FURTHER WORK ON DEVELOPMENT OF DESIGN RECOMMENDATIONS FOR BOLTED JOINTS MADE WITH LOCAL SPECIES OF TIMBER

by Dr. S.R.deS. Chandrakeerthy, A.K.W. Jayawardena & L.S. Siriwardena

Introduction

In Sri Lanka timber is a popular structural material used for certain specific applications such as roof structures, formwork structures and falsework structures. For structural design of timber structures, designers use the design procedure given in CP 112 (1). However, as CP 112 does not cover local species of timber, designers have to guess values such as basic stresses, basic loads etc., applicable for local timber. This unavailability of design information is a great hindrance to the designer. Efforts on development of basic stresses (2,3) of local timber and basic loads for bolted joints (4) using local timber have produced some progress, but further work needs to be done. This paper reports on work done on development of basic loads for bolted joints using one further local timber species namely Hora.

Experimental programme and background to its development

Background to the Development of the Test Programme

As timber is a highly variable material affected by many variables, in order to develop design recommendations for bolted joints on the same lines as in Table 27 of CP 112, it is necessary to conduct an adequate number of tests under controlled conditions, results of which can be reduced to a standard condition. As there is no British Standards which lays down procedure for testing bolted joints, it was necessary to base the experimental investigation on previous investigations of various researchers. A comprehensive literature survey was conducted (5,6,7,8,9,10,11) on previous research on strength of bolted joints. Based on that survey, variables to be considered, selection of materials, specimen sizes, preparation of specimens and method of testing were decided with suitable alterations where necessary to suit local conditions. Background to such decisions needed for an experimental programme on bolted joints in timber is well documented (4) and since the procedure in this investigation is not very different, it is not repeated here in detail. However, relevant information on variables, sizes of specimens, fabrication of specimens and methods of testing pertaining to this investigation are given very briefly below. Where details adopted were different to previous work (4), background to such decisions were also given below.

(a) <u>Type of timber species:</u>

Hora (Diptero Carpus Zeylanicus) was selected based on its high density, low cost to the user, availability and popularity. It is a class I timber recommended for structural work (12). Hora is highly recommended by timber merchants and timber saw mill owners, although it is not favoured by structural engineers. Its high density was a significant factor in its selection so that full range of densities of local

Dr. S.R. De S. Chandrakeerthy, BSc.Eng.(Hons) Cey, PhD, (Sheffield), is a Senior Lecturer at University of Moratuwa.

Mr.A.K.W. Jayawardene, BSc.Eng. 1st Class Hons Asst. Lecturer in Civil Engineering, University of Moratuwa.

Mr. L.S. Siriwardene, BSc.Eng. Hons. Civil Engineer, National Water Supply and Drainage Board.

timber can be covered very early by development of strength data of Hora along with Halmilla studied earlier (4) and tests on a low density timber in the near future.

(b) **Thickness of members:**

It was decided to adopt 1" (25 mm), 1½" (38 mm) & 2" (50 mm) as the thickness of thinner member.

(c) **Diameter of bolts:**

Bolt sizes adopted were 3/8" (9.5 mm), ½"(12.7 mm) & 5/8" (15.9mm) in diameter and bolts were hexagonal headed complying with BS 916 (13).

(d) **Direction of the load to the grain direction of timber :**

Tests were carried out on joints with load parallel to the grain direction and joints with loads perpendicular to the grain direction. Loads in any other direction is expected to be obtained using Hankinsons's formula given in CP 112(1)

(e) **Type of tests:**

Double shear tests on single bolt with timber middle and side plates were performed.

(f) **Mode of testing:**

Bolted joints were loaded in compression.

(g) **Dimensions of test specimens:**

Figure 1 shows the dimensions of test specimens to be loaded parallel to and perpendicular to the grain. The dimensions were same as those adopted in the earlier investigation (4).

(h) **Number of tests per joint Configuration:**

It was decided to adopt six tests for each variable under investigation. The number of tests adopted was one more than what was used earlier (4) and this extra test was expected to give a better statistical treatment, as well as to help in situations in which one test may be abandoned or rejected

(i) **Selection of materials:**

Bolts and timber samples for experimental work were selected randomly from stocks available in the market.

(j) **Fabrication:**

Fabrication details were same as those of the earlier investigation (4), except for the type of washers. The washers used in this investigation were those available in the market which did not comply with CP 112 recommendations (1). This deviation was allowed after careful thought because (a) the washer sizes recommended in CP112 are not used in Sri Lanka presently; (b) those washer sizes are not available in the market; (c) it will be difficult to persuade manufacturers to produce those washer sizes due to prevailing small and irregular demand; and (d) if for a specific structure washers were specially turned out to CP112 recommendations, the actual design loads will be equal or higher than those recommended here, thus producing a safe design.

(k) **Testing equipment:**

Same equipment was used as that for the earlier investigation (4).

(l) **Rate of loading and Duration of Test:**

This was same as for the earlier investigation (4).

(m) **Moisture content:**

Treatment to account for variations in moisture content was same as for the earlier investigation (4).

Test Programme

Based on the above background information, the following test programmes were conducted.

MAIN TEST SERIES

(Species Name: Hora)

Thicknesss of Thinner member	Diameter of Bolt	Direction of Grain to load
1. 1" (25mm)	3/8" (9.5mm), ½"(12.7 mm) 5/8"(15.9mm)	Parallel Perpendicular
2. 1½" (38 mm)	3/8"(9.5mm), ½"(12.7mm) 5/8"(15.9mm)	Parallel Perpendicular
3. 2" (50mm)	3/8"(9.5mm), ½"(12.7mm) 5/8"(15.9mm)	Parallel Perpendicular

Subsidiary Test series on variation of joint strength with Moisture content

(Species Name: Hora)

Thickness of Thinner member	Diameter of Bolt	Direction of Grain to load
1" (25mm)	5/8" (15,9mm)	Perpendicular

Each joint was loaded recording the load-deformation response of the joint until the maximum load was attained or excessive deformation took place. On failure of test specimens, portions were cut from uncrushed timber of the failed members and used to determine the moisture content by the oven drying method. Similarly portions were cut to measure specific gravity. For each joint configuration 6 tests were conducted as mentioned above. The number of tests in the main test series was 108 while in the subsidiary test series was 9. The total number of joints tested was 116, which excludes numerous control tests such as moisture content & specific gravity.

Experimental Results and Analysis

General Behaviour of Joints

In general, the overall behaviour of tests was approximately same among the test specimens of the same group. In most of the test specimens the load-slip curves were such that the initial part is more inclined to horizontal than the rest. According to previous researchers this irregularity may be due to overcoming of frictional forces during initial slip.

There were only three modes of failure as follows:

(i) Splitting of end members, which was predominant when the application of load was parallel to grain.

(ii) Splitting of middle members, was predominant when the application of load was perpendicular to grain.

(iii) Bending failure of the bolts took place when the ratio of thickness of middle members to diameter of bolts was large but this type of failure was very rare in the case of Hora.

These failures were similar to those

observed by other researchers. The failure by splitting occured suddenly without warning by large deformations, and as the diameter increases chance of a splitting failure increases. Hence it can be concluded that the designer should use the minimum size of bolt with adequate load carrying capacity whenever possible.

Derivation of Design Loads

Since the current practice (6) of evaluation of design loads is based on a statistical basis, it is necessary to calculate the mean ultimate load and standard deviation for each joint configuration of the species. Working load at 1% exclusion limit is given by the formula,

$$\text{Working load} = \frac{M - k\sigma}{F}$$

where, M = mean ultimate load
σ = Standard deviation
k = 2.33 for 1% exclusion
F = 2.5 for bolts (6)

The experimental results, relevant statistical information and working loads of 1% exclusion limit are summarized in Table 1.

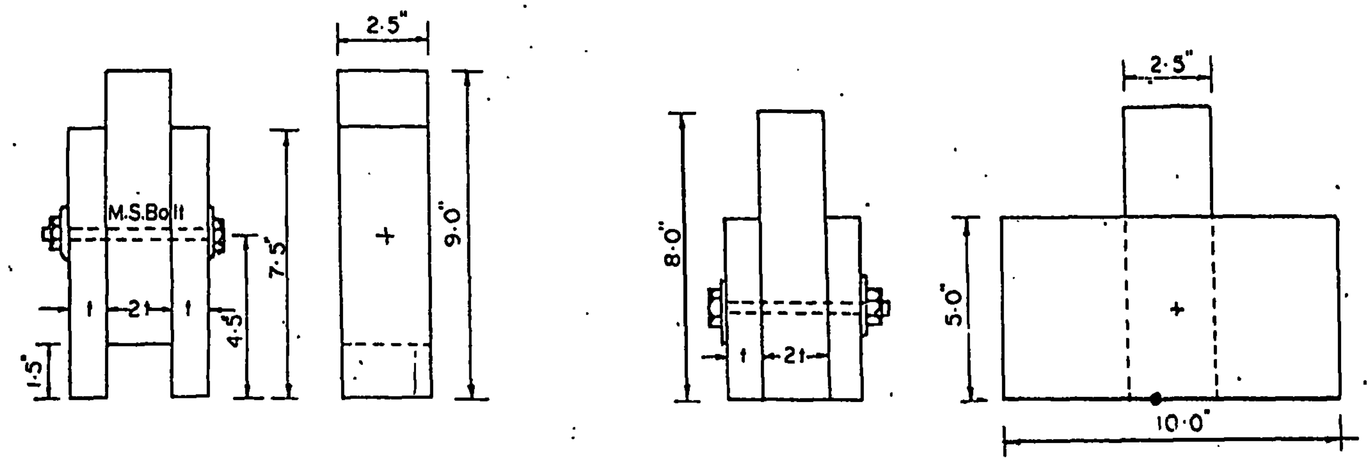
Since working load at 1% exclusion limit is derived from ultimate loads only, it is necessary to apply further checks to ensure that (a) joint slip at working load is not excessive; (b) working load is below the limit of proportionality and (c) few test results with unusually high ultimate loads do not

Table 1

Main test series

Species name - Hora

Thickness of thinner member (mm)	Diameter of Bolt(mm)	Direction of grain to load	Mean Ult. Load (kg)	Std . deviation	coeff. of variation (%)	Working load at % exclusion	Average m.c. (%)
25	9.5	Par.	2507.7	64.00	2.56	941.03	21.68
		Perp.	2473.3	130.64	5.28	867.56	19.12
	12.7	Par.	2640.0	125.43	4.75	939.00	20.88
		Perp.	2645.0	190.97	7.22	880.00	21.94
	15.9	Par.	2920.0	155.95	5.34	1022.65	18.64
		Perp.	2956.7	296.22	10.02	906.60	20.76
38	9.5	Par.	4260.0	436.71	10.25	1296.98	23.87
		Perp.	4433.3	347.95	7.85	1449.03	20.88
	12.7	Par.	5333.3	242.21	4.54	1907.58	20.92
		Perp.	5590.0	345.66	6.18	1913.84	20.63
	15.9	Par.	5733.3	395.51	6.90	1924.70	22.17
		Perp.	5746.6	349.78	6.09	1972.67	22.18
50	9.5	Par.	3950.0	206.98	5.24	1387.09	17.14
		Perp.	5093.3	449.12	8.82	1618.74	21.51
	12.7	Par.	4876.6	354.27	7.26	1620.46	22.42
		Perp.	7006.6	1062.72	15.16	1812.18	23.25
	15.9	Par.	5650.0	312.60	5.53	1968.65	19.62
		Perp.	8096.6	913.67	11.28	2387.09	22.09



PARALLEL TO GRAIN

PERPENDICULAR TO GRAIN

FIG 1: TEST SPECIMENS

increase the working load unrealistically. Hence the working load was reduced where necessary to satisfy the following consideration:

(a) working load should be less than or equal to $\frac{M - k\sigma}{F}$

(b) joint slip at the working load should be less than the allowable limit for joint slip (10) taken as 2.6 mm (1.025×10^{-3} inch);

(c) Working load should be below the limit of proportionality of the load-joint slip curve;

(d) Working load is such that the minimum ultimate load value of the six tests must achieve a load factor of 2 times the working load.

The results of subsidiary test series were computed and the log (ult. load) vs. moisture content relationship is shown in figure 2. The mathematical representation of the straight portion of the relation is given by,

$$\log \left[\frac{S\,15}{St}\right] = 0.004636(Mt - M15)$$

where S15, St are the ultimate joint strengths at moisture contents of 15% and t% represented by M15 & Mt respectively. The working loads were corrected for moisture content in accordance with Lavers (14) for variation in S.G. The corrected working loads are termed design loads at 15% m.c. & presented in Table 2.

Finally as the design loads are for 3 member joints under double shear, these loads were reduced to basic loads in a two member joint under single shear and presented in Table 3. These values can be used on similar lines to those in Table 27 of CP112.

Conclusions

Following conclusions can be drawn from this investigation:-

(1) Basic loads developed in Table 3 for Hora can be used in conjunction with design procedure given in CP112;

(2) Joints can accommodate large deformations if steel bolts used for connections are smaller. Hence it is advisable to use the minimum size of bolt which satisfies the strength requirement so that there will be adequate warning before failure.

SPECIES NAME – HORA

LOG (ULT LOAD) Vs. MOISTURE CONTENT

FIG.2

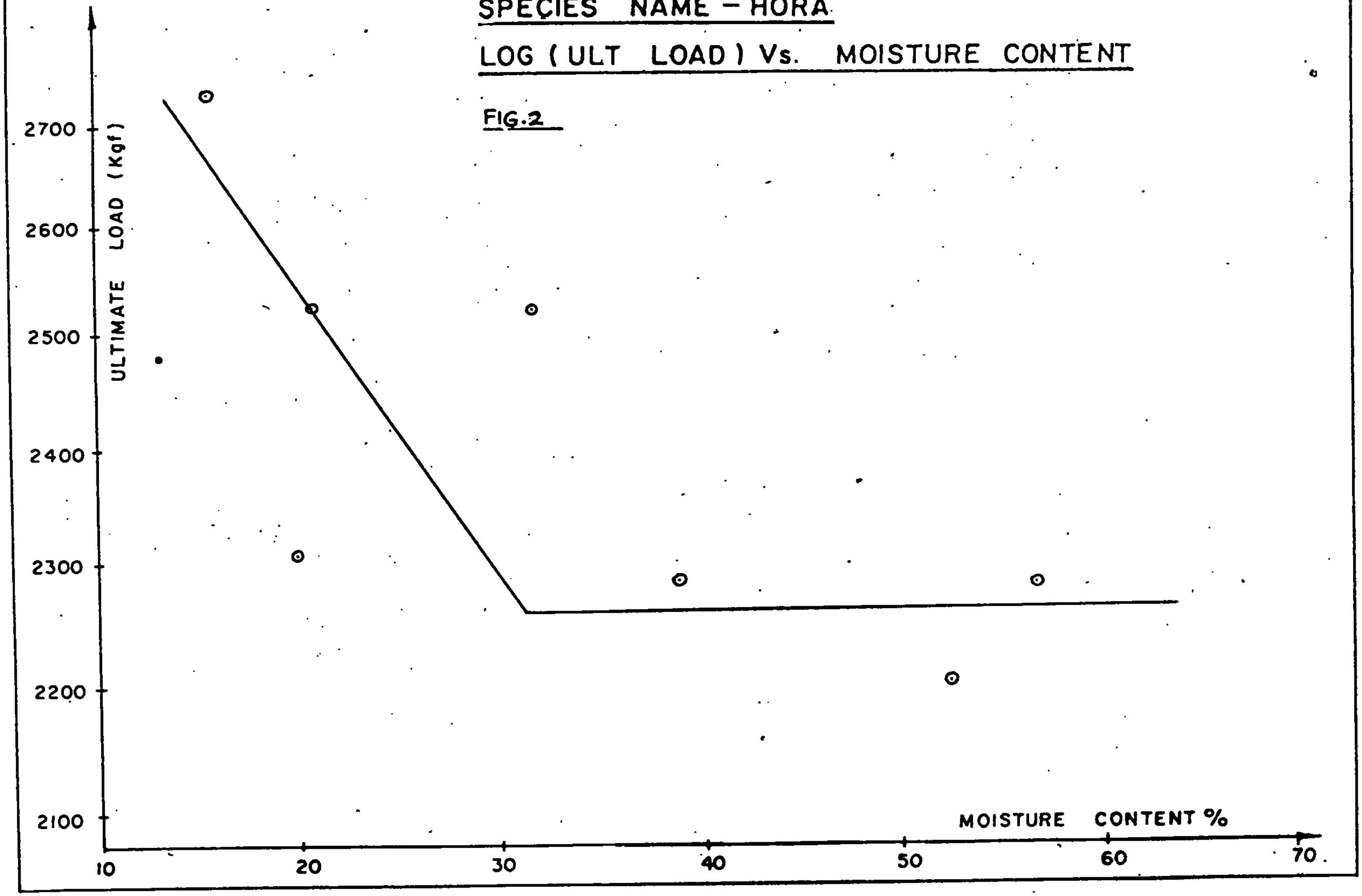


TABLE 2

Design load in kN per Bolt in Double Shear

Species name Hora

PARALLEL TO GRAIN						PERPENDICULAR TO GRAIN			
Thick-ness of tinner member (mm)	Dia-meter of Bolt (mm)	Working load at % exclu-sion (kN)	m.c %	Av. slip (mm)	Design load at 15% m.c (kN)	Working load at 1% exclusion	m.c. %	Av. Slip (mm)	Design load at 15% m.c. (kN)
25	9.5	9.231	21.68	3.22	7.801	8.510	19.12	5.41	4.171
	12.7	9.210	20.88	1.65	9.873	8.633	21.94	3.68	6.609
	15.9	10.032	18.64	2.03	11.097	8.894	20.76	3.38	7.748
38	9.5	12.723	23.87	4.22	11.766	14.215	20.88	6.96	5.390
	12.7	18.713	20.92	3.17	15.447	18.775	20.63	7.47	6.569
	15.9	18.881	22.17	2.23	19.282	19.352	22.18	4.95	10.378
50	9.5	13.607	17.14	4.27	8.893	15.880	21.52	7.57	6.129
	12.7	15.986	22.43	4.63	9.109	17.777	23.25	7.90	6.410
	15.9	19.312	19.62	2.77	20.536	23.417	22.09	10.03	7.054

* note: The design loads in columns 6 and 10 have been adjusted to average specific gravity also.

TABLE 3

Basic Load per Bolt in a two member joint at 15% m.c.

Species name - Hora

Thickness of thinner member (mm)	Diameter of Bolt (mm)	Parallel to grain (kN)	Perpendicular to grair (kN)
25	9.5	3.900	2.085
	12.7	4.936	3.304
	15.9	5.548	3.874
38	9.5	5.883	2.695
	12.7	7.723	3.284
	15.9	9.641	5.189
50	9.5	4.446	3.064
	12.7	4.554	3.205
	15.9	10.268	3.527

(3) The modes of failure observed in the test programme were splitting of end members, splitting of middle member & bending failure of bolts.

(4) In a design recommendation for strength of bolted joints it is generally expected, while other variables remain constant, that design load should increase when

(a) Bolt diameter increases;
(b) thickness of thinner member increases;
(c) loading direction changes from perpendicular to grain to a direction parallel to grain.

Although this is a general trend, even the CP 112 values do not always satisfy this pattern. The trend observed in the recommended values is similar to that of CP 112.

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