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**TECHNICAL PAPER No. 27**

**MECHANICAL STRESS -  
GRADING OF  
LADDER STILES**

by

**A. Anton**



**FORESTRY COMMISSION OF N.S.W.**  
**Wood Technology and Forest Research Division**  
**Sydney 1978**

## Mechanical Stress Grading of Ladder Stiles

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This paper gives an account of the work done as a result of which Mechanical Stress Grading of ladder stiles was established in Australia.

This work was initiated in 1966 and covers activity between 1966 and 1971.

The Forestry Commission of New South Wales holds patent rights for MICROSTRESS and COMPUTERMATIC Timber Stress Grading Machines which have been patented under the names of "Booth and Anton" in the following countries:

UNITED STATES	Patent No.	338851
AUSTRALIA	" "	285255
NEW ZEALAND	" "	140933
GREAT BRITAIN	" "	11044486
SOUTH AFRICA	" "	65/1266
CANADA	" "	793545

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## MECHANICAL STRESS GRADING OF LADDER STILES

### Summary:

Mechanical grading of Douglas Fir (Oregon) stiles for extension ladders started in 1966 by selecting ladder stock for the Post Master General's Department. Since then Electricity authorities of New South Wales and various County Councils followed up by specifying mechanically graded Douglas Fir stiles for their ladders.

The increasing demand for mechanically graded stiles comes as a result of the findings on investigations on broken ladders in the field. The results of these investigations have shown that the accident could have been prevented if the timber (Douglas Fir) used in the stiles of the broken ladder was selected to our mechanical grading specifications.

The estimated number of Oregon ladder stiles processed through our stress grading machine for various ladder manufacturers in New South Wales since 1966 is of the order of 80,000. 21,000 were graded during 1970 and 8,500 from 1st of January 1971 until 15th May 1971. The demand of mechanically graded ladder stiles is increasing rapidly. The reason for this could be attributed to the excellent field results of ladders manufactured with machine stress graded (M.S.G.) stiles and due to the fact that specifying authorities appreciate the mechanical grading system with its quality control scheme behind it to warrant the quality of the timber used in their equipment.

In related experiments aimed to develop ladders of superior safety we have studied the effect of reinforcing ladders with extruded fibre-glass rod. This technique which will be reported elsewhere has been shown to have little effect on the strength of accepted machine graded stiles but does provide an additional safety factor by causing the stile to always break in a tough manner even if damaged to a degree by rough handling.

In general the criteria for accepted wooden stiles to be used in extension ladders can be summed up as follows:-

- (i) The timber should have a minimum 1:40 low probability value of modulus of rupture of 10.3 GPa (7000 p.s.i.)
- (ii) A specified minimum modulus of elasticity value, for Douglas Fir 10.3 GPa ( $1.5 \times 10^6$  p.s.i.), to secure the above "M.R." value and to warrant a tough failure when the material is tested to destruction.

The phenomenon that there exists a minimum "E" value for timber above which tough fracture in bending occurs was observed by Mr. Anton during the initial investigation on M.S.G. of Douglas Fir stiles and it has been documented in a preliminary report addressed Post Master General's Department (P.M.G.) on the 7th July 1966.

## MECHANICAL STRESS GRADING OF LADDER STILES

Following the requirements of Regulation 142 of "Scaffolding and Lifts Act, 1912-1960"

The standard material for stiles of industrial wooden extension ladders in N.S.W. and to a great extent all over Australia is Douglas Fir imported from Canada and U.S.A.

Recent work with Sitka spruce from the West Coast of Canada and U.S.A. has shown that this species could provide an attractive alternative to Douglas Fir.

When ladders are used under industrial conditions they must comply with the safety regulations, which invariably stipulate that the best materials be used and proven manufacturing methods be adopted to prevent accidents.

The larger ladder users carefully inspect the ladder stiles for quality prior to acceptance to be sure that sufficient steps have been taken to observe the regulation requirements.

Visual inspection and grading of ladder stock for the P.M.G. Department ran into difficulties about 1965 due to:-

- (a) increased need for ladders
- (b) shortage of trained inspectors
- (c) inferior quality of Douglas Fir ladder stock imported to Australia
- (d) awareness of the need for increased safety in this type of equipment to eliminate the accident rate as part of a major safety campaign throughout our industries.

In an endeavour to secure a higher degree of safety through stringent visual rules in selecting wooden stock for ladders, a supply crisis developed without achieving the objective.

To overcome the above problems the Division of Wood Technology (now Wood Technology and Forest Research Division = WIFRD) proposed to the P.M.G. Department and some ladder manufacturers that an experiment be carried out to select ladder stock by stiffness evaluation using the grading machine.

The first experiment was made on a batch of 21 stiles selected at random at the rate of 1 in 10 from a batch of Douglas Fir (Oregon) ladder stock.

A grading program for the "Microstress"\* grading machine was selected which would enable the range of modulus of elasticity in the stile population to be sorted into five "E" ranges. It was found after a

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\* also relates to "Computermatic" Timber Stress Grading Machines

preliminary run that the full range of modulus of elasticity typical of Douglas Fir population was present in the clear material.

After grading, the stiles were measured for modulus of elasticity "E" on the flat at the least stiff zone as indicated by the grading machine, then tested to destruction in third point bending in this zone on edge. This preliminary investigation has shown that:-

- (i) "E" varies from stile to stile as well along the length of the same stile.
- (ii) Out of 21 stiles 15 had an "E" value in the least zone greater than 10.3 GPa ( $1.5 \times 10^6$  p.s.i.).
- (iii) The 1:40 low probability value for modulus of rupture for material with an "E" value greater than 10.3 GPa ( $1.5 \times 10^6$  p.s.i.) would be well above 41.4 MPa (6000 p.s.i.).

Hence it appeared that mechanically graded ladder stiles with an "E" value greater than 10.3 GPa ( $1.5 \times 10^6$  p.s.i.) would have a well established low probability value for modulus of rupture and a well determined range of modulus of elasticity.

These two factors could be used to improve the design of ladders and secure higher safety.

In view of the need for a safe ladder and the indication from the preliminary investigation that greater acceptance rate for ladder stock was anticipated against that of visual selection, a further large scale experiment was carried out.

This experiment was carried out by using the WIFRD grading machine programmed to discriminate material with an "E" value greater than 10.3 GPa ( $1.5 \times 10^6$  p.s.i.) on 769 commercial stiles such as would be offered by a ladder maker for inspection. They were first visually graded by Post Office inspectors to P.M.G. visual specifications.

The yield of accepted stiles visually was 51% and by machine grading 74%. Furthermore the agreement between the methods was poor - the visual inspection accepting stiles which by M.S.G. were not acceptable and vice versa. The results of the comparison of the two methods of grading in this experiment are tabulated below:

MSG		VISUAL GRADE		MSG OF VISUALLY ACCEPTED STILES		MSG OF VISUAL REJECT STILES	
Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail
565	204	394	375	326	68	237	138

After verification of stiffness all the accepted stiles by the machine were used in the manufacture of ladders and placed in normal field service. They carried an embedded tag disc with the statement that they were machine graded. As far as is known none of these ladders has failed in the field.

The rejected stiles were tested for stiffness then tested to destruction first at the least stiff zone and then at other points many of which were above "E" - 10.3 GPa ( $1.5 \times 10^6$  p.s.i.). There were 333 breaking tests obtained from 204 rejected stiles. During the breaking of these stiles it was soon noted that there were two basic types of fractures present. A tough fracture occurred where the stiles failed first in compression and after maximum load was passed the stile was still capable of carrying a high percentage of the maximum load and was in one piece. Brittle fracture on the other hand was characterised by initial break in tension followed by catastrophic fracture of the stile into two pieces. Clearly there would be a difference in the safety performance of the two types of stiles even if they broke at the same load.

Analysis of the results showed that as the modulus of elasticity increased the probability of brittle fracture was reduced. If an "E" cut off point of 10.3 GPa ( $1.5 \times 10^6$  p.s.i.) was chosen the 2.5% lower probable minimum modulus of rupture was found to be 48.3 MPa (7000 p.s.i.) and at the same time the probability of a brittle fracture occurring was reduced to a negligible level. It was hard to be precise on this latter point since the concept of what represents the borderline between brittle and non brittle fracture is hard to define in quantitative terms even though typical cases of each type of fracture are quite obvious as shown in attached load deflection curves obtained during breaking tests.

Small clear samples were taken following bending tests and values for the properties listed below were obtained.

- Compression parallel to the grain
- Izod
- Denison (Toughness Test)
- Number of growth rings per inch
- Density
- Slope of grain
- Moisture Content
- Shear parallel to grain

The correlation coefficients between the various mechanical and physical properties versus modulus of elasticity "E" and modulus of rupture "R" are tabulated below.

TABLE OF CORRELATION COEFFICIENTS (333 VALUES)								
	R	Compression // to grain	Izod value	Denison toughness value	Number of rings per inch	Density	Slope of grain	Shear // to grain
E	0.54	0.54	0.50	0.45	-0.34	0.35	0.22*	0.04
R	1.00	0.73	0.24	0.47	-0.48	0.67	0.16*	0.30

\* The correlation coefficient for slope of grain is expected to be higher when measured at the point where fracture takes place.

From the above results it was decided that the best practical way of predicting the strength and performance characteristics of Oregon stiles was by stiffness evaluation using the stress grading machine which measures "E" along the length of the stile as it passes through.

Density when measured at the point or close to the region where modulus of rupture was determined shows a high correlation with modulus of rupture and a poor one with modulus of elasticity. To use density as a criterion for selecting ladder stock has been considered of little practical value since its correlation to "E" has been shown to be poor. It has to be reminded that "E" and tough fracture are related.

The measured deflection values in the laboratory tests to determine modulus of elasticity were used to evaluate the accuracy of the stress grading machine. The accuracy of the grading machine was proven remarkably high as shown in the "S.G.M. Efficiency Chart".

Commercial use of M.S.G. for P.M.G. Department ladders was then introduced and has proven very successful. The increased yield of stiles enabled the back log in supply to be overcome and as a result of these successes the use of machine graded ladders has been adopted by Electricity Supply Authorities. Ladder breakage in service appears to have been reduced to negligible proportions.

At present the following is the practice for machine grading of seasoned Douglas Fir ladder stiles with the "Computermatic" grader: (Douglas Fir stiles must be dried to a m/c not greater than 18% before submitted for grading).

Five grades are sorted in one pass and the accepted stiles are divided by the machine into three grades according to the following program. This allows the accepted stiles to be matched more effectively in pairs to give a ladder with more uniform deflection properties. There are two reject grades which are not marked by the grading machine and find their way into other products.

GRADE	"E" RANGE (Minimum)	REMARKS	
1	15.4 GPa ( $2.24 \times 10^6$ p.s.i.)	Accepted stiles	Extreme fibre stress during M.S.G. 20.7 MPa (3000 p.s.i.)
2	12.8 GPa ( $1.85 \times 10^6$ p.s.i.)		
3	10.3 GPa ( $1.5 \times 10^6$ p.s.i.)		
4	7.7 GPa (below $1.12 \times 10^6$ p.s.i.)	Rejected stiles	
5	7.7 GPa ( )		

A sample stile is taken from every 100 accepted and it is measured for stiffness on the flat over the same span and load as the machine to verify correctness of grading. The sample is then broken on edge using third point bending to determine modulus of rupture and mode of failure. Moisture content and other properties are determined from samples taken near to the broken section.

This information is accumulated on quality control charts and records to indicate any trend in grade performance. So far in close to 80,000 stiles no alteration to the program has been found necessary.

Dependent variable	Independent variable	Symbol	Number of values	Mean	S.D.	Correlation coefficient between Y and $X_i$ (r)
Modulus of rupture MPa (p.s.i.)	-	Y	122	72.5 (10518)	12.4 (1800)	-
	Modulus of elasticity "e" (10 <sup>6</sup> GPa x p.s.i.)	$X_1$	122	13.70 (1.98)	2.28 (0.33)	0.61
	Compression // to grain MPa (p.s.i.)	$X_2$	122	52.90 (7667)	10.20 (1474)	0.45
	Izod value <sup>j</sup> (ft. lbs)	$X_3$	122	11.30 (8.36)	4.68 (3.45)	0.37
	Denison toughness value <sup>j</sup> (in. lbs)	$X_4$	122	14.70 (130.0)	5.50 (49)	0.18
	Annual rings per cm (inch)	$X_5$	122	7.50 (19)	3.70 (9.30)	-0.01
	Density <sup>3</sup> kg/m <sup>3</sup> (lbs/ft <sup>3</sup> )	$X_6$	122	568.70 (35.50)	68.90 (4.30)	0.52
	Slope of grain	$X_7$	122	0.042	0.042	0.09
	Moisture content %	$X_8$	122	13.00	1.80	-0.17

CORRELATION MATRIX (input variables)

(122 values)

			Comp. // grain $X_2$	IZOD $X_3$	Density $X_6$
Y	1.00	0.61*	0.45	0.37*	0.52
$X_1$	-	1.00	0.54	0.55*	0.51
$X_2$	-	-	1.00	0.36	0.56
$X_3$	-	-	-	1.00	0.29
$X_6$	-	-	-	-	1.00

Note: (i) The highest value of correlation coefficient is between "R" and "E".

(ii) The relationship between "E" versus IZOD value is greater than that of "R" versus IZOD value. This supports the suggested proposition by the author in 1966 that there is a relationship between modulus of elasticity and tough fracture in clear timber.

A statistical multiple regression analysis of the most significant independent variables ( $X_1$ ) versus modulus of rupture Y was carried out the results of which are given below.

(1) "E" v<sup>s</sup> "R"       $Y = \bar{Y} + b(x_1 - \bar{x}_1)$

$\bar{Y} = 10518$

$b = 3470.17$

$\bar{x}_1 = 1.98$

$x_1 =$  value of "E"  $10^{-6}$  p.s.i.

Correlation coefficient 0.61 highly significant (> 1% level)

(2) Regression equation of

R against "E" and Density combination

$$Y = \bar{Y} + b_1(x_1 - \bar{x}_1) + b_6(x_6 - \bar{x}_6)$$

Where mean Modulus of Rupture =  $\bar{Y} = 10518$  p.s.i.

mean modulus of elasticity  $\bar{x}_1 = 1.98 \times 10^{-6}$  p.s.i.

mean Density  $\bar{x}_6 = 35.54$  lb/ft<sup>3</sup>

Regression coefficient  $b_1 = 2619.77$

Regression coefficient  $b_6 = 128.1$

Note - these equations/calculations are shown in Imperial terms.

Coefficient of Determination R = 0.430 highly significant ( 1% level)

The same work was carried out for the following combinations of  $X_i$

(a) Modulus of Elasticity }  
Density }  $V^S$  Modulus of Rupture  
Compression }

R = 0.432 highly significant ( 1% level)

(b) Modulus of Elasticity }  
Izod }  $V^S$  Modulus of Rupture  
Density }  
Compression }

R = 0.433 highly significant ( 1% level)

The statistical evaluation of the results from the quality control tests support the original decision to use "E" as a strength indicator for ladder stiles stock.

The following additional requirements have been applied industrially as a result of experience to machine graded stiles.

- (a) It is necessary to test the timber to see that its moisture content has an average value of 15% and a maximum value not exceeding 18%. The moisture content restriction is imposed to secure prevention of checking and splitting of stiles around the rungs.
- (b) It is necessary to check visually for compression fractures as they do not always cause rejection by the machine - about 10 compression fractures have been found in 80,000 stiles.
- (c) Accepted stiles by the machine are visually checked to ensure that they are free of any defect the severity or position of which may affect the useful life of the ladder or its performance in service.

These defects to name a few are:-

- (i) Severe surface checks.
- (ii) Slope of grain exceeding one in fifteen.
- (iii) Small marginal pin knots appearing on the narrow face of the stile.

Ladder stiles from Sitka spruce of undefined origin have been investigated and the same "E" value of 10.3 GPa ( $1.5 \times 10^6$  p.s.i.) has been found to be suitable for dividing stiles into tough and brittle fracture types.

A current investigation of Sitka spruce (ladder grade) from the west coast of Canada reveals that an "E" value of 7.7 GPa ( $1.4 \times 10^6$  p.s.i.) could be sufficient to exclude brittle material and secure a 1:40 minimum probable MR of 48.3 MPa (7000 p.s.i.).

So far the concept has not been extended quantitatively to other timber species but has been noted for clear radiata pine and poplar during experimental testing.

Theoretically all that is required for a material to show tough fracture is to possess a suitable balance between modulus of elasticity in compression and tension and high tensile strength. In related experiments aimed at developing ladders of superior safety by using fibreglass rod reinforcement on the tension side of the stile has shown, a change in mode of failure of stiles of low "E" value which otherwise would have broken in a brittle manner.

The reinforcing of low "E" stiles in tension, forces them to break in a tough manner, by failing primarily in compression due to the improvement in tensile strength provided by the fibreglass rod.

The mechanical properties of the fibreglass rod used are as follows.

Modulus of elasticity = 12.4 GPa ( $1.8 \times 10^6$  p.s.i.)

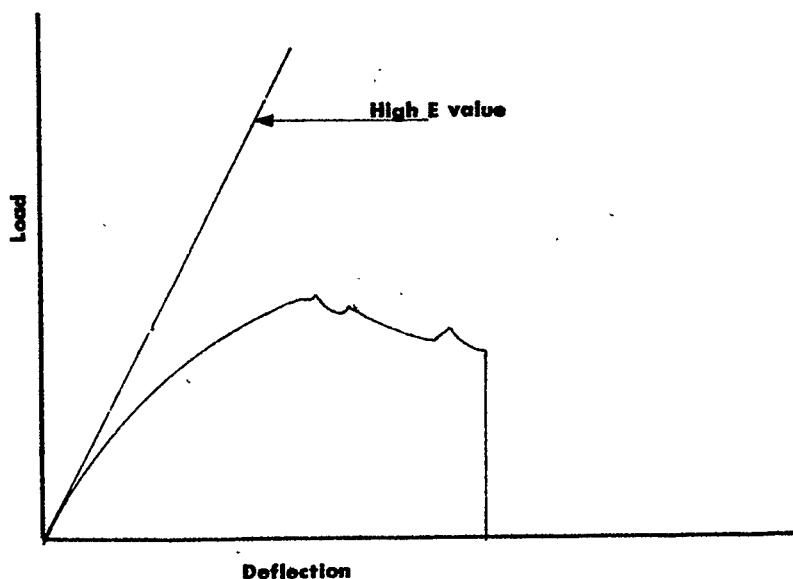
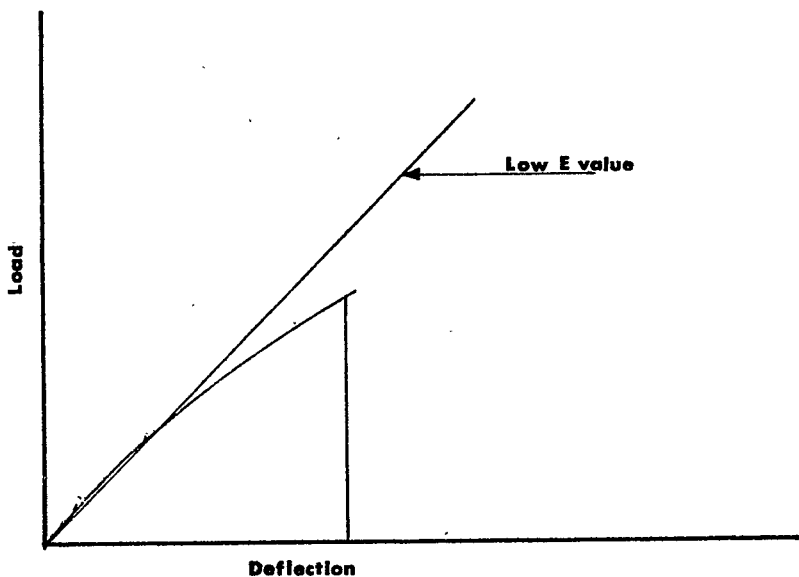
Tensile strength = 551.6 MPa (80,000 p.s.i.)

This technique has been shown to have little effect on the strength of accepted mechanically graded stiles with an "E" value greater than 10.3 GPa ( $1.5 \times 10^6$  p.s.i.) but does provide an additional safety factor by causing the stile to always break in a tough manner even if damaged to a degree by rough handling.

Ladders of this superior type using reinforced machine graded stiles are now commercially available manufactured to a specification jointly developed by the Division of Wood Technology and the Electricity Authority of N.S.W. The new Australian standard for ladders will include this type of ladder as well as the unreinforced M.S.G. type. The performance of all these various types of ladders has been verified in a series of full scale tests. The tests were made to destruction with the ladders extended and resting against a pole. The test ladders, of the extension type, were specially manufactured from accepted and reject machine graded stiles, both unreinforced and reinforced with fibreglass rod and steel wire. The results proved conclusively the superiority of accepted M.S.G. stiles either unreinforced or reinforced with fibreglass rod.

Steel wire reinforcing was shown to have no value as expected and rejected M.S.G. stiles as predicted failed catastrophically. These tests were jointly sponsored by the Electricity Authority of N.S.W., the Prospect County Council and the Forestry Commission of New South Wales.

TYPICAL LOAD DEFLECTION CURVES  
For  
Douglas Fir ladder stiles



Efficiency Control Chart for Ladder Stiles

"COMPUTERMATIC" CM-216 - Program III

