# The Need for Information

# Concerning the Wood Properties Within One Board

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# The need for information concerning the wood properties within one board

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In the "Karlsruhe calculation model" [1] each board is divided into cells with a length of 150 mm. Each cell is assigned a density and a KAR-value (Knot Area Ratio). Based on these values, the estimated MOE and strength of each cell is calculated by regression equations. As two cells with equal density and KAR-value may have different strength and stiffness properties, a value, taken at random from the residue of the regression equation, is added to the calculated value of MOE and strength respectively.

In this paper, the simulation of the strength and stiffness properties is shown, using three different boards with given density and KAR-values (cf. *Table 1a*). For each cell the MOE in tension and the tensile strength have been calculated according to the following regression equations:

$$\ln(E_t) = 8.2 + 3.13 * RHO - 1.17 * KAR + X(0\,;0.180) \quad (1)$$

$$\ln(f_t) = -4.22 + \ln(E_t) * (0.876 - 0.093 * KAR) + X(0\,;0.187) \quad (2)$$

where

$E_t$ = MOE in tension (MPa),
$f_t$ = tensile strength (MPa),
RHO = ovendry density ($g/cm^3$),
KAR = Knot Area Ratio ( - ),
$X(0\,;s_R)$ = value randomly taken from the residue of the regression equation with mean value = 0 and stand. dev. = $s_R$.

For each board, one set of simulated MOE and strength values is also given in *Table 1a*. Here we can see that the strength and stiffness values of neighbouring cells differ widely, even in case of knot - free cells. Furthermore, the lowest strength and stiffness values do not necessarily occur in the cells with the highest KAR-value (cf. board II, cell No. 17).

A total of 1000 simulations were performed for each board and the lowest strength and stiffness values of each simulated board recorded and statistically evaluated. The corresponding mean value and stand. dev. are given in *Table 1b* (example: in the case of board I, the lowest MOE and strength were simulated to be on average 7420 MPa and 25.4 MPa respectively).

In the case of board III in particular, representing a high - quality board, the simulations seem to underestimate the strength and stiffness properties. This is due to the high residues of the regression equations: the values X, randomly taken from these residues, are also high, so that the strength and stiffness values of the cells are controlled to a high degree by these random values. Consequently the probability that a cell with very low MOE and strength occurs, is very high. Due to this fact, the bearing capacity of high - quality glulam beams actually seems to be underestimated by the "Karlsruhe calculation model".

Examinations of 640 board sections from 100 boards [2] showed that the variation of the MOE within one board is lower than assumed by the total residue of the regression equations. These investigations showed that the MOE-values of one board may be on average higher, equal to or lower than expected by the regression equation: a board is "better" or "worse" than the overall average. This tendency is shown in *Fig. 1*. The total residue $s_R$ of the regression equations may therefore be split up into two parts:

- the distance $\Delta_i$ of the board from the regression line, and
- the variation $s_{R,i}$ of the MOE within one board (residue).

In order to estimate the effect of a lower variability of strength and stiffness values within one board, the three boards *from Table 1a* were simulated a second time, with a 50% lower stand. dev. $s_R$ of the residue. The simulation results are shown in *Table 2a* : the strength and stiffness values of neighbouring cells differ less and the probability that the lowest MOE and strength values occur in the cell with the highest KAR-value increases. Hence the lowest strength and stiffness values are less governed by the random values of the residue.

If the mean values of the lowest MOE and strength values (after 1000 replications) *from Table 2b* are compared with the corresponding values *from Table 1b*, we see that a lower residue leads to an increase of those simulated values. This effect is more pronounced in the case of a high - quality board (board III) than in the case of a "normal" board.

In this paper I have tried to show that a more realistic simulation of the strength and stiffness properties of one board is (only) possible, if the undoubtedly existing lower variability of these properties within one board is taken into account. The present underestimation of the high - quality glulam beams by the "Karlsruhe calculation model" could thus be at least modified, if if not completely eliminated.

Literature:

[1] Colling, F. 1988: Estimation of the effect of different grading criterions on the bending strength of glulam beams using the "Karlsruhe calculation model". IUFRO, Turku, Finland.

[2] Colling, F.; Scherberger, M. 1987: Die Streuung des Elastizitätsmoduls in Brettlängsrichtung. Holz als Roh- und Werkstoff 45: 95 - 99.

Table 1a: Simulated MOE and strength values (with total residue)

| cell No. | board I RHO = 0.43 $g/cm^3$ | | | board II RHO = 0.43 $g/cm^3$ | | | board III RHO = 0.50 $g/cm^3$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | KAR | $E_t$ MPa | $f_t$ MPa | KAR | $E_t$ MPa | $f_t$ MPa | KAR | $E_t$ MPa | $f_t$ MPa |
| 1 | 0 | 11900 | 55,8 | 0,15 | 9980 | 42,0 | 0 | 14820 | 67,6 |
| 2 | 0,35 | 8820 | **26,3** | 0 | 13280 | 50,8 | 0 | 16530 | 61,5 |
| 3 | 0 | 12330 | 58,9 | 0,19 | 9870 | 41,1 | 0,07 | 14150 | 62,4 |
| 4 | 0 | 13360 | 64,1 | 0 | 13360 | 64,1 | 0 | 16630 | 77,7 |
| 5 | 0 | 15620 | 82,0 | 0 | 15620 | 82,0 | 0 | 19450 | 99,3 |
| 6 | 0 | 14660 | 65,2 | 0,14 | 12450 | 50,0 | 0 | 18250 | 79,1 |
| 7 | 0,26 | 9260 | 39,5 | 0 | 12560 | 64,5 | 0,12 | 13580 | 62,1 |
| 8 | 0 | 14570 | 77,2 | 0 | 14570 | 77,2 | 0 | 18140 | 93,5 |
| 9 | 0 | 12830 | 71,8 | 0 | 12830 | 71,8 | 0 | 15970 | 87,0 |
| 10 | 0,23 | 10700 | 35,8 | 0,13 | 12030 | 43,2 | 0,08 | 15880 | 57,5 |
| 11 | 0 | 19290 | 57,8 | 0 | 19290 | 57,8 | 0 | 24010 | 70,0 |
| 12 | 0 | 15240 | 51,4 | 0 | 15240 | 51,4 | 0,05 | 17890 | 56,5 |
| 13 | 0,38 | 9700 | 41,8 | 0 | 15140 | 85,2 | 0 | 18840 | 103,2 |
| 14 | 0,14 | 12980 | 39,8 | 0,27 | 11150 | **31,2** | 0 | 19040 | 62,8 |
| 15 | 0 | 13820 | 57,1 | 0 | 13820 | 57,1 | 0 | 17210 | 69,2 |
| 16 | 0 | 15260 | 57,0 | 0 | 15260 | 57,0 | 0,11 | 16710 | 55,9 |
| 17 | 0 | 9150 | 44,7 | 0 | **9150** | 44,7 | 0,05 | **10750** | **49,2** |
| 18 | 0 | 14900 | 69,6 | 0,14 | 12650 | 53,4 | 0 | 18560 | 84,3 |
| 19 | 0,24 | **7210** | 47,9 | 0 | 9550 | 75,3 | 0 | 11880 | 91,2 |
| 20 | 0 | 12770 | 47,9 | 0 | 12770 | 47,9 | 0 | 15900 | 58,1 |
| 21 | 0 | 14390 | 52,1 | 0,27 | 10490 | 31,3 | 0,09 | 16120 | 53,1 |
| 22 | 0,43 | 8470 | 33,4 | 0 | 14000 | 74,4 | 0 | 17430 | 90,2 |
| 23 | 0 | 15290 | 70,6 | 0,13 | 13130 | 55,2 | 0 | 19309 | 85,6 |
| 24 | 0 | 14420 | 52,4 | 0,15 | 12100 | 39,5 | 0 | 17950 | 63,5 |
| 25 | 0 | 15550 | 58,8 | 0,07 | 14320 | 51,5 | 0,06 | 18040 | 63,5 |
| 26 | 0,07 | 13190 | 44,1 | 0 | 14310 | 50,3 | 0 | 17820 | 61,0 |
| 27 | 0,27 | 13420 | 32,2 | 0,24 | 13900 | 34,0 | 0 | 22920 | 64,8 |
| 28 | 0 | 10510 | 64,2 | 0 | 10510 | 64,2 | 0,10 | 11640 | 64,2 |
| 29 | 0 | 16520 | 45,3 | 0 | 16520 | 45,3 | 0 | 20560 | 54,9 |
| 30 | 0,29 | 8680 | 33,5 | 0,15 | 10220 | 43,5 | 0 | 15460 | 70,0 |

Table 1b: Lowest MOE and strength values after 1000 simulations (with total residue)

| | **board I** | | **board II** | | **board III** | |
|---|---|---|---|---|---|---|
| | $E_t$ MPa | $f_t$ MPa | $E_t$ MPa | $f_t$ MPa | $E_t$ MPa | $f_t$ Mpa |
| mean $\overline{x}$ | 7420 | 25.4 | 8330 | 31.8 | 11590 | 48.0 |
| stand. dev. s | 838 | 3.3 | 830 | 3.8 | 1042 | 4.9 |

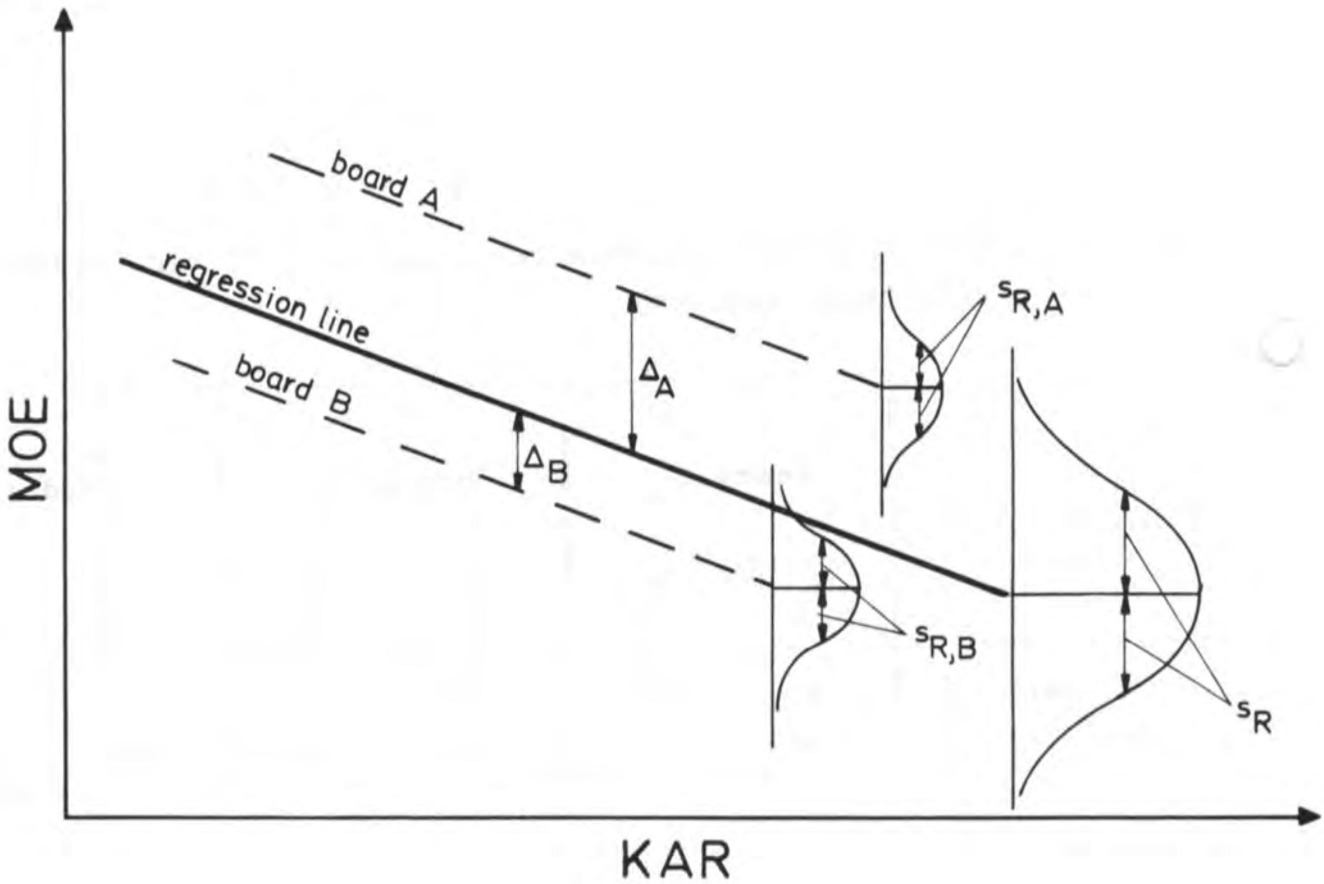


Fig. 1: Splitting up of the total residue $s_R$ of the regression equation

Table 2a: Simulated MOE and strength values (with reduced residue)

| cell | board I RHO = 0.43 g/cm$^3$ | | | board II RHO = 0.43 g/cm$^3$ | | | board III RHO = 0.50 g/cm$^3$ | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | KAR | $E_t$ MPa | $f_t$ MPa | KAR | $E_t$ MPa | $f_t$ MPa | KAR | $E_t$ MPa | $f_t$ MPa |
| 1 | 0 | 12900 | 59,3 | 0,15 | 10830 | 44,6 | 0 | 16060 | 71,8 |
| 2 | 0,35 | 9050 | **29,3** | 0 | 13630 | 56,5 | 0 | 16970 | 68,5 |
| 3 | 0 | 13130 | 60,9 | 0,19 | 10530 | 42,5 | 0,07 | 15070 | 64,5 |
| 4 | 0 | 13670 | 63,5 | 0 | 13670 | 63,5 | 0 | 17020 | 77,0 |
| 5 | 0 | 14780 | 71,8 | 0 | 14780 | 71,8 | 0 | 18400 | 87,0 |
| 6 | 0 | 14320 | 64,1 | 0,14 | 12160 | 49,1 | 0 | 17830 | 77,6 |
| 7 | 0,26 | 9780 | 39,0 | 0 | 13250 | 63,7 | 0,12 | **13290** | **58,4** |
| 8 | 0 | 14280 | 69,7 | 0 | 14280 | 69,7 | 0 | 17770 | 84,5 |
| 9 | 0 | 13400 | 67,2 | 0 | 13400 | 67,2 | 0 | 16680 | 81,5 |
| 10 | 0,23 | 10700 | 38,2 | 0,13 | 12020 | 46,1 | 0,08 | 15870 | 61,3 |
| 11 | 0 | 16430 | 60,3 | 0 | 16430 | 60,3 | 0 | 20450 | 73,1 |
| 12 | 0 | 14600 | 56,9 | 0 | 14600 | 56,9 | 0,05 | 17140 | 62,6 |
| 13 | 0,38 | 9330 | 36,0 | 0 | 14550 | 73,2 | 0 | 18120 | 88,7 |
| 14 | 0,14 | 12420 | 43,8 | 0,27 | 10660 | **34,3** | 0 | 18210 | 69,2 |
| 15 | 0 | 13900 | 60,0 | 0 | 13900 | 60,0 | 0 | 17310 | 72,7 |
| 16 | 0 | 14610 | 59,9 | 0 | 14610 | 59,9 | 0,11 | 15990 | 58,8 |
| 17 | 0 | 11310 | 53,1 | 0 | 11320 | 53,1 | 0,05 | 14340 | 61,3 |
| 18 | 0 | 14440 | 66,2 | 0,14 | 12260 | 50,7 | 0 | 17980 | 80,2 |
| 19 | 0,24 | 8730 | 43,8 | 0 | 11560 | 68,8 | 0 | 14390 | 83,4 |
| 20 | 0 | 13370 | 54,9 | 0 | 13370 | 54,9 | 0 | 16640 | 66,5 |
| 21 | 0 | 14190 | 57,3 | 0,27 | **10340** | 34,4 | 0,09 | 15900 | 59,3 |
| 22 | 0,43 | **8460** | 30,7 | 0 | 14000 | 68,4 | 0 | 17420 | 82,9 |
| 23 | 0 | 14620 | 66,7 | 0,13 | 12560 | 52,1 | 0 | 18200 | 80,8 |
| 24 | 0 | 14200 | 57,5 | 0,15 | 11920 | 43,2 | 0 | 17680 | 69,6 |
| 25 | 0 | 14750 | 60,9 | 0,07 | 13590 | 53,3 | 0,06 | 17110 | 65,7 |
| 26 | 0,07 | 13040 | 49,3 | 0 | 14150 | 56,3 | 0 | 17610 | 68,2 |
| 27 | 0,27 | 11700 | 34,9 | 0,24 | 12120 | 36,9 | 0 | 19980 | 70,3 |
| 28 | 0 | 12130 | 63,6 | 0 | 12130 | 63,6 | 0,10 | 13430 | 63,5 |
| 29 | 0 | 15200 | 53,4 | 0 | 15230 | 53,4 | 0 | 18920 | 64,7 |
| 30 | 0,29 | 9300 | 35,0 | 0,15 | 10950 | 45,4 | 0 | 16250 | 73,1 |

Table 2b: Lowest MOE and strength values after 1000 simulations (with reduced residue)

| | **board I** | | **board II** | | **board III** | |
|---|---|---|---|---|---|---|
| | $E_t$ MPa | $f_t$ MPa | $E_t$ MPa | $f_t$ MPa | $E_t$ MPa | $f_t$ Mpa |
| mean $\bar{x}$ | 8170 | 27.5 | 9480 | 35.4 | 13690 | 55.8 |
| stand. dev. s | 544 | 2.2 | 572 | 2.4 | 689 | 3.3 |