DESIGN RECOMMENDATIONS FOR BOLTED JOINTS USING LOCAL TIMBER

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Abstract

As properties of local timber species were not incorporated in CP 112, structural designers find it difficult to design with confidence, bolted joints in structures using local timber. This investigation was directed to provide some information to overcome this shortcoming.

A literature survey was conducted on previous research investigations on behaviour of bolted joints. Based on this, an experimental programme was drawn up to obtain design loads for bolted joints using Halmilla as the local timber. Both diameters and thicknesses of members currently used in laminated timber roof truss designs in Sri Lanka were covered in the test programme.

On analysis of experimental results, design loads were recommended which can be used in conjunction with CP 112.

1. Introduction

Design of timber structure in Sri Lanka, is carried out in accordance with CP 112 (1). However, as local timber species are not incorporated in the above code, it does not guide the designer well, apart from broadly providing the design procedure. Hence the designer has to guess or use his discretion to decide on suitable values for strength data of local timber. This often leads to either conservative designs or serious structural failures. Some progress is already made in providing designers with basic stresses for structural members using local timber. Thus an urgent need exists to provide design data for design of bolted joints using local timber, and this investigation is directed at providing some of this much needed design data for bolted joints.

2. Experimental programme and background to its development

2.1 Background to the development of the test programme

In order to develop design recommendations for bolted joints as in Table 27 of CP 112 (1), it is necessary to conduct an adequate number of appropriate tests under some standard condition, as timber is a highly variable material. However there is no British standard comparable to BS 373 : The testing of small clear specimens of timber (2) that lays down the procedure to be followed in the testing of metal fasteners like bolted joints. Thus a thorough literature survey (4, 5, 6, 7, 8, 9 & 10) was conducted on previous investigations on the behaviour of timber joints. The many variables considered, the mode of testing, and the methods of evaluating the working loads, all varied from one researcher to another. Hence many decisions had to be taken based on previous research literature and current trends in timber usage, to develop the experimental programme. Such decisions and background to them are described below.

(*a*) *Type of Species :* Halmilla (Berrya Cordifolia), a Class 1 timber species in Sri Lanka, was selected for study based on recommendations by Forest Department for use in laminated timber trusses, and its popularity.

(*b*) *Thickness of Members :* It was decided to adopt 1″, 1½″ and 2″ as the thickness of thinner member based on recommendation by the Forest Department as well as their wide usage in laminated roof trusses in Sri Lanka.

(*c*) *Diameter of Bolts :* It was decided to adopt 3/8″, 1/2″ and 5/8″ ϕ mild steel bolts for reasons given in (*b*) above. The bolts were hexagonal headed and were manufactured to comply with BS 916 (3).

(*d*) *Direction of the Load to the Grain Direction of Timber :* The anisotropic behaviour of timber makes it necessary to assess basic loads when applied at different angles to the grain direction. It was decided to carry out tests on joints parallel to grain and joints perpendicular to grain only. To obtain the design loads in other directions Hankinson's formula will be used as suggested in CP 112 (1).

(*e*) *Type of Tests :* Double shear tests with timber side plates were performed which affords an easier testing condition than that of single shear joints. Double shear test is free of experimental errors like bad alignment etc.

(*f*) *Mode of Testing :* The bolted joints were loaded under compression and not tension, which incidentally was easier to accomplish in the laboratory.

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Further there will be no differences in the stress distribution under a bolt whether in compression or tension provided the end distances are satisfying CP 112 (1) requirements.

(*g*) *Dimensions of Test Specimens :* The selection of specimen sizes was mainly governed by the minimum end and edge distances suggested in clause 322 (*g*) of CP 112 and partly by some research publications (4 and 5). The dimensions of test specimens when loaded parallel and perpendicular are shown in Figure 1.

(*h*) *Number of Tests per Joint Configuration :* The extent of investigations must be such that a statistical treatment of the data can be done to take account of natural variations within the specimens. Considering the recommendation by many publications (7, 6, 4) and the availability of financial resources, it was decided to conduct 5 tests for each variable under investigation (6).

(*i*) *Selection of Materials :* Bolts were selected at random from stocks available in the market made by a reputed manufacturer. Similarly the timber used to make members of the joint were also selected at random.

(*j*) *Fabrication :* In the case of fabrication of joints it was decided to adopt the following:—

1. The hole size was made equal to the Nominal bolt diameter + 1/32″ to satisfy the requirements of CP 112 which is a maximum clearance of 1/16″;
2. It was ensured that a minimum of one complete thread protrudes from the nut;
3. The washers used, which were turned at the workshop, University of Moratuwa, were in accordance with the requirements of CP 112, Table 50;
4. The nuts were tightened to a constant, but unspecified torque which will be far too small to cause crushing of the timber.

(*k*) *Testing Equipment :* The Amsler testing machine which can continuously record coherent values of loads and displacements was used. The displacements were measured on a dial gauge which records the cross-head movement of the loading plates of the machines. The load is indicated directly by the machine.

(*l*) *Rate of Loading and Duration of Test :* The test specimens were subjected to a constant strain loading of 0.1″/min. and that rate of loading was maintained within 30%. This rate of loading was such that the duration of the test lasted 5 to 10 minutes.

(*m*) *Moisture Content :* The strength of timber varies with the moisture content and as the variations of moisture content among the test-specimens were expected, it was decided to measure the moisture content of each test specimen and to carry out a subsidiary test series to enable us to derive the design loads at the standard moisture content for Sri Lanka of 15% (8). Thus it was decided to conduct 10 tests on 3/8″ diameter bolts and 1″ thick member joints, immersed in water for some days and then tested at various stages of drying.

2.2 Test Programme

Based on the above background information, the following test programme was conducted:—

Main Test Series

Species Name : Halmilla

	Thickness of Thinner Member	*Diameter of Bolt*		*Direction of Grain*
(1)	1"	3/8", 1/2"	5/8"	Parallel Perpendicular
(2)	1½"	3/8", 1/2"	5/8"	Parallel Perpendicular
(3)	2"	3/8", 1/2"	5/8"	Parallel Perpendicular

Subsidiary Test Series on Variation of Joint Strength with Moisture Content

Species Name : Halmilla

Thickness of Thinner Member	*Diameter of Bolt*	*Direction of Grain*
1"	3/8"	Parallel

The loading is continued until a maximum load is reached or the joint fails or excessive deformation takes place. On failure of test specimens, portions were cut from uncrushed timber material and used to determine moisture content by the oven drying method and the specific gravity. For each joint configuration five tests were conducted. Total number of tests in the main series were ninety, while total number of tests in the subsidiary tests were ten.

3. Experimental Results and Analysis

3.1 General Behaviour of Joints

According to the test programme, main test series consisted of 10 groups of tests, totalling ninety and the subsidiary test series consisted of 10 tests. In general, the overall behaviour of the joints was uniform among the

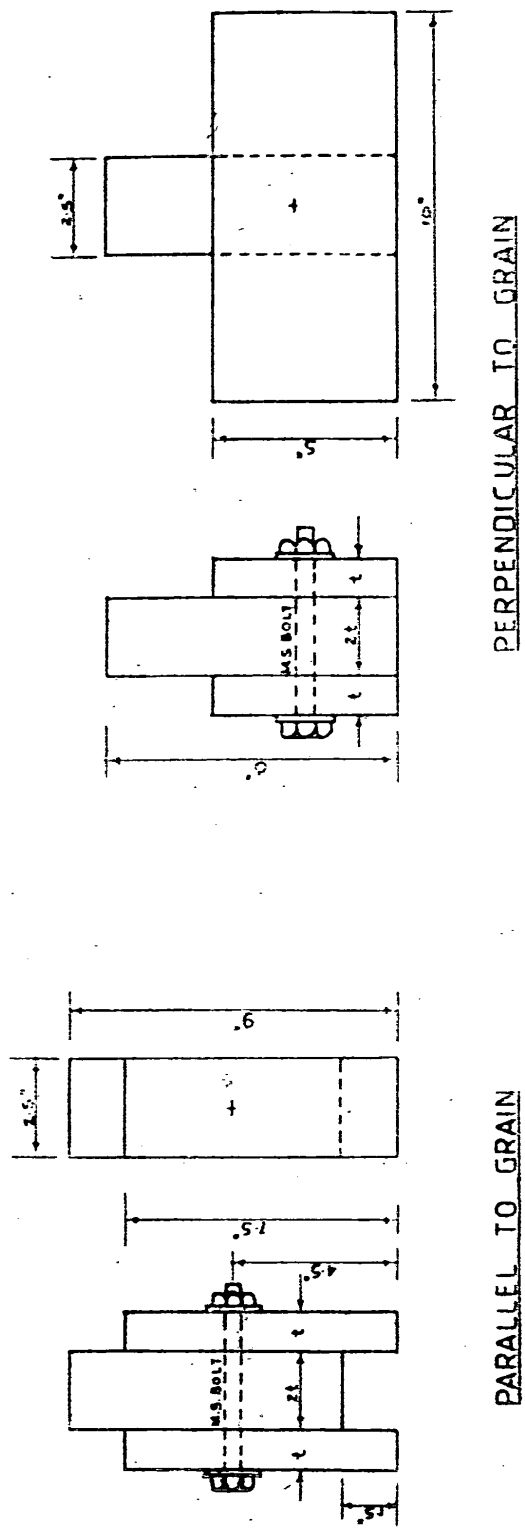
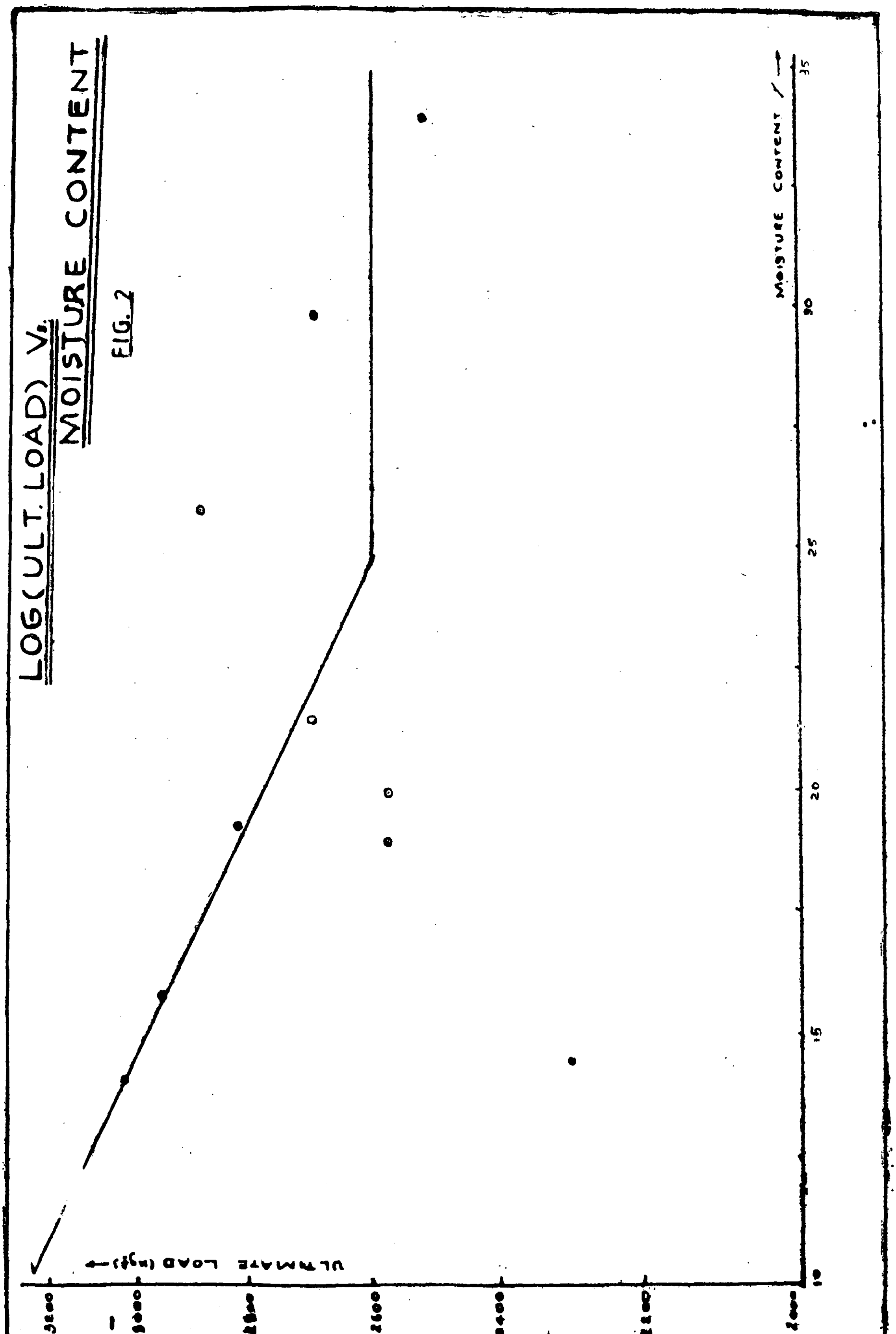


FIG. 1: TEST SPECIMENS


LOG(ULT. LOAD) Vs. MOISTURE CONTENT
FIG. 2
MOISTURE CONTENT %
10
15
20
25
30
35
ULTIMATE LOAD (kgf)
2000
2200
2400
2600
2800
3000
3200

tests in the same group. In most of the tests, there was an irregular variation of the load with deflection within the initial stages of loading. As identified by previous researchers, this may be due to slip which occurs as it overcomes frictional forces due to initial tightening.

The failure of the joint was found to be due to splitting of timber and/or due to yielding of steel bolts as shown in figures 3, 4 and 5. Splitting of timber took place

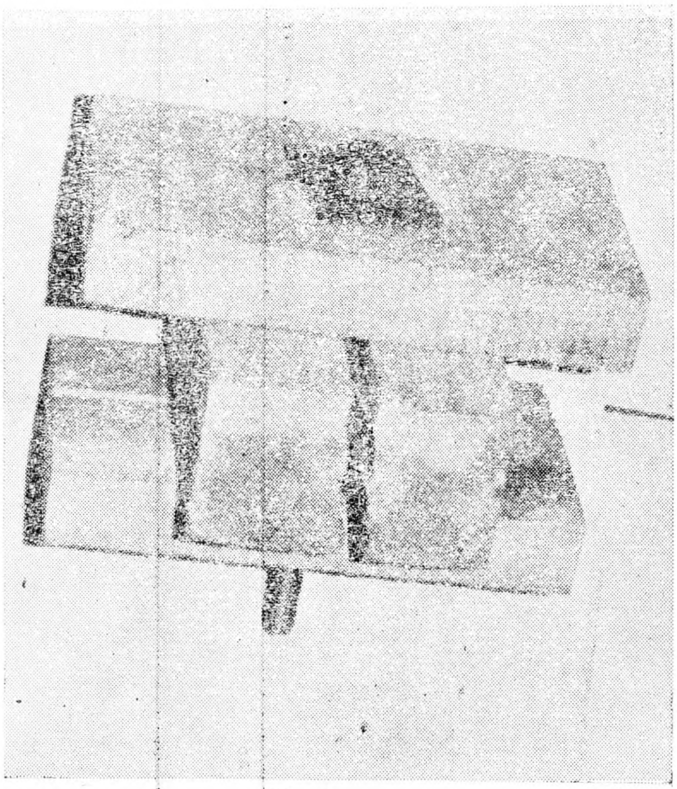


Fig. 3

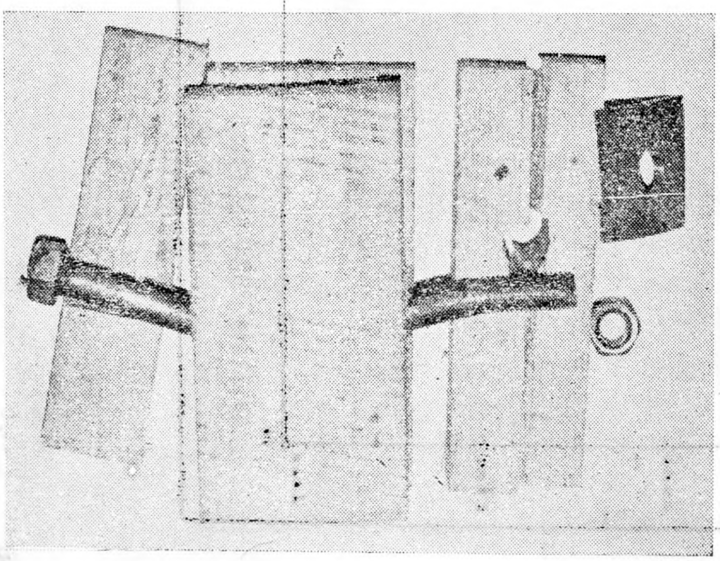


Fig. 4

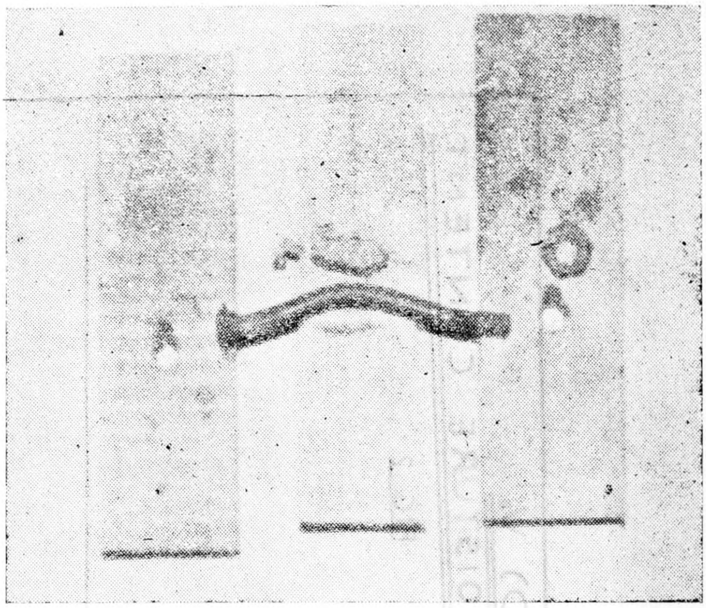


Fig. 5

in those joints where the ratio of "thickness of the middle member/the diameter of m.s. bolt" is low. Further, failure by splitting of timber without yielding of bolt, gives rise to sudden failures without warning in the form of large deformations. Hence designer should use minimum size of bolts whenever 'possible'.

3.2 Derivation of Design Loads

Experimental results are summarized in Tables 1 and 2.

To account for the many variations encountered in practice it was decided to calculate the mean ultimate load and the standard deviation for each series of tests, as currently done by researchers in timber joints (7). Mean value of the ultimate load was calculated using the following formula:

$$\text{Mean Ultimate load} = \frac{\text{Summation of the ultimate loads of all the specimens}}{\text{Number of specimens}}$$

$$\bar{x} = \left\{ \sum_{i=1}^{n} x\, i \right\} / n$$

The value of the standard deviation is calculated by the formula—

Std. deviation$= \sqrt{\dfrac{E\,(xi - \bar{X})^2}{n-1}}$ where the sample size N is five.

TABLE 1

Experimental Results

Thickness of thinner member (m)	*Dia. of Bolt c-(m)*	*Direction of Grain*	*Mean UTT. Load (KG)*	*Std. Deviation Variation*	*Coeff of Variation (%)*	*Allowable load (KG)*	*Average m. c. (%)*
1	3/8	Parallel	2723	180	6.6	921	18.5
		Perpend.	2368	104	4.4	859	18.8
	1/2	Parallel	3042	267	8.8	968	18.8
		Perpend.	2760	76.5	2.8	1033	17.5
	5/8	Parallel	3560	412	11.6	1040	20.6
		Perpend.	3770	607	16.1	942	18.3
1½	3/8	Parallel	3676	401	10.9	1097	18.5
		Perpend.	3470	230	6.6	1174	16.4
	1/2	Parallel	3892	285	7.3	1291	19.2
		Perpend.	5000	474	9.5	1560	17.1
	5/8	Parallel	6242	186	3.0	2323	16.7
		Perpend.	5786	557	9.6	1795	20.0
2	3/8	Parallel	3618	451	12.5	1027	17.9
		Perpend.	3322	363	11.0	990	16.3
	1/2	Parallel	4862	532	10.9	1450	17.4
		Perpend.	4924	980	20.0	1060	17.3
	5/8	Parallel	6070	317	5.2	2133	15.6
		Perpend.	7636	1143	15.0	1989	17.2

SUPPLEMENTARY TEST SERIES

TABLE 2

Moisture Content (%)	14.6	14.1	15.8	18.95	19.3	20.0	21.4	25.8
Ultimate load (Kg)	2300	3020	2940	2570	2800	2580	2700	2900
Moisture Content (%)	29.8	33.5						
Ultimate load (Kg)	2700	2520						

TABLE 3

DESIGN LOAD IN KN.PER BOLT IN DOUBLE SHEAR

SPECIES NAME : HALMILLA

	Parallel to grain					*Perpendicular to grain*			
Thickness of thinner member (in)	*Dia. of Bolt (in)*	*Design Load (KN)*	*m.c. (%)*	*Av. Slip (in)*	*Design Load at 15% m.c.*	*Design Load (KN)*	*m. c. (%)*	*Av. Slip (in)*	*Design Load at 15% m.c.*
1	3/8	9.04	18.5	0.13	9.5	8.33	18.8	0.20	8.79
	1/2	9.27	18.8	0.08	9.78	9.89	17.5	0.10	9.81
	5/8	10.33	20.6	0.09	11.18	9.36	18.3	0.11	9.81
1½	3/8	11.47	18.5	0.10	12.05	12.27	16.4	0.15	12.52
	1/2	12.21	19.2	0.06	12.96	14.75	17.1	0.17	15.20
	5/8	23.37	16.7	0.08	23.94	18.05	20.0	0.11	19.38
2	3/8	9.60	17.9	0.07	10.00	9.25	16.3	0.14	9.42
	1/2	14.05	17.4	0.08	14.54	10.27	17.3	0.17	10.61
	5/8	21.19	15.6	0.09	21.37	19.76	17.2	0.13	20.39

TABLE 4

DESIGN LOAD PER BOLT IN A TWO MEMBER JOINT AT 15% m.c.

SPECIES NAME : HALMILLA

Thickness of thinner member (in)	*Dia. of bolt (in)*	*Design load Parallel to grain (KN)*	*Design load Perpendicular grain (KN)*
1	3/8	4.75	4.39
	1/2	4.89	4.90
	5/8	5.59	4.90
1½	3/8	6.02	6.26
	1/2	6.48	7.60
	5/8	11.97	9.69
2	3/8	5.00	4.71
	1/2	7.27	5.30
	5/8	10.68	10.19

The coefficient of variation is defined as the percentage of Std. deviation to the mean value. The working load is obtained from the general formula,

$$\text{Working load} = \frac{\text{Mean Ultimate load} - K \times \text{std. deviation}}{\text{Load Factor } F}$$

Where K = 2.33 for 1% exclusion
F = 2.5 for bolts. This value was decided in accordance with Sunley and Brock (7).

Although the allowable load is obtained as shown above it is necessary to check any possibility of excessive joint slip. Further, it is necessary to ensure that the working loads obtained are not above the limit of proportionality or do not occur at an excessive slip. This was done by inspecting each load-deflection curve before taking a final decision on allowable load.

The Log (ultimate load) Vs. moisture content relationship is as shown by Fig. 2. The mathematical equation for the straight line portion of this curve is given by $\text{Log} \frac{S\,15}{St} = 0.006154\,(Mt - M\,15)$ where S 15, St are the ultimate joint strengths at moisture contents of 15% and t% represented by M_{15} and M_t respectively. Corrections for specific gravity is done in accordance with Lavers (10). The Final design loads at std. moisture content were determined and are shown in Tables 3 and 4.

4. Conclusions

Following conclusions can be drawn from this investigation :—

(1) Design loads for joints developed in Table 4 can be used in conjunction with CP 112 for boltd joint using Halmilla;

(2) Only few failure modes exist for bolted joints. Those are splitting of timber members and or bending failure of the bolt;

(3) Joints can accommodate large deformations before failure, if the steel bolt yields. Hence for a given thickness of timber, if the smallest size of bolt consistent with required load carying capacity is used, there will be adequate warning before failure than when a larger size bolt is used.

5. Acknowledgements

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