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Group Action Factor of Nail Fastener on the Wood Connection With Plywood Sides Plate

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Abstract

The group action factor was observed in this experimental study. The 18 mm thickness of plywood was used as side's plate and the main members were made from meranti (shorea sp.) and sengon (paraserianthes falcataria) species. The correlations of group action factor with a number of nails in a row was investigated under uni-axial compression loading test with one to ten nails variation in a row. The member connections with multiple 3 rows with 3, 6, and 9 nails in each row were also tested both under uni-axial compression and tension loading. The group action factor correlated to the number of nails for single row was obtained using the regression analysis. The regression equations presented was group action factor at the proportional limit (C_{gp}), group action factor at the 5% offset diameter ($C_{g5\%}$), and group action factor at the ultimate load (C_{gu}). The connection strength at 5% offset diameter and proportional limit was closed to the strength design based on the draft of Indonesian Timber Code 2000. The ultimate strength is extremely higher than the design value, giving a sufficient safety factor. Based on this result, a simplified group action factor equation for connection with plywood side's plate was proposed.

Keywords: *Group action factor, proportional limit, 5% offset diameter, ultimate load.*

Abstrak

Faktor aksi kelompok diteliti dalam studi eksperimental ini. Plywood *dengan tebal 18 mm digunakan sebagai pelat penyambung sisi dan kayu utama terbuat dari meranti* (shorea sp.) *dan sengon (*paraserianthes falcataria*). Korelasi antara faktor aksi kelompok dengan jumlah paku dalam satu baris diteliti dari pengujian dengan beban tekan uni-aksial dengan variasi satu sampai dengan sepuluh buah paku. Sambungan dengan 3 baris majemuk dengan 3, 6, dan 9 paku dalam satu baris juga diuji dengan uji beban tekan dan tarik uni-aksial. Faktor aksi kelompok yang dikorelasikan dengan jumlah paku untuk satu baris didapat dari analisa regresi. Persamaan-persamaan regresi yang disajikan adalah faktor aksi kelompok pada batas proporsional (C_{gp}), faktor aksi kelompok pada 5%* offset diameter *($C_{g5\%}$) dan faktor aksi kelompok pada batas ultimit (C_{gu}). Kekuatan sambungan pada 5%* offset diameter *mendekati kekuatan sambungan dari harga disain berdasarkan* draft *Peraturan Kayu Indonesia 2000. Kekuatan ultimit sambungan jauh lebih tinggi dari harga disain, memberikan faktor keamanan yang memadai. Berdasarkan hasil kajian ini, suatu persamaan sederhana untuk perhitungan faktor aksi kelompok dengan pelat penyambung sisi plywood disarankan.*

Kata-kata Kunci: *Faktor aksi kelompok, batas proporsional, 5% offset diameter, beban ultimit.*

1. Introduction

The connection failure modes may depend on the properties of wood main member, wood side plate and nail. Several failure modes may occur as shown in **Figure 1**. There are six failure modes possible for single shear and four failure modes for double shear connections, Soltis 1999. The connection design strength due to axial load of single nail was different from the strength of a group of nails because the force was not distributed uniformly in each nail. The purpose of this experimental study was to observe the group action factor, the failure behavior and the strength of the connections. The 18 mm thickness of plywood was used as a connection side's plate and main members were made from *meranti* and *sengon* species. The correlation of group action factor with a number of nails in a row was investigated under uni-axial compression test with one to ten nails variation in a row for total of 60 specimens. The 36 member connection specimens using three rows with 3, 6, and 9 nails in every row were also made for compression and tension tests.

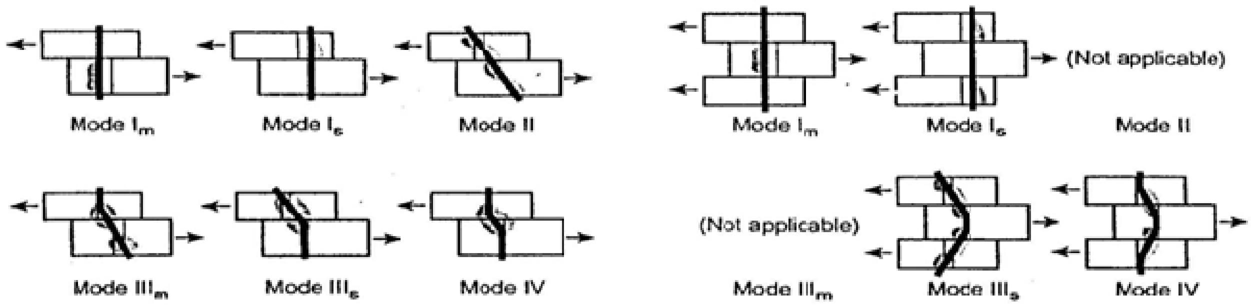

Figure 1. Yield modes on the connections (a) single shear (b) double shear
Source: Soltis (1999)

The basic nail strength for different yield modes in the draft of Indonesian Timber Code (SNI-03-xxxx-2000) which is adopted from NDS (AWC, 2005) may be calculated by **Equations (1)** to **(6)**. The experimental result of the multiple nail connections was compared to this design value to evaluate the group action factor. In the NDS 2005, besides number of nail; type of fastener, ratio of the axial stiffness of wood and side's plate, slip modulus between the main member and side's plates and spacing of the fastener were needed to determine the value of C_g. In this experimental study, the complicated equation of C_g in NDS 2005 for wood connection with plywood sides plate is going to be simplified based on number of nails. The single nail strength at possible failure modes are:

mode I_s: $$N_{Is} = \frac{3{,}3Dt_sF_{es}}{K_D} \quad (1)$$

mode III_m: $$N_{IIIm} = \frac{3{,}3k_1DpF_{em}}{(1+2R_e)K_D} \quad (2)$$

$$k_1 = -1+\sqrt{2(1+R_e)+\frac{2F_{yb}(1+2R_e)D^2}{3F_{em}p^2}} \quad (3)$$

mode IIIs: $$N_{IIIs} = \frac{3{,}3k_2Dt_sF_{em}}{K_D(2+R_e)} \quad (4)$$

$$k_2 = -1+\sqrt{2\frac{(1+R_e)}{R_e}+\frac{2F_{yb}(1+2R_e)D^2}{3F_{em}t_s^2}} \quad (5)$$

mode IV: $$N_{IV} = \frac{3{,}3D^2}{K_D}\sqrt{\frac{2F_{em}F_{yb}}{3(1+R_e)}} \quad (6)$$

where:

N = yield strength (N)
K_D = 2,2 for $D \leq 4.3$ mm,
$0.38D + 0.56$ for 4.3 mm < D < 6.4 mm,
3.0 for $D \geq 6.4$ mm.
F_{em} = main member dowel bearing strength (MPa),
$F_e = 16600\ G^{1.84}$ (psi)
F_{es} = side member dowel bearing strength (MPa)
F_{yb} = dowel bending yield strength (MPa)
R_e = F_{em}/F_{es}
t_s = side member thickness (mm)
D = nail diameter (mm)
p = nail penetration depth (mm)

The design of single nail strength N calculated by **Equations (1)** to **(6)**. The wood and plywood properties to calculate single nail strength was based on the material properties test results as was shown in **Table 1**. And the design of adjusted single nail strength *Z'* calculated by **Equation (7)**.

$$Z' = NC_MC_tC_{pt}C_{rt}C_dC_{di}C_{eg}C_{tn} \quad (7)$$

Where:

Z' = adjusted design strength (*N*)
C_M = wet service factor
C_t = temperature factor
C_{pt} = preservation factor
C_{rt} = fire resistance factor
C_d = penetration depth factor
C_{di} = diaphragm factor
C_{eg} = end grain factor
C_{tn} = toe-nail factor

All C factors was assumed to be 1.0 except for C_d and the design of connection strength *Z* calculated by **Equation (8).**

$$Z = n\phi_Z Z' \quad (8)$$

where

Z = design of connection strength (N)
n = total number of nail
ϕ_Z = resistance factor = 0.65

2. Method and Materials

This research based on the theoretical and experimental studies. The materials were tested based on the ASTM D143-94 standard testing for small clear specimen, ASTM 2005. The main member of the specimen was designed using *sengon* species which has lower specific gravity (G) than plywood, and *meranti* species which have higher specific gravity as shown in **Table 1**. The single row specimen was tested under uni-axial compression loading and the multiple rows connection was tested both under uni-axial compression and tension loadings.

Table 1. Average value of material data

Material	G	$F_{c//}$ (MPa)	$F_{t//}$ (MPa)	mc (%)
Sengon 36x60	0.29	20.65	52.33	12
Meranti 32x70	0.49	45.07	86.63	12
Plywood 18x60	0.38	22.19	52.11	12
Nail	diameter= 2mm	length= 40mm	F_{yb}=(130.4 – 214 d) 1000 (psi)*)	

*) NDS 2005
G = specific gravity, Fc// = compression strength parallel to the grain, Ft// = tension strength parallel to the grain, mc = moisture content
Source: Rosiman (2007)

Table 2. Adjusted single nail design strength

Type	Yield Mode	Yield strength (*N*)	Adjusted nail strength*) (*N*)
Sengon-plywood	I_s	1 247.000	330.478
	III_m	***360.521*****)**	
	III_s	417.908	
	IV	382.325	
Meranti-plywood	I_s	1 247.000	456.438
	III_m	707.612	
	III_s	531.712	
	IV	***497.932*****)**	

*) including C_d , **) critical value, predicted failure mode
Source: Rosiman (2007)

Based on the material properties in **Table 1** and **Equations (1)** to **(6)**, the design strength of a single nail was calculated. The result was then presented in **Table 2**. It was shown that the critical failure mode for *sengon* with lower specific gravity than plywood was mode III_m and for *meranti* with higher specific gravity than plywood was mode IV. The design strength of the connections with multiple nails was as shown in **Table 3**.

Table 3. The design of connection strengt

Type	n	Connection strength Z *) (kN)
Sengon-plywood	2 x 9 = 18	3.867
	2 x 18 = 36	7.733
	2 x 27 = 54	11.600
Meranti-plywood	2 x 9 = 18	5.340
	2 x 18 = 36	10.681
	2 x 27 = 54	16.021

*) including ϕ_Z, without C_g
Source: Rosiman (2007)

The variation of number of row and nails in one row on the specimens was shown as in Appendices, from **Figure A** to **D** and the experimental settings for three rows compression test and three rows tension test were described in **Figures 2a** and **2b**. The test was done under displacement control at 0.6 mm per minute rate using universal testing machine.

(a)

(b)

Figure 2. Experimental settings (a) three rows compression test, (b) three rows tension test

3. Results and Discussion

3.1 The group action factor

The investigation was made to the group action factor at different level of strength, such as at proportional limit (C_{gp}), 5% offset nail diameter ($C_{g5\%}$) and ultimate (C_{gu}) as described in **Figure 3**. The compression tests result for single row was shown as in **Table 4** and **Figures 4** and **5**. The C_g data for regression analysis was generated from the multiple nail strength divided by n times of single nail strength. Although the data were scattered and have a low R^2, the result of C_g at different level of strength was close.

The result for three rows connection was shown as in **Table 5** and **Figures 6, 7** and **8**. The result of C_g at compression test at proportional limit was lower than tension test, but the opposite result was occurred for $C_{g5\%}$ and C_{gu} at three rows test. Although the data of three row test were scattered but the R^2 was higher than single row test.

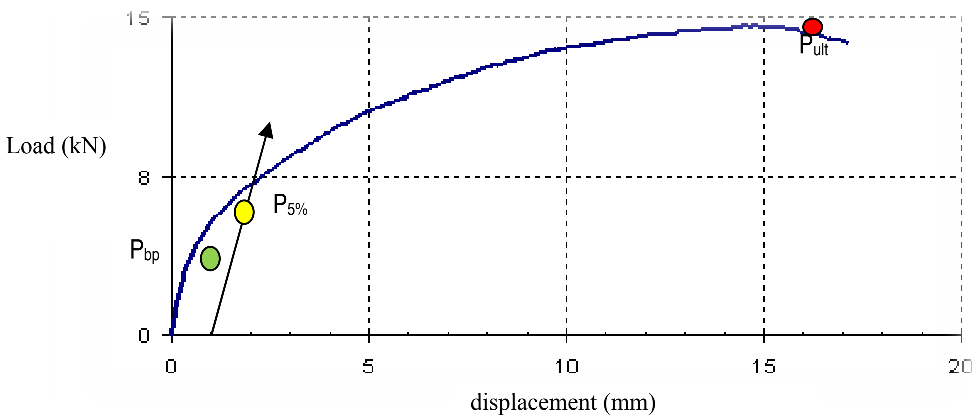

Figure 3. Typical load vs deflection curve of the connection

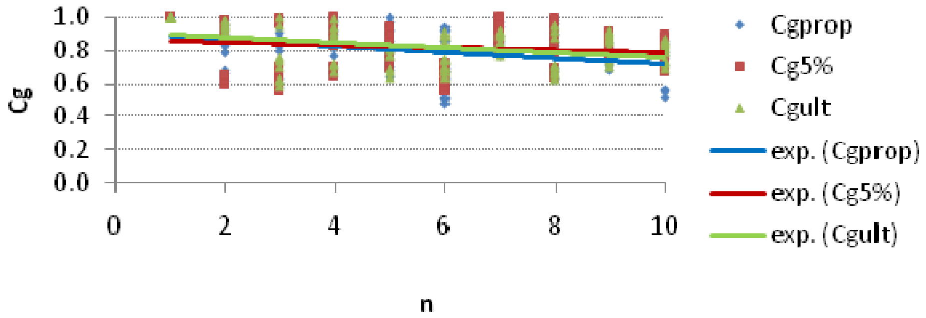

Figure 4. Group action factor of one row *sengon*-plywood nail connection

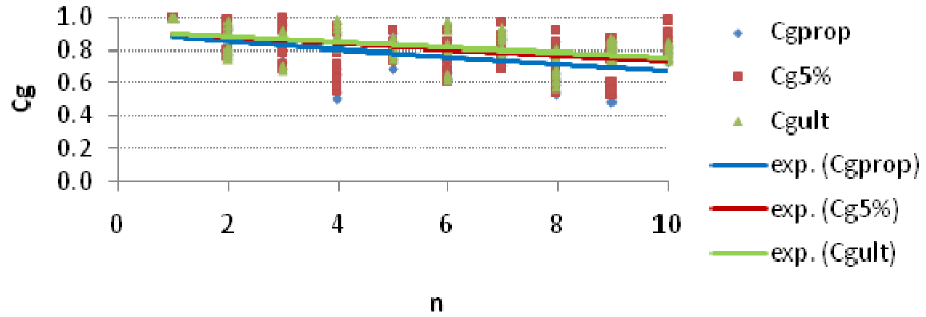

Figure 5. Group action factor of one row *meranti*-plywood nail connection

Table 4. Group action factor for single row

Specimen	Force	Equations*)	R^2
Sengon-plywood	P_{bp}	$C_{gp} = 0.906\ e^{-0.02n}$	0.13
	$P_{5\%}$	$C_{g5\%} = 0.863e^{-0.01n}$	0.23
	P_{ult}	$C_{gu} = 0.912\ e^{-0.01n}$	0.13
Meranti-plywood	P_{bp}	$C_{gp} = 0.898\ e^{-0.02n}$	0.18
	$P_{5\%}$	$C_{g5\%} = 0.921e^{-0.02n}$	0.14
	P_{ult}	$C_{gu} = 0.920\ e^{-0.02n}$	0.19

*) without outlier

Table 5. Group action factor for three rows

Specimen	Force	Equations*)	R^2
Compression (-)	P_{bp}	$C_{gp} = 0.989\ e^{-0.03n}$	0.56
	$P_{5\%}$	$C_{g5\%} = 1.020\ e^{-0.02n}$	0.57
	P_{ult}	$C_{gu} = 0.959\ e^{-0.01n}$	0.28
Tension (+)	P_{bp}	$C_{gp} = 1.023\ e^{-0.03n}$	0.67
	$P_{5\%}$	$C_{g5\%} = 0.995\ e^{-0.02n}$	0.54
	P_{ult}	$C_{gu} = 0.938\ e^{-0.02n}$	0.31

*) without outlier

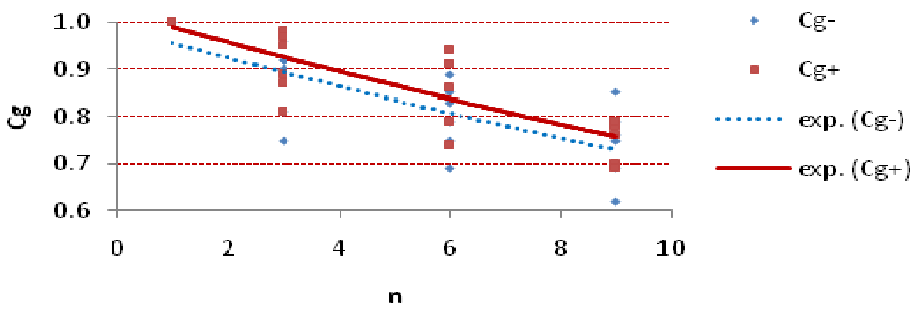

Figure 6. Group action factor of three row nail connection at the proportional limit

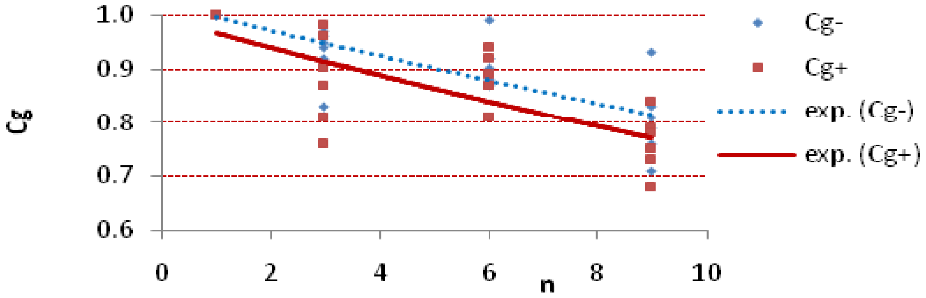

Figure 7. Group action factor of three row nail connection at the 5% offset nail diameter

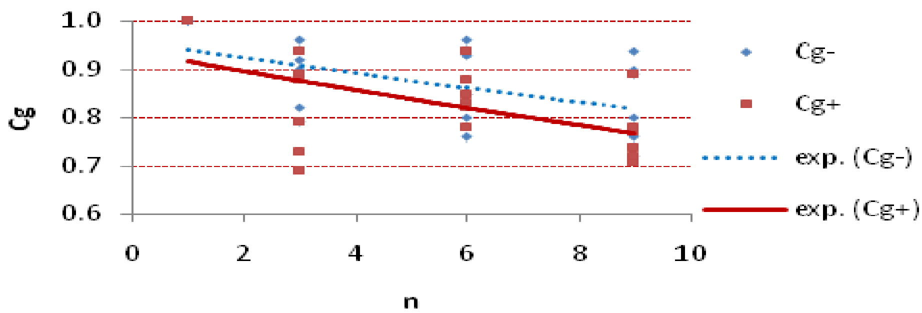

Figure 8. Group action factor of three row nail connection at the ultimate strength

Based on the single and multiple rows tests, the proposed conservative simplified group action factor $C_g = e^{-0.03(n-1)}$ based on $C_g = 1$ for n =1, and $C_g = 0.76$ for n=10 which is observed manually may be used for design connection with plywood sides plate.

3.2 The strength of connections

The comparison of the experimental strength to the design value was done for both types of specimen as shown in **Figures 9** and **10**. The result showed that the strength at proportional limit and 5% offset was lower than the design value. It means that without considering C_g the connection will exceed the elastic limit under design load. But the ultimate strength could achieve 2.5 to 3.0 times the design value as was shown in appendices **Table A** and **Table B**, giving a significant safety factor to prevent collapse.

3.3 The failure modes

The Failure modes on *sengon* connection with lower specific gravity than plywood was mode III_m and for *meranti* connection with higher specific gravity than plywood was mode IV, match with the value prediction in **Table 2**.

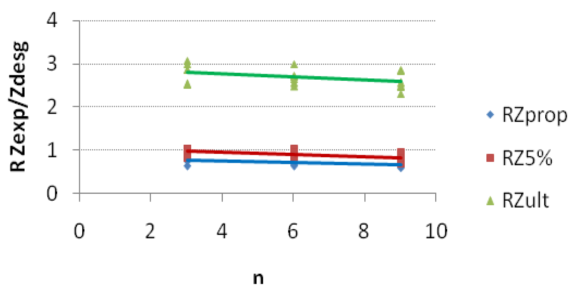

Figure 9. Ratio of experimental to design strength of *sengon*-plywood connection

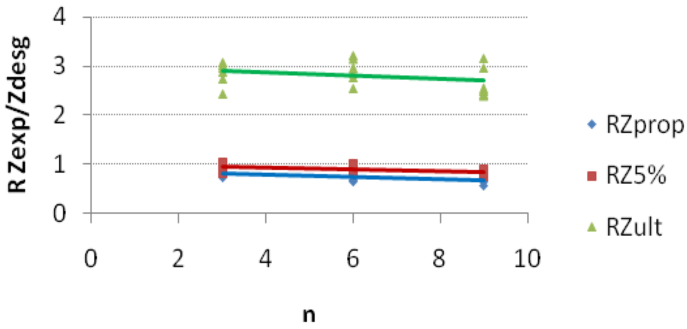

Figure 10. Ratio of experimental to design strength of *meranti*-plywood connection

Figure 11. Failure at three rows - six nails tension specimen (a) sengon-*plywood* (b) meranti-*plywood*

At tension test as was shown in **Figures 12** to **15**, the nail in *sengon*-plywood was fail in single curvature and in the *meranti*-plywood fail in double curvature because the higher specific gravity of meranti. Plywood has more damage both outside or inside at *meranti*-plywood connection. The main wood member has more damage for *sengon*-plywood.

Figure 12. Nail failure modes (a) *sengon*-plywood - mode III_m, (b) *meranti*-plywood - mode IV

Figure 13. Damage on the outside surface of plywood sides plate, (a) *sengon*-plywood (b) *meranti*-plywood

Figure 14. Damage on the inside surface of plywood sides plate, (a) *sengon*-plywood (b) *meranti*-plywood

Figure 15. Damage on the surface of wood main member, (a) *sengon*-plywood (b) *meranti*-plywood

4. Conclusions

1. The experimental value of the connection strength at proportional limit and 5% offset diameter was found in between 0.7 – 1.0 of the strength design based on the draft of Indonesian Timber Code (SNI-03-xxxx-2000). It means that the design strength (without C_g) slightly exceeded the elastic range under the design load.

2. The ultimate strength is more than 2.5 times of the design strength will give a satisfied safety factor from near collapse.

3. It was proof that the failure modes prediction by yield limit equations was accurate and the equations can be applied to calculate the strength of wood connection with plywood side's plate.

4. The proposed simplified group action factor $C_g = e^{-0.03(n-1)}$ may be used for the design connection with plywood side plates to maintain the connection remain in the elastic range under the design load.

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Appendices

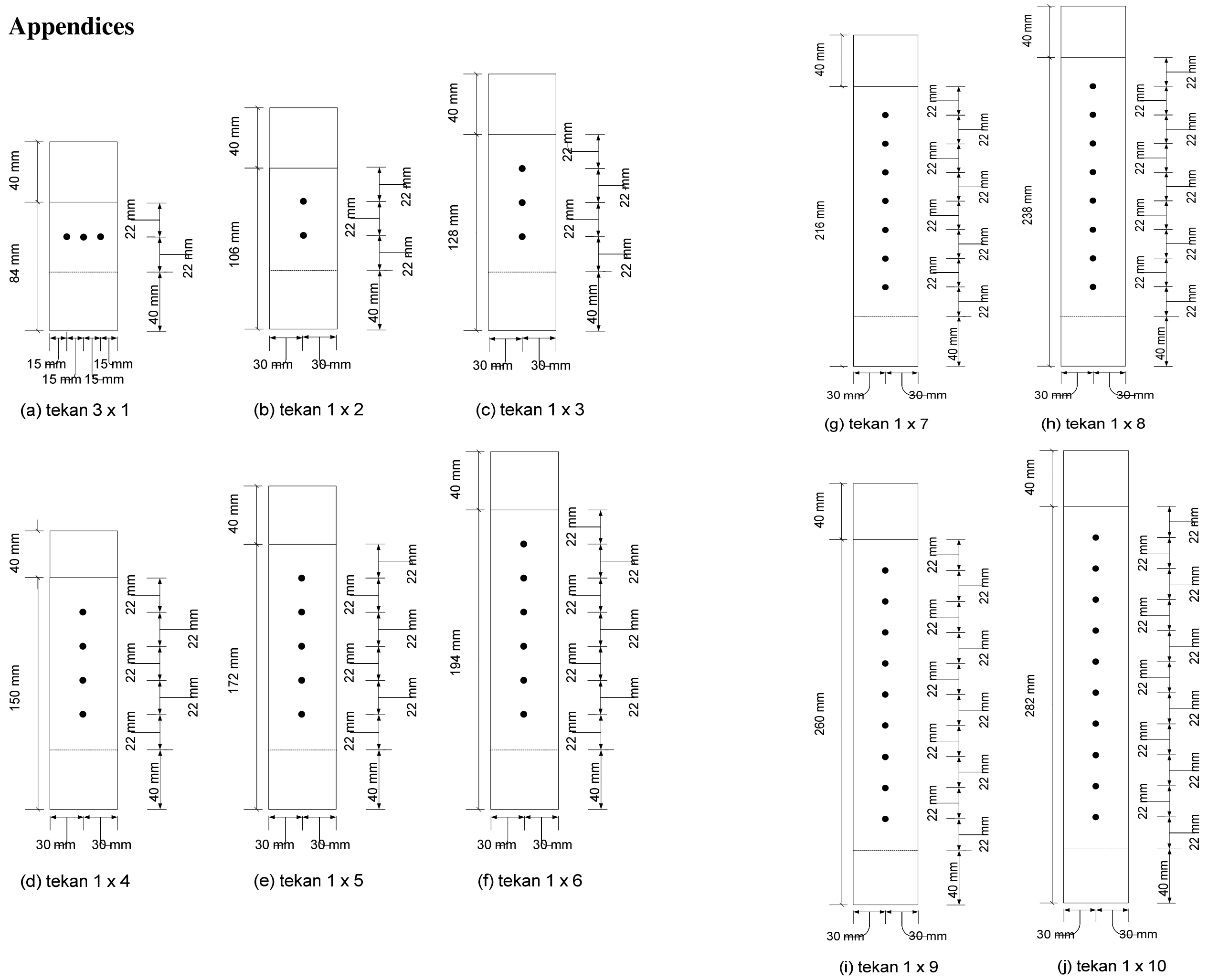

Figure A. Single row specimen variations for compression loading test

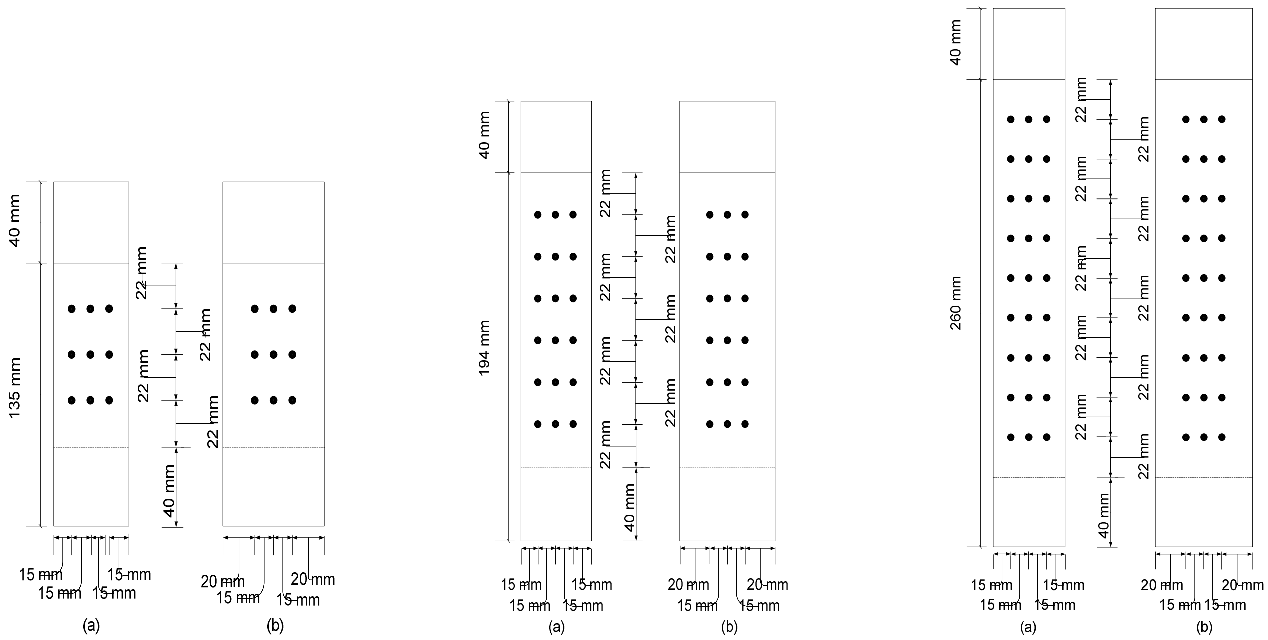

Figure B. Multiple rows specimen variations for compression loading test

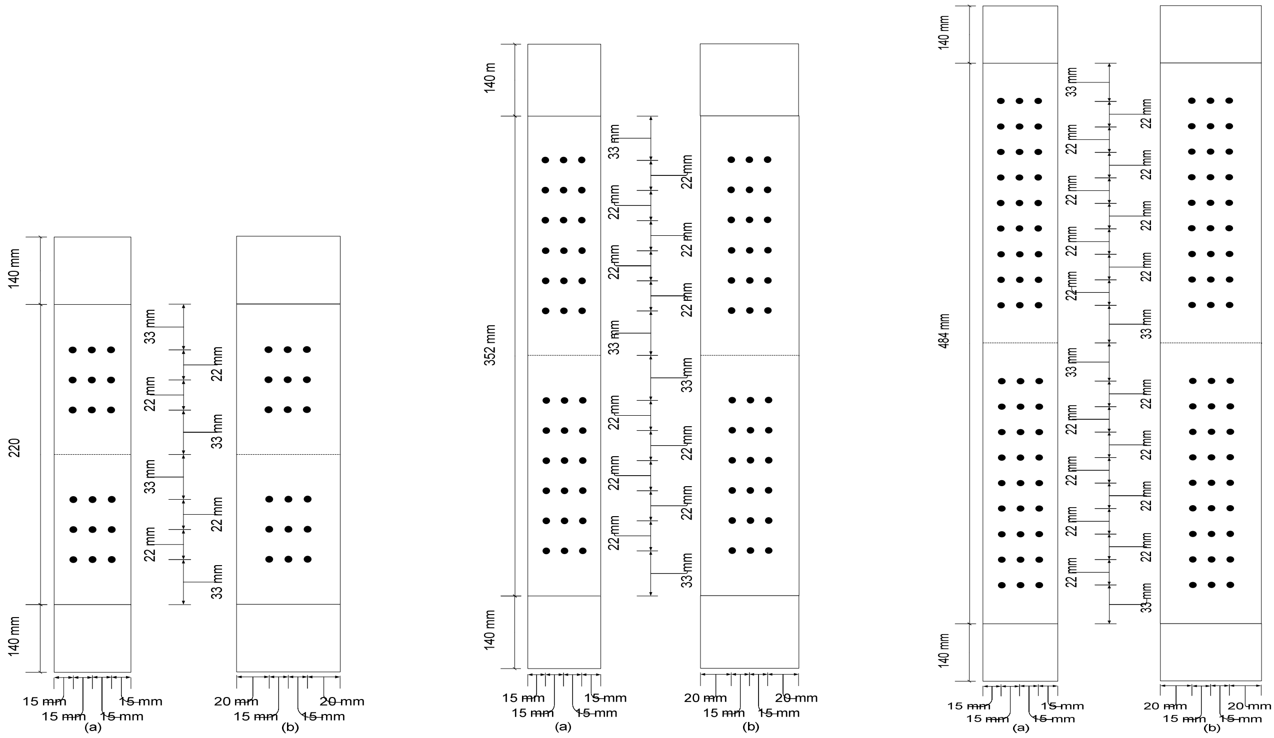

Figure C. Multiple rows specimen variations for tension loading test

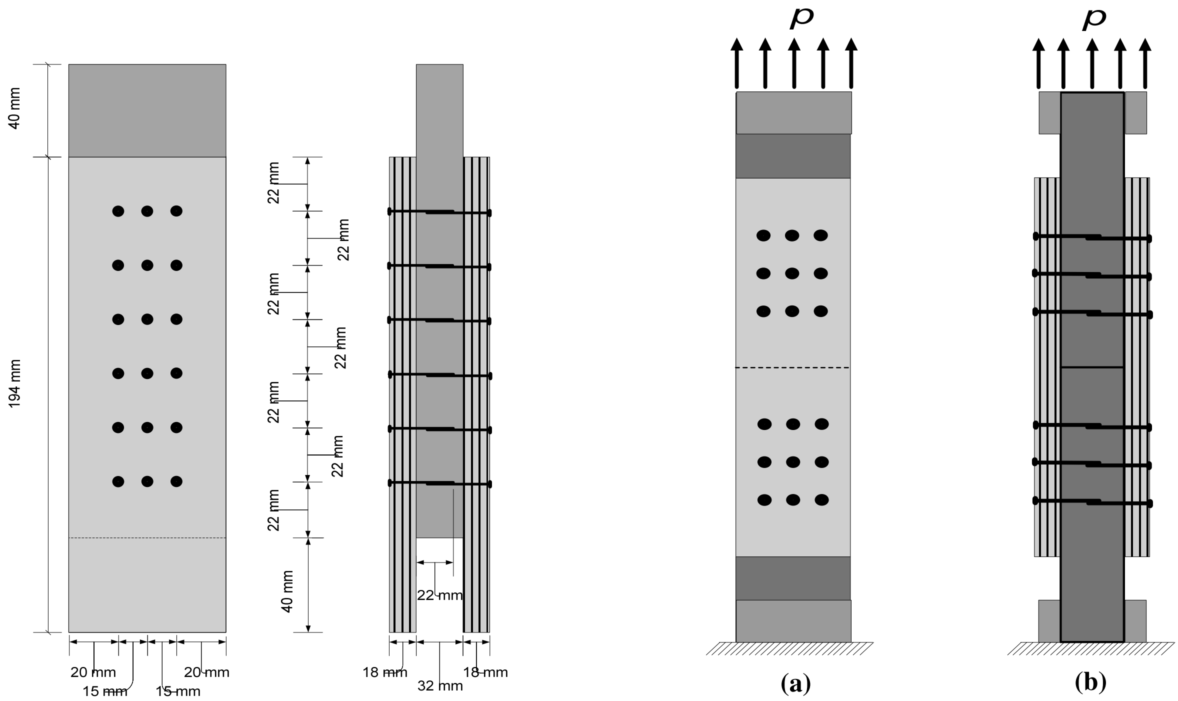

Figure D. Example of compression specimen with three rows and 6 nails each row (left), tension specimen with three rows and 3 nails for each row (right)

Table A. Ratio of experimental to design strength of *sengon*-plywood connection

Sengon-*plywood*	Specimen	n	Design strength SNI, Z (kN)	Experimental Load			Ratio		
				P_{bp} (kN)	$P_{5\%}$ (kN)	P_{ult} (kN)	P_{bp}/Z	$P_{5\%}$/Z	P_{ult}/Z
Compression	SCSN3x3a	18	3.867	2.950	3.850	11.901	0.76	1.00	3.08
	SCSN3x3b	18	3.867	3.000	3.890	9.795	0.78	1.01	2.53
	SCSN3x3c	18	3.867	2.450	3.910	11.075	0.63	1.01	2.86
	SCSN3x6a	36	7.733	5.600	7.420	21.082	0.72	0.96	2.73
	SCSN3x6b	36	7.733	5.800	8.000	23.073	0.75	1.03	2.98
	SCSN3x6c	36	7.733	4.920	7.120	19.762	0.64	0.92	2.56
	SCSN3x9a	54	11.600	7.500	9.600	26.678	0.65	0.83	2.30
	SCSN3x9b	54	11.600	7.800	10.100	29.690	0.67	0.87	2.56
	SCSN3x9c	54	11.600	8.400	11.250	33.241	0.72	0.97	2.87
	STSN3x3a	18	3.867	3.210	3.510	9.751	0.83	0.91	2.52
	STSN3x3b	18	3.867	3.100	3.870	11.571	0.80	1.00	2.99
	STSN3x3c	18	3.867	2.900	3.250	11.041	0.75	0.84	2.86
Tension	STSN3x6a	36	7.733	5.950	7.390	20.969	0.77	0.96	2.71
	STSN3x6b	36	7.733	5.200	6.520	19.174	0.67	0.84	2.48
	STSN3x6c	36	7.733	6.150	7.010	20.532	0.80	0.91	2.66
	STSN3x9a	54	11.600	6.920	8.200	28.562	0.60	0.71	2.46
	STSN3x9b	54	11.600	7.810	8.820	32.927	0.67	0.76	2.84
	STSN3x9c	54	11.600	7.620	9.550	29.013	0.66	0.82	2.50

Table B. Ratio of experimental to design strength of *meranti*-plywood connection

Meranti-*plywood*	Specimen	n	Design strength SNI, Z (kN)	Experimental Load			Ratio		
				P_{bp} (kN)	$P_{5\%}$ (kN)	P_{ult} (kN)	P_{bp}/Z	$P_{5\%}$/Z	P_{ult}/Z
Compression	SCMR3x3a	18	5.340	3.970	4.690	14.602	0,74	0,88	2.73
	SCMR3x3b	18	5.340	4.500	5.310	16.120	0.84	0.99	3.02
	SCMR3x3c	18	5.340	4.720	5.190	16.402	0.88	0.97	3.07
	SCMR3x6a	36	10.681	7.800	10.200	30.372	0.73	0.95	2.84
	SCMR3x6b	36	10.681	8.100	10.400	34.237	0.76	0.97	3.21
	SCMR3x6c	36	10.681	6.800	9.800	27.250	0.64	0.92	2.55
	SCMR3x9a	54	16.021	11.000	13.800	47.608	0.69	0.86	2.97
	SCMR3x9b	54	16.021	10.200	12.900	40.551	0.64	0.81	2.53
	SCMR3x9c	54	16.021	9.200	12.100	50.610	0.57	0.76	3.16
	STMR3x3a	18	5.340	3.980	4.320	15.320	0.75	0.81	2.87
	STMR3x3b	18	5.340	4.250	5.100	12.979	0.80	0.95	2.43
	STMR3x3c	18	5.340	4.750	5.520	15.799	0.89	1.03	2.96
Tension	STMR3x6a	36	10.681	7.280	9.100	29.435	0.68	0.85	2.76
	STMR3x6b	36	10.681	8.940	10.100	33.550	0.84	0.95	3.14
	STMR3x6c	36	10.681	8.410	10.600	31.500	0.79	0.99	2.95
	STMR3x9a	54	16.021	10.200	12.700	38.303	0.64	0.79	2.39
	STMR3x9b	54	16.021	11.620	13.180	38.720	0.73	0.82	2.42
	STMR3x9c	54	16.021	11.200	14.200	39.809	0.70	0.89	2.48