# Presentation notes:

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

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In preparation to the Olympic winter games in Norway in 1994 several sports arenas were built with roof constructions where the span was up to 100 metres. These were made by Moelven Limtre AS as trusses in which the joints were shaped as dowel connections in combination with gusset plates slotted into the wooden components.

An experimental study was done in order to examine the capacity and ductility of this construction principle. This presentation is limited to the most important ductility results, and to the definitions and parameters used in this study. The complete study is presented in Norwegian in Siem (1999).

The Norwegian words in the figures are translated in the figure texts.

## Tests with single dowels – series 1

The characteristics of a dowel joint with one or more slotted gusset plates may be characterized based on the outer- and inner parts of the component cross-section, as defined in Figure 1. Inner- and outer parts have gusset plates on two sides and one side, respectively – both with a dowel through them. The inner- and the outer parts were examined by a test specimen designed as type I and type Y.

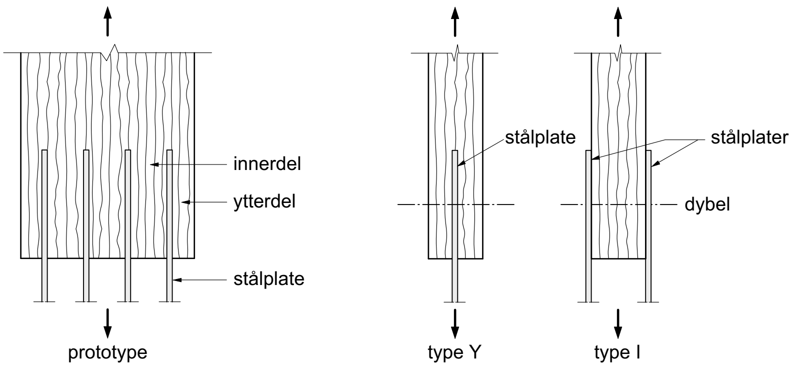


*Figure 1 Definition of inner- and outer parts as well as test specimen types (innerdel = inner part, ytterdel = outer part, stålplate = steelplate, dybel = dowel)*

The experiments were planned, conducted and analysed using Analysis of variance (ANOVA). The method assumed that there was a relation between the process when producing and grouping the test specimens and using the analysis models. The model examined the effects of the wood thickness for types I and Y, the dowel types as well as the material variation between lamellas of the same grading. The wood thickness was examined by seven geometrical variants. These are shown in Figure 2 and specified in Table 1. The dowel types represented one type with a smooth surface and one with longitudinal grooves called a friction surface. The test specimens were produced of components with three lamellas, each 4.9 metres long. The dowels were installed in the middle lamella, Figure 2. Thus the dowel types and the geometries within type I and type Y respectively were tested with specimens made of the same lamella. It was impossible to produce all geometries of materials from the same components. Therefore, type Y was produced from one group of components and type I from another group. Each group included 5 components.

The varied parameters in the tests were:
Dowel types, *D* (G – smooth surface, R – friction surface)
geometries, *G* (see Figure 2)
lamellas, *L*
components groups, *S*.

In the analytic results and in the figures the parameters are represented by the symbols stated with large characters.

*Table 1 The dimensions of the test specimen*

| 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 |

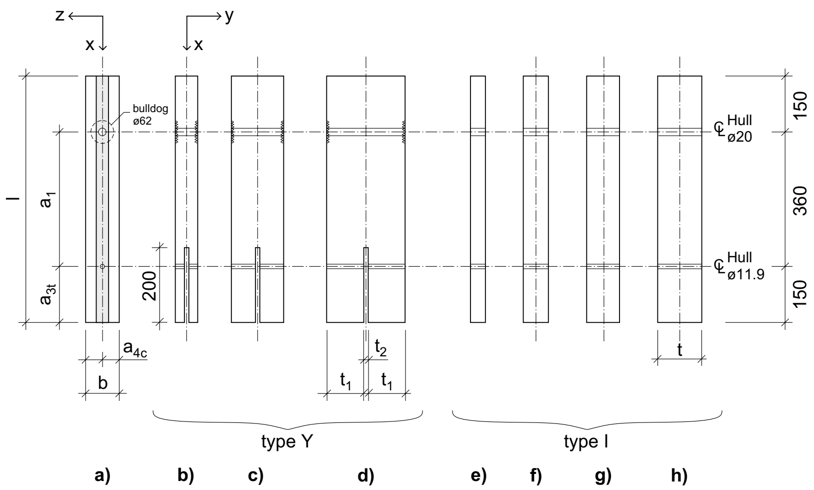


*Figure 2 Test specimen geometry for tests with single dowels (hull = hole)*

**Ductility definitions**

In order to be able to study some possible definitions of the ductility of joints and investigate who was the most appropriate, five different definitions were expressed. In the definitions the deformations $u_{s1}$ and $u_{s2}$ were introduced as defined in Figure 3 and Figure 4. Further, $K_1$, was defined as

$$K_1 = \frac{F_{26} - F_{01}}{u_{26} - u_{01}}$$

And the indexes had the meaning: l – limit ($u_l \leq 5$ mm), u – ultimate, f – failure, G – smooth, R – friction.

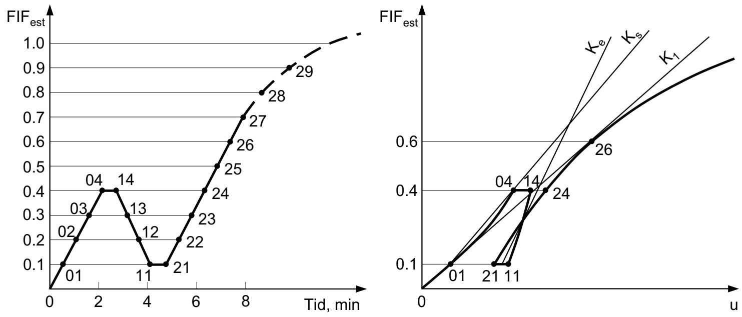


*Figure 3 Loading procedure according to NS-ISO 6891*

Extensions *Δ*$u_u$ and *Δ*$u_f$, which are two alternative expressions for ductility, were defined as:

$$\Delta u_u = u_u - u_l$$

$$\Delta u_f = u_f - u_l$$

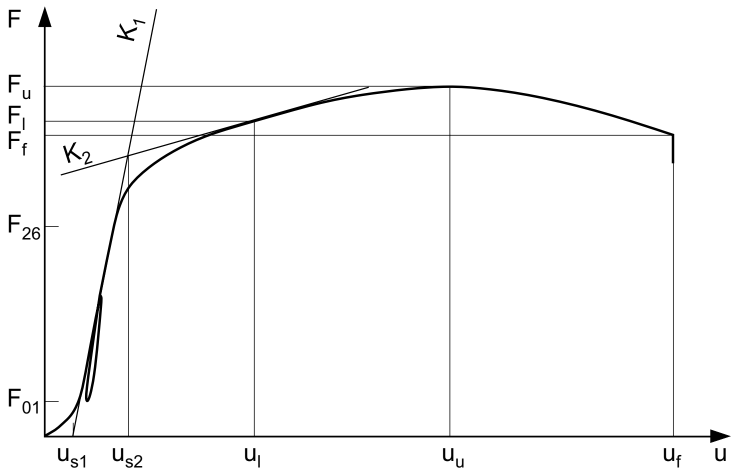


*Figure 4 Parameters used for defining ductility concept*

Ductility was defined as:

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

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

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

**Results and discussion – series 1**

The analyses of the specimens in component groups type Y and type I, showed no significant difference in the density between the geometries or dowel types. However, the difference was significant between the lamellas. Therefore, there is reason to believe that the test conditions within one lamella were so alike that the result differences are caused by variation in geometry and dowel type, and not due to variation in the material properties. The density variation for type I is shown in Figure 5.

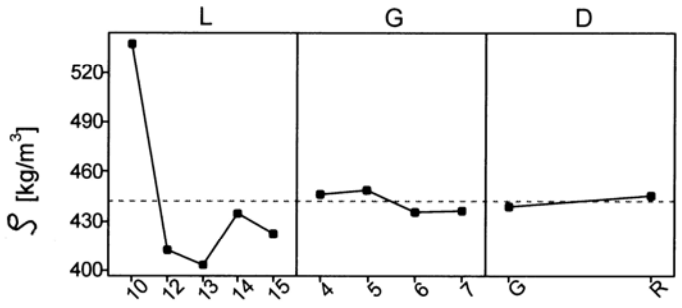


*Figure 5 The mean value of the lamella densities L, the geometries G and the dowel types D for type I*

The failure displacement $u_f$ and the extensions $\Delta u_u$ and $\Delta u_f$ are shown in Figure 6. The ductilities $D_{s,u}$, $D_s,f_1$ and $D_s,f_2$ are shown in Figure 9. For type Y the values are based on the results from three components and for type I the results from five components are used. The results for all variants are shown as mean values for smooth- and friction dowel types, respectively.

The failure displacement and the extensions rose with increasing thickness for both type Y and type I. The ANOVA analyses showed a significant difference in these sizes between the geometries for both types. Further, both $u_f$ and $\Delta u_f$ were significantly larger for friction dowels than for smooth, for type Y as well as for type I. For $\Delta u_u$ the difference between friction- and smooth dowels was not as distinct, and for geometry 5 the value for the smooth dowels was larger than for the friction ones. The reason for this was a knot in the cracking area under the dowel in one of the test specimen. In the ANOVA analyses no significant difference in $\Delta u_u$ could be found between the dowel types.

The mean value of the extension $\Delta u_u$ for type Y and of the extension $\Delta u_f$ for type I are shown in Figure 7 and Figure 8. There is a distinct difference in the mean value in the figures in $\Delta u_u$ and $\Delta u_f$, respectively between the geometries. In Figure 8 there is a large difference in the mean value for $\Delta u_f$ for the dowel types and the different lamellas. The ANOVA analyses showed significant difference.

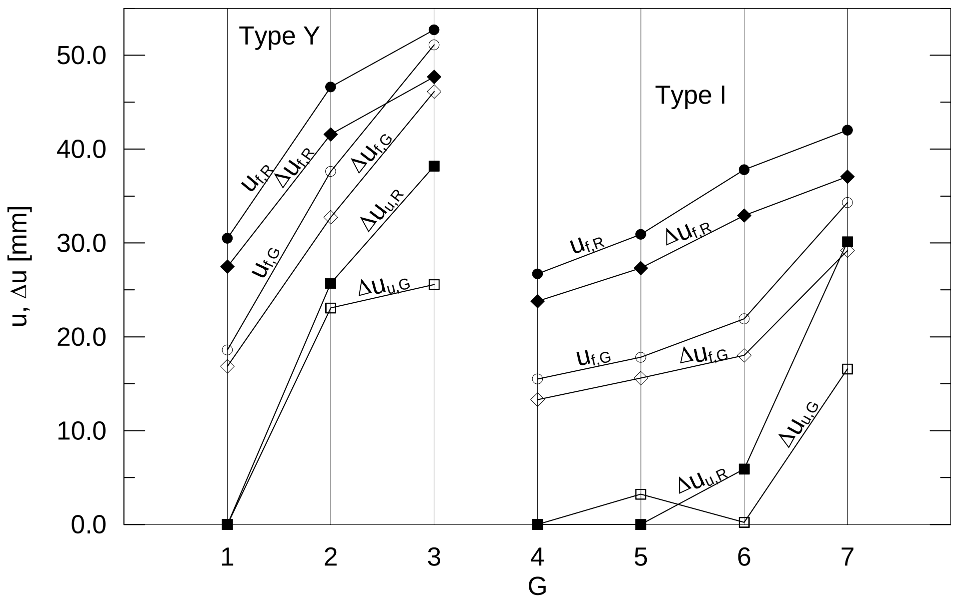


*Figure 6 Failure displacement and extension*

Figure 9 shows the ductility of the joint as function of dowel type and geometry, expressed by the three alternative definitions of the ductility.

The ductility $D_{s,u}$ showed low values for failure mode 1 and increasing values for the geometries with failure modes 2 and 3. The variance analyses confirmed the tendency. There was no distinct difference between the ductility of the friction dowels and the smooth ones.

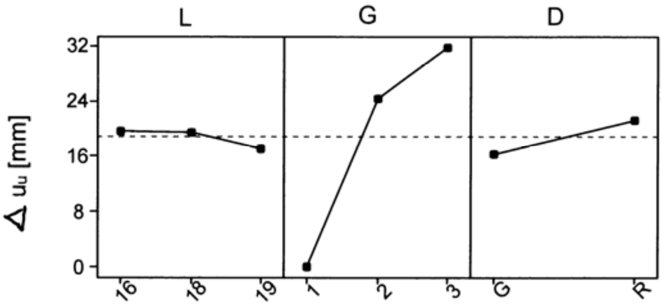


*Figure 7 The mean value of $\Delta u_u$ for type Y as function of lamella L, geometry G and dowel typeD*

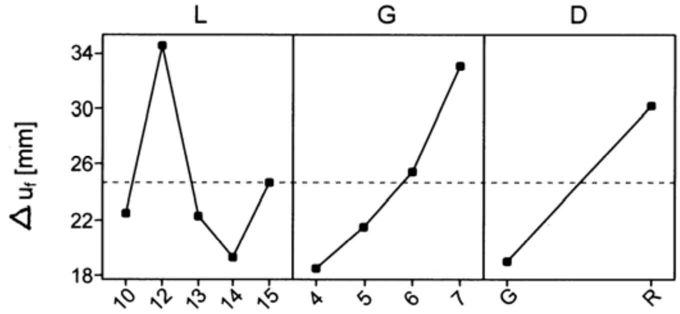


*Figure 8 The mean value of $\Delta u_f$ for type I as function of lamella L, geometry G and dowel type D*

The ductility $D_{s,f1}$ and $D_{s,f2}$ gave almost the same result, but the sizes as well as the tendencies were distinctively different compared to $D_{s,u}$. For type I both $D_{s,f1}$ and $D_{s,f2}$ got decreasing values with increasing wood thickness, despite the fact that both $\Delta u_u$, $\Delta u_f$ and $D_{s,u}$ got increasing values. This indicates the fact that $D_{s,f1}$ and $D_{s,f2}$ are not representative definitions for the ductility of the connection.

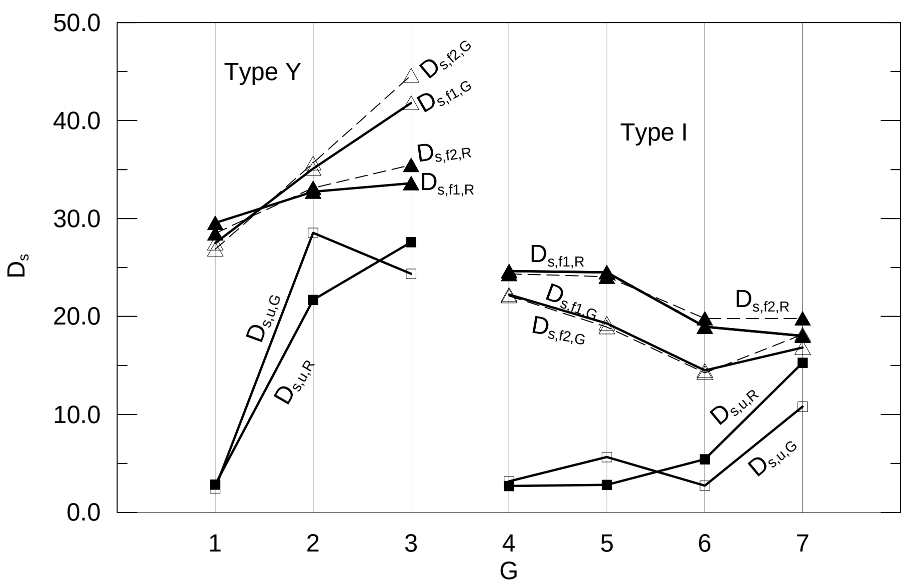


*Figure 9 The ductilities $D_s$*

The mean value of the extensions in Figure 6 increased with one exception. With increasing thicknesses for both types Y and I, and in addition, the values for friction dowels were higher than for smooth ones. The exception was due to a knot in the fraction area under the dowel in one specimen. This resulted in the extension $\Delta u_{u,G}$ being larger for smooth dowels than friction ones for geometry 5 and that smooth dowels for geometry 5 gave larger values than smooth dowels for geometry 6.

The geometry effect was the most evident and most significant effect for both extension definitions. Figure 6 showed very clearly that the thickest geometries endured large extensions from the moment when the limit load was reached until the ultimate load and the failure load were reached. This means that the thickest geometries are able to redistribute the load if the limiting load is used as a basis for calculations for statically indefinite constructions. For $\Delta u_u$ it was merely the geometrical effect which was significant. The extension $\Delta u_f$ showed clearly that all geometries tolerated severe deformations after the limiting load had been passed and before failure occurred. In addition, this extension had significantly higher values for friction dowels than for smooth ones for type Y as well as for type I.

The ductility definition was defined in three different ways in the equations. The results showed that $D_{s,u}$ had low values for failure mode 1 as an average, but increased when thicker geometries resulted in higher failure modes. The results showed a tendency, especially for type I, that friction dowels were more ductile than smooth ones, but the effect was not significant. Both $D_{s,f}$ –concepts had decreasing values when the wood thickness increased for type I despite the fact that the failure displacement $u_f$ increased severely at the same time. The increasing values for $F_l$ /$K_l$ with increasing thickness were dominating compared to the failure displacement and led to the fact that the deformation capacity was not expressed. The most interesting fact about the $D_{s,f}$-concepts was the importance of the differences between them. The small differences showed that imbalances, frictions etc. which were included in $D_{s,f1}$, but excluded in $D_{s,f2}$, were of little significance to the result. The size of $K_2$, which was set equal to zero for $D_{s,f1}$, but which varied for $D_{s,f2}$, had no significant importance to the result either.

A common understanding of the concept of ductile connection is that the connection has deformation- or rotation capacity in such a way that it may redistribute forces internally in a larger connection or into other construction elements. The extensions shown in Figure 6 clearly indicated the deformation capacity of the different connections, and thereby that they were suitable as ductility concepts. The ductility concept $D_{s,u}$, which gives a relative deformation capacity on to maximum load, gave a result which showed that the thickest connections were the most ductile. This characteristic of the ductility did not indicate as clearly as the thinner connections that the deformation capacity for friction dowels was considerably larger than for smooth ones. The ductility $D_{s,f}$ gave the wrong impression of the development of the deformation capacity at increasing geometry thickness. The failure displacement $u_f$ provided more limited information than $\Delta u_f$ and therefore it was less suitable as a ductility indicator. Therefore, measures $\Delta u_u$, $\Delta u_f$ and $D_{s,u}$ characterized the ductile behaviour of the connection in the best possible way.

Observations in connection with separate tests indicated that knots directly under the dowel, which the dowel had direct contact with after small deformations, prevented the further deformation development for the connection and resulted in a more fragile connection. On the other hand, knots that were situated across developing cracks, and which were at a distance from the dowel, limited the fracturing and resulted in a more ductile connection.

### Dowel columns with 3 and 4 dowels – series 2 and 3

Test series with 3 and 4 dowels in one column were carried out. The geometry of the tests is shown in Figure 10.

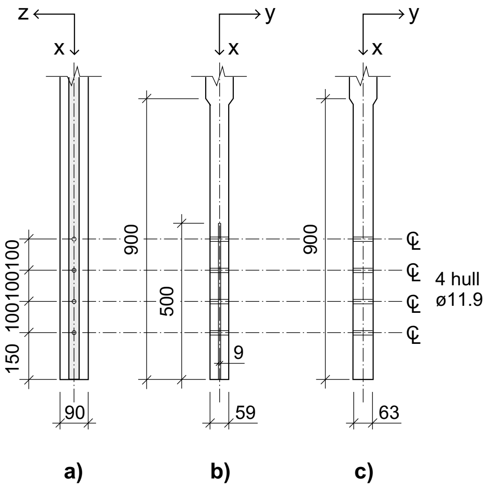


*Figure 10 Lower part of test specimens with four dowels in one column and placed in the same lamella*

The test results showed that both extension and ductility were significantly higher for single dowels than for dowel columns. An example is shown in Figure 11 where A is the number of dowels in the connection. The extension results $\Delta u_f$ and the ductility results $D_s$ are shown in Table 2 and 3.

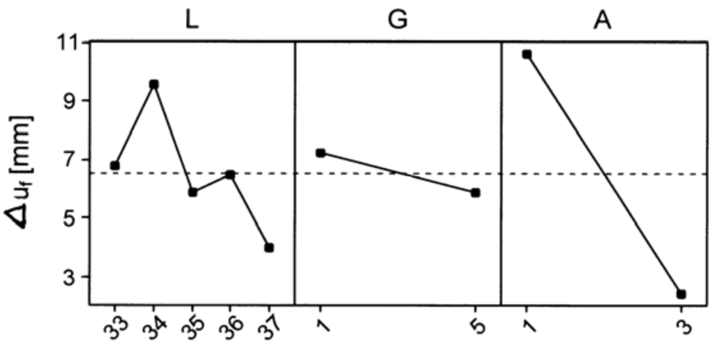


*Figure 11 The mean value of $\Delta u_f$ in lamellas, in geometry and for numbers of dowels*

## Summing up ductility results

Table 2 shows the results from the extension $\Delta u_f$ and Table 3 shows the ductility $D_s$.

*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

An experimental study has been conducted in order to investigate a connection type which has been frequently used in Norway during the last few years for long span gluelam timber trusses. The effect of changes in dowel surface, the failure mode of the connection, variation in material properties and number of dowels in one column, has been studied. In order to be able to minimize the number of tests and at the same time show significant effects with varying parameters, the tests were planned in such a way that variance analysis could be used in the statistical treatment of the results. The tests were limited to dowel connections with slotted gusset plates exposed to short-term loading in the fibre direction. 12 mm dowels with smooth- and friction surface were used. The main conclusions from the tests were:

- Friction dowels give larger displacement at failure and larger extension than smooth dowels.
- The ductility and the extension of connections with single dowels increase with increasing thicknesses in the wood.
- For connections with failure mode 1 the ductility and the extension decrease significantly in dowel columns compared to single dowels.
- Statistical planning of tests using ANOVA analyses is suitable in order to decrease the number of tests and at the same time enable significant effects to be demonstrated during parameter studies.

## References

Siem J. (1999): Capacity and ductility of dowel connections in wood constructions. NTNU, Trondheim, Norway, ISBN: 82-471-0414-8, ISSN 0802-3271 (in Norwegian)