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Strengthened of Wooden Trusses Structure and Retrofitting Methods to Increase Load Capacity

Ketut Sulendra[1], Gidion Turu'allo[2], Atur Siregar[3]

[1,2,3]Tadulako University, Palu, Indonesia

ABSTRACT: Assessing after the strong earthquake, several wooden truss structures were damaged. The damage varies from dislocation of the truss mounts with their supports, displacement between the curtain rods and truss frames as well as damage to the truss joints themselves. This research will study the types of damage, causes and methods of strengthening and repairing element of roof truss and frame that were damaged after a strong earthquake based on the level of damage, method and materials suitable for implementation. Data on the damage to the truss structure described were obtained from field assessments as well as secondary data from earthquake events from various regions in Indonesia and other parts of the world and segmental testing of truss. Failed in tension, compression, shear and support were found due to insufficiency of connecting devices and incomplete configuration of truss elements. The age factor and the wood material preservation system also cause the level of damage to the frames of these horses to be higher. Conventional strengthening methods using wood, iron, stainless steel, steel wire/cable, and the addition of connecting devices such as pegs, nail, screw, bolts, steel plates, tooth plate connects, and steel anchors are sufficient to increase the strength and rigidity of the wooden truss frame structure system. but not significantly increase the ductility. Alternative materials based on resins and polyurethane / polyether adhesives and healed wood have the potential to used. The results showed that the use of this type of material can increase the ductility and strength of 20-40% over conventional reinforcement systems such as nails and other connecting devices. Retrofitting L joint with strip plate, C70.35.0.45 stainless steel and L35.35.3 can increase maximum load capacity with ratio 1.25; 1.64 and 1.87 respectively.

KEYWORDS: assessment, type of damage, wooden truss structure, retrofitting methods

1. INTRODUCTION

Post-earthquake strong often found building the building suffered heavy damage until failure structure. On buildings structure wood damage happen because several factors include design and construction techniques that have not implemented earthquake resistant building designs(Idris et al., 2019), (Paulik et al., 2019), (Alih & Vafaei, 2019). Insufficient connecting devices and inadequate connecting systems fulfil condition technical cause element structure the wooden frame and roof shifted, damage and failures off the connection post happen earthquake strong. Consequence burden cyclic like wind and earthquake cause a number of the point at the join experiences damage namely at the Roof to Wall Connection and the top roof frame (Stevenson et al., 2019). A number of methods and techniques retrofit has been proposed and applied to wooden structural buildings. As materials and technology develop, the materials used for reinforcement do not only material wood and iron based but also steel, epoxy resin and other materials. Type and model of connector used for retrofit also has lots forms and variations. Each material and method used certainly has its own advantages and disadvantages. Iron material will add weight to the structure and tends to corrode over time wood contain high water content, while steel is more rust-resistant but the price is more expensive than iron. *Adhesive* materials tend not to add weight to the structure but require a working method high accuracy and technology. Rehabilitation wooden structures are carried out post experience degradation strength, stiffness and ductility must fulfill rule *The International Council on Monuments and Sites* (ICOMOS):

1. Proposal reinforcement must in accordance with form structure exist
2. Rehabilitation solutions can do repeatedly and at any time can done
3. Form structure beginning still maintained
4. Stiffness from the join results rehabilitation must approach mark at first.
5. If using material wood, kind wood replacement must the same like wood exist
6. Endurance from wood replacement must confirmed enough good
7. Steel plate elements can used on the connection traditional dry for guard durability between elements the wood.
8. Connection can made with one tool connection or material *adhesive*. (Negrão, 2020)

Failure typical from frame hood wood on pedestals caused by style pull on the joint stem double from rafter elements and beams. With replace only in parts the join just more economical compared to replace the whole with material steel roof truss fees required. No more of 2/3 if replace with structure steel roof truss. Estimation time required about two months without lower closing the hood. Restoration from building structure wood with objective add mark cultural with development important from whole behavior structure building especially in vulnerable areas earthquake. Damage structure building wood can happen because a number of because among others:

1. Natural defects from material the wood
2. Degradation biological
3. Fire
4. Influence environment and weather and change humidity
5. Initial design, construction, maintenance and mistreatment
6. Overload (Negrão, 2020).

2. DATA, MATERIAL AND METHODS

2.1. Data

Data from study this in the form of primary data results assessment damage frame sawhorse wood post Palu earthquake 28 September 2018 and testing of segmental wooden truss L joint. Secondary data form analysis damage structure building frame and trusses wood post-earthquake strong. Causes and levels category damage frame sawhorse post-earthquakes are also studied. A number of method reinforcement as well as repair damage building structure wood and frame sawhorse wood is also served. Comparison effectiveness and efficiency from a number of method reinforcement and variation type the materials used are also explained as supporting data.

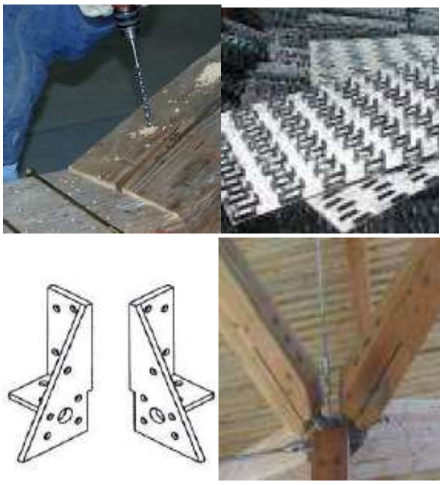

Figure 1. Steel screws, tooth plates, double and triple grips, special plates (Bian et al., 2013)

It is emphasized that a successful adhesive bonded joint depends upon several factors:

1. Appropriate design of the join
2. Selection of suitable adhesive
3. Adequate preparation of the adherend surface
4. Controlled fabrication of the joint protection of the joint itself from un acceptably hostile conditions in service
5. Post-bonding quality assurance

For maximum success joint design should follow several general principles, namely to:

1. Stress the adhesive in the direction of the maximum strength (i.e. in compression or in shear)
2. Provide for the maximum bond area
3. Make the adhesive layer as uniform as possible
4. Maintain a thin and continuous bond line (Robert & Brown, 2004).

2.2. Materials

Materials used for retrofit building structure frame wood and horse's wood varies. Material base wood, plate iron, stainless steel, steel lightweight, FRP, adhesive and epoxy resin are also included among them. Timber structure joining technology with type bolt wood and steel, bolts, nails, rivets, screws steel, tooth plate, *metal pendant connect or* and special plate connections are very possible applied.

Types of double and triple grip jointers to strengthen connections are commonly used between beam elements and wooden structural floor plates. Meanwhile, tooth plate connecting tools are used in connections between truss frame elements. Strengthening connections between columns and beams or between beams uses special plates and bolts

Figure 2. Various types of steel plate-based roof frame reinforcement (Branco et al., 2018)

Figure 3. Various types of roof frame reinforcement with stainless steel (Negrão, 2020)

Figure 4. Remaining parts of the rafter V-shape wedge extension ((Abramyan & Ishmametov, 2016)

If repair structure wood needed so method assessment special and reliable field required for determine suitability level necessary repairs. Very important thing for evaluate material replacement solutions repair and strengthening as well as know how significant work and costs. Innovation new and treatment repair as well as reinforcement important for known. Enhancement strength and rigidity as well as enhancement ductility element from structure wood. For connection reinforcement help reduce gap mechanism for good distribution load. Weakness material wood can overcome with increase strain sliding and strong pull wood upright straight to cross section. Also reduce propagation the crack. Repair and strengthening should no change rigidity and whole behavior structure initially. Weakness main reinforcement iron form corrosion because wood contain high water content. Currently use steel stainless is replacement from material fragile iron rusty. Enhancement burden quake on standard planning to increase behavior post elastic from element structure form deformation and capacity dissipation, use steel suitable stainless with condition this.

Figure 5. Repair methods using *stainless steel elements* (Corradi et al., 2019)

Protection and strengthening of materials wood nanostructure based _carried out by Marzi (2015). Wood contains nano composite materials natural structure. This material resembles a pipe strongly bonded with lignin which has a high dissipation capacity and fracture energy. This research applies polymeric resin reinforcement with carbon nanotubes (CNTs) to specific locations in historic wooden structures. So it is possible for direct application in the field. Experimental tests have been carried out on a small scale in the laboratory.

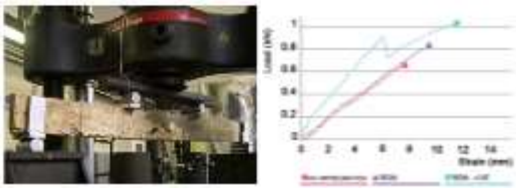

Figure 6. Beam test setup with strengthening of CNTs and its results (Marzi, 2015).

The results of this research conclude that wood as a natural nano-composite has great potential to be developed in the future with the advantages of long-term stability, durability, weather resistance and strong adhesion. The application of strengthening nano-composite materials in the form of polymeric resins with CNTs can be promoted and developed in the future in the fields of civil and architectural engineering with the main focus on strengthening historic wooden structures .

(Bhandary, 2020) does study wooden frame structure with adhesive connection application with wind and earthquake loads. In research This The connection tools used are nails and *polyurethane* and *polyether adhesive materials*.

Table 1. Physical and mechanical properties of connection elements (Bhandary, 2020)

Type of connection	Material	Dimension (mm)	Shear strength (kN/mm^2)
Nail	Collated framing nails	20-3/8"	
Adhesive	Polyurethane	-	0,0059
Adhesive	Polyether	-	0,0027

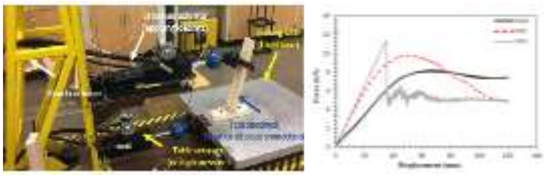

Figure 7. Setting up and load (Bhandary, 2020)

Research results show that joints with adhesive materials have 20-40% more high strength from connection nails. While the deformation of 90% more nail connections larger than the connection material adhesive. Meanwhile, the initial stiffness of the connection polyurethane adhesive 147% more tall from nail joints. However, the adhesive connection type has disadvantages form nature of failure brittle.

Behavior of wood-steel L-shaped joints, steel dowel joints loaded quasi-static studied in study this. Four steel pegs are used as a connection device with variations in the X and Y directions between the pegs. In addition to conducting experimental tests, validation was also carried out with *the Finite Element Method (FEM)* . Damage occurs in the post-loaded steel pin-hole contact area. Experimental and numerical tests show an increase in stiffness and moment capacity as the distance between the pegs increases.

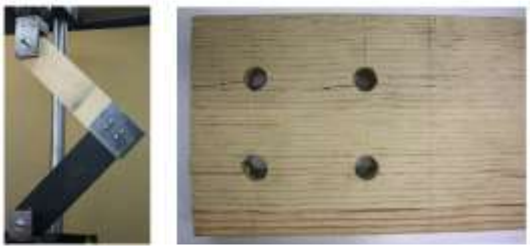

Figure 8. Test object and test setup and pattern crack test object (Dourado et al., 2018)

2.3. Methods

The research was conducted using an experimental method in the laboratory. The experiments were carried out through full-scale bending tests of L-type wooden beam joints. The experimental procedures followed the stages outlined in the research framework. The data analysis involved the following:

1. Interpret results from tensile and compressive tests, parallel and perpendicular to the grain, bending tests, specific gravity, and moisture content.
2. Interpret results from full-scale L-joint tests, including load capacity analysis, deflection, and damage models of the specimens, along with conclusions based on the data interpretation.
3. The primary material employed was teak wood (Tectona grandis L.f). The beams were air-dried for approximately 3 (three) months to achieve an equilibrium moisture content of 20%. Once the timber reached a stable condition or was air-dried, specimens for tensile, compressive, bending, specific gravity, and moisture content tests were prepared. The test specimens consisted of L-type joints made from teak wood beams with dimensions of 70x 140x800, totaling 4 (four) pieces. The connection between the two beams utilized bridle joints. Four variations of connecting methods were employed: wooden. Three joints retrofitting with L35.35.3, 70.35.0.45 stainless steel and 60.4 strip plate. The model of the test specimen is illustrated in Figure 9.

Figure 9. Setting up of all specimen

3. RESULTS AND DISCUSSION

3.1. Ability wooden roof frame withhold burden

Weak location from wooden roof frame located at the Roof to Walls Connection and the top frame the roof (Stevenson et al., 2019). The weakness points of wooden roof trusses consist on peak and supported of the truss. Based to this study, retrofitting of the segmental wooden roof truss done with L35.35.3, 70.35.0.45 stainless steel and 60.4 strip plate.

3.2. Comparison characteristic physical and mechanical from material connector

The connecting material used for reinforcement wooden roof frame generally made from base wood, iron, steel, steel stainless steel, steel light. A part from materials the mature This developed material adhesive- based such as epoxy resin, polyethene, polyether and healed wood. Following results are comparison characteristics from material. Comparison of physical and mechanical of each material showed on the table 2, 3 and 4 respectively.

Table 2. Comparison characteristics various variation connector/fasteners

Type of materials connector	*Significantly added weight*	*corrosive*	*Load capacity*	*Displacement capacity*	*Ductility*	*Energy Dissipation*
Wooden	√					
Steel	√	√				
Stainless steel			√	√	√	√
Adhesive			√	√	√	√
Healed wood			√	√	√	√

Table 3. Comparison of connectors/fasteners

Type of connector	*High price*	*Easy to construction*	*High technology*	*Load capacity*	*Ductility*	*Energy Dissipation*
Wooden dowel		√				
Steel screws		√				
Bolt		√				

Nail		√				
Rivet nail		√		√	√	√
Special bolt	√		√	√	√	√
Adhesive	√		√	√	√	√
Steel plate connector	√		√	√	√	√
Steel dowel		√		√	√	√

Table 4. Comparison results testing reinforcement joints with adhesive vs bolted

Name of researcher	Specimen shape	Load (kN)	Displacement (mm)	Stiffness (kN/mm)	Connector Types
(Bhandary, 2020)	T Joint	2650	6.70	0.396	adhesive
(Dourado et al., 2018)	T Joint	4230	9.75	0.434	steel dowel
(Marzi, 2015)	Jupiter Joint	2750	8.00	0.344	adhesive
(Gavanski & Kopp, 2017)	L Joint	1700	12.00	0.142	bolted

Table 5. Comparison results testing reinforcement joints with various retrofitting materials

Material Retrofitting	P,cr (kN)	P,max (kN)	Δ,cr (mm)	Δ,max (mm)	P,max Ratio Inintial/Retrofit
-	2.50	6.40	16.00	45.00	1.00
Strip 60.4	6.50	8.00	16.00	47.00	1.25
C70.35.0.45)	4.50	10.50	22.00	52.00	1.64
L35.35.3	7.80	12.00	16.00	45.00	1.87

Based to table 4 steel dowel fasteners better than adhesive and bolted connector, with high stiffness and less displacement. Based to table 5 retrofitting L joints with retrofitting with strip plate, C70.35.0.45 and L 35.35.4 can increase load capacity with ratio 1.25; 1.64 and 1.87 respectively.

4. CONCLUSIONS

Conclusion outlined based on data, analysis and discussion from part previously are:

1. Building structure wood will too experience damage significant post-earthquake strong if its design and construction ignore standard planning building stand earthquake.
2. Reinforcement structure wooden roof frame depends from type and category the damage as well as availability materials and technologies available in the region.
3. Reinforcement with method conventional made from base wood and iron like replace part elements and improvements experienced connection damage own weakness form add heavy structure and materials iron tend experience corrosion on the moisture content of the material tall wood.
4. Reinforcement wooden roof frame with connector stainless steel and steel light still a lot of potential for developed because not add heavy structure as well as capable increase strength connection.
5. Reinforcement with adhesive materials such as epoxy resin, polyethene, polyether and healed wood are capable increase ductility connection as well as not add heavy structure however need high technology as well as level high accuracy in its implementation.
6. Recommended connector to applies i.e. steel dowel and adhesive materials with high stiffness at the joints and less displacement.
7. Retrofitting L joint with strip plate, C70.35.0.45 stainless steel and L35.35.3 can increase maximum load capacity with ratio 1.25; 1.64 and 1.87 respectively.

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