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An Investigation on Coconut-timber Waste as Construction Material for Earthquake Resistant Wooden House in North Sulawesi, Indonesia Abstract This paper presents a current study into the use of coconut-timber waste as an alternative construction material to build earth- quake-resistant timber house in North Sulawesi, Indonesia. The objectives of this research are: to obtain the physical and mechanical properties of coconut-timber, to identify the strength classification of coconut-timber, to design a model of earth- quake-resistant house made of coconut-timber, and to perform structural analysis of the house under earthquake load.

Research methods include: (1) Laboratory testing of the physical and mechanical properties comprising of moisture content test, density test, tensile test parallel to grain, compression test parallel to grain, compression test perpendicular to grain, shear strength parallel to grain, flexural test, and toughness. All tests were performed according to the American Standard Testing Material (ASTM) D143-09; (2) Identification of strength classification of coconut-timber based on the Indonesian Standard (SNI) 03-3527- 1994; (3) Design of an earthquake-resistant coconut-timber house; (4) Calculation of the dimensions of structural elements of earthquake-resistant coconut-timber house; and (5) Testing of the performance of the coconut-timber house under earthquake load with ETABS software.

Results from this research are expected to support the beneficial usage of local coconut-timber waste as construction material for timber house in an effort to mitigate the risk of earthquake hazard in North Sulawesi. Introduction North Sulawesi Province is one of the regions in Indonesia that has a high risk of earthquake because it is geologically located in one of the path of the Pacific Rim. Based on the map of earthquake regions used as a reference for structural building design, the province of

North Sulawesi in Indonesia is located in Earthquake Region 5 which is categorized as a high-risk zone with earthquake scale between 5-7 Richter.

Building construction made of timber offers many benefits such as relatively higher structural stability and integration. This is due to the fact that timber has higher strength-to-weight ratio compared to steel and concrete. This weight or mass of construction has a linear correlation to the lateral force (inertia) sustained by the construction. These properties have caused timber to become an alternative building material for earth- quake prone areas such as North Sulawesi. Coconut (Cocos nucifera Linn) is one of the many potential plantation crops commodity grown in North Sulawesi with a total area of 277.649 Ha in 2015, covering 15 districts. The total area is comprised of 37.675 Ha of coconut tree plantation that are not yet productive, 225.003 Ha of coconut tree plantation that are productive and 17.259 Ha of coconut tree plantation with coconut trees aged over 50 years and needed rejuvenation because of their declining fruit productivity (Data from Dinas Perkebunan Prov. Sulut, 2015). This rejuvenation is needed to allow more space for new coconut plantation.

The largest waste from the rejuvenation of coconut trees are the trunks from old coconut trees. If the trunks are left unprocessed, they can become breeding places for diseases that could strike coconut seedlings, which in turn will bring disadvantages to the local farming communities. Processing and utilization of the unpro- ductive coconut trees as a construction material for timber house can be an alternative solution to the handling of coconut tree trunks after the rejuvenation, which will be beneficial to the local communities.

In general, the anatomical structure of a coconut tree con- sists of vascular bundle and ground tissue in the form of paren- chyma. Macroscopically, there are differences in the density (distribution) of vascular bundle based on its location (height and depth) in the coconut tree trunk. More toward the center, the density of vascular bundle decreases, while toward the vertical the density of vascular bundle increases (Sudarna, 1990).

The ability of vascular bundle as a support for timber strength is closely related to the thickness of fibre cell wall and silica con- tent in the cell (Rahayu, 2001). Density of coconut-timber varies depending on depth and height of the trunk. The density decreases with increasing trunk height and increases from the central part to the edge of the trunk. More toward the center of the trunk, coconut-timber is softer. Moreover, the density of coconut-timber also varies according to variety, location and age of the coconut tree (Polomar, 1990).

Density of coconut-timber can be categorized into three based on the thickness of timber starting from the part closest to the bark. High density wood (>0.6 g/cm3) covers 53% of the trunk, generally located closest to the bark with thickness from 7.5 cm to 12.5 cm, having characteristic of very resistant to scratches; medium density wood (0.4-0.6 g/cm3) covers 25% of the trunk, is in the thickness from 5 cm to 10 cm after the high-density-wood part, having characteristics of slightly resis- tant to scratches and cannot withstand humid weather; and low density wood (<0.4

g/cm3) covers 22% of the trunk, located in the center, quite soft, quickly weathered, cannot withstand scratches and humid weather. The Indonesian standard about the quality and dimensions of construction timber, SNI 03-3527-1994, uses the physical prop- erties (Air-dry Density) to classify timber into 5 strength classes (Table 1). Table 1. Mechanical properties of timber Strength Class Air-dry Density Absolute Flexural Strength Absolute Compressive Strength (Kg/cm2) (Kg/cm2) I ? 0.90 ? 1100 ? 650 II 0.90 - 0.60 1100 - 725 650 - 425 III 0.60 -0.40 725 - 500 425 - 300 IV 0.40 - 0.30 500 -360 300 - 215 V ? 0.30 ? 360 ? 215 Source: SNI 03-3527-1994.

The specific objectives of this research are: (1) To obtain the physical and mechanical properties of coconut-timber as a con- struction material for timber house and to identify the strength class of coconut-timber; (2) To design a earthquake-resistant timber house model made of coconut-timber; and (3) To test the performance of the coconut-timber house under earthquake load. This research is one of the applications of building construc- tion engineering to mitigate earthquake disaster through the design of timber house that is safe for earthquake prone areas.

This research is important as an effort to utilize and to increase the value of local coconut-timber waste from unproductive coco- nut trees to be used as a construction material to build earth- quake-resistant timber house. Moreover, results of this research are expected to support the empowerment of local economy by utilization of potential sustainable local natural resources. Research Method Research methods (Figure 1) comprise of laboratory tests, design of coconut-timber house prototype that is resistant to earthquake and performance test of the prototype of coco- nut-timber house under earthquake load.

The experimental stage in the laboratory consists of physical and mechanical properties tests which cover moisture content test, density test, tensile test parallel to grain, compression test parallel to grain, compression test perpendicular to grain, shear strength parallel to grain, flexural test, and toughness (Figure 2). Samples for the tests were obtained from unproductive coconut trees from Minahasa Selatan region in North Sulawesi. Total numbers of samples were 791. Experimental tests were performed at the Civil Engineering Material Testing Laboratory and Mechanical Engineering Material

Testing Laboratory, Manado State Polytechnic. Test methods were based on the American Standard Testing Material (ASTM) D143-09.

Results from this experimental stage were used as references in design stage of a 6m x 6m model of coconut-timber house. The design stage of the prototype includes the drawing of design plan of the timber house and calculation of coconut-tim- ber structural elements. The design stage was performed in accordance to design principles and standards of building model by considering earthquake load.

Preparation of dimensions of structural elements which consist of beam, column, floor panel, wall panel and roof was performed after the structural analysis calculation. The next stage was testing of the performance of coco- nut-timber house prototype. Performance test of structure was done by analysis of the structure under earthquake load with simulation of structural model. The software used for the simu- lation was ETABS (Structural software for building analysis and design). Fig. 1. Research Method Fig. 2. Mechanical properties tests of coconut-timber at the Material Testing Laboratory, Manado State Polytechnic Results A. Characteristics of coconut-timber as timber house construction material. Table 2.

Test results from the mechanical properties tests in the laboratory No. Characteristics of coconut-timber Test result 1 Modulus of Elasticity (kg/cm2) 67000 2 Flexural strength (kg/cm2) 458.66 The experimental test results are presented in Table 2. According to the categories of timber strength classification in SNI 03-3527-1994, the strength class of coconut-timber is as 3 Compressive strength parallel to grain (kg/cm2) 4 Compressive strength perpendicular to grain (kg/cm2) 399.3 179.79 follow: • The air-dry density is in the range of strength class I and II, 5 Shear strength parallel to grain (kg/cm2) 65.13 6 Density (gr/cm3) 0.9 7 Moisture content (%) 15.95 therefore can be used as structural timber, which usage 8 Tensile strength - parallel to the grain (kg/cm2) 44760.1 requires calculation of load.

• The compressive strength parallel to grain is in the range of strength class III, therefore can be used as non-structural timber, which usage does not require calculation of load. • The flexural strength is in the range of strength class III to IV, therefore can be used as auxiliary building material or temporary building. 9 Toughness (kgf) 424.74 B. Structural Design and Floor Plan of Coconut-timber House. Results of structural design of a coconut-timber house with a floor plan size of 6 m x 6 m are shown in Figure 3. The result of the design of a coconut-timber house model is shown in Figure 4. Fig. 3. Design of coconut-timber house: (A). Floor Plan; (B).

Portal Frame X-axis; and (C). Portal Frame Y-axis. Fig. 4. Design drawing and model of coconut-timber house. C. Calculation of the dimensions of Structural Elements of Coconut-timber House Structural calculation of coconut-timber house includes roof frame structure, ceiling structure: main beam, secondary beam, floor beam and floor board, floor structure: main beam, second- ary beam, floor beam and floor board, and columns.

Determination of the dimensions of coconut-timber house struc- tural elements was performed in accordance to design princi- ples, standards and implementation methods building model construction by considering earthquake load. Design results of dimensions of the coconut-timber house structural elements are presented in Table 3. D. Structural Analysis of coconut-timber house struc- ture under earthquake load. Structural performance test is done by analysis of structure under earthquake load with simulation of structural model. The software used for this simulation process is ETABS (Structural software for building analysis and design).

The sway mode caused by earthquake on the frame structure of coconut-timber house generated by ETABS software can be seen in Figure 5. Result from the structural analysis of the frame structure of coconut-timber house under earthquake load with ETABS soft- ware shows that the construction is safe under earthquake load. Table 3. Calculation result of the dimensions of coconut-timber house structural elements No.

Construction Element Dimension 1 Roof truss Compression b=8 cm and h=12 cm Tension b=8 cm and h=12 cm 2 Ceiling Main beam b=10 cm and h=18 cm Secondary beam b=10 cm and h=18 cm Floor beam b=5 cm and h=10 cm Floor boards b=25 cm and h=2,5 cm 3 Floor Main beam b=15 cm and h=20 cm Secondary beam b=15 cm and h=20 cm Floor beam b=5 cm and h=10 cm Floor boards b=25 cm and h=2,5 cm 4 Upper columns b=15 cm and h=15 cm 5 Lower columns b=15 cm and h=15 cm Fig. 5. Sway mode due to earthquake load acting on the frame structure of coconut-timber house (generated with ETABS) Conclusions and Expected Outcomes Results of laboratory testing that conform the SNI 03-3527- 1994 classification, the strength class of coconut-timber can be used as structural construction timber, of which usage requires the calculation of load; as a non-structural construction timber, of which usage does not require the calculation of load; and as a temporary construction material.

The determination of the dimensions of coconut-timber house structural elements was performed based on the experi- mental results from the laboratory tests of the physical and mechanical properties of coconut-timber. The prototype of coconut-timber house was built based on the design and struc- tural analysis followed by structural performance test against earthquake load using ETABS software. Results from the struc- tural analysis of the coconut-timber house frame structure under earthquake loading using ETABS software show that the house is safe.

Results from this research are expected to support the bene- ficial usage of the potentiality of coconut-timber as a construc- tion material for timber house in an effort to mitigate the risk of earthquake hazard in North Sulawesi. References 1) ASTM Standard Methods for Testing Small Clear Specimens of Timber. ASTM Designation D143 - 09. Annual Book of ASTM Standards, Vol. 04.10. ASTM, West Conshohoken, PA, 2009. 2) Killmann W. dan F. Fink. 1996. Coconut Palm Stem Processing Technical Handbook. Protrade: Depart. Furniture and Wooden Products Deutche Gesellschaft. Federal Republic of Germany. 3) Polomar, R.N. 1990. State of the Art: Coconut Utilization Asia and Pasific Coconut Community. Jakarta.

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