

Article

The Structural Effectivity of Bent Piles in Ammatoan Vernacular Houses

Wasilah^{*†}

Architectural Engineering, Faculty of Science and Technology, Alauddin Islamic

State University; wasilah@uin-alauddin.ac.id

* Correspondence: wasilah@uin-alauddin.ac.id; Tel.: +62-812-410-0969

† Current address: H.M Yasin Limpo Road, Samata-Gowa, South Sulawesi, Indonesia

Academic Editor: Name

December 2018 version submitted to Entropy; Typeset by LATEX using class file

mdpi.cls

Abstract: One of the building is Ammatoa Kajang vernacular house that exist for a hundred years ago as a residential house building. Building should be replaced with buildings and exist for should be replaced with exists since. These traditional houses are unique in their use of bent piles. This research examines the strength of the structural system of Ammatoan vernacular houses based on said houses' ability to adapt to various environmental conditions and natural phenomenon. This study seeks to enrich these studies by examining the specific structural strength of these buildings. In the face of modernization and extreme climate change, the continued existence of such traditional houses has been threatened. Disaster may strike at any time, and as such we must explore the structural strength of their structures to predict these buildings' ability to endure such events. This research applies an interpretative model to explore the

structural system, using a load test to examine the houses' structural strength. Although such a model assumes each building has the same pitch, each house has its own pitch. Therefore, measurement results cannot be applied generally to describe the structural strength of every Ammatoan house. This research also notes that the pin joint system, material selection, and application of grounded foundation are factors that promote these buildings' continued endurance and ability to withstand earthquakes.

Keywords: bent piles 1; structural systems 2; vernacular houses 3; Ammatoan houses 4; building structure 5; effectivity 6; strength 7

1. Introduction

The structure of a building refers to the constitution of its elements, which bears the load of the main construct; examination of structure focuses on elements that actually bear the load, without considering whether they appear to do so. Generally, such a structure consists of a foundation, walls, columns, floors, and trusses (Heinz Frick ,1997).

Traditional architectures tend to rely on simple structures, with their stability determined by traditional peoples' empirical experience, intuitive knowledge, and attempts to pass knowledge from generation to generation. Structure is closely linked to the anatomy of a building, i.e. the sub-structure and upper structure. Construction, meanwhile, is closely linked to the methods, techniques, and means through which elements are bound, lifted, connected, etc.

The Ammatoans, also known as the Kajang, have maintained a traditional lifestyle for hundreds of years and synergized with their local natural environment. This consistency in traditional values significantly influences the structures and forms of

Ammatoan architecture. As with other traditional buildings in South Sulawesi, Ammatoan vernacular houses are stilt houses. They are characterized, however, by relative homogeneity; simplicity; small room dimensions; use of natural materials; and lack of ornamentation or other signs of social stratification.



Figure 1. Ammatoan Wood House

Another key characteristic of traditional Ammatoan houses is the bent pile structural system. This system has been used by the Ammatoans for hundreds of years, and each pile is capable of standing for decades (or even centuries) without any instability. This becomes interesting to be investigated further about the strength of building structures so that they can last long.

These buildings are built following the principle of *mappasituppu* (Hartawan et. al., 2015), which invokes the natural characteristics of the trees used; requires the use of bent piles; and sets a specific location for each pile. This structural system has remained the primary one in Kajang, and can support Ammatoan vernacular houses—as well as the

various activities within—for over a hundred years. It is this system that is examined in this research.

All parts of Ammatoan houses are made entirely from wood. Columns, beams, walls, stairs, and all floors use wood material, while for roof cover used zinc and thatch material. As such, these timber structures have relatively little weight, providing these residential buildings with a clear advantage. Consequently, these buildings have minimal shear force.

Wood is a natural material, which has three main axes. Along the primary axis, the strength and stiffness are superior; in terms of strength–material density ratio, it is even stronger than other materials. However, wood is relatively weak and soft along the two others axes, and as such it can crack and cause structural failure. Since wood has different mechanical properties along its three axes, then a nonlinear analysis is needed for analysis.

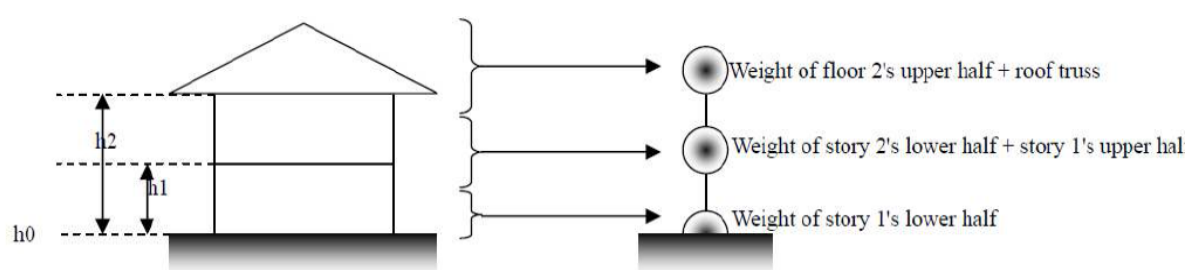


Figure 2. Weight Modeling of Each Floor of a Wood House Model

(Suwantara and Suryantini, 2014)

Through their physical structure, construction, and material, traditional or vernacular houses convey different values (Rapoport, 1969). As such, previous studies of Ammatoan houses have focused primarily on the integration of Ammatoan cultural values in their architecture. This study seeks to enrich these studies by examining the specific structural

strength of these buildings. In the face of modernization and extreme climate change, the continued existence of such traditional houses has been threatened. Disaster may strike at any time, and as such we must explore the structural strength of their structures to predict these buildings' ability to endure such events. The key contribution is recognize the specific structural strength of the vernacular houses of ammonia in modernization and extreme climate change as a basis for consideration in building similar house buildings in South Sulawesi.

2. Research Methods

This study examines structural system of Ammatoan vernacular houses, as influenced by the culture and beliefs of local society. This research applies an interpretative model to explain the meaning of the bent piles and their output in Ammatoan vernacular houses. Analysis was done using SAP2000 software to observe the strength and endurance of these bent piles. In modeling and analysis, the finite element method is used.

This research involves:

- a) The material and joints used in Ammatoan vernacular houses were identified; this was intended to recognize the material types before mechanical testing.
- b) Mechanical testing was conducted, applying ASTM. It was found that mechanical strength is influenced by flexural strength, compressive strength, tensile strength, shear, and MOE.

- c) The results of mechanical testing were examined using numerical analysis, as well as wind load and live load. This was used to predict the strength of the bent pile structural system, including in its ability to endure earthquakes.

Ammatoan vernacular houses are made using local wood material, primarily bitti wood (*Vitex cofassus*). However, information about this wood is limited, and the wood available is of limited diameter as it comes from young trees. Therefore, it is necessary to determine the characteristics and properties of bitti wood. Bitti wood is classified as Class II in terms of durability (Forest Botanical Departments, 1972), and has an elastic modulus of 100,000 kg/cm². (Wiryomartono, 1976). The volume of the load structure application complies with the terms of the *Procedure for Planning the Wood Structures of Buildings* (1987). Its wind load is 40 kg/m²; live load is 200kg/m²; and wood volume is 1000 kg/m³. This information was input into the SAP2000 model. Structure Modeling, Data Input includes:

1. Material Properties, the quality of the material used is Wood. Beams and Columns: E13 ($f_c' = 28 \text{ MPa}$)
2. Structure Dimension, the structural dimensions that will be used in this ammatoa house structure model are :
 - a. Beams B1 = 300 x 300 mm²
 - b. Beam B2 = 200 x 300 mm²
 - c. Column C1 = 500 x 500 mm²
3. Loading, the loading structure used in this model is:
 - a. Dead Load (DL)
 - Reinforced concrete: 1000 kg / m³
 - b. Life Expenses (LL)
 - Roof Floors: 100 kg / m²

- Other floors: 200 kg / m²

c. Earthquake Load

The earthquake load used in this study is the earthquake load time history Bulukumba, South Sulawesi taken from the USGS Earthquake Hazards Program.

Based on research by Hapid (2010), bitti wood has a consistency of 11.17–17.88% vessels, 57.49–70.32% fibers, 10.74–19.30% rays, and 5.40–8.98% parenchyma. Cell measurement found an average fiber length of 0.86–1.44 mm, average fiber diameter of 17.81–20.59 μm , average lumen diameter of 11.93–13.86 μm , and average cell wall thickness of 2.61–4.02 μm . It had a green and air-dry moisture content of 59.32–110.22% and 9.66–20.82%, respectively. Specific gravity in green, air-dry, and oven-dry conditions were 0.48–0.70, 0.48–0.75, and 0.50–0.80, respectively. Radial, tangential, and longitudinal shrinkage of the wood from green to oven-dry condition was 3.64–7.44%, 1.79–4.32%, and 0.18–0.49% respectively, with a T/R ratio of 1.42–2.03. Radial, tangential, and longitudinal swelling of the wood from oven-dry to wet condition was 3.673, 4.374%, and 0.342% respectively, with a T/R ratio of 1.32–3.26. Static bending strength, MOE, and MOR were 460.37–803.17 kg/cm², 67.75–97.22 (x103 kg/cm²), 634.13–1046.39 kg/cm², respectively.

3. Results

The upper structure refers to certain elements of the construction: columns, load-bearing beams, and roof frames. In principle, the roof of a building serves the same function as its walls, namely to cover the building and protect it from the elements (heat, cold, etc.). Light construction refers to the construction system used in tropical areas.

The structure used for Ammatoan traditional houses is made primarily with bitti wood, a locally available material. It relies solely on a peg jointing system, including in roof construction. The main piles of the structure are embedded some 100 centimeters in the ground. They are arranged in a grid, measuring 6 x 9 meters. Two types of piles are used in construction: the piles that support the roof trusses (average length: $\pm 4\text{m}$) and the piles that support the floor beams (average length: $\pm 1.5\text{m}$). All of the piles are made with bitti wood, with a diameter of 15 to 20 cm. These wooden piles are made using entire tree trunks, and are not straight but bent or curved.

The floors of Ammatoan houses are supported by beams that measure 10 to 15 cm in diameter, with wooden boards providing the floor itself. The second-story beams are close together ($\pm 40\text{ cm}$) and connected to the primary pile. These beams are covered with boards, which are nailed to the beams.

Ammatoan vernacular houses consist of 20 primary piles, made using bitti wood (*Vitex cofassus*). These materials have the following mechanical characteristics: flexural strength of 460.37–803.17, modulus of elasticity of 67.75–97.22 MPa, parallel comprehensive strength of 62.51 MPa, vertical fiber of 136.84 MPa, and parallel tensile strength of 331.59 MPa.

Output analysis shows the following advanced solver:

- | | |
|--|-------|
| a) Number of joints | = 105 |
| b) Number of frame/cable/tendon elements | = 188 |
| c) Number of shell elements | = 24 |
| d) Number of load patterns | = 3 |
| e) Number of acceleration load | = 6 |
| f) Number of load cases | = 5 |

Stiffness At Zero (Unstressed) Initial Conditions

- a) Number of stiffness degrees of freedom = 510
- b) Number of mass degrees of freedom = 255
- c) Maximum number of eigen modes sought = 12
- d) Minimum number of eigen modes sought = 1
- e) Number of residual-mass modes sought = 0
- f) Number of subspace vectors used = 24
- g) Relative convergence tolerance = 1.00e-09
- h) Found mode 1 of 12: EV= 1.7944866E+03, f=6.742023, T=0.148323
- i) Found mode 2 of 12: EV=2.9935333E+03, f=8.707875, T=0.114839
- j) Found mode 3 of 12: EV=4.3114325E+03, f=10.450352, T=0.095691
- k) Found mode 4 of 12: EV=4.3642055E+03, f=10.514115, T=0.095110
- l) Found mode 5 of 12: EV=5.4550936E+03, f=11.754962, T=0.085070
- m) Found mode 6 of 12: EV=6.8357308E+03, f=13.158689, T=0.075995
- n) Found mode 7 of 12: EV=7.0710202E+03, f=13.383237, T=0.074720
- o) Found mode 8 of 12: EV=7.3839175E+03, f=13.676140, T=0.073120
- p) Found mode 9 of 12: EV=7.4417295E+03, f=13.729574, T=0.072835
- q) Found mode 10 of 12: EV=7.5363680E+03, f=13.816600, T=0.072377
- r) Found mode 11 of 12: EV=2.5618453E+04, f=25.473967, T=0.039256
- s) Found mode 12 of 12: EV=3.2740592E+04, f=28.798071, T=0.034725

This structural analysis found that the piles of the Ammatoan vernacular houses are extremely strong, more than capable of handling the live load and dead load, with a roof structure that can readily resist the wind load. The third level of the structure, or the house

ceiling, has beams that support the carrying of the load, as found in the structural test. Therefore, the ceiling may require frequent replacement to ensure the maximal performance of the house structure.

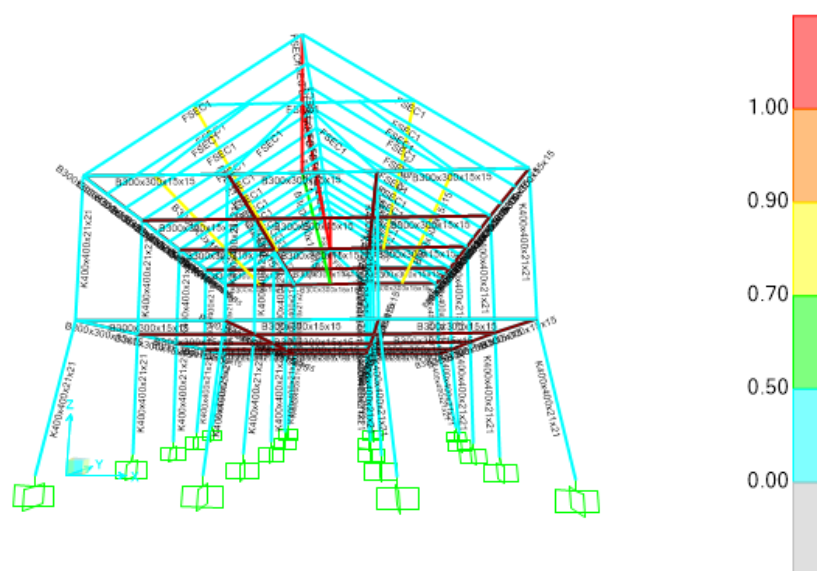


Figure 3. The structural load of an Ammatoan vernacular house

According to the load analysis, the results of which are shown in Figure 3, all piles can properly carry the load. These piles, cyan in the figure above, have the strength to support the building for a long period of time. Field research found several Ammatoan vernacular houses have been standing for more than 80 years. The piles of these houses have never been replaced, and have consistently been able to carry the load without any indication of damage. However, some supporting beams are colored red in this figure, indicating that these beams tend to lack the ability to handle their load. Many social activities are held in the body of the house, such as weddings, funerals, discussion, etc. Consequently, there is a high probability that these beams require replacement. The Fmax diagram of the load, shown below, shows the influence of various factors.

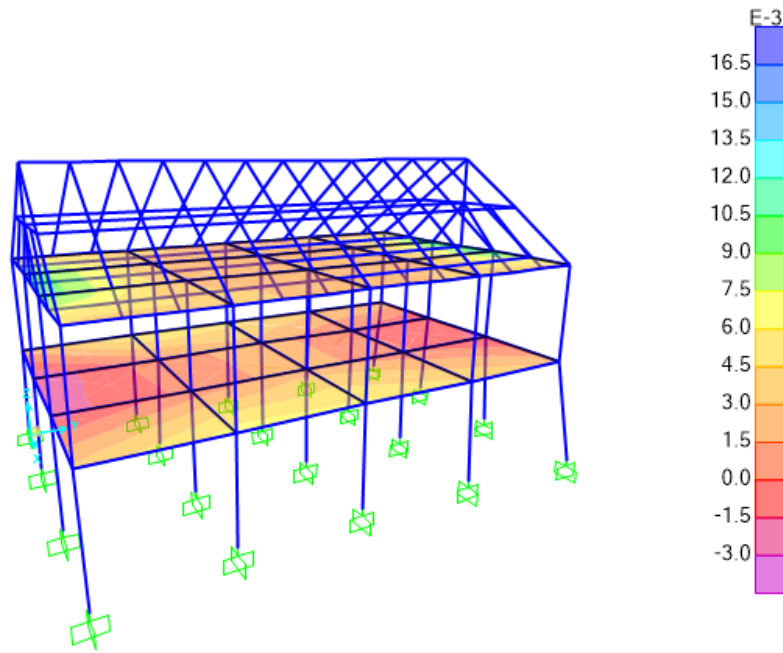


Figure 4. Fmax diagram

An Fmax diagram depicts the maximum force per length unit in the middle of an element. Its main orientation is presented in such a way that the shear force per length unit is zero. The second floor, or the house body, has a lower main force load than the third level. This can be observed in the color gradation of Figure 4. The relative virtual work (RVW) diagram below shows the virtual work energy as an indication of force and displacement load pressure.

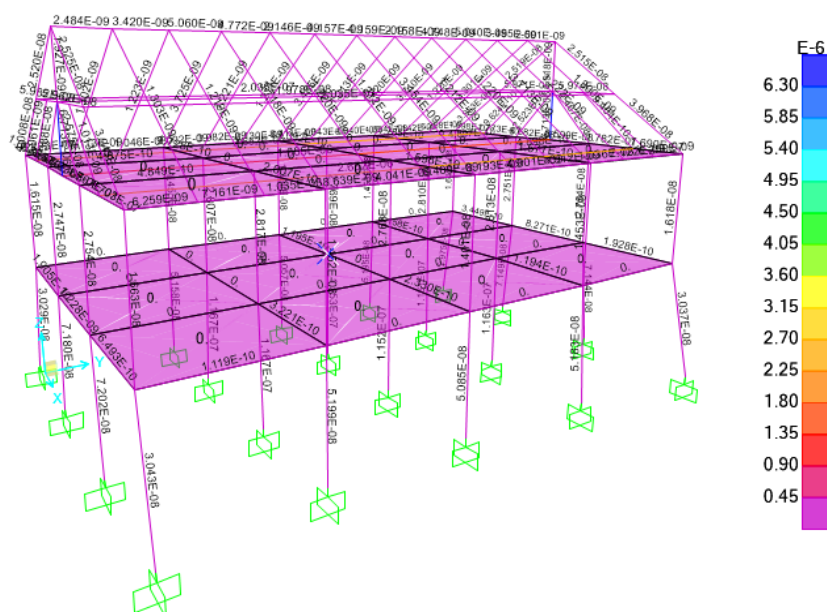


Figure 5. RVW Output

Relative virtual work analysis presents the virtual work percentage of an element relative to the balance of structural elements. It has the benefit of decreasing structural deflection by indicating the element with the highest energy percentage and significantly influences deflection if stiffness is modified.

Figure 5 depicts the virtual work energy percentage of Ammatoan vernacular houses, with pressure caused by the pattern of force and load displacement. This condition explains that, when the percentage of element stiffness is higher than structural deflection, it is significantly more influential than a lower percentage.

Analysis found that element stiffness is fairly low, and that structural modification is not significantly influence by load (dead load, live load, wind load, and earthquake load). These results reflect the development principle of Ammatoan houses, which is oriented towards sustainability. The use of natural forms in piles indicates elemental stiffness

without modification. As a result, the RVW results indicate that the bent pile structure functions better than a modified pile.

Such vernacular houses have proven to stand firm during earthquakes and other natural disasters. This study explains its results through analysis of output values, ranging in value from 9.3 to 10 (Figure 6). Referring to an earthquake magnitude estimate for the Bulukumba area (where the Ammatoans live) by the USGS Energy Resources Program, this structure will handle earthquakes without collapsing or experiencing severe damage. However, in earthquakes, such houses will shake and cause an apparent motion of 30–60 cm (Figure 7). The red line in Figure 7 shows the initial position of the Ammatoan living room, while the blue line shows the apparent motion during earthquakes. The difference between the red and blue line on the second story (living area) is about 30–35 cm, while the difference for the third story (attic) is about 40–60 cm.

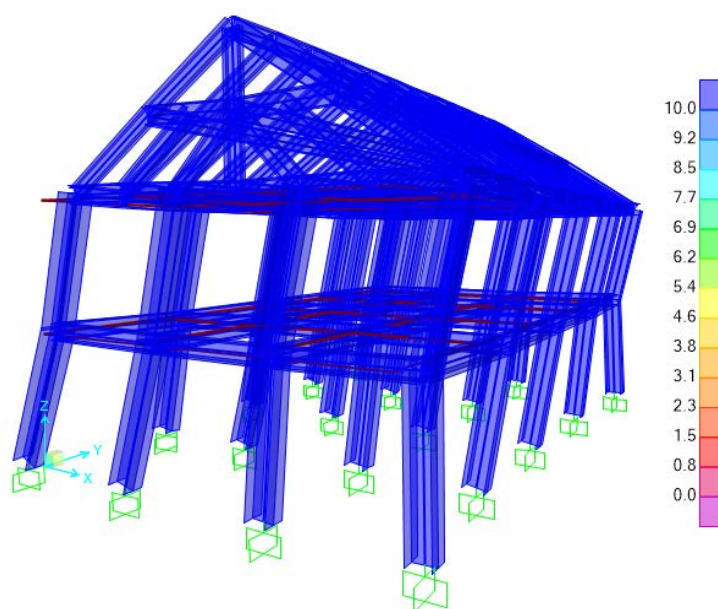


Figure 6. Illustration of the joint system of an Ammatoan vernacular house

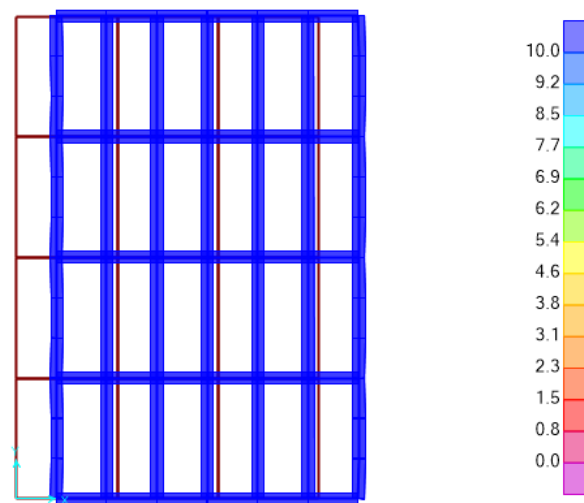


Figure 7. Illustration of the joint system of an Ammatoan vernacular house

The primary success of Ammatoan vernacular architecture lies in its ability to withstand climate, time, and earthquakes, a situation influenced by the pin joint system, grounded foundation engineering, and pile technique. These three factors are basic elements of Ammatoan residential buildings, as stated in *Pasang ri Kajang*, the guideline for local life.

4. Discussion

The joints of Ammatoan vernacular houses consider the pedestal foundation, the free positioning, and stiffness. The pedestal foundation of Ammatoan vernacular houses comes from the wood piles being sunk 1 m into the ground. Ammatoan vernacular houses use both rigid joints and free positioning. Rigid joints are used to connect pillars and beams on the first floor, as well as on the *padongko* beam. Free joints are used in the floor system and to support the ceiling under the roof.



Figure 8. Frame of an Ammatoan house

Loading on the attic of the house shows the strength of the roof structure is rather weak so it is not recommended to accommodate the maximum load. The overall strength of bitty wood has approached its true strength so that its utilization is far more maximal. The obstacle is the beam connection system which does not adjust to the loading pattern of buildings and activities in the building.

House construction in Ammatoan communities may be categorized as environmentally friendly, because houses utilize such natural materials as nipa palm leaves (for roofing), palm fibers and rattan (for binding), bamboo (for floor material), and bitti wood (for walls). Most Ammatoan vernacular houses use timber as their primary material. To build the house, three dowel beams (*padongko*) are arranged horizontally, from the left to the right side of the house. A large horizontal beam is positioned from the left to the right side, and bound to one column (*latta'*) above the house.

Supporting piles are formed from sections or cut trees. Usually, piles in structural systems are square sections, made using raw logs that are carved without any clear object.

In Ammatoan vernacular houses, the structural system that supports the main floor consists of bent piles (*benteng*), as well as *unebba*, *besere*, *arateng*, *pattolo*, and flooring. Floorboard size is determined by the size of available material.

A primary component of the roof structure is the truss. Generally, wood truss construction is a cantilever construction, the primary supporting structure of the roof. Wooden truss construction requires no deformation, especially after implementation. For the roof load to be carried by wooden trusses through the girders, joints must be positioned precisely. Additionally, there must be no bending stress on the bar; only ordinary compressive and tensile stress.

A wooden truss involves wooden beams of a specific dimension that are assembled into isosceles triangles. Trusses are positioned in beam rings, using specific angles. Frame structure may use wood or roller joints (wall plates or respective columns). There are two types of joint systems used in Ammatoan vernacular houses: joints between the piles (*benteng*) and floor beams (*arateng*), and joints between piles (*benteng*) and roof beams (*padongko*).

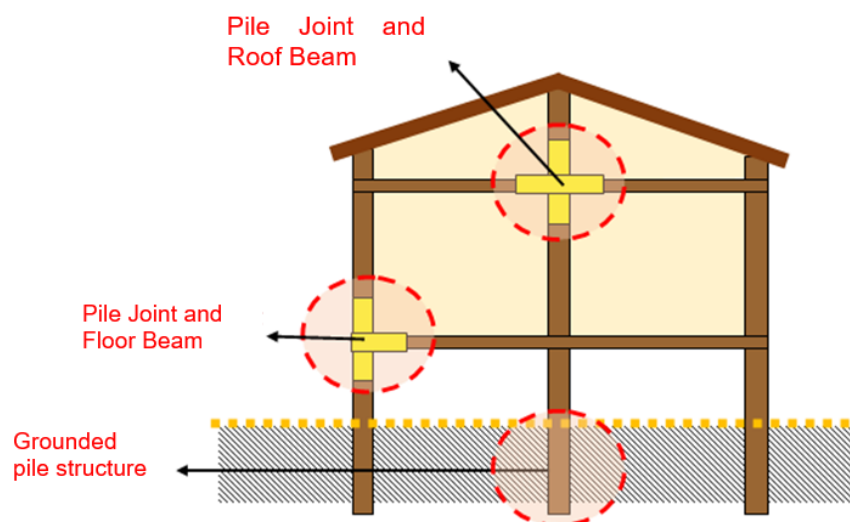


Figure 9. Illustration of the joint system of an Ammatoa vernacular house

There are two types of joints used in Ammatoan houses, while the column system is a deep pile system. This simple technology reflects the principle of synergizing with nature (creating balance, sustainability, harmony between man and nature, and ancestral knowledge). In the architecture of the Ammatoan people, these principles have been realized through trial and error. As a result, the Ammatoans have found a form and structure sufficient to carry loads stably for decades.

5. Conclusions

- a) A natural understanding of building materials can be combined with traditional expertise to present a structurally sound construction that is also environmentally conscious.
- b) Testing for structural strength applied an assumption of equal pile pitch. However, each Ammatoan house has a different level of pitch. Therefore, measurement results cannot be generalized to describe the structural strength of every house in Kajang; rather, the results are only applicable to the sample used in this research.
- c) The natural forms and characteristics of tree trunks has led to wood becoming a main building material, a joint system, and a foundation system, and significantly determined the structural strength of Ammatoan stilt houses. Moreover, the pin joint system, grounded foundation, and selection of piles are primary factors in the success of Ammatoan architecture.

Acknowledgments: The author would like to express her gratitude to the staff of the Architectural Engineering Laboratory, Faculty of Science and Technology, Alauddin Islamic State University, for sharing their wisdom during the course of this research.

References

1. National Standardization Agency of Indonesia (BSN). 2012. Tata cara perencanaan struktur kayu untuk bangunan gedung [Procedure for planning the wood structures of buildings]. SNI-03-xxxx-2000. Bandung
2. Burley, A. L, N.J. Enright, and M.M. Mayfield. 2011. Demographic response and life history of traditional forest resource tree species in a tropical mosaic landscape in Papua New Guinea. *Journal of Forest Ecology & Management*. Vol. 262 Issue 5, pp. 750–758.
3. Hartawan, B. Suhendro, E. Pradipto, and A. Kusumawanto, 2015, Perkembangan sistem struktur bangunan rumah Bugis Sulawesi Selatan [The development of the structural system of the Bugis houses of South Sulawesi]. *Proceedings of the 5th Annual Engineering Seminar (AES 2015)*, "Free Trade Engineers: Opportunity or Threat". Faculty of Engineering, Gadjah Mada University. Yogyakarta. pp. 51–60.
4. Misam Dogan, 2010, Seismic analysis of traditional buildings: Bagdadi and Himis, *Anadolu University Journal of Science and Technology A: Applied Sciences and Engineering*, Vol. 11, No. 1, pp. 35–45.
5. Rapoport, A. 1969. *House form and culture*, Prentice-Hall.
6. Suwantara, I Ketut and Putu Ratna Suryantini. 2014. Kinerja sistem struktur rumah tradisional Ammu Hawu dalam merespon beban seismik [Performance of the Ammu

- Hawu structural system in responding to seismic loads]. *Jurnal Permukiman* Vol. 9, No. 2. pp. 102–114.
7. Hildayanti, Andi, Nur Adyla S, Happy Ratna Santosa. 2014. Analysis of housing areas with a sustainable community approach. *IJSER* 2014.
 8. Hapid, Abdul. 2010. Struktur anatomi dan sifat fisika-mekanik kayu bitti (*Vitex cofassus reinw*) dari hutan rakyat yang tumbuh di Kabupaten Bone dan Wajo Sulawesi Selatan [The anatomical structure and physical-mechanical properties of bitti wood (*Vitex cofassus reinw*) from community forests grown in Bone and Wajo Regencies, South Sulawesi]. Thesis. Faculty of Forestry, Gadjah Mada University. Yogyakarta.
 9. Wasilah and A. Hildayanti. 2017. Filosofi penataan ruang spasial vertikal pada rumah tradisional Saoraja Lapinceng Kabupaten Barru [Philosophy of vertical spatial planning in Saoraja Lapinceng traditional houses, Barru Regency]. *Jurnal RUAS (Review of Urbanism and Architectural Studies)*. Vol. 14, No. 2.
 10. Wasilah, and T. Fahmyddin. 2018. The advancement of the built environment research through employment of structural equation modeling (SEM). *IOP Conference Series: Earth and Environmental Science*.
 11. Wiryomartono. 1976. *KONSTRUKSI KAYU Jilid 1 [WOOD CONSTRUCTION Volume 1]*. Yayasan Penerbitan FIP-IKIP, Yogyakarta.
 12. Ludwig, Steiger. 2010. *Kontruksi kayu [Wood construction]*. Erlangga: Jakarta.
 13. Fajrin, J., Handayani, T., Anshari, B. and Rofaida, A. 2008. Pengembangan desain dan konstruksi rumah panggung sebagai rumah murah berbasis teknologi kayu laminasi [Developments in the design and construction of cheap stilt houses using laminated wood technology]. Research Report, Mataram University, Mataram.

14. Luthan, Putri, L. A. 2015. Pengembangan konsep rumah tinggal tradisional Mandailing di Sumatera Utara [Conceptual development of traditional Mandailing houses in North Sumatra]. Gunadarma University. Depok
15. Rifai and A. Jiba, 2010. Perkembangan Struktur dan Konstruksi Rumah tradisional Suku Bajo di pesisir Pantai Parigi Moutong [Developments in the structure and construction of traditional Bajo houses along the coast of Parigi Moutong Beach]. Tadulako University, Palu.
16. Sardjono, Budi, and A. Nugroho. 2014. Menengok arsitektur permukiman masyarakat Badui arsitektur berkelanjutan dari halaman sendiri [Looking at the architecture of Baduy settlements: sustainable architecture from our own yard]. Dipenogoro University, Semarang.
17. Setijanti, Purwanita, J. Silas, S. Firmaningtyas, and Hartatik. 2012. Eksistensi rumah tradisional Padang dalam menghadapi perubahan iklim dan tantangan jaman [The existence of traditional Padang houses in the face of climate change and the changing times]. Sepuluh November Institute of Technology, Surabaya.
18. Mehta, Kishor C. 2013. Wind load: guide to the wind load provisions of ASCE 7-10. ASCE Press, Virginia.
19. Forrest Product Laboratory. 2010. Wood as an engineering material (wood handbook). USDA, United States.
20. Breyer, Donald E. 2007. Design of wood structures. McGraw-Hill, New York.
21. Rimang, Siti Suwadah. 2016. Sejarah Kajang [History of Kajang]. Lentera Kreasindo, Makassar.

22. Tika, Mansyur, et al. 2015. Ammatoa, Makassar: Lembaga Kajian dan penulisan sejarah budaya Sulawesi selatan [Ammatoa, Makassar: Institute for the studies and writing of the cultural history of South Sulawesi].