TWP Timber and Wood Products Research Centre

CSR I-BEAMS

R.W.CLINCH, AIWSc., MIEAust.
M.STEEDMAN, Dip.CE.
TWP REPORT NO. 166
APRIL 1991

, ROCKHAMPTON, AUSTRALIA 4700. TELEPHONE (079) 361177 TELEX AA49176

SUMMARY

I–Beams made from Slash Pine flanges and either hardboard or particleboard webs were fabricated and evaluated for flexural stiffness. Prior to fabrication the web and flange materials were evaluated for flexural stiffness. In addition the rupture strength in tension of the web materials was determined.

From these data a mathematical model was developed for the stiffness of a composite I–Beam. It varied from the classical rigidity model which is based on the product of stiffness and second moment of area (EI).

The effect of holes in the web was evaluated. The essential ingredient is the magnitude of shear force at the point at which a hole can be made. Assuming a uniformly distributed load on the beam, a large circular hole can be drilled where the shear force is zero. Smaller holes can be drilled in proportion to the increase in shear force.

TABLE OF CONTENTS

1.0 INTRODUCTION

This study on wood composite I–Beams is an advancement on work previously conducted by Clinch (1987) and Clinch and Steedman (1989).

In this study, I–Beams were to be fabricated from Slash Pine flanges and either hardboard or particleboard webs. The I–Beams were to be evaluated for flexural stiffness. This work is somewhat parallel to that carried out by Tang (1990), however, the I–Beams in the Tang studies were fabricated by Truss–Joist Inc., (USA).

Prior to fabrication, both the web and flange materials were to be evaluated for flexural stiffness. In addition, the rupture strength in tension of the web materials was to be determined. This property is assumed to be the best indicator of strength of the web material in determining Modulus of Rupture of the composite I–Beam (Leichti et al, 1990).

From these data a mathematical model was to be developed for the stiffness of a composite I–Beam. The classical rigidity model for composite beams is based on the sums of products of stiffness and second moment of area (EI), of each component.

In addition the effect of holes in the web was to be evaluated. The major factor in the placement of holes in a web is the shear carried by the web. In I–Beams, the webs are designed to carry all the shear force, while the flanges are designed to provide all the moment resistance. (McLain, 1990).

2.0 CHARACTERISATION OF WEB MATERIAL

Prior to fabrication of the beams, the web materials, that is, particleboard and hardboard (Weatherflex), were evaluated for stiffness and rupture strength.

2.1 Flexural Stiffness of Particleboard

The particleboard selected for the web material was ordinary grade and 12 mm thick. Specimens 330 mm long by 100 mm wide were selected from strips taken along the lengthwise edges (E) of boards and along the centre (C).

Specimens were tested for flexure in an Instron Universal Testing Machine in the 0.5 kN range, using a 300 mm span. Results are shown in Table I. The mean value of MOE was 4,246 MPa with a c.v. of 9.4%. Moisture content was 10%.

2.2 Rupture Strength of Particleboard

Dog–bone specimens of a standard profile were cut from the specimens used in the flexural test. Specimens were tested in tension to failure in the Instron Machine in the 5.0 kN range. Results are shown in Table II. The mean stress at failure was 13 MPa with a c.v. of 14%. A t–test was made of results, which showed the strength of the "centre" specimens were not different from that of the "edge" specimens.

2.3 Flexural Stiffness of Hardboard

In a manner similar to the testing of particleboard, the flexural stiffness of hardboard specimens was determined. Results are shown in Table III. The mean MoE was 4,440 MPa with a c.v. of 12.4%.

2.4 Rupture Strength of Hardboard

As with the particleboard, "dog–bone" specimens were cut from the specimens on completion of flexural testing, and tested in tension to failure. Results are shown in Table IV.

3.0 CHARACTERISATION OF FLANGE MATERIAL

The flange material was specially selected F11 Slash Pine which had been machine stress graded. Its visual appearance was consistent with Structural Grade 1.

3.1 Flexural Stiffness of Flanges (Flat)

The flange material, which was to be utilised in beams in the flat direction, was evaluated in flexure using an in–grade procedure where the span in the 4–point loading system was 18h, i.e., 18 x 45 mm or 810 mm. Results for the 70 mm x 45 mm specimens are shown in Table V. The mean MoE was 16,908 MPa with a c.v. of 9.4%.

Results for evaluation of the 90 mm x 45 mm specimens are shown in Table VI. The mean MoE was 16,531 MPa with a c.v. of 8.7%.

Analyses were made of the in–grade stiffness of both sets of specimens in the flat direction as shown in Appendix 1 and Appendix 2. The 70 mm x 45 mm specimens were consistent with an F–grade of F22, while the 90 mm x 45 mm specimens were consistent with an F–grade of F22 or better.

3.2 Flexural Stiffness of Flanges (High)

Although the flange specimens were to be used in the flat direction, flexural evaluations were conducted in the "high" direction for both the 70 mm x 45 mm and 90 mm x 45 mm sticks.

Results are shown in Table VII and Table VIII. Specimens were consistent with an F–grade far in excess of F11, and more likely F17 to F22.

4.0 FLEXURAL PROPERTIES OF I–BEAMS

4.1 Particleboard Webbed Beams

Three particleboard webbed I–beams were made up from the 70 mm x 45 mm flanges "flat", with the 12 mm particleboard web embedded 12 mm deep into each flange.

A resorcinol formaldehyde adhesive was used to effect the bond. The overall height of each beam was 170 mm, with the distance between flanges being 80 mm. These beams were made up in ascending order of stiffness and strength of their components.

They were tested in flexure with 4–point loading and gave results shown in Tables IX, X and XI. The MoE of the beams were (1P) 16,600 MPa, (2P) 16,100 MPa and (3P) 16,400 MPa respectively.

4.2 Hardboard Webbed Beams

In a manner similar to that for the particleboard beams, 3 beams with 9.5 mm hardboard webs were made up and tested in flexure. Results are shown in Tables XII, XIII and XIV.

The MoE of the beams were (1H) 15,800 MPa, (2H) 16,000 MPa, and (3H) 17,400 MPa.

4.3 Hardboard Webbed Beam No. 1 With Holes

The Hardboard webbed beam (H1) was progressively drilled with holes and loaded. Tables XV through XXII show the change in MoE as holes were added, and finally a slot was cut out of the centre of the web. Without holes the value of MoE was 15,800 MPa as in Plate 1, with the central zone slotted out and 2–80 mm holes plus 2–60 mm holes as in Plate 2, the MoE had reduced to 14,500 MPa.

5.0 MATHEMATICAL MODEL OF I–BEAMS

Using the data from the six beams, the average values of MoE for the beams, MoE for the flange material and MoE for the web material, as well as average second moment of area, as shown in Table XXIII, a mathematical model was developed.

The classical rigidity model that:

$$(EI)_{beam} = (EI)_{flanges} + (EI)_{web}$$

was tested using the data in Table XXIV.

i.e.

$$(16{,}400 \times 2.58 \times 10^7) = (16{,}100 \times 2.46 \times 10^7) + (4{,}150 \times 0.04 \times 10^7)$$

$$42{,}312 \times 10^7 = 39{,}606 \times 10^7 + 166 \times 10^7$$

$$42{,}300 \neq 40{,}000 + 200$$

A better relationship for the data was:

$$E_{beam} = E_{flanges} + E_{web} * 17.5 \left[\left(\frac{tw}{B}\right)\left(\frac{Ew}{Ef}\right)\left(\frac{h}{H}\right)^3\right]$$

i.e.

$$16{,}400 = 16{,}100 + 4{,}150 * 17.5 \left[\frac{2.78}{70}\left(\frac{80}{170}\right)^3\right]$$

$$16{,}400 = 16{,}100 + 300$$

Note that $\frac{tw \times Ew}{E_f}$ transforms the web thickness to 2.78 mm

The relationship holds reasonably well for extrapolated beam depths, however this needs to be tested further.

6.0 CONCLUSION

The combined stiffnesses of the composite I–beams investigated in this study do not follow the classical rigidity model. However, a relationship was developed which is essentially that:

$$E_{beam} = E_{flanges} + E_{web} * I_{factor}$$

This needs to be investigated further.

The placement of holes in webs is governed by the shear force pattern of a beam loaded with a uniformly distributed load. Where the shear force is zero, in the centre of a beam, large holes can be drilled, or even slotted, with no drastic effect on the stiffness of a beam. In a graduated way, smaller holes can be drilled as the shear force increases towards the end of a beam.

7.0 ACKNOWLEDGEMENTS

The authors wish to acknowledge the support for this project by Dr Alan Halligan, Technology Controller, CSR Wood Panels Groups, under TWP contract T74–564. Also advice from Mr Roger Thomas and technical help from Mr Paul Furber, both active in TWP, is appreciated.

8.0 REFERENCES

Clinch, R.W., (1987), Bending Tests on Particleboard and Plywood Webbed I–Beams for APRI, TWP Report No. 144, Capricornia Institute, Rockhampton.

Clinch, R.W., and Steedman, M. (1989), Tests on Prototype Particleboard Webbed I–Beams, TWP Report No. 156, Capricornia Institute, Rockhampton.

Leichti, R.J.,Falk, R.H., and Laufenberg, T.L., (1989) Prefabricated Wood Composite I–Beams: A Literature Review, Wood and Fiber Science, Vol.22, No.1, pages 62–79.

McLain, T.E., (1990) How I–Joists Work, Wood Design Focus, Vol.1, No.1., pages 18–19.

Tang, R.C., (1990), Composite Wood I–Joist Research at Auburn University, Wood Design Focus, Vol.1, No.1., pages 7–8.

TABLE I P'BOARD DATA

Flexure Test

SPEC	Δ	P/ Δ	I	Density p	E
	chart	N/mm	mm4	kg/m3	Mpa
C1	4.2	89.29	14328	728	3505
C2	3.5	107.14	14328	765	4206
C3	3.2	117.19	14400	774	4578
C4	3.2	117.19	14400	790	4578
C5	3.0	125.00	14400	785	4883
C6	3.5	107.14	14400	778	4185
C7	3.8	98.68	14328	745	3874
E1	3.8	98.68	14328	752	3874
E2	3.5	107.14	14400	777	4185
E3	3.5	107.14	14472	766	4164
E4	3.0	125.00	14544	802	4834
E5	3.2	117.19	14472	781	4555
E6	3.5	107.14	14472	790	4164
E7	3.8	98.68	14400	756	3855
			MEAN	**771**	**4246**
			StDev	**20**	**399**
			c.v.	**0.026**	**0.094**
			5%ile	**738**	**3588**

TABLE II PART'BOARD DATA

Tensile Test

SPEC	Width	Thickness	Fail Load	Fail Stress
	mm	mm	kN	MPa
C1	20.6	12	2.60	10.52
C2	20.2	12	3.25	13.41
C3	20.8	12	3.25	13.02
C4	20.5	12	3.33	13.54
C5	20.8	12	3.58	14.34
C6	20.6	12	3.25	13.15
C7	21.1	12	2.93	11.57
E1	24.6	12	2.53	8.57
E2	20.1	12	3.46	14.34
E3	20.6	12	3.15	12.74
E4	20.8	12	3.92	15.71
E5	21.0	12	3.53	14.01
E6	20.2	12	3.54	14.60
E7	20.5	12	3.03	12.32
			MEAN	**12.99**
			StDev	**1.83**
			c.v.	**0.141**
			5%ile	**9.98**

TABLE III HARDBOARD DATA

Flexure Test

SPEC	**Δ**	**P/ Δ**	**I**	**Density p**	**E**
	chart	N/mm	mm4	kg/m3	Mpa
1A	8.9	42.13	6859	986	3455
1B	8.3	45.18	6859	997	3705
1C	9.0	41.67	6895	996	3399
1D	8.1	46.30	6895	999	3777
2A	6.5	57.69	6859	1003	4731
2B	7.0	53.57	6859	994	4393
2C	6.7	55.97	6895	1009	4566
2D	7.0	53.57	6930	1003	4348
3A	6.3	59.52	6930	1050	4831
3B	6.2	60.48	6930	1048	4909
3C	5.7	65.79	6859	1045	5395
3D	6.0	62.50	6823	1050	5152
4A	6.3	59.52	6930	1031	4831
4B	5.8	64.66	6930	1031	5248
4C	6.0	62.50	6859	1034	5126
4D	6.5	57.69	6859	1031	4731
5A	7.6	49.34	6895	974	4026
5B	7.5	50.00	6895	962	4079
5C	7.4	50.68	6859	981	4156
5D	7.8	48.08	6859	992	3943
6A	6.8	55.15	6930	1021	4476
6B	7.0	53.57	6930	1024	4348
6C	6.8	55.15	6859	1033	4523
6D	6.7	55.97	6788	1042	4638
			MEAN	**1014**	**4449**
			StDev	**26**	**551**
			c.v.	**0.026**	**0.124**
			5%ile	**971**	**3541**

TABLE IV HARDBOARD DATA

Tensile Test

SPEC	Width	Thickness	Fail Load	Fail Stress
	mm	mm	kN	MPa
1A	19.9	9.5	3.52	18.62
1B	20.0	9.5	3.72	19.58
1C	20.1	9.5	3.65	19.11
1D	20.4	9.5	3.83	19.76
2A	20.2	9.5	4.20	21.89
2B	20.4	9.5	4.16	21.47
2C	19.7	9.5	4.26	22.76
2D	19.8	9.5	4.17	22.17
3A	20.3	9.5	4.63	24.01
3B	20.2	9.5	4.70	24.49
3C	21.0	9.5	4.97	24.91
3D	20.2	9.5	4.60	23.97
4A	20.4	9.5	4.92	25.39
4B	20.2	9.5	5.10	26.58
4C	20.2	9.5	4.88	25.43
4D	20.5	9.5	4.78	24.54
5A	20.4	9.5	3.88	20.02
5B	20.7	9.5	4.05	20.59
5C	20.2	9.5	4.01	20.90
5D	20.6	9.5	4.02	20.54
6A	20.8	9.5	4.43	22.42
6B	20.4	9.5	4.48	23.12
6C	19.8	9.5	4.35	23.13
6D	19.1	9.5	4.00	22.04
			MEAN	**22.39**
			StDev	**2.22**
			c.v.	**0.099**
			5%ile	**18.74**

TABLE V 7045 DATA

2P=0.6 kN Flexure Test Flat

SPEC	Δ chart	P/Δ N/mm	E Mpa
15	0.76	394.74	14008
10	0.72	416.67	14786
4	0.69	434.78	15429
20	0.69	434.78	15429
8	0.69	434.78	15429
22	0.68	441.18	15656
17	0.67	447.76	15890
5	0.67	447.76	15890
12	0.66	454.55	16130
21	0.66	454.55	16130
19	0.65	461.54	16379
1	0.63	476.19	16899
11	0.63	476.19	16899
14	0.60	500.00	17743
16	0.59	508.47	18044
18	0.59	508.47	18044
3	0.59	508.47	18044
7	0.58	517.24	18355
6	0.58	517.24	18355
2	0.55	545.45	19356
9	0.55	545.45	19356
13	0.54	555.56	19715
	MEAN	**476**	**16908**
	StDev	**45**	**1592**
	c.v.	**0.094**	**0.094**
	5%ile	**402**	**14281**

		TABLE VI	9045 DATA	
		2P=0.6 kN	Flexure Test	Flat
SPEC	Δ	**P/Δ**	**E**	
	chart	N/mm	Mpa	
1	0.62	483.87	13355	
6	0.55	545.45	15055	
11	0.54	555.56	15334	
2	0.53	566.04	15623	
10	0.53	566.04	15623	
4	0.52	576.92	15924	
8	0.52	576.92	15924	
7	0.50	600.00	16561	
13	0.49	612.24	16899	
3	0.48	625.00	17251	
14	0.47	638.30	17618	
12	0.46	652.17	18001	
15	0.46	652.17	18001	
5	0.45	666.67	18401	
9	0.45	666.67	18401	
	MEAN	**599**	**16531**	
	StDev	**52**	**1445**	
	c.v.	**0.087**	**0.087**	
	5%ile	**513**	**14147**	

TABLE VII **7045 DATA**

SPEC	Δ	P/Δ	E
		2P=0.4 kN	Flexure Test High
	chart	N/mm	Mpa
15	0.76	263.16	14527
4	0.70	285.71	15772
10	0.70	285.71	15772
20	0.70	285.71	15772
8	0.66	303.03	16728
12	0.66	303.03	16728
17	0.66	303.03	16728
1	0.66	303.03	16728
11	0.65	307.69	16985
22	0.65	307.69	16985
7	0.63	317.46	17524
16	0.63	317.46	17524
6	0.62	322.58	17807
19	0.62	322.58	17807
5	0.61	327.87	18099
18	0.61	327.87	18099
3	0.60	333.33	18401
21	0.60	333.33	18401
2	0.57	350.88	19369
13	0.56	357.14	19715
14	0.56	357.14	19715
9	0.54	370.37	20445
	MEAN	**318**	**17529**
	StDev	**27**	**1467**
	c.v.	**0.084**	**0.084**
	5%ile	**274**	**15108**

TABLE VIII 9045 **DATA**

2P=0.4 kN Flexure Test High

SPEC	**Δ**	**P/Δ**	**E**
	chart	N/mm	Mpa
1	0.82	243.90	13464
2	0.73	273.97	15123
6	0.72	277.78	15333
11	0.71	281.69	15549
10	0.69	289.86	16000
4	0.68	294.12	16235
8	0.66	303.03	16727
13	0.62	322.58	17806
14	0.61	327.87	18098
3	0.60	333.33	18400
7	0.60	333.33	18400
12	0.60	333.33	18400
15	0.59	338.98	18712
5	0.58	344.83	19034
9	0.55	363.64	20073
	MEAN	**311**	**17157**
	StDev	**33**	**1821**
	c.v.	**0.106**	**0.106**
	5%ile	**256**	**14152**

TABLE IX BEAM 1P DATA

Flexure Test

E top =	15429	MPa
E bot =	15429	MPa
Eweb =	4246	MPa
Web t =	12	mm
I tot =	2.5813E+07	mm4

LOAD kN	Δ mm
0	0.00
1	1.04
2	2.18
3	3.28
4	4.36
5	5.44
6	6.49
7	7.54

E eff = **16573** Mpa

TABLE X BEAM 2P DATA

Flexure Test

E top =	16130	MPa
E bot =	16899	MPa
Eweb =	4246	MPa
Web t =	12	mm
I tot =	2.5804E+07	mm4

LOAD	Δ
kN	mm
0	0.00
1	1.14
2	2.39
3	3.55
4	4.66
5	5.76
6	6.87
7	7.95

E eff = **16052** Mpa

TABLE XI BEAM 3P DATA

Flexure Test

E top =	15656	MPa
E bot =	18044	MPa
Eweb =	4246	MPa
Web t =	12	mm
I tot =	2.5802E+07	mm4

LOAD	Δ
kN	mm
0	0.00
1	1.23
2	2.41
3	3.51
4	4.58
5	5.65
6	6.73
7	7.83

E eff = **16351** Mpa

TABLE XII BEAM 1H DATA

	Flexure Test	**No Holes**
E top =	14008	MPa
E bot =	14786	MPa
Eweb =	3584	MPa
Web t =	9.5	mm
I tot =	2.5773E+07	mm4

LOAD	Δ
kN	mm
0.0000	0.00
0.9775	0.96
1.9558	2.12
2.9394	3.28
3.9177	4.37
4.9013	5.48
5.8796	6.57
6.8632	7.68

E eff = **15765** Mpa

TABLE XIII BEAM 2H DATA

Flexure Test

E top =	15429	MPa
E bot =	15890	MPa
Eweb =	4051	MPa
Web t =	9.5	mm
I tot =	2.5777E+07	mm4

LOAD kN	Δ mm
0	0.00
1	1.27
2	2.45
3	3.56
4	4.69
5	5.79
6	6.89
7	7.97

E eff = **16032** Mpa

TABLE XIV BEAM 3H DATA

Flexure Test

E top =	16899	MPa
E bot =	18355	MPa
Eweb =	4509	MPa
Web t =	9.5	mm
I tot =	2.5776E+07	mm4

LOAD	Δ
kN	mm
0	0.00
1	1.10
2	2.18
3	3.17
4	4.18
5	5.21
6	6.22
7	7.23

E eff = **17415** Mpa

TABLE XV BEAM 1H DATA

Flexure Test **2-80 mm Holes**

E top =	14008	MPa
E bot =	14786	MPa
Eweb =	3584	MPa
Web t =	9.5	mm
I tot =	2.5773E+07	mm4

LOAD	Δ
kN	mm
0	0.00
1	1.09
2	2.31
3	3.46
4	4.59
5	5.72
6	6.84
7	7.95

E eff = **15749** Mpa

TABLE XVI BEAM 1H DATA

Flexure Test **4-80 mm Holes**

E top =	14008	MPa
E bot =	14786	MPa
Eweb =	3584	MPa
Web t =	9.5	mm
I tot =	2.5773E+07	mm4

LOAD	Δ
kN	mm
0	0.00
1	1.13
2	2.35
3	3.51
4	4.65
5	5.78
6	6.91
7	8.02

E eff = **15679** Mpa

TABLE XVII BEAM 1H DATA

Flexure Test **4-80** **+2-38**

E top =	14008	MPa
E bot =	14786	MPa
Eweb =	3584	MPa
Web t =	9.5	mm
I tot =	2.5773E+07	mm4

LOAD	Δ
kN	mm
0	0.00
1	1.09
2	2.28
3	3.45
4	4.57
5	5.70
6	6.84
7	7.97

E eff = **15644** Mpa

TABLE XVIII BEAM 1H DATA

	Flexure Test	**4-80**	**+2-50**
E top =	14008	MPa	
E bot =	14786	MPa	
Eweb =	3584	MPa	
Web t =	9.5	mm	
I tot =	2.5773E+07	mm4	

LOAD	Δ
kN	mm
0	0.00
1	1.12
2	2.36
3	3.49
4	4.62
5	5.76
6	6.88
7	8.01

E eff = **15644** Mpa

TABLE XIX BEAM 1H DATA

Flexure Test **4-80** **+2-80**

E top =	14008	MPa
E bot =	14786	MPa
Eweb =	3584	MPa
Web t =	9.5	mm
I tot =	2.5773E+07	mm4

LOAD	Δ
kN	mm
0	0.00
1	1.15
2	2.35
3	3.53
4	4.67
5	5.82
6	6.96
7	8.11
8	9.30

E eff = **15439** Mpa

TABLE	XX	BEAM 1H	DATA	
		Flexure Test	**4-80**	**+2-80**
	E top =	14008	MPa	**+2-38**
	E bot =	14786	MPa	
	Eweb =	3584	MPa	
	Web t =	9.5	mm	
	I tot =	2.5773E+07	mm4	

LOAD	Δ
kN	mm
0	0.00
1	1.22
2	2.48
3	3.70
4	4.91
5	6.07
6	7.24
7	8.37
8	9.55

E eff = **15142** Mpa

TABLE XXI BEAM 1H DATA

	Flexure Test	**4-80**		**+2-80**
E top =	14008	MPa		**+2-60**
E bot =	14786	MPa		
Eweb =	3584	MPa		
Web t =	9.5	mm		
I tot =	2.5773E+07	mm4		

LOAD	Δ
kN	mm
0	0.00
1	1.19
2	2.48
3	3.64
4	4.81
5	6.00
6	7.20
7	8.38
8	9.62

E eff = **14918** Mpa

TABLE XXII BEAM 1H DATA

	Flexure Test	**SLOT**	**+2-80**
E top =	14008	MPa	**+2-60**
E bot =	14786	MPa	
Eweb =	3584	MPa	
Web t =	9.5	mm	
I tot =	2.5773E+07	mm4	

LOAD	Δ
kN	mm
0	0.00
1	1.24
2	2.51
3	3.74
4	4.99
5	6.20
6	7.44
7	8.61
8	9.80

E eff = **14520** Mpa

TABLE XXIII **HARD + PART**

BEAM	FLANGE	FLANGE E MPa	AVE. E MPa	WEB E MPa	WEB t mm	TRANS t mm	BEAM I x E7 mm4	BEAM E MPa
1H	T	14008	14397	3584	9.5	2.36	2.5768	15765
	B	14786						
2H	T	15429	15660	4051	9.5	2.46	2.5777	16032
	B	15890						
3H	T	16899	17627	4509	9.5	2.43	2.5776	17415
	B	18355						
1P	T	15429	15429	4246	12	3.30	2.5813	16573
	B	15429						
2P	T	16130	16515	4246	12	3.09	2.5804	16052
	B	16899						
3P	T	15656	16850	4246	12	3.02	2.5802	16351
	B	18044						
	Mean	16080	**16080**	**4147**	11	**2.78**	2.5790	**16365**
	StDev	1273	1150	312	1.37	0.41	0.0019	585.63
	c.v.	0.079	0.071	0.075	0.12	0.146	0.0007	0.036
	5%ile	13979	14183	3632	8.74	2.11	2.5759	15398

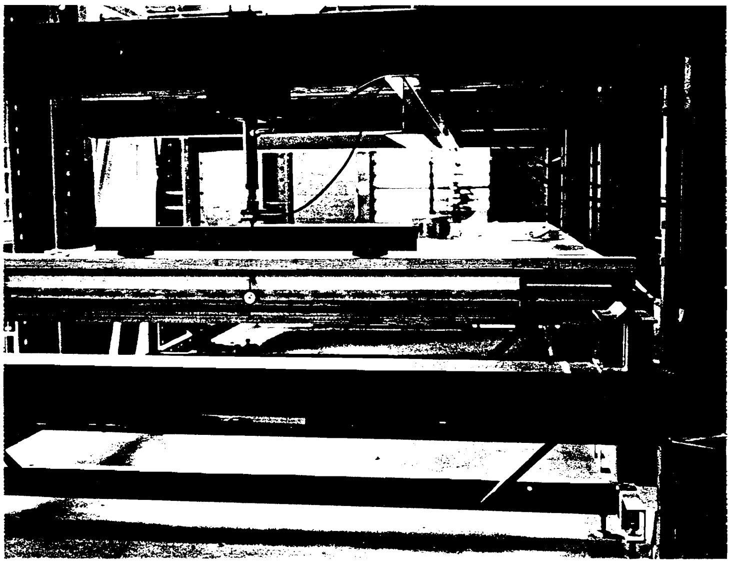

Plate 1

Typical I–Beam Without Holes

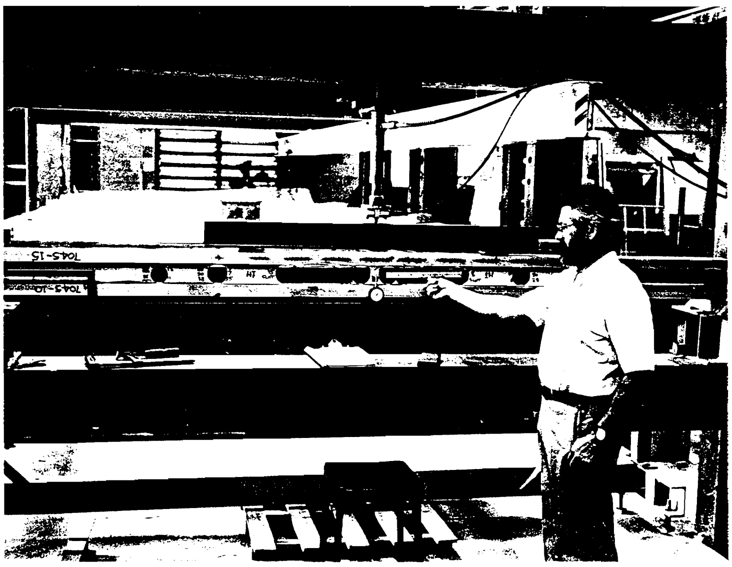

Plate 2

Beam H–1 With Slots, 2–80mm Holes Plus 2–60mm Holes

APPENDIX 1

CALCULATIONS OF IN-GRADE STIFFNESS (**E***) (FLAT) OF SLASH PINE 70 x 45 mm STUDS

(Ref: Draft Australian Standard: Methods For Evaluation of Strength and Stiffness of Graded Timber)

STIFFNESS

From Table V: P/Δ (mean) = 476 N/mm
coeff. var. V_E = 0.094

Calculations: Deflection $\delta = PL^3/28.173\, E_m I$ (note: P is half total load)

$E_m = PL^3/ 28.173\ \delta I$

$E_m = (476) \times 10^3 \times 810^3 \times 12 / 28.173 \times 70 \times 45^3$

$E_m = \underline{16\,908}$ MPa

Sampling Factor $k_s = 1 - (0.7 \times V_E / n^{0.5})$

$k_s = 1 - (0.7 \times 0.094 / 22^{0.5})$

$k_s = \underline{0.986}$

Material Factor $\gamma_E = \underline{1}$

Basic Working Stress $E^* = k_s \times E_s / \gamma_E$

$E^* = 0.986 \times 16\,908 / 1$

$E^* = 16\,671$ MPa

$E_{0.05} = 16\,908 - 1.65(16\,908 \times 0.094)$

$E_{0.05} = \underline{14\,281}$ MPa

Sampling Factor $k_s = 1 - (2.7 \times V_E / n^{0.5})$

$k_s = 1 - (2.7 \times 0.094 / 22^{0.5})$

$k_s = \underline{0.956}$

Material Factor $\gamma_E = \underline{0.7}$

Basic Working Stress $E^* = k_s \times E_s / \gamma_E$

$E^* = 0.946 \times 14\,281 / 0.7$

$E^* = 19\,305$ MPa

Adopt the smallest value of E*, i.e. **E* = 16 671 MPa**

APPENDIX 2

CALCULATIONS OF IN-GRADE STIFFNESS (**E***) (FLAT) OF SLASH PINE 90 x 45 mm STUDS

(Ref: Draft Australian Standard: Methods For Evaluation of Strength and Stiffness of Graded Timber)

STIFFNESS

From Table 1: P/Δ (mean) = 599 N/mm
coeff. var. V_E = 0.087

Calculations: Deflection $\delta = PL^3/28.173\ E_m I$ (note: P is half total load)

$E_m = PL^3/\ 28.173\ \delta I$

$E_m = (599) \times 10^3 \times 810^3 \times 12\ /\ 28.173 \times 90 \times 45^3$

E_m = 16 531 MPa

Sampling Factor $k_s = 1 - (0.7 \times V_E/\ n^{0.5})$

$k_s = 1 - (0.7 \times 0.087\ /\ 15^{0.5})$

$k_s = 0.984$

Material Factor $\gamma_E = 1$

Basic Working Stress **E*** $= k_s \times E_s\ /\ \gamma_E$

E* $= 0.984 \times 16\,531/\ 1$

E* = 16 271 MPa

$E_{0.05} = 16\,531 - 1.65(16\,531 \times 0.087)$

$E_{0.05}$ = 14 147 MPa

Sampling Factor $k_s = 1 - (2.7 \times V_E/\ n^{0.5})$

$k_s = 1 - (2.7 \times 0.087\ /\ 15^{0.5})$

$k_s = 0.939$

Material Factor $\gamma_E = 0.7$

Basic Working Stress **E*** $= k_s \times E_s\ /\ \gamma_E$

E* $= 0.939 \times 14\,147/\ 0.7$

E* = 18 984 MPa

Adopt the smallest value of E*, i.e. **E* = 16 271 MPa**