

Article

The Structural Effectivity of Bent Piles in Ammatoan Vernacular Houses

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Abstract: Ammatoa Kajang vernacular houses are buildings that have existed for a hundred years as residential house buildings. 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 phenomena. 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 that each building has the same pitch, each house has its own pitch. Therefore, the 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 a grounded foundation are factors that promote these buildings' continued endurance and ability to withstand earthquakes.

Keywords: bent piles; structural systems; vernacular houses; Ammatoan houses; building structure; effectivity; strength

1. Introduction

The structure of a building refers to the constitution of its elements, which bears the load of the main construction; the examination of a 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 [1,2].

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 [3–6]. 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 [7].

The Ammatoans, also known as the Kajang, have maintained a traditional lifestyle for hundreds of years and synergized with their local natural environment (see Figure 1). This consistency in traditional values significantly influences the structures and forms of Ammatoan architecture [8,9]. As with other traditional buildings in South Sulawesi, Ammatoan vernacular houses are stilt houses. They are characterized, however, by a relative homogeneity, simplicity, small room dimensions, use of natural materials, and lack of ornamentation or other signs of social stratification [10].



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 in relation to further investigations about the strength of building structures and how they can last long.

These buildings are built following the principle of *mappasituppu* [11], 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. The columns, beams, walls, stairs, and all the floors use wood material, while the roof cover is made of 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 a minimal shear force.

Wood is a natural material, which has three main axes [12]. Along the primary axis, the strength and stiffness are superior; in terms of the 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, a nonlinear analysis is required.

Through their physical structure, construction, and material, traditional or vernacular houses convey different values [13] (Rapoport, 1969) (see Figure 2). 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 [14]. 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 [15,16]. The key contribution is the recognition of the specific structural strength of these vernacular Ammatoan houses within modernization and extreme climate change as a basis for consideration in building similar house buildings in South Sulawesi.

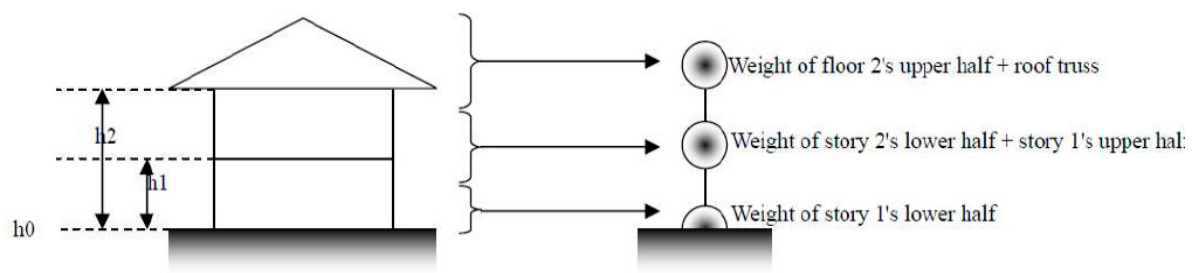


Figure 2. Weight modeling of each floor of a wood house model. (Suwantara and Suryantini, 2014).

2. Research Methods

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

This research involves the following:

- (a) The material and joints used in Ammatoan vernacular houses were identified, in order to recognize the material types before a mechanical testing.
- (b) A mechanical testing was conducted, applying Wood. It was found that the mechanical strength is influenced by flexural strength, compressive strength, tensile strength, shear, and modulus of elasticity (MOE).
- (c) The results of the mechanical testing were examined using a numerical analysis, as well as a wind load and live load. This was used to predict the strength of the bent pile structural system, including 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 [17] (Forest Botanical Departments, 1972), and has an elastic modulus of 12,000 kg/m². 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 [18–20]. This information was entered into the SAP2000 model. The Structure Modeling, Data Input (see Table 1) includes:

1. Material Properties: the quality of the material used is Wood. Beams and Columns: E13 (fc' = 28 MPa)
2. Structure Dimension: the structural dimensions that will be used in this Ammatoa house structure model are:
 - a. Beams B1 = 300 × 300 mm
 - b. Beam B2 = 200 × 300 mm
 - c. Column C1 = 500 × 500 mm
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: 50 kg / m²

- Other floors: 150 kg / m²
- c. Earthquake Load

The earthquake load used in this study is the earthquake load time history Bulukumba, South Sulawesi taken from the U.S. Geological Survey (USGS) Earthquake Hazards Program.

Table 1. Data Input for Structure Modeling in SAP 2000.

No.	Item		Value	Unit
1	Material Properties		28	Mpa
2	Structural dimensions	Beams B1	300 × 300	Mm
3		Beams B1	200 × 300	Mm
4		Column C1	500 × 500	Mm
5	Dead Load (DL)	Reinforced concrete	1000	kg/m ³
6	Life Expenses (LL)	Roof Floors	50	kg/m ²
7		Other floors	150	kg/m ²
8	Wind load		40	kg/m ²

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. The 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. The 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. The radial, tangential, and longitudinal shrinkage of the wood from a green to an 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. The radial, tangential, and longitudinal swelling of the wood from an oven-dry to a wet condition was 3.673, 4.374%, and 0.342%, respectively, with a T/R ratio of 1.32–3.26. The static bending strength, MOE, and MOR were 460.37–803.17 kg/cm², 67.75–97.22 (× 10³ kg/cm²), 634.13–1046.39 kg/cm², respectively [21].

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.). The 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 for its roof construction. The main piles of the structure are embedded about one meter into the ground. They are arranged in a grid, measuring 6 × 9 meters. Two types of piles are used in the construction: the piles that support the roof trusses (average length: ± 4 m) and the piles that support the floor beams (average length: ± 1.5 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 (± 40 cm) and connected to the primary pile. These beams are covered with boards, which are nailed to the beams.

The strength of a bent pole in the Ammatoan house structure was tested using SAP2000, and it was analyzed through FE models. The 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 the 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 = 0.000000001
- (h) Found mode 1 of 12: EV = 1794.4866, f = 6.742023, T = 0.148323
- (i) Found mode 2 of 12: EV = 2993.5333, f = 8.707875, T = 0.114839
- (j) Found mode 3 of 12: EV = 4311.4325, f = 10.450352, T = 0.095691
- (k) Found mode 4 of 12: EV = 4364.2055, f = 10.514115, T = 0.095110
- (l) Found mode 5 of 12: EV = 5455.0936, f = 11.754962, T = 0.085070
- (m) Found mode 6 of 12: EV = 6835.7308, f = 13.158689, T = 0.075995
- (n) Found mode 7 of 12: EV = 7071.0202, f = 13.383237, T = 0.074720
- (o) Found mode 8 of 12: EV = 7383.9175, f = 13.676140, T = 0.073120
- (p) Found mode 9 of 12: EV = 7441.7295, f = 13.729574, T = 0.072835
- (q) Found mode 10 of 12: EV = 7536.3680, f = 13.816600, T = 0.072377
- (r) Found mode 11 of 12: EV = 25618.453, f = 25.473967, T = 0.039256
- (s) Found mode 12 of 12: EV = 32740.592, 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 replacements to ensure the maximal performance of the house structure.

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 that several Ammatoan vernacular houses have been standing for more than 80 years. The piles of these houses have never been replaced, and have been able to consistently 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 in Figure 4 below, shows the influence of various factors.

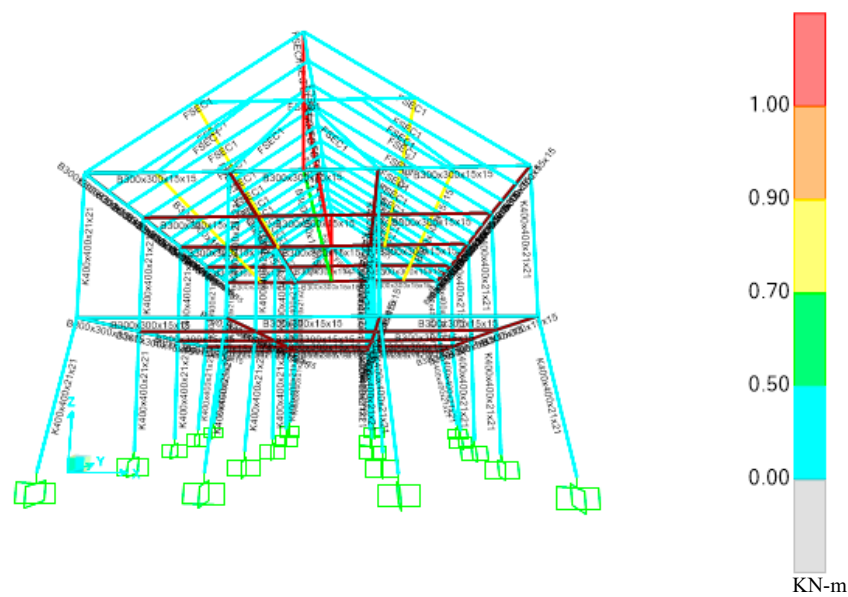


Figure 3. The structural load of an Ammatoan vernacular house.

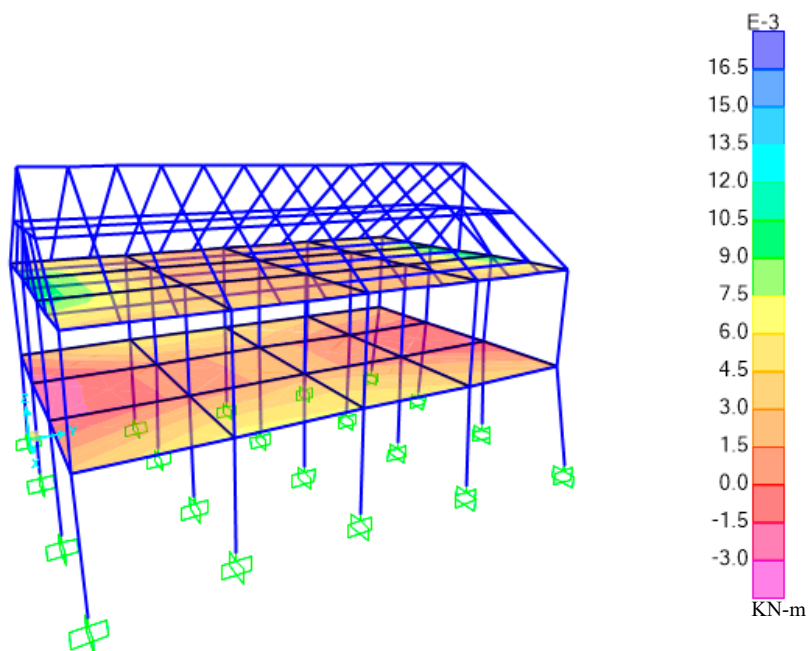


Figure 4. Fmax diagram.

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 in Figure 5 shows the virtual work energy as an indication of the force and displacement load pressure.

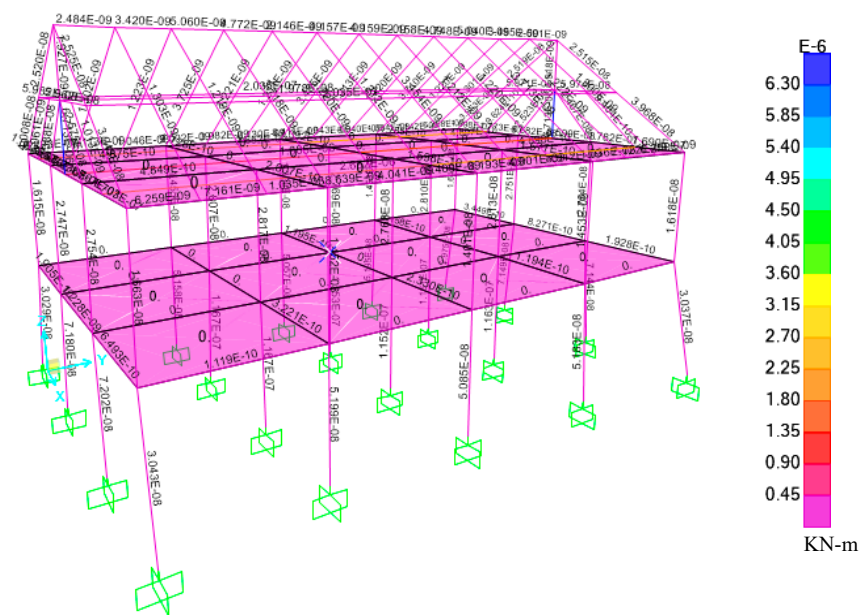


Figure 5. RVW (Relative virtual work) Output Model.

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

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

The analysis found that the element stiffness is fairly low, and that the structural modification is not significantly influenced by the load (dead load, live load, wind load, and earthquake load). These results reflect the development principle of Ammatoan houses, which is oriented toward sustainability. The use of natural forms in piles indicates an elemental stiffness without any modification. As a result, the Relative Virtual Work 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 an 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 U.S. Geological Survey (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.

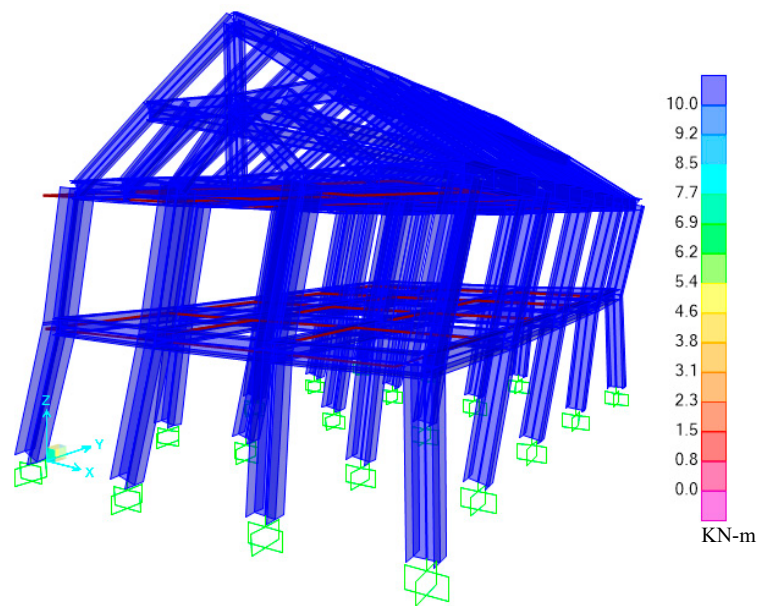


Figure 6. Illustration of the joint system of an Ammatoan vernacular house.

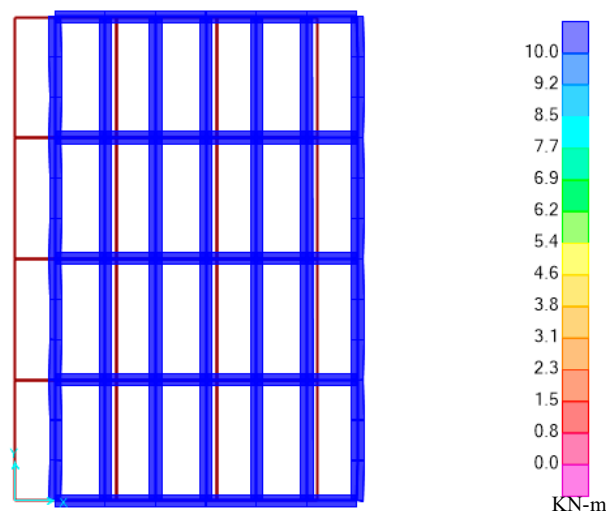


Figure 7. Illustration of the joint system of an Ammatoan vernacular house.

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 take into consideration the pedestal foundation, the free positioning, and the 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. In Figure 8 shows the frame of an Ammatoan house.



Figure 8. Frame of an Ammatoan house.

The loading on the attic of the house shows that the strength of the roof structure is rather weak, so it is not recommended for accommodating 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.

The 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. The floorboard size is determined by the size of available material.

A primary component of the roof structure is the truss. Generally, a wood truss construction is a cantilever construction, the primary supporting structure of the roof. A 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 [22]. The trusses are positioned in beam rings, using specific angles. The 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 the piles (*benteng*) and roof beams (*padongko*).

There are two types of joints used in Ammatoan houses, while the column system used is a deep pile system (see Figure 9). 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 able to carry loads stably for decades.

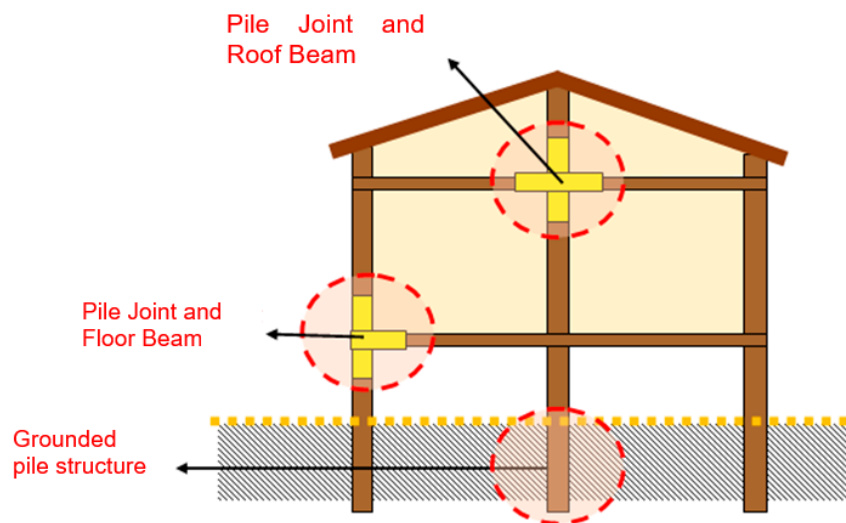


Figure 9. Illustration of the joint system of an Ammatoa vernacular house.

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) The testing for structural strength applied an assumption of equal pile pitch. However, each Ammatoan house has a different level of pitch. Therefore, the 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 this 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.

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References

1. Frick, H. *Seri Strategi Arsitektur 1 – Pola Struktural dan Teknik Bangunan di Indonesia [Architectural Strategy Series 1 - Structural Patterns and Building Engineering in Indonesia]*; Penerbit Kanisius: Yogyakarta, Indonesia, 1997.
2. Rifai, A.J. *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, Indonesia, 2010.
3. Burley, A.L.; Enright, N.J.; Mayfield, M.M. Demographic response and life history of traditional forest resource tree species in a tropical mosaic landscape in Papua New Guinea. *J. For. Ecol. Manag.* **2011**, *262*, 750–758. [[CrossRef](#)]
4. Fajrin, J.; Handayani, T.; Anshari, B.; Rofaida, A. *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, Indonesia, 2008.
5. Hildayanti, A.; Suriadi, N.A.; Santosa, H.R. Analysis of housing areas with a sustainable community approach. *Int. J. Sci. Eng. Res.* **2014**, *5*, 1511–1517.

6. Luthan, P.L.A. *Pengembangan Konsep Rumah Tinggal Tradisional Mandailing di Sumatera Utara [Conceptual Development of Traditional Mandailing Houses in North Sumatra]*; Gunadarma University: Depok, Indonesia, 2015.
7. Wiryomartono. *KONSTRUKSI KAYU Jilid 1 WOOD CONSTRUCTION Volume 1*; Yayasan Penerbitan FIP-IKIP: Yogyakarta, Indonesia, 1976.
8. Rimang, S.S. *Sejarah Kajang [History of Kajang]*; Lentera Kreasindo: Makassar, Indonesia, 2016.
9. Tika, M. *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]*; Pustaka Refleksi: Makassar, Indonesia, 2015.
10. Wasilah, W.; Hildayanti, A. Filosofi penataan ruang spasial vertikal pada rumah tradisional Saoraja Lapinceng Kabupaten Barru [Philosophy of vertical spatial planning in Saoraja Lapinceng traditional houses, Barru Regency]. *J. RUAS (Rev. Urban. Archit. Stud.)* **2017**, *14*, 70–79. [[CrossRef](#)]
11. Hartawan; Suhendro, B.; Pradipto, E.; Kusumawanto, A. Perkembangan sistem struktur bangunan rumah Bugis Sulawesi Selatan [The development of the structural system of the Bugis houses of South Sulawesi]. In *Proceedings of the 5th Annual Engineering Seminar (AES 2015), Free Trade Engineers: Opportunity or Threat*, Faculty of Engineering, Gadjah Mada University, Yogyakarta, Indonesia, 12 February 2015; pp. 51–60.
12. Breyer, D.E. *Design of Wood Structures*; McGraw-Hill: New York, NY, USA, 2007.
13. Rapoport, A. *House Form and Culture*; Prentice-Hall: Englewood Cliffs, NJ, USA, 1969.
14. Setijanti, P.; Silas, J.; Firmaningtyas, S.; Hartatik. *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, Indonesia, 2012.
15. Suwantara, I.K.; Suryantini, P.R. Kinerja sistem struktur rumah tradisional Ammu Hawu dalam merespon beban seismik Performance of the Ammu Hawu structural system in responding to seismic loads. *J. Permukiman* **2014**, *9*, 102–114.
16. Wasilah, S.; Fahmyddin, T. The advancement of the built environment research through employment of structural equation modeling (SEM). In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2018.
17. Forrest Product Laboratory. *Wood as an Engineering Material (Wood Handbook)*; USDA: Washington, DC, USA, 2010.
18. Mehta, K.C. *Wind Load: Guide to the Wind Load Provisions of ASCE 7-10*; ASCE Press: Reston, WV, USA, 2013.
19. Dogan, M. Seismic analysis of traditional buildings: Bagdadi and Himis. *Anadolu Univ. J. Sci. Technol. A Appl. Sci. Eng.* **2010**, *11*, 35–45.
20. National Standardization Agency of Indonesia (BSN). *Tata Cara Perencanaan Struktur Kayu Untuk Bangunan Gedung Procedure for Planning the Wood Structures of Buildings*; SNI-03-xxxx-2000; National Standardization Agency: Bandung, Indonesia, 2012.
21. Hapid, A. 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. Master's Thesis, Faculty of Forestry, Gadjah Mada University, Yogyakarta, Indonesia, 2010.
22. Ludwig, S. *Konstruksi Kayu Wood Construction*; Erlangga: Jakarta, Indonesia, 2010.

