DESIGN RECOMMENDATIONS FOR NAILS DRIVEN IN TO "GINISAPU" TIMBER TO MAKE STRUCTURAL CONNECTIONS

by

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GINISAPU is a structural timber widely used with nailed joints in temporary and permanent structures. Lack of design information on design of nailed joints in this timber makes it difficult for structural designers either to improve designs or to evolve new applications. This paper reports a study directed to fill that need.

The study consisted of a market survey and a structural users' survey to identify nail sizes and timber sizes currently in use, and an experimental investigation covering shear tests, withdrawal tests, moisture content and specific gravity measurements, and tensile tests on nails..

Design recommendations made can be used in accordance with the design process of BS 5268. Loads that can be resisted by nailed joints in GINISAPU are more than those in the strongest timber category of BS 5268.

1.0 Introduction

In Sri Lanka sawn timber is used for many structural applications such as roofwork, ceiling structures, temporary floors or floors subjected to chemical attack, formwork, falsework, pedestrian bridges for temporary access or aesthetic considerations, temporary towers, supports for excavations, and shoring or underpinning of structures in distress. Except for some elementary structural forms, these timber structures incorporate some form of joints. Nailed joints are very popular here due to possibility of fast construction, lower cost, availability of nails in abundance, small capital investment required on tools, simple fabrication and easy availability of carpenters in any locality. Joint design often governs the final selection of member sizes in a structure. Thus joint design, often confronted by designers, is a task of no mean importance.

Timber structures are designed in accordance with BS 5268[1]. As it does not cover local species of timber, guidance available is mainly confined to spelling out the design process. Extrapolation of those design recommendations to cover the local situation by simple reasoning is most difficult for nailed joints, because structural behaviour of nails depends not on one factor such as density but on many additional factors such as susceptibility to splitting and extent of mobilisation of frictional resistance. Thus local research is the only answer. Previous researchers[2,3,4,5] have provided design information on design of nailed joints in local species of timber, but the number of species covered was few. So considerable scope still exists to encompass further local timber species.

Ginisapu (Michelia champaca) is a timber species widely used with nailing. It is considered soft enough to permit easy driving of nails during fabrication and strong enough to resist loads efficiently during service. Availability, economy, and amenability to preservative treatment are further qualities which make it popular. Yet, designers lack design information to design nailed joints in this timber species.

This study was directed at the evolution of design recommendations on nailed joints in Ginisapu timber, for use in conjunction with BS 5268[1].

2.0 Experimental Programme and its Development

2.1 Background to the Development

Timber is a highly variable material and, hence, any tests to be conducted should be carefully controlled as regards testing conditions and influential variables so that all test results can be reduced to a standard condition. Standard procedures[6,7,8] are now available for testing timber joints, but they require modifications to suit local conditions and the specific purpose of these tests due to: (a) significant differences in certain aspects of testing between the different procedures; (b) need for end and edge distances

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to be at least the same as those used in the standard which will be used for timber design: (c) need for changing thickness of members to obtain optimum resistance of the nails; (d) moisture content and relative humidity values being different from those prevalent locally; (e) need to avoid spending effort on accumulation of information irrelevant to this study; and (f) the fact that some requirements of those procedures are in place to compare performance of different types of fasteners or different timber species, rather than determination of structural behaviour.

A literature survey [1 to 15] was conducted to identify the important variables that influence structural behaviour of nailed joints and also to ascertain the recent trends in development of design recommendations for nailed joints. The variables that affect load carrying capacity of nails in lateral shear are: species of timber, size of nails, type of nails, dimensions of the test specimen (thickness of members; spacing, end and edge distances; number of nails per joint; and specimen sizes), moisture content of timber, relative density of timber, fabrication details and rate of loading. The variables that affect withdrawal loads of nails are: species of timber, depth of penetration, nail diameter, type of nail, relative density of timber, fabrication details, rate of loading, nail location (end and edge distances, and spacing), and direction of nail driving (slanted or perpendicular to face). Latest technique of developing design recommendations was found to be based on a statistical procedure using ultimate loads. The results were suitably adjusted later to ensure that the basic load recommended neither exceeds limit of proportionality nor developes excessive joint slip. This process is described later in the paper.

The manner in which test conditions and variables were controlled is described in the succeeding sections.

<u>(a) Type of timber species :</u> Ginisapu (Michelia champaca) was selected for this study for reasons given earlier (see Introduction). The survey conducted with structural timber users confirmed the demand for Ginisapu for formwork and falsework structures. Large construction sites preferred this species over Mango or Rubberwood due to the potential for greater reuse, since it is more durable and retains shape better.

<u>(b) Sizes of nails:</u> All the available nail sizes used structurally were considered for inclusion in this study. However, for a nail diameter having several nail lengths, suitable length was selected as in Table 59 of BS 5268[1]. The nail sizes (see Table 1) were selected based on the market survey, the survey of structural timber users, and Table 59 of BS 5268[1]. SWG 6 nails of 4 inch length were originally included in the test programme, but at the time of purchasing this size was not available anywhere. Hence SWG 5 nails of 4 inch length were used instead. Metric sizes of nails are not yet available.

<u>(c) Type of nails used :</u> As only cold drawn wire nails are used in Sri Lanka presently, this type was selected.

<u>(d) Type of tests :</u> As nailed joints resist lateral shear loads, withdrawal loads or both, tests to determine lateral load resistance in shear and withdrawal load resistance were performed.

<u>Shear test</u>

BS 6948[6] recommends both single and double shear tests, while ASTM[7] recommends single shear tests. ISO 6891[8] makes no specific recommendations on shear tests. Single shear test was selected due to the following advantages: (i) It is the simplest test that gives basic lateral loads in single shear directly; (ii) Nail can be positioned to obtain its optimum strength by varying thickness of headside and pointside timber sections; (iii) The fabrication of the joint is much easier and less prone to errors; (iv) It consumes less timber; (v) Failure loads are smaller requiring only light test equipment; and (vi) Deformations are greater, hence, deformations can be observed and measured easily.

Of the two types of single shear tests, ASTM[7] arrangement was selected due to following advantages: (i) It uses less nails; (ii) It uses considerably less timber; (iii) Fabrication is easier; (iv) Failure load is less allowing use of light test equipment; and (v) Deformation is larger due to less nails, hence, can be easily observed and measured.

<u>Withdrawal test</u>

This test is similar in all standard methods[6,7]. ISO 6891[8] makes no specific recommendations on withdrawal tests. It consists of driving the nail into the timber and extracting it out by gripping the nail head by some attachment. Too small a depth of penetration will result in a small failure load which is difficult measure, and too deeper penetration will make it difficult to grip the nail head for pulling out.

<u>(e) Dimensions of the test specimens:</u>

<u>Shear test</u>

Member thicknesses used by previous researchers[2,9,10,11,12] and standard methods[6,7] show no agreement, but the ratio headside member thickness to nail length was maintained around 0.375 to 0.5. The member thicknesses were selected in this study so that: (a) optimum strength of the nail can be developed in the joint, which is considered to be when headside thickness is three-eighths of the nail length[14]; (b) thicknesses correspond as far as possible to timber size used in Sri Lanka; and (c) either headside or pointside thickness or both given in BS 5268[1] can be maintained. It should be noted that headside and pointside thicknesses of BS 5628[1] cannot always be maintained, since for a particular nail diameter it refers to a range of nail lengths which are not available in Sri Lanka. Member thicknesses adopted are shown in Figure 1.

Spacing of nails, end and edge distance were determined to satisfy BS 5268[1] and BS 6948[6] for nails driven after pre-drilling. This saved timber, as specimen sizes would be very large if nails were driven without pre-drilling. For the purpose of the length dimension, all the specimens were divided into two sets, with SWG 12, 10 and 8 nails forming one set while SWG 5 nails formed the other set. The spacing, end and edge distances were calculated based on the largest size of nail in each set, so that all specimens satisfied BS 5268[1] and BS 6948 [6]. The adopted values are shown in Figure 1.

In accordance with Brock[9], four nails were used per joint with nails driven in two rows of two nails each (see Figure 1). One nail recommended by ASTM[7] was considered too small and eight nails recommended in BS 6948[6] was considered too much.

Withdrawal test

Dimensions of specimens for this test depends on diameter of nail, depth of penetration, spacing, end and edge distances.

Depth of penetration was taken as the greater of half the length of the nail or 25mm. This gave sufficient space for gripping the nail head as well as a measurable pull out force. It satisfied BS 6948[6] requirements, but satisfied ASTM[7] requirements for SWG 8 and 5 nails only.

Pre-drilling is not allowed for nails under withdrawal loads, hence, nails were driven without pre-drilling. For this test too, to make fabrication easier, specimens were divided into two sets, with one set for SWG 12, 10 and 8 nails while the other set was for SWG 5 nails. The dimensions of the specimens in each set were based on the largest diameter of nail in that set, so that all specimens satisfied BS 5268[1] and BS 6948[6] requirements for spacing, end and edge distances. The values adopted also satisfied ASTM[7] requirements, and dimensions adopted are shown in Figure 2.

(f) Mode of testing : For shear tests, Brock[9] has adopted compressive loading, ASTM[7] recommends tensile loading, while Idris[11] has adopted and BS 6948[6] has recommended both compressive or tensile loading. Compressive loading was adopted in this study because: (i) it is easy to achieve in many testing machines; (ii) uses less timber; (iii) many researchers[9,10,12] have adopted compressive loading; (iv) stresses in the nail and in timber near the nail are the same for both types of loading provided end and edge distances are kept as specified in BS 5268[1].

For withdrawal tests, only one method is available consisting of gripping the nail head and pulling it out.

(g) Number of specimens per test : There is no consensus regarding number of replications per test. Brock[9] has suggested 10 to 20 replications, while Booth and Reece[10] have suggested 5 replications. ASTM[7] recommends at least 10 replicants for withdrawal and 5 replications for shear, while BS 6948[6] recommends 20 and 15 respectively. In this study 10 replications were used for each test.

(h) Selection of material : Nails and timber samples were selected randomly from stocks available in the market so that they are as far as possible representative of normal production stock. Defective nails and timber so selected were rejected.

(i) Fabrication details : For the shear tests, the specimens were drilled to a diameter not greater than 0.8 times the nail diameter as specified in BS 5268[1]. First the two nails on one diagonal were driven and then the balance nails were driven.

For the withdrawal test, nails were driven without pre-drilling in accordance with BS 5268[1], one at a time making sure each is driven perpendicular to the timber surface.

(j) Conditioning of specimens : Specimens were made from seasoned timber in ambient conditions inside the laboratory. After fabrication, specimens were stored in ambient conditions for at least 12 hours before testing, that too in ambient conditions inside the laboratory. This satisfied the BS 6948[6] and ASTM[7] requirements except for temperature and relative humidity which are different in Sri Lanka.

(k) Rate of loading : Timber can resist higher loads under higher rates of loading, hence, rate of loading should be controlled and kept as low as possible. ASTM[7] recommends a loading rate of 2.54 mm/minute for both withdrawal and shear tests. BS 6948[6] recommends a loading rate of 2.54 mm/minute for withdrawal tests, and a constant rate in different cycles with a total loading time of 10 to 15 minutes for shear tests. In this study loading was done at a rate not exceeding 2.54 mm/minute so that the duration of a test was always greater than 10 minutes.

(l) Moisture content tests : In each shear test, a sample of timber was obtained near the failure zone to determine the moisture content. In withdrawal tests, moisture content variation was not considered as it was unimportant[1].

It is uncertain whether shear strength is affected by moisture content. Brock[9] has suggested that shrinkage of wood, with the lowering of moisture content, can cause cracking near nails which would result in the nails to be withdrawn easily, thus reducing the strength of the joint. Further, moisture may reduce friction between nail and timber. The studies by Chandrakeerthy et al[4,5] did not establish any relationship between moisture content and shear strength for the two test series, one in which moisture content of timber was varied before fabrication and in the other where moisture content was varied after fabrication. In this study this aspect was further studied by conducting a subsidiary test series with the hope of developing a relationship between shear strength and moisture content and then using it to reduce all test results to 15% moisture content (dry condition). In this series, all 15 specimens were initially kept submerged in water for 10 days. From the day were removed from water, two specimens were tested daily allowing the rest to dry gradually.

(m) Specific gravity tests : Specific gravity of timber varies from specimen to specimen and strength of a nailed joint was found to vary with specific gravity[14, 15]. Hence specific gravity of each specimen was determined so that strength can be adjusted accordingly.

2.2 Experimental Programme

It consisted of a shear test series, a withdrawal test series, and a subsidiary test series which dealt with relationship of moisture content to shear strength of nailed joints. Tensile tests were also done on nails. In addition moisture content test and specific gravity test were done for each specimen. A total of 65 shear tests, 40 withdrawal tests, 10 tensile tests, 105 moisture content tests and 105 specific gravity tests were conducted.

3.0 Experimental Results and Analysis

3.1 Performance of Nailed Joints in Shear

The typical failure mode was by plastic bending and withdrawal of nails from pointside. After ultimate load was reached, deformation increased with reduction of load until two members parted each other. However, the 100mm long SWG 5 nail (shorter SWG 5 nail) failed differently with nail heads sunk into the headside timber in addition to plastic bending and withdrawal of nails from pointside. Unusual failure mode and lower ultimate loads (see Table 2) indicate that for 100mm long SWG 5 nail, the length is insufficient to develop its full strength.

Deformation of joints indicate that adequate warning was available before failure. Load/slip curves show three regions consisting of elastic deformation, plastic deformation and, finally, a falling curve corresponding to pull out of nails.

3.2 Performance of Nailed Joints Under Withdrawal

Observed failure mode was the same for all tests consisting of the nail being pulled out clear of timber. Slip versus load readings could not be recorded since there was minimal deformation before ultimate load and at ultimate load withdrawal of the nail occurred rapidly with no time available for measurements. SWG 12 and 10 nails showed no adequate warning before failure. Coefficient of variation was low (see Table 3) but increased as diameter of nail became small.

3.3 Moisture Content Test Series

Since in published literature, there is no relation between shear strength of nailed joints and moisture content, this test series was carried out. Anticipated relationship was one similar to Wilson's[10] relationship on strength properties of timber and moisture content. According to this relationship, logarithm of shear strength of joint should decrease with moisture content linearly up to fibre saturation point and remain constant thereafter. The study showed that strength values are independent of moisture content. This is possible because all the specimens failed primarily by withdrawal of nails, and according to BS 5268[1] withdrawal loads are not dependent on moisture content.

As a safe procedure, it was decided to use two different methods for applying moisture content corrections to shear loads and obtain the minimum value from either method for each test result. The two relationships were : (i) As observed in the experimental study, shear strength values are independent of moisture content; (ii) Combination of Wilson's[10] relationship and the method recommended in BS 5268[1] for applying variations of shear loads of nails with moisture content, which consists of multiplying the dry shear load value (18% moisture content) by 0.7 to obtain green shear load (30% moisture content at fibre saturation point).

As in BS 5268[1] no adjustment for moisture content was done for withdrawal load test results.

3.4 Tensile Tests on Nails

Mechanical properties of nails are summarised as follows :

(i) Percentage elongation - 5.2%; (ii) Percentage reduction in area - 53.5%; (iii) Design yield strength of SWG 12, 10 and 8 nails - 636.4 N/mm^2 ; and (iv) Design yield strength of SWG 5 nails - 574.0 N/mm^2. Design yield strength was derived statistically for 1% exclusion on mean yield strength values observed. The large design yield strength values for smaller diameter nails can be attributed to the greater amount of cold working undergone by such nails.

3.5 Development of Design Recommendations

The various steps adopted for development of design recommendations and their sequence are as follows : (i) Adjustment of strength values to a common moisture content of 15% which reflects the dry condition of timber in Sri Lanka. (This correction is not relevant for withdrawal loads); (ii) Adjustment of specific gravity results to a common average value (0.487) and corresponding adjustment of strength values; (iii) Derivation of basic loads in statistical terms with the aid of the mean and the standard deviation of test results[16] see (Tables 2 and 3), with an exclusion limit of 5% and a suitable factor of safety; and (iv) Ensuring elastic behaviour without excessive slip at the derived basic load and lowering the basic load if necessary.

Adjustment of strength values to 15% moisture content was done as described under 3.3. Adjustment to the average specific gravity was done using the theory of direct proportionality.

Basic load was derived in a manner similar to that adopted by previous researchers[10,12,13]. Formula used considers statistically the variability of the material, and allows for variation in shape and size, accidental overloading, faults in workmanship etc. by a factor of safety. Formula used is

$$\text{Basic load} = (M - ks)/F$$

where M = Mean ultimate load; k = 1.64 for 5% exclusion; s = standard deviation; and F = factor of safety.

Value of 5% exclusion was adopted to comply with BS 5268[1]. Sunley and Brock[13] have recommended F between 2.5 and 3 with 3.5 for some extreme cases. Booth and Reece[10] recommend F = 3. Hence a value of 3 was adopted in this study.

Limit of excessive slip was taken as 0.0026 mm[4] and the basic loads recommended were not allowed to exceed this limiting slip or the limit of proportionality.

Recommended values of dry basic single shear lateral loads for round wire nails inserted as right-angles to the grain are shown in Table 4. Recommended values of basic withdrawal loads for round wire nails driven at right-angles to the grain are shown in Table 5. Values for other conditions should be obtained in accordance with BS 5268[1]. The given values refer to clear wood and should be modified by the strength proportion of the grade of timber considered.

Dry basic single shear lateral loads recommended were found to be directly proportional to the sectional area of the nail, while basic withdrawal loads recommended were found to be directly proportional to the nail diameter.

4.0 Conclusions

The following conclusions are made from this study :

a) Nail sizes currently used for structural applications are: SWG 12 - 2"long; SWG 10 - 2" long; SWG 8 - 3" long; SWG 5 - 4" long; and SWG 5 - 6"long;
b) Nail diameter, nail length and material properties of nails are generally compatible with strength of timber tested in single shear and joints show a significant elastic range and a plastic range. However, SWG 5 - 4" long nail is not long enough to give optimum performance.
c) In developing design recommendations for nails in shear, headside and pointside thicknesses of members given in BS 5268[1] cannot always be adopted and hence varied to suit the optimum strength development of the available nail lengths;
d) Nails in withdrawal should be avoided, whenever possible, in structural applications because of inefficiency as well as inadequate warning before failure;

e) Dry basic single shear lateral loads and dry basic withdrawal loads are greater than BS 5268[1] values for their strongest grade of timber;

f) Design recommendation made above for nailed joints can be used in conjunction with the BS 5268[1] design process. As graded timber is not available in Sri Lanka, recommendations refer to clear wood. If graded timber is to be used, the above values should be multiplied by the strength proportion of the grade considered; and

g) Mean specific gravity of Ginisapu was 0.487.

5.0 References

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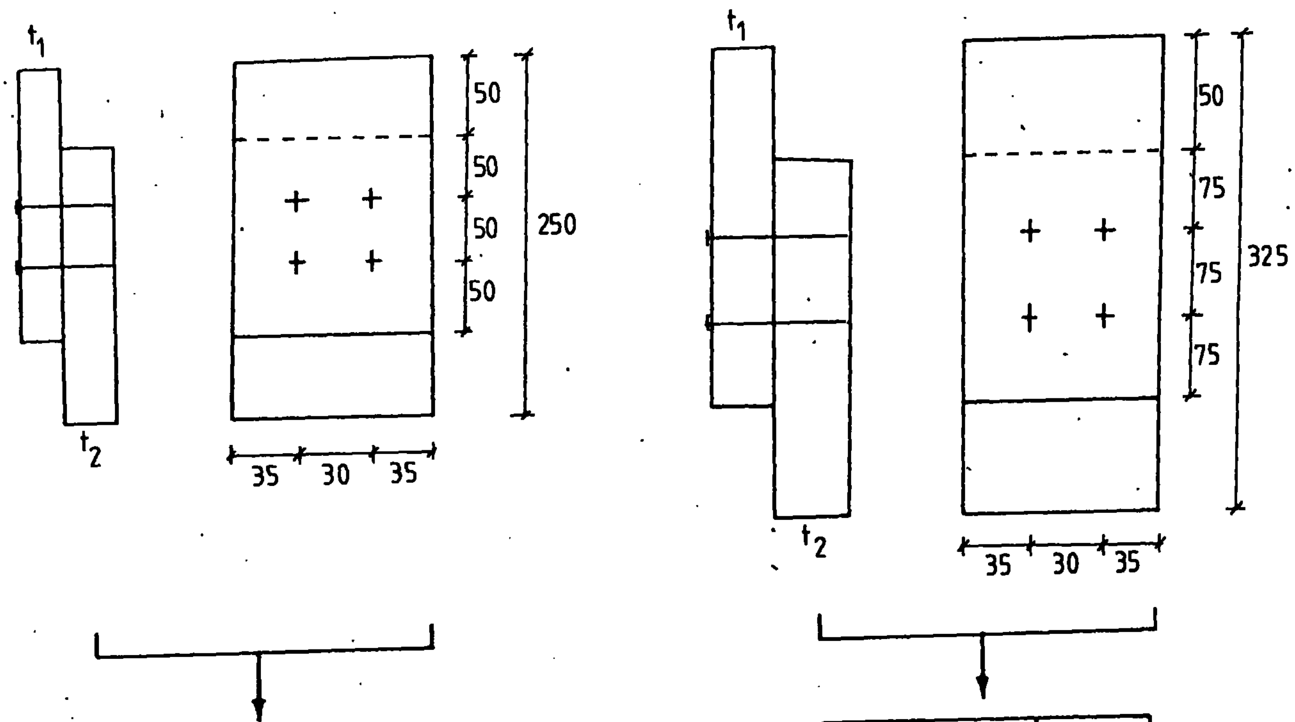
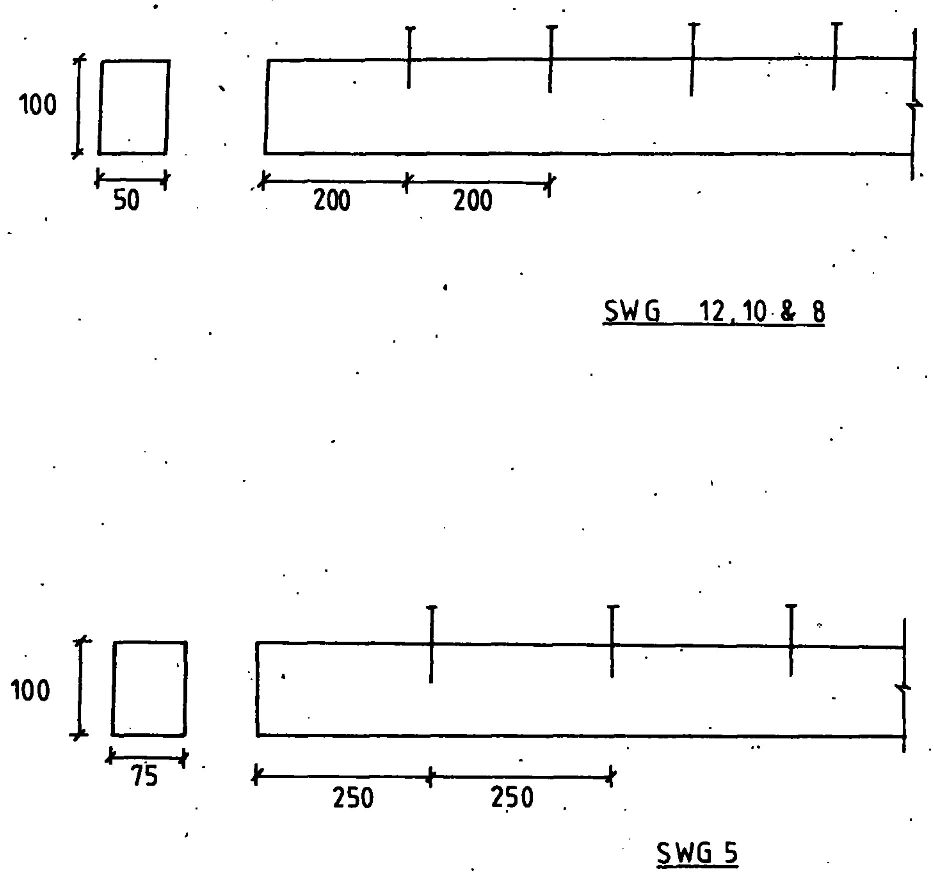


SWG	t_1(in)	t_2(in)
12	0·75	1·25
10	0·75	1·25
8	1·25	1·75

SWG	t_1(in)	t_2(in)
5	2·25	3·75

ALL DIMENSIONS (UNLESS STATED OTHERWISE)
ARE IN MILLIMETRES

FIGURE 1 - DIMENSIONS OF SHEAR TEST SPECIMENS



ALL DIMENSIONS ARE IN MILLIMETRES

FIGURE 2 - DIMENSIONS OF WITHDRAWAL TEST SPECIMENS

SWG size	Nail diameter inch (mm)	Nail length inch (mm)
12	0.104 (2.06)	2 (50)
10	0.128 (3.2)	2 (50)
8	0.160 (4.0)	3 (75)
5	0.212 (4.9)	4 (100)
5	0.212 (5.4)	6 (150)

TABLE 1 - Nail Sizes Used

Diameter of nail SWG	Thickness of members		Mean Ultimate load (kN)	Standard deviation	Coefficient of variation (%)
	Headside (inch)	Pointside (inch)			
12	3/4	1¼	6.043	0.765	12.66
10	3/4	1¼	7.191	0.951	13.22
8	1¼	1 3/4	14.450	1.452	10.05
5	1½	2½	28.675	4.396	15.33
5	2¼	3 3/4	34.688	1.627	4.69

TABLE 2 - Mean Ultimate Load of Nailed Joints in Single Shear, After Adjustment to 15% Moisture Content and Average Specific Gravity

Diameter of nail SWG	Mean ultimate load per unit penetration (N/mm)	Standard deviation	Coefficient of variation (%)
12	41.800	4.351	10.41
10	44.521	1.839	4.13
8	52.947	3.420	6.46
5	79.632	1.776	2.23

TABLE 3 - Mean Ultimate Loads of Nailed Joints in Withdrawal, After Adjustment to the Average Specific Gravity

Diameter of nail		Standard thickness of members		Basic lateral load for defect free timber (N)
SWG	mm(in)	Headside mm(in)	Pointside mm(in)	
12	2.64 (0.104)	18.75 (0.75)	31.25 (1.25)	399.0
10	3.25 (0.128)	18.75 (0.75)	31.25 (1.25)	469.3
8	4.06 (0.160)	31.25 (1.25)	43.75 (1.75)	1005.7
5	5.39 (0.212)	56.25 (2.25)	93.75 (3.75)	2315.1

TABLE 4 - Basic Single Shear Lateral Loads for Round Wire Nails, Driven at Right-angles to the Grain of GINISAPU

Diameter of nail		Basic withdrawal loads per 1mm of pointside penetration for defect free timber (N/mm)
SWG	mm(in)	
12	2.64 (0.104)	11.55
10	3.25 (0.128)	13.84
8	4.06 (0.160)	15.78
5	5.39 (0.212)	25.57

TABLE 5 - Basic Withdrawal Loads for Round Wire Nails Driven at Right-angles to the Grain of GINISAPU