Acehnese Vernacular House: The Study of Constructions and Materials Resilience

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Abstract. The substructure is an essential part of vernacular buildings, especially in an earthquake region. The substructure durability is proven since the vernacular house sustains while modern house destructed after the experienced earthquake. The use of substructure in the earthquake region is dominated by the stepped on stone pillars while the non-earthquake territory is dominated by pierced to the ground pillars. Researches hypothesized vernacular buildings in the ring of fire area will stable uses a stepped on the stone substructure and the joint wood system which interlocks the blocks. The purposes of this research are to determine whether the substructure can withstand the existing load, including earthquake and the wood material performance related to its durability in facing the weather and destructive biological factor. The test was done using a monotonic testing method to analyze the load exposed to the substructure. The moisture testing was also conducted in wood materials using Wood Moisture Detector MD818, and wood chemical structure was tested using FTIR. The result showed that the Aceh vernacular house was able to withstand earthquake load, including durable construction and material system. Aceh Besar vernacular house durability on earthquake was influenced by structure properties with a ductile value of 2.27.

1. Introduction

Rapoport in House Form and Culture (1969) stated that material, site, and construction were the factors that support the creation of vernacular buildings shape. Vernacular buildings, including housing and others, which in their construction process are related to environment and natural resources availability. Vernacular buildings are built spontaneously and shaped through trial and error processes, which represents the will and need of the residents. The shaping process of vernaculars has a strong relation with geographical, climate, and material availability. Based on the geographical condition, Indonesia is located in a highly active tectonic zone since three big earth's plates, and nine little plates meet there creating complex plate meeting paths [1]. Aceh is a region with a high-intensity earthquake where the peak occurred in 2004 with the scale of 9.3 SR, which became the catastrophe with the highest mortality in Indonesia. The sudden movement of the stone layer inside earth creates energy which disperses to all directions in the form of an earthquake and seismic waves. When this wave reaches the earth's surface, its vibration can destruct everything on it like buildings and other infrastructures [2]. A sharp ground shock, inappropriate reinforcement details, and material weight are the main factors in structure failure in modern buildings [3]. When modern buildings destroyed by an earthquake, the vernaculars built by the community who consider local geographical conditions are proven able to withstand an earthquake without exposing any damage. The substructure is the main
structure to withstand an earthquake, and it should be calculated to be able to hold an earthquake as well as should not fail before the upper structure [4]. The substructure acts as damper friction to reduce the earthquake impact on the upper structure [5]. This research aims to find how a sub-construction system in Aceh vernacular house can survive after an earthquake without experiencing any structural failure. Therefore, a series of tests are done in buildings structures and constructions as well as material durability used in Aceh house.

2. Acehnese Sub Structure

![Figure 1. Aceh house model.](image)

The research sample used is Aceh house located in Aceh Besar, Aceh, Indonesia. The location selection was based on how big the earthquake intensity and its history occurred in a region. The selection process was based on the buildings which met the criteria, i.e., building survived after an earthquake, having a platform house structures, oldest and the buildings who did not expose to changes in structure, construction, and material. Thus, in this Aceh house research, the sample was Rumah Aceh Chik Lampisang since this house could withstand to 130 years, did not experience material change and could survive without experiencing structural damage after exposed with 9.3 SR earthquake.

The structure system in Aceh vernacular house construction was frame structure. Based on substructure typology, Aceh house consisted of the wood pillar which round in shape with a diameter of 20 cm stepped on a stone. In joints, the local community applied to join without the nails method consisted of rok and thoi joints wedged on the central pillar. *Rok* is a wood that serves as the block in the transversal direction. This joint is interlocking each other creating a rigid bond. As shown in Figure 3, detailed dimensions of joining the system in Aceh house, i.e. (1) *Thoi* block has a wood part protrude outside in 40 cm. This block size in this house is 28/7 cm; (2) *Rok* block with 10/4 cm in size is a joint wood system entered to the central pillar, *rok* block protrude outside in 9 cm; (3) Every joint in testing sample uses a wedge with 4/7 cm in size.

![Figure 2 Aceh house wood joint.](image)
Aceh house uses nature material as building materials where the selection is based on local resources availability. Wood becomes the first option for the locals to build houses. Wood in Aceh house can survive for hundreds of years without experiencing gradual changing processes. The wood used varies based on building parts where wood for building pillars has strong and stable properties. In Aceh house, *Artocarpus heterophyllus* wood is used as pillar while *Azadirachta excels* wood is used for blocks joints [6].

3. Material and Methods

3.1. Monotonic Test

Monotonic is a test on wood joints by giving lateral loads from horizontal direction until the structure experiences failure. Previous research used the monotonic method was tested for the *Performance of Ammu Hawu Structure System in Responding to Seismic Load*; this previous research focused on the critical connection in the structure [7]. In this research monotonic tests used FEMA (Federal Emergency Management Agency) P-750 standard issued by NEHRP (National Earthquake Hazards Reduction Program) about the building design which could minimize risk caused by an earthquake. The selection of the sample was based on criteria of (1) experiencing the highest lateral load, (2) position, which determined the structure system, (3) exposing the most significant climate impacts. Therefore, based on these criteria, the most appropriate sample was the substructure, which was a wood joint located in the outmost part and corners of a building.

The testing sample in the monotonic Test was a joint wood with a scale of 1:1 and made of replacement wood which derived from *Artocarpus heterophyllus* Sumatera. The wood had passed the natural drying process; thus, having a moisture level below 20%. *Artocarpus heterophyllus* wood had a type, durability class and moisture similar to that used in real research, i.e., a 130 years old Aceh Chik Lampisan house. The result from the monotonic Test was analyzed using ductility calculation, an earthquake coefficient that a building can withstand and structure response on earthquake calculation in a particular region based on the standards of SNI 1726 2002, SNI 1726 2012, and NEHRP-FEMA 750.

3.2. Moisture Wood Test

Moisture in wood affects the wood durability, wood prone to destroyed if it contains high moisture. Factors affecting the wood mechanical properties are divided into two categories, i.e., external factors which are related to wood durability, environment humidity, loading, and the defect caused by mushrooms and wood damaging insects. Internal factors are related to wood density and eye defect [8]. Therefore, a measure of wood moisture is required. This research used Building Materials Wood Moisture Detector MD818. The measurement was done in daylight using the apparatus directly pierced to a wooden pillar.

3.3. FTIR

Fourier transform infra-red (FTIR) is an instrument used to measure infrared radiation absorption in various wavelengths called infrared spectrometer [9]. FTIR test was conducted to identify and analyze the functional group and extractive substances contained in wood.

4. Result and Discussion

4.1. Monotonic Test
The monotonic Test was started by giving a lateral load on the testing sample. The load was given in the first minute gradually from 0 to 12 kg for two minutes. Then, the lateral load giving was increased by 2 kg, 4 kg to 6 kg every one minute until the sample experienced failure. The time interval required until the sample failed was when the increased load reached 192 kg in the 18th minute. In this Test, there were 80 steps of lateral load giving. 

Wood joints experienced failure in the rok woodblock part. This failure was located in two parts of the rok wood block. The first failure occurred in the upper part of the rok woodblock when lateral wood reached 170 kg with the deflection of 125.62 mm. The second one occurred in the subpart of the rok woodblock when the load reached 188 kg with the deflection of 167.36 mm. In this monotonic Test, the wood joints' failure could be seen since there was a crack in the rok block. The failure of this wood joint only occurred in the woodblock part, and there were no ejected joints, thus, in the first step of the Test, it could be concluded that the failures in wood joints occurred preceded by woodblock crack.

The monotonic test result was translated into the graph to present the lateral load (kg) and deflection (mm) data. Data in this graph were required to analyze the melting and maximum deflections values in the sample to measure the capability of structure response on earthquake. The durability of building on earthquake could be measured from various categories, i.e., building ductility, earthquake coefficient that the building could withstand and building a response to earthquake based on the standard of SNI 1726 2002, SNI 1726 2012 and NEHRP-Fema 750.

\[ \mu = \frac{\Delta_{\text{max}}}{\Delta_{y}} = \frac{180}{79} = 2.27 \]  

(1)
i.e., 1. Ductility calculation result.

The analysis result from graph 2 showed that the melting deflection in the test sample located in point 79 mm while the maximum deflection occurred in the point 180 mm. Based on the calculation of the Aceh house building pillar material, the ductility value reached 2.27, which meant that Aceh house had partial ductility criteria [10]. This partial ductility indicated that the building could withstand the middle-class earthquake load. The ductility value was needed to determine the earthquake reduction factor (R) in the calculation of earthquake response in equation 3.

\[ \sum_{i=1}^{n} V_i \cdot \sum_{i=1}^{n} W_i \cdot V = C_s \times W \rightarrow C_s = \frac{V_1}{W_1} \rightarrow C_s = \frac{170 \text{ kg}}{480.8 \text{ kg}} = 0.353 \]  

i.e., 2. Earthquake durability calculation result.

Analysis of building durability on earthquake than was conducted using equivalent static analysis. Static analysis is designing building structure on earthquake load impact statically. Principally, changing the horizontal load worked on the structure. Based on the calculation of the total weight ratio held by building and load worked on the structure, it is shown that the earthquake coefficient that the building can withstand is 0.353.

\[ C_s = \frac{S_D}{I_e} \cdot \frac{0.353 \cdot 0.970}{32/1} = 0.303 \]  

i.e., 3 Structure response of earthquake calculation.

The analysis was then continued by calculating the structure response on earthquake in Aceh Besar region using data from earthquake power inside the location (SDS), i.e., 0.97 based on the spectra design issued by Puskim PU. The earthquake coefficient of Aceh Besar vernacular house could withstand 0.353, and the structure response on earthquake in the Lampisang region was 0.303. Based on the earthquake durability parameter on the standard of SNI 1726 2002 and SNI 1726 2012, it could be concluded that Aceh Besar vernacular house construction system could withstand the earthquake load.

4.2. Moisture test

The percentage of moisture in wood profoundly influences the wood durability because the water content inside a wood creates disturbances such as mushrooms which can reduce the wood quality. Mushroom generally attack wood which has high water content, i.e., above 20%. Mushroom can modify and reduce the wood compiler substances and cause weight loss. Wood is composed of main compilers, i.e., cellulose, hemicellulose, and lignin. These three components affect the chemical and physical properties of wood. The change of dimension, environment effect, and degradation can reduce wood strength [11]. In the Test of water content in the Aceh house wood pillar, this pillar had
various water content percentages from 14.5% to 19%. This low moisture in Aceh house occurred because the wood was dried by the locals previously. The interview result showed that the Aceh community used natural drying technique, which relied on air where the wood was left untouched outdoor for one to two months. In the past, wood drying aimed to eliminate latex inside the wood and facilitate the peeling process of tree bark to make pillars. The drying done by the community prevented the mushroom attack and wood powder so that the wood used in Aceh Besar vernacular building was protected from biological attacks. This causes the Aceh Besar vernacular house wood has high durability proved by the age of building reaching 130 years old.

4.3. FTIR test

![Figure 6. IR spectrum.](image)

Source: NIST Chemistry WebBook 2019

*Artocarpus heterophyllus* contains bioactive compounds, i.e., flavonoid [12], which is a phenol compound group that serves as antimicrobial and antifungal as well as has insecticide properties on various types of insects [13]. Fraction contains in *Artocarpus heterophyllus* wood which has anti termites properties are n-hexane, ethyl ether, and ethyl acetate.

![Figure 7. FTIR testing result.](image)

FTIR testing result confirmed the presence of extractive substances like n-hexane, ethyl ether, and ethyl acetate in the 130 years old sample. This was seen from the IR spectrum shown in Figure 10. The wave produced was close to that of n-hexane, ethyl ether, and ethyl acetate in Figure 9. Thus, it could be confirmed that the extractive substance still resided in the wood sample. The hydrocarbon group compounds dissolved in *Artocarpus heterophyllus* wood n-hexane extract are n-undecane and n-
dodecane. N-dodecane compound was suspected of having acted as an antioxidant [14]. The bioactive properties from the n-undecane compound were suspected of destroying the growth of protozoa symbiont with termites [15]. The presence of those compounds increase wood durability so that wood can survive for centuries from termites attack.

4.4. Findings
This research produced several findings based on the conducted test result, i.e.:

1) The construction system of Aceh Besar vernacular house has excellent performance in facing an earthquake by the use of wood joining system which interlocks pillar and block. This wood joining system creates building to be able to withstand an earthquake without experiencing structure failure or collapse.

2) The amount of load exposed until the wood joints experienced failure is 170 kg. This analysis shows that during failure, the wood joining system still can respond to a more significant earthquake load compared to the maximum value that occurred in the Aceh Besar region.

3) Material durability in Aceh vernacular house building is caused by the use of wood material which has passed the locals drying process technique thus, preventing the mushroom attack and wood powder. The wood used in Aceh Besar vernacular house is protected from biological attack caused by the water contained inside the building pillar material.

4) Durability is influenced by the presence of extractive substances like ethyl ether fraction and ethyl acetate, which can slow termite growth. The presence of n-hexane fraction and ethyl acetate in Artocarpus heterophyllus wood makes the wood durable from termites attack although it has been 130 years old. Those substances still contain so that building pillar material can survive from termites attack.
5. Conclusions
A vernacular Aceh house can survive from earthquake load because the construction system is formed from local’s knowledge in wood joining system technique which can respond to the earthquake and able to make the buildings stand without having any damage. The selection of wood material in vernacular houses by the locals can support the durability of the building based on its immunity to biological attacks by the use of Artocarpus heterophyllus wood which has extractive substances which are poisonous to termites and wood natural drying process which increases wood durability. However, further research should be done to determine the durability of the Aceh vernacular house structure and construction system by conducting the Test in all building structure components.

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