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Load Capacity, Stiffness and Dissipation Energy of L-Shape Joints with Material Variation

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ABSTRACT: Joints structure are the weak points of all structural system. The limited length of structural elements in frame, truss and other structural systems requires a joint system during construction. Furthermore, the joint system must be strong, rigid, and have sufficient energy dissipation resist to reverse loads. Wood, steel, and concrete are common construction materials used for building, bridges, and other civil engineering applications. Joint of structural systems need to be tested and analysis to determine their load capacities, especially cyclic loads such as earthquake and wind loads. This research aims to compare several load capacities, stiffness, and energy dissipation from the testing of bridle or knee joints made of wood, steel and concrete. The wooden bridle joint test specimens were made from the type of wooden which is a type of softwood (*Gmalina arborea)*. The test specimens were formed from a pair of beams with dimensions of 70x140x800 mm that were connected using bolts, nails, screws, and wooden pins as initial specimens. The retrofitting specimen used was a strip plate with dimensions of 60.4 and a length of 300 mm on each of its side edges. Meanwhile, the test object knee joint made of steel from previous research consists of tubular steel 300.300.6.9 with a length of 850 mm each. The concrete knee joints are in the form of beams with dimensions of 200x400 and a length of 1550 mm, with reinforcement of 4Ø25 (A_s) and 2Ø25 ($A_{s'}$) as well as shear reinforcement Ø10-100, and column elements with a cross-section of 300x700 and a length of 2700 mm, with longitudinal reinforcement of 6Ø20 (A_{st}) and 4Ø12 (intermediate) and shear reinforcement Ø12-80. Testing was conducted in two directions of loading (opened and to closed) until maximum loads and deflections values were obtained. The results obtained from the tests were then compared for strength, stiffness, and energy dissipation. The experimental test results show that the maximum load of the concrete joint has the highest value followed by the steel and wooden joints. This means it is proportional to its strength and stiffness. Stiffness in to opened and to closed load directions shows that the concrete joint has the highest value, about 8 times greater than the steel joint, while the steel joint has a stiffness 4 times greater than the wooden joint. The energy dissipation value of the steel joint about 2 and 4 times greater than the wooden joint the concrete joint. The maximum deflection value after testing shows that the wooden joint has the highest value followed by the steel and concrete joints.

KEYWORDS: Structural Behaviors, Bridle/Knee Joints, Cyclic Load, Hysteretic Loops.

INTRODUCTION

The primary building structural materials are concrete, steel, and wood have distinct characteristics. Wood is a renewable and eco-friendly resource with great promise to advance sustainability in various industries, particularly those associated with construction and building materials. To maximize wood uses, here we show a processing route that transforms low-value wood (residual, damaged, decayed, disposed or fractured) into lightweight and strong structural materials. Moreover, recyclability as well as excellent resistance against organic solvents are demonstrated, providing a promising valorization and sustainability pathway for low-value (Dong, 2022). Concrete is a superior structural material due to its high compressive strength, resistance to extreme weather, and fire resistance. Flexible concrete can be molded to any design, requires minimal maintenance, and is economical due to its readily available raw materials. The combination with reinforcing steel produces a sturdy, durable, and earthquake-safe structure. Steel is a superior structural material due to its extremely high tensile and compressive strength, durability, earthquake resistance (high ductility), and accelerated construction. Steel offers design flexibility, is environmentally friendly (recyclable), and is more cost-effective in terms of long-term maintenance compared to conventional materials. The limitations of the length of structural elements in buildings, especially in buildings and bridges, require efforts to connect them so that the length of the structural elements meets the needs. Structural elements made of wood, concrete, especially stressed concrete, and steel in their construction process require a good joints system to resist the loads acting on them. Joints are the weakest points of a structural system. Joints must have sufficient strength, stiffness, and energy absorption to cyclic loads, especially seismic and wind loads. One indication of a good joint is its ability resist to cyclic loads, shown by sufficient dissipation energy, so that the structure as a whole can resist to cyclic loads with a load value for a sufficiently long duration without experiencing sudden degradation of strength and stiffness.

Table 1. Superiority and Weakness of Structural Materials

Material Types	Superiority	Weakness
Wood	Lightweight, eco-friendly, high aesthetics	Eaten by termites, rotting, flammable
Concrete	High compressive strength, durable, rigid	Heavy, easy to crack, difficult to change
Steel	High tensile strength, quick to install	Rusty, expensive, not fireproof

Concrete joint elements, especially their hysteretic loops tend to be "thin" with a smaller energy absorption area (Nagaraju and Suda 2022; Purwanto and Santosa 2017; Wang, Zhang, and Fu 2016). In contrast, the hysteretic loops of steel beam-column joints tend to be "fat" (Lv, Yang, and Lin 2024; Nagaraju and Suda 2022; Said and Hashim). In other cases, the hysteretic loop diagrams of wooden materials are closer to the shape of the hysteretic loops of steel beam-column joint. The model diagram hysteretic representation of the stiffness and energy absorption capacity of a joint. Steel and wood joints tend to be stiffer compared to concrete joints, while steel and wood joints have greater energy absorption capacity than concrete joints (Fanaie and Monfared. 2016; He et al. 2010, 2018; Rahmzadeh and Alam 2017; Tong et al. 2016). To strengthen wood joints, various methods and materials commonly used in the field are often employed (Branco, Descamps, and Tsakanika 2018; Corradi, Osofero, and Borri 2019; Sulendra, Turu'allo, and Siregar 2025). Research on retrofit at the joints of frame structures is still limited. (Wang et al., 2019) conducted tests on the exterior joints of CFST columns (*concrete-fillet steel tube)*with IWF profile steel with end plate joint (*end plate joint)* and *T-stub bolted joint*. Testing was conducted until damage occurred at the bolt penetration in the type of joint *end plate*. Meanwhile, in the type of joint, testing of the exterior joint of CFST (concrete-fillet steel tube) with WF profile steel with end plate joint (end plate joint) and T-stub bolted joint was conducted. Damage occurred at the bottom flange of the steel profile beam. Retrofit of the joint on the exterior of the reinforced concrete has been performed (Ghobarah et al., 1999) with testing of the strengthening of beam-column joints using corrugated steel jacket method. Franco et al., 1995) conducted earthquake response testing on plate-beam-column joints. Tsonos, 1999). conducted lateral load response testing on the strengthening of reinforced concrete beam-column joints. Meanwhile another study conducted testing on the strengthening of beam-column joints with bolts (Wallace et al., 2000). Similar testing was conducted who strengthened buildings to determine the performance of their structural models post-strengthening (Bracci et al., 1995). The results of the reinforcement show the ability to withstand loads several times after reinforcement has been carried out. Drzacky et al., (2019) conducted this experimental test focused on determining the effectiveness of several joint modifications in relation to their dissipation properties . The best results, and the highest level of effectiveness, were obtained for joints reinforced with plates that have a high coefficient of friction and steel bolts. Tightening the nut on the bolt that replaces the pin affects the pre-stressed of the joint, which is the friction force between the plates. The friction force increases proportionally with the increase in the degree of stressed concrete. However, the compressive deformation of wood limits the maximum possible friction force. Fully tightening the brake plate to the wood using screws is the most effective method. Plates made of oak wood can be used as an alternative to brake plates; however, their damping efficiency is not that high. Reinforcing the joint with nails yields good results, as does the use of a combination of nails and inserted plates.

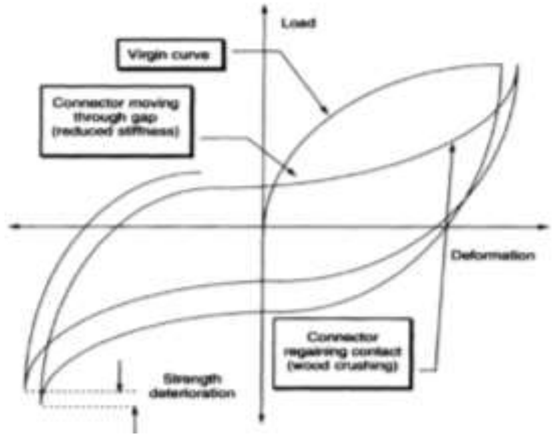

Figure 1. Typical hysteretic of Behaviour of Timber Structure (Ceccotti, 1995)

Figures 1 and 2 show the typical hysteretic behavior of timber structural components under several loading cycles. The hysteretic loops are shown to be "medium" in shape. For concrete beam-column connections, the hysteretic loops are "thinner" than those of timber elements.

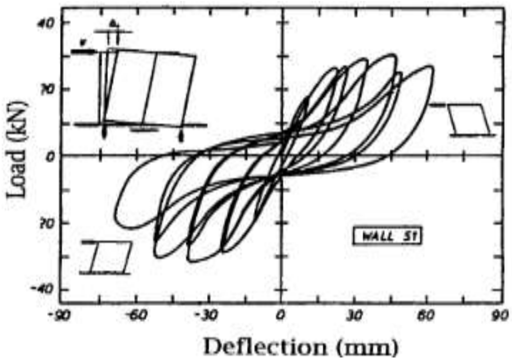

Figure 2. Typical Hysteretic Loops of Wood Assemblies (Fanaie and Monfared 2016).

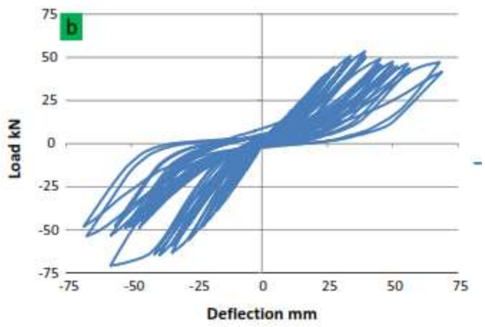

Figure 3. Hysteretic Loops of RC Beam-Column (Said and Hashim 2016)

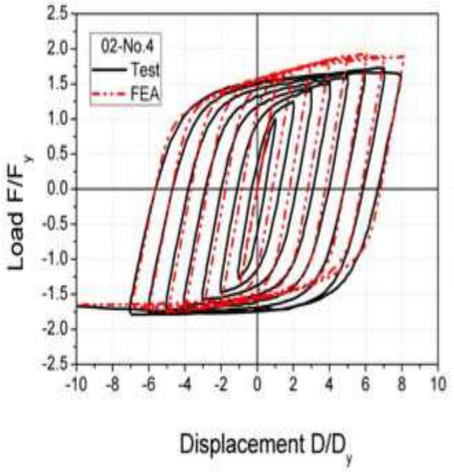

Figure 4. Hysteretic Loops Steel Beam-Column Joint (He et al. 2010)

Figure 4 shows hysteretic loops from cyclic testing of tubular steel beam-column connections, which show a "fatter" hysteretic loops curve shape compared to similar connections made of wood and concrete.

DATA, MATERIALS AND METHODS

This research began by testing the properties of *Gmalina arborea* wood with a joint shape as in Figure 5 with a cross-sectional size of 2x70x140 with each segment being 800 mm long of solid wood formed into a bridle joint.

Figure 5. Bridle or Knee Joint of *Gmalina arborea*

Table 2. Properties of *Gmalina arborea*

f_t (MPa)	$f_{c//}$ (MPa)	f_{fl} (MPa)	$f_{c\perp}$ (MPa)	τ (MPa)
34.63	41.76	29.71	13.05	1,31
34.01	42.90	28.50	13.40	1.34
37.34	42.27	29.07	13.10	1.33
35.38	42.14	29.01	13.45	1.34
35.34	42.27	29.07	13.25	1.33

The last row in the table is the average value. The others result data obtained are: E_w = 6458.78 MPa; ɣ = 0.584 gram/cm^3 and ω = 19.68%.

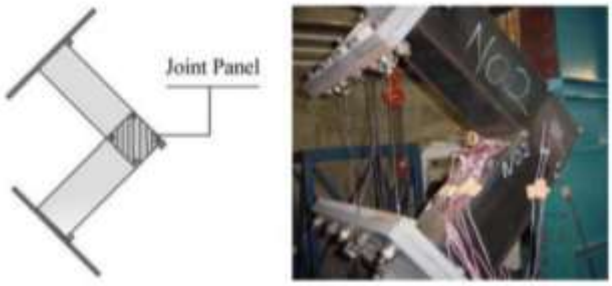

Figure 6. Bridle or Knee Joint of Tubular Steel (He et al. 2010)

Table 3. Section Properties of Tubular Steel

Flange		Web	
t = 5.6 mm	329 MPa	t = 5.7 mm	320 MPa
= 8.5 mm	320 MPa	t = 8.5 mm	310 MPa
E_s = 194,000 MPa		192,000 MPa	
υ = 0.29		υ = 0.29	

The cross-section of the tubular steel used is 300.300.6.9, with each segment being 850 mm long.
Details of the reinforcement of the beam column joint as shown in the following image.

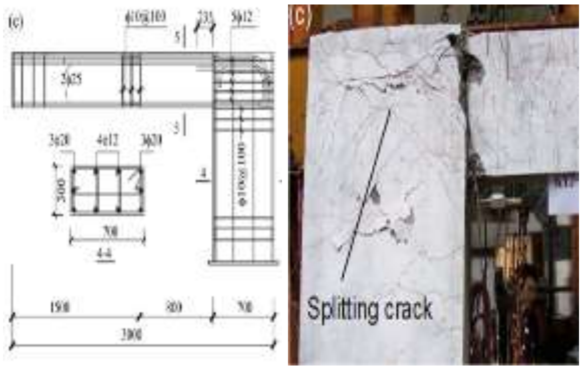

Figure 7. RC Knee Joint Specimen (Wang et al. 2016)

Table 4. Properties of RC knee joint specimens

Column (mm)		Beam (mm)	
h = 700	b = 300	h = 400	b = 200
6Ø20 + 4Ø12 (A_{st})		4Ø25 (A_s), 2Ø25 (A_s')	
Ø12-80 (A_v)		Ø10-100 (A_v)	

3. RESULTS AND DISCUSSION

Tests were conducted on elbow joints under opened and closed loading. Loading was carried out until the maximum load and deflection were obtained. The test results are presented in Table 5 below.

Table 5. Load and Displacement Results Testing Data

Connec-tor Types	Results of Testing			
	Load Directions		Load (kN)	Deflection (mm)
	Opened (+)	Closed (-)	P, maks	Δ, maks
Bolt	√		13.75	23
Nail	√		12.50	24
Screw	√		11.00	27
Pin	√		6.75	15
Bolt		√	8.65	44
Nail		√	7.35	38
Screw		√	6.75	42
Pin		√	6.40	45
Bolt	√		25.00	30
Nail	√		21.50	30
Screw	√		18.2	30
Pin	√		15.50	30
Bolt		√	10.50	41
Nail		√	9.00	41
Screw		√	8.80	49
Pin		√	8.00	47

Of the 16 test specimens, 8 were initial test specimens and 8 were reinforced test specimens with strip plates with dimensions of 60.4 with a length of 300 mm each. The connection tool between the strip plate and the test specimen was a screw with a length of 1.5 inches, totaling 5 on each side. Based on Table 5 and Figures 9 and 10, the results of strength and energy absorption from previous studies are compared, the results are as follows.

Figure. 8 Test of Wooden Joint with Closed Direction Loading

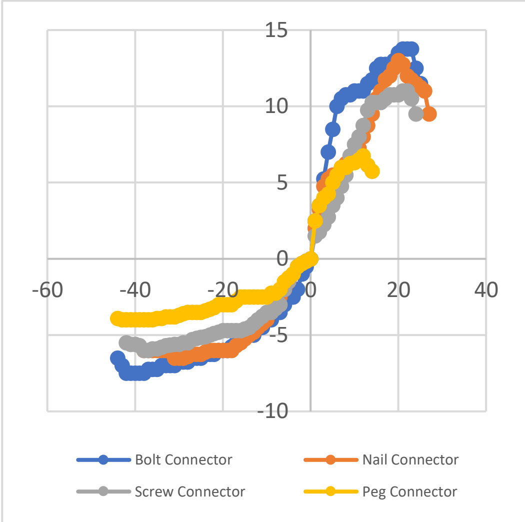

Figure. 9 The Skeletons Diagram of Initial Wooden Joints

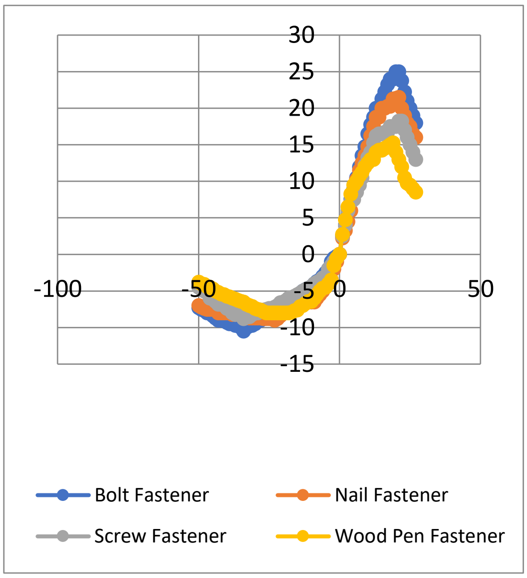

Figure. 10 Load The Skeletons Diagram of Retrofitting Wooden Joints

The energy dissipation area of the hysteretic loops curve in Figure 10 is about 30 kN.m.

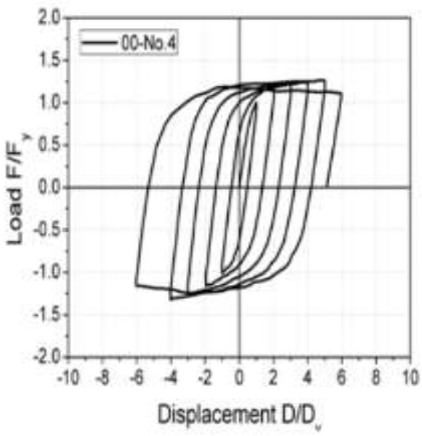

Figure 11. Hysteretic Loops Curve of Steel Knee Joint (He et al. 2010)

Table 6. Testing Results of Tubular Steel Knee Joint

P_y (kN)	P_u (kN)	Δ_y (mm)	Δ_{max}(mm)
122	166	15	200
-120	-155	15	200

The energy dissipation area of the test in Figure 11 is approximately 60 kN.m

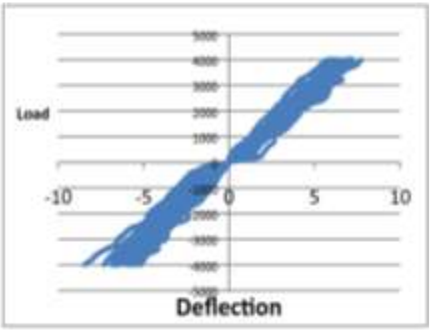

Figure 12. Load (N)-Displacement (mm) Diagram of Concrete Knee Joints (Nagaraju and Suda 2022)

The energy dissipation area of the test in Figure 12 is approximately 15 kN.m.

Table 7. Stiffness of Various Material of Knee Joints

Material	$P_{,max}$(kN)	Δ_{max}(mm)	k(kN/mm)
Wooden	+10.50	+41.00	0.26
Wooden	-8.63	-44.00	0.20
Steel	166.00	200	0.83
Steel	-155.00	-200	0.77
Concrete	400.00	75.00	5.33
Concrete	-400.00	-75.00	5.33

4. CONCLUSSIONS

a) Experimental test results show the maximum load for concrete joints is the highest, followed by steel and wood joints, it is proportional to its strength and stiffness.

b) The maximum deflection value after testing shows that concrete joints have the highest value, followed by steel and wood joints.

c) Stiffness in the positive and negative load directions shows that concrete joints have the highest value, approximately 8 times greater than steel joints, while steel joints have a stiffness approximately 4 times greater than wood joints.

d) The energy dissipation value of the steel joint about 2 and 4 times greater than the wooden joint the concrete joint.

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