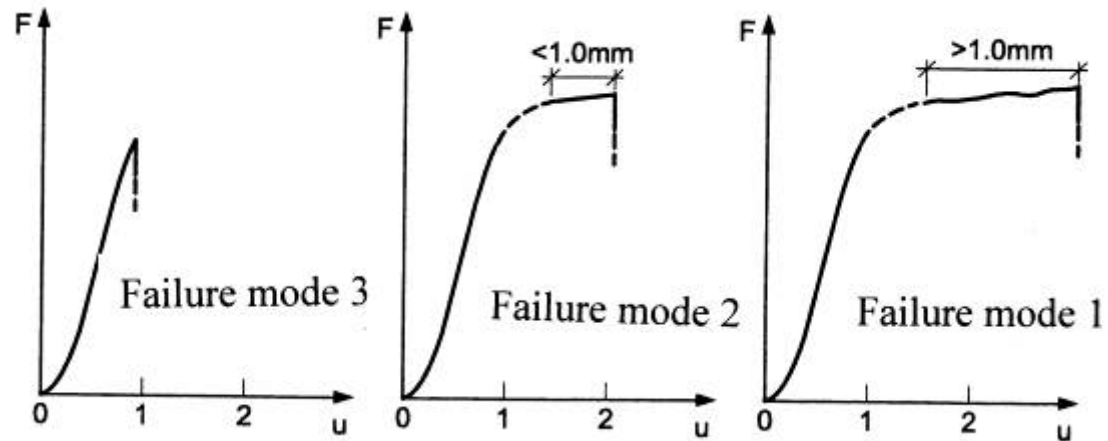
$$D_s = \frac{u_u}{u_y}$$

| Failure mode | Ductility class | Ductility           | $\gamma_m$ |
|--------------|-----------------|---------------------|------------|
| 1            | 1               | $1 \leq D_s \leq 3$ | 1,3        |
| 2            | 2               | $3 < D_s \leq 6$    | 1,2        |
| 3            | 3               | $D_s > 6$           | 1,1        |

# Rodd

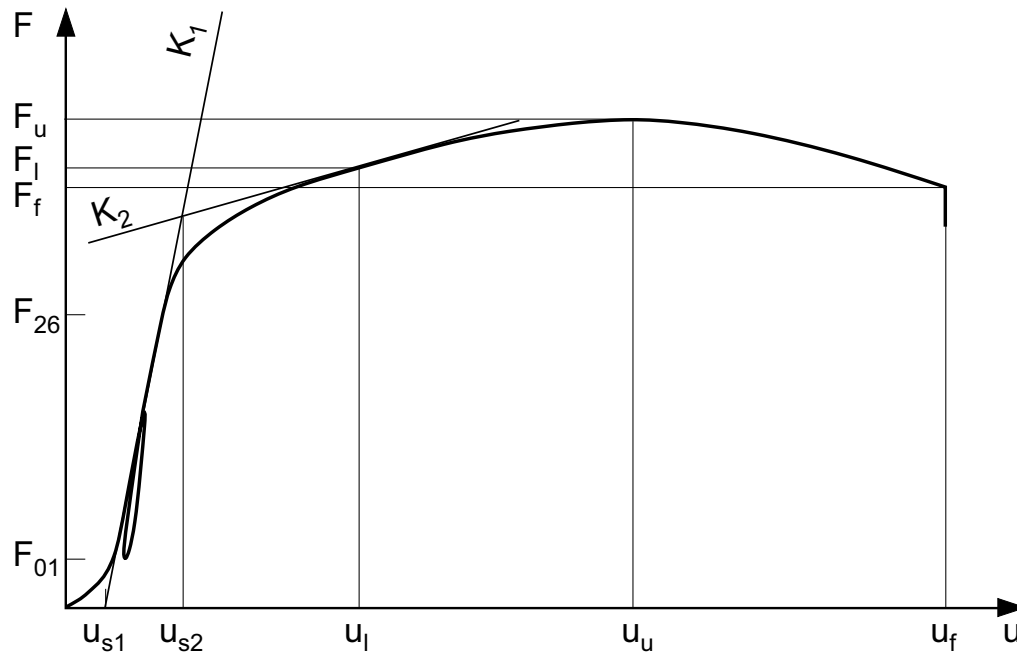


$$f_h = \frac{F_u}{t d} = \frac{F_{u1} + 2F_{u2}}{t d}$$





# Ductility and extension



$$D_{s,u} = \frac{u_u}{\frac{F_l}{K_1}} = \frac{K_1}{F_l} u_u$$

$$D_{s,f1} = \frac{u_f}{\frac{F_l}{K_1}} = \frac{K_1}{F_l} u_f$$

$$D_{s,f2} = \frac{u_f - u_{s1}}{u_{s2} - u_{s1}}$$

$$\Delta u_u = u_u - u_l$$

$$\Delta u_f = u_f - u_l$$

# Parameters

- Dowel surface (Smooth/friction)
- Geometry (3 + 4 variants with increasing thickness)
- Material properties (5 different lamellas)
- Number of dowels in a column (3 and 4)

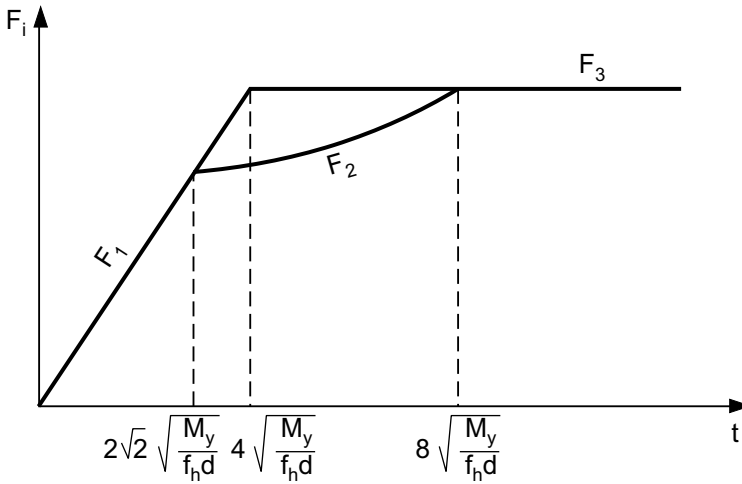
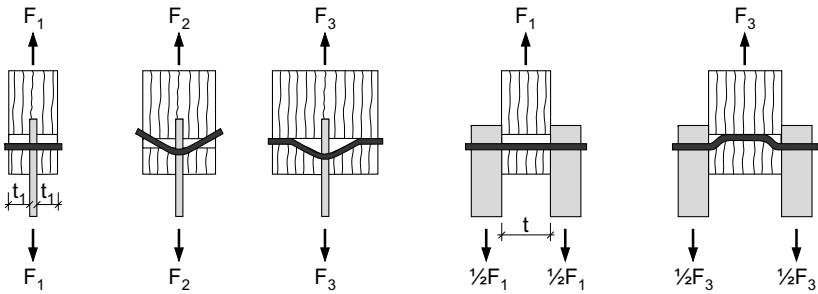
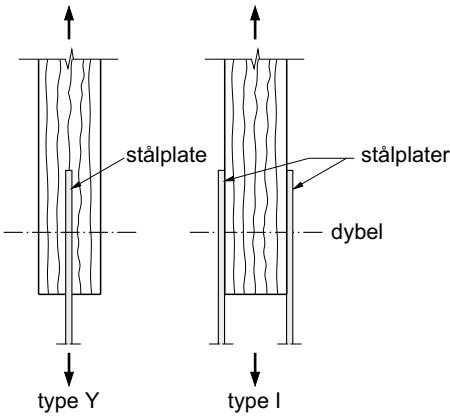
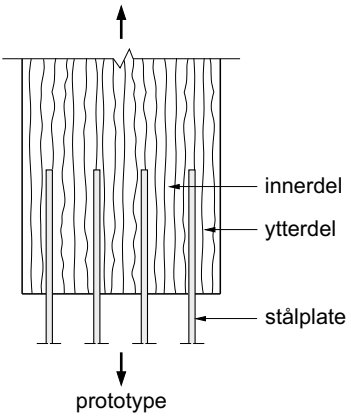
# Dowel surface

- Smooth
- Friction = Longitudinal grooves

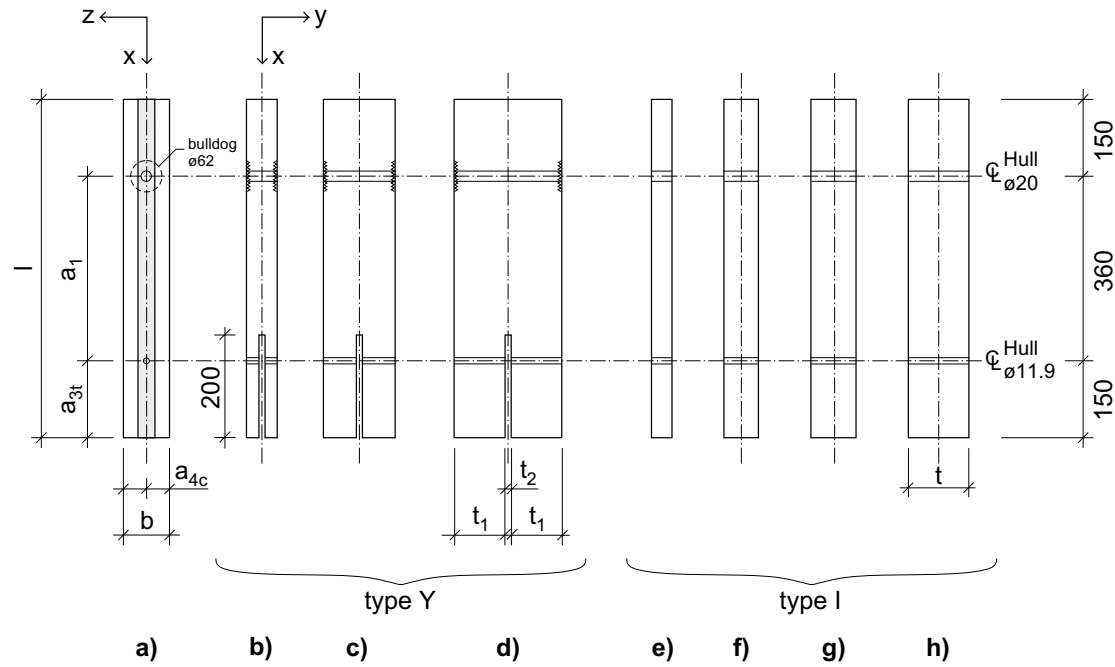




# Geometry

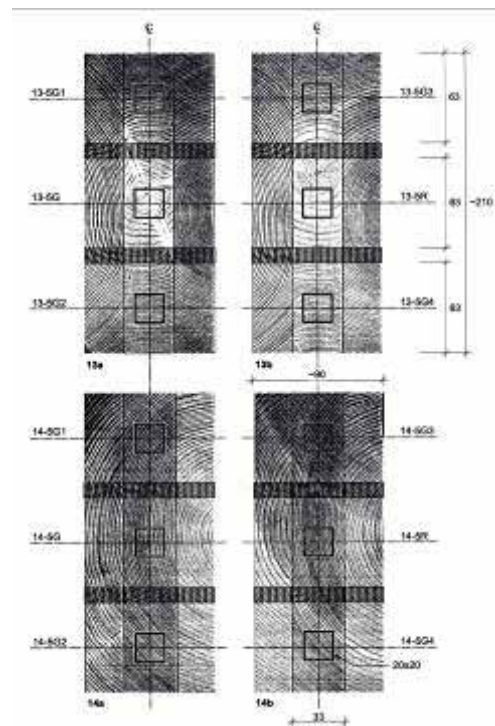
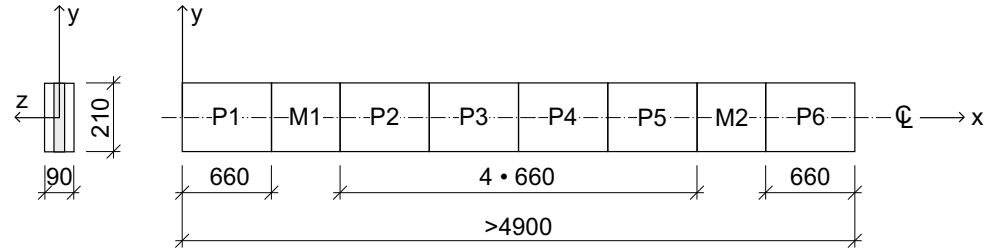


# Geometry



| Type | Geometry | Name of Figure | $t$ [mm] | $t_1$ [mm] | $t_2$ [mm] | $b$ [mm] | $a_1$ [mm] | $a_{3t}$ [mm] | $a_{4c}$ [mm] | $l$ [mm] |
|------|----------|----------------|----------|------------|------------|----------|------------|---------------|---------------|----------|
| Y    | 1        | b              | 50       | 25         | 9          | 90       | 360        | 150           | 45            | 660      |
|      | 2        | c              | 120      | 60         | 9          | 90       | 360        | 150           | 45            | 660      |
|      | 3        | d              | 200      | 100        | 9          | 90       | 360        | 150           | 45            | 660      |
| I    | 4        | e              | 40       | -          | -          | 90       | 360        | 150           | 45            | 660      |
|      | 5        | f              | 63       | -          | -          | 90       | 360        | 150           | 45            | 660      |
|      | 6        | g              | 90       | -          | -          | 90       | 360        | 150           | 45            | 660      |
|      | 7        | h              | 115      | -          | -          | 90       | 360        | 150           | 45            | 660      |

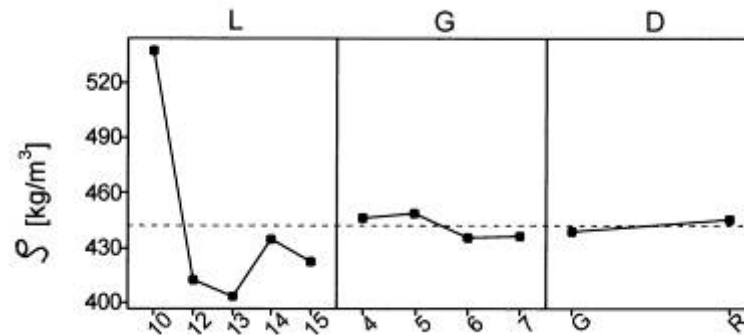
# Material properties, Lamellas





# Result – Density, ANOVA

Typical result



Model

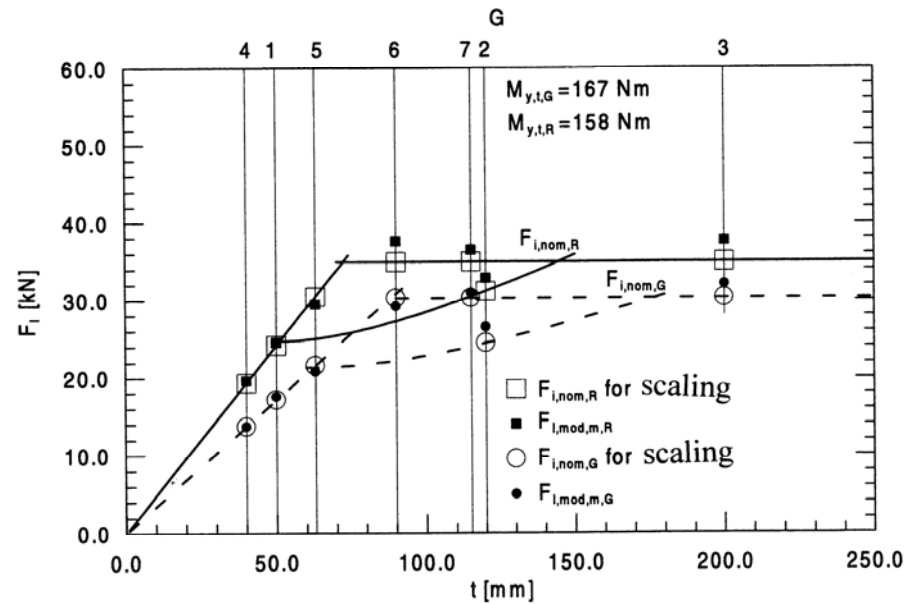
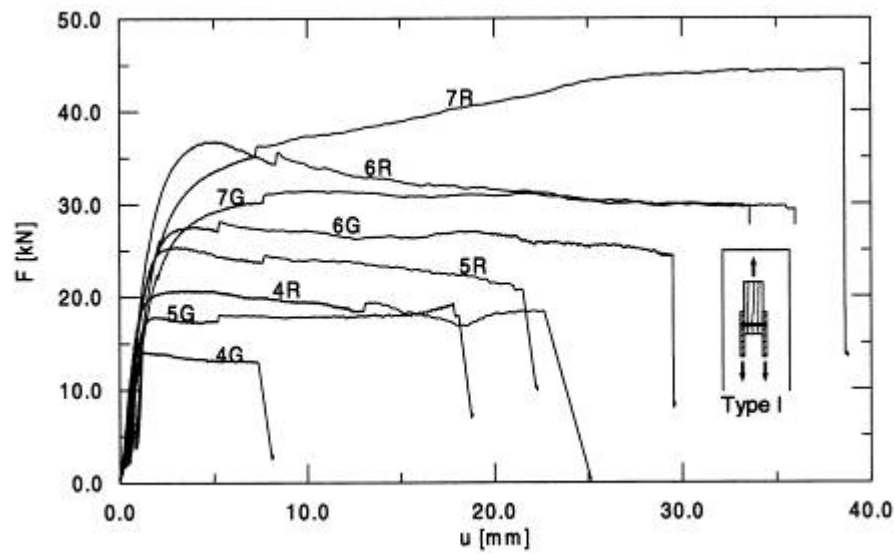
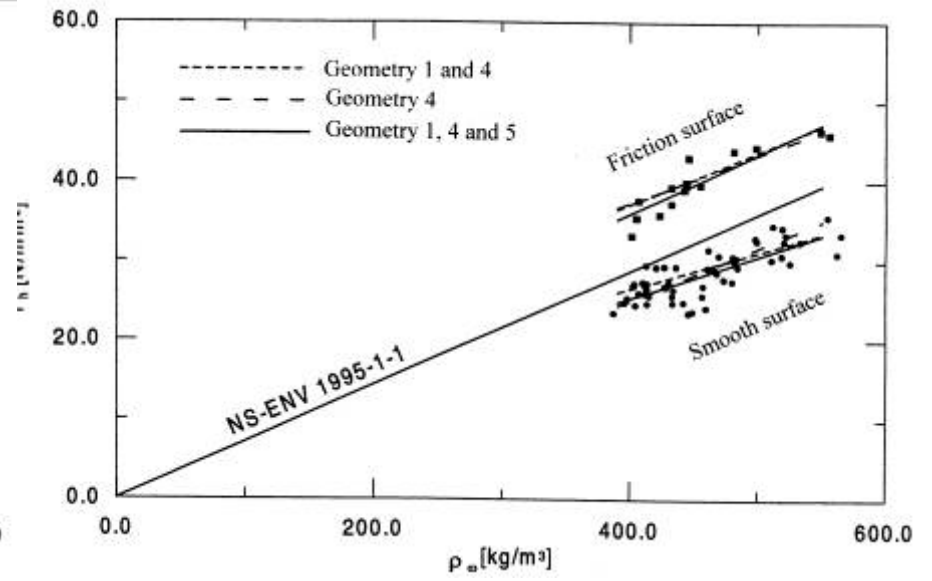
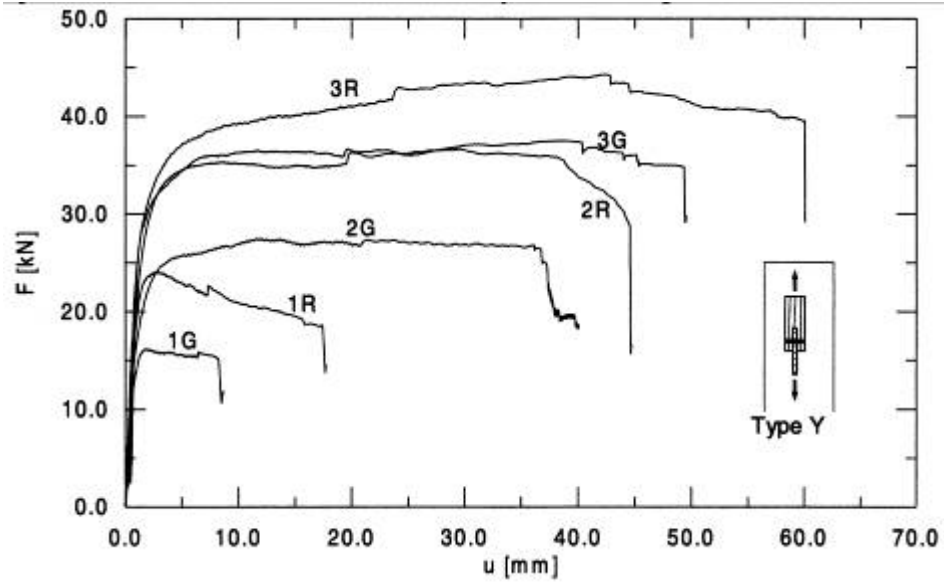
$$y_{ijkl} = \eta + l_i + g_j + d_k + lg_{ij} + ld_{ik} + gd_{jk} + \varepsilon_{l(ijk)}$$

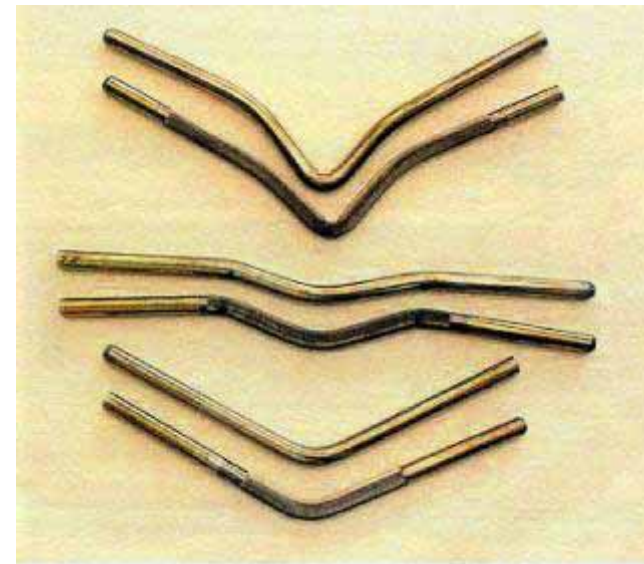
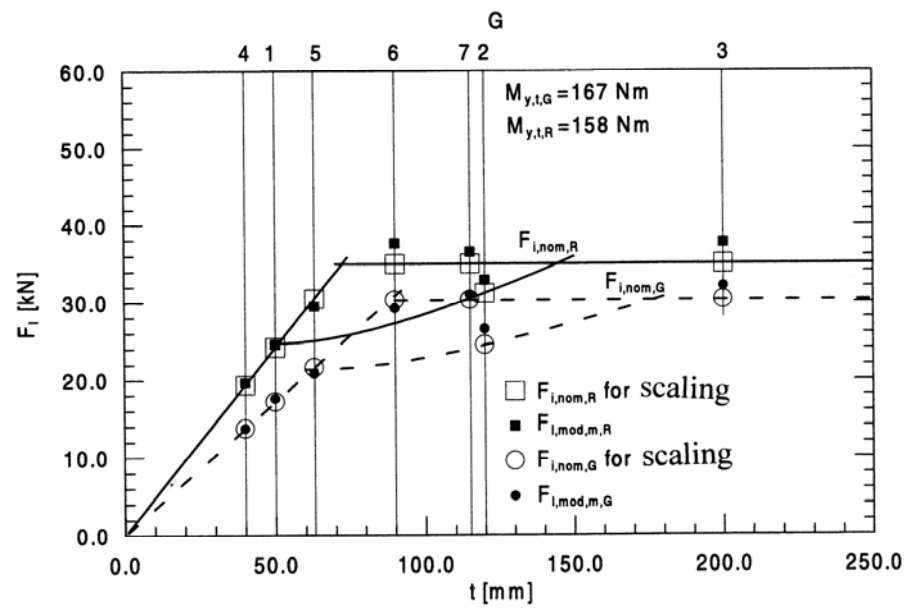
n- mean value

l – material property

g - geometry

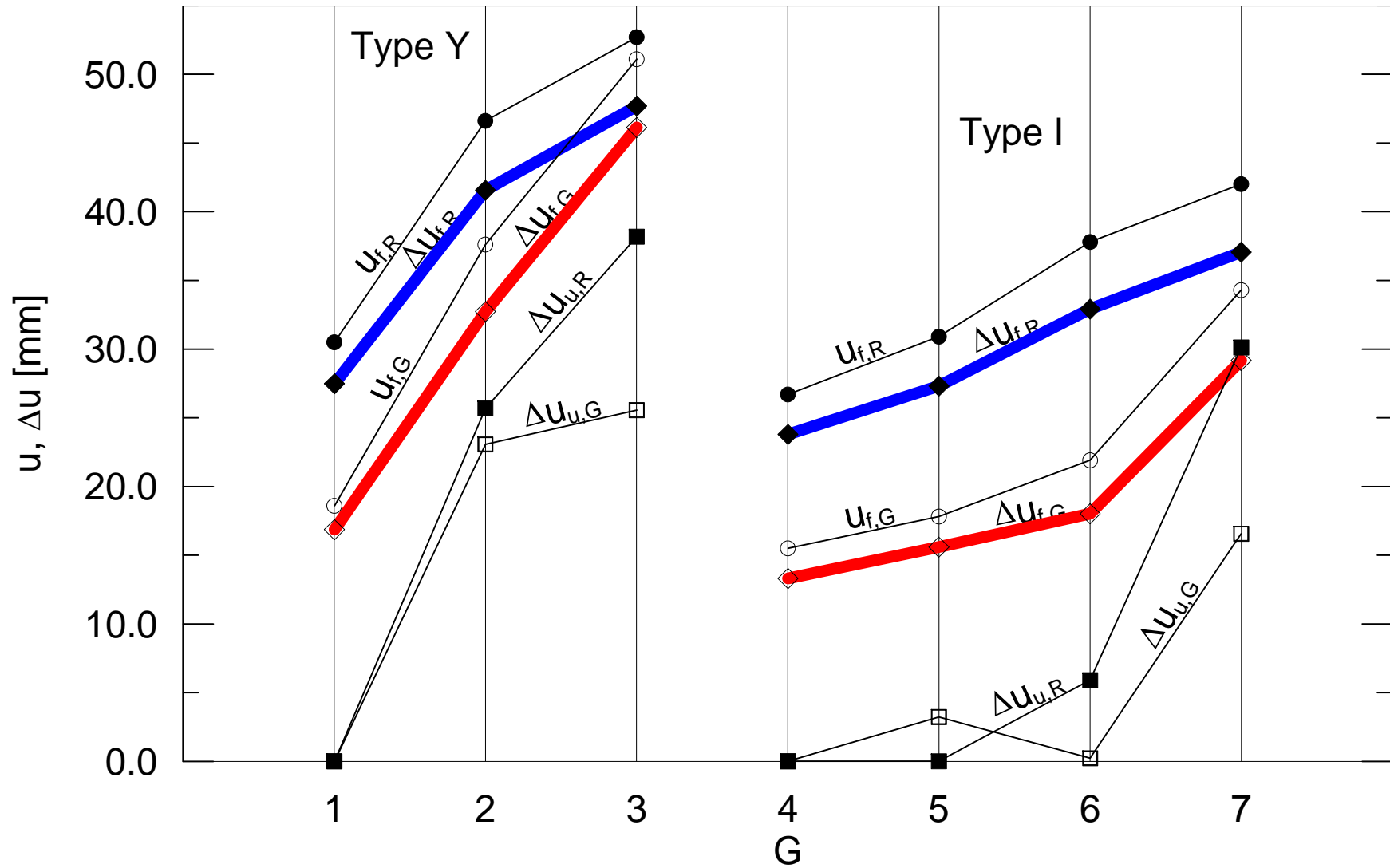
d – dowel type



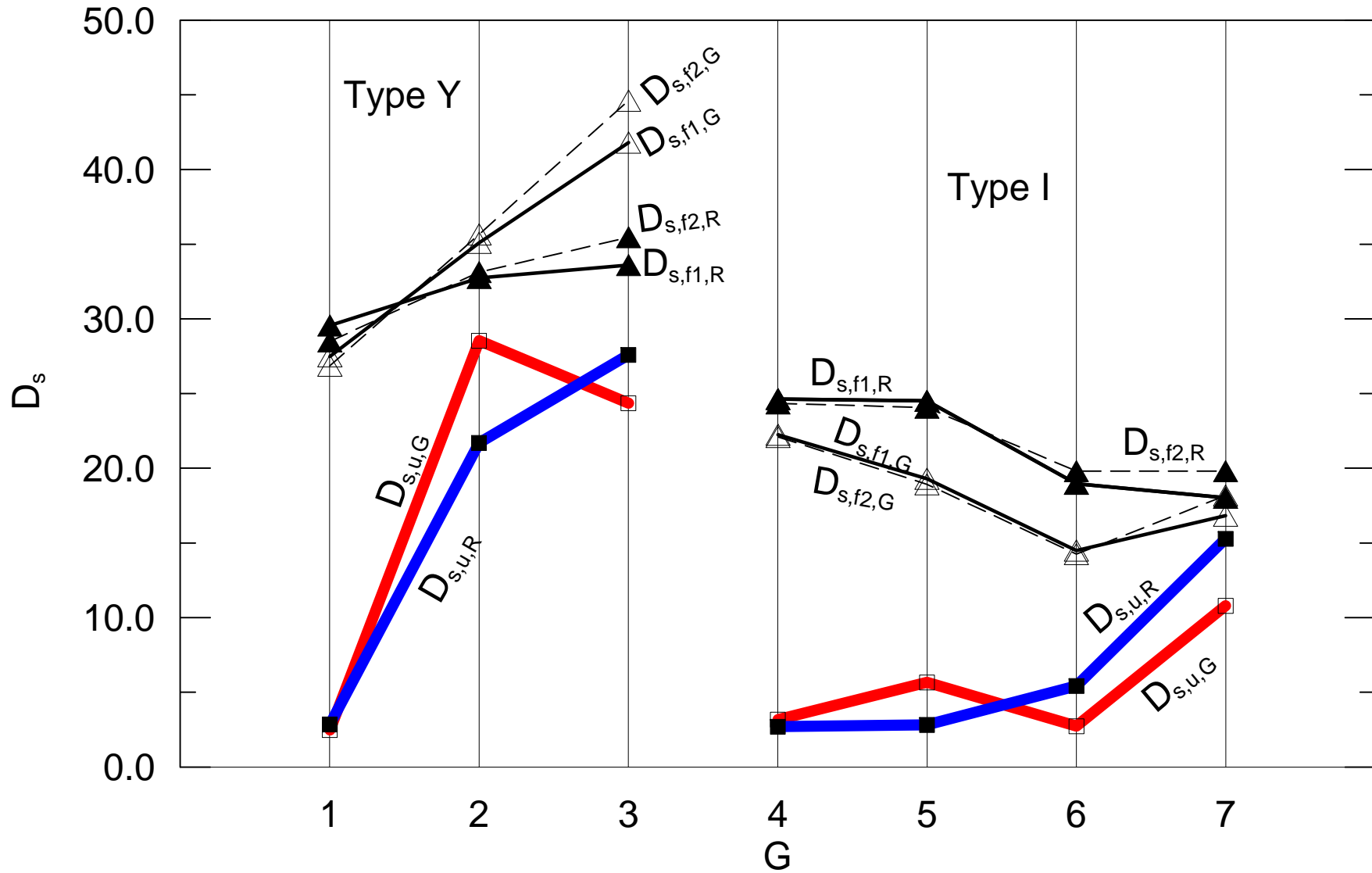




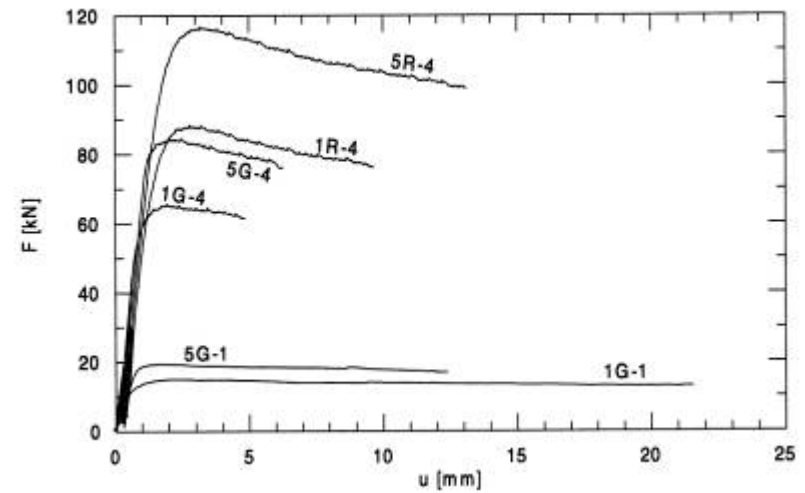
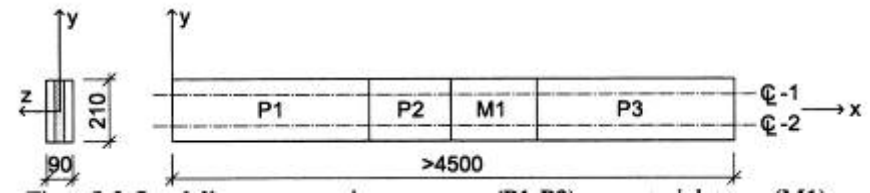
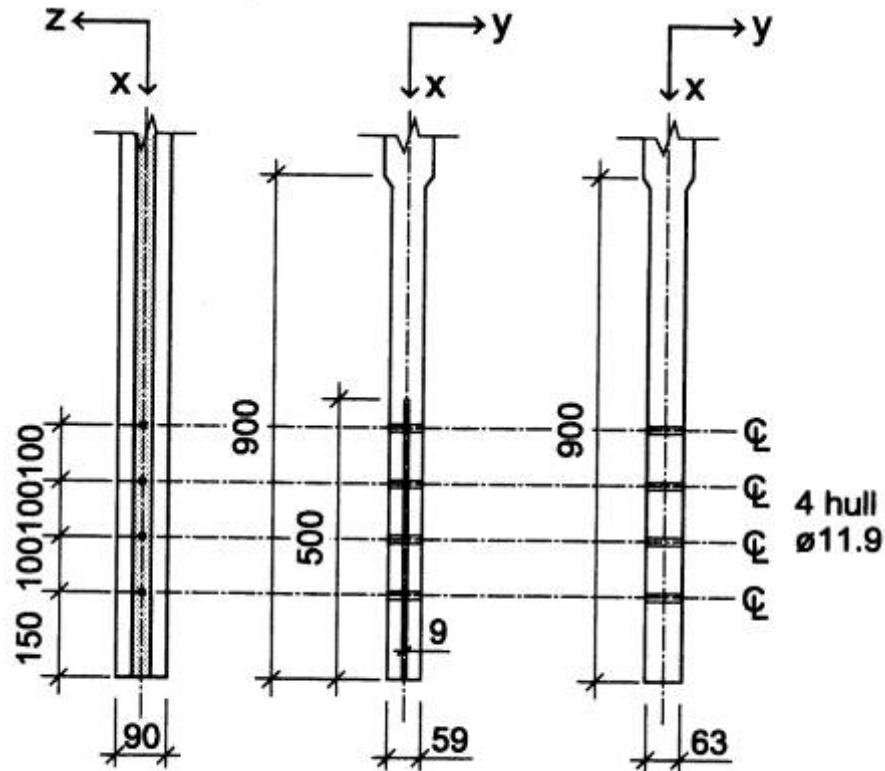
# Extension



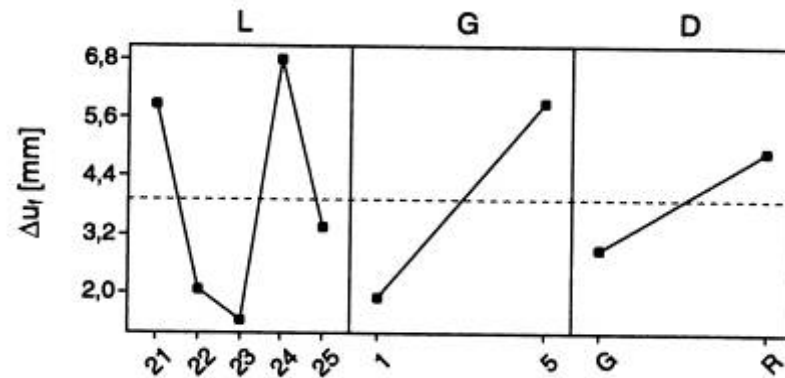
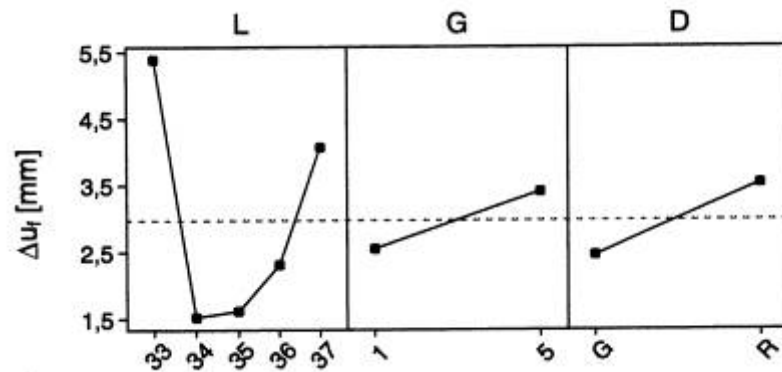
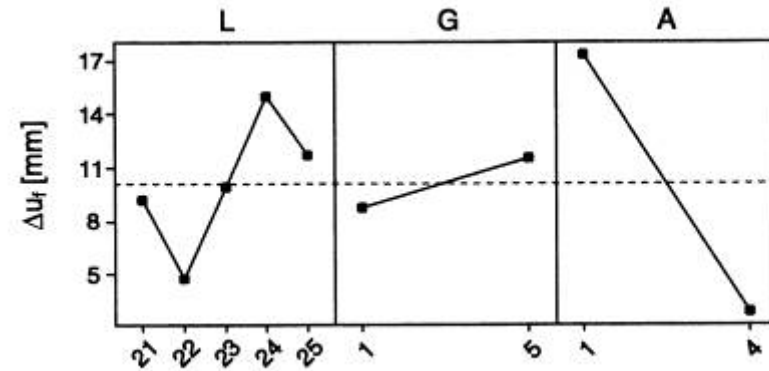
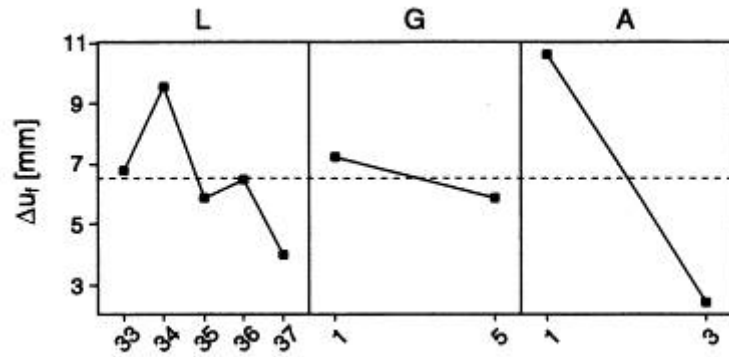
# Ductility

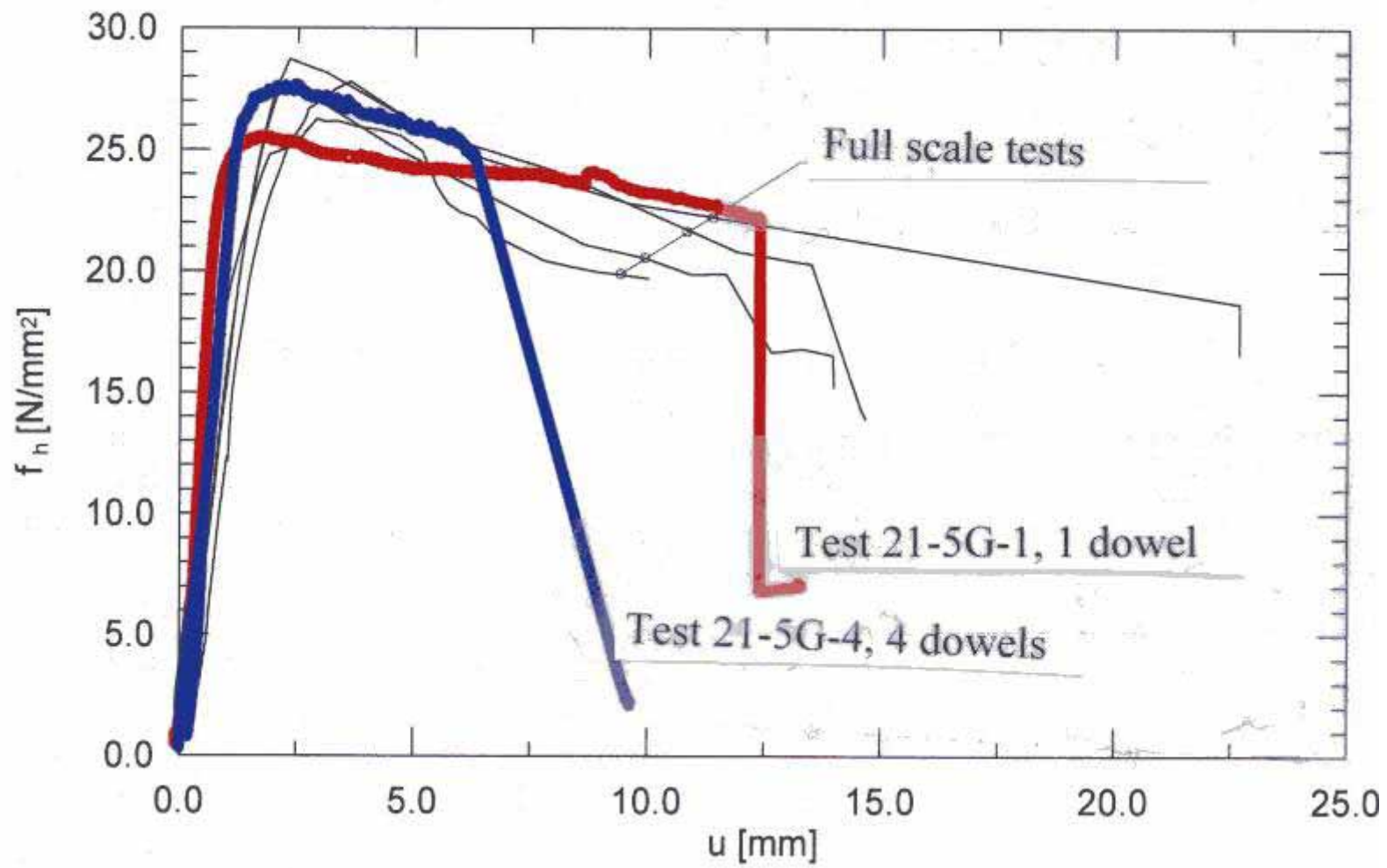


# 3 and 4 dowels



# Extension, 3 and 4 dowels





# Extention and ductility results

*Table 2 Extension results  $\Delta u_f$*

| Test series      | 1  |    |    |    |    |    |    | 2  |     |    |     | 3  |     |     |     |
|------------------|----|----|----|----|----|----|----|----|-----|----|-----|----|-----|-----|-----|
| Geometry         | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 1  | 1   | 5  | 5   | 1  | 1   | 5   | 5   |
| No. of dowels    | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 4   | 1  | 4   | 1  | 3   | 1   | 3   |
| $\Delta u_{f,G}$ | 17 | 33 | 46 | 13 | 16 | 18 | 29 | 15 | 2.4 | 20 | 3.4 | 12 | 2.2 | 9.1 | 2.6 |
| $\Delta u_{f,R}$ | 27 | 42 | 48 | 24 | 27 | 33 | 37 | -  | 1.4 | -  | 8.4 | -  | 2.9 | -   | 4.2 |

*Table 3 Ductility results  $D_s$*

| Test series   | 1   |    |    |     |     |     |    | 2   |     |     |     | 3   |     |     |     |
|---------------|-----|----|----|-----|-----|-----|----|-----|-----|-----|-----|-----|-----|-----|-----|
| Geometry      | 1   | 2  | 3  | 4   | 5   | 6   | 7  | 1   | 1   | 5   | 5   | 1   | 1   | 5   | 5   |
| No. of dowels | 1   | 1  | 1  | 1   | 1   | 1   | 1  | 1   | 4   | 1   | 4   | 1   | 3   | 1   | 3   |
| $D_{s,u,G}$   | 2,5 | 29 | 24 | 3.2 | 2.8 | 2.7 | 11 | 2.8 | 2   | 7.5 | 1.7 | 3.6 | 2   | 2.3 | 1.8 |
| $D_{s,u,R}$   | 2.9 | 22 | 28 | 2.7 | 2.8 | 5.4 | 15 | -   | 1.5 | -   | 1.7 | -   | 1.8 | -   | 2.1 |



# Conclusions

- Friction dowels give larger extension than smooth dowels
- The ductility and the extension of connections with single dowels increase with increasing thicknesses of the wood
- For connections with failure mode 1 the ductility and the extension decrease significantly in dowel columns compared to single dowels