Load Testing of Timber Hardwood Bridge Beams

Low Volume Roads Conference
Christchurch July 2003

Paper submitted by: John Laskewitz, Local Government and Transportation Group Manager & Chris Thomas, Graduate Civil Engineer, MWH Invercargill

Abstract

To obtain a better understanding of the load carrying capacity of it's timber bridges, the Southland District Council engaged MWH to undertake a project to load test a number of used hardwood timber beams. The information that the testing provided was used to recalculate bridge posting limits for in-service structures. By using this new information the Southland District Council was able to provide a higher level of service to road users by using less conservative posting limits.

Introduction

The Southland District Council has approximately 150 bridges constructed using hardwood timber beams and other timber components. Posting limits for these bridges have historically been calculated using an allowable bending stress value of f_b = 14 MPa for the timber beams multiplied by an individual beam rating based on it's condition.

To gain a better understanding of whether this value is conservative or tends to overpredict the strength of the timber beams, a series of load tests were carried out on used timber beams.

Methodology

All of the beams to be load tested were inspected prior to testing and their overall dimensions were measured and recorded. Three measurements of the beams depth and width were taken over the length of the beam and then averaged to determine the section properties.

The beams were also rated using a visual analysis and by impact testing where the beams were struck with a hammer and the response used to assess the condition of the beam. From the visual and impact testing the beams were given a condition rating where a beam in brand new condition is considered have a rating of 130%, or being capable of carrying 30% overstress for short periods of time.

Visual signs of poor condition include pitting of the surface and dark staining of the underside of the beam. When struck with a hammer a beam in new condition will produce a crisp sound whereas a beam in poor condition will produce a dull hollow thud. The worst section of the beam dictates the rating that is applied to the whole beam. This rating method is subjective and can vary depending on the skills and experience of the person carrying out the assessment.

The lengths, dimensions and ratings for the beams used in the testing are included in the appendix to this report. Note that the beam number is based on an inventory number and as such is not sequential.

The beam to be tested was then placed on timber packers at each end and a deflection gauge was placed underneath the point of application of the load (the midpoint of the beam) and also at each end of the beam. The packers were spaced at 5400mm from centre to centre for each of the beam tests. A hydraulic jack was placed on top of the beam and a 20 tonne excavator was used as the counterweight to jack against.

The bucket of the digger was placed on the ground in front of the tracks to prevent rotation of the excavator in the event that it was easier to lift the digger than bend the beam. The counterweight placed no direct weight on the beam. The test set up is shown in figure 1 below. (Note that the beam obscures the deflection gauges at the two ends.)

Figure 1. Beam test setup

The pressure in the ram was then increased by an initial amount 2,000 kPa (9.32 kN force) and then stepped up in 1,000 kPa (4.66 kN) amounts. This corresponded to a maximum force of approximately 60 kN being placed on the beam. The initial deflection in the gauges and the deflection at each load increment was recorded. The maximum force that could be applied to the beam was limited by the maximum stroke of the jack.

This was repeated for a total of 12 beams.

Theory

The analysis of the strength of the beams has been carried out using simple bending theory. It was assumed that the beam being tested is simply supported at both ends and the point load is applied at approximately the centre of the beam. The bending moment in the beam was calculated from M = P*(a b / L) where P = Applied point load, L = total length of the beam, a = distance from end of beam to point load and b = L – a.

The bending strength of the beam was calculated by rearranging $M = f_b Z$ to give $f_b = M / Z$, where Z is the section modulus of the beam and f_b is the allowable bending stress. The section modulus was calculated using $Z = bd^2 / 6$, where b = width of the beam and d = depth of the beam.

To analyse the response of the beam the deflection at the two ends of the beam and directly below the applied load were measured. The deflections at the two ends of the beam were recorded to monitor any settlement of the ground or crushing of the packers and was used to correct the deflection at the centre of the beam.

The deflection at the centre of the beam was then used to calculate the modulus of elasticity from $\Delta = (PL^3 / 48EI)*(3a/L – 4(a/L)^3)$ for a non-central point load where Δ = midspan deflection of the beam in mm and I = moment of inertia of the section. The modulus of elasticity was used to determine whether the beam was responding in it's elastic or plastic range. A plot of a typical load deflection curve showing both elastic and plastic response is shown in figure 2 below. The change to plastic behaviour is characterised by the change in slope of the curve and by large deflection increases for a small load increase.

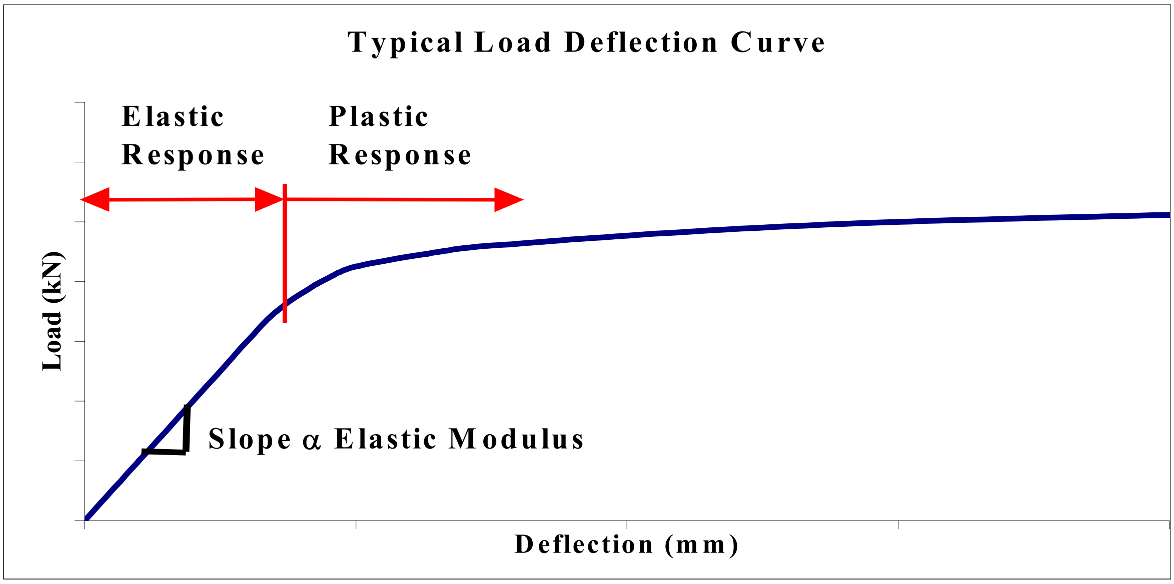


Figure 2. Typical load deflection curve

Results

The load deflection curve for beam number 002 is shown in figure 3 below. Load deflection curves for the other beams are included in the appendix. It shows the test results as well as a linear trendline. The testing gave results for the modulus of elasticity in the elastic region of between 15 and 25 GPa. These values compare well to the values in table 1[1] below for species of timber commonly imported to Southland for bridge building.

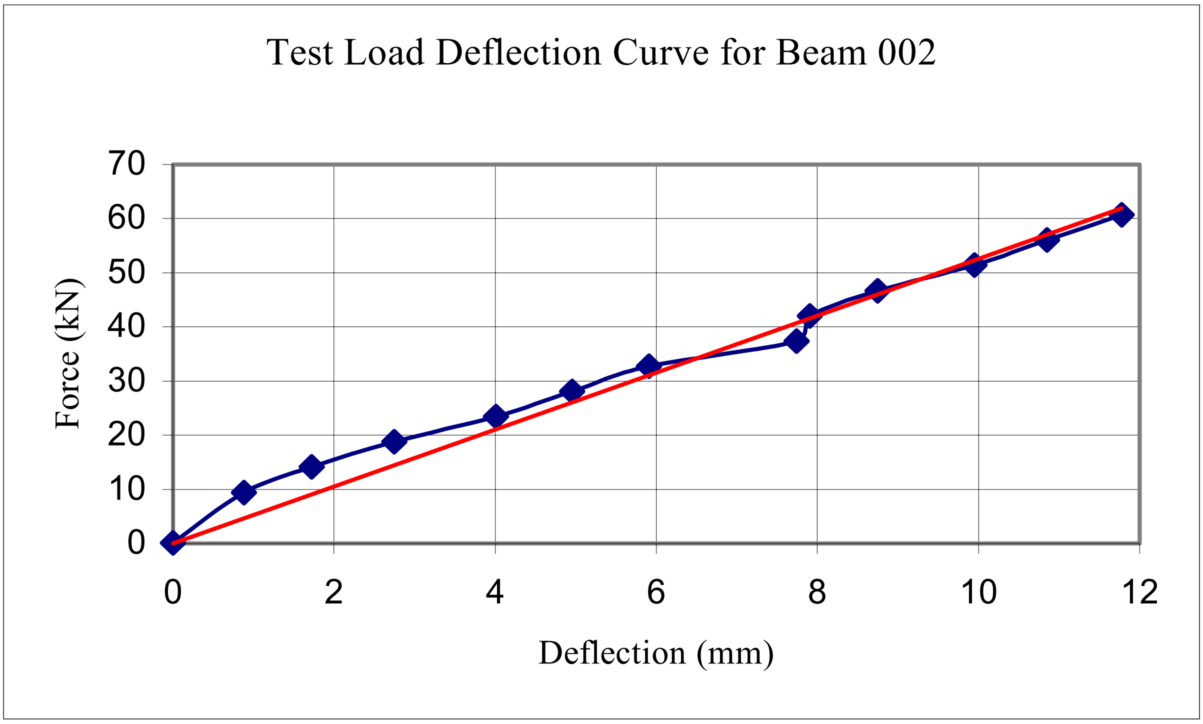


Figure 3. Load deflection curve from test results

Name	Modulus of Elasticity (GPa)
Brush Box	15
Grey Ironbark	24
Tallowwood	18

Table 1. Hardwood timber properties[1]

During the testing of the beams, bending strengths ranging from 16 MPa to 26 MPa were observed within the constraints of the equipment available. These values are shown in figure 4 below as well as the expected value for the bending strength. The expected value for the beam is it's condition rating multiplied by f_b =14 MPa which has been used for posting calculations previously. A column showing the observed bending strength divided by the beam rating is also shown (Observed f_b for beam @ 100%). This relates the bending strength back to the value that would be used in calculations.

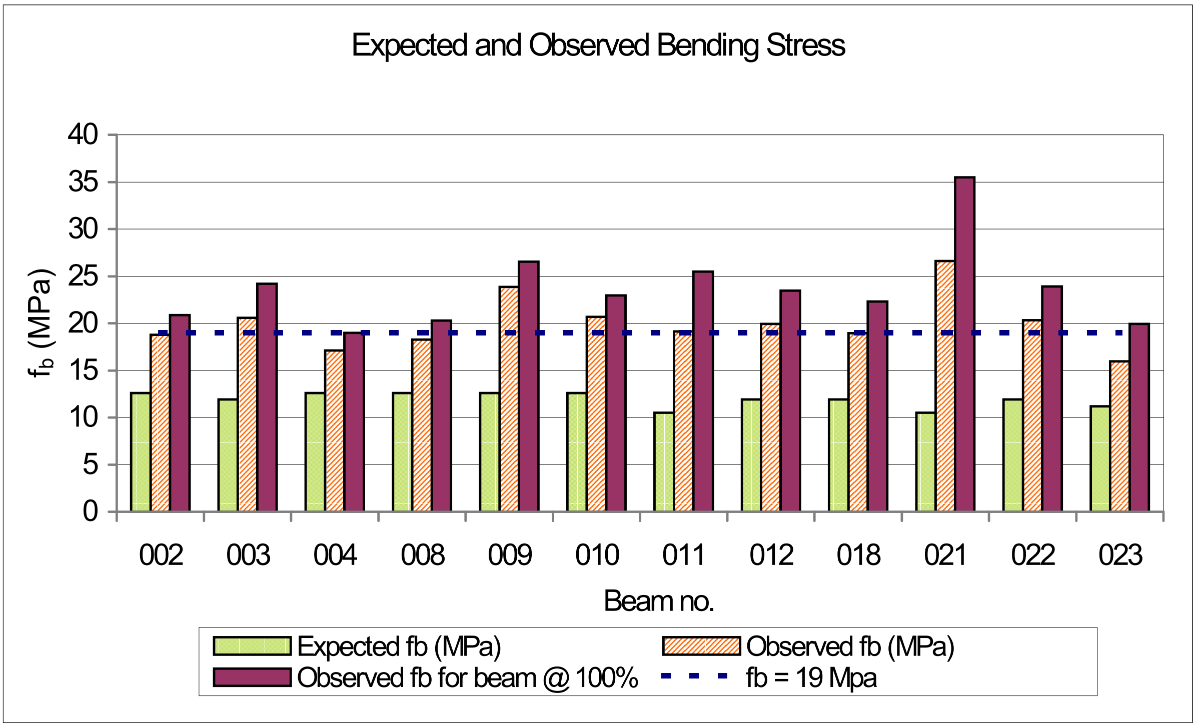


Figure 4. Expected and observed bending strengths

Discussion

The value of 19 MPa is shown as a dashed line in figure 4 above. It can be seen that all of the adjusted observed results are at least equal to this value and this is suggested as a suitable value for bridge posting purposes in the Southland District.

There is still a degree of conservatism in using this value as the testing indicates that the beams were still within the elastic range and were not being overstressed. The results do not indicate the increase in load required to induce plastic behaviour in the beam. To do this further testing to rupture of a beam could be carried out to determine the maximum bending strength that could be used. This is by it's nature destructive and would require a testing rig with a larger resistance to the jack force as well as allowing larger deflections.

It should be noted that the beams had been exposed on four sides to the weather for an extended period prior to and during testing and there had been a wet period prior to the testing. The outer layer and in some cases the centre of the beam would have had a higher moisture content than in-service conditions. This adds some conservatism to the results as the properties of the beam are affected negatively with increasing water content. This level of moisture content would not be expected in service due to protection from the decking above.

Conclusion

The testing of the timber beams has shown that the accepted value of f_b = 14 MPa underestimates the capacity of the hardwood timber beams in use in the Southland District. The analysis shows that a value of f_b = 19 MPa can be used with some conservatism for calculating the strength of the districts hardwood timber bridges.

The hardwood timber in use in the Southland District includes a range of species, seasoning and moisture content characteristics. By testing a number of beams in varying condition and recovered from different areas of the district these characteristics have been accounted for, allowing the result to be reasonably applied district wide.

Without this testing it is very difficult when carrying out calculations to determine the appropriate f_b from literature as it can vary depending on the degree of seasoning, the moisture content of the timber and its species.

If a beam is put into service before it is adequately seasoned there can be a reduction in the value of f_b of between 20 and 50%. Adequate seasoning for the size of section used for bridge beams can be in the order of 12 months. Changes in the moisture content of the beam also has an effect on the value of f_b. A 1% increase in the moisture content has the effect of decreasing f_b by 4%. The value of f_b also varies depending on species in the range of 15 – 30 MPa.

It is very rare for there to be detailed information about the seasoning, moisture content and species of timber used for a particular bridge and it is therefore difficult to determine a value for fb from literature. This testing provides evidence of the material properties for the range of timber currently in use in the Southland District.

The increase in the allowable bending strength has allowed bridge posting limits to be set at higher levels than previously, improving the level of service for road users and reducing the pressure for immediate bridge replacement or upgrade.

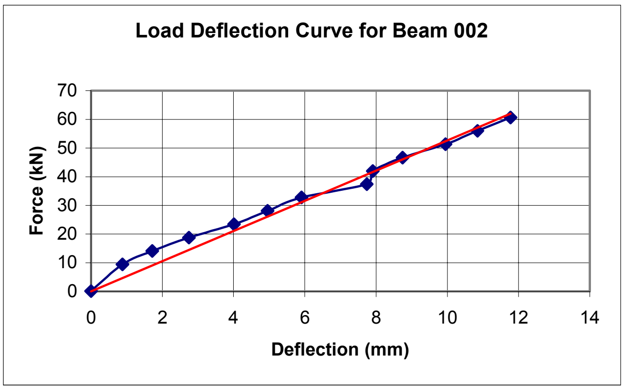
It should be noted that these results can not necessarily be applied directly in other regions due to differences in timber species and seasoning as outlined above.

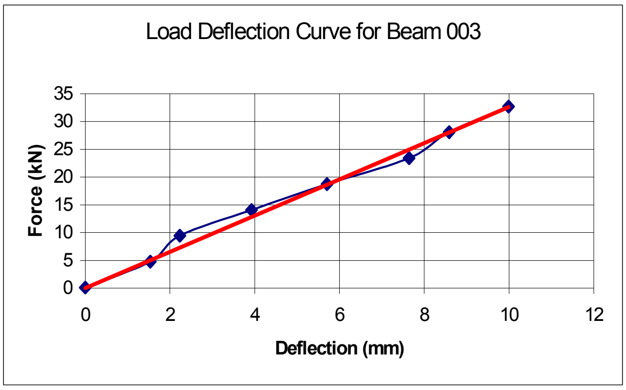
References

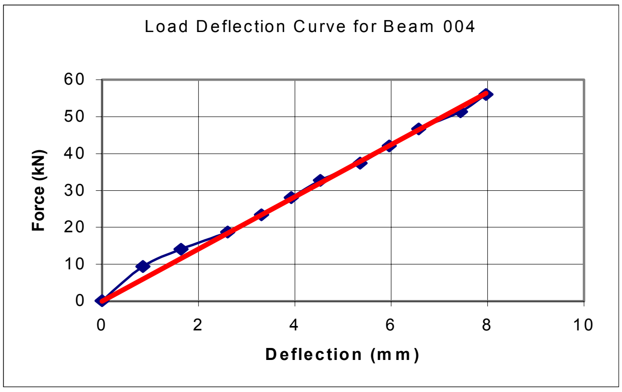
1. Bootle, K R. *Wood in Australia – Types, properties and uses*, Forestry Commission of NSW 1983.

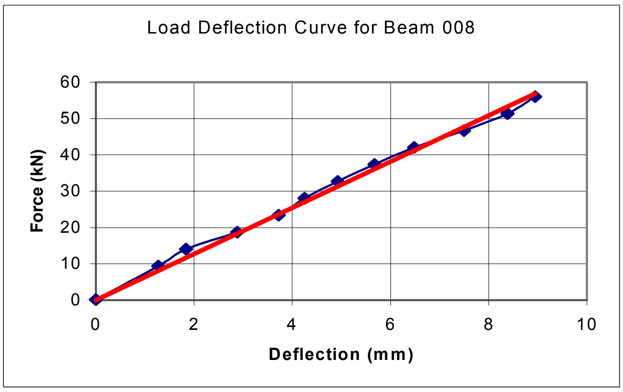
Appendix

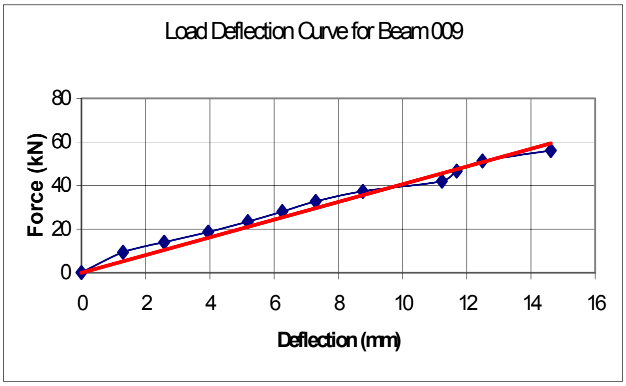
Beam no.	Length (mm)	Depth (mm)	Width (mm)	Rating
002	5700	358.3	210.0	90%
003	5800	344.3	156.3	85%
004	5800	350.7	218.7	90%
008	5900	347.3	209.3	90%
009	5600	345.0	159.7	90%
010	5900	302.3	203.7	90%
011	5700	341.0	149.7	75%
012	5800	310.3	213.7	85%
018	5700	349.7	214.3	85%
021	5900	297.3	164.0	75%
022	5200	349.7	156.0	85%
023	5400	345.3	205.7	80%

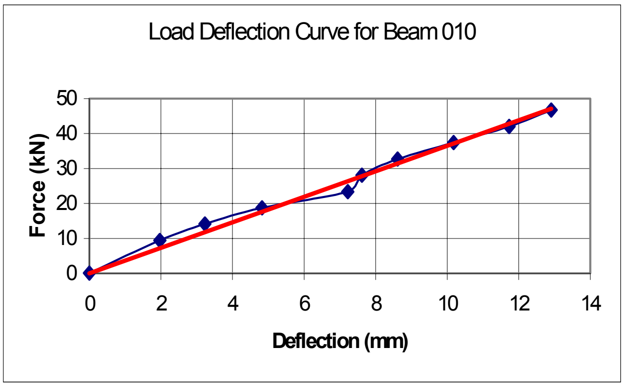


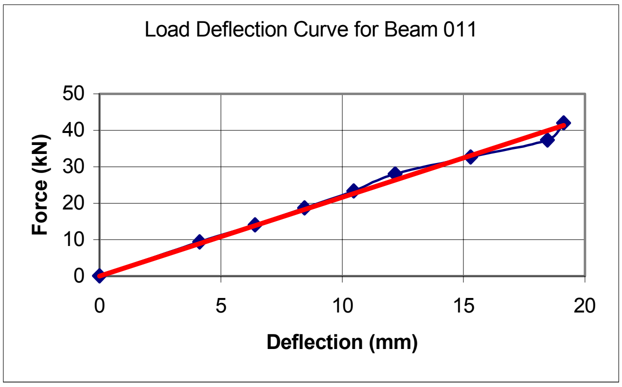


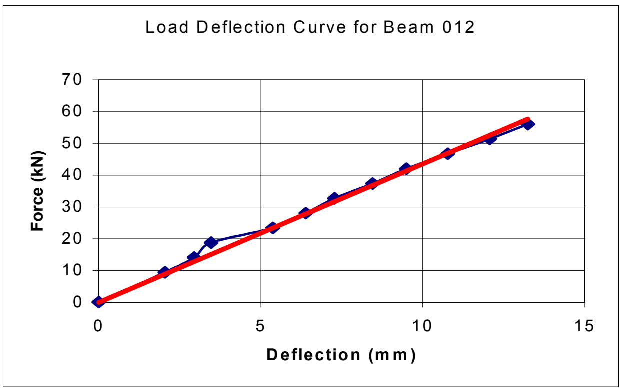


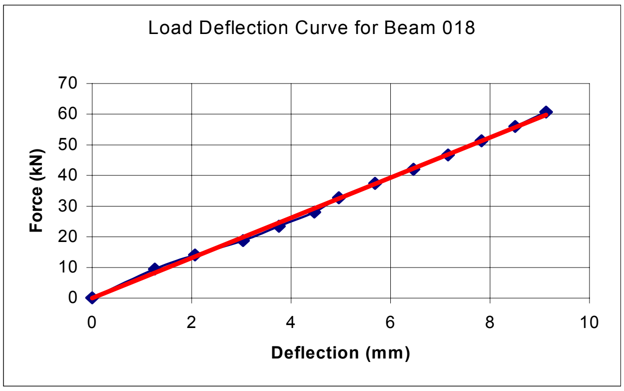


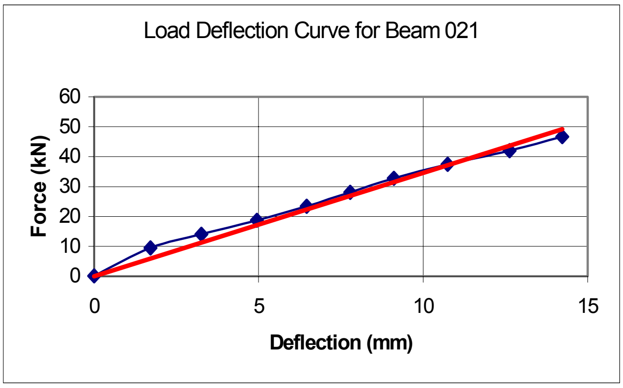

Load Deflection Curve for Beam 009
Force (kN)
Deflection (mm)

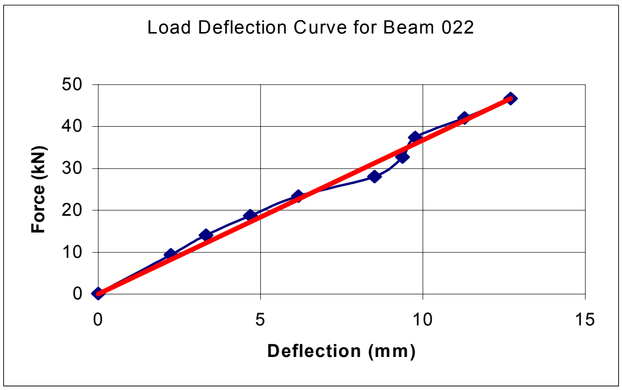

Load Deflection Curve for Beam 010
Force (kN)
Deflection (mm)


Load Deflection Curve for Beam 011
Force (kN)
Deflection (mm)


Load Deflection Curve for Beam 012
Force (kN)
Deflection (mm)


Load Deflection Curve for Beam 018
Force (kN)
Deflection (mm)


Load Deflection Curve for Beam 021
Force (kN)
Deflection (mm)



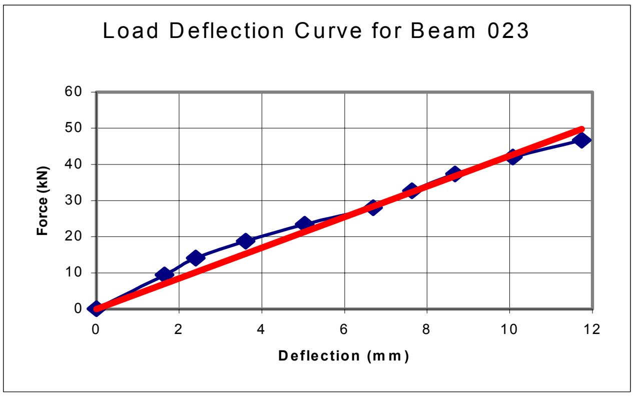


Table taken from Wood in Australia – Types, properties and uses by K R. Bootle

Common names	Latin name	Density kg/m^3	Hard (Janka) (kN)	Rupture (MPa)	Elasticity (GPa)	Crush strength (MPa)	Impact (Izod value) (J)	Availability
Apple, Black	Planchonella australis	880	8.8	145	17		18	NA
Apple, Rough Barked	Angophora floribunda	850	8.6	110	11		18	U
Apple, Smooth Barked	Angophora costata	990	10	132	16	62	24	NA
Ash, alpine	Eucalyptus delegatensis	620	4.9	132	16	62	18	C
Ash, Blue Mountains	Eucalyptus oreades	700	5.2	93	13	48	14	U
Ash, Mountain	Eucalyptus regnans	680	4.9	110	16	63	20	C
Ash, Silver (Qld)	Flindersia bourjotiana	620	5	92	13	52	14	O
Ash, Silvertop	Eucalyptus sieberi	820	9.5	136	17	70	20	C
Bean, Black	Castanospermum australe	770	7.5	115	15	65	11	UO
Beech, Myrtle	Nothofagus cunninghanii	700	5.9	108	14	56	13	CO
Belah	Casurina cristata	1150	20	121	16	48	13	UO
Blackbutt	Eucalyptus pilularis	900	9.1	144	19	77	22	C

Blackbutt, New England	Eucalyptus andrewsii	930	9.5	140	14	68	19	CO
Blackbutt, Westn Aust	Eucalyptus patens	850	6.9	99	13	65	11	U
Blackwood	Acacia melanoxylon	640	5.9	99	13	48	13	CO
Bloodwood, brown	Eucalyptus trachypholia	1050	13	89	13	65	6.9	U
Bloodwood, Red	Eucalyptus gummifera	900	8.8	115	15	70	11	U
Box, Brush	Tristania conferta	900	9.5	123	15	68	15	P
Box, Grey	Eucalyptus microcarpa	1120	15	163	20	80	18	P
Box, grey, coast	Eucalyptus bosistoana	1100	13	163	21	73	26	P
Box, Swamp	Tristania suaveolens	900	9	82	9.4	54	8.7	U
Box, yellow	Eucalyptus melliodora	1100	13	122	14	68	12	P
Brigalow	Acacia harpophylla	900	10	127	18	58	16	P
Brownbarrel	Eucalyptus fastigata	750	6.4	107	14	65	13	P
Candlebark	Eucalyptus rubida	740	5.9	95	13	55	11	U
Carabeen, yellow	Eucalyptus tessellaris	620	4.9	107	15	55	7.8	U
Cedar, Red	Toona australis	420	2.3	65	9.4	36	5.5	P
Gidgee	Acacia cambagei	1250	19	159	18	101	16	P
Gum,Grey	Eucalyptus propinqua	1080	14	140	18	72	21	P
Gum, Maiden's	Eucalyptus maidenii	950	11	147	19	84	22	U
Gum, Manna also Viminalis	Eucalyptus viminalis	750	6	108	14	61	12	P
Gum, Mountain	Eucalyptus dalrympleana	700	5.7	117	13	50	8.2	C
Gum, Southern Blue	Eucalyptus globulus	900	12	146	20	83	23	CP
Gum, Sydney Blue	Eucalyptus saligna	850	9	140	18	68	18	CP
Gum, red, forest	Eucalyptus tereticornis	1050	12	120	14	70	16	P
Gum, Red River	Eucalyptus camaludensis	900	10	101	11	55	8.1	CO

Gum, Rose (Flooded)	Eucalyptus grandis	620	7.5	122	17	66	16	SC
Gum, Round Leaved	Eucalyptus denei	960	12	140	23	54	11	U
Gum, Scribbly	Eucalyptus haemastoma	930	7.5	95	13	60	10	NA
Gum, Shining	Eucalyptus nitens	700	5.8	99	13	58	16	P
Gum, Spotted	Corymbia maculata	950	11	150	23	75	24	C,O
Gum, white, Dunn's	Eucalyptus dunnii	800	7.2	135	22	69	21	U
Gum, Yellow	Eucalyptus leucoxylon	1010	11	111	12	67	8.5	U
Ironbark, Grey	Eucalyptus paniculata	1120	14	181	24	95	27	P
Ironbark, Red	Eucalyptus sideroxylon	1130	13	135	17	75	14	P
Ironbark, red, broadleaved	Eucalyptus fibrosa	1140	14	167	24	79	18	P
Ironbark, red, narrowleaved	Eucalyptus crebra	1090	14	118	16	70	13	P
Ironwood or Grey Myrtle	Backhousia myrtifolia	1020	9.7	118	16	70	13	U
Ironwood , Cooktown	Erythrophleum chlorostachys	1220	ND		ND		ND	P
Jarrah	Eucalyptus marginata	820	8.5	112	13	61	10	SCO
Karri	Eucalyptus diversicolor	900	9	132	19	72	24	SCO
Mahogany, Brush or Red Carabeen	Geissois benthamii	650	5.8	108	14	56	12	NA
Mahogany, Red	Eucalyptus resinifera	950	12	140	18	76	15	P
Mahogany, Rose &Rosewood	Dysoxylum fraseranum	720	8.3	116	12	68	ND	P-U
Mahogany, Southern	Eucalyptus botryoides	920	9	130	18	77	18	P
Mahogany, White	Eucalyptus acmeniodes	1000	10	130	17	76	14	U
Mallet, Brown	Eucalyptus astringens	980	15	179	19	94	ND	U
Marri	Eucalyptus calophylla	850	7.1	125	17	66	23	P
Messmate	Eucalyptus obliqua	780	7.1	118	15	61	15	P

Messmate, Gympie	Eucalyptus cloeziana	1000	12	137	17	73	13	U
Myall	Acacia pendula	1100	est 14	189	19	60	23	P
Peppermint, broad leaved	Eucalyptus dives	820	8.4	110	14	66	12	P
Peppermint, narrowleaved	Eucalyptus australiana	800	7.1	117	14	62	12	NA
Pine, Cypress, white	Callitrus glauca	680	6.5	79	9	53	4.6	CO
She-Oak, Rose (Forest Oak)	Casurina torulosa	920	14	145	20	72	17	P
Stringybark,Blue leaved (NSW)	Eucalyptus agglomerata	880	7.5	135	17	63	14	U
Stringybark, Brown (VIC)	Eucalyptus baxteri	900	7.5	130	16	70	15	U
Stringybark, Red (VIC)	Eucalyptus macrorhyncha	900	8.7	123	16	63	16	U
Stringybark, Silvertop (NSW)	Eucalyptus laevopinea	860	8.8	143	18	73	18	CP
Stringybark, White	Eucalyptus eugeniodes	880	8.8	133	17	68	15	P
Stringybark, Yellow	Eucalyptus muellerana	870	8.5	132	17	72	14	P
Tallowwood	Eucalyptus microcorys	990	8.6	134	18	73	17	P
Turpentine	Syncarpia glomerifera	930	12	142	16	76	9.5	P
Wandoo	Eucalyptus wandoo	1110	15	142	17	82	16	U
Woolybutt	Eucalyptus longifolia	1070	11	128	16	77	13	P