Journal of Ocean, Mechanical and Aerospace
-Science and Engineering-, Vol. 30

April 30, 2016

Finite Element Analysis of Wood Structural Joints on Traditional Wooden Ship

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Paper History

Received: 15-April-2016
Received in revised form: 25-April-2016
Accepted: 30-April-2016

ABSTRACT

Traditional ship often made by woods materials and it was made without proper engineering procedure. This research focuses on a case study in Bagan Siapiapi, Riau Province, Indonesia where a large wooden ship was manufactured. One of the sources of material failure in the manufacturing of wooden ship is located at the joint. In this research, a modification of joint design has been studied where 4 design model have been offered by using glue as the attachment materials and 5 other design by using bolt as the connection method. A finite element method was used to study the strength of the joint which has been guided by a standard issued by Indonesian Classification Bureau. There are 9 design of joints were modeled and studied which have been varied using two different wooden materials such as 'keruing' and 'meranti'. A uniform loading was applied on all models and materials. The applied loadings are buoyancy force, gravity force, and pre-stress loading at the bolt. The result from simulation generates a stress-contour indicating the stress level on the materials. It was concluded that the model of connection hooked straight lip which is connected with 4 pieces M14 bolts with wood material keruing a recommended model for traditional wooden boat building. This design gives 1.605 mm deformation with maximum stress of 217.51 MPa.

KEY WORDS: *Traditional Ship, wood joints, finite element method.*

NOMENCLATURE

ρ	Density of fluid
V_{ter}	Volume of submerged part
F_{apung}	Bouyancy load
g	Gravitational force

1.0 INTRODUCTION

Bagan Siapiapi has been known as the biggest wooden ship manufacturer in Indonesia. Ship produced in this region has been used not only in Indonesia but also outside Indonesia. The ship was used by fisherman to catch the fish. Manufacturing of this wooden ship is still undergoing by conventional and traditional method without any proper engineering procedure. It is often that the ship was made through series knowledge passed by one generation to the other generation. Therefore, there is no standard in the manufacturing of a wooden ship.

Series effort to improve the design of the wooden ship in Bagan Siapiapi has been started by Damanik [1] in 2004. In his research, determination of center of gravity and estimation of ship's loading have been studied. It has been recommended that there is a need for further study in the subject of determination of critical point in the joint based on stress analysis. Stress analysis is an important parameter in the design of ship structure. The analysis and the manufacturing of wooden ship are still conducted based on a proper engineering procedure and standard. However there is a lack of research in the wooden ship.

Stress in the ship structure are often comes from a non-uniform loading due to sea wave. There is a loading combination between hydrostatic and hydrodynamic loads and it will results in bending moment and shear stress at the joint. Therefore, the joint should be designed carefully because at this point the loading becomes critical. In order to obtain the maximum stress at the ship structure, an experimental method or numerical method can be used to investigate the particular stress.

This purpose of this research is to develop several designs of joints at the wooden structure applied to the traditional wooden ship. The analysis was conducted based on numerical methods which use a finite element method to investigate the resulting stress. The expected results are the recommended design of joint and the optimum joint design which gives a high strength with minimum geometry.

2.0 METHODOLOGY

Joint area is the weakest point in the ship structure and responsible for the most of structural failure in the ship structure. There are two methods to connect the structure. The first one is using glue while the other method is using bolt. As for the joint in the wooden ship structure, the reference is based on [3] while the standard for experimental of wooden structure is based on the Indonesia classification bureau.

2.1 Design of Wood Joints using Bolt

The choice of bolts in the wooden joint is based on the thickness of the wooden structure. According to Indonesia classification bureau, for 110 mm of thickness, the choice of bolt is M14. The number of bolt to be used is chosen based on width of the joint which is 230 mm. Therefore the number of bolts to be used is 4. The position of the bolts is also regulated in the standard of Indonesia classification bureau as shown in Table 1.

Table 1: Position the mounting bolts based on standards BKI [4]

Edge cut with a hand	Edge cut with machines	Edge profile does not result snippet
$1{,}75d_b$	$1{,}50d_b$	$1{,}25d_b$

Thus, the calculation results be obtained as follows:

a. Distance to the edge of the bolt (S1) = 1.75 x 14 mm = 24.5 mm
b. Distance to the edge of the bolt unencumbered (S2) = Distance to edge bolt (S1) = 24.5 mm
c. The distance between the bolt (S) = 275 mm - (24.5 (2) + 14 mm) = 212 mm

Based on the design parameters of the above, it can be made a model joint design of timber ships Siapiapi chart, shown in Figure 1 to Figure 5.

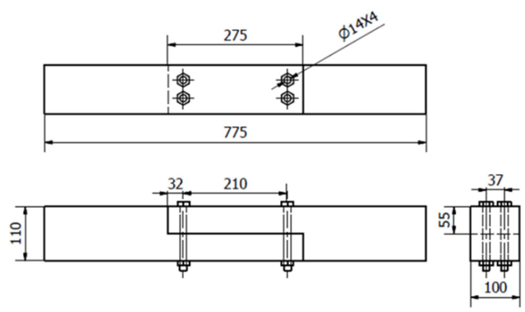

Figure 1: Design of Straight Lip Joint with Bolt (B1)

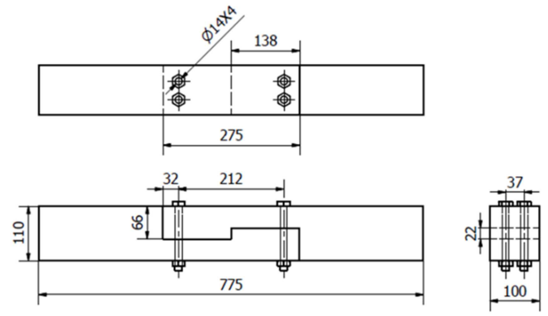

Figure 2: Design of Hook Straight Lip Joint with Bolt (B2)

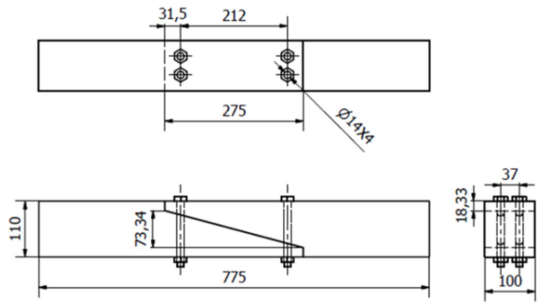

Figure 3: Design of Oblique Lip Joint with Bolt (B3)

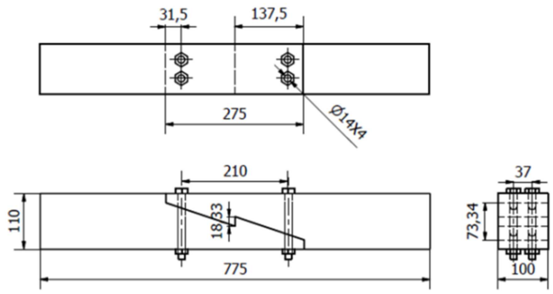

Figure 4: Design of Hook Oblique Lip Joint with Bolt (B4)

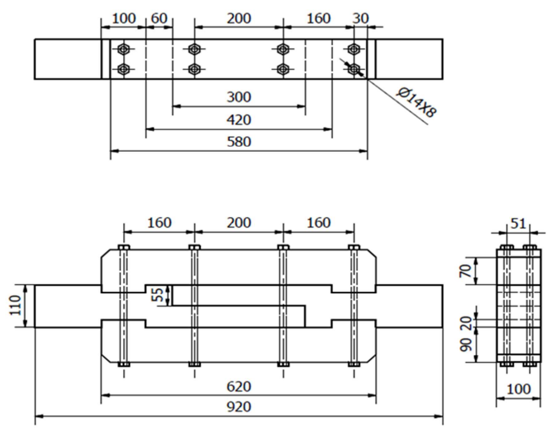

Figure 5: Design of Key Pinch Joint (B5)

2.2 Design of Wood Joints using Glue

According to standard of Indonesia classification bureau, at the joint connected by glue, the required thickness must be less than 1 over ten of the height, but must not less than 5 mm and not more than 20 mm. The requirements for the experiment on the joint connected by glue are:

a. Experimental subject must be from the part connected by the glue.
b. The part connected by the glue must have addition length around 150 mm.
c. The experiment must be conducted at least 10% from 'gading-gading', deck beams and all important element of strength longitude.
d. The specimen should not be given the ultimate handling in excess of that provided at the actual construction.

According the above requirements, thus the development of design for the gading-gading joint on the wooden ship can be presented in Figure 6 to Figure 9.

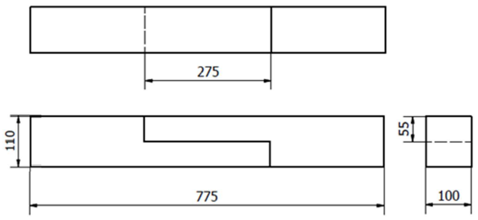

Figure 6: Design of Straight Lip Joint (L1)

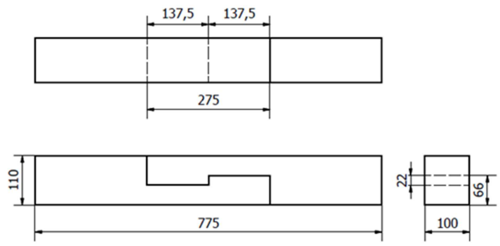

Figure 7: Design of Hook Lip Joint (L2)

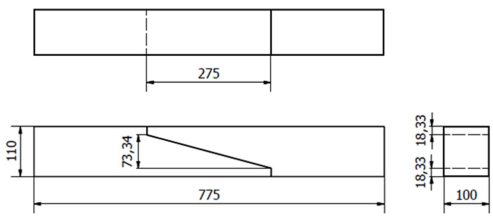

Figure 8: Design of Oblique Lip Joint (L3)

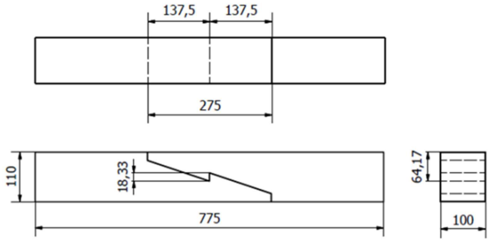

Figure 9: Design of Hook Oblique Lip Joint (L4)

2.3 Finite Element Method

2.3.1 Loading Conditions

The loading on the wooden ship is limited to the external loading, which is the loads due to buoyancy force and the loads due to its own weight. The buoyancy force is obtained based on the volume of the wooden ship, density of the fluid, and also based on the gravity force. The volume is determined based on the previous research, which was defined as the total mass of the wooden ship divided by the density of the fluid. The total mass of the wooden ship is 6308.04 kg [1]. Therefore, the volume can be found by using the following equations.

$$V_{submerged} = \frac{Mass\ of\ Ship}{\rho_{fluids}}$$

$$V_{submerged} = \frac{6308{,}04\ kg}{1012\ \ kg/m^3}$$

$$V_{submerged} = 6{,}15\ m^3$$

Using the above equation, the buoyant force is obtained:

$$F_{floatable} = \rho_{sea\ water}\ x\ g\ x\ V_{submarget}$$

$$F_{floatable} = 1025\ \ kg/m^3\ \ x\ 9{,}18\ \ m/s^2\ \ x\ 6{,}15\ m^3$$

$$F_{floatable} = 61.839{,}7875\ Newton$$

2.3.2 Meshing Strategy

The meshing strategy applied in this research is based on the coarse type or default. This meshing strategy can be used for the general cases but not for the contact part where it needs refinement mesh. The refinement mesh can be seen at the bolts as show in Figure 10 to Figure 12.

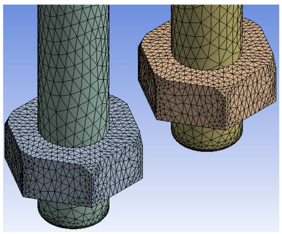

Figure 10: Refinement on Bolt

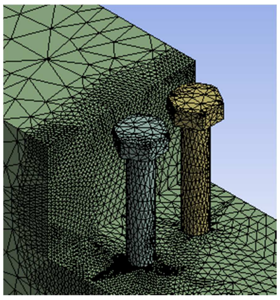

Figure 11: Meshing on the connection bolt with refinement on the contact between the joint with the bolt

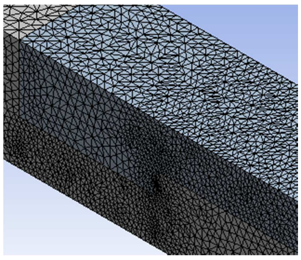

Figure 12: Refinement mesh in the contact area connection

2.2.3 Material Model

The materials studied in this research are keruing and meranti. The mechanical properties of these wooden materials can be seen in Table 2 and Table 3. Only 9 mechanical properties are required in the analysis [6]. The ratio of fiber orientation for the elasticity modulus and shear modulus are based on the previous study [7].

Table 2: Mechanical properties of Keruing Wood

No	Parameter	Axis	Value
1	Elastic Modulus	x	15000 MPa
2		y	10000 MPa
3		z	833,33 MPa
4	Shear Modulus	xy	1379 MPa
5		yz	114,91 MPa
6		xz	91,33MPa
7	Poisson Ratio	x	0,33
8		y	0,33
9		z	0,33
10	Density		780 Kg/m^3

Table 3: Mechanical properties of Meranti Wood

No	Parameter	Axis	Value
1	Elastic Modulus	x	13900 MPa
2		y	9266,6 MPa
3		z	772,22 MPa
4	Shear Modulus	xy	1379 MPa
5		yz	114,91 MPa
6		xz	91,33 MPa
7	Poisson Ratio	x	0,33
8		y	0,33
9		z	0,33
10	Density		865 Kg/m^3

The material for bolts is steel material and its mechanical properties can be found in Table 4.

Table 4: Mechanical properties of structural steel

Densitas	7850	Kg/m^3
Elastic Modulus	200	GPa
Poisson's ratio	0,3	
Bulk Modulus	166,7	GPa
Shear Modulus	76,9	GPa
Yield Strength	250	MPa
Ultimate Tensile Strength	460	MPa

2.2.4 Boundary Conditions

The boundary conditions are necessary for the inclusion of rigid body motion [8]. The axis definition on the model of Bagan Siapiapi traditional wooden ship can be found in Figure 13. At the joint connected by glue, the applied load is based on the Archimides principle. The applied load is due to buoyancy force and its value is 61.840 N at two planes in the z direction, and also the gravity force is 9.806 m/s2 in the z direction. Fixed support is applied for this design in the +x and –x direction. The boundary condition for this design can be seen in Table 5.

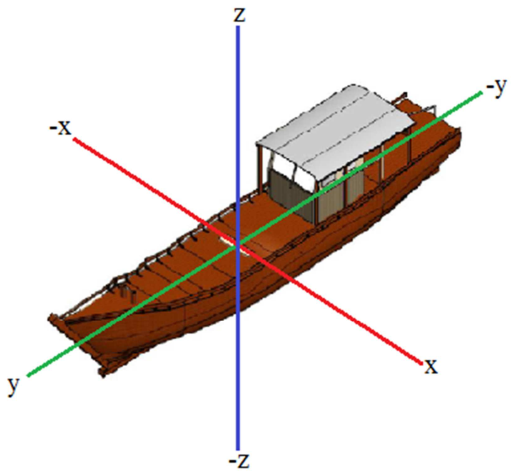

Figure 13: Axis direction to determine the boundary conditions on the connection tusks traditional ship Bagan Siapiapi

Table 5: Connection boundary conditions the glue

Working Force	Axis					
	X	-x	y	-y	z	-z
The buoyant force	-	-	-	-	-	√
Gravity force	-	-	-	-	√	-
Support	√	√	-	-	-	-

Bolt connection has two force direction additional worked, which bolt pretension in the y direction and -y, as shown in Table 6.

Table 6: Boundary conditions of bolt joints

Working Force	Axis					
	x	-x	y	-y	z	-z
The buoyant force	-	-	-	-	-	√
Gravity force	-	-	-	-	√	-
Support	√	√	-	-	-	-
Bolt Pretension	-	-	√	√	-	-

As for the connected part by glue, the contact definition is frictionless with interface treatment is assumed by adjust to touch in order to define that both joints is connected without any offset. This is because it was assumed that two objects connected by glue have an coefficient of friction value approaching infinity. Besides that, the other factor involves is the selection of the type of glue such as hyper glue.

Definition of contact in the joint is based on the friction coefficient. The value of friction coefficient is determined based on the friction between two bodies such as wood to wood or metal to metal. The values of coefficient of friction for these cases are presented in Table 7.

Table 7: Static friction coefficient between two contact areas

Material	Coefficient of Station Friction, μ_s
Metal on metal	0,15 – 0,20
Masonry on masonry	0,60 – 0,70
Wood on wood	0,25 – 0,50
Metal on masonry	0,30 – 0,70
Metal on wood	0,20 – 0,60
Rubber on concrete	0,50 – 0,90

3.0 RESULT AND DISCUSSION

3.1 Equivalent Von-Misses Stress

The simulation results of the 18 models connection with a variety of materials and joining methods can be seen in Table 8.

Table 8: Von Misses equivalent tension at the connection with glue and wood screws

No	Design Connection	Tension Equivalent (MPa)		Maximum tension Location
		min	max	
1	LKM1	0,1795	191,14	Support
2	LKM2	0,5372	122,18	Support
3	LKM3	0,3656	170,24	Connection
4	LKM4	0,4521	188,03	Connection
5	LKK1	0,2437	126,1	Support
6	LKK2	0,5363	123,38	Support
7	LKK3	0,2966	173,1	Connection
8	LKK4	0,4762	187,86	Connection
9	BKM1	0,1322	181,37	Bolt 14 mm
10	BKM2	0,0764	222,25	Bolt 14 mm
11	BKM3	0,1547	363,36	Bolt 14 mm
12	BKM4	0,1829	338,32	Bolt 14 mm
13	BKM5	0,0454	221,79	Bolt 14 mm
14	BKK1	0,129	181,33	Bolt 14 mm
15	BKK2	0,0754	217,51	Bolt 14 mm
16	BKK3	0,155	363,36	Bolt 14 mm
17	BKK4	0,168	341,37	Bolt 14 mm
18	BKK5	0,0483	232,3	Bolt 14 mm

Description Code : L = Connection Glue, B = Connection Bolt,
KM = Wood Meranti, KK = Wood Keruing, 1-5 = Design Connection

According to the data presented in Table 6, the best design of wooden joint to be applied based on equivalent stress is LKM2. This is because the maximum equivalent stress is 122.18 MPa, much lower than the other types of joint. The joint which has the maximum equivalent stress is BKM3. The value of its maximum equivalent stress is 363.36 MPa at 14 mm bolts. The stress contour in the joint LKM2 and BKM3 can be found in Figure 14 and Figure 15.

At the part connected by glue, the maximum equivalent stress occurs at two different places which are support area and joint area. The maximum equivalent stress for the support area occurs at the design LKM1, LKM2, LKK1 and LKK2. As for the joint area, the maximum equivalent stress occurs at the design LKM3, LKM4, LKK3 and LKK4. For the connected part by bolts, the maximum equivalent stress occurs at the 14 mm bolts for all designs.

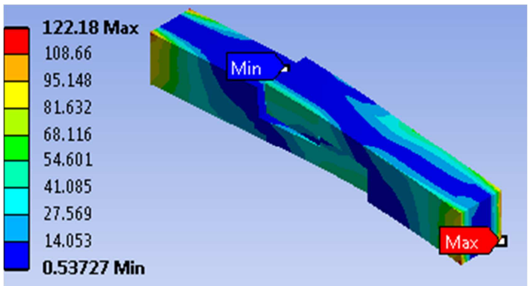

Figure 14: Equivalent tension on LKM2

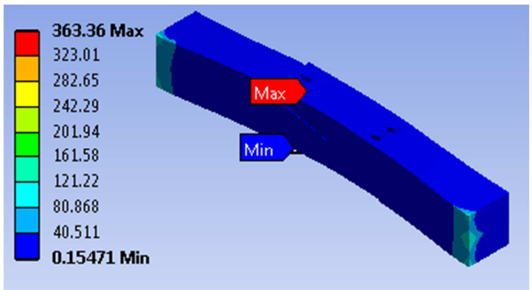

Figure 15: Equivalent tension on BKM3

3.2 Total Deformation

Besides the equivalent stress, the deformation in the wooden joint is also important to be considered in the selection of wooden joint design. Simulation results calculate the deformation for 18 joint designs and its value can be seen in Table 9.

Table 9: Result Deformation Design Connection Wood

No	Design Connection	Deformation (mm)
1	LKM1	24,386
2	LKM2	27,586
3	LKM3	21,293
4	LKM4	21,457
5	LKK1	24,208
6	LKK2	27,179
7	LKK3	20,905
8	LKK4	21,133
9	BKM1	1,635
10	BKM2	1,694
11	BKM3	1,487
12	BKM4	1,6091
13	BKM5	1,5921
14	BKK1	1,521
15	BKK2	1,576
16	BKK3	1,487
17	BKK4	1,4979
18	BKK5	1,4829

Description Code : L = Connection Glue, B = Connection Bolt,
KM = Wood Meranti, KK = Wood Keruing, 1-5 = Design Connection

Based on the simulation results using the finite eglueent method (Table 8 and 9), it showed that the highest stress at the joint occur at the joint No. B3 (oblique lip joint with bolt) for both meranti and keruing. The value of stress for this type of joint is 363.36 MPa. The design which produces the smallest stress is the safest one and it is obtained by design No. L2 (hook lip joint) which use the meranti wood materials. The value of stress for this type of joint is 122.18 MPa. If the design is evaluated based on the deformation, thus the design No. L2 (hook lip joint) which use meranti wood materials produces the deformation around 27.586 mm, be seen in Figure 16. The smallest deformation is occur at the design No. B5 which use keruing wood materials. The design can be seen in Figure 17. The datail for equivalent stress and total deformation for the safest and best design are presented in Figure 18 and 19.

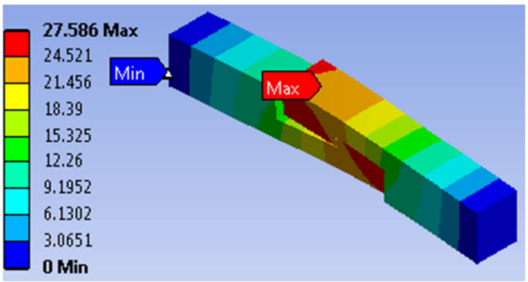

Figure 16: Deformation on LKM2

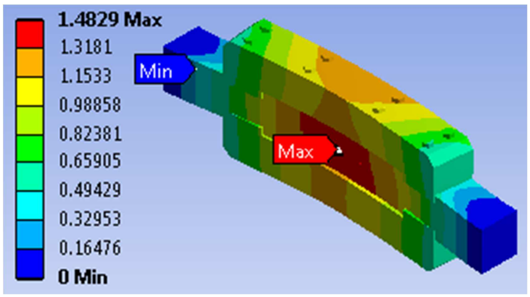

Figure 17: Deformation on BKK5

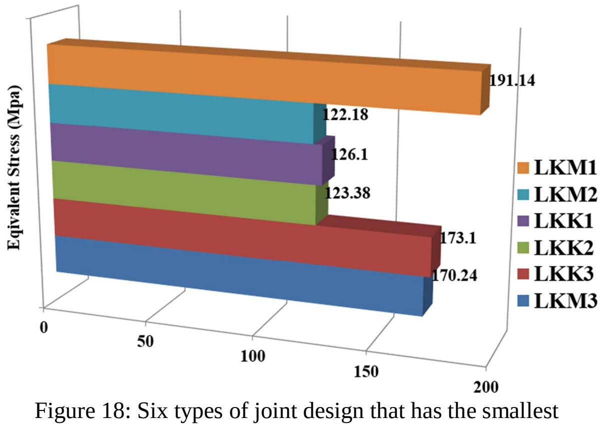

Figure 18: Six types of joint design that has the smallest tension value

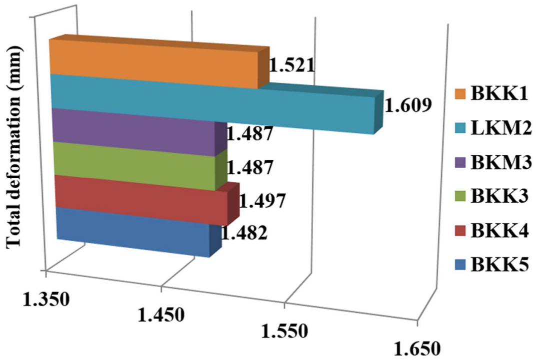

Figure 19: Six types of connections with joint design with the smallest deformation value

4.0 CONCLUSION

The study conducted in this numerical simulation produces 18 simulation models. These models are then used to study the strength of the wooden joint in the traditional wooden ship structure. It can be concluded that:

- The design of joints No.1 (L1/B1) produces a relative small stress compare to the other design of joints.
- In general, the use of glue in the joint parts produces a smaller stress; however it is heavily depends on the type of the glue itself.
- Both of wooden materials meranti and keruing have a relatively similar performance subjected to applied loads in wooden ship structure.

It is suggested that the results from simulations needs a validation experimentally.

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