IMPACT STRENGTH OF MODIFIED WOOD SPECIES

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Summary: At present commercial methods are available to improve the durability of wood by hydro-thermo-mechanical action without any preservative chemical component. The methods aim at modifying part of the cell fibre structure that provide the food for wood deteriorating organisms. This opens market perspectives for timber where environmental demands can no longer be met by traditional chemically treated wood. Besides the durability also swelling and shrinkage and the UV-sensitivity is considerably reduced. Although this modified wood might be considered as an alternative structural material, it should be taken into account that some of the mechanical properties are changed. Over 4000 km of galvanised steel guard-rail is located along the major traffic roads in the Netherlands. An innovative design for an alternative timber guard-rail was made and a pilot project set up. Although the durability requirements could well be met by the modified wood the ability to withstand impact loads was questioned. For this reason impact bending tests were carried out covering seven wood species of various grade including three modified wood species. Some wood species didn't show any significant bending strength reduction while others like the modified wood species showed a 50% reduction.

Keywords: Timber, impact, bending strength, durability, modified wood.

1 INTRODUCTION

In the Netherlands there is a governmental incentive to stimulate the use of renewable raw materials in building. For this reason initiatives were taken to set up pilot projects to show the viability of timber for structures that normally are designed in steel. One of the projects is the design of a timber guard-rail for heavy traffic roads as an alternative for the traditional steel guard-rail. Reason being the water pollution caused by the fact that the zinc coating of the steel boards drops off after a number of years in service. Although the amount of zinc might seem low per meter, multiplied with 4000 km of guard-rail these quantities become considerable. Zinc coating that lasts longer costs much more and therefore timber might well be considered too. After a thorough design process the guard-rail shown in Fig. 1 was finally chosen. The curved parts should be able to take impact loads of small vehicles while the sturdy poles in the middle take the high load from busses and lorries.

Durability aspects particularly if designed in timber are very important. Maintenance schemas are set to 15 or 20 years indicating that large-scale repair was unwanted at shorter intervals. Considering these demands the choice of wood species became important besides the availability of the species. Now here is where the new heat modified wood species came to mind again. However, unlike most civil engineering structures the relevant type of loading for guard-rails is impact. Old test data shows that timber is well able to withstand impact-bending loads. Would the heat-treated products be able to resist impact load as good as the untreated wood? To answer this question an investigation was set up testing seven wood species in impact bending of which three were of the new heat modified type.

2 WOOD MODIFICATION

Wood has a polymeric cell wall structure, which contains cellulose, hemicellulose and lignin as the main constituencies. The water absorption and therefore the swelling and shrinkage of wood is due to the forming of hydrogen bounds of water molecules between the hydroxyl (OH-)groups of these constituencies as water molecules needs more space. Thermal modification of wood is a treatment where the cell wall polymers are altered by heat. This can lead to cross linking of the OH-groups and therefore to a reduction of the potential positions for water molecules. In other words the hygroscopicity is reduced. Another result is that molecule chains are cut in smaller pieces. A well-known advantage is the reduced sensitivity to bio degradation. However, a draw back is the loss of strength and increased brittleness. However, the last decade new types of thermal treatment were investigated which claim the have minimised the negative effects to a considerable extend. Examples of new thermal treatment methods are known as Perdure (France), Stellac (Finland) and the Plato (Dutch) process. Wood treated according to the Plato process has a better resistance against brown rot, fungi, white and soft rot, Homan et al. (2000).

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The average loss in bending strength vary from 5% to 18% which is less than other thermal treatments. The potential market is cladding, garden fences, furniture, poles, sheds and retaining walls for canals.

3 THE IMPACT STRENGTH OF TIMBER

During the Second World War, when wood was used to a considerable extent for structural members for training aircraft's and gliders, it became evident that additional test data were necessary to improve the understanding of the behaviour of wood under impact load. Therefore, a comprehensive test program was initiated at the Forest Products Laboratory, Madison in the US, to study the effect of rate of loading on the bending and compression parallel to the grain, Liska (1955). The planks were small in size and free of defects and as straight grained as possible. Loading times ranged from 0.3 to 150 seconds. The bending tests were performed in a hydraulic testing machine with a constant head movement. The average of the controls (references) mentioned in Fig. 2 refer to the standard bending tests of Maple. The data for all wood species tested follow the same tendency. At the highest loading rate the strength is about 20 to 30% higher than the standardised bending strength.

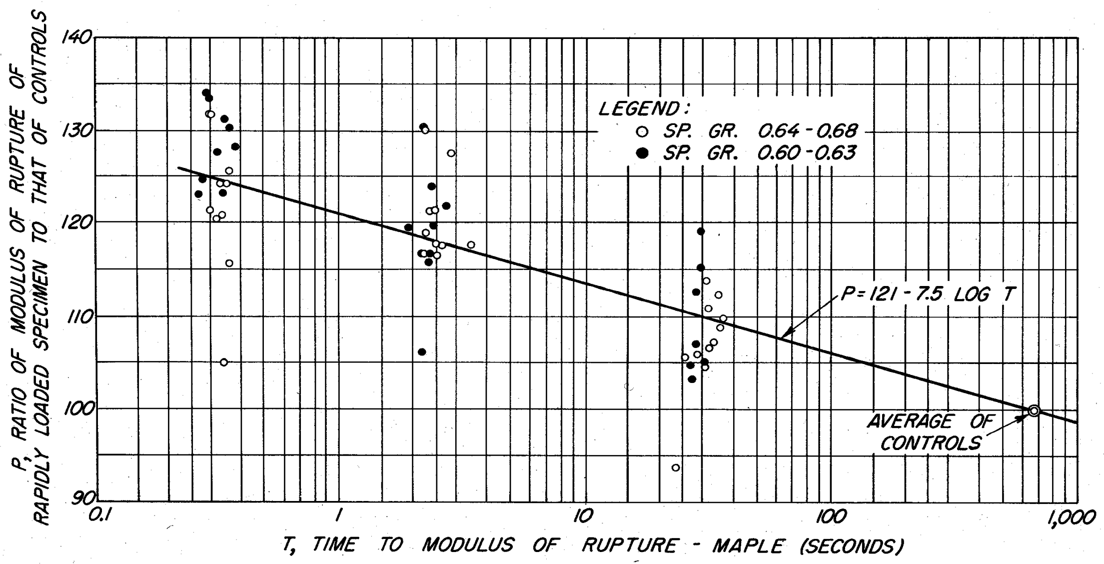
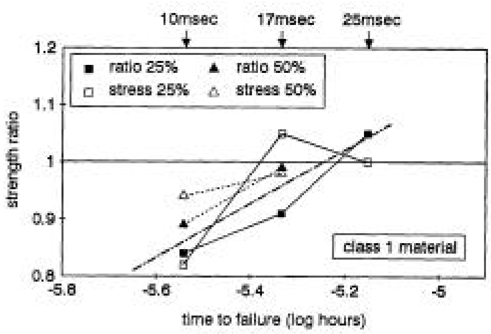


Figure 2: Ratio of static and impact bending strength versus loading rate for Maple, Liska (1955).

More recently Madsen et. al. (1986) and Jansson (1992) studied the impact bending strength on simply supported timber beams by a weight dropped from various heights. The drop height of the 345 kg weight varied from 50, 150 and 300 mm height resulting in a maximum impact velocity of 2,3 m/s. The average times to failure were 25, 17 and 10 milliseconds. Essential in these tests by Jansson (1992) is that the impact force was measured directly by means of a load cell between the drop weight and the test specimen. In the analyses of the results the importance of separating the applied load in a part, which introduce bending stresses and a second part which sets the beam into motion is demonstrated. It should be pointed out that in former timber tests the inertia forces were always disregarded, as they were assumed negligible. Analytical procedures earlier to estimate the inertia effect were explored but rejected. Jansson (1992) turned to a Modal Analysis approach to tackle this problem. Some of his experimental results are given in Fig. 3. The impact bending strength decreases with decreasing time to failure. The deviation from the test results mentioned earlier is considerable. No strength increase of 20 to 30% but a strength decrease of 15% for the shortest loading time than 10 milliseconds was observed.



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4 IMPACT TEST

The aim of the research was to compare the static and impact bending strength in flat wise bending of a number of wood species.

4.1 Rate of impact loading

In the European guard-rail test standard EN 1317 a number of performances levels are specified. The performance level H2 of the Dutch guard-rail was arbitrarily set by the authorities. The two tests prescribed for H2 level are full-scale crash tests with a heavy 18-ton bus and a care. The bus shouldn't break through the structure while for the care test the acceleration of the passengers is limited. As the bus crash tests is regarded as the governing test case for strength the loading speed in the impact tests was deduced from this test. The bus entrance speed is 70 km/h (19.4 m/s). It will hit the guard rail at an angle of 20^0 which leads to a lateral speed of 19.4 sin 20^0= 6.7 m/s. For this reason a load speed of 7.0 m/s was chosen in the impact test.

4.2 The test apparatus and instrumentation

In principle the test apparatus consists of a weight that is dropped from a height and that hits the simply supported beam, span 1400 mm, at mid span. The total weight of the drop piece was 199.0 kg. The weight was instrumented with an accelerometer. The de-acceleration of the drop weight, thought to be a key to determine the excitation force didn't work. As shock waves in the weight itself overruled the de-accelerating signal completely. A transducer (LVDT) attached to the bottom side of the timber specimen directly underneath the impact location, Fig. 4, took the beam deflection. This LVDT was hidden in a stronghold below the specimen to prevent any damage of the device after failure of the specimen. A high-speed video camera (9000 frames per second or one frame every 0.111 ms) enabled monitoring the behaviour during the test. Failure was defined as t he visual appearance of the first crack.

Figure 4: Transducer attached to specimen

4.3 The wood species

The number of specimens per wood species was limited to twenty per wood species. Seven wood species were chosen, Angelim Vermelho (tropical wood), Douglas Fir, Ash, Larch and three so-called heat treated or heat modified wood species. With the PLATO process Douglas Fir was modified (PLATO is a Dutch patented process) while Spruce (Picea Abies) and Pine (Pinus Silvestries) were modified using the Finnish STELLAC process. Clear free were Angelim Vermelho, Douglas Fir and Ash while the others were of a commercial grade including knots and other deficiencies. The PLATO wood was of the lowest grade involving the biggest knots. In the evaluation of the test results these wood species are referred to as Mod.I to III species. All specimens were conditioned at 80% RH and 20^0 C. The batches for standard and impact bending were matched on the basis of MOE.

5 STATIC BENDING TESTS

The standardised static bending tests were carried out corresponding to EN 408. Three-point bending was chosen as it corresponds with the impact test. The specimens of about 1600 mm length were symmetrically positioned on the supports of 1400 mm span and loaded until failure. The load deflection curve was recorded.

5.1 Impact tests

In the impact tests an unexpected phenomenon was recorded by the high speed camera, which appeared to be of importance for the simulations and interpretation of the test results. The pictures clearly showed that after an initial contact and impulse transfer the beam accelerated more rapidly than the weight and lost contact. The impulse transfer was apparently so high that the beam speeded up more than the drop-weight fell. After a short time the drop-weight made contact again and transferred a second impulse. The second separation between both was much smaller and shorter than the first time. Finally, the drop-weight established a permanent contact and worked its way down until failure of the beam occurred. In Fig. 5 two curves are drawn. The bottom one resembles the output signal of the accelerometer attached to the weight and the second one is the deflection both versus time. On the left axis the beam deflection in given in millimetres. The bouncing effect can be observed in this deflection curve, as it isn't a straight curve. Certainly the first bump is clearly visible. The deflection data was used for computer input to simulate the test and find answers to what the bending stress was at time of failure. Janssen (1992) showed that the previous applied analytical methods to determine the bending stresses from the experimental data were questionable. In pursuit of a more reliable method a computer simulation programmes was adopted. The tuning of the simulation programme to fit the recorded test data is obviously very important. In this programme the inertia influences are taken into account in a more accurate manner than in the analytical methods.

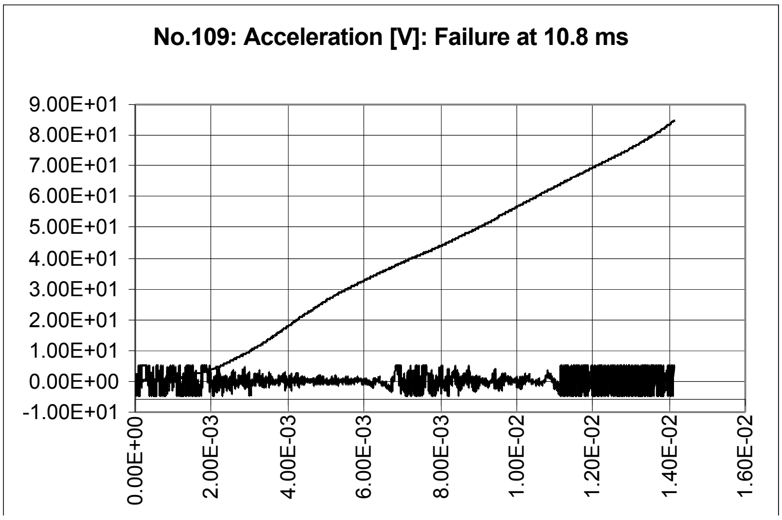

Figure 5: Deflection [mm] versus time [s] at the bottom the accelerometer signal

The FEM simulation model was based on Timoshenko elements. A. Kok (1997) developed this particular simulation model suited to load the beam by impulses and to attach lumped masses at any given time. The model accounts for all inertia effects. A single impulse at the beginning of the simulation represents the initial contact and after a given time the drop-weight, characterised as a lumped mass of a certain quantity and velocity, can be attached to mid span elements. Damping can be introduced to diminish the effect of higher order vibrations. For every specimen the relevant material properties, MOE, density and dimensions were given in the input file. The simulation generated deflection, rotation, bending moments and shear forces. It allowed plotting the simulated time deflection curve, which can be laid over the time deflection graph recorded as shown in Fig. 6.

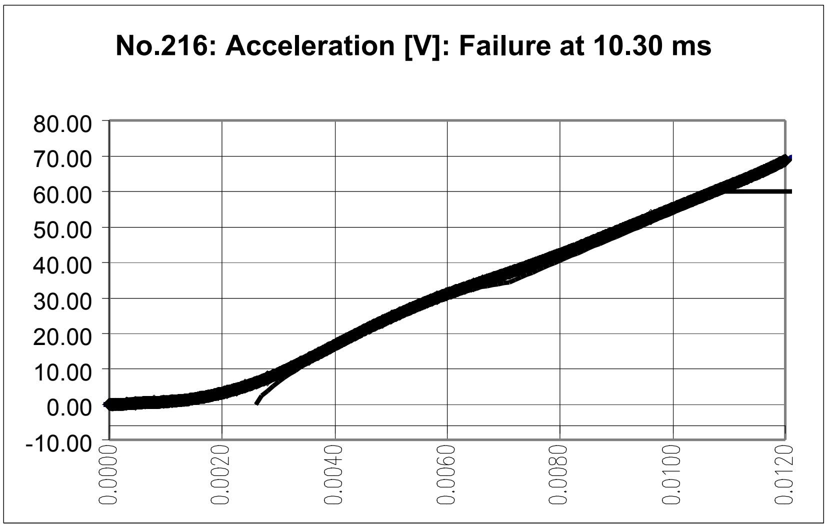

Figure 6: Test and simulation result of deflection [mm] versus time [s]

As shown in the first 2 ms the initial impulse is transferred to the beam during this time. It will be clear that the mathematical beam in the simulation exposed to an impulse reacts immediately. To have agreement the initial contact in the simulation is delayed. The delay time and the initial impulse are chosen such that both experimental and simulation time deflection curve are in good agreement. What happens in the first 2 ms is a point of interest. During this time span the beam accelerates to keep up with the speed of the drop-weight as the drop-weight is dominant in mass. The drop-weight will hardly slow down to allow the beam to speed up. During 0.002 ms the drop-weight will travel about 0.002x7000 mm/s = 14 mm. As Fig. 6 shows the beam deflects about 5 mm in that time span still leaving a difference of 9 mm to be explained. The top surface of the beam must have been penetrated by the drop-weight. However, inspection of the contact surface did not reveal a lasting mark of any reasonable depth (< 1 mm). No other effect could be thought of to explain this phenomenon. Perhaps at these loading rates the behaviour of timber is different of what happens at low loading regimes. The video camera could not give conclusive evidence of such penetration, as it was not focussed at this spot. It was noted that the contact between the specimen and the drop-weight was longer than expected and that it corresponded well with the LVDT readings. As impact test of concrete showed a much more prolonged elastic behaviour under this type of loads, timber might behave similar.

Having set the simulation input variables such that the deflection versus time corresponds well with the test data the model generates the corresponding bending stresses at any location along the beam. The overall majority of beams failed at mid span. For that reason the mid-span bending moment was taken as the governing value for the derivation of the bending strength. Only in some cases knots and slope of grain caused failure initiation a distance from mid span. In Fig. 7 a plot is given of a typical mid span bending moment versus time plot. The maximum bending moment is given in the top right corner in Newtonmeter. The bending stress is derived in the traditional way assuming Hook’s law applies for these conditions.

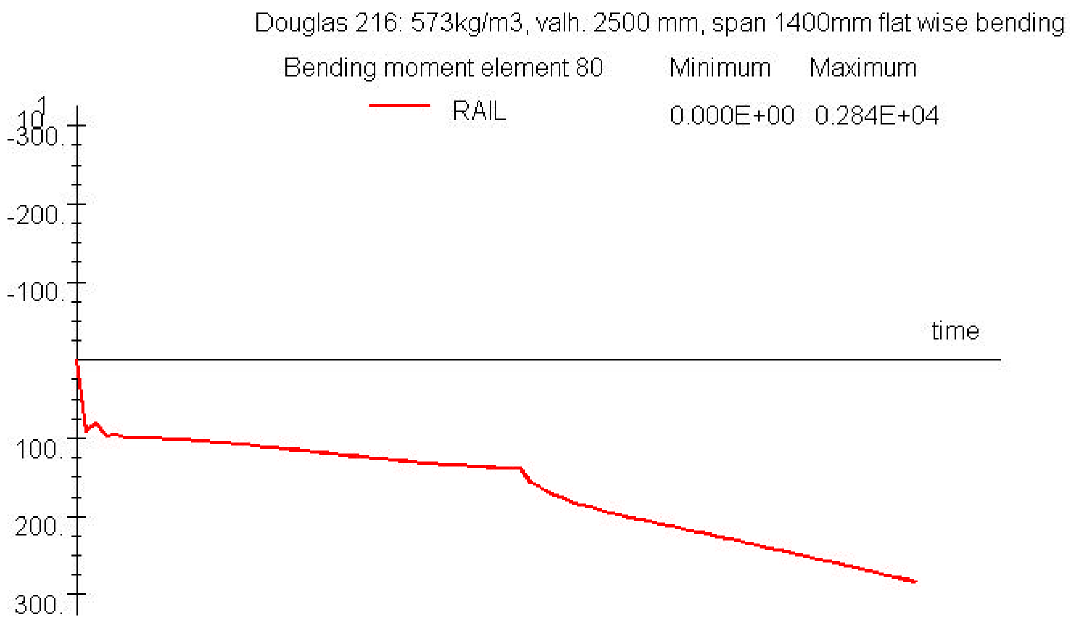

Figure 7: Simulated bending moment [Nm] versus time [s] at mid span

6 EVALUATION OF THE RESULTS

The results are graphically represented in Fig. 8. The strength ratio impact bending / standard bending is given in the lower part of Fig. 8. The wood species associated with the column numbers are given in Table 1. Notices the ratio in Column (3) for Ash, which is higher than 1, while for all other wood species it is considerable smaller than 1. Table 1 contains the results of the simulation per wood species and complimentary the data of the standard bending tests. To drawn more reliable conclusions only based on differences in mean bending strength the statistical t-test was applied. The analysis concludes that with 95% certainty the mean bending strength of Angelim Vemelho, Larch, Mod. I., Mod. II and Mod III wood species in impact bending is indeed significantly different from the standard bending strength. No significant difference was found for Douglas Fir and Ash.

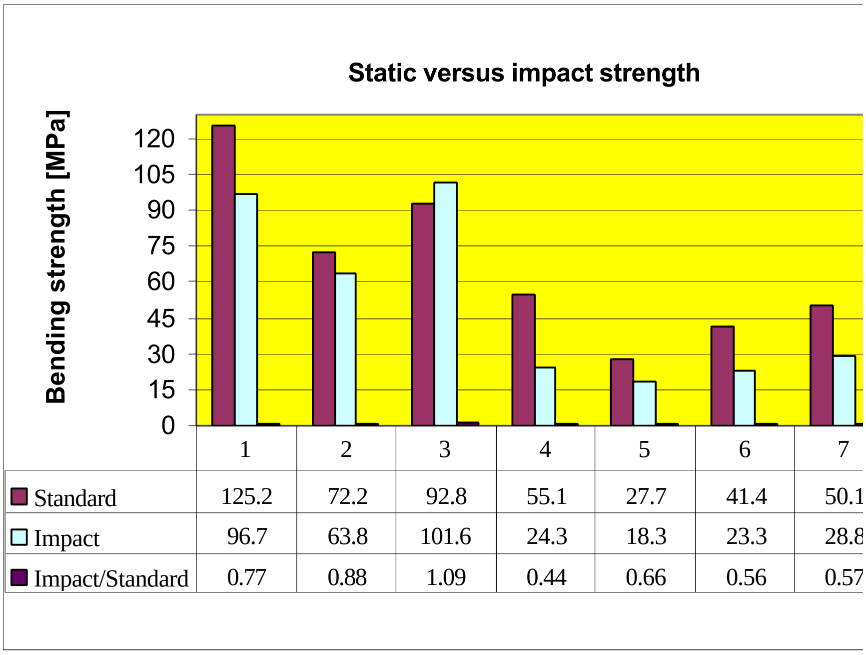

Figure 8: Overview of the impact and static strength results

Table 1: Results of standard and impact strength tests

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Wood species	number of tests	Standard bending	c.v.	number of tests	Impact Bending	c.v.
	n	[MPa]	[%]	n	[MPa]	[%]
Angelim Vermelho (1)	11	125.2	13	10	96.7	38
Douglas Fir (2)	10	72.2	14	10	63.8	39
Ash (3)	4	92.8	9	7	101.6	12
Larch (4)	11	55.1	26	10	24.3	29
Mod.I (5)	12	27.7	23	11	18.3	37
Mod II (6)	13	41.4	24	22	23.3	20
Mod III (7)	17	50.1	24	14	28.8	27

The difference between standard and impact strength has some relation with grade quality as the wood species of commercial grade (containing knots) reduced more in strength than others. Apart from Ash the other wood species free of any knots such as Angelin Vermehlo and Douglas Fir, dropped in bending strength only 23 and 12% respectively. The other wood species with knots such as Larch and the heat-treated modified wood species bending strength dropped 40 to 60 % in strength. The influence of knots turns out to be of significant importance. This agrees with the conclusion by Jansson (1992) that commercial timber behaves worse than clear and free wood specimens.

7 SUMMARY AND CONCLUSIONS

Standard and impact bending tests have been performed on matched timber specimens in flat wise three point bending. The span was 1400 mm while the specimens had a cross-section of about 40x130 mm. Seven wood species were investigated Angelim Vermelho, Douglas Fir, Ash, Larch and three heat modified wood species of Pine, Spruce and Douglas. The number of specimens per wood species in the static and impact test was 10 with some exceptions.

The standard bending tests were performed according to EN 408. For the impact tests a tailor made apparatus was built in absents of any standardised apparatus. The load application consisted of a 199 kg drop-weight which fell from 2.5m height and reached a speed at impact of 7 m/s. During impact the deflection was recorded at mid span. Failure was defined as the occurrence of the first crack. A high-speed camera (9000 frames a second) was used to record the time to failure. In order to determine the bending strength a simulation programme was used. The dynamic programme was tuned in such a way as to simulate the most important phenomenon observed during the impact test up to failure.

Reviewing the strength values derived it was concluded that the mean impact bending strength is in most cases lower than the static bending strength. It was concluded that no significant bending strength difference could be demonstrated for Ash and Douglas Fir. However, all other wood species especially those of commercial grade (containing knots) showed a considerable reduction in strength from 40% up to 60%. Despite the low number of tests the conclusions are in line with the results of Jansson (1992). Furthermore, it was concluded that all modified wood species failed in a very brittle way with short fibres while the drop of bending strength was considerable.

Although from a durability point of view modified wood species have good prospects and may open new markets, their poor behaviour to resist impact loads should be considered when applied in structural engineering. As a result of these tests the use of these modified wood species was no longer considered as a viable option for the timber guard-rail design. It was finally decided to apply tropical hardwood (Angelim Vermehlo) for its high (but reduced) strength in order to limit the cross-sectional dimensions of the timber members and for durability considerations.

8 ACKNOWLEDGEMENT

Thanks to the laboratory staff of Steel & Timber structures. Especially, Hylke Katsma and P. Stolle for their assistance in testing and active participation in solving all practical problems. I also want to express my thanks to Dr. A. Kok for his stimulating help applying his simulating programme. Furthermore, I would like to acknowledge the ministry of Traffic and Waterways DWW and Centrum Hout for their financial support in financing this research project and also to WIT Press who agreed in publishing part of Leijten (2001).

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