STRENGTH AND FAILURE OF GANGNAIL CONNECTORS

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ABSTRACT

Basic resistance of nails to withdrawal and lateral loads was studied to determine the strength and failure of gangnails, a modern type of timber connector basically used for wooden trusses. Two types of gangnails manufactured in the Philippines and used in the experiment differed mainly in plate thickness, tooth size and spacing, tooth type, and number of teeth. Test results showed that the strength of gangnails was governed by the tensile strength of the gangnail plate, the shearing strength of the gangnail tooth, and bearing strength of the wood member. Three types of failure patterns were observed, namely, breaking of the plate, shearing of the teeth, and bearing failure in the wood.

INTRODUCTION

Common nails, screws, spikes, and bolts carry limited loads. Though they can be applied easily, the number of connectors that can be placed per unit area is limited because of splitting failure. Split rings, toothed rings, shear plates and other mechanical connectors are very expensive, require skilled labor for their application, and carry limited load. During the last decade, these connectors are not popularly used in timber construction.

Technological advances in timber engineering and the continuing search for more economical and more efficient jointing techniques have brought about the development of various types of light-gauge-metal gussets. The most famous of these are the gangnails. These are now gaining widespread acceptance, particularly in assembling wood trusses in the United States, Australia, Canada, Europe, Africa, and Southeast Asian countries. Their greatest use, however, has been in trusses roofs for light-construction houses and industrial buildings, including warehouses and farm structures.

The standard sizes and types of gangnails studied and used in some Southeast Asian countries, including the Philippines, are patterned from designs used in Australia and the United States using wood found in their respective places. This study presents results that may be used in the proper selection and design of gangnail connectors using wood found in the tropics.

MATERIALS AND METHODS

Types of Gangnails. — Two types of gangnails are fabricated in the Philippines. These are gage 18 and gage 14. They differ in plate thickness, number of teeth per sq. mm of connector, tooth type and geometry (Fig. 1). Gangnail gage 18 possesses, in one plate, two types of extended teeth, one is 7/16 in. (11 mm) in length, the other is 9/16 in. (14 mm). Gangnail gage 14 has only one type of teeth. The material with which gangnails are made is basically coil steel, which has been zinc-coated (galvanized) by the hot dip process. The material is then slit and processed through high speed, stamping presses to manufacture the complete line of gangnails. The plates are designed at a yielding strength of 2110 kg/cm^2 and an ultimate strength of 3515 kg/cm^2.

Wood Members. — The moisture content of Yang wood *(Dipterocarpus lutricatus)* used in the test ranged from 15 to 40%. In air-dry condition, Yang has an average specific gravity of 0.614, an ultimate tensile strength parallel to grain of 1045 kg/cm^2, ultimate shear strength parallel to grain of 115 kg/cm^2 and an ultimate compression strength parallel to grain of 455 kg/cm^2. It is the most popular local wood specie used in timber structures in Thailand.

Experimental Investigation. — The test program is divided into three parts. Part 1 consists of tension testing of gangnail gages 14 and 18 loaded parallel and perpendicular to their axis (Table 1). Part 2 is the investigation of the plate strength capacity of gangnail gage 14 (Table 2) and Part 3 is the investigation of tooth strength of gangnail gage 18 (Table 3).

Part 2 was carried out to investigate the tooth strength capacity of gangnail gage 18 based on a fixed number of teeth by first removing all the long teeth in the gangnail and subsequently removing all the short teeth.

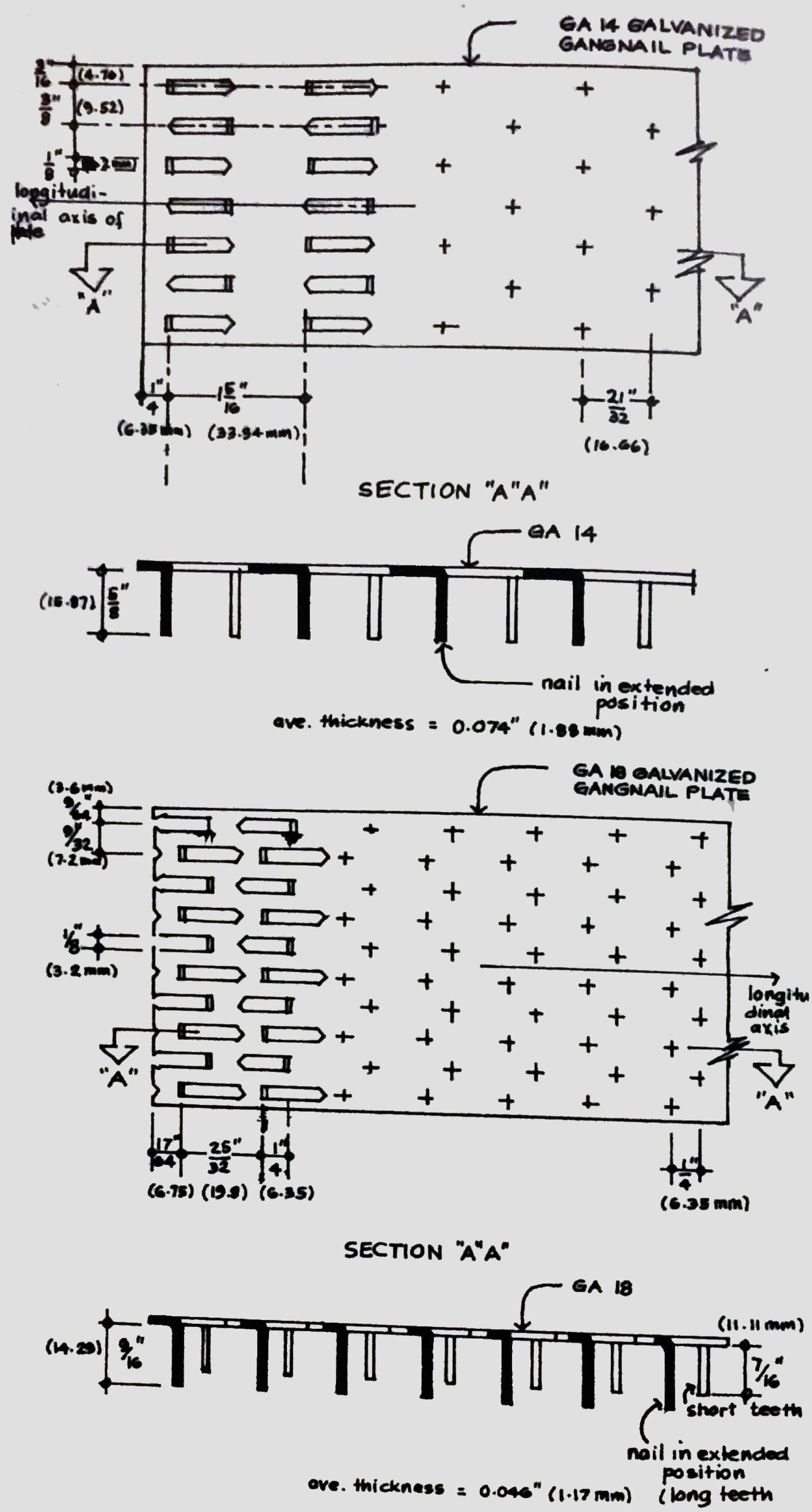

Fig. 1. Detail of gangnail connector plates.

Table 1. Outline of test programe for determination of gangnail strength.

Gangnail Type	Loading Direction	Gangnail Size in x in (mm x mm)	Wood Dimension, mm
Gangnail Gage 18	Longitudinal axis of plate	1 x 5, net width = $\frac{25''}{32}$ (25 x 127) (20mm)	51 x 51 x 305
		2 x 5, n. w. = $\frac{25''}{16}$ (51 x 127) (40mm)	51 x 89 x 305
	Lateral axis of plate	1 x 4, n. w. = $\frac{7''}{16}$ (25 x 102) (11mm)	51 x 63 x 305
		3 x 4, n. w. = $\frac{7''}{8}$ (76 x 102 (22mm)	51 x 102 x 305
Gangnail Gage 14	Longitudinal axis of plate	1 x 5, eff teeth = 12 (25 x 127)	51 x 51 x 305
		2 1/4 x 7, eff teeth = 30 (57 x 178)	51 x 76 x 305
	Lateral axis of plate	1 x 4, eff teeth = 8 (25 x 102)	51 x 51 x 305
		2 1/2 x 4, eff teeth = 12 (63 x 102)	51 x 63 x 305

Table 2. Outline of test program for plate strength determination of gangnail gage 14.

Nominal Size in x in (mm x mm)	Total Width mm	Edge Dist Right mm	Edge Dist Left mm	Net Width mm
1 1/2 x 7 (38 x 178)	38	2.41	4.09	25
2 1/4 x 7 (57 x 178)	57	2.54	4.09	38
3 x 7 (76 x 178)	76	2.54	2.54	51

Table 3. Outline of test program for tooth strength determination of gangnail gage 18.

Loading Direction	No. & Type of Tooth	Gangnail Size in x in (mm x mm)	Wood Dimension, mm
Longitudinal axis of plate	12 short	1 x 5 (25 x 127)	51 x 51 x 305
	12 long	1 x 5 (25 x 127)	51 x 51 x 305
Lateral axis of plate	12 short	1 x 4 (25 x 102)	51 x 76 x 305
	12 long	1 x 4 (25 x 102)	51 x 76 x 305

Description of Specimen, Loading Apparatus and Testing Procedure. — The specimen joint was composed of two nominal 51 mm lumbers connected by a pair of gangnail connector plates, symmetrically placed about the joint. A 25-mm diameter hole was bored at the other end of the wood members to accommodate the gripping apparatus. The specimen joint was formed in the same manner as is contemplated in practical use. The lengths of the connected members were determined based on the type of gripping apparatus used in the experiment.

The width of the wood member was so chosen to accommodate the gangnail that the recommended minimum edge distance did not exceed 6.35 mm (i.e. the minimum distance from the plate's edge to the edge of the wood) (Gangnail Phil., Inc., 1975; Hoyle, 1972). This is to avoid premature splitting at the edges of the lumber. For the same reason, a gap of 12.7 mm was provided at the connected ends. This was carried out by either removing or bending the teeth within that area. The gangnails were pressed into the wood using the universal testing machine. Before pressing, the perpendicularity of the teeth was checked to ensure vertical penetration of the teeth into the wood. Two dial gages were used to measure the slip at equal intervals of load. The connection was tested at a rate of approximately 0.90 mm/min (rate of motion of the movable cross head) so that the maximum load is attained in not less than 5 nor more than 20 minutes (ASTM, 1978). The slip of the joint was measured from the beginning of the application of load and at regular load intervals. The joint slip was taken based on the average of the dial gage readings. The connection was tested until the ultimate load was reached. After the test, a 25 mm section was taken from the wood member for the moisture content and specific gravity tests.

RESULTS AND DISCUSSION

Three different modes of failure were observed in the gangnail connected members, namely:

(1) *Plate Failure or Breaking of Gangnail Plates*

This type of failure is characterized by breaking of the gangnail plate at the portion of minimum cross-section. Gangnail gage 18, the thinner type, which has more teeth per sq. mm of connector failed by this type when loaded both in the direction parallel and perpendicular to its axis. The failure means that the teeth of gangnail gage 18 were stronger and can carry higher loads than the plate. The average ultimate strength was found to be 3400 kg/cm.^{2}.

Direct tension tests conducted for gangnail gage 14 to determine its plate strength when the teeth are not carrying any load showed that the ultimate plate strength ranged from 2950 to 3720 kg/cm^2, with an average ultimate strength of 3320 kg/cm^2. The specified ultimate plate strength is 3515 kg/cm^2 (Guide sheet for Zinc-coated Galvanized Coil Steel. Automated Building Components, Pty. Ltd., Melbourne, Australia, June 20, 1973).

(2) *Tooth Failure or Shearing of the Gangnail Teeth*

Gangnail gage 14 behaved the opposite way when subjected to tensile loads. Its failure was caused by shearing of the teeth at the base, the weakest part in this particular type of gangnail construction. The reason for this is that gangnail gage 14, as compared to gage 18, has a thicker plate and a bigger plate cross-section. From the test results, the average ultimate strength per tooth was found to be approximately 81 kg.

(3) *Bearing Failure in Wood*

Failure of this type is similar to that of nails loaded laterally, that is tearing of the wood by the gangnail teeth at the vicinity of the teeth. This means that the bearing strength of the wood is lower than both the plate and the tooth strength of the gangnail connector. After the wood failed, the teeth were bent before being finally pulled out, a failure generally called "teeth pull-out". Gangnail gage 18 tested for long and short teeth behaved this way when loaded parallel and perpendicular to axis of plate.

Based on the results of the experiment, the main factors affecting strength of gangnail connectors are: (1) *Strength of gangnail plates.* When the tensile strength of the gangnail plates is very much lower than the shearing strength of the gangnail teeth and the bearing strength of the wood, the gangnail connector fails by breaking of plate. The size and spacing of the teeth affect the net plate area or the unpunched area since the latter is reduced when the tooth size is increased and the spacing decreased. Regardless of the thickness of gangnails and the type of wood used, the strength of gangnail plates is affected by the magnitude of the net plate area. Table 4 shows the unit plate strength of gangnail gage 18 loaded in the longitudinal and lateral axis of the plate; and, (2) *Size of tooth.* When the tooth size is reduced, the shear area of the tooth is reduced and the gangnail fails by shearing of the teeth. Likewise, it affects the net plate area as previously discussed.

It can thus be drawn that, for a certain size of gangnail and wood type, there is an optimum plate thickness and tooth geometry wherein both the plate and teeth of the gangnail fail separately under the same load. The average strength per tooth of gangnail gage 14, failing by shearing of teeth when loaded both in the longitudinal and lateral axis of the plate is given in Table 5. The ultimate strength per tooth is obtained by dividing the ultimate load by the total number of effective teeth.

Results of the test for gangnail gage 18 test for short and long teeth failing by bearing failure of wood is summarized in Table 6. It was observed that the ultimate loads of gangnail gage 18 when loaded in the longitudinal axis of the plate were higher than when loaded in the lateral axis of the plate. This can be explained by the smaller bearing area of the latter as compared to the former with the same number of teeth. It was also noted that the ultimate bearing strength obtained when gage 18 is loaded in the longitudinal direction is lower than those in the lateral direction. This is because the stiffness of the teeth is not equal in the longitudinal and lateral directions. As a result, the tooth loaded in the longitudinal axis was bent before it was subsequently pulled out, while the tooth loaded in the lateral axis was merely pulled out.

Based on the test results and the failure patterns of gangnails in this investigation, the following steps are recommended regarding the selection and design of gangnail plates:

(1) For a certain size of gangnail, the ultimate tensile strength should be first evaluated based on the total net area of the gangnail plate and the tensile properties of the material;

(2) Based on the tooth size of the gangnail plate, the ultimate shearing strength per

Table 4. Comparison of unit place strength of gangnail gage 18 loaded in longitudinal and lateral axis of plate.

Load Direction	Gangnail Size (mm x mm)	Sample Mark	Ultimate Condition Load, kg	Ultimate Condition Slip, cm	Unit Plate Strength kg/cm [1]
Longitudinal axis of plate	Nominal size 1'' x 5'' (25 x 127) net plate width = 25''/32 (20mm)	A1	1640	0.825	826
		A2	1624	0.696	818
		A3	1669	0.721	841
		A4	1579	0.569	796
		A5	1640	0.635	826
		Ave.	1630	0.688	821
		Std. Dev.	32.97	0.096	16.46
	Nominal size 2'' x 5'' (51 x 127) net plate width = 25''/16 (40mm)	A6	3368	0.594	850
		A7	3218	0.602	809
		A8	3362	0.632	847
		A9	3290	0.831	829
		A10	—	—	—
		Ave.	3310	0.665	833
		Std. Dev.	70.54	0.112	18.93
Lateral axis of plate	Nominal size 1'' x 4'' (25 x 102) net plate width = 7''/16 (11mm)	A11	870.2	0.521	783
		A12	882.4	0.508	794
		A13	896.3	0.485	791
		A14	839.6	0.513	755
		A15	786.7	0.457	708
		Ave.	855.0	0.483	769
		Std. Dev.	43.55	0.025	36.00
	Nominal size 3'' x 4'' (76 x 102) net plate width = 7''/8 (22mm)	A16	1652	0.516	743
		A17	1657	0.505	746
		A18	1687	0.452	759
		A19	1767	0.465	795
		A20	1594	0.495	717
		Ave.	1672	0.488	751
		Std. Dev.	63.37	0.028	28.46

$$\frac{\text{Average unit plate strength in the longitudinal direction}}{\text{Average unit plate strength in the lateral direction}} = 1.08$$

[1] Ultimate load/net plate width

Table 5. Strength per tooth of gangnail gage 14 loaded in longitudinal and lateral axes of plate.

Load Direction	Gangnail Size mm x mm	Sample Mark	Ultimate Condition Load, kg	Ultimate Condition Slip, cm	Strength per tooth kg
Longitudinal axis of plate	Nominal	B1	1082.0	1.01	90.18
	size:	B2	1073.0	1.23	89.42
	1''x5''	B3	1100.0	1.00	91.63
	(25 x 127)	B4	838.4	1.04	69.87
	no. of eff	B5	1053.0	0.92	87.72
	teeth: 12	Ave.	1030.0	1.04	85.76
		Std. Dev.	108.0	0.114	8.99
	Nominal	B6	2269.0	1.02	75.64
	size:	B7	2301.0	1.03	76.70
	2 1/4''x7''	B8	2515.0	1.04	83.84
	(57 x 178)	B9	2232.0	1.01	74.39
	no. of eff	B10	2241.0	1.04	74.69
	teeth: 30	Ave.	2312.0	1.03	77.05
		Std. Dev.	117.1	0.015	3.90
Lateral axis of plate	Nominal	B11	616.1	0.68	77.01
	size:	B12	624.2	0.57	78.03
	1'' x 4''	B13	661.0	0.71	82.62
	(25 x 102)	B14	608.0	0.54	75.99
	no. of eff	B15	594.0	0.64	74.33
	teeth: 8	Ave.	621.0	0.63	77.59
		Std. Dev.	25.0	0.074	3.12
	Nominal size:	B16	924.0	0.61	77.00
	2 1/2'' x 4''	B17	950.4	0.63	79.20
	(63 x 102)	B18	985.2	0.74	82.10
	no. of eff	B19	1033.0	0.61	86.07
	teeth: 12	B20	1008.0	0.61	84.03
		Ave.	980.10	0.65	81.68
		Std. Dev.	43.7	0.053	3.64

$$\frac{\text{Average strength per tooth in the longitudinal direction}}{\text{Average strength per tooth in the lateral direction}} = 1.02$$

Table 6. Summary of test results for gangnail gage 18 tested in short and long teeth loaded in the longitudinal and lateral axes of plate.

Load Direction	Tooth Type	Sample Mark	Bearing Area $(cm)^2$	Ultimate Load (kg)	Load per tooth (kg)	Strength per unit Bearing area kg/cm^2
Longitudinal axis of plate	Short teeth	C1	0.353	867.2	72.27	205
		C2		810.4	67.53	191
		C3		808.0	67.33	191
		C4		821.3	68.44	194
		C5		810.1	67.51	191
				Ave. 823.4	68.56	194
	Long teeth	C6	0.453	1110.0	92.50	204
		C7		1040.0	86.67	191
		C8		963.0	80.25	177
		C9		934.3	77.86	172
		C10		999.7	83.31	184
				Ave. 1009.0	84.12	186
Lateral axis of plate	Short teeth	C11	0.130	559.0	46.58	358
		C12		538.6	44.88	345
		C13		579.4	48.28	371
		C14		581.4	48.45	373
		C15		565.1	47.09	362
				Ave. 564.7	47.06	362
	Long teeth	C16	0.167	811.9	67.66	405
		C17		750.7	62.56	375
		C18		771.1	64.26	385
		C19		799.7	66.64	399
		C20		780.4	65.03	389
				Ave. 782.8	65.23	390

$$\frac{\text{Ave. ult. load in lateral axis of plate for short teeth}}{\text{Ave. ult. load in longitudinal axis of plate for short teeth}} = 0.70$$

$$\frac{\text{Ave. ult load in lateral axis of plate for long teeth}}{\text{Ave. ult. load in longitudinal axis of plate for long teeth}} = 0.77$$

tooth should be determined based on the shearing area and the shearing properties of the material. The value obtained should be more or less equal to that obtained in (1), if the gangnail connectors were to be properly designed. This condition may be difficult to achieve in practical design of gangnail plates; and,

(3) Based on the properties of wood to be used, i.e. the bearing strength, and the orientation of gangnail plate, the ultimate bearing strength of the joint should be determined.

The minimum of the three values obtained would govern the failure of the gangnail plate. In other words, the smallest value is the strength of the joint.

LITERATURE CITED

AMERICAN SOCIETY FOR TESTING MATERIALS. 1978. Standard methods of testing metal fasteners in wood. ASTM Standards D1761, Part 22, pp. 552-568.

GANGNAIL PHILIPPINES, INC. 1975. Technical design manual; Gangnail wooden truss systems, 1st ed., Mandaluyong, Rizal, Phil.

HOYLE, R. H., JR. 1972. Nails and nailed joint. Wood technology in the design of structures. Mt. Press Publ. Co. Montana, pp. 135-152; 306-307.